EuropeAid

ENVIRONMENT & CLIMATE CHANGE

EC Cooperation:

Responding to climate change

Sector Script for Water Supply & Sanitation

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This document was developed by EuropeAid in cooperation with DG RELEX, DG DEV and DG ENV with the support of the "environmental integration advisory services" project. It was designed to provide practical guidance on the links between climate change and a specific sector, together with possible responses to climate-related challenges. The purpose of this "script" is to support political dialogue on climate change implications between the European Commission, partner governments and other national partners involved in EC development and external cooperation activities, as well as to facilitate strengthened climate change integration in ongoing and future cooperation programmes and projects, with a focus on developmental benefits for the partner countries.

This sector script is one of a series prepared in a standard format. Scripts are available for the following topics:

- Introduction and Key Concepts
- Agriculture & Rural Development (incl. forestry, fisheries and food security)
- Ecosystems & Biodiversity Management
- Education
- Energy Supply
- Health
- Infrastructure (incl. transport)
- Solid Waste Management
- Trade & Investment (incl. technological development, employment and private sector development)
- Water Supply & Sanitation

Note that the script is not country or region-specific, and has been prepared to cover a wide range of possible effects and responses. Users are invited to appreciate which elements, among those proposed, are relevant to their specific needs and circumstances.

Note: This sector script was written with a focus on the management and supply of freshwater, as well as sanitation and wastewater treatment. A special focus is also dedicated to coastal zone management. The text makes references to other related and complementary scripts.

Users of this script are advised to read it in conjunction with the Introduction and Key Concepts information note, which introduces the series and puts things in context.

Comments are welcome and can be addressed to the following e-mail:
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SECTOR: WATER SUPPLY & SANITATION

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Climate change impacts on the water and sanitation sector

In summary, the challenges related to the water sector include having too much water, having too little of it and dealing with polluted water. A significant proportion of the world's population already lives in areas subject to high or very high water stress, caused by an imbalance between available water resources and water use. Climate change is likely to exacerbate the current issues faced by the water sector, in various ways, but it is not the only underlying cause. Water sector policy and decision makers should include climate-related considerations as an important element for the sustainability of intervention strategies – while also integrating other sources of pressure in their analysis.

For many regions of the world, climatic models are not consistent on the direction as well as the amplitude of long-term changes in rainfall. These uncertainties make the prediction of long-term climate change effects on the water sector particularly difficult. Still, in general it can be anticipated that climate change will affect both the quantity and the quality of available water. Changes in the available quantity of freshwater are likely to result from changes in rainfall quantity and/or intensity, the melting of glaciers, changes in the volume and frequency of floods, sea level rise and the increased frequency of sea surges. Changes in water quality (e.g. increased concentrations of pollutants, pathogens and disease vectors, increased salinity or turbidity) are likely to result from increased variability in flows, the increased incidence of floods and changes in water temperature.

In addition, water supply, sanitation and wastewater treatment infrastructure may be damaged or made temporarily unusable by extreme weather events, and its functioning may be disrupted by damage to other infrastructure, in particular energy infrastructure. Migrations induced by climate change, especially rural-urban migrations, may also put stress on the capacity of local authorities to supply water, sanitation and wastewater treatment services to fast-growing populations.

At the watershed level, changes in the availability and quality of water are likely to exacerbate existing or latent conflicts between various types of water users – and to generate new conflict situations, including transboundary ones.

Coastal zones, estuaries and low-lying delta areas are particularly likely to suffer from the exacerbation of water-related problems caused by climate change. On the "sea front", they already have to cope with rising sea levels and an increase in the frequency and intensity of storms and sea surges; these phenomena are expected to be amplified in future. Simultaneously, these areas will have to face most of the water-related problems also experienced inland. Coastal zones are considered "hotspots" of vulnerability to climate change because, on top of being very much exposed to its consequences, they are highly populated and tend to be magnets of economic development. In developing and emerging countries, large numbers of people with how adaptive capacity (because of poverty) are exposed to significant risks.

Adapting to climate change

Given the prevailing uncertainties, large investments "betting" on a specific direction and amplitude in the availability of water may not be wise; measures that generally enhance resilience to increased variability in the availability of water, and/or contribute to disaster risk reduction, may be a better choice.

In the water sector, adaptation options can be divided into supply- and demand-side options. Supply-side measures aim to increase water supply, by exploiting more intensively existing water sources or exploiting new sources; their main drawback

is that they may have damaging environmental consequences and/or be unsustainable in the long-term. Demand-side measures involve trying to reduce water consumption by various categories of users, so that total demand does not exceed the limited supplies available; this approach is generally more sustainable, but it may turn out not be as effective as desired – or may have adverse social consequences. In practice, elements of both approaches are often implemented simultaneously. Where more frequent or severe storms, heavy rainfall episodes and floods are identified as a possible effect of climate change, adaptation measures also include protecting water sources from contamination by flood water. Generally speaking, making water supply and sanitation infrastructure more resilient to extreme climate events and other anticipated consequences of climate change, and monitoring trends in migrations and human settlements as a basis for investment planning, also support adaptation capacity.

Given the existing water stress-related challenges and their expected aggravation in coming decades, it is widely accepted that the responsibility for implementing adaptation measures will not fall exclusively on water management agencies (and their private partners is any): all types of users (households, farmers, industrial users etc.) will also have to do their bit. The importance of building on traditional knowledge has been highlighted as critical to successful adaptation.

The challenges brought about by climate change will only reinforce the need to develop water governance institutions, including watershed management organisations, at the appropriate levels (local, regional, transboundary). To foster adaptation to more difficult conditions, these organisations may have to reallocate existing water rights among users, and generally to devise more equitable, efficient and transparent ways of allocating these rights. Integrated water resources management (IWRM) should be an effective approach to develop adaptation measures to climate change. In some regions, water governance could also be helped by the development of forecasting systems, and the integration of forecasts into decision support systems for water management.

To adapt, coastal zones and low-lying delta areas are likely to place a particular emphasis on flood control measures, flood disaster risk management and managed retreat from the areas most at risk.

Contributing to climate change mitigation

The relationship between climate change mitigation measures and the water sector is a reciprocal one. Water management policies and measures can influence greenhouse gas (GHG) emissions (positively or negatively). Mitigation measures adopted in a variety of other sectors can also influence water resources and their management. There may also be trade-offs between adaptation and mitigation options (e.g. desalinating water will result in higher GHG emissions if the energy used for these purposes is derived from fossil fuels); ideally, such tradeoffs should be made explicit by assessing simultaneously adaptation and mitigation options – and options that support sustainable development goals should be preferred to those that do not.

The water supply sector can reduce its contribution to GHG emissions by gradually switching from fossil fuel-based to renewable sources of energy. Water reservoirs, whether they are built for the purpose of water supply and irrigation, flood control or hydropower production, can be a source of methane emissions; these can be reduced by building deeper reservoirs, and by clearing as much vegetation as possible before filling new reservoirs. Expanding irrigated agriculture (where sufficient water is available for this purpose and this does not clash with other water sector objectives and priorities) may have both positive and negative effects in terms of GHG emissions, depending on circumstances and techniques used. Human sewage and wastewater treatment are sources of GHG (methane and nitrous oxide) emissions – although these are by far not the largest sources of global emissions; the adoption of improved sanitation and wastewater management techniques offers many opportunities (during transport, treatment and final disposal) to reduce GHG emissions – in addition to producing well-known benefits in terms of public health, water resource conservation and environmental protection.

u HOW CLIMATE CHANGE MIGHT AFFECT THE WATER AND SANITATION SECTOR

Climate change may affect water supply and sanitation through a range of biophysical and socio-economic impacts. The table below shows the main links between such impacts and the sector.

	Water & Sanitation
Biophysical effects	
Changes in temperature and rainfall patterns	•
Shifts in seasons	•
Increase in extreme weather events / natural disasters	•
Raised sea level and increased coastal erosion	•
Desertification, soil erosion	•
Reduction in the availability of freshwater	•
Reduction in the quality of water	•
Changes in hydrological flows, in permafrost	•
Loss of habitats, changes in ecosystems and related services	•
Increase in disease and pest outbreaks	•
Changes in atmospheric pollution patterns	
Socio-economic impacts	
Damage to infrastructure	•
Reduced availability of energy (hydropower)	•
Population displacement and human migrations	•

The relationships between climate change and the water sector do not exist in isolation but in the context of, and interacting with socio-economic and other environmental conditions.

In summary, the challenges related to the water sector include having too much water, having too little of it and dealing with polluted water. The World Water Council reports that 1.1 billion people currently live without access to safe drinking water, and 2.6 billion people live in areas without adequate sanitation. A significant proportion of the world's population already lives in areas subject to high or very high water stress[1], caused by an imbalance between available water resources and water use. Independently from the potential long-term effects of climate change, water stress is caused by current climate variability, demographic pressures, wasteful behaviour by various types of users (which often derives from inadequate economic incentives), lack of sanitation and wastewater

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[1] The World Water Council uses a water stress indicator (also known as the "water exploitation index") calculated as the ratio of annual water withdrawal to total renewable water resources, for a given region. Regions where this ratio is comprised between 0.4 and 0.8 are under "high stress". Those where the ratio exceeds 0.8 are under "very high stress".

treatment, and the rejection of polluted industrial effluents without adequate treatment. Climate change is likely to exacerbate the current issues faced by the water sector, in various ways, but it is not the only underlying cause. Water sector policy and decision makers should include climate-related considerations as an important element for the sustainability of intervention strategies – while also integrating other sources of pressure in their analysis.

Some of the possible consequences of climate change on the water sector are described below. Note in this regard that whereas general circulation models usually agree that average temperatures will increase and that sea levels will rise (by how much remains disputed), for many regions of the world climatic models are not consistent on the direction as well as the amplitude of long-term changes in rainfall. Since rainfall is a key determinant of water quality and availability, these uncertainties make the prediction of long-term climate change effects on the water sector particularly difficult.

1.1. Water supply

Water is used by rural and urban households for a variety of purposes including drinking, cooking, hygiene and recreation. It is also used as an input, with various degrees of intensity, by enterprises of all sizes in the primary (agriculture and mining), secondary (industry and manufacturing) and tertiary (services including tourism) sectors. Among many existing uses, river water is also used as a source of renewable energy, for the production of hydropower. Water quality requirements are variable depending on the intended use but are usually highest where water is to be used for direct human consumption in food and drinks.

Climate change may affect both the quantity and the quality of available water – as well as the predictability with which water is available in a given region at a given time of the year. Quantity can be affected in the following ways:

- the flow of rivers of all sizes and the level of the lakes and ponds fed by these rivers may change as a result of changes in rainfall quantity and/or intensity (in particular if these changes occur in source regions); depending on circumstances, average stream flows may increase or decrease; they may also show increased variability, with periods of low or interrupted flows alternating with periods of flooding;

> Primary supplies may originate from a variety of sources:
>
> surface water directly collected from rivers, lakes, ponds or even puddles – possibly with intermediate storage in open-air or underground tanks and reservoirs;
>
> surface water harvested during episodes of rainfall and stored for later use in open-air or underground tanks and reservoirs;
>
> underground water pumped from aquifers or various types of wells and boreholes;
>
> in some places, seawater desalination, used to offset insufficient freshwater supplies.

- the flow of rivers fed by glaciers and snowmelt changes as glaciers melt at an accelerating rate all over the world and the volume of snowfall in mountainous areas tends to be more variable or to decrease compared with a few decades ago; at the moment, the acceleration in the melting rate of glaciers tends to increase stream flows (with floods and increased riverbank erosion as a consequence), but as the melting proceeds, it is anticipated that average stream flows will be severely reduced in future; in a similar way, the level of mountain lakes currently tends to increase (which in high-altitude regions involves a higher risk of catastrophic events such as glacial lake outburst floods) – but may decrease in future when the volume of water stored in glaciers has been significantly reduced;
- the recharge rate of aquifers may change as a result of changes in rainfall quantity and/or intensity, and the associated changes in the volume and frequency of floods (in the floodplains of semi-arid regions, aquifers are primarily recharged by annual floods);
- in coastal and deltas regions, sea-level rises and the more frequent occurrence of sea surges may lead to salinity intrusions in aquifers, gradually making local water sources unusable for most purposes.

The quality of water supplies can also be affected, in the following ways:

- lower flows result in reduced effluent dilution, which in many cases may lead to increased salinity and increased concentration of pollutants;
- greater flows (e.g. as a result of the accelerated melting of glaciers) may carry more sediment and thus increase water turbidity, making it less suitable for consumption; heavy precipitation episodes, which increase soil erosion processes, have the same effect;
- floods may result in chemical and microbiological pollution and the contamination of water supplies;
- the concentration of pathogens and disease vectors may increase as a result of higher water temperatures possibly combined with water stagnation (related to reduced flows).

In addition to problems related with the quantity and quality of water available, water supply infrastructure (notably water purification plants and pumping stations) may be damaged or made temporarily unusable by extreme weather events such as droughts, floods, storms, etc. Its functioning may also be disrupted by damage to other infrastructure on which it depends, in particular energy infrastructure.

Migrations induced by climate change, especially rural-urban migrations, may put stress on the capacity of local authorities to supply water to fast-growing populations. Urban slums tend by definition to provide inadequate supply of water and other essential services; existing problems are likely to be amplified if water scarcity and quality problems are compounded by the rapid growth of population in areas with poor basic infrastructure. If the number of "climate refugees" increases as is currently expected, supplying water to refugee camps may also become a growing issue.

1.2. Wastewater management and sanitation

Basic decentralised sanitation infrastructure (e.g. pit latrines), as well as centralised municipal and industrial wastewater treatment installations, may be made temporarily unusable, or suffer lasting damage, as a result of more frequent and/or more severe floods and other extreme weather events.

Municipal wastewater treatment installations may be unable to cope with the increased volumes of water received during more frequent and intense episodes of heavy precipitation – which is an issue if sewers collect a mix of used water and runoff. Conversely, these installations may also work less effectively if the volumes of wastewater received decrease below their operating thresholds during drought periods.

Migrations induced by climate change, especially rural-urban migrations, may put stress on the capacity of local authorities to provide basic sanitation services as well as municipal wastewater treatment. Again, ill-equipped human settlements such as urban slums and refugee camps, which may see their population swell as a direct or indirect consequence of climate change, are likely to suffer more than other areas of lack of sanitation and wastewater treatment capacity.

1.3. Watershed management and water governance

Changes in the availability and quality of water resulting from climate change are likely to exacerbate existing or latent conflicts between various types of water users – and to generate new conflict situations, including transboundary ones. Competing uses typically include water for domestic consumption, agriculture (including livestock) and irrigation, aquaculture, energy production (hydropower, cooling of thermal power plants), industry and services, recreational uses, biodiversity and ecosystem conservation. Increasing competition for a scarce resource, and the conflicts that may result, are likely to make the task of watershed management authorities and the allocation of water rights more complicated.

1.4. Special focus: coastal zone management

Coastal zones, estuaries and low-lying delta areas are particularly likely to suffer from the exacerbation of water-related problems caused by climate change. On the "sea front", they already have to cope with rising sea levels and an increase in the frequency and intensity of storms and sea surges; these phenomena are expected to be amplified in future. This has and will have adverse consequences for human settlements, for coastal ecosystems, for all types of infrastructure (including water supply and treatment installations) and also for the capacity to supply freshwater, as many coastal aquifers are threatened by salinity intrusions.
Simultaneously, these areas will have to face most of the water-related problems also experienced inland and described above. Unless measures are adopted to improve water quality, they may suffer in particular

from the reduced quality of the water brought by rivers as flows diminish: downstream sections of rivers tend to be the most polluted. This may put severe stress on an important source of potable water, while causing ecological problems such as the destruction of wetland ecosystems and toxic algal blooms (caused by the excessive concentration of nutrients, primarily nitrogen and phosphorous) – with dire consequences for biodiversity, aquaculture, coastal fisheries, tourism etc. Coastal zones and low-lying delta areas are also particularly threatened by other consequences of changes in hydrological regimes that take place in upstream areas: they may suffer, for instance, from the increased frequency and/or intensity of river floods – or from the reduced supply of sediment, as more and more dams are built upstream to secure water supply or control floods.

Coastal zones are also considered "hotspots" of vulnerability to climate change because, on top of being very much exposed to its consequences, they are highly populated and tend to be magnets of economic development. In developing and emerging countries, large numbers of people with low adaptive capacity (because of poverty) are thus exposed to significant risks.

1.5. "Downstream effects" on other sectors

Obviously, with water being so essential to life and human activities, all the effects described above can themselves be expected to impact on other sectors. Changes in water quality and availability, as well as problems related to sanitation and wastewater treatment, will notably affect health, nutrition, food safety and security, agricultural and livestock productivity, coastal fisheries and aquaculture, forestry, industry, some services (notably tourism), energy production, all types of infrastructure including transport, human settlements, biodiversity, the functioning of ecosystems and the provision of ecosystem services. They may also determine the emergence of new conflicts or aggravate existing ones. This note will not attempt to cover all these aspects in detail. Rather, they are covered in the sector scripts dedicated to Agriculture & Rural Development, Ecosystems & Biodiversity Management, Energy Supply, Health, Infrastructure and Trade & Investment

V ADAPTING TO CLIMATE CHANGE IN THE WATER AND SANITATION SECTOR

Computer-generated image shows floating city for 50000 inhabitants

We have already mentioned that for many regions of the world, there are still significant uncertainties regarding the direction as well as the amplitude of long-term changes in rainfall and thus future hydrological conditions. This makes the choice of adaptation measures in the water sector particularly difficult. In the presence of such uncertainties, large investments "betting" on a specific direction and amplitude in the availability of water may not be wise; measures that generally enhance resilience to increased variability in the availability of water, and/or contribute to disaster risk reduction, may be a better choice. Note however that in many regions, considering that other pressures on water than climate change are also at work, increasing water stress is the most likely trend.

In the water sector adaptation options can be divided into supply- and demand-side options. Supply-side measures aim to increase water supply, by exploiting more intensively existing water sources or exploiting new sources. Their main drawback is that they may have damaging environmental consequences (e.g. if the diversion of water for human use reduces the quantity of water available for supporting biodiversity and the functioning of ecosystems) and/or be unsustainable in the long-term (exhaustion of the resource). Demand-side measures involve trying to reduce water consumption by various categories of users, so that total demand does not exceed the limited supplies available. This approach is generally more environmentally friendly and sustainable, but it may turn out not be as effective as desired (since demand reduction depends on the aggregate behaviour of many individuals and entities) – or may have adverse social consequences (e.g. if water prices increase to a level that makes water unaffordable for the poor). In practice, elements of both approaches are often implemented simultaneously.

Another distinction that is often made is between autonomous and planned adaptation measures. Autonomous adaptation measures are those spontaneously adopted by households and enterprises, outside the framework of any "grand design" or specific policy from the national authorities, to cope with water stress situations or other water-related problems; they are not specifically designed to cope with climate change, and may be more or less effective. Planned adaptation measures, on the other hand, result from the implementation of deliberate policy choices and/or action plans designed to respond to climate change and increasing climate variability. In the water sector, so far autonomous measures have been much more frequent than planned ones. One reason for this may be the uncertainties that prevail regarding future hydrological conditions.

When considering climate change adaptation measures in relation to water, it is also useful to think of who will be in charge of implementing them. Given the existing water stress-related challenges and their expected aggravation in coming decades, it is widely accepted that the responsibility for implementing adaptation measures will not fall exclusively on water management agencies (and their private partners is any): all types of users (households, farmers, industrial users etc.) will also have to do their bit.

Relatively little is in fact known about how organisations and individuals will react to the challenges posed by the increasing water scarcity and the deterioration in its quality – and to policy measures designed to address these issues. Water-related policies should consider how to provide various categories of users the right incentives to adopt the right measures. Regulatory measures (including sanctions for non-compliance) and a redefinition of water rights certainly have a role to play, but so do measures that make

use of economic signals and incentives. In this regard, water pricing policies (based on transparent price-setting mechanisms and, where relevant to social objectives and economically sound, on differentiated prices across user categories) are likely to play an increasing role.

Finally, the importance of building on traditional knowledge has been highlighted as critical to successful adaptation. Incorporating this element into climate change policies should support the development of effective adaptation strategies that are cost-effective, participatory and sustainable.

2.1. Water supply

Where increasing water scarcity or more irregularity in the availability of water is expected, possible adaptation measures include:

(a) demand-side options:

- improving water efficiency, i.e. reducing the amount of water that is used or consumed to produce a given output or achieve a given objective – and promoting water conservation; this covers a wide range of possible measures, including for instance: repairing leaks in water storage, distribution and irrigation systems; educating households, farmers and small enterprises to avoid waste in the use of water; improving irrigation systems (e.g. switch to drip irrigation); modifying industrial processes to make them less water-intensive; promoting the on-site recycling of water by industrial and enterprise users; etc.;
- recycling and reusing municipal wastewater – as well as water recovered from irrigation drains, provided it is not too saline nor too laden with fertilisers and/or pesticides;
- expanding the use of water metering and pricing, and increasing water prices – which are de facto ways of promoting efficiency and of discouraging wasteful and uneconomic uses;
- in irrigation systems, transporting water by means of pipelines rather than open irrigation channels, to reduce evaporation;
- promoting indigenous practices for sustainable water use;
- reducing demand by developing imports of "virtual water" – i.e. stop encouraging the local production of some water-intensive products (e.g. some agricultural products that are produced only because of the existence of significant water subsidies) and instead buy them from regions better endowed with water; note that this concept is sustainable only if "imports" (which may in fact come from other regions of a country, not necessarily from abroad) do not require transport over excessively long distances – otherwise this adaptation measure is incompatible with mitigation objectives;

(b) supply-side options:

- investing in rainwater harvesting systems, which collect and store rainfall during wet seasons for use during dry seasons;
- protecting groundwater recharge areas (e.g. by not developing them and by promoting the kind of vegetation that, given local circumstances, can maximise water retention and infiltration);
- increasing the use of surface water (after adequate treatment to guarantee quality standards that match the intended uses) to complement groundwater sources – provided surface water flows with sufficient regularity or predictability;
- searching for and exploiting new sources of freshwater, such as deeper aquifers and aquifers located further away from population centres;
- diverting water from relatively water-rich basins to relatively water-poor ones – an option that should be considered with great caution however since the ecological consequences of water diversion schemes are usually very serious, possibly to the point of resulting in net economic losses for society in the long term;
- desalinating seawater or brackish water – provided this can be done using renewable sources of energy, since the process is energy-intensive and does otherwise contribute to increases in GHG emissions.

Increased water volumes are not generally an issue for water supply, on the contrary – as long as the increase occurs "smoothly" and is reasonably evenly distributed across seasons. However, increased water volumes are likely to be associated with heavy precipitation events and an increase in the frequency and/or intensity of floods – which may be severely disruptive for the supply of potable

water. Where more frequent or severe storms, heavy rainfall episodes and floods are identified as a possible effect of climate change, adaptation measures include:

- protecting water sources from contamination by flood water – which may involve adopting structural measures to reduce the incidence or severity of floods (e.g. upstream reforestation, restoration of wetlands, building of dams, embankments, flood overflow routes and other flood defences, building of reservoirs for stormwater, increase in the capacity of drainage and runoff evacuation systems);
- protecting water supply infrastructure from disruption by extreme weather events.

Where a decrease in water quality is expected, possible adaptation measures include:

- developing or enhancing "pre-supply" water treatment and purification systems (e.g. water purification plants to make surface water potable);
- improving the sanitation infrastructure (which ideally should be developed simultaneously with water supply infrastructure, but in practice is often neglected) and developing or enhancing municipal wastewater treatment systems, to reduce the contamination of water sources;
- imposing and enforcing stricter standards for the treatment of industrial wastewater, to reduce another cause of contamination of water sources.

Where damage to water supply infrastructure and/or disruptions in the functioning of this infrastructure are considered a serious risk (as a result of extreme weather events), possible adaptation measures include:

- making such infrastructure as "climate-resilient" as possible, including (to the extent possible) in the choice of locations;
- ensuring that the energy infrastructure on which water supply depends is gradually made more "climate-resilient" – and as a complementary measure, developing autonomous power generation capacity at critical sites such as pumping stations, so that they can keep operating during power cuts.

Water policy makers should also closely monitor trends in migrations and human settlements, with a specific focus on slums, so as to keep track of the most pressing needs in terms of water supply and sanitation, and to integrate them in sector investment planning.

2.2. Wastewater management and sanitation

Where damage to sanitation and wastewater treatment infrastructure, and/or disruptions in the functioning of this infrastructure, are considered a serious risk (as a result of extreme weather events), adaptation involves making such infrastructure as "climate-resilient" as possible, including (to the extent possible) in the choice of locations and in the capacity to keep operating during events such as power cuts. Any structural measures aimed at reducing the incidence or severity of floods (see above section) should also be helpful.

Where the effective operation of wastewater treatment installations is threatened by increasing variability in the volumes received, or by excessive or insufficient volumes received, possible adaptation measures include:

- separating the collection of wastewater from the collection of runoff, to make volumes received less sensitive to variation in rainfall;
- adapting the design of installations so that capacity can be adjusted at relatively short notice to the actual volumes received.

2.3. Watershed management and water governance

The challenges brought about by climate change will only reinforce the need to develop water governance institutions, including watershed management organisations, at the appropriate levels (local, regional, transboundary). Experience has shown that the existence of a unique River Basin Authority, handling all requests from water users and coordinating watershed protection measures as well as water and sanitation infrastructure investments, can be a key element in the success of water management policies and in the prevention of water-related conflicts. In large watersheds however (e.g. large rivers with multiple tributaries), management organisations may be needed at the basin as well as sub-basin levels (and thus at transnational, national and/or regional level), and have to interact with each other according to predefined rules: ultimately, the appropriate management scale should be determined by the extent to which it facilitates effective action in response to specific needs and constraints. Transboundary cooperation mechanisms, which already exist for most

large, transnational river basins, will notably have to be strengthened.

To foster adaptation to more difficult conditions, these organisations may have to reallocate existing water rights among users, and generally to devise more equitable, efficient and transparent ways of allocating these rights. As a priority, sufficient allocations should be made to cover the basic needs of households (in particular poor ones) at an affordable price, and enough water should also remain available to avoid irreversible and severe environmental damage and to secure the long-term provision of essential ecosystem services. Provided these truly essential needs are met, it may be useful to test (and if successful to deploy on wider scales) the use of market-based mechanisms to allocate remaining water rights. Market-based mechanisms have the advantage of building flexibility into the system (with changing price levels helping adjust demand to fluctuations in the availability of water), and also of ensuring that scarce water is allocated to those uses that are most valued by society.

At a more "technical" level, integrated water resources management (IWRM) should be an effective approach to develop adaptation measures to climate change, but it is a relatively new concept and various definitions exist. Features of integrated water management strategies include: recognizing the links between water quantity and quality, optimising the balance between surface and groundwater use, coordinating land and water resources management (to take account of their reciprocal interactions), reshaping planning processes accordingly, protecting and restoring natural ecosystems, consulting/involving the various stakeholders, improving the flow of information between them and setting up conflict resolution mechanisms.

In some regions, water governance could also be helped by the development of forecasting systems, including seasonal weather forecasting systems, and the integration of forecasts into decision support systems for water management. This would provide some advance warning of the level of precipitation to be expected, and help water management authorities develop more timely responses (such as warning to water users and short-term transfers of water allowances to priority users when a drought is anticipated).

Generally speaking, a thorough analysis of the cause-effect relationships that connect water scarcity with conflicts, as well as the wider adoption of participatory negotiation mechanisms, should also be helpful in designing approaches to prevent the emergence or aggravation of water-related conflicts, and find solutions for existing ones.

2.4. Special focus: coastal zone management

Coastal zones and low-lying delta areas may place a particular emphasis on:

- flood control measures (e.g. closing of estuaries, building of dikes and sea defences) – with due consideration for the potential environmental impacts of such measures;
- flood disaster risk management: measures can be aimed at mitigating risk (e.g. protection and restoration of coastal wetlands and natural barriers such as sand dunes, mangroves and coral reefs), improving awareness and preparedness (e.g. mapping of flood prone areas, flood warning systems, evacuation plans) and reducing the exposure and vulnerability of populations and infrastructure (e.g. "flood proof" buildings);
- managed retreat from the areas most at risk.

Otherwise, no "coast-specific" measures are required but the need for developing integrated adaptation responses is if anything even greater than in other areas. IWRM (see above section) is definitely a suitable approach for coastal zones, which will have to develop or reinforce coordination with water managers in upstream areas. Integrated coastal zone management (ICZM), another "holistic" approach, is also a most relevant concept likely to enhance the capacity of local authorities to face up to climate-related challenges. ICZM aims to make the management of coastal zones more sustainable by considering simultaneously all the interacting factors that determine economic, social and ecological outcomes, strengthening multidisciplinary planning and coordination mechanisms and bringing together the various stakeholders to address issues with a long-term view. ICZM, which like IWRM is a relatively new approach, should provide an ideal platform for addressing climate-related challenges along other issues. Both approaches can in fact be combined into "integrated coastal area – river basin management".

2.5. Constraints to adaptation, and dealing with uncertainty

Constraints on adaptation to climate change in the water sector are likely to be many. The latest IPCC report on climate change and water identifies five categories of constraints:

(a) "Physical or ecological: it may not be possible to prevent adverse effects of climate change through either technical means or institutional changes. For example, it may be impossible to adapt where rivers dry up completely.

(b) Technical, political or social: for example, it may be difficult to find acceptable sites for new reservoirs, or for water users to consume less.

(c) Economic: an adaptation strategy may simply be too costly in relation to the benefits achieved by its implementation.

(d) Cultural and institutional: these may include the institutional context within which water management operates, the low priority given to water management, lack of co-ordination between agencies, tensions between different scales, ineffective governance, and uncertainty over future climate change all act as institutional constraints on adaptation.

(e) Cognitive and informational: for example, water managers may not recognise the challenge of climate change, or may give it low priority compared with other challenges. A key informational barrier is the lack of access to methodologies to cope consistently and rigorously with climate change." (Bates et al. 2008: 49)

In turn each of these constraints (or more typically a mix) once recognised will require an appropriate response. Uncertainty with regard to future hydrological conditions may prevail, but this can be at least partly addressed by improved monitoring in the water sector or the instigation of monitoring together with studies that examine constraints, linkages and consequences, employing a scenario-based approach (possibly combined with probabilistic assumptions) for a range of possible climatic outcomes. 'Adaptive management' also offers ways of coping with uncertainty. This approach involves the use of water management measures that are "robust to uncertainty", i.e. provide benefits regardless of what ultimately occurs: water efficiency measures, for instance, combined with improved water management techniques, enhance general system resilience and should be "winning strategies" whatever the ultimate climatic outcomes. Similarly, flood management strategies based on reducing exposure to flood damage (e.g. by relocating some population and infrastructure away from floodplains) and allowing floods in certain areas to reduce risks in other areas are better at coping with uncertainty than some traditional flood protection measures. Managed retreat from coastal areas threatened by rising sea levels is now also increasingly seen as a more adequate response (in some areas at least) than the building of "coastal defences at all costs".

W OPPORTUNITIES FOR REDUCING GHG EMISSIONS IN THE WATER AND SANITATION SECTOR

Sun-tracking panels can be 40 percent more efficient than fixed panels, such as those on the roof of this San Diego water treatment plant.

The relationship between climate change mitigation measures and the water sector is a reciprocal one. Water management policies and measures can influence greenhouse gas (GHG) emissions (positively or negatively). Mitigation measures adopted in a variety of other sectors can also influence water resources and their management. There may also be trade-offs between adaptation and mitigation options (e.g. desalinating water, pumping water from deeper aquifers to increase supply in water-stressed areas, or improving pre-supply water treatment to offset declining water quality will result in higher GHG emissions if the energy used for these purposes is derived from fossil fuels); ideally, such tradeoffs should be made explicit by assessing simultaneously adaptation and mitigation options – and options that support sustainable development goals should be preferred to those that do not.

3.1. EFFECTS OF WATER MANAGEMENT POLICIES AND PRACTICES ON GHG EMISSIONS

The water supply sector can reduce its contribution to GHG emissions by gradually switching from fossil fuel-based to renewable sources of energy. This will be especially important as water distribution networks and water treatment stations are developed, and as techniques such as deep-well pumping are increasingly adopted as an adaptation to growing water scarcity.

Water reservoirs, whether they are built for the purpose of water supply and irrigation, flood control or hydropower production, can be a source of GHG (methane) emissions as a result of the anaerobic decomposition of vegetation in water; this is particularly the case in shallow reservoirs in tropical areas. On the other hand, reservoirs also absorb carbon dioxide at their surface, as part of the natural carbon cycle. Methane emissions can be reduced by building deeper reservoirs, and by clearing as much vegetation as possible before filling new reservoirs (to avoid the decomposition of large amounts of vegetation under water). There are still many scientific uncertainties as to the net effects of water reservoirs on GHG emissions; these effects should be evaluated on a case-by-case basis using available knowledge.

Expanding irrigated agriculture (where sufficient water is available for this purpose and this does not clash with other water sector objectives and priorities) may have both positive and negative effects in terms of GHG emissions, depending on circumstances and techniques used. If enhanced yields are obtained and residues are returned to the soil, carbon storage in soils should increase. On the other hand, increased use of fertilisers is likely to increase nitrous oxide (N_2O) emissions; the energy used to power irrigation system pumps may also be a source of carbon dioxide (CO_2) emissions if it originates from the burning of fossil fuels; and wetland rice fields are known to be a rather significant source of methane (CH_4) emissions. The net effects of an increase in water use for irrigation purposes (which in some regions is likely to be an appropriate adaptation measures) should thus be calculated on a case-by-case basis – and emissions can be reduced by the adoption of sound agricultural practices (see script on Agriculture and Rural Development).

Human sewage and wastewater treatment are sources of GHG (methane and nitrous oxide) emissions – although these are by far not the largest sources of global emissions. The individual sanitation systems (e.g. septic tanks and pit latrines) and decentralised, "natural" treatment processes such as infiltration systems, or the absence of treatment, that prevail in developing

countries are generally considered to generate more GHG emissions than more modern, centralised sewage and wastewater treatment techniques. The adoption of improved sanitation and wastewater management techniques offers many opportunities (during transport, treatment and final disposal) to reduce GHG emissions (e.g. controlling methane production from anaerobic digestion of wastewater sludge and recovering the gas) – in addition to producing well-known benefits in terms of public health, water resource conservation and environmental protection. On the other hand, more sophisticated water treatment requires the use of energy, which if not produced from renewable sources adds to GHG emissions. Another option is the promotion of low-water-use or dry toilets and ecological sanitation approaches, which recycle nutrients and carbon (e.g. by means of composting) and thus reduce net wastewater-associated GHG emissions.

3.2. Mitigation measures in other sectors influencing the water sector

As a result of changes in hydrological regimes, the construction of hydropower plants (as a way of increasing renewable energy production capacity) often results in significant adverse ecological impacts on river ecosystems and fisheries, as well as changes in the availability of water. Typically, water becomes more readily available in the neighbourhood of dams – but may become scarcer in downstream areas if, for instance, annual floods are suppressed or the size and duration of artificial floods is much less than the average size and duration of natural floods. Hydropower production may thus overall result in increased water stress and increased competition between downstream water users.

Geothermal energy systems (which may be developed for the same purpose) may draw significantly on local water resources; however, it is possible to design them in such a way that the water injected is re-used, thus reducing environmental impacts. The use of biomass for electricity generation, as renewable a substitute for fossil fuels, generally has positive effects on water ecosystems as it reduces demand for cooling water and its discharge into rivers.

Evaporative cooling, as an alternative to traditional air conditioning, means substantial savings in annual cooling energy use for buildings. However, this type of cooling places an extra pressure on available water resources – unless other measures (e.g. insulation, improvements in architectural design) are simultaneously adopted to reduce the accumulation of heat in buildings.

Land management and agricultural practices adopted for climate change mitigation purposes may have both positive and negative impacts on water resources. On the positive side, many of the practices advocated for enhancing carbon storage in soils (e.g. reduced tillage, enhanced vegetative cover) also prevent soil erosion, which can improve water quality. The more efficient use of fertilizers (to reduce nitrous oxide emissions) also has positive impacts on water quality. Wetland and peatland restoration, which enhance carbon sequestration capacity, also provide benefits in terms of improved water quality and decreased flooding.

On the other hand, practices such as reduced tillage may intensify the leaching of nutrients or pesticides into groundwater, thus intensifying water pollution. Such negative effects can be avoided, however, by adopting more environmentally friendly agricultural practices.

Afforestation and reforestation provide many benefits (in terms of carbon storage and otherwise) and tend to regularise hydrological flows, but they also entail the development of more massive root systems than other types of vegetation, and some tree species tend to “pump” a lot of water from the soil which is then lost through evapotranspiration. In specific circumstances (e.g. afforestation with fast-growing species on non-forest land), afforestation schemes may result in decreased water flows and water shortages during drought periods.

On the other hand, preventing or slowing deforestation and forest degradation, and promoting more sustainable approaches to forest management, may help conserve water resources, prevent the flooding of downstream areas and reduce runoff, erosion and the siltation of rivers – which are positive impacts as far as water management is concerned. The extent to which these benefits may be achieved may vary a lot across regions and situations, so it is recommended to assess them on a case-by-case basis.

X ILLUSTRATIVE EXAMPLES

Illustrative example 1: Egypt's water sector and climate change

Background

By the definition of the World Water Council, Egypt is already a water-stressed country (see footnote 3); it is likely to suffer aggravated stress under climate change. It is estimated that the rate of water utilisation has already reached the maximum sustainable rate (i.e. practically 100% of the renewable freshwater supply is abstracted and used); climate change, which is likely to make the country hotter and drier, will make it more vulnerable to water stress. 95% of the water used by this arid country comes from the Nile river. Agriculture accounts for approx. 85% of total annual consumption – and is a key and growing economic sector, contributing about 20% of GDP. Rice and sugarcane are the largest consumers of irrigation water. More than 70% of the cultivated area relies on low-efficiency irrigation systems, characterised by high water losses. Land productivity is declining, and poor irrigation practices cause waterlogging (i.e. saturation with water, which makes soils soggy and unsuitable for cultivation) and salinity problems as well as a deterioration in water quality. Other issues include the low efficiency of municipal water distribution systems, and the lack of capacity for treating wastewater. In response to these problems, Egyptian authorities have adopted a National Water Resources Policy (2002) that is no longer exclusively focused on water supply but incorporates some principles of integrated water resource management. It rests on three major pillars, namely:

- improving water use efficiency, notably by improving irrigation efficiency and promoting the reuse of agricultural drainage water;
- protecting water quality, by improving water sanitation coverage and developing wastewater treatment systems, and controlling pollution;
- increasing water supply.

Implications of climate change

The anticipated effects of climate change compound the current issues in various ways and make improved water management all the more important:

- Sea-level rise may have multiple adverse impacts, including impacts on freshwater availability, in the Nile delta and coastal areas (where a large share of the population lives). Seawater intrusion already contributes to increased salinity levels in the Northern Delta.
- Increased temperatures may reduce the productivity of major crops while increasing their water requirements, resulting in a decrease in crop water efficiency and an increase in irrigation demand.
- An increase in water stress is likely as a decline in rainfall is anticipated while the population is expected to grow significantly from now to 2050. All sectors are likely to be affected by increased water stress.
- There are significant uncertainties about the future flow patterns of the Nile. The ongoing expansion of irrigated areas, which may appear as a suitable adaptation measure, will in fact reduce the capacity of Egypt to cope with future fluctuations in flow.

While acknowledging these impacts and integrating them in water management strategies, it is nevertheless important to recognise that land use policies, demographic evolution and economic growth strategies have at least as much importance, and should be taken into account in planning and decision making.

Illustrative example 2: Tanzania's Great Ruaha River

Background

The catchment of the Great Ruaha River, in Tanzania, is occupied by 6 million people who cultivate a variety of crops, dominated by irrigated rice in the semi-arid and sub-humid parts of the catchment. A significant part of the country's electricity supply is provided by the Mtera and Kidatu hydropower schemes on the river.

The Great Ruaha was once considered a perennial river, however reduced rainfall particularly in the lower parts of the catchment has reduced flow. There are concerns that climate change may aggravate this trend. From 1993, dry-season flows ceased over significant stretches downstream from the Ihefu wetland, with consequences for rural livelihoods, electricity supply, tourism as well as the environment. Concern was such that in 2001 the Prime Minister announced government support for a programme aimed at re-establishing a year-round flow by 2010.

Responses

In 2003 a programme aimed at re-establishing continuous flow commenced. WWF worked with communities in eight districts in the catchment to both develop better catchment management and contribute to poverty reduction. Local Water Users' Associations (WUAs) were created to restore catchments and improve water management by physically rehabilitating the source catchments; negotiating agreements with major users (mainly agricultural) to improve water diversion schedules; and better enforcing existing water laws so as to stop illegal diversions.

The restoration of headwaters and riparian zones involved a number of measures including: controlling the practice of valley-bottom area cultivation; selectively removing alien species known to have a high demand for water, while restoring indigenous vegetation and reducing charcoal production; excluding cattle from sensitive areas; and re-locating some settlements away from river banks. Simultaneously, agreements were made with irrigators to improve water use efficiency via better coordination of water deliveries and reduced water abstraction during the dry season. A dam was constructed to provide water for livestock in a less sensitive area of the catchment, thus supporting breeding activities. Livelihood strategies were also diversified into new, less water-intensive activities such as retailing and beekeeping, and training allowed rice farmers to improve yields through the adoption of better practices.

Outcomes

Since 2004 sustained flows into the Ihefu wetlands have been restored, and the zero-flow periods downstream of these wetlands have been significantly reduced. Importantly, local institutions have been strengthened that will render communities less vulnerable to future conditions of water scarcity. The Water Users' Associations have a voice in larger catchment decision processes which ultimately contribute to the development and implementation of national water policies.

Lessons from the Great Ruaha project show how a range of simple community-based measures, both physical and institutional, can restore essential ecosystem services and increase resilience to water scarcity in the face of the challenges posed by climate change. In particular, the benefits of strengthening the capacities of communities and organisations to improve governance, diversify livelihoods and promote adaptive management practices have been demonstrated. This approach has significant potential for scaling up, especially as it rests on relatively inexpensive measures.

Illustrative example 3: Water sector adaptation in the Maldives

The Maldives, with a territory made up of many small and low-lying islands, is one of countries most exposed to the predicted effects of climate change, primarily but not exclusively as a result of the rise in sea levels. The country's National Adaptation Programme of Action (NAPA), adopted under the UN Framework Convention on Climate Change (UNFCCC), includes two priority adaptation projects related to water and sanitation.

Freshwater is an extremely scarce resource in the Maldives. The recent Indian Ocean tsunami aggravated the situation, with flooding causing the salinization of groundwater and damaging water storage infrastructure. This event highlighted the vulnerability of water resources, and showed how they could be further threatened by the impacts of climate change, in particular salinity intrusions resulting from the rise in sea levels and flooding caused by storms and sea surges. The government thus decided to invest in two actions aimed at increasing the country's resilience to the effects of climate change on water resources:

- an increase in rainwater harvesting and storage capacity on public land and in public buildings – including measures to protect the new infrastructure from flooding and high wave incidents, and the development of community awareness to encourage the adoption of private measures;
- the development of backup desalination systems, which could provide freshwater in situations of emergency such as wide-scale contamination of groundwater by seawater.

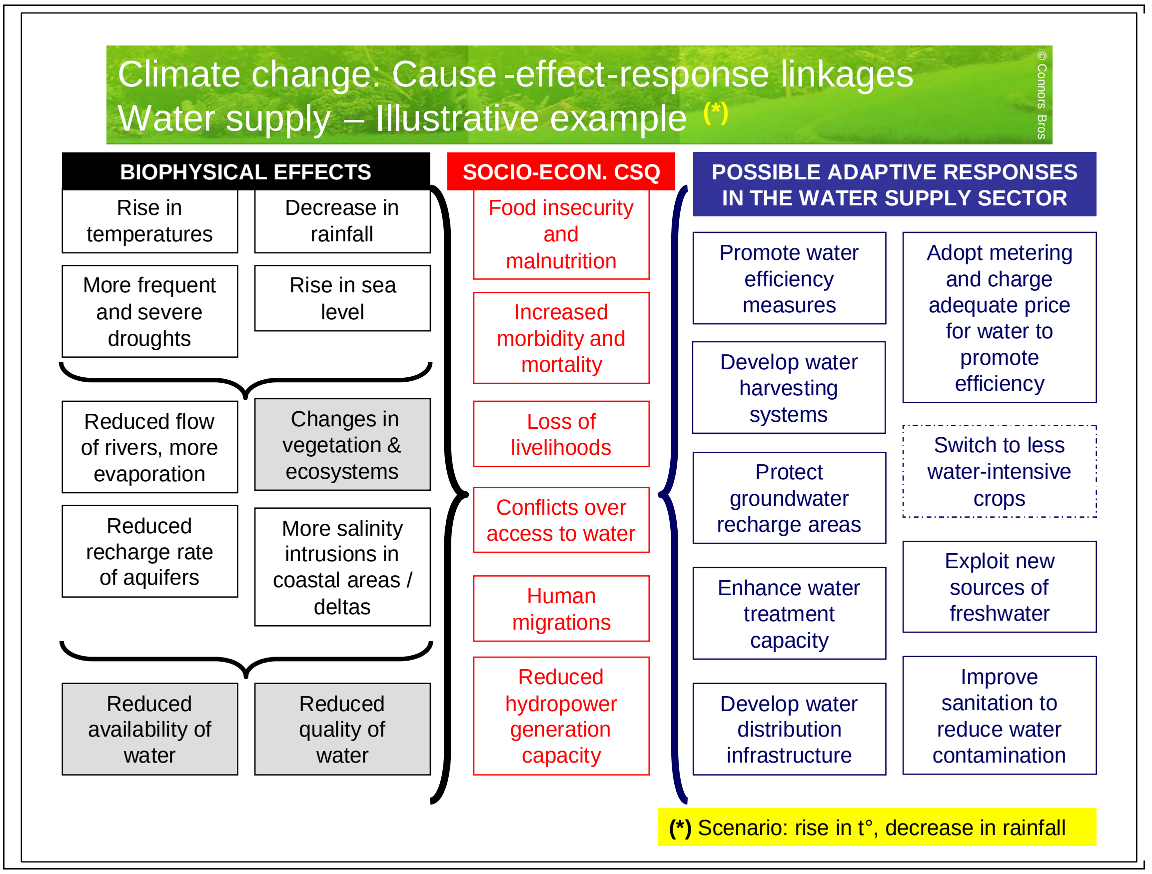
In the same planning exercise, a project has been designed to develop (on one island) an adequate wastewater treatment system, which could then be replicated on other islands. This is considered to be part of the national climate change adaptation strategy because the lack of adequate wastewater treatment has been identified as a significant threat to both the quality of freshwater supplies (and thus to health), and the quality of the environment (as untreated water discharge along the coasts damages coral reef biodiversity and reduces the potential of coastal fisheries). Improving wastewater treatment should thus simultaneously increase the resilience of human populations, economic systems and ecosystems.

y ILLUSTRATION OF LINKAGES

Below is an illustration (in a format that was voluntarily kept simple[2]) of the linkages between biophysical effects of climate change, potential socio-economic consequences and possible adaptive responses. It is provided to help visualize some important cause-effect relationships and how adaptive responses relate to the identified manifestations and impacts of climate change.

Legend:

Changes to ecosystems	Grey boxes show biophysical impacts that are not exclusively or even primarily caused by climate change – but are also significantly influenced by other pressures resulting from human activities.
Develop migration & conflict management capacities	Boxes framed with a dotted line show possible responses that are in principle not under the direct control of the concerned sector authorities – but depend on the development of a cross-sectoral coordinated response.



2 These illustrations are not meant to be comprehensive, or to be universally applicable; the simple format retained does not allow showing the multiple systemic interactions (including feedback loops) between various elements.

Z REFERENCES

General references:

(1) ABDALATI, W. and K. STEFFEN (2001) – Greenland ice sheet melt extent: 1979–1999. J. Geophys. Res., 106(D24), 33983–33988.

(2) BATES, B.C., Z.W. KUNDZEWICZ, S. WU and J.P. PALUTIKOF, Eds. (2008) – Climate Change and Water, Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva. (The majority of this sector script summarises key elements of this IPCC report)

(3) BOUTKAN, E. and A. STIKKER (2004) – 'Enhanced water resource base for sustainable integrated water resource management', Nat. Resour. Forum, 28, 150-154.

(4) HOANH, C.T., H. GUTTMAN, P. DROOGERS and J. AERTS (2004) – 'Will we produce sufficient food under climate change? Mekong Basin (South-east Asia)', in AERTS, J.C., J.H. AERTS and P. DROOGERS, Eds. – Climate Change in Contrasting River Basins: Adaptation Strategies for Water, Food, and Environment, CABI Publishing, Wallingford, 157–180.

(5) IPCC (2007) – Climate Change 2007 – Impacts, Adaptation and Vulnerability, contribution of Working Group II to the Fourth Assessment Report, Intergovernmental Panel on Climate Change/Cambridge University Press. Available on: http://www.ipcc.ch/ipccreports/assessments-reports.htm (see in particular Chapter 3 on "freshwater resources and their management" and Chapter 6 on "coastal systems and low-lying areas)

(6) World Water Council website: www.worldwatercouncil.org

Illustrative example

(7) BATES, B.C., Z.W. KUNDZEWICZ, S. WU and J.P. PALUTIKOF, Eds. (2008) – Climate Change and Water, Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, p. 84.

(8) BOKO, M., I. NIANG, A. NYONG et al. (2007) – 'Africa', Climate Change 2007 – Impacts, Adaptation and Vulnerability, contribution of Working Group II to the Fourth Assessment Report, Chapter 9, Intergovernmental Panel on Climate Change/Cambridge University Press. Available on: http://www.ipcc.ch/ipccreports/assessments-reports.htm.

(9) ICID (2005) – Water Policy Issues of Egypt, Country Policy Support Programme (CPSP), International Commission on Irrigation and Drainage, New Delhi. Available on: http://www.icid.org/cpsp_report7_web.pdf.

(10) WWF (2008) – Water for Life: Lessons for climate change adaptation from better management of rivers for people and nature.

(11) Republic of Maldives (2007) – National Adaptation Programme of Action (NAPA), Ministry of Environment, Energy and Water, Male'. Available on: http://unfccc.int/cooperation_support/least_developed_countries_portal/submitted_napas/items/4585.php

{ FURTHER INFORMATION AND SUPPORT

For further support in relation to the use of sector scripts, including the identification of sources of information on climate change projections in specific regions, you may contact the team in charge of providing advisory services for environmental integration in EC development/external co-operation:

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