COMMON QUESTIONS:

WETLAND, CLIMATE CHANGE, AND CARBON SEQUESTERING

Prepared by:

Jon Kusler
Association of State Wetland Managers, Inc.

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PREFACE

The following guide addresses frequently asked questions with regard to wetlands, carbon sequestering, and climate change.

It is based upon a wetlands and climate change project conducted by the Association of State Wetland Managers (ASWM) in 2002-2005 and a literature review. It is based upon two workshops and synthesis papers prepared by Jon Kusler, ASWM in 1999 and 2000 and an international symposium co-conducted by ASWM as part of the Quebec 2000 international wetland conference. It is also based upon a number of summary papers prepared by Virginia Burkette with Jon Kusler. These efforts were funded by the U.S. Geological Survey and the U.S. Environmental Protection Agency.

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See also Wetlands and Climate Change: Adapting to an Uncertain Climate
http://www.aswm.org/propub/wetlandsandclimate.pdf

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COMMON QUESTIONS

WETLAND, CLIMATE CHANGE, and CARBON SEQUESTERING

Will wetlands be affected by climate change?

A. Yes. Wetlands are among the ecosystems which will be most affected by even small changes in climate and resulting changes in hydrologic regimes such as sea level rise and decreased surface and ground water levels in the West. Many wetlands will be destroyed; rare and endangered plants and animals will be threatened in others. See more discussion below.

What climate change factors will affect wetlands?

A. A number of climate change factors will affect wetlands:

- **Increase in CO_2.** Carbon dioxide has increased 30% since pre-industrial times. A doubling is anticipated by 2100.
- **Increase in air, water, and soil temperatures.** Over the past century the global mean surface temperature has risen 0.5-1.10F (IPCC, 1996). The Intergovernmental Panel on Climate Change (IPCC) has estimated that global surface air temperatures will increase another 2-8F in the next hundred years with a "best guess" increase of 3.5 degrees by 2100. The most significant increases will occur in the northern latitudes. The temperature of wetlands, lakes, streams, rivers, estuaries, oceans, and ground waters will also, consequently, increase. There will be more "ice off" days of lakes and streams and a warming of the soils in northern latitudes. These changes will be the most rapid increase in temperatures at any time in the last 100,000 years, challenging the adaptive capabilities of temperature sensitive wetland plants and animals which will often be unable to migrate northward due to the rapidity of the climate change or the fragmentation in systems.
- **Changes in the amounts and timing of precipitation.** Pursuant to various climate change models, it is estimated that overall, precipitation will increase in the U.S., but not for all areas. For example, somewhat decreased precipitation may be expected in the Southwest while increased precipitation will occur in the Southeast[1]. In addition, ground and surface water levels can be expected to fall in the Midwest and northern states despite somewhat increased precipitation if evaporation and evapotranspiration rise sharply due to temperature increases.

Changes in precipitation will affect all wetlands

[1] See http://www.epa.gov/globalwarming/impacts/stateimp/

- **Intensification of climatological events.** Higher temperatures and "speeding up" the water cycle will likely result in more severe climatological events such as hurricanes, tornadoes, thunderstorms, and winter storms affecting wetland systems. It may also increase the intensity of severe precipitation events (heavy downpours of more than two inches per day). It has been estimated that the frequency of such severe events has increased by 20 percent in the U.S. since the beginning of the century. Severe climatological events such as intense rainfall in a region are likely to bring more sediment into some wetlands (e.g. alluvial, estuarine) while increasing erosion in others (down cutting of sediment-starved streams in floodplains, coastal and estuarine erosion).

Erosion due to storm waves

- **Lengthened growing season in northern latitudes.** Based upon satellite imagery, it has been estimated that the growing season in northern latitudes (between 45 degrees and 70 degrees north) has increased by a total of twelve days. More increases are expected.
- **Sea level rise.** The IPCC has estimated that by 2100 sea level is expected to rise .09 to .88 meters inches due to thermal expansion of ocean water and melting of glaciers and ice caps (IPCC, 2001). Globally, relative sea level has been 4 to 10 inches over the last 100 years.

Other changes with possible significance to wetland ecosystems are also occurring such as an increase in atmospheric methane and a decrease in ozone with increased infrared exposure. For example, since 1979, ultraviolet radiation has increased significantly north of 40 degrees latitude (U.S. Global Change Research Program, 1997).

What will be the impacts of these climate change factors on wetlands?

A. Likely impacts of climate change factors include:

- **Increased productivity due to increased $C0_2$.** Increased CO_2 will increase the primary productivity of most wetland plants except were sunlight, precipitation or temperature is a limiting factor. Increase in primary productivity would enhance the habitat value of some wetlands although some shift in plant and animal species might also be expected and variations in responses. There are indications that this increased productivity will also result in increased methane emissions.
- **Wetland changes due to decreased frosts.** The natural ranges of both natural and invasive wetland plant species that are killed by frost such as mangroves and Melaleuca in Florida will be extended northward and upslope in mountainous areas. So will the ranges of temperature sensitive animals and insects such as fish and mosquitoes including various disease vectors (e.g., mosquitoes). This will likely mean a northward migration of dengue fever, cholera, and several strains of malaria.

- **Wetland changes due to decreased precipitation (some areas).** Impacts will be particularly great where precipitation remains steady or decreases. Increases in temperatures combined with reductions in precipitation will likely reduce surface and ground water levels in northern latitude wetlands, destroying or reducing in size many wetlands. Lowered water levels will result in release of carbon and methane. Decreased precipitation in some areas (e.g., the Southwest) will reduce runoff and water tables. This will reduce freshwater wetland size and will convert some wetlands to dry land. Such a result is particularly likely for forested, shrub, fresh meadow, and other shallow water or high ground water wetlands which are particularly sensitive to small hydrologic changes. It will also affect temporary and seasonal wetlands. Some of these areas can be converted to upland by lowered water tables of only a few inches. Decreased precipitation may also result in reduced river flows and increased impoundment of waters with subsequent saltwater intrusion into estuary areas and estuarine wetlands. The deleterious effects of such changes in boreal forest wetlands has been, to some extent, documented.
- **Wetland changes due to increased precipitation (other areas).** Increased precipitation in some areas such as the Southeast (U.S. Global Climate Change Program, 1997) will result in increased ground water levels and increased water levels in wetlands and lakes. This is likely to further result in:
    - An increase in size of some freshwater wetlands (lake fringe, riverine fringe, depressional, flat, slope) due to the inundation or saturation of new fringe areas.
    - An increase in the number of depressional, flats, lake fringe, riverine, and slope wetlands (i.e., some will appear where they have not been before).
    - A shift in wetland type and associated vegetation and fauna in some instances from saturated soil and shallow water fresh meadows and shrub/scrub or forested wetlands to marsh and open water types. This will favor fish species and waterfowl requiring open water.

- **Wetland changes due to an increase in severe meteorological events.** All wetland systems are, to a greater or lesser extent, already subject to disturbance by extreme rainfall, flooding, and high winds. Under natural conditions, wetland vegetation and animals may suffer temporary damage such as toppling of trees and some loss of wildlife. But, most of the damage from such events is temporary. For example, Hurricane Andrew caused considerable damage to trees in the Everglades but apparently little long-term damage to the wetland ecosystem. In some instances, extreme and infrequent events may result in accelerated deposition of carbon rich sediments in wetlands. This may fill wetlands but also contribute to carbon stores. Increased frequency of extreme events may, however, cause irreversible damage to some wetland systems that are already stressed. For example, animals with no place to go during a flood due to fragmentation of wetland ecosystems and destruction of refugia may die. Rare and endangered species with small populations may be destroyed. Exotics may invade seriously damaged areas. Sediment-rich runoff from agricultural or urban areas due to extreme events may fill depressional, fringing, and other types of wetlands. Extreme events may also combine with sea level rise to increase shoreline erosion and land loss in coastal areas.

- **Wetland changes due to sea level rise.** Projected sea level rises of .09 to .88 meters by 2100 combined with coastal subsidence in some areas will likely have severe impact on coastal and estuarine wetlands, particularly on the Atlantic and Gulf coasts. There will be wetland losses where there is insufficient plant growth and sediment deposition to equal sea level rise and coastal or estuarine wetlands cannot migrate inland. This is a particular problem for deltaic systems such as the Mississippi Delta where sediment-trapping reservoirs have been constructed along inflowing rivers and subsidence is occurring due to compaction of sediments, oil and gas removal, and isostatic adjustments. Loss of many of these wetlands can be expected with some return of the carbon contained in the peats and soils to the atmosphere. In other instances, the carbon will be redeposited in new marshes or transported to the open ocean.
    - Rapid, substantial changes in sea level pose significant threats to coastal and estuarine wetlands where back-lying lands are developed and sediment regimes have been disturbed. Sea levels could rise .09 to .88 meters by year 2100. A one meter in sea level rise would inundate twenty thousand square kilometers (seven thousand square miles) of dry land in the United States—about the size of Massachusetts. Some research studies indicate that mangroves and marsh ecosystems can remain viable despite sea level rise due to accumulation of organic matter and sediments at the present 1-3mm rate of sea level rise per year.[2] However, accelerated future rates in sea level rise will likely result in a shift in species composition, decreased marsh productivity (plant biomasss), and marsh destruction. Coastal and estuarine wetlands will be submerged and destroyed where they are unable to either migrate inland or grow upward through deposition of organic matter and sediment.
    - Not only coastal and estuarine wetlands but community composition and aerial extent of communities of submerged aquatic vegetation (e.g., sea grasses) may be affected by increased water depths, increased storm disturbances, reduce light penetration, and changing salinities.

Increased CO_2 will increase biomass production

[2] See http://www.nrel.colostate.edu/brd_global_change/proj_50_sea_level.html; http://gsa.confex.com/gsa/2001SE/finalprogram/abstract_4621.htm

- **Wetland changes due to increased mean air, water, and soil temperatures.** Projected temperature rise of 2-9 degrees F may significantly impact some wetland flora and fauna with northerly shifts in vegetation and animal species where adequate migration pathways and time for such migration. Other species (e.g., endangered plants and animals) may be destroyed or their numbers seriously reduced by rapid shifts in temperature and/or precipitation. Increased air, water and soil temperatures could have both direct and indirect impacts upon wetland plants (e.g., temperate forests) and animals (e.g., cold water fish).
    - Increase in mean annual temperatures and resulting increases in water temperatures may result in destruction of wetland rare and endangered plant and animal species with sensitivity to small temperature changes and no alternative, nearby habitat. This is particularly true for montane and alpine communities and species near the peaks of mountains and unable to move or disperse to higher elevations.
    - Temperature increases will cause northerly and upslope shifts in ranges for wetland trees (e.g., temperate forests) and other plant and animals with narrow water temperature tolerances (e.g., trout). Because of the sensitivity of many plants to temperature changes, the growth capabilities of specific plants may be moved 200 to 300 km north for each degree centigrade increase in temperature and about 60 to 90 miles for each degree Fahrenheit. The IPCC concluded more generally that the "composition and geographic distribution of many ecosystems…will shift as individual species respond to changes in climate, there will likely be reductions in biological diversity and in the goods and services that ecosystems provide." Under natural, unfragmented conditions, many species would migrate north or upslope on mountains with rising temperatures. But, this will be impossible or difficult where such migrations are hindered by dams, fills, or other impediments.

Increased temperatures will increase evaporation, drying many wetlands

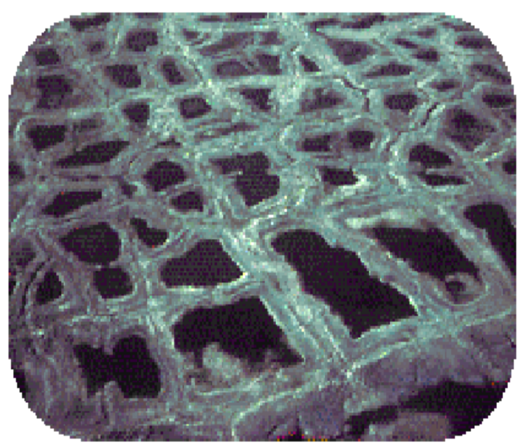
- Temperature increases will likely result in the melting of permafrost, increased decomposition rates, and releasing carbon dioxide and changing methane and nitrous oxide emissions and creating open water wetlands or aquatic ecosystems.
- There will also be significant indirect effects of temperature, evaporation, and transpiration increases. These will likely result in less runoff (unless compensated by increased rainfall), less infiltration, and lowered ground water levels.

Why will impacts on wetlands often be more severe than impacts on upland systems?

A. Wetland ecosystems will be more severely impacted by climate change (in comparison to many terrestrial ecosystems) for three several reasons:

- Flora and fauna in wetlands are especially sensitive to small, permanent changes in water levels while similar small changes in water levels often have less impact upon rivers, streams, and lakes. For example, lowering long-term, mean water levels even a few inches in a wetland can make the difference between a forested, shrub, or "fresh meadow" or a wetland and dry ground. A similar drop in water levels will usually have more limited impact on lakes, rivers and other aquatic ecosystems.
- Wetlands have often been fragmented and cut off hydrologically and ecologically from other wetlands and aquatic ecosystems by dams, dikes, fills, roads, drainage, and other landscape level alterations. Due to this fragmentation, wetland plants and animals cannot naturally "migrate" to other locations over time in response to temperature and water level changes. Similarly, many coastal or estuarine wetlands will be unable to move inland in response to sea level rise, due to construction of dikes, levees, fills, or other development which fix the landward boundary.
- Many wetlands are already severely stressed due to hydrologic changes, water pollution, changes in sediment regimes, and other activities of mankind. These stresses have lowered biodiversity in wetlands. Reduced numbers of types of plants and animals makes the wetlands more vulnerable to small changes in temperature and water regimes.

Impacts will vary depending upon the types, magnitudes, and rate of changes in temperature, precipitation, hydroperiod, and other factors and the plant and animal species in a wetland. Each plant species (and there are more than 6,000 listed wetland plants alone) may respond somewhat differently although certain general responses may be expected. For example, increased CO_2 may be expected to increase plant growth overall but this will not necessarily be true for all plant species and contexts with a broad range of limiting factors on growth such as nitrogen and suitable substrate. Similarly, a combination of increased temperature and constant or reduced precipitation will likely result in decreased runoff and lowered ground water levels, causing the drying of some wetlands and a decrease in size or change in wetland types for some others. But, this result is less likely for wetlands adjacent to large water bodies.



Increased temperatures will melt permafrost

What types of wetlands will be most affected by climate change?

A. Wetland types likely to be substantially impacted by climate change include:

- **Coastal and estuarine wetlands.** As already discussed, coastal and estuarine wetlands may be destroyed if sea level rise exceeds the rate of deposition and inland migration is not possible. For example, a two-foot rise in the Everglades would move the land/sea boundary several kilometers inland. In salt marshes there will be a change in terms of species composition or vegetation types. Submerged aquatic vegetation, coastal marshes, mangroves, bald cypress swamps, coastal bottomland hardwood forests, and other wetland types may all be affected.
- **Tundra (permafrost) wetlands and other open tundra wetlands.** Areas of permafrost wetland may be melted and converted to open water by temperature increases. Water levels in other open peatlands may fall due to rising temperatures. Carbon dioxide releases and possibly methane releases from methane hydrates may result. Open tundra may be invaded by boreal forests.
- **Wetland boreal forests.** Climate change is likely to have significant impact upon boreal forests through the loss of southern boreal forests, invasion of northern tree lines into tundra areas, increased fire, and increased pest outbreaks. A combination of temperature increase and the lowering of ground water tables may expose peat and organic soils to oxidation. However, increases in carbon dioxide may also result in increased forest vegetation.
- **Alpine wetlands near the tops of mountains.** Even small amounts of warming may destroy “relic” plant and animal species in alpine wetlands since there will be little opportunity to migrate to other locations.
- **Prairie potholes.** Reductions in wetland size and the disappearance of some wetlands can be expected with substantial increases in temperatures and only modest increases in precipitation in the Prairie Pothole Region. Waterfowl production may be reduced by the reduced precipitation in the spring or fall and reduced water levels when migrations occur even if overall precipitation levels do not change.
- **Playas, vernal pools, other seasonal wetlands.** Temporary, shallow wetlands will be particularly sensitive to increases in temperatures and increased evaporation and transpiration. They will also be sensitive to decreases or increases in precipitation.
- **Other depressional, slope, flats, river and lake fringe wetlands.** Some drying, decrease in wetland size, and conversion to uplands can be expected for most freshwater wetlands where precipitation is decreased or remains steady while temperatures are substantially increased since these wetlands are very sensitive to small changes in ground water levels. However, there may be exceptions such as the Great Lakes where lowering of water levels may expose wide flats or benches which will be colonized by wetland vegetation.

On the other hand, some riverine, lake fringe, and other wetlands in regions of the nation with increased rainfall such as the Southeast will increase in size and vegetation density may increase in wetlands overall due to rising CO_2 levels. Increased size of coastal wetlands is unlikely where shorelines have been “hardened” by bulkheads or other structures.

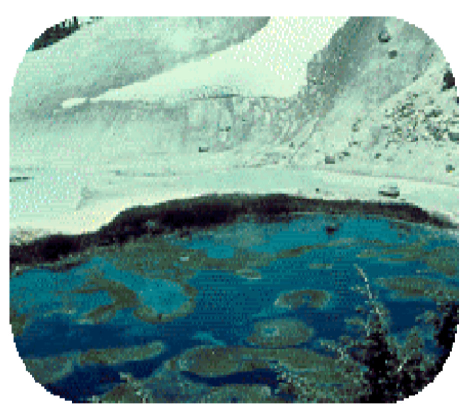
What wetland functions will likely be most affected by climate change?

A. The impact of climate change on the services and goods wetlands provide for society will vary by type of wetland and by function/value.

- **Fisheries production.** With rising water temperatures in lakes, streams and wetlands, reduction in the numbers of cold water fish (e.g., trout) and increase in warm water fish such as bass may be expected. With rapid sea level rise and destruction of salt marshes which cannot migrate inland, reduced yields of ocean and estuarine fish species which depend upon coastal and estuarine wetlands for rearing or food chain support may also be expected.
- **Shellfish production.** A reduction in the size of coastal and estuarine wetlands and adjacent "flats" and increases in water depths will reduce shellfish production.
- **Waterfowl production.** Increased temperatures with only slightly increased precipitation in the prairie pothole region will convert some wetlands to dry land, reduce others in size, and shift marshes with standing water to saturated soil wetland types (e.g., shrub or forested wetlands). Changed water regimes during the spring and fall may adversely affect waterfowl even if precipitation remains constant.
- **Habitat for rare and endangered species.** The role of wetlands throughout the Nation as habitat for rare and endangered species may be compromised wherever species are dependent upon specific hydrologic and temperature conditions and flora and fauna cannot migrate to new locations. This is particularly true for systems that are already stressed by water pollution and human-induced alterations and are highly fragmented. Species extinctions and biodiversity loss are probable; species range and ecosystem structure will also change. Further damage due to invasions by exotic species with northward extension of ranges is also likely.
- **Food chain support.** Destruction of coastal and estuarine wetlands by rapid sea level rise would result in loss of detritus and other food chain support for estuarine and coastal fish, shellfish, and other fauna. Similarly, destruction or reduction in the size of slope, depressional, flats, and some river and lake fringe wetlands due to a combination of increased temperatures and/or reduced precipitation would reduce food chain support for not only wetland species but for river, lake, and upland birds and animals which depend upon wetlands as a source of food. On the other hand, some increase in food chain support might be expected in some situations due to increased primary productivity resulting from increases in CO_2 (assuming that there are not other limiting factors).

Sea level rise will destroy many wetlands like these on Cape Cod

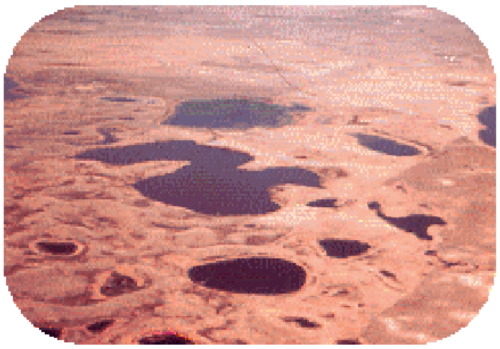
- **Water quality buffering and pollution control.** Destruction of coastal and estuarine wetlands due to sea level rise would result in loss of their water quality pollution control functions. Similar losses would occur where depressional, slope, flats, and river and lake fringe wetlands are diminished in size or destroyed by lowered ground or surface water elevations due to reduced precipitation and/or increased temperatures. On the other hand, some increase in water quality buffering could occur for freshwater wetlands due to CO_2 induced increases in the density and amounts of vegetation (assuming adequate water levels to maintain wetlands and lack of other limiting factors). Some wetlands would increase in size and numbers in areas of increased rainfall.
- **Wave attenuation and erosion control.** The destruction of coastal and estuarine wetlands by sea level rise would expose back-lying lands to added force from hurricanes and winter storm winds and waves. However, the increased density of wetland trees and other vegetation due to increased CO_2 might also enhance the wave attenuation and erosion control functions of surviving estuarine, coastal, and freshwater wetlands.
- **Production of forestry products and natural crops.** Increased CO_2 will result in increased growth of trees and other natural wetland crops such as wild rice, and cranberries if such increases are not "limited" by phosphorus, nitrogen, or other limiting factors. Nevertheless, there could also be loss of coastal, estuarine, and freshwater wetlands and the forestry products they produce by sea level rise, increased severe meteorological events, and decreased precipitation in some instances. For example, bottomland hardwoods are particularly susceptible to hurricanes.
- **Carbon storage and sequestering.** Increased CO_2 could result in increased plant growth in wetlands and the potential for increased carbon sequestration where there are not other limiting factors. But, the carbon storage and sequestering role of tundra wetlands could also be reduced by the melting of permafrost, drainage (in some instances) and the subsequent release of carbon dioxide and other atmospheric gases. Carbon storage and sequestering by northern, nonpermafrost peatlands would also likely be reduced by a combination of increased temperatures and reduced ground and surface water levels, causing oxidation of the peat.
- **Flood conveyance and flood storage.** The flood conveyance and flood storage roles of wetlands for major (infrequent) flood events would probably not be substantially affected by climate change since these roles depend more upon wetland configuration and size than biotic factors. However, increased vegetation growth due to increases in CO_2 might reduce flood conveyance capacity for riverine wetlands by increasing the "roughness" of wetland-dominated floodplains. Sediment loadings due to increased severe meteorological events could also fill depressional, riverine and other wetland types with resulting reduction in flood conveyance and flood storage capability.



Alpine wetlands will be particularly affected by global warming

Could land and water management practices be adopted to reduce the impacts of climate change on wetlands?

A. Yes and no. There is no practical option to protect the very large numbers of wetlands as a whole in the U.S. (e.g., over 25 million Prairie Pothole wetlands alone) from increased temperatures, decreased precipitation, or rising sea levels short of controlling climate change through limits on emissions of carbon dioxide and other greenhouse gases.



There will be no way to protect millions of Prairie Potholes

However, the federal government, states, local governments, and the private sector (e.g. duck clubs, The Nature Conservancy) could selectively apply management measures (Payne, 1992) to specific wetlands on a wetland-by-wetland basis to increase the resiliency of wetland systems or to reduce or partially compensate for impacts.

General strategies for reducing the impacts of climate change and achieving other objectives including protection of carbon stores include:

- **Better control the draining of wetlands.** With an existing, limited number of wetlands remaining to provide services and goods to society (flood conveyance, flood storage, pollution control, fish production, etc.) estimated to be less than 50% of former acreage and the prospect of more diminished numbers and sizes of wetlands from a broad range of causes, it makes good sense to better protect existing wetlands from drainage or filling or drainage through regulations, plans, acquisition, and other techniques. This is true even if significant climate changes do not occur. With the possibility of climate change, it would be particularly important to protect types of wetlands (e.g. coastal, estuarine) which provide essential services (e.g., food chain support, fisheries, shellfish) and which could be further reduced in size or number or otherwise adversely affected by climate change.
- **Prevent additional stresses.** It would, for the same reasons, make good sense to better control air and water pollution, vegetation removal, and invasion of exotics, grazing by live stock and other stresses upon existing wetlands. Stresses reduce existing wetland functions and the numbers and types of wetland plant and animal species. With reduced biodiversity and resiliency, wetlands are also more susceptible to climate change.
- **Prevent fragmentation.** Efforts to prevent fragmentation of wetlands and related floodplain, riparian, and aquatic ecosystems by dams, dikes, levees, fills, and upland activities are needed to protect existing wetland functions and values such as flood conveyance, fisheries, and water quality protection. Prevention of fragmentation becomes even more important to permit the migration of flora and fauna in response to climate change induced temperature changes and to permit animals to find refuge during floods. On the other hand, fragmentation may also reduce (in some instances) invasion by exotic species.

- **Create upland setbacks and buffers.** Efforts to create wetland, floodplain, and riparian buffers can help protect existing tidal and freshwater wetlands by reducing pollution and sediment loading upon wetlands, providing food chain support, and providing habitat for species such as song birds, deer, and amphibians, that use wetlands only a portion of the time. Upland buffers will be even more important for coastal and estuarine wetlands if sea levels rise due to climate change because such buffers would provide room for wetlands to "migrate". Upland buffers would similarly give freshwater wetlands in the Southeast and other areas subject to increased rainfall room to increase in size.
- **Control exotics.** Efforts to control exotic species in wetlands can protect wetland functions such as providing fish or waterfowl habitat under existing conditions. Control will be even more important with climate change and the northward migration of certain exotics. However, measures to control exotics (e.g., isolation of wetlands from other water bodies) may also reduce the migration of desirable species.
- **Protect low flows and residual water.** Efforts by fish and wildlife agencies and environmental organizations to protect the low flows of rivers and other water bodies during hot summer months or droughts through "appropriation" of low flow water rights, adoption of regulations or other techniques can serve a broad range of goals under existing conditions. Protection of low flows and other residual water is needed to maintain oxygen levels and to protect fish, amphibians, and other aquatic organisms. Such efforts will be even more important for areas with increased temperatures and decreased precipitation caused by climate change.
- **Control extraction of peat.** Control of extraction of peat can help protect habitat and other wetland functions as well as protect carbon stores. Twenty-three states produced about 900,000 tons of peat worth about $20 million in 1988. Florida and Michigan were the major producers of peat. Most of this peat was for soil conditioning and potting soil.
- **Restore and create wetlands.** Wetland restoration and creation can, under existing conditions, help compensate for existing loss of wetland functions (flood storage, flood conveyance, water quality buffering) (Kusler, 1990; Kentula, 1992). Such efforts may also be able to reduce the impacts of climate change. This is particularly true if restoration or creation includes design features that allow for adaptive management. For example, inclusion of water control structures in the design of restoration and creation projects allows water level manipulation in the event of summer temperature increases or reduced precipitation.
- **Conduct stocking and captive breeding.** Stocking of wetlands and related water bodies with fish can help replenish stocks depleted by stresses under existing conditions such as water pollution, invasion of exotic predators (e.g., lamprey), or over harvesting. Captive breeding programs for other wildlife species can also supplement natural stocks and prevent extinctions. For example, the International Crane Foundation maintains an active captive-breeding program for rare cranes in Baraboo, Wisconsin. In the event of climate change, broader stocking and captive breeding programs may also be used to bolster depleted populations or to move species to northward wetlands and water bodies as water temperatures and vegetation change.

- **Conduct regional inventories and prepare management plans for wetlands at greatest risk from climate change.** Regional inventories of wetlands at risk could help regulatory, acquisition, and other management efforts. Such inventories could be part of broader state and local wetland conservation planning efforts or local wetlands and watershed management efforts. Such inventories could include designation of protection, acquisition, and restoration priorities based upon anticipated climate changes. For example, a plan might recommend acquisition of deeper, open water wetlands in a prairie pothole area where significant increases in temperature and decreases in precipitation are expected. Deeper water areas would convert to marshes under such conditions, partially offsetting the loss of shallow marshes needed for waterfowl feeding and nesting.

These strategies could be combined regionally and for individual wetlands. Many but not all of these would be "no risk" or "low risk" options and justified under existing conditions as well.

Do wetlands contain large stores of carbon?

A. Yes. There is a significant amount of carbon stored in wetland soils, peats, litter, and vegetation in the U.S. and globally (estimated 500-700 GT globally). Globally, the amount stored in wetlands may approach the total amount of atmospheric carbon (estimated at 753 GT).

However, total carbon stored in wetlands in the U.S. is uncertain because no comprehensive inventory of wetland soil carbon has been done in the U.S. and most quantitative measurements of soil and peat carbon and carbon and methane fluxes to date has focused on boreal peatlands and rice paddies in other countries. Most measurements have been in the upper meter of soil or peat and few studies have considered the full depth of wetland organic soils. Peatlands are found in some areas of the U.S. (Minnesota, Alaska). There is a relatively small acreage of rice paddies. But most U.S. wetlands are of other types--slope wetlands, depressional wetlands, coastal and estuarine salt marshes, lake fringe wetlands, and riverine wetlands. Particularly large amounts of carbon may be broadly dispersed in the thick sediments of deltaic and riverine wetlands.

Floodplain alluvium may contain large amounts of carbon

Do wetlands store carbon from sources throughout watersheds?

A. In some instances, yes.

Wetlands may also be more important than formerly believed as sinks of carbon produced from upland agriculture, forestry, and other land uses and not simply carbon fixed by photosynthesis within wetlands. Carbon from watershed sources in the form of soil organic carbon, leaves, tree trunks (major floods), and other materials is washed into low lying wetland areas throughout the landscape and deposited at the toes of slopes of hills and mountains (slope wetlands), in depressions in agricultural landscapes (depressional wetlands like the Prairie Potholes), in lake fringe wetlands along the Great Lakes and tens of thousands of smaller lakes, in riverine and floodplain wetlands along major rivers like the Mississippi, and in coastal and estuarine wetlands like the Mississippi Delta where total sedimentary deposition has been enormous (tens of thousands of feet). Some, but not all of the carbon deposited in these wetlands is recycled to the atmosphere by aerobic and anaerobic decomposition. But even this decomposition takes considerable time and a portion may be stored for hundreds, thousands of years, or longer. By acting as sinks and storing carbon produced throughout wetland drainage areas, wetlands may magnify the importance of carbon sequestering by upland agriculture and forestry activities. Loss of carbon from upland agricultural and forestry sites through erosion and surface water transport to wetlands does not necessarily mean loss to the atmosphere.

What types of wetlands contain the most significant carbon stores?

Peatlands contain particularly large organic deposits

A. Peatlands contain the most carbon. However, coastal wetlands, prairie potholes, river and lake fringing wetlands and other wetland types may also contain significant amounts of carbon.

Do wetlands continue to sequester carbon?

A. Yes. Peatlands in the Northern U.S. (Minnesota, Maine) and Alaska continue to sequester small quantities of carbon. Other types of wetlands may also sequester modest amounts of carbon as a result of plant growth within the wetlands and by acting as sinks for carbon and sediment generated throughout the landscape as discussed above.

Will climate change release some of the carbon stored in wetlands?

A. Yes. The release of this carbon may exceed sequestering if temperatures rise due to climate change. This is particularly true if water levels fall. Even more of the carbon stored in wetlands in the U.S. and globally will be released if wetlands continue to be drained. Upon drainage bacteria which live in aerated conditions will oxidize much of the carbon and return it to the atmosphere. Serious subsidence may then occur in some areas (e.g., the Sacramento Delta, the Everglades). Release and sequestration will depend upon atmospheric carbon dioxide levels, temperature, water levels, fires, tree harvesting, and land management practices. Fires may accelerate this release.

Will climate change affect the carbon sequestering capabilities of wetlands?

A. Yes, but it is unclear just how. Increased CO_2 and increased temperatures may increase photosynthesis and sequestering in some circumstances. However, increased temperatures will also increase decomposition and evapotranspiration leading to lowered water levels in some instances. Lowered water levels will lead to increased oxidation and return of carbon to the atmosphere.

Can wetland management practices help protect carbon stores?

A. Yes. A variety of practices can help protect existing carbon stores and the ability of wetlands to sequester carbon. Examples include:

- Control drainage and other land and water management practices which lead to dewatering of wetlands and oxidation.
- Control fires including deep burns.
- Allow natural revegetation to occur.
- Control peat harvesting and other removal of carbon from wetlands.

Increased temperatures and decreased precipitation will result in more fires and release of carbon

Do wetlands produce significant quantities of methane?

A. Yes. Total emissions from wetlands have been estimated to be in the 15-22% range of total global methane emissions. Most of these emissions are at lower latitudes rather than in the U.S., for example the Amazon floodplain. Because methane is a very active greenhouse gas, the climate change forcing function of methane from some types of wetlands may exceed the function of carbon sequestering, particularly on short term basis. However, methane emission rates have been measured primarily for peatlands and rice paddies. Methane emissions are lower for coastal and estuarine wetlands, pocasins, playas, and some other wetland types. And, methane breaks down rather quickly in the atmosphere (10-17 years) while carbon storage in wetlands may take place for very long periods. In the long term (500-1000) years methane has a decreasing affects.

Will climate change affect methane production?

A. Yes. Methane production depends upon water levels, temperature, and water chemistry. Increased temperatures and precipitation at some latitudes will increase methane production.

Could wetland creation, restoration, or enhancement be used to increase carbon sequestering and reduce methane emissions?

A. Yes. In some instances. For example, water control structures could be used to increase the duration of saturation. However, in many other instances carbon storage will be a "value added" reason to protect and restore along with protection or restoration of plant and animal species, pollution control, flood storage, etc. However, creation, restoration, and enhancement may also result in increased methane production (depending upon the design and management.

Is there sufficient scientific basis now to change wetland management practices to protect wetlands from climate change and protect carbon stores?

A. Arguably, yes. This is particularly true where changes may be undertaken at modest cost and serve multiple additional objectives. For example, better controlling wetland drainage will not only improve the resilience of these wetlands to climate change but protect carbon stores, biodiversity, food chain support, flood storage and conveyance, and a host of other functions/values. Providing buffers to allow migration of estuarine wetlands will serve multiple objectives in addition to reducing the impacts of climate change including protection of wave retardation and erosion control, protection of estuaries from pollution, and protection of fish and shellfish spawning areas.

Setbacks can provide room for coastal/estuarine wetlands to move inland

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SUGGESTED WEB SITES

(We have found the following sites to be helpful. Note, many of these sites deal with providing broader climate-related information and do not address wetlands directly.)

www.devonian.ualberta.ca/peatland/bogsearch.cfm
Build-A-Bog. S. Zoltai. Peatland Resource Center. University of Alberta, Devonian Botanic Garden web site.

www.dieoff.org/page129.htm
The Carbon Bomb: Climate Change and the Fate of the Northern Boreal Forests. Global Warming, Climate Change, Boreal Forests, Ecology, Economics, Ecological Economics, Science, Environment, and Politics. Good, interesting article.

iisd.ca/climatechange.htm
International Institute for Sustainable Development. This site has a variety of pages dealing with wetlands and climate change including the results of a Canadian wetlands and climate change workshop.

www.climate.org/topics/links/index.shtml
Climate Institute. Excellent site with climate-related links by the Climate Institute

www.forester.net/ec_0105_constructed.html
Erosion Control. Constructed Wetlands for Erosion Control. Natalie Goldstein. Good summary article on constructed wetlands for erosion control.

http://www.eia.doe.gov/environment.html
Energy Information Administration. Environment. General information concerning EIA programs.

www.npwrc.usgs.gov/resource/literatr/firewild/firesoil.htm
U.S. Geological Survey. Fire in North American Wetland Ecosystems and Fire-Wildlife Relations: An Annotated Bibliography. Useful bibliography but not focused on climate change.

geochange.er.usgs.gov/pub/carbon/fs97137
U.S. Geological Survey. Global Environmental Change and the Carbon Cycle. Can the Global Carbon Budget be Balanced? The site describes the Mississippi Basin Carbon Project.

www.epa.gov/globalwarming/
U.S. Environmental Protections Agency. Global Warming. This extensive site has many useful global climate references and links including and extensive discussion of methane and carbon sequestering.

www.epa.gov/globalwarming/impacts/stateimp/
U.S. Environmental Protections Agency. Global Warming Impacts. State Impacts. State-by-state projection of possible global warming impacts. Interesting site.

gaim.unh.edu/Products/Reports/Report_6/Wetlands.html
Global Wetland Distribution and Functional Characterization: Trace Gases and the Hydrologic Cycle. Results of a Joint GAIM-DIS-BAHC-IGAC-LUCC Workshop, GAIM 1993-1997. Report with research priorities concerning wetlands and greenhouse gases.

www.ipcc.ch/
Intergovernmental Panel on Climate Change. See this site for copies of the IPCC documents and many other excellent links concerning climate change.

water.usgs.gov/pubs/circ/circ1182/
U.S. Geological Survey. Land Subsidence in the United States. D. Galloway, D.R. Jones, and S.E. Ingebritsen. U.S. Geological Survey Circular 1182. Excellent USGS publication concerning subsidence problems in the U.S. Two case studies involve drainage of wetland systems—the Sacramento San Joaquin Delta and the Everglades.

www.iisd.org/wetlands/wandcs/scienceofwetlands/index.htm
Physical and Biotic Processes Affecting Carbon Cycling in Prairie Wetlands. Results of a workshop. 1/15/99. In April 1999 Canadian scientists and policy-makers met at the Oak Hammock Conservation Centre in Manitoba to consider whether prairie and parkland wetlands are net sinks or sources of greenhouse gases and to provide recommendations regarding the recognition of wetlands as carbon sinks under the Kyoto Protocol.

www.ramsar.org
The Ramsar Convention on Wetlands. This overall Ramsar Convention Bureau web site contains or references many reports available dealing with wetlands and climate change. Conduct a search of the site with the site search engine on the topic of wetlands and climate change and get 100 references and active links.

http://unfccc.int/resource/docs/convkp/kpeng.html
Kyoto Protocol to the United Nations Framework Convention of Climate Change. Actual text.

http://www.pewclimate.org/docUploads/aquatic%2Epdf
Report: Aquatic Ecosystems and Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States. Prepared for the Pew Center on Global Climate Change, January 2002, N. Poff, M. Brinson, and J. Day, Jr. Much of this excellent report concerns wetlands. Good bibliography.

http://ramsar.org/cop8/cop8_doc_11_e.htm
Dam, R., H. Gitay and M. Finlayson. Climate Change and Wetlands: Impacts, Adaptation and Mitigation. This is an excellent international summary. It contains a good bibliography.

Association of State Wetland Managers, Inc.

1434 Helderberg Trail, Berne, NY 12023
Phone: (518) 872-1804; Fax: (518) 872-1804; www.aswm.org

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