SNAP CODE:	**110501**
	110502
	110503
	110504
	110505
	110506
	110601
SOURCE ACTIVITY TITLE:	**OTHER SOURCES AND SINKS**
	Wetlands (Marshes-Swamps)
	Undrained Marshes
	Drained Marshes
	Bogs
	Fens
	Swamps
	Floodplains
	Lakes
NOSE CODE:	**301.05.01**
	301.05.02
	301.05.03
	301.05.04
	301.05.05
	301.05.06
	301.06.01
NFR CODE:	**N/A**

1 ACTIVITIES INCLUDED

This chapter covers emissions of methane (CH_4) and to a lesser extent sulphur produced in naturally saturated soils, in areas either permanently or seasonally flooded with fresh water. Note that this chapter covers shallow lakes (110601), typically defined by depths of less than 2 m, as well as the wetland (1105) SNAP-codes. Lakes of greater than 2m depth should not generally be treated as wetlands. The chapter does not cover agricultural wetlands such as rice fields, though the biogeochemical processes are the same. (See Schütz et al., 1989, for experimental measurements from Italian rice fields.)

The main emission, CH_4, is produced by anaerobic bacteria (methanogens) in the soil, diffused through soil water and transported to the atmosphere by plants, ebullition, or diffusion. Type of vegetation soil characteristics, and local climate are three important factors affecting methane emissions; data about these factors are used to make global and regional estimates.

Natural sulfur gases such as OCS (carbonyl sulfide), DMS (dimethyl sulfide), H_2S and CS_2 are emitted from brackish wetlands and wetlands with high soil sulfur, usually as the result of microbiological activity, though partly by chemical reduction of sulfate (some H_2S) or possibly by algae or other plants (DMS). These gases will be briefly discussed as they are not considered a significant source of pollutants. The bacteria which produce the sulfur gases usually out-compete methanogens, so methane production is inhibited by saline conditions. Brackish marshes have usually been omitted from inventories of methane emissions.

Wetland areas are affected by human management when drained for agriculture or construction; maintained for wildlife habitat or water treatment; or built/converted for water storage and transport such as canals or farm ponds. These changes in area may be estimated if adequate data are available from local sources.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

Wetlands are estimated to produce about 20% of the annual global methane emissions. Recent global estimates have been 100 - 110 Tg (10^{12} g) per year, with a range of about 50 - 150 Tg CH_4 emitted per year. These estimates are reviewed in Matthews (1993).

Biogenic sulfur gases emitted from wetlands and soils are estimated to be less than 2% of the total sulfur budget; 5-12 Tg S per year out of a total of 310 Tg. Less than 10% of the world's soils are in brackish marsh, so sulfur emissions from saline marshes are on the order of 1-2 Tg; insignificant compared to anthropogenic sources (Warneck, 1988; Andreae, 1984). Early studies which indicated a much larger source of biogenic sulfur gases from wetlands were either not reproduced, or may have been an artifact of the sampling process (see Chin and Davis, 1993, for further discussion).

3 GENERAL

3.1 Description

CH_4 is produced by anaerobic bacteria (methanogens) in the soil, diffused through soil water and transported to the atmosphere by plants, ebullition, or diffusion. Ground water table position, type of vegetation, soil characteristics, available substrates and local climate are all important factors affecting methane emissions. Further, methanogenesis is the final step in the anaerobic degradation chain, requiring organic by-products from other bacteria as food, and emitting methane as a waste (Gujer and Zehnder, 1983). For this reason, methane emission usually requires days to weeks to become significant at the beginning of the season. Methane in turn is a food source for aerobic bacteria called methanotrophs, so it can be oxidised in the aerobic root zone of plants or aerobic layers in soil or water. Approximately 10 - 40% of the methane produced in saturated soil is eventually emitted to the atmosphere. (See Conrad, 1996, and references therein.)

Biogenic sulfur gases are formed during anaerobic decomposition, from chemical reactions with the sulfate ion, and possibly also by some species of marsh vegetation (Patrick and DeLaune, 1977; Warneck, 1988; Chin and Davis, 1993).

3.2 Definitions

Many terms are used to describe naturally occurring flooded areas: wetland, mire, bog, fen, wet tundra, swamp, wet meadow and marsh are among the most common. In common usage the terms are imprecise and sometimes interchangeable. For the purposes of this chapter:

Wetland is used as an overall term for any area of permanently or seasonally flooded soils, where soils are saturated long enough for the soil to become reduced, a methanogen population established, and methane emitted from the soil. The types of wetlands are differentiated by their vegetation, which affects the amount of organic substrate available and transport of CH_4; and by season of flooding or thawing.

The following definitions are derived from Zoltai and Pollet (1983), Aselmann and Crutzen (1989), though a similar scheme was used by Matthews and Fung (1987).

A bog is a peat forming wetland, usually with mossy vegetation, sometimes with boreal forest, waterlogged from precipitation only.

A fen is a peat forming wetland with water flowing through the system, usually with grasses and sedges in addition to moss; less acidic than a bog and more productive.

Bogs and fens make up most of the boreal wetlands in tundra ecosystems, though they may be found at other latitudes.

Swamps are forested wetlands, with much less accumulated organic matter than bogs, usually found in temperate or tropical latitudes.

A marsh is a wetland with grass, sedges or reed vegetation.

A flood plain is the area seasonally covered by water along rivers or lakes. They are significant sources of methane principally in South America and Africa.

A shallow lake is a body of water warm enough for methane to be produced in sediment and shallow enough (<2m) that methane can diffuse or bubble to the surface. Canals and farm ponds might also be considered in this category as well as natural bodies of water.

The SNAP classifications "undrained and brackish marshes", "drained marshes" are preserved for consistency with previous work, but essentially all marshes which still fit unto the definition of wetland are treated identically in the following.

3.3 Techniques

Methane fluxes from wetlands have commonly been estimated by measuring its accumulation in closed chambers. In the past few years, area estimates from various types of eddy correlation measurements have become more common. Areas of wetlands have been estimated from maps, Gore (1983) for example, and from digitized databases of soils and vegetation. Season of methane emission is usually estimated from local climate data.

3.4 Emissions

Wetlands emit methane, carbon dioxide and biogenic sulfur gases, together with minor quantities of N_2O and NO. However, methane is the only gas emitted that is globally significant. Biogenic CO_2 is simply recycled (although wetlands do play a role in the global carbon cycle as the amounts of C stored in peatlands are significant - ca 412 Gt of C world wide; Woodwell et al., 1995). Biogenic sulfur gases are insignificant compared to anthropogenic sulfur emissions.

3.5 Controls

Natural wetlands have commonly been drained in temperate and tropic zones for agriculture, construction and peat harvest. These activities have "controlled" emissions by destroying the wetlands. Arctic and high latitude boreal wetlands are not drained because the ground is frozen much of the year; no controls appear reasonable.

4 SIMPLER METHODOLOGY

Methane emission from wetlands (W_{CH4}, in mass units) is estimated by:

$$W_{CH_4} = \sum_{i}^{7} \left(A_i \cdot F_i \cdot S_i \cdot cf\right) \qquad \textbf{(01)}$$

Where i = 1, 2, ... , 7 for the 7 wetland types; A_i is the area in each wetland type; F_i is the seasonal average flux (in mass/area/time units, usually mg CH_4 m^{-2} day^{-1}); S_i is the length of the season of methane emission. The season is the time the soil is thawed for boreal and northern temperate wetlands, and the length of time the soil is inundated for flood plains and seasonal marshes and swamps. "cf" is the appropriate units conversion factor.

5 DETAILED STATE OF THE ART METHODOLOGY

The detailed methodology is essentially the same as the simple methodology. The estimates may be improved by introducing wetland types characterized specifically by country; or using local flux measurements rather than the averaged ones given in section 8. Any information specific to a country rather than a global database should improve the precision of the estimate.

6 RELEVANT ACTIVITY STATISTICS

Wetland area data are found in a series of tables in Aselmann and Crutzen, 1989. They show percent wetland area in 2.5° latitude x 5° longitude cells. Matthews and Fung (1987) used a different classification scheme and divided their estimate into 1°x 1° cells. Their data base is documented by Matthews (1989) and is available by FTP from the US NCAR (National Center for Atmospheric Research) data site: ncardata.ucar.edu.

Maps of some wetland areas in Europe may be found in Gore (1983) volume 4A: General Studies and volume 4B: Regional Studies. Great Britain, Ireland, Finland and Sweden are covered in particular detail. Most of these maps are based on research done in the country of origin.

Local government agencies and researchers may be able to provide rainfall and temperature data to determine seasonality; and more precise land use data for wetland areas.

7 POINT SOURCE CRITERIA

All wetland sources are considered area sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Methane:

Bartlett and Harriss (1993) did a thorough review of flux measurements from wetlands and shallow lakes for the purpose of making global estimates. The following table is adapted from their work. They combined measurements from fens and bogs.

Climate Zone	Flux by Wetlands Type ($mgm^{-2}d^{-1}$)					
	Bogs	Fens	Marsh	Swamp	Flood-plain	Shallow Lakes
Arctic	96	96				
Boreal	87	87	87	87		35
Temperate	135	135	70	75	48	60
Tropical	199	199	233	165	182	148

The climate zones are arctic: 60 - 90° latitude; boreal: 45 - 60° latitude; temperate: 20 - 45° latitude; tropical: 0 - 20° latitude. These climate zones apply best to the American continents, as most of the northern hemisphere studies are from Canada and the U.S., and most southern hemisphere studies were done in Brazil.

Biogenic Sulfur gases:

Steudler and Peterson estimated a total annual emission of 5.8 g S m^{-2} yr^{-1} in a study which measured all principal biogenic sulfur gases emitted from a brackish marsh over the period of a year.

9 SPECIES PROFILES

10 UNCERTAINTY ESTIMATES

The data quality for making an estimate of methane emissions from wetlands is moderate (D rating).

Wetland flux estimates are probably the greatest source of uncertainty in making global estimates of methane. Although there are measurements in all wetland types from the principal wetland areas, fluxes may vary over several orders of magnitude at a single site. Inter-annual variation of seasonal averages can vary as much as an order of magnitude. Most boreal and temperate zone flux measurements have been made in North America and Scandinavia, and most tropical zone measurements have been made in Central and South America. Since there are few or no other measurements of methane flux from other parts of the world, the uncertainty of using the available measurements cannot be calculated, but may be large. Measurements of methane flux in Europe have, however, fit in the range of other boreal and high temperate zone measurements.

The estimated areas of wetlands may differ greatly depending on the underlying vegetation databases. The differences in area estimates between Matthews and Fung (1987) and Aselmann and Crutzen (1989) are discussed at length in the latter paper and in Bartlett and Harris (1993). Their total areas are very close but their distribution differs greatly, particularly in the tropics. Their estimates of total area for the northern hemisphere temperate and boreal zones are very close, but their vegetation classes are not strictly comparable.

The flux estimates for biogenic sulfur gases is poorer (an E rating). There are few measurements of all sulfur gases and the measured emissions are extremely variable.

The comments on the uncertainties of flux measurements of methane also apply to the biogenic sulfur gases. Additional variability is due to flux which varies with the tide (H_2S), or with daylight (DMS). Since not all researchers have measured all gases, it is difficult to get a total sulfur estimate. Since there is still possible contamination of the samples during measurement for the earlier data, there can be four orders of magnitude difference between measurements made in the same area by different researchers.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

As noted in 10, the emissions flux estimates are probably the greatest source of uncertainty. Additionally, linking flux estimates to wetland classification is an important problem. As it is not known exactly which parameters affect flux, then it is difficult to devise good parameterisation schemes. A further problem arises from differences in techniques used in measuring fluxes - such factors may explain some of the variability found of measurements.

Development of better techniques for remote sensing and evaluation is probably an essential component of inventory improvement.

12 SPATIAL DISAGGREGATION CRITERIA

Methane emissions are estimated by the different types of wetlands defined in section 3.2.

13 TEMPORAL DISAGGREGATION CRITERIA

Methane emissions vary seasonally, usually following soil temperature, plant growing season or saturation season, though exceptions may be found (Svensson and Rosswall, 1984; Whalen and Reeburgh, 1992; Westermann, 1993). For example, in the high northern latitudes wetlands are usually classified as bogs, forested bogs, and fens with maximum emissions from June to September. Methane emission increases when soil temperature increases above 0 degrees but has been measured at very low levels from frozen soil. Seasonal wetlands such as flood plains will only emit methane during the wet season, and methane emissions vary within wetlands along moisture gradients (Svensson, 1976; Moore et al., 1990; Granberg et al., 1997). Dry, aerated soils are usually sinks of methane; drought or other change in water table may cause a source area to become a sink (Harriss et al., 1982, Whalen et al., 1991, Oechel, 1993).

All fluxes given in section 8 are averaged diurnally and seasonally.

14 ADDITIONAL COMMENTS:

Very recently, Cao et al. (1996) and Christensen et al. (1996) have modeled the carbon system and methane emissions from wetlands. This type of model is considerably more complicated but allows modeling changes of methane emissions due to changes in climate. At present these models are validated against global estimates using measured fluxes (Matthews and Fung, 1987; Aselmann and Crutzen, 1989; Bartlett and Harris, 1993). The models are not yet generally available.

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

17 REFERENCES

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