6

Climate change mitigation measures and water

6.1 Introduction

The relationship between climate change mitigation measures and water is a reciprocal one. Mitigation measures can influence water resources and their management, and it is important to realise this when developing and evaluating mitigation options. On the other hand, water management policies and measures can have an influence on greenhouse gas (GHG) emissions and, thus, on the respective sectoral mitigation measures; interventions in the water system might be counter-productive when evaluated in terms of climate change mitigation.

The issue of mitigation is addressed in the IPCC WGIII AR4 (Mitigation), where the following seven sectors were discussed: energy supply, transportation and its infrastructure, residential and commercial buildings, industry, agriculture, forestry, and waste management. Since water issues were not the focus of that volume, only general interrelations with climate change mitigation were mentioned, most of them being qualitative. However, other IPCC reports, such as the TAR, also contain information on this issue.

Sector-specific mitigation measures can have various effects on water, which are explained in the sections below (see also Table 6.1). Numbers in parentheses in the titles of the sub-sections correspond to the practices or sector-specific mitigation options described in Table 6.1.

6.2 Sector-specific mitigation

6.2.1 Carbon dioxide capture and storage (CCS) (refer to (1) in Table 6.1)

Carbon dioxide (CO_2) capture and storage (CCS) is a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere. The injection of CO_2 into the pore space and fractures of a permeable formation can displace *in situ* fluid, or the CO_2 may dissolve in or mix with the fluid or react with the mineral grains, or there may be some combination of these processes. As CO_2 migrates through the formation, some of it will dissolve into the formation water. Once CO_2 is dissolved in the formation fluid, it is transported by the regional groundwater flow. Leakage of CO_2 from leaking injection wells, abandoned wells, and leakage across faults and ineffective confining layers could potentially degrade the quality of groundwater; and the release of CO_2 back into the atmosphere could also create local health and safety concerns. [CCS SPM, 5.ES]

It is important to note that, at this point, there is no complete insight into the practicality, consequences or unintended consequences of this carbon sequestration concept. Avoiding or mitigating the impacts will require careful site selection, effective regulatory oversight, an appropriate monitoring programme, and implementation of remediation methods to stop or control CO_2 releases. [CCS 5.ES, 5.2].

6.2.2 Bio-energy crops (2)

Bio-energy produces mitigation benefits by displacing fossil-fuel use. [LULUCF 4.5.1] However, large-scale bio-fuel production raises questions on several issues including fertiliser and pesticide requirements, nutrient cycling, energy balances, biodiversity impacts, hydrology and erosion, conflicts with food production, and the level of financial subsidies required. [LULUCF 4.5.1] The energy production and GHG mitigation potentials of dedicated energy crops depends on the availability of land, which must also meet demands for food as well as for nature protection, sustainable management of soils and water reserves, and other sustainability criteria. Various studies have arrived at differing figures for the potential contribution of biomass to future global energy supplies, ranging from below 100 EJ/yr to above 400 EJ/yr in 2050 (Hoogwijk, 2004; Hoogwijk et al., 2005; Sims et al., 2006). Smeets et al. (2007) indicate that the ultimate technical potential for energy cropping on current agricultural land, with projected technological progress in agriculture and livestock, could deliver over 800 EJ/yr without jeopardising the world's food supply. Differences between studies are largely attributable to uncertainty in land availability, energy crop yields, and assumptions about changes in agricultural efficiency. Those with the largest projected potential assume that not only degraded/surplus lands are used, but also land currently used for food production, including pasture land (as did Smeets et al., 2007). [WGIII 8.4.4.2]

Agricultural practices for mitigation of GHGs could, in some cases, intensify water use, thereby reducing streamflow or groundwater reserves (Unkovich, 2003; Dias de Oliveira et al., 2005). For instance, high-productivity, evergreen, deep-rooted bio-energy plantations generally have a higher water use than the land cover they replace (Berndes and Börjesson, 2002; Jackson et al., 2005). Some practices may affect water quality through enhanced leaching of pesticides and nutrients (Machado and Silva, 2001; Freibauer et al., 2004). [WGIII 8.8]

Agricultural mitigation practices that divert products to alternative uses (e.g., bio-energy crops) may induce the conversion of forests to cropland elsewhere. Conversely, increasing productivity on existing croplands may 'spare' some forest or grasslands (West and Marland, 2003; Balmford et al., 2005; Mooney et al., 2005). The net effect of such trade-offs on biodiversity and other ecosystem services has not yet been fully quantified (Huston and Marland, 2003; Green et al., 2005). [WGIII 8.8]

If bio-energy plantations are appropriately located, designed and managed, they may reduce nutrient leaching and soil erosion and generate additional environmental services such as soil carbon accumulation, improved soil fertility, and the removal of cadmium and other heavy metals from soils or wastes. They may also increase nutrient recirculation, aid in the

Table 6.1: *Influence of sector-specific mitigation options (or their consequences) on water quality, quantity and level. Positive effects on water are indicated with [+]; negative effects with [−]; and uncertain effects with [?]. Numbers in round brackets refer to the Notes, and also to the sub-section numbers in Section 6.2.*

Water aspect	Energy	Buildings	Industry	Agriculture	Forests	Waste
Quality						
Chemical/ biological	CCS(1) [?] Bio-fuels(2) [+/-] Geothermal energy(5) [-] Unconventional oil(13) [-]		CCS(1) [?] Wastewater treatment(12) [-] Biomass electricity(3) [-/?]	Land-use change and management (7) [+/-] Cropland management (water)(8) [+/-]	Afforestation (sinks)(10) [+]	Solid waste management; Wastewater treatment(12) [+/-]
Temperature	Biomass electricity(3) [+]			Cropland management (reduced tillage) (9) [+/-]		
Quantity						
Availability/ demand	Hydropower(4) [+/-] Unconventional oil(13) [-] Geothermal energy(5) [-]	Energy use in buildings(6) [+/-]		Land-use change and management (7) [+/-] Cropland management (water)(8) [-]	Afforestation (10) [+/-] Avoided/ reduced deforestation (11) [+]	Wastewater treatment(12) [+]
Flow/runoff/ recharge	Bio-fuels(2) [+/-] Hydropower (4) [+/-]			Cropland management (reduced tillage) (9) [+]		
Water level						
Surface water	Hydropower (4) [+/-]			Land-use change and management (7) [+/-]		
Groundwater	Geothermal energy(5) [-]			Land-use change and management (7) [+/-]	Afforestation(10) [-]	

Notes:

(1) Carbon capture and storage (CCS) underground poses potential risks to groundwater quality; deep-sea storage (below 3,000 m water depth and a few hundred metres of sediment) seems to be the safest option.

(2) Expanding bio-energy crops and forests may cause negative impacts such as increased water demand, contamination of underground water and promotion of land-use changes, leading to indirect effects on water resources; and/or positive impacts through reduced nutrient leaching, soil erosion, runoff and downstream siltation.

(3) Biomass electricity: in general, a higher contribution of renewable energy (as compared to fossil-fuel power plants) means a reduction of the discharge of cooling water to the surface water.

(4) Environmental impact and multiple benefits of hydropower need to be taken into account for any given development; they could be either positive or negative.

(5) Geothermal energy use might result in pollution, subsidence and, in some cases, a claim on available water resources.

(6) Energy use in the building sector can be reduced by different approaches and measures, with positive and negative impacts.

(7) Land-use change and management can influence surface water and groundwater quality (e.g., through enhanced or reduced leaching of nutrients and pesticides) and the (local) hydrological cycle (e.g., a higher water use).

(8) Agricultural practices for mitigation can have both positive and negative effects on conservation of water and on its quality.

(9) Reduced tillage promotes increased water-use efficiency.

(10) Afforestation generally improves groundwater quality and reduces soil erosion. It influences both catchment and regional hydrological cycles (a smoothed hydrograph, thus reducing runoff and flooding). It generally gives better watershed protection, but at the expense of surface water yield and aquifer recharge, which may be critical in semi-arid and arid regions.

(11) Stopping/slowing deforestation and forest degradation conserve water resources and prevent flooding, reduce run-off, control erosion and reduce siltation of rivers.

(12) The various waste management and wastewater control and treatment technologies can both reduce GHG emissions and have positive effects on the environment, but they may cause water pollution in case of improperly designed or managed facilities.

(13) As conventional oil supplies become scarce and extraction costs increase, unconventional liquid fuels will become more economically attractive, but this is offset by greater environmental costs (a high water demand; sanitation costs).

treatment of nutrient-rich wastewater and sludge, and provide habitats for biodiversity in the agricultural landscape (Berndes and Börjesson, 2002; Berndes et al., 2004; Börjesson and Berndes, 2006). [WGIII 8.8] In the case of forest plantations for obtaining bio-fuels, negative environmental impacts are avoidable through good project design. Environmental benefits include, among others, reduced soil degradation, water runoff, and downstream siltation and capture of polluting agricultural runoff. [LULUCF Fact Sheet 4.21]

6.2.3 Biomass electricity (3)

Non-hydro renewable energy supply technologies, particularly solar, wind, geothermal and biomass, are currently small overall contributors to global heat and electricity supply, but are increasing most rapidly, albeit from a low base. Growth of biomass electricity is restricted due to cost, as well as social and environmental barriers. [WGIII 4.ES] For the particular case of biomass electricity, any volumes of biomass needed above those available from agricultural and forest residues [WGIII Chapters 8 and 9] will need to be purpose-grown, so could be constrained by land and water availability. There is considerable uncertainty, but there should be sufficient production possible in all regions to meet the additional generation from bio-energy of 432 TWh/yr by 2030, as projected in this analysis. [WGIII 4.4.4] In general, the substitution of fossil fuels by biomass in electricity generation will reduce the amount of cooling water discharged to surface water streams.

6.2.4 Hydropower (4)

Renewable energy systems such as hydro-electricity can contribute to the security of energy supply and protection of the environment . However, construction of hydro-electric power plants may also cause ecological impacts on existing river ecosystems and fisheries, induced by changes in flow regime (the hydrograph) and evaporative water losses (in the case of dam-based power-houses). Also social disruption may be an impact. Finally, water availability for shipping (water depth) may cause problems. Positive effects are flow regulation, flood control, and availability of water for irrigation during dry seasons. Furthermore, hydropower does not require water for cooling (as in the case of thermal power plants) or, as in the case of bio-fuels, for growth. About 75% of water reservoirs in the world were built for irrigation, flood control and urban water supply schemes, and many could have small hydropower generation retrofits added without additional environmental impacts. [WGIII 4.3.3]

Large (>10 MW) hydro-electricity systems accounted for over 2,800 TWh of consumer energy in 2004 and provided 16% of global electricity (90% of renewable electricity). Hydro projects under construction could increase the share of hydro-electricity by about 4.5% on completion and new projects could be deployed to provide a further 6,000 TWh/yr or more of electricity economically, mainly in developing countries. Repowering existing plants with more powerful and efficient turbine designs can be cost-effective whatever the plant scale. [WGIII 4.3.3.1]

Small (<10 MW) and micro (<1 MW) hydropower systems, usually run-of-river schemes, have provided electricity to many rural communities in developing countries such as Nepal. Their present generation output is uncertain, with predictions ranging from 4 TWh/yr to 9% of total hydropower output at 250 TWh/yr. The global technical potential of small and micro-hydro is around 150–200 GW, with many unexploited resource sites available. [WGIII 4.3.3.1]

The many benefits of hydro-electricity, including irrigation and water supply resource creation, rapid response to grid demand fluctuations due to peaks or intermittent renewables, recreational lakes, and flood control, as well as the negative aspects, need to be evaluated for any given development. [WGIII 4.3.3.1]

6.2.5 Geothermal energy (5)

Geothermal resources have long been used for direct heat extraction for district urban heating, industrial processing, domestic water and space heating, leisure and balneotherapy applications. [WGIII 4.3.3.4]

Geothermal fields of natural steam are rare, most being a mixture of steam and hot water requiring single or double flash systems to separate out the hot water, which can then be used in binary plants or for direct heating. Re-injection of the fluids maintains a constant pressure in the reservoir, hence increasing the field's life and reducing concerns about environmental impacts. [WGIII 4.3.3.4]

Sustainability concerns relating to land subsidence, heat extraction rates exceeding natural replenishment (Bromley and Currie, 2003), chemical pollution of waterways (e.g., with arsenic), and associated CO_2 emissions have resulted in some geothermal power plant permits being declined. This could be partly overcome by re-injection techniques. Deeper drilling technology could help to develop widely abundant hot dry rocks where water is injected into artificially fractured rocks and heat extracted as steam. However, at the same time, this means a claim on available water resources. [WGIII 4.3.3.4]

6.2.6 Energy use in buildings (6)

Evaporative cooling, as a mitigation measure, means substantial savings in annual cooling energy use for residences. However, this type of cooling places an extra pressure on available water resources. Cooling energy use in buildings can be reduced by different measures, for example reducing the cooling load by building shape and orientation. Reducing this energy means, in the case of using water for cooling, a lower water demand. [WGIII 6.4.4]

6.2.7 Land-use change and management (7)

According to IPCC Good Practice Guidance for LULUCF, there are six possible broad land-use categories: forest land, cropland, grassland, wetlands, settlements, and other. Changes in land use (e.g., conversion of cropland to grassland) may result in net changes in carbon stocks and in different impacts on water resources. For land-use changes other than land converted to forest (as discussed in Section 6.2.10), previous IPCC documents contain very few references to their impacts on water resources. Wetland restoration, one of the main mitigation practices in agriculture [WGIII 8.4.1.3], results in the improvement of water quality and decreased flooding. [LULUCF Table 4.10] Set-aside, another mitigation practice identified by WGIII, may have positive impacts on both water conservation and water quality. [WGIII Table 8.12]

Land management practices implemented for climate change mitigation may also have different impacts on water resources. Many of the practices advocated for soil carbon conservation – reduced tillage, more vegetative cover, greater use of perennial crops – also prevent erosion, yielding possible benefits for improved water and air quality (Cole et al., 1993). These practices may also have other potential adverse effects, at least in some regions or conditions. Possible effects include enhanced contamination of groundwater with nutrients or pesticides via leaching under reduced tillage (Cole et al., 1993; Isensee and Sadeghi, 1996). These possible negative effects, however, have not been widely confirmed or quantified, and the extent to which they may offset the environmental benefits of carbon sequestration is uncertain. [WGIII TAR 4.4.2]

The group of practices known as agriculture intensification (Lal et al., 1999; Bationo et al., 2000; Resck et al., 2000; Swarup et al., 2000), including those that enhance production and the input of plant-derived residues to soil (crop rotations, reduced bare fallow, cover crops, high-yielding varieties, integrated pest management, adequate fertilisation, organic amendments, irrigation, water-table management, site-specific management, and others), has numerous ancillary benefits, the most important of which is the increase and maintenance of food production. Environmental benefits can include erosion control, water conservation, improved water quality, and reduced siltation of reservoirs and waterways. Soil and water quality is adversely affected by the indiscriminate use of agriculture inputs and irrigation water. [LULUCF Fact Sheet 4.1]

Nutrient management to achieve efficient use of fertilisers has positive impacts on water quality. [WGIII Table 8.12] In addition, practices that reduce N_2O emission often improve the efficiency of nitrogen use from these and other sources (e.g., manures), thereby also reducing GHG emissions from fertiliser manufacture and avoiding deleterious effects on water and air quality from nitrogen pollutants (Dalal et al., 2003; Paustian et al., 2004; Oenema et al., 2005; Olesen et al., 2006). [WGIII 8.8]

Agro-forestry systems (plantation of trees in cropland) can provide multiple benefits including energy to rural communities with synergies between sustainable development and GHG mitigation. [LULUCF 4.5.1] However, agro-forestry may have negative impacts on water conservation. [WGIII Table 8.12]

6.2.8 Cropland management (water) (8)

Agricultural practices which promote the mitigation of greenhouse gases can have both negative and positive effects on the conservation of water, and on its quality. Where the measures promote water-use efficiency (e.g., reduced tillage), they provide potential benefits. But in some cases, the practices could intensify water use, thereby reducing streamflow or groundwater reserves (Unkovich, 2003; Dias de Oliveira et al., 2005). Rice management has generally positive impacts on water quality through a reduction in the amount of chemical pollutants in drainage water. [WGIII Table 8.12]

6.2.9 Cropland management (reduced tillage) (9)

Conservation tillage is a generic term that includes a wide range of tillage practices, including chisel plough, ridge till, strip till, mulch till and no till (CTIC, 1998). Adoption of conservation tillage has numerous ancillary benefits. Important among these benefits are the control of water and wind erosion, water conservation, increased water-holding capacity, reduced compaction, increased soil resilience to chemical inputs, increased soil and air quality, enhanced soil biodiversity, reduced energy use, improved water quality, reduced siltation of reservoirs and waterways, and possible double-cropping. In some areas (e.g., Australia), increased leaching from greater water retention with conservation tillage can cause downslope salinisation. [LULUCF Fact Sheet 4.3] Important secondary benefits of conservation tillage adoption include soil erosion reduction, improvements in water quality, increased fuel efficiency, and increases in crop productivity. [LULUCF 4.4.2.4] Tillage/residue management has positive impacts on water conservation. [WGIII Table 8.12]

6.2.10 Afforestation or reforestation (10)

Forests, generally, are expected to use more water (the sum of transpiration and evaporation of water intercepted by tree canopies) than crops, grass, or natural short vegetation. This effect, occurring in lands that are subjected to afforestation or reforestation, may be related to increased interception loss, especially where the canopy is wet for a large proportion of the year (Calder, 1990) or, in drier regions, to the development of more massive root systems, which allow water extraction and use during prolonged dry seasons. [LULUCF 2.5.1.1.4]

Interception losses are greatest from forests that have large leaf areas throughout the year. Thus, such losses tend to be greater for evergreen forests than for deciduous forests (Hibbert, 1967; Schulze, 1982) and may be expected to be larger for fast-growing forests with high rates of carbon storage than for slow-growing forests. Consequently, afforestation with fast-growing conifers on non-forest land commonly decreases the flow of water from catchments and can cause water shortages during droughts (Hibbert, 1967; Swank and Douglass, 1974). Vincent (1995), for example, found that establishing high-water-demanding species of pines to restore degraded Thai watersheds markedly reduced dry season streamflows relative to the original deciduous forests. Although forests lower average flows, they may reduce peak flows and increase flows during dry seasons because forested lands tend to have better infiltration capacity and a high capacity to retain water (Jones and Grant, 1996). Forests also play an important role in improving water quality. [LULUCF 2.5.1.1.4]

In many regions of the world where forests grow above shallow saline water tables, decreased water use following deforestation can cause water tables to rise, bringing salt to the surface (Morris and Thomson, 1983). In such situations, high water use by trees (e.g., through afforestation or reforestation) can be of benefit (Schofield, 1992). [LULUCF 2.5.1.1.4]

In the dry tropics, forest plantations often use more water than short vegetation because trees can access water at greater depth and evaporate more intercepted water. Newly planted forests can use more water (by transpiration and interception) than the annual rainfall, by mining stored water (Greenwood et al., 1985). Extensive afforestation or reforestation in the dry tropics can therefore have a serious impact on supplies of groundwater and river flows. It is less clear, however, whether replacing natural forests with plantations, even with exotic species, increases water use in the tropics when there is no change in rooting depth or stomatal behaviour of the tree species. In the dry zone of India, water use by *Eucalyptus* plantations is similar to that of indigenous dry deciduous forest: both forest types essentially utilise all the annual rainfall (Calder, 1992). [LULUCF 2.5.1.1.4]

Afforestation and reforestation, like forest protection, may also have beneficial hydrological effects. After afforestation in wet areas, the amount of direct runoff initially decreases rapidly, then gradually becomes constant, and baseflow increases slowly as stand age increases towards maturity (Fukushima, 1987; Kobayashi, 1987), suggesting that reforestation and afforestation help to reduce flooding and enhance water conservation. In water-limited areas, afforestation, especially plantations of species with high water demand, can cause a significant reduction in streamflow, affecting the inhabitants of the basin (Le Maitre and Versfeld, 1997), and reducing water flow to other ecosystems and rivers, thus affecting aquifers and recharge (Jackson et al., 2005). In addition, some possible changes in soil properties are largely driven by changes in hydrology. The hydrological benefits of afforestation may need to be evaluated individually for each site. [WGIII TAR 4.4.1]

Positive socio-economic benefits, such as wealth or job creation, must be balanced by the loss of welfare resulting from reductions in available water, grazing, natural resources, and agricultural land. Afforestation of previously eroded or otherwise degraded land may have a net positive environmental impact; in catchments where the water yield is large or is not heavily used, streamflow reduction may not be critical. [LULUCF 4.7.2.4]

6.2.11 Avoided/reduced deforestation (11)

Stopping or slowing deforestation and forest degradation (loss of carbon density) and sustainable management of forests may significantly contribute to avoided emissions, may conserve water resources and prevent flooding, reduce runoff, control erosion, reduce siltation of rivers, and protect fisheries and investments in hydro-electric power facilities; and at the same time preserve biodiversity (Parrotta, 2002). [WGIII 9.7.2]

Preserving forests conserves water resources and prevents flooding. For example, the flood damage in Central America following Hurricane Mitch was apparently enhanced by the loss of forest cover. By reducing runoff, forests control erosion and salinity. Consequently, maintaining forest cover can reduce siltation of rivers, protecting fisheries and investment in hydro-electric power facilities (Chomitz and Kumari, 1996). [WGIII TAR 4.4.1]

Deforestation and degradation of upland catchments can disrupt hydrological systems, replacing year-round water flows in downstream areas with flood and drought regimes (Myers, 1997). Although there are often synergies between increased carbon storage through afforestation, reforestation and deforestation (ARD) activities and other desirable associated impacts, no general rules can be applied; impacts must be assessed individually for each specific case. Associated impacts can often be significant, and the overall desirability of specific ARD activities can be greatly affected by their associated impacts. [LULUCF 3.6.2]

6.2.12 Solid waste management; wastewater treatment (12)

Controlled landfill (with or without gas recovery and utilisation) controls and reduces GHG emissions but may have negative impacts on water quality in the case of improperly managed sites. This also holds for aerobic biological treatment (composting) and anaerobic biological treatment (anaerobic digestion). Recycling, reuse and waste minimisation can be negative for waste scavenging from open dump sites, with water pollution as a potential consequence. [WGIII Table 10.7]

When efficiently applied, wastewater transport and treatment technologies reduce or eliminate GHG generation and emissions. In addition, wastewater management promotes water conservation by preventing pollution from untreated discharges to surface water, groundwater, soils, and coastal zones, thus reducing the volume of pollutants, and requiring a smaller volume of water to be treated. [WGIII 10.4.6]

Treated wastewater can either be reused or discharged, but reuse is the most desirable option for agricultural and horticultural irrigation, fish aquaculture, artificial recharge of aquifers, or industrial applications. [WGIII 10.4.6]

6.2.13 Unconventional oil (13)

As conventional oil supplies become scarce and extraction costs increase, unconventional liquid fuels will become more economically attractive, although this is offset by greater environmental costs (Williams et al., 2006). Mining and upgrading of oil shale and oil sands requires the availability of abundant water. Technologies for recovering tar sands include open cast (surface) mining, where the deposits are shallow enough, or injection of steam into wells *in situ* to reduce the viscosity of the oil prior to extraction. The mining process uses about four litres of water to produce one litre of oil but produces a refinable product. The *in situ* process uses about two litres of water to one litre of oil, but the very heavy product needs cleaning and diluting (usually with naphtha) at the refinery or needs to be sent to an upgrader to yield syncrude at an energy efficiency of around 75% (NEB, 2006). The energy efficiency of oil sand upgrading is around 75%. Mining of oil sands leaves behind large quantities of pollutants and areas of disturbed land. [WGIII 4.3.1.4]

6.3 Effects of water management policies and measures on GHG emissions and mitigation

As shown in the previous section, climate change mitigation practices in various sectors may have an impact on water resources. Conversely, water management policies and measures can have an influence on GHG emissions associated with different sectors, and thus on their respective mitigation measures (Table 6.2).

6.3.1 Hydro dams (1)

About 75% of water reservoirs in the world were built for irrigation, flood control and urban water supply schemes. Greenhouse gas emissions vary with reservoir location, power density (power capacity per area flooded), flow rate, and whether the plant is dam-based or run-of-river type. Recently, the greenhouse gas footprint of hydropower reservoirs has been questioned. Some reservoirs have been shown to absorb carbon dioxide at their surface, but most emit small amounts of GHGs as water conveys carbon in the natural carbon cycle. High emissions of methane have been recorded at shallow, plateau-type tropical reservoirs where the natural carbon cycle is most productive, while deep-water reservoirs exhibit lower emissions. Methane from natural floodplains and wetlands may be suppressed if they are inundated by a new reservoir, since methane is oxidised as it rises through the water column. Methane formation in freshwater involves by-product carbon compounds (phenolic and humic acids) that effectively sequester the carbon involved. For shallow tropical reservoirs, further research is needed to establish the extent to which these may increase methane emissions. [WGIII 4.3.3.1]

The emission of greenhouse gases from reservoirs due to rotting vegetation and carbon inflows from the catchment is a recently identified ecosystem impact of dams. This challenges the conventional wisdom that hydropower produces only positive atmospheric effects (e.g., reductions in emissions of CO_2 and nitrous oxides), when compared with conventional power generation sources (World Commission on Dams, 2000).

Lifecycle assessments of hydropower projects available at the time of the AR4 showed low overall net greenhouse gas emissions. Given that measuring the incremental anthropogenic-related emissions from freshwater reservoirs remains uncertain, the UNFCCC Executive Board has excluded large hydro projects with significant water storage from its Clean Development Mechanism (CDM). [WGIII 4.3.3.1]

6.3.2 Irrigation (2)

About 18% of the world's croplands now receive supplementary water through irrigation (Millennium Ecosystem Assessment, 2005a, b). Expanding this area (where water reserves allow), or using more effective irrigation measures, can enhance carbon storage in soils through enhanced yields and residue returns (Follett, 2001; Lal, 2004). However, some of these gains may be offset by carbon dioxide from energy used to deliver the water (Schlesinger, 1999; Mosier et al., 2005) or from N_2O emissions from higher moisture and fertiliser nitrogen inputs (Liebig et al., 2005), though the latter effect has not been widely measured [WGIII 8.4.1.1.d]. The expansion of wetland rice area may also cause increased methane emissions from soils (Yan et al., 2003). [WGIII 8.4.1.1.e]

6.3.3 Residue return (3)

Weed competition for water is an important cause of crop failure or decreases in crop yields worldwide. Advances in weed control methods and farm machinery now allow many crops to be grown with minimal tillage (reduced tillage) or without tillage (no-till). These practices, which result in the maintenance of crop residues on the soil surface, thus avoiding water losses by evaporation, are now being used increasingly throughout the world (e.g., Cerri et al., 2004). Since soil disturbance tends to stimulate soil carbon losses through enhanced decomposition and erosion (Madari et al., 2005), reduced- or no-till agriculture often results in soil carbon gain, though not always (West and Post, 2002; Alvarez, 2005; Gregorich et al., 2005; Ogle et al., 2005). Adopting reduced- or no-till may also affect emissions of N_2O, but the net effects are inconsistent and not well quantified globally (Cassman et al., 2003; Smith and Conen, 2004; Helgason et al., 2005; Li et al., 2005). The effect of reduced tillage on N_2O emissions may depend on soil and climatic conditions: in some areas reduced tillage promotes N_2O emissions; elsewhere it may reduce emissions or have no measurable influence (Marland et al., 2001). Furthermore, no-tillage systems can reduce carbon dioxide emissions from

***Table 6.2:** Influence of water management on sectoral GHG emissions. Increased GHG emissions are indicated with [−], (because this implies a negative impact) and reduced GHG emissions with [+]. Numbers in round brackets refer to the Notes, and also to the sub-section numbers in Section 6.3.*

Sector	Quality		Quantity		Water level	
	Chemical/ biological	Temperature	Average demand	Soil moisture	Surface water	Ground water
Energy		Geothermal energy(7) [+]	Hydro dams(1) [+/-] Irrigation(2) [-] Geothermal energy(7) [+] Desalinisation(6) [-]		Hydro dams (1) [+/-]	
Agriculture			Hydro dams(1) [-]	Irrigation(2) [+/-] Residue return(3) [+]		Drainage of cropland(4) [+/-]
Waste	Wastewater treatment(5) [+/-]					

Notes:

(1) Hydropower does not require fossil fuel and is an important source of renewable energy. However, recently the GHG footprint of hydropower reservoirs has been questioned. In particular, methane is a problem.

(2) Applying more effective irrigation measures can enhance carbon storage in soils through enhanced yields and residue returns, but some of these gains may be offset by CO_2 emissions from the energy used to deliver the water. Irrigation may also induce additional CH_4 and N_2O emissions, depending on case-specific circumstances.

(3) Residue returned to the field, to improve water-holding capacity, will sequester carbon through both increased crop productivity and reduced soil respiration.

(4) Drainage of agricultural lands in humid regions can promote productivity (and hence soil carbon) and perhaps also suppress N_2O emissions by improving aeration. Any nitrogen lost through drainage, however, may be susceptible to loss as N_2O.

(5) Depending on the design and management of facilities (wastewater treatment and treatment purification technologies), more or less CH_4 and N_2O emissions – the major GHG emissions from wastewater – can be emitted during all stages from source to disposal; however, in practice, most emissions occur upstream of treatment.

(6) Desalinisation requires the use of energy, and thus generates GHG emissions.

(7) Using geothermal energy for heating purposes does not generate GHG emissions, as is the case with other methods of energy production.

energy use (Marland et al., 2003; Koga et al., 2006). Systems that retain crop residues also tend to increase soil carbon because these residues are the precursors for soil organic matter, the main store of carbon in soil. Avoiding the burning of residues (e.g., mechanising the harvest of sugarcane, eliminating the need for pre-harvest burning; Cerri et al., 2004), also avoids emissions of aerosols and GHGs generated from fire, although carbon dioxide emissions from fuel use may increase. [WGIII 8.4.1.1.c]

6.3.4 Drainage of cropland (4)

Drainage of croplands in humid regions can promote productivity (and hence soil carbon) and perhaps also suppress N_2O emissions by improving aeration (Monteny et al., 2006). Any nitrogen lost through drainage, however, may be susceptible to loss as N_2O (Reay et al., 2003). [WGIII 8.4.1.1.d]

6.3.5 Wastewater treatment (5)

For landfill CH_4, the largest GHG emission source from the waste sector, emissions continue several decades after waste disposal, and thus estimation of emission trends requires models which include temporal trends. CH_4 is also emitted during wastewater transport, sewage treatment processes, and leakage from anaerobic digestion of waste or wastewater sludges. The major sources of N_2O are human sewage and wastewater treatment. [WGIII 10.3.1]

The methane emissions from wastewater alone are expected to increase by almost 50% between 1990 and 2020, especially in the rapidly developing countries of eastern and southern Asia. Estimates of global N_2O emissions from wastewater are incomplete and based only on human sewage treatment, but these indicate an increase of 25% between 1990 and 2020. It is important to emphasise, however, that these are business-as-usual scenarios, and actual emissions could be much lower if additional measures were put in place. Future reductions in emissions from the waste sector will partially depend on the post-2012 availability of Kyoto mechanisms such as the CDM. [WGIII 10.3.1]

In developing countries, due to rapid population growth and urbanisation without concurrent development of wastewater infrastructure, CH_4 and N_2O emissions from wastewater are generally higher than in developed countries. This can be seen by examining the 1990 estimated methane and N_2O emissions and projected trends to 2020 from wastewater and human sewage. [WGIII 10.3.3]

Although current GHG emissions from wastewater are lower than emissions from waste, it is recognised that there are substantial emissions that are not quantified by current estimates, especially from septic tanks, latrines, and uncontrolled discharges in developing countries. Decentralised ‘natural’ treatment processes and septic tanks in developing countries may result in relatively large emissions of methane and N_2O, particularly in China, India and Indonesia. Open sewers or informally ponded wastewaters in developing countries often result in uncontrolled discharges to rivers and lakes, causing rapidly increasing wastewater volumes going along with economic development. On the other hand, low-water-use toilets (3–5 litres) and ecological sanitation approaches (including ecological toilets) where nutrients are safely recycled into productive agriculture and the environment, are being used in Mexico, Zimbabwe, China and Sweden. These could also be applied in many developing and developed countries, especially where there are water shortages, irregular water supplies, or where additional measures for the conservation of water resources are needed. All of these measures also encourage smaller wastewater treatment plants with reduced nutrient loads and proportionally lower GHG emissions. [WGIII 10.6.2] All in all, the quantity of wastewater collected and treated is increasing in many countries in order to maintain and improve potable water quality, as well for other public health and environmental protection benefits. Concurrently, GHG emissions from wastewater will decrease relative to future increases in wastewater collection and treatment. [WGIII 10.6.2]

6.3.6 Desalinisation (6)

In water-scarce regions, water supply may take place (partly) by desalinisation of saline water. Such a process requires energy and this implies the generation of GHG emissions in the case of fossil-fuel utilisation. [WGII 3.3.2]

6.3.7 Geothermal energy (7)

Using geothermal energy for heating purposes does not generate GHG emissions, as is the case with other methods of energy generation (see also Section 6.2.5).

6.4 Potential water resource conflicts between adaptation and mitigation

Possible conflicts between adaptation and mitigation might arise over water resources. The few studies that exist (e.g., Dang et al., 2003) indicate that the repercussions from mitigation for adaptation and *vice versa* are mostly marginal at the global level, although they may be significant at the regional scale. In regions where climate change will trigger significant shifts in the hydrological regime, but where hydropower potentials are still available, this would increase the competition for water, especially if climate change adaptation efforts in various sectors are implemented (such as competition for surface water resources between irrigation, to cope with climate change impacts in agriculture, increased demand for drinking water, and increased demand for cooling water for the power sector). This confirms the importance of integrated land and water management strategies for river basins, to ensure the optimal allocation of scarce natural resources (land, water). Also, both mitigation and adaptation have to be evaluated at the same time, with explicit trade-offs, in order to optimise economic investments while fostering sustainable development.[WGII 18.8, 18.4.3]

Several studies confirm potential clashes between water supply, flood control, hydropower and minimum streamflow (required for ecological and water quality purposes) under changing climatic and hydrological conditions (Christensen et al., 2004; Van Rheenen et al., 2004). [WGII 18.4.3]

Adaptation to changing hydrological regimes and water availability will also require continuous additional energy input. In water-scarce regions, the increasing reuse of wastewater and the associated treatment, deep-well pumping, and especially large-scale desalination, would increase energy use in the water sector (Boutkan and Stikker, 2004), thus generating GHG emissions, unless 'clean energy' options are used to generate the necessary energy input. [WGII 18.4.3]