State of the resource

PART 3

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Part 3 of the Report highlights the key issues associated with the Earth's natural water cycles (chapter 10) and identifies the changes occurring in the water cycle (chapter 11) and how they affect hazards and opportunities for using water resources (chapter 12). It concludes with a discussion of the available information – and the information that is lacking – to quantify the resource and patterns of change (chapter 13).

Water resources are made up of many components associated with water in its three physical states (liquid, solid and gas). Under natural conditions water results from complex interactions between atmospheric, land surface and subsurface processes that affect its distribution and quality. The components of the water cycle (rainfall, evaporation, runoff, groundwater, storage and others) therefore all differ in their chemical and biochemical qualities, spatial and temporal variability, resilience, vulnerability to pressures (including land use and climate change), susceptibility to pollution and capacity to provide useful services and to be used sustainably. A consequence of this variability is that while human pressures have resulted in large modifications to the global cycle, the directions and degrees of change are complex and difficult to ascertain.

The uneven distribution over time and space of the natural resource and its modification through human use and abuse are sources of water crisis in many parts of the world. Broad overviews at the global scale are difficult because of the spatial and temporal complexity arising from the conjunction of land, water and atmospheric elements – made worse by incomplete monitoring and fragmented availability of data to quantify the resource and its changes.

The main components of water have come to be designated as blue, green and white water:

- **Blue water** is liquid water moving above and below the ground and includes surface water and groundwater. As blue water moves through the landscape, it can be reused until it reaches the sea.

- **Green water** is soil moisture generated from rainfall that infiltrates the soil and is available for uptake by plants and evapotranspiration. Green water is non-productive if evaporated from soil and open water.

- **White water** (sometimes considered the non-productive part of green water) is water that evaporates directly into the atmosphere without having been used productively and includes losses from open water and soil surfaces.

In addition, grey and black water refer to the quality of the resource.

- **Grey water,** usually wastewater, may be poor in quality, but usable for some purposes.

- **Black water** is so heavily polluted (usually with microbes) as to be harmful (to humans and ecosystems) or at least economically unusable.

About 60% of total global water fluxes (flows, movements and transfers between physical states) are attributable to green water flow, the component of the water cycle most susceptible to land use and land cover changes, and to changes in atmospheric conditions that control evaporative demand, such as temperature, solar radiation and atmospheric vapour pressure deficit. In addition, there is the Earth's 'solid' water, the contribution that snow and ice make to the global resource and how these components may be affected by changes in climate conditions.

Detecting and quantifying changes involve separating natural variability in climate and hydrologic processes from the variability and trends caused by other factors that influence the hydrologic landscape and then measuring and quantifying this variability. This hydrologic landscape has already been highly modified by land use changes, which can both accelerate (for example, through urbanization and vegetation degradation) and dampen (for example, through afforestation) hydrologic responses. It is also modified by engineered systems, including in-stream effects (such as dams, direct abstractions, return flows and interbasin transfers) and off-stream effects (such as irrigation). Climate change is being superimposed on an already complex hydrologic landscape, making its signal difficult to isolate, and yet making its influence felt throughout the water supply, demand and buffering system. There are already detectable changes in some parts of the world in the first-order climate parameters of temperature and rainfall. But this signal is not yet discernable in many parts of the world in second-order parameters of importance to water resources managers, such as changes in runoff and groundwater.

Chapter 11 reviews the scientific evidence of change in the components of the water cycle, focusing on impacts related to climate change. While trends in precipitation have been noted in some parts of the world, in other areas precipitation patterns have remained about the same within the period of observed data. There is evidence of changes in seasonality and frequency of heavy precipitation events in some areas. Despite the evidence of temperature changes, there is little evidence of detectable changes in evaporation and evapotranspiration. Part of the reason may stem from decreased solar radiation due to increased aerosol use or cloud cover, but difficulties in obtaining representative measurements could be obscuring any trends. Similarly, detecting trends in soil moisture is constrained by limited observations, while model studies are subject to uncertainties about the model and data input assumptions.

Despite the limitations of global datasets, many studies have shown changes in runoff and streamflow. Many have focused on low (drought) or high (flood) extremes (chapter 12). Except in regions with flows affected by glacier meltwater, the general conclusion is that global trends are not present or cannot be detected at this stage, although climate change–related trends are evident in some regions. Many rivers have been altered by engineered systems, including dams, diversions, return flows and interbasin transfers and by land use modifications. The same is true of groundwater resources, which have been heavily used for human supply and agriculture for many years. While many groundwater abstraction schemes access fossil water (water unrelated to current conditions), renewable groundwater resources depend on highly variable recharge volumes. It is thus realistic to expect future recharge regimes to reflect changes in the driving hydrologic processes (such as precipitation and evapotranspiration) that might result from anticipated climate changes. That these are not yet detectable could be related to the buffering capacity of groundwater (slower processes), as well as to the lack of a suitably integrated global database. While changes have been observed in natural lakes and wetlands in recent decades in many parts of the world, the primary factors driving these changes are region specific.

The strongest evidence for the effects of climate change on water resources comes from areas where the rate at which the solid phase of water (snow and ice) is converted into liquid is important. In permafrost regions changes have been detected in the depth of frozen ground and in the duration, thickness and areal extent of the seasonal freeze and thaw within seasonally frozen regions. Potential impacts include surface settlement, swamping, landslides and greater sediment loads. More than 15% of the world's population live where water resources availability depends heavily on snowmelt from ephemeral snowpacks or perennial glaciers. Changes have been observed in snow cover extent and snow water equivalent and in the frequency with which precipitation falls as snow.

Despite observations that the snow cover season has shortened and that this change appears to have accelerated in recent decades, some inconsistencies remain in the data sources. There is considerable evidence to suggest that glaciers have retreated globally since the mid-19th century and that this retreat has accelerated since the mid-1970s in response to rising air temperature and changes in the amount and kind of precipitation.

Among the consequences of a changing hydrologic cycle is its interaction with the terrestrial carbon cycle, because of positive feedbacks to climate change. The terrestrial biosphere is thought to have taken up roughly 25% of anthropogenic carbon emissions during the last century, and how long this can continue is unclear. Observations suggest that the rate of carbon uptake depends on hydrologic and climate conditions, as well as land use. But long-term observations are sparse, making trend detection difficult.

Most climate scientists agree that global warming will result in an intensification, acceleration or enhancement of the global hydrologic cycle, and there is some observational evidence that this is happening already. Data limitations in length of record, continuity and spatial coverage contribute to the uncertainty, while natural climate variability and multiyear variability associated with large-scale atmospheric circulation patterns influence the interpretation of many trends in ways that are not yet fully understood. Improving data collection and reducing the uncertainties associated with modelling studies are important for future impact assessments.

Hazards (chapter 12) can result from too much water (floods, erosion, landslides and so on) or too little (droughts and loss of wetlands or habitat) and from the effects of chemical and biological pollution on water quality and in-stream ecosystems. Water-related hazards can be naturally occurring or anthropogenic. The chapter states that the natural variability of water resources and changes, whatever the cause, can also provide positive opportunities – with careful management. In many areas hydrologic extremes have increased. Deaths and material damage from extreme floods can be high, and more intense droughts, affecting increasing numbers of people, have been observed in the 21st century. Such droughts have been linked to higher temperatures and decreased precipitation, but are also frequently a consequence of resource mismanagement.

Changes in cultivation and interruptions in sediment delivery through the construction of dams can lead to changes in erosion and sediment transport. In some developing countries rapidly expanding population has driven land clearing and rapid expansion of cultivated land. The water quality and ecology of many of the world's rivers have been altered partly by changes in flow and partly by inputs of chemical and biological waste from human activities. Global warming is expected to lead to changes in water temperature, with substantial effects on energy flows and matter recycling, resulting in algal blooms, increases in toxic cyanobacteria bloom and reductions in biodiversity, among other impacts.

The increased exposure to potential climate change hazards has led to more awareness of water resources management. The response of management strategies to potential climate change threats is an opportunity to implement more resource-sustainable policies and practices. For example, in areas of increasing water stress, groundwater is often an important buffer resource, capable of responding to increased water demands or compensating for the declining availability of surface water. There are significant opportunities for both mitigation and adaptation strategies, such as stronger observation networks (chapter 13), increased integration of groundwater and surface water supplies (including artificial recharge), improved early warning and forecasting systems for hazardous events, improved risk-based approaches to management and greater community awareness of sustainable water resources use.

Management of global water resources requires reliable information about the state of the resource and how it is changing in response to all the drivers that affect it. Worldwide, water observation networks are inadequate for current and future management needs and risk further decline (chapter 13). There are insufficient data to understand and predict the current and future quantity and quality of the resource. Political protocols and imperatives for sharing data are also inadequate. While new technologies in satellite remote sensing and modelling present opportunities, their value is limited by our inability to ground truth and validate much of the simulated information. To improve monitoring and to use data more effectively and efficiently, countries need to place observations and continual assessments of water resources higher on the political and development agendas. The financial and human resources that countries can commit to achieving these improvements will differ greatly. But unless a worldwide effort is made to improve our knowledge and understanding of changes in the global water resource, future management will be undertaken in an environment of greater uncertainty and high risk.