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Rozanov, A.B.

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IIASA
International Institute for Applied Systems Analysis □ A-2361 Laxenburg □ Austria
Telephone: +43 2236 807 □ Fax: +43 2236 71313 □ E-Mail: info@iiasa.ac.at

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Andrei B. Rozanov

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The author worked with the Food and Agriculture (FAP) and Forest Resources (FOR) Projects during the summer of 1994 as a member of the Young Scientists' Summer Program (YSSP).

IIASA International Institute for Applied Systems Analysis □ A-2361 Laxenburg □ Austria
Telephone: +43 2236 807 □ Fax: +43 2236 71313 □ E-Mail: info@iiasa.ac.at

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Foreword

IIASA, the Russian Academy of Sciences and Russian governmental organizations initiated the Siberian Forest Study in 1992, with the overall objective of the Study to be:

- identification of possible future sustainable development options of the Siberian forest sector (assess the biospheric role of Siberian Forests, and identify suitable strategies for sustainable development of forest resources, the industry, the infrastructure and the society);
- identification of policies for the different options to be implemented by Russian and international agencies.

The first Phase of the Study was to build relevant and consistent databases for the upcoming analyses of the Siberian forest sector (Phase II). Nine cornerstone areas have been identified for the assessment analyses, namely further development of the databases, greenhouse gas balances, forest resources and forest utilization, biodiversity and landscapes, non-wood functions, environmental status, forest industry and markets, transportation infrastructure, and socio-economics.

An important component of the greenhouse gas balances' cornerstone is the emissions of methane. The work presented in this paper deals with a first cut analysis of the methane emissions from forest and agricultural land in Russia. This task has been carried out by A. Rozanov during his stay at IIASA in 1994 and 1995.

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1 Introduction

Methane (CH_4) is present in soils and atmosphere as a trace gas. Methane is also a "greenhouse" gas, which means that the change of its concentration in the atmosphere will affect the Earth's temperature.

Methane is oxidized in the atmosphere with OH^- radicals. The latter are formed from ozone through the O_3 photodissociation in the presence of vapor, which also brings up implications of methane emissions for ozone layer thinning. Present in the troposphere in small quantities of about 0.04 pptv, the atmospheric OH^- remains the main oxidant for not only methane, but also for CO. The increase in emission of any of these two gases will reduce the OH^- concentrations and, thus, accelerate the greenhouse effect. Although the sources of methane are multiple, it is comparatively easier to decrease the CH_4 emissions than those of other greenhouse gases, since only a 10% reduction is necessary to stabilize the methane concentration in the atmosphere (Hogan, 1991).

The oxidation of methane with OH^- in the Earth's troposphere is the main sink for CH_4 now, accounting for 90% of the oxidized methane. However, some 5% of it are oxidized in soils by methanotrophic microorganisms. Considering the two ways of methane oxidation, the role of biological sinks may increase in the future, proportionally to the increase in methane concentrations.

Average methane concentrations in soils are relatively (by 25%) higher than its content in the atmosphere and are closely related to the latter (**Розанов**, 1985). This phenomenon makes soils one of the important components of global methane cycle with soils performing the role of both methane sources and sinks.

The methane concentrations in the atmosphere increased by a factor of five (Lelieveld and Crutzen, 1993) since the last glacial maximum (18,000 years) when the atmospheric mixing ratio of CH_4 was 0.35 ppmv (parts per million by volume) (Raynaud *et al.*, 1988). Furthermore, during the past 300 years of extensive agricultural development, fossil fuel burning, and coal mining the CH_4 mixing ratios have increased progressively from 0.75 to 1.7 ppmv. The mixing rations grew especially fast during the last few decades at 0.8–1.0% per year (Blake and Rowland, 1988; Khalil *et al.*, 1989).

Despite the glacial/interglacial changes, it is evident that the rapid increase of the past few centuries and decades in the atmospheric CH_4 concentrations is the aftereffect of extensive agricultural and industrial development.

2 Overview of Methane Emission from Virgin and Agricultural Lands

2.1 World sources and sinks of methane

The sources of methane emission into atmosphere are both natural and anthropogenic in their origin. However, as far as sinks are concerned we continue to rely more on nature's ability to oxidize excessive methane "waste" than try to utilize it by technological advancements. Methane oxidation in the troposhere and microbial CH_4 utilization in soils still remain the main mechanisms for natural disposal of methane.

Table 1. Present-day sources and sinks of global methane cycle as estimated by Lelieveld J. and Crutzen P.J., 1993.

Sources	**Tg/yr**	***Tg/yr***	***Sinks***
Natural wetlands	125±70	*455±50*	*Oxidation in troposphere*
Rice fields	70±50	*30±25*	*Removal by soils*
Enteric fermentation	80±20	*45±10*	*Oxidation in stratosphere*
Landfills	40±25		
Biomass burning	30±15		
Animal wastes	25±10		
Domestic sewage	25±10		
Coal mining	35±10		
Oil-and-gas	80±45		
Termites	30±30		
Oceans	10±5		
Freshwaters	5±5		
CH_4 hydrates	5±5		
Total	560±90	*530±85*	*Total*
Atmospheric increase: 30±5			

Similar, though a bit more narrow, margins for methane emission are given in the Report to Congress on Current and Future Methane Emission from Natural Sources (Hogan, 1993). *Table 1* clearly shows that the balance of CH_4 occurring at present approximately equals emission from coal mining. Gas and oil drilling, gas venting and transmission provide for an even greater input of methane.

Furthermore, possible emission from *undeveloped oil-and-gas fields* via oil and gas seepage is not usually taken into consideration as a natural source of methane. No data at all is available on the latter, and evidently, it is essential to set up a range of experiments at the proved fields to assess their influence on the background methane emission. Another methane time bomb is *permafrost* which is relatively well-studied and contains (according to data obtained in Alaska) considerable quantities of trapped CH_4 that could be discharged into the atmosphere if permafrost starts melting. Though current emission from deep layers of permafrost is nil, the future discharge may involve some 60 Tg CH_4 within the nearest 100 years (Hogan, 1993). The total stock of ground ice in Russia is estimated at 19,000 km^3 (Danilov–Danil'yan and Korlyakov, 1993). No data is currently available on CH_4 concentrations in Russian permafrost and a special research program is required for the assessment of its stock.

The methane emission from natural sources, such as natural wetlands is a background emission, which presumably kept the current rates for the past few decades. However, the actual emission levels might have been affected by the sporadic massive discharges of methane stored in peat due to peat mining and drainage of natural wetlands.

Additional methane "storage facilities" and discharge sources were created due to land flooding for water-powered plants and for rice cultivation. However, considering the areas of irrigated, drained and flooded areas in comparison to those of only mires of Russia, the CH_4 emission and uptake presumably would not be affected much by the land-use changes involving such relatively small territories. Furthermore, mires keep discharging the stored methane at some 4 mg/sq. m/h via drainage trenches for at least 20 years after the land amelioration (Panikov and Zelenev, 1991), while the flow of methane from irrigated land produces rather low (0–1.4 mg/h) methane emission rates (**Минько**, 1986).

Table 2. Natural and drained mires, irrigated, paddy (rice) lands and land flooded by man-made water reservoirs (million ha) in Russia.

Peat Mires	Irrigated land	Rice fields	Flooded land	Drained mires
179.5	6.2	0.3	4.5	6.3

2.2 Natural mechanisms for methane generation and oxidation in soils

Though soils are one of the three natural methane sinks on the Earth, they are also the major methane source, providing more than 20% of the total methane emissions.

Methane emissions from soils are due to termites and microorganisms. Lying out of termite habitats, Russia is still a major source of CH_4 generated by the anaerobic microorganisms of the wetlands. Soil methane producers are mainly bacteria, though some other procariots are also capable of generating methane. The following soil-inhabiting microorganisms produce methane in soils (**Заварзин**, 1984).

Methanobacterium
Methanobrevibacter
Methanococcus
Methanomicrobium
Methanospirillum

Methanogenium
Methanoplanus
*Methanotermus**
Methanotrix
Methanolobus
Methanococcoides
Methanosarcina

Methane generation is the only source of energy for the above microorganisms, which makes them a highly-specialized group. Only three groups of compounds may be used by methanogenic bacteria as a source for methane production: H_2+CO_2; formiate, acetate, methanol and methilamides. Since the substrata used by methane-generating organisms are of rather narrow range, they are incapable of decomposing high-molecular organic compounds present in soils and plant residues. Thus, a very specific methanogenic community is formed of methane-generating bacteria and other microorganisms that are "preparing" the substrata for them. This community is a typical bio-consortium, sometimes with distinct morphological features (**Заварзин**, 1984).

Methane produced in soils is of microbial origin, and thus, dependent on the ecological suitability of particular soils for methane-generating microorganisms. The main limiting facto for both methane-generating microorganisms and methanotrophic ones is the **Period of Biological Activity (BPA)**.

Methane producers are strictly anaerobic microorganisms. Besides the anaerobic reduced environment, the limiting factors for methane production by the above microorganisms are **Eh, pH and temperature** of their habitat. Contrary to the wetlands of the tropical areas, the PBA in Russia is limited to only 100–150 days per year, which greatly diminishes the potential annual flux. More than 80% of the total methane emissions occur during the PBA.

The winter flux of CH_4 is not high, though not to be disregarded, when sufficient data is available. It most probably occurs due to dissipation into the atmosphere of the methane accumulated during the PBA. However, since methane-generating bacteria are still insufficiently studied, there might be some forms capable of generating methane at temperatures below zero. However, their activities will still be controlled by cell-freezing temperatures and will depend on concentrations of salts and in the cell.

Since reduction of C to CH_4 is a Red/Ox reaction, it requires reductants, which are readily provided by soils in the form of iron and manganese. Oxidation of Fe_{2+} to Fe_{3+} and MnO_4^- to MnO_2 are probably the main counterpart processes of methane generation in soils. The availability of the above elements for oxidation makes soils an ideal media for methanogenic community. Sulphur plays a role in the methane generation process in some soil groups rich in sulphur, and probably the biggest one in tionic Fluvisols, which are not identified in Russia.

The following examples, generated according to soil Red/Ox reactions listed by Kaurichev and Orlov (**Кауричев, Орлов**, 1982) demonstrate reactions of Fe^{2+} to Fe^{3+} oxidation and synthesis of methane and haematite (1) or goethite (2).

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* Microorganisms of *Methanotermus* genus are specific of andosols of geysers and volcanoes in Kamchatka, and thus, are active throughout the year in spite of the PBA constraints on the surrounding territories.

$$C^{4+} + 2FeO + H_2O + 2H^+ + 2e^- \rightarrow CH_4 + Fe_2O_3 \quad (1)$$

$$C^{4+} + FeO + H_2O + 3H^+ + 3e^- \rightarrow CH_4 + FeOOH \quad (2)$$

Specific chemical processes, especially those involving microbiological activity, are still not studied enough to lay a foundation for quantitative estimations. Given reactions do not cover the participation of ferments, enzymes and catalysis. Still, they generally reflect the Red/Ox process and may be used for calculations* to estimate the volume of generated methane, provided the competing reactions are taken into account. The availability of organic debris is another aspect of methane emission rates from soils. Soils should have high humus content and/or biological productivity to supply the methanogenic communities with necessary substrata.

The above gross reactions show that the process of methane generation may be accompanied with a pH increase in soil solution. It means that according to the Le Shatelie principle, the process is shifted to methane generation by additional input of H^+ ions into the system. Thus, for example, acid rains may further accelerate methane emissions from natural wetlands. This aspect needs special attention and experiments taking into account individual soil properties and initial pH values, since *in vitru* pH optimum for methanogenic bacteria lies within the pH 6–8 interval.

Methane oxidation in soils is also a biological process controlled by methanotrophic microorganisms and the environmental conditions of their activity. Oxidation of methane in soils may go by two different routes. The first one is direct oxidation with O_2 (3).

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (3)$$

The second is linked to the soil minerals since iron or manganese oxides undergo reduction in the process [e.g., (4)]. In both ways, methane is eventually oxidized to CO_2 and H_2O. The first process occurs only with the presence of oxygen, while the second may take place in anaerobic environment. Thus, it is clearly seen that methane oxidation starts at the same point as CH_4 generation.

$$4Fe_2O_3 + CH_4 \rightarrow 8FeO + CO_2 + 2H_2O \quad (4)$$

The depth of the anaerobic part of the soil profile is one of the crucial points for methane emissions. Usually, up to 3/4 of the total produced methane is oxidized within soil/water by methanotrophic organisms if the soil (peat/water) depth exceeds 10 m. That is why the spatial distribution of methane-generating and methane-oxidizing environments is so important.

2.3 Spatial distribution of methane sources and sinks

Considering the low concentrations of methane in the atmosphere, and in most aerobic soils, the methanotrophic bacteria usually share the same soils that are inhabited with methane-generating communities for the benefit of easier access to their main source of energy.

* $Eh = a - b*pH - c*lgC_i$, where a,b and c are standard tabular values at given temperature, and C_i is the activity of Red/Ox ion.

However, while methanogenes tend to inhabit the deeper layers of soil the methanotrophs are shifted to the oxygen-bearing topsoil and upper soil layers.

The highest concentrations of methanogenic bacteria within a soil profile and, respectively, the highest emission CH_4 rates were observed in the 20–40 cm, and sometimes deeper layers of anaerobic soils. These layers usually contain a considerable amount of organic matter to be metabolized by the methanogenic community, and provide the adequately reduced environment. Obviously, the number of methanotrophs is the largest within the 0–20 cm layer of topsoil.

Such a distribution of methane-producing and methane-oxidizing micro-organisms within a soil profile provides reasonable doubt as to the possibility for an increase of methane emissions due to a change in the environmental conditions toward increase in number of methanogenes. The increase in methane production will be followed by an increase in the population growth of methanotrophic organisms, which will probably compensate the increasing production of CH_4 by intrasoil oxidation. However, an assessment of these interactions is an objective for specific modeling, which is out of the scope of this report.

The extension of wetland areas due to climate change may be a reason for the considerable increase in methane emissions. The geographical distribution of methane-generating bacteria is relatively well studied. They tend to water basins, inundated soils, and rocks with relatively high organic matter content.

However, the modeling of future methane emission should take into account the rate of forthcoming waterlogging, and the rate at which the methanogenic communities and methanotrophs will explore the new habitats. No experimental data is available yet on the two latter parameters for any territory in the world.

The methane emissions are usually unevenly distributed, not only in space, but also throughout the year, peaking in mid-summer. The seasonal curves for boreal and cold regions are similar in their shape, with maximum emission rates depending on soil type, and length of production period corresponding well with PBA.

3 Methane Emissions from Natural and Agricultural Wetlands

3.1 Methodology for assessing methane emission from soils

The methodological aspects of CH_4 emission measurements are well developed by now (Panikov and Zelenev, 1991; Inoue, 1994). However, the problem of extrapolating the obtained point data still persists and requires geographical solutions to obtain space-related information for regional and global estimations of methane emissions from land areas.

The methane fluxes $\mathbf{q_m}$ (emission and uptake) are in many respects soil-dependent, being a function of both climatic and soil properties. Equations 5–7 explicitly illustrate the complexity of the issue.

$$\frac{\partial q_m}{\partial t} = -D_{m(T)} \cdot \frac{\partial C_{m(t)}}{\partial z} \qquad (5)$$

$$\frac{\partial Cm}{\partial t} = \alpha \cdot div q_m + \beta \cdot \left(\sum_{i=1}^{n} n'_i \cdot a_{i(t)} - \sum_{i=1}^{n} n''_j \cdot a_{j(t)} \right) \qquad (6)$$

$$\frac{\partial a}{\partial t \partial x} = f(T, C_c, pH, Eh) \qquad (7)$$

Where, $\mathbf{q_m}$ is methane flux; $\mathbf{D_{(T)}}$ is temperature-dependent diffusion coefficient for methane; $\mathbf{C_m}$ is methane concentration; **z** – soil depth, **n'** – number and **a'** – activity of methanogenic and respectively **n"**, **a"** – those of methanotrophic organisms, **T** – temperature, and $\mathbf{C_{c(z)}}$ is the concentration of metabolizable carbon. α and β are empiric coefficients, while **f** is an empitic function.

Thus, both methane emission and uptake in soils are totally dominated by diffusion (), which by itself is a function of soil porosity, temperature, included into diffusion coefficient and methane concentration gradient. The latter, in turn, depends on the rate of methane generation and oxidation at a given depth and thus reflects the distribution of methanogenic and methanotrophic organisms with depth, their number, and activity. The climatic parameters (mainly temperature and, indirectly, rainfall) influence both the number and the activity of methanogenic and methanotrophic organisms. The number and the activity of the above organisms is also controlled by soil pH and Eh values.

Unfortunately, most of the actual measurement data is not directly linked to soils, i.e., a type of soil and its respective properties are not described or identified. That seems to be a serious drawback for further calculations and geographical extrapolations. Usually, the publications on methane emission contain geographical coordinates (sometimes only approximate latitude) which help to expertly identify the described sites of bogs, fens and other land classes with particular types of soils at least at the level of Big Soil Groupings, and sometimes Soil Units of SMW: FAO/UNESCO Soil Map of the World (1974).

The following expert scheme, cross-references some frequently cited land classes to FAO/UNESCO Soil Units.

Wet coniferous forest	Gleyic Luvisols and Podzoluvisols
Wet deciduous forest	Gleyic Cambisols and Gleyic Greyzems
Salt marsh	Gleyic Solonchak and Gleyic Solonetz
Well-drained tundra	Gelic Regosols and Cambisols; Lithosols, Rankers and Rendzinas on permafrost
Moist tundra	Gelic Gleysols
Forested fen	Eutric Histosols and Eutric Gleysols
Forested bog	Dystric HIstosols and Dystric Gleysols
Conifer swamp	Humic Gleysols
Sedge meadow	Mollic Gleysols
Alluvial formations	Fluvisols
Open bogs	Dystric Histosols
Open fens	Eutric Histosols
Bogs and fens on permafrost	Gelic Histosols

Since methane emissions vary more from depression to hillock than between different types of wetlands, the percentage of hillocks was set to 50% for both fens and bogs.

The following approach was generated to assess the background methane emission from soils of Russia's natural wetlands. Methane is generated by soil microorganisms in a rather limited number of soils, i.e., Histosols, Gleysols, Fluvisols, and some gleyic soils of different Big Soil Groupings. The number of second-level soil units referring to the above-mentioned groups of soils is limited to 18 as far as the territory of the Russian Federation is concerned.

The areas occupied by soils, that are "capable" of generating methane was calculated from the FAO/UNESCO 1:5,000,000 Soil Map of the World (1974).

Thus, 355 mapping units containing soils given in *Table 1* were identified within the territory of Russia. These mapping units occur from 1 to 20 times on the surface of the map and cover some 60% of the total area of Russia. The actual areas are of wetlands and soils with reduction environment present for at least a season comprise little less than 30% of the territory. The verified areas in *Table 1* refer to corrected values obtained from the ratio of areas calculated from the SMW (16.8 billion sq. km) and given by official statistics (17.1 billion sq. km).

The actual field and laboratory measurements of methane emission rates are referred to one of the delineated soil groupings, and respectively to the enclosing mapping unit, however complex it might be. The total emission rates for the territory under discussion (whether it is a forestry unit, administrative region, individual country, or the whole World) are calculated for the accumulated areas of soils with experimentally obtained methane emission factors averaged for each soil grouping.

Such soils as Fluvisols that are not characterized by experimental data extensively enough to enable detailed statistical analysis and estimation at soil units level may be referred to at the Major Soil Grouping level.

As far as background emissions are concerned, the calculations based on soil maps may be regarded as rather accurate (making certain reservations for the generalization of both soil and chemical data, accuracy of mapping, methane emission measurements, etc.). Thus, the bigger the soil group we use for this assessment the less accurate results emerge. The area of the studied territory, partially the lesser the data coverage, the higher the dispersion of actual data.

The calculations of methane emissions from soils by mapping units are suggested to be conducted according to the following formulas, depending on data availability.

$$Em = \sum_{i=1}^{n} a_i \cdot \int_{t_1}^{t_2} r_{i(t)} \partial t \tag{8}$$

where **Em** is the accumulated methane emission from area **a** of the mapping unit component **i** for the period of time $\mathbf{t=t_2-t_1}$, provided we know the distribution function $\mathbf{r_i}$ of emission rate for every **i**-th component during time **t**.

Unfortunately, at the current state of knowledge on methane emission rates the latter provision is usually not observed. However, the following approximations may be used for the purpose of regional assessment, assuming winter fluxes to be zero or insignificant.

$$Er_i = \int_{t_1}^{t_2} r_{i(t)} \partial t \approx \overline{r_i} \cdot PBA_i \cdot \tag{9}$$

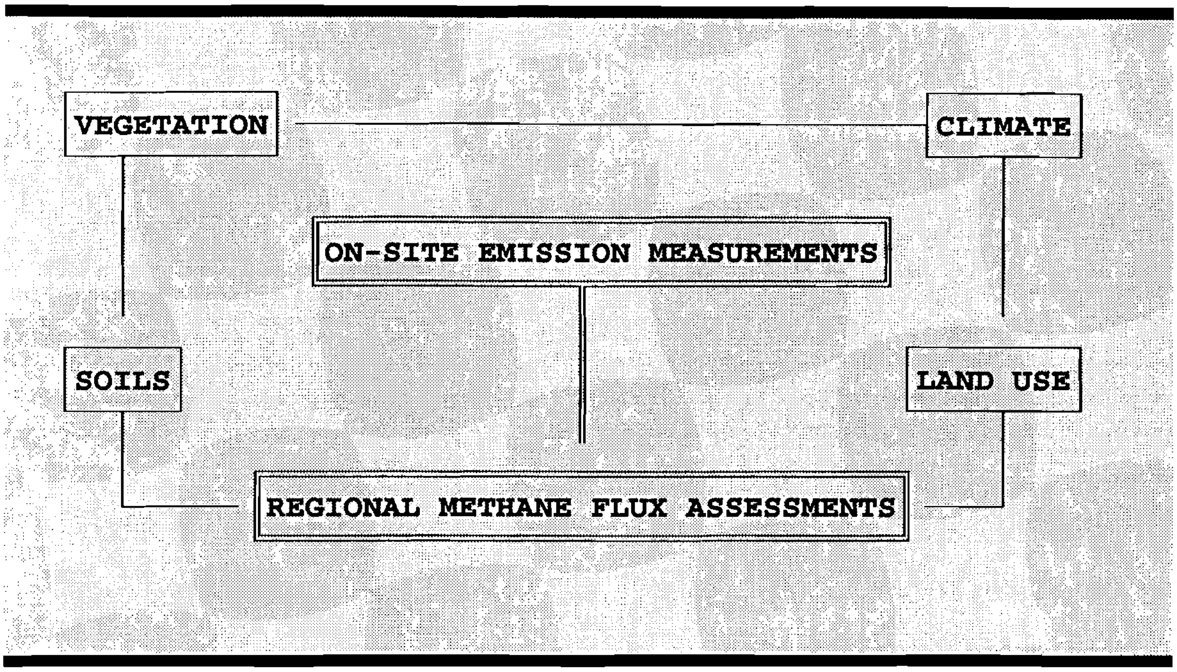
where $\mathbf{Er_i}$ is the accumulated methane emission at the measurement point and $\mathbf{PBA_i}$ is the Period of Biological Activity for the **i**-th soil.

An even rougher estimation may be based on setting an average PBA value for boreal areas not affected by permafrost to 150 days, and for those of permafrost territories – 100 days per year.

$$\begin{bmatrix} Em = 100 \cdot \overline{r_i} \;|: i \in Permafrost \\ Em = 150 \cdot \overline{r_i} \;|: i \notin Permafrost \end{bmatrix} \tag{10}$$

Furthermore, relying on exclusive soil data, we are unable to take into consideration the areas of drained and irrigated soils, which are not identified on the SMW. Overlaying the Soil Map with that of Land Use may somewhat improve the results. Depending on the study at hand, the drained and irrigated areas may be taken into consideration based on statistical data for land development. Referring to land-development data, the areas of drained soils should be subtracted from Gleysols and Gleyic soils, while the areas of drained peatlands should be cut from that of Histosols.

Subsequent overlaying of the soil map with a climatic one (essential for extensive areas located in different climatic regions) and that of land use will give both a better understanding of the spatial distribution of methane sources and a more accurate assessment of emission rates. For example Gleysols in different climatic zones under cultivation will provide no input of methane or at least much lower emission rates than those under natural vegetation in different climates.



The methane emissions from paddy soils of rice fields, which are also not marked on the SMW, should be calculated from statistical data on rice production. The areas of irrigated land may be disregarded for a while due to insufficient and contradictive data on methane emission from referring exclusively to irrigated Chernozems.

A detailed digital land-use map is essential to:

1. make the current assessments more accurate;
2. predict changes of methane emission resulting from changes in land-use practices, changes in extension of irrigated, drained and cultivated areas.

3.2 Methane emission from natural wetlands and drained tundra

Of the diverse functions soils perform in the biosphere, one of the most important are the functions of soils as semipermeable geomembrane (Розанов, 1989), regulating the exchange of gases between the geosphere and the atmosphere (Blum, Aguillar, 1992).

Three Major Soil Groupings (MSG) are most commonly associated with the methane production in soils: Histosols, Gleysols, and Fluvisols. The gleyic Soil Units of different MSGs (Podzols, Podzoluvisols, Cambisols, Greyzems, Solonetz, and Solonchaks), hereafter referred to as Gleyic soils, also take part in methane production due to stagnation of surface waters and reduction processes during that period. Furthermore, methane emission also occurs in well-drained tundra regions with sheet or discontinuous permafrost. The soils of tundra, usually classified as gelic at the second sublevel (where applicable) belongs to Cambisols (forested tundra), Regosols, Lithosols, Rankers and Rendzinas*. Though, emission rates in the above areas are rather small in comparison with those, for example, of Histosols, the

* The area of Rendzinas on permafrost totalled to 0, probably due to their little significance as soil cover components in the studied region.

extensive territories covered by these soils make them an important component of methane-producing soil complex.

Table 3. The main methane producing groups of soils in Russia.

Soils	Permafrost area, km^2	Non-permafrost area, km^2	Total Area, km^2
Gleysols	1,850,655.4	762,533.6	2,613,189.0
Fluvisols	86,576.1	191,790.2	278,366.3
Histosols	1,098,638.3	696,424.4	1,795,062.6
Gleyic soils	245,989.3	725,334.2	971,323.5
Weakly-developed frozen soils	4,584,495.4	6,157.6	4,590,653.1
Total	7,866,354.5	2,382,240.0	10,248,594.5
Percent of the total land area of Russia:			59.93

The calculations of land areas made according to the list of methane-producing Soil Units given in Appendix 1, show that some 60% (*Table 3*) of the total land area of Russia may be considered as generating methane. Furthermore, almost 80% of these soils are located in the permafrost area. The actual wetlands are distributed in a more proportional manner occupying 3.3 and 2.3 million sq. km in permafrost and non-permafrost areas, respectively, with Histosols of mires distributed as 11:7 between permafrost and non-permafrost territories.

Table 4. Methane emission rates (Tg/year) from Boreal, Subboreal and Arctic soils.

Soil groups	Area, km^2	CH_4 emission
Boreal and Subboreal Histosols	684206.4	8.25
Arctic and Subarctic Histosols	1079363.9	10.45
Boreal and subboreal Gleysols	749155.8	2.93
Arctic Gleysols	1818187.8	15.74
Boreal and subboreal gleyic soils	672471.1	0.08
Arctic gleyic soils	241673.7	0.03
Arctic weakly-developed soils	2446442.7	1.25
Boreal and subboreal Fluvisols	34784.5	0.25
TOTAL SOILS	9838019.5	38.99

Table 5. Methane emission from soils in Russia.

Soil Unit		Area, km^2	N	EF, $mg/m^2/day$	Annual CH_4 emission, Tg
Bg	F	57248.4	2	0.72	0.01
Bx	F	6049.6	0		
Dg	F	105382.5	1	0.1500	0.00
Gc	F	18861.3	0		
Gd	F	252254.0	5	24.25	0.92
Ge	F	65979.7	7	24.45	0.24
Gh	F	226134.0	5	31.86	1.08
Gm	F	106988.2	6	42.75	0.69
Gx	F	78938.6	0		
J	F	34784.5	2	47.53	0.25
Lg	F	187264.8	0		
Mg	F	60881.6	4	0.07	0.00
Od	F	508037.1	25	87.14	6.64
Oe	F	158407.8	17	67.90	1.61
Ox	F	17761.5	0		
Pg	F	233215.1	5	1.97	0.07
Rx	F	40137.9	0		
Sg	F	26110.5	0		
Zg	F	2368.2	0		
Bg	T	75564.7	0		
Bx	T	2057623.0	0		
Dg	T	72521.5	0		
Gd	T	289107.9	0		
Ge	T	25992.3	0		
Gh	T	35028.2	6	58.98	0.21
Gm	T	43414.0	10	116.31	0.50
Gx	T	1424645.4	20	105.51	15.03
I	T	1574543.6	19	7.96	1.25
J	T	7923.1	0		
Mg	T	15384.3	0		
Od	T	653142.7	1	11.6000	0.76
Oe	T	258719.5	2	343.6154	8.89
Ox	T	167501.7	5	48.0361	0.80
Pg	T	67971.3	1	4.6000	0.03
Rx	T	871719.6	0		
Sg	T	10231.9	0		
U	T	179.5	0		

As seen from *Table 5*, Histosols are characterized by having the highest methane emission rates. Gleysols on permafrost, though accumulating much less organic matter and displaying lower emission rates than Histosols, occupy vast territories and present the largest sources of natural methane flow into the atmosphere.

So far, the measurements of methane fluxes in soils were limited to soils with high emission rates (predominantly those of peatlands), and soils on permafrost, due to the vast areas they occupy and, thus, to the considerable input of CH_4 they provide. However, *Table 5* shows that some of the soils that are characterized by reduced environment, and permanently or seasonally low Eh values, are still not covered by direct measurements of methane fluxes.

The above calculations were generated with the UNMAP program (Appendix 3) which was made to process soil area data obtained from the FAO/UNESCO SMW and Emission Factors data compiled into the EMISSION database from available publications.

Histosols of both Boreal and Arctic regions are the main source of soil-derived methane jointly contributing into the atmosphere some 24 Tg/year. Another 15 Tg/year are provided by the northern Gleysols, which cover extensive areas in Russia.

Some two thirds of more than 300 Mapping Units identified for Russia on the FAO/UNESCO SMW, contain soils capable of generating methane. The total assessed amount of 39 Tg CH_4 per year is some 35% of the average Global emissions from wetlands. However, it should be taken into account that some of the Arctic soils are either only seasonal wetlands, or represent soils of dry tundra, not included into the global assessments of wetland areas. Nevertheless, these soils are accumulating a considerable amount of organic matter serving the substrata for methane production and experience seasonal chemical reduction.

Containing a considerable amount of permafrost, the Arctic regions attract extensive scientific attention as a potential source of methane, once the permafrost starts to melt due to global warming. The concentrations of methane in the permafrost layers is scarcely covered by core sample data, obtained from different parts of the globe. The possible global emissions from partial permafrost thawing could be as high as 60 Tg within the coming 100 years, but could also be 0 according to different scenarios. Data available on CH_4 concentrations in permafrost is too scarce and to varying to make general estimations for the territory of Russia.

3.3 Methane emission due to land-use changes, from paddy rice fields, irrigated and flooded lands

Land-use changes in Russia during the last few decades were growing extensively. The area of irrigated agriculture grew from 3.684 million ha in 1975 to 6.150 million ha in 1990. The areas of wetlands drained for agricultural purposes experienced a comparable growth ending at 6.3 million ha in 1990.

Drainage of mires decreases methane emissions from drained soils due to better soil aeration and destabilization of anaerobic conditions essential for methane production. However, the actual decrease in methane emissions from the drained territory is less than might be expected. The Russian wetlands are drained by a network of drain channels. These open drain trenches become "refugee camps" for methanogenic communities. Though, occupying only some 2% of the drained territory, the open drains first serve as valves for releasing the methane trapped in anaerobic soils, and then become major local methane generators. According to Bouwman (1990) the methane trapped in anaerobic soils may be released under human impact. Panikov and Zelenev (1991) showed that the release and production of methane via drainage trenches continues even 20 years after the territory was drained. The above authors also demonstrated that the application of organic fertilizers may dramatically increase the CH_4 emissions. The experiment with well-drained arable grey forest soils in Pouschino, showed that the application of straw increased methane emission from 0–0.04 to 0–0.43 mg C-CH_4/sq.m/h.

Considering the emission rate of 3.9 mg/sq.m/h measured by Panikov and Zelenev (1991) at the drain trenches Kalinin oblast', and the low emission of 0–0.08 from the drained land between channels the following formula may be applied:

$$E_d = \frac{10 \cdot A_d \cdot (W_d \cdot F_d + W_i \cdot F_i)}{W_d + W_i} \tag{11}$$

Substituting 6.3 for drained area A_d, million ha; 0.3 g/sq.m/yr for emission factor F_i (interchannel land); 100 m for average distance between draining channels W_i; 14.0 g/sq.m/yr for F_d (emission factor for drainage channels), and 2 m for common channel width, we can roughly assess the current CH_4 emissions from drained wetlands as 3.6 Tg/year.

The methodology for assessing methane emissions from paddy soils under rice crops was developed by Khalil for IPCC/OECD (1994). Although rice paddy soils are one of the major world methane sources, the rice fields in Russia are too scarce to provide a considerable input to the country's total methane emission.

Russia owns half the rice fields of the former USSR. The total cropping area of rice in Russia for the past 10 years comprised, as an average, some 300 thousand ha, which is a little less than 0.3% of the world area of 144.529 million ha of rice fields. Taking into consideration that even in the southernmost part of Russia, there is only one rice-cropping season, the total methane emission may be estimated according to IPCC/OECD (1994) methodology using the emission factor of 3.48 kg/ha/day for continuously flooded rice with a growing period of 103 days and a flooding period of 100 days at an average temperature of 18°C . The total amount of methane generated from the flooded rice in Russia is about 0.1 Tg per year.

The rate of methane emissions from paddy rice depends also on the nature and intensity of fertilizer application, and type of the flooded soil (from the viewpoint of humus content). However, taking into account that most of the Russian rice paddys are chernozems, and the technology for rice-growing in the area is rather uniform, these factors may hardly affect both the diversity of methane emission rates in different rice-growing regions and the total methane input.

Methane emissions were also reported from arable lands undergoing soil changes due to irrigation (**Минько**, 1986; **Розанов**, 1985). The experiments were conducted in the Odessa region of the Ukraine, where southern chernozems were irrigated with alkali waters of the Sasik brakish-lagoon. The mentioned emission rates varied from 0 to 40 mg CH_4/sq.m./h, which makes the emission rates comparable to those from a well-drained tundra. An average emission rate for chernozems covered by experimental data is 8 mg CH_4/sq.m./day. The emission rate was found dependent of irrigation schedule, soil temperature, texture and initial moisture content.

Irrigation techniques seem to be a crucial point for methane emissions from irrigated land, i.e. no noticeable emission was registered, unless the irrigated soil land was flooded at least for a short period of time. However, it was noted that, despite the general oxidation environment within the soil profile of arable soil, local cores of anaerobic conditions may exist in individual aggregates, providing adequate conditions for the generation of methane.

The application of brackish lagoon waters to dry territories probably extends the habitat of methane-generating microorganisms that are transported to dry lands with irrigation water and via irrigation channels.

The data given in the above publications refers only to Chernozem soils in the vicinity of brackish lagoons. Thus, further experiments are essential to assess the existing methane emission from irrigated land. However, based on available data, the total methane emission from the 6.2 million ha of irrigated soil in Russia, stipulating that all the irrigated soils are fine-textured chernozems, or behave like chernozems under irrigation, are situated in a temperate zone and are periodically flooded by irrigation, a rough assessment may be made of the methane discharged from these soils. According to our calculations the total methane emission from the irrigated lands of Russia may hardly exceed the amount of 0.7 Tg CH_4 per year.

Vast areas of Russia were flooded during the past few decades due to the building and operation of hydropower plants, abandonment of waterlogged irrigated land, etc. The total amount of land abandoned due to flooding is 4.2 million ha. Despite the variability in the organic matter content in flooded soils, an average CH_4 emission factor may be generated for these lands regarding them as alluvial formations with an emission rate of 48 mg CH_4/sq.m./day (Hogan, 1993) and the length of emission period of 150 days, since they are situated mainly in temperate regions. The territories flooded by water reservoirs are usually unaccounted for in global methane emission assessments. In Russia, they provide for methane emission input four times higher than paddy rice and all the irrigated lands taken together.

Table 6. Methane emissions from irrigated, flooded and paddy rice lands.

Land type	Area, million ha	Emission Factor (EF), mg CH_4/sq.m./day	PBA, days	E, Tg/y
Paddy rice	0.3	35	100	0.1
Flooded land	4.5	48	150	3.2
Irrigated land	6.2	8	150	0.7
Total	7.5	91		4.0

The land-use changes in Russia during the 20th century account for 4 Tg/year increase in methane emission due to irrigation, flooding and cultivation of paddy rice. The decrease in methane emission due to drainage of wetlands does not compensate for the total emission growth from land-use changes.

4 Methane Emission from Livestock and Agricultural Wastes in Russia: A Region-by-region Assessment

4.1 Methodological and data aspects of assessing methane emission from livestock and agricultural wastes in Russia

Animal Sources of Methane

The methane emission rates from livestock greatly depends on the group of animals under study with respect to their digestive system. Ruminant animals – *cattle, buffalo, goats, sheep, and camels* – are the main source of methane in animal husbandry. Pseudoruminant – *horses, mules, and asses* – and monogastic animals – *swine* – provide for much lower input, since most of methane generated by animals comes from rumen. Poultry has a very low methane emission rate and may be disregarded.

The ruminant digestive system of cattle, their weight and the amount of manure produced, makes cattle the most important source of agricultural methane emission. Methane emissions from manure are usually much smaller than those resulting from enteric fermentation and become relevant in overall calculations mainly for advanced manure management systems. The latter refer to confined animal husbandry with stall-feeding and Liquid/Slurry (Hashimoto and Steed, 1993) and Anaerobic Lagoon manure management (Safley *et al.*, 1992).

Free grazing is a seasonal and rather short phenomenon in Russia depending on length of vegetative period, and thus varies from one region to another, while stall-feeding is dominant for most of the year. The Anaerobic Lagoon manure management system is not commonly used.

The private and small farms usually exert either Daily spread (during summer) or Solid storage (throughout the year). The above practices are characterized by very low Methane Conversion Factors (MCFs) ranging 0.1 to 1.5% in cool and temperate climates. Hereinafter, the climates with average annual temperature below 15°C are referred to as cool, and those with average temperature ranges from 15 to 25°C as temperate.

Collective farms and state-owned agricultural enterprises, which own some 80% of cattle along with Solid storage, which requires substantial manpower, also widely exercise the Liquid/Slurry manure management (about 30% of total cattle manure) with much higher MCFs ranging from 10% in cool climates to 35% in temperate regions. These systems are, on the one hand, more cost-effective for big farming enterprises, and, on the other hand, provide storage facilities (usually concrete tanks) for manure to be accumulated during winter (for six months or more) to be applied to the fields in due time.

Discharges of liquid manure from farms with insufficient storage facilities into gullies, which caused river pollution, were reported in the Moscow region, but are hard to assess in terms of their volume for the lack of monitoring data.

Basic Data

Of the above-mentioned animals Russia breeds mainly *cattle, sheep, goats, horses, and swine.* Data on the number of heads for each group subdividing cattle into dairy and non-dairy is available for the period of 1987 to 1991 from the Russian State Committee on Statistics (GOSKOMSTAT). These data are presented according to administrative regions of Russia.

The length of pasture period is assumed to be 90 days for cool regions and 140 days for temperate zone.

The following average CH_4 emission factors are available for Russia pre-calculated and averaged from different climatic regions (IPCC/OECD, 1994):

Enteric Fermentation CH_4 Emission Factors for Cattle

Dairy cows (average milk production – 2,550 kg/year)	81 kg CH_4 /head/year
Non-dairy cows (including beef cows, bulls and young)	56 kg CH_4 /head/year

Manure Management CH_4 Emission Factors for Cattle and Swine

Dairy cows	6 kg CH_4 /head/year
Non-dairy cows	4 kg CH_4 /head/year
Swine	4 kg CH_4 /head/year

Manure management for sheep, goats and horses in Russia is conducted entirely under the dry system. The following average universal CH_4 emission factors are given for fermentation (Crutzen *et al.*, 1986) and manure management under the dry system (Woodbury and Hashimoto, 1993):

Enteric Fermentation CH_4 Emission Factors for Other Livestock

Sheep	8 kg CH_4 /head/year
Goats	5 kg CH_4 /head/year
Horses	18 kg CH_4 /head/year
Swine	1.5 kg CH_4 /head/year

Manure CH_4 Emission Factors for Other Livestock in Developed Countries

Sheep	0.19 (cool) 0.28 (temperate) kg CH_4 /head/year
Goats	0.12 (cool) 0.18 (temperate) kg CH_4 /head/year
Horses	1.40 (cool) 2.10 (temperate) kg CH_4 /head/year

4.2 Methane emission from livestock enteric fermentation

The global methane emissions from livestock enteric fermentation (mainly ruminants) were estimated by Lelieveld and Crutzen (1993) as 80±20 Tg per year. According to our calculations (*Table 7*) Russia accounts for approximately 6% (4.2 Tg) of that amount. Dairy and non-dairy cattle taken together account for 78% of the total CH_4 emissions from enteric fermentation.

Table 7. Methane emission from livestock enteric fermentation in major socio-economic regions of Russia in 1991.

Socio-economic region	DAIRY	NON-DAIRY	SWINE	SHEEP, GOATS	HORSES	Total livestock
Central Chernozem region	138.5	155.8	6.3	19.3	2.7	322.5
Central region	251.8	261.6	6.2	14.5	2.8	536.9
East Siberia	112.5	136.8	3.4	57.7	6.2	316.6
Far East	50.5	57.2	2.3	0.4	4.3	114.7
North region	42.6	42.6	1.3	3.0	0.5	89.9
North-Caucasus region	191.2	236.6	9.3	112.3	4.3	553.6
North-West region	48.1	44.9	1.7	2.3	0.5	97.5
Pre-Volgian region	228.2	274.7	7.6	90.2	5.9	606.6
Ural region	257.3	302.6	6.2	44.6	8.4	619.1
Volgo-Vyatka region	111.2	128.8	3.3	11.1	1.4	255.7
West Siberia	220.1	252.7	5.2	36.5	9.4	524.0
TOTAL, Russian Federation	1665.7	1910.3	53.1	392.3	46.6	4068.0

The CH_4 input from enteric fermentation is rather evenly developed between the main cattle-breeding socio-economic regions of Russia. The Northern, North-Western and the Far-East regions are characterized by low methane emission rates from this source due to unfavorable climatic conditions.

4.3 Methane emission from agricultural waste

Due to its location (predominantly in a cool climate with mean annual temperatures below 15°C), Russia produces rather low input in methane emissions from animal waste. The total emission of 435 Gg hardly reaches 4.5% of the global 25 Tg calculated by Lelieveld and Crutzen (1993).

Table 8. Methane emission from agricultural waste in major socio-economic regions of Russia in 1991.

Socio-economic region	DAIRY	NON-DAIRY	SWINE	SHEEP, GOATS	HORSES	Total livestock
Central Cherno-zem region	10.3	11.1	16.8	1.5	0.2	39.9
Central region	18.7	18.7	16.5	1.1	0.3	55.2
East Siberia	8.3	9.8	9.0	4.5	0.6	32.1
Far East	3.7	4.1	6.2	0.0	0.4	14.4
North region	3.2	3.0	3.4	0.2	0.0	9.9
North-Caucasus region	14.2	16.9	24.7	8.7	0.4	64.8
North-West region	3.6	3.2	4.5	0.2	0.0	11.5
Pre-Volgian region	16.9	19.6	20.1	7.0	0.5	64.2
Ural region	19.1	21.6	16.6	3.4	0.8	61.5
Volgo-Vyatka region	8.2	9.2	8.7	0.9	0.1	27.1
West Siberia	16.3	18.1	14.0	2.8	0.8	52.0
TOTAL Russian Federation	123.4	136.5	141.5	30.3	4.2	435.8

The spatial distribution of CH_4 emissions from manure management is identical to that of emissions from enteric fermentations since the producers remain the same. The manure management practices are rather uniform throughout the country and, thus, do not influence much the spatial variability in emission rates from agricultural sources.

5 General Assessment of Methane Emissions from Natural and Agricultural Sources in Russia and Prospects Outline for CH_4 Emission Modeling

The total emission from natural and agricultural sources in Russia, according to our assessment is 47.5 Tg/year (*Table* 9), a little less than 1/3 of the world total 150 Tg/year estimated by Hogan (1993).

Table 9. Estimated CH_4 emissions from Soils and Agricultural Sources in Russia.

Source	Estimated CH_4 Emission, Tg/year
Natural Soils	39.0
Areas Flooded by Hydropowerplants	3.2
Paddy rice	0.1
Irrigated lands	0.7
Animal Enteric fermentation (mainly ruminants)	4.1
Manure management	0.4
TOTAL CH_4 emission from soils and agricultural sources for Russia	47.5

National or regional modeling of future CH_4 emissions from natural and agricultural sources in Russia requires much more experimental data, than currently available. It also necessitates the availability of land-use data, and land-use change models to predict the dynamics for area distribution changes, including wetlands, irrigated, drained, and flooded lands. To include the effects of permafrost thawing on future methane, experimental data on rates of expansion of microbial communities should be obtained to correlate it with thawing rates. Leakages of fossil methane from undeveloped oil-and-gas fields through soils should be assessed and separated from emissions of soil microbial origin.

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APPENDIX 1

Daily CH_4 Emission Factors for Assigned Soil Units, Taken or Recalculated from Different Printed Sources

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, $mg/m^2/day$	CITATION
Moscow region	Field, control	F[1]	55.32	Mg	0.02	Panikov & Zelenev 1991.
Moscow region	Field, PK	F	55.32	Mg	0.02	Panikov & Zelenev, 1991.
Moscow region	Field, NPK	F	55.32	Mg	0.02	Panikov & Zelenev, 1991.
Moscow region	Field, NPK+stow	F	55.32	Mg	0.215	Panikov & Zelenev, 1991.
Tver region	Drained bog	F	56.1	Od	0.04	Panikov & Zelenev, 1991.
Tver region	Drain trench	F	56.1	Od	3.9	Panikov & Zelenev, 1991.
Tver region	Bog, mound	F	56.1	Gh	0.15	Panikov & Zelenev, 1991.
Tver region	Bog, depression	F	56.1	Od	5.2	Panikov & Zelenev, 1991.
Tver region	Lake shore	F	56.1	J	0.52	Panikov & Zelenev, 1991.
Tver region	Bog, hillock	F	56.1	Od	115.2	Panikov & Zelenev, 1991.
Tver region	Bog, depression	F	56.1	Od	45.5	Panikov & Zelenev, 1991.
Tver region	Bog	F	56.1	Od	0.55	Panikov & Zelenev, 1991.
Tver region	Bog	F	56.1	Od	4.4	Panikov & Zelenev, 1991.
Tver region	Bog	F	56.1	Od	36.6	Panikov & Zelenev, 1991.
Tver region	Forested fen, hillock	F	56.1	Oe	0.03	Panikov & Zelenev, 1991.
Tver region	Forested fen, depression	F	56.1	Oe	0.07	Panikov & Zelenev, 1991.

[1] P - permafrost, logical field: F - faulse, T - true.

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, $mg/m^2/day$	CITATION
Syktyvkar region	Bog	F	61.41	Od	0.67	Panikov & Zelenev, 1991.
Syktyvkar region	Forested bog, hillock	F	61.41	Od	-0.52	Panikov & Zelenev, 1991.
Syktyvkar region	Forested bog, depression	F	61.41	Gd	2.22	Panikov & Zelenev, 1991.
Syktyvkar region	Wet forest	F	61.41	Dg	0.15	Panikov & Zelenev, 1991.
Vorkuta region	Swamp, mound	T	67.59	Ox	0	Panikov & Zelenev, 1991.
Vorkuta region	Swamp, mound base	T	67.59	Ox	0.33	Panikov & Zelenev, 1991.
Vorkuta region	Swamp, depression	T	67.59	Ox	4.32	Panikov & Zelenev, 1991.
Minnesota, Marcell Forest & Zerkel	Bog, forested	F	47	Od	100	Harris *et al.*, 1992.
Minnesota, Marcell Forest & Zerkel	Bog, nonforested	F	47	Od	306	Harris *et al.*, 1992.
Minnesota, Marcell Forest & Zerkel	Fen, forested	F	47	Oe	85	Harris *et al.*, 1992.
Minnesota, Marcell Forest & Zerkel	Wild rice bed	F	47	Gh	493	Harris *et al.*, 1992.
Minnesota, Marcell Forest & Zerkel	Meadow, sedge	F	47	Gm	664	Harris *et al.*, 1992.

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, $mg/m^2/day$	CITATION
Minnesota, Marcell Forest & Red Lake	Bog, forested	F	47	Od	89	Crill P. *et al.*, 1982
Minnesota, Marcell Forest & Red Lake	Bog, nonforested	F	47	Od	199	Crill P. *et al.*, 1982
Minnesota, Marcell Forest & Red Lake	Fen, forested	F	47	Oe	142	Crill P. *et al.*, 1982
Minnesota, Marcell Forest & Red Lake	Fen, nonforested	F	47	Oe	348	Crill P. *et al.*, 1982
Minnesota, Marcell Forest	Bog, nonforested	F	47	Od	177	Verma et. al., 1992
Minnesota, Marcell Forest	Bog, forested, hummock	F	47	Od	21	Dise N.B., 1992
Minnesota, Marcell Forest	Bog, forested, hollow	F	47	Gd	93	Dise N.B., 1992
Minnesota, Marcell Forest	Fen lagg	F	47	Ge	17.33	Dise N.B., 1992
Minnesota, Marcell Forest	Bog, nonforested	F	47	Od	356	Dise N.B., 1992
Minnesota, Marcell Forest	Fen, nonforested	F	47	Oe	402	Dise N.B., 1992
Alberta	Fen, nonforested, poor	F	54	Ge	1	Vitt *et al.*, 1990

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, $mg/m^2/day$	CITATION
Alberta	Fen, nonforested, rich	F	54	Oe	65	Vitt *et al.*, 1990
Alberta	Fen, nonforested, rich	F	54	Oe	24	Vitt *et al.*, 1990
Alberta	Meadow, sedge	F	54	Gm	148	Vitt *et al.*, 1990
Schefferville	Fens, nonforested	F	55	Oe	30.5	Moore & Knowles, 1987
Schefferville	Fens, nonforested, center	F	55	Oe	72	Moore, Roulet & Knowles, 1990
Schefferville	Fens, nonforested, margin	F	55	Ge	30	Moore, Roulet & Knowles, 1990
Schefferville	Fens, nonforested, flooded	F	55	Oe	33	Moore, Roulet & Knowles, 1990
Schefferville	Fen, forested, margin	F	55	Ge	28	Moore, Roulet & Knowles, 1990
Schefferville	Fen, nonforested, patterned, ridges	F	55	Gh	7.5	Moore, Roulet & Knowles, 1990
Schefferville	Fen, nonforested, patterned, pool	F	55	Oe	48	Moore, Roulet & Knowles, 1990
Schefferville	Fen, rich, nonforested, Horiz.	F	55	Oe	20	Moore, Roulet & Knowles, 1990
Schefferville	Fen, poor, nonforested, Horiz.	F	55	Ge	65.33	Moore, Roulet & Knowles, 1990

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, $mg/m^2/day$	CITATION
Schefferville	Fen, ribbed, ridge	F	55	Ge	8.67	Moore, Roulet & Knowles, 1990
Schefferville	Fen, ribbed, pool	F	55	Oe	66	Moore, Roulet & Knowles, 1990
Mont St. Hilaire	Swamps, basin	F	45	Gd	28	Moore, Roulet & Knowles, 1990
Mont St. Hilaire	Bog, domed, center	F	45	Od	0.67	Moore, Roulet & Knowles, 1990
Mont St. Hilaire	Bog, domed, margin	F	45	Od	0.67	Moore, Roulet & Knowles, 1990
Low boreal forest	Swamps, conifer	F	45	Pg	7.1	Roulet *et al.*, 1992
Low boreal forest		F	45	Pg	0.15	Roulet *et al.*, 1992
Low boreal forest		F	45	Pg	0.2	Roulet *et al.*, 1992
Low boreal forest		F	45	Pg	0.2	Roulet *et al.*, 1992
Low boreal forest	Swamps, hardwood	F	45	Bg	1.2	Roulet *et al.*, 1992
Low boreal forest		F	45	Bg	0.25	Roulet *et al.*, 1992
Low boreal forest	Swamps, thicket	F	45	Gh	69.3	Roulet *et al.*, 1992
Low boreal forest		F	45	Gh	0.4	Roulet *et al.*, 1992
Low boreal forest	Marshes	F	45	Gm	1.2	Roulet *et al.*, 1992
Low boreal forest		F	45	Gm	0.5	Roulet *et al.*, 1992

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, mg/m^2/day	CITATION
Low boreal forest	Bog, open	F	45	Od	20.6	Roulet *et al.*, 1992
Low boreal forest	Bog, forested	F	45	Od	5.8	Roulet *et al.*, 1992
Low boreal forest	Fen	F	45	Oe	3	Roulet *et al.*, 1992
Moor House	Bog, blanket, pool	F	55	Od	62	Clymo & Reddaway, 1971
Moor House	Bog, blanket, lawn	F	55	Gm	35.33	Clymo & Reddaway, 1971
Moor House	Bog, blanket, hummock	F	55	Gd	8.67	Clymo & Reddaway, 1971
Southern Hudson Bay lowlands	Marshes	F	55	Gm	31	Crill P. *et al.*, 1992
Southern Hudson Bay lowlands	Fen, shrub and tree	F	55	Ge	2.5	Crill P. *et al.*, 1992
Southern Hudson Bay lowlands	Fen, open	F	55	Oe	7.9	Crill P. *et al.*, 1992
Southern Hudson Bay lowlands	Fen, pools	F	55	Oe	133	Crill P. *et al.*, 1992
Southern Hudson Bay lowlands	Bog, pools	F	55	Od	60	Crill P. *et al.*, 1992
Southern Hudson Bay lowlands	Bog, open	F	55	Od	54	Crill P. *et al.*, 1992
Southern Hudson Bay lowlands	Bog, shrub-rich	F	55	Od	48	Crill P. *et al.*, 1992

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, $mg/m^2/day$	CITATION
Southern Hudson Bay lowlands	Bog, treed	F	55	Gd	1.8	Crill P. *et al.*, 1992
Southern Hudson Bay lowlands	Forest, conifer	F	55	Pg	3.3	Crill P. *et al.*, 1992
Subarctic mire, ombrotrophic		T	68	Od	11.6	Svensson & Rosswall, 1984
Subarctic mire, intermediate		T	68	Ox	58	Svensson & Rosswall, 1984
Subarctic mire, mineratrophic		T	68	Oe	360	Svensson & Rosswall, 1984
Alaska, North Slope & Denali	Tundra, wet coastal	T	68	Rx	119	Sebacher *et al.*, 1986
Alaska, North Slope & Denali	Tundra, moist	T	68	Gx	4.9	Sebacher *et al.*, 1986
Alaska, North Slope & Denali	Tundra, moist	T	68	Gx	40	Sebacher *et al.*, 1986
Alaska, North Slope & Denali	Fen, alpine	T	68	Oe	289	Sebacher *et al.*, 1986
Alaska, North Slope & Denali	Marsh, boreal	T	68	Gm	106	Sebacher *et al.*, 1986
Alaska, Fairbanks	Tundra, tussock	T	65	Gh	22.4	Whalen & Reeburg, 1988
Alaska, Fairbanks	Meadow, wet composite	T	65	Gm	32.2	Whalen & Reeburg, 1988
Alaska, Fairbanks	Tundra, moss, 1987	T	65	I	0.9	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, moss, 1987	T	65	I	10.1	Whalen & Reeburg, 1992

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, $mg/m^2/day$	CITATION
Alaska, Fairbanks	Tundra, moss, 1987	T	65	I	29	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, moss, 1987	T	65	I	3.8	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, intertussock, 1987	T	65	I	2.8	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, intertussock, 1987	T	65	I	25.2	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, intertussock, 1987	T	65	I	12.4	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, intertussock, 1987	T	65	I	5.9	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, Carex sedge	T	65	Gm	33.5	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, Carex sedge	T	65	Gm	3.2	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, Carex sedge	T	65	Gm	23	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, Carex sedge	T	65	Gm	451.9	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, Eriophorum	T	65	Gh	29.5	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, Eriophorum	T	65	Gh	60.8	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, Eriophorum	T	65	Gh	48.8	Whalen & Reeburg, 1992
Alaska, Fairbanks	Tundra, Eriophorum	T	65	Gh	96.8	Whalen & Reeburg, 1992
Alaska, North Slope	Alpine tundra	T	68	I	0.6	Whalen & Reeburg, 1990
Alaska, North Slope	Tundra, moist	T	68	Gx	31	Whalen & Reeburg, 1990

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, $mg/m^2/day$	CITATION
Alaska, North Slope	Tundra, wet	T	68	Gx	90	Whalen & Reeburg, 1990
Alaska, North Slope	Bog, low brush	T	68	Ox	45	Whalen & Reeburg, 1990
Alaska, North Slope	Forest, spruce	T	68	Pg	4.6	Whalen & Reeburg, 1990
Alaska, North Slope & Foot hills	Tundra, meadow and tussock	T	69	Gm	30	King *et al.*, 1989
Alaska, North Slope	Tundra, tussocks	T	69	Gm	3.4	Morissey & Livingstone, 1992
Alaska, North Slope	Tundra, intertussocks	T	69	I	2.9	Morissey & Livingstone, 1992
Alaska, North Slope	Tundra, meadow	T	69	Gm	64.4	Morissey & Livingstone, 1992
Alaska, North Slope	Tundra, high polygons	T	69	I	4.9	Morissey & Livingstone, 1992
Alaska, North Slope	Tundra, low polygons	T	69	Gh	61.9	Morissey & Livingstone, 1992
Alaska, North Slope	Tundra, basins	T	69	Gx	46.1	Morissey & Livingstone, 1992
Alaska, Yukon Kuskokwin delta	Tundra, wet meadow	T	61	Gm	144	Bartlett *et al.*, 1992
Alaska, Yukon Kuskokwin delta	Tundra, upland	T	61	I	2.3	Bartlett *et al.*, 1992

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, $mg/m^2/day$	CITATION
Alaska, Yukon Kuskokwin delta	Moss carpet, wet	T	61	I	1.6	Yarrington & Wynn-Williams, 1985
Yakutia	Alas, dry land	T	62	E	38.1	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	223	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	321.4	Nakayama *et al.*, 1994
Yakutia	Alas, dry land	T	62	I	32	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	9	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	11.8	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	177.8	Nakayama *et al.*, 1994
Yakutia	Alas, dry land	T	62	I	77.9	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	512.3	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	1022.5	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	338.5	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	900.5	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	1921.7	Nakayama *et al.*, 1994
Yakutia	Alas, dry land	T	62	I	53.2	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	457.9	Nakayama *et al.*, 1994

LOCATION	SITE	P	Latitude	Soil Unit	CH_4, mg/m^2/day	CITATION
Yakutia	Alas, wetland	T	62	Gx	671.9	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	1041.2	Nakayama *et al.*, 1994
Yakutia	Alas, dry land	T	62	I	67.8	Nakayama *et al.*, 1994
Yakutia	Alas, wetland	T	62	Gx	232.8	Nakayama *et al.*, 1994
Yakutia	Alas, dry land	T	62	I	0	Nakayama *et al.*, 1994

APPENDIX 2

CH_4 Emission Factors (EF) and Annual Emission for Methane-generating Soils in Non-permafrost (a) and Permafrost (b) Areas of Russia

(a) **Non-permafrost areas**

Soil unit	Soil	Soil area	N	EF, mg/m^2/day	Emission, Tg/year
Bg	Gleyic Cambisols	57248.4	2	0.73	0.01
Bx	Gelic Cambisols	6049.6	0		
Dg	Gleyic Podzoluvisols	105382.5	1	0.15	0.00
Gc	Calcaric Gleysols	18861.3	0		
Gd	Dystric Gleysols	252254.0	5	24.25	0.92
Ge	Eutric Gleysols	65979.7	7	24.45	0.24
Gh	Humic Gleysols	226134.0	5	31.86	1.08
Gm	Mollic Gleysols	106988.2	6	42.75	0.69
Gx	Gelic Gleysols	78938.6	0		
J	Fluvisols	34784.5	2	47.53	0.25
Lg	Gleyic Fluvisols	187264.8	0		
Mg	Gleyic Greyzems	60881.6	4	0.07	0.00
Od	Dystric Histosols	508037.1	25	87.14	6.64
Oe	Eutric Histosols	158407.8	17	67.90	1.61
Ox	Gelic Histosols	17761.5	0		
Pg	Gleyic Podzols	233215.1	5	1.97	0.07
Rx	Gelic Regosols	40137.9	0		
Sg	Gleyic Solonetz	26110.5	0		
Zg	Gleyic Solonchak	2368.2	0		
Total soils in non-permafrost areas					11.51

(b) Permafrost areas

Soil unit	Soil	Soil area	N	EF, mg/m²/day	Emission, Tg/year
Bg	Gleyic Cambisols	75564.7	0		
Bx	Gelic Cambisols	2057623.0	0		
Dg	Gleyic Podzoluvisols	72521.5	0		
Gd	Dystric Gleysols	289107.9	0		
Ge	Eutric Gleysols	25992.3	0		
Gh	Humic Gleysols	35028.2	6	58.98	0.21
Gm	Mollic Gleysols	43414.0	10	116.31	0.50
Gx	Gelic Gleysols	1424645.4	20	105.51	15.03
I	Lithosols	1574543.6	19	7.96	1.25
J	Fluvisols	7923.1	0		
Mg	Gleyic Greyzems	15384.3	0		
Od	Dystric Histosols	653142.7	1	11.60	0.76
Oe	Eutric Histosols	258719.5	2	343.62	8.89
Ox	Gelic Histosols	167501.7	5	48.04	0.80
Pg	Gleyic Podzols	67971.3	1	4.60	0.03
Rx	Gelic Regosols	871719.6	0		
Sg	Gleyic Solonetz	10231.9	0		
U	Rankers	179.5	0		
Total soils on permafrost					27.48

APPENDIX 3

Tree Structure and Listing of UNMAP Program Calculating CH_4 Emissions from Soils of Russia

System: UNMAP
Author: Andrei B. Rozanov
October, 1994
Tree Diagram

```
UNMAP.PRG
│    WL.DBF (database)
│    SOILS.DBF (database)
├────AREA.PRG
│    │  RUSSIA.DBF (database)
│    │  SOILS.DBF (database)
│    ├────SPERM.PRG
│    └────SHOT.PRG
├────COMU.PRG
│      WETS.DBF (database)
│      SOILS.DBF (database)
│      RUSSIA.DBF (database)
│      WL.DBF (database)
├────SAF.PRG
│      CH4.DBF (database)
│      CH4TMP.DBF (database)
│      WETS.DBF (database)
├────CH4EM.PRG
│    │  CH4STAT.DBF (database)
│    │  STATMP.DBF (database)
│    │  EMISSION.DBF (database)
│    ├────ADATA.PRG
│    │      SOILS.DBF (database)
│    │      CH4STAT.DBF (database)
│    └────STAT.PRG
│           SOILS.DBF (database)
│           CH4STAT.DBF (database)
├────FACTS.PRG
│      SOILS.DBF (database)
│      CH4.DBF (database)
├────EFMU.PRG
│      CH4.DBF (database)
│      CH4E.DBF (database)
└────ANNUAL.PRG
       SOILS.DBF (database)
```

```
*:*******************************************************************
*:
*:       Program: H:\ANDY\SOILS\UNMAP.PRG
*:
*:        System: UNMAP
*:        Author: Andrei B. Rozanov
*:     Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/18/94     14:30
*:
*:         Calls: AREA.PRG
*:              : COMU.PRG
*:              : SAF.PRG
*:              : CH4EM.PRG
*:              : FACTS.PRG
*:              : EFMU.PRG
*:              : ANNUAL.PRG
*:
*:          Uses: WL.DBF
*:              : SOILS.DBF
*:
*:     CDX files: WL.CDX
*:              : SOILS.CDX
*:
*: Documented 10/18/94 at 16:03              FoxDoc version 2.10
*:*******************************************************************
   **************************************************
   * Methane emissions from Russian natural wetlands *
   **************************************************
   SET TALK OFF
   SET DATE GERMAN
   CLOSE ALL
   ? "Calculating areas for Soil Units"
   DO area
   ? "Selecting Unique Mapping Units with CH4-generating soils"
   DO comu
   ? "Calculating area factors for Mapping Units"
   DO saf
   * End processing area data
   CLOSE DATABASES
   DELETE FILE wl.dbf
   DELETE FILE wl.cdx
   ****************************
   * Start processing CH4 data *
   ****************************
   ? "Calculating emission factors for soil units"
   DO ch4em
   * Insert Soil Unit emission factors into CH4.DBF
   DO facts
```

```
? "Calculating CH4 Emission Factors for Mapping Units"
DO efmu
* Copy Emission Factors to Soils database?
* calculate and display
* methane emission from soils
DO annual
CLOSE DATABASES
USE soils
SUM (ef_avg * sarea * 150 / 10 ^ 9) FOR (NOT permafrost) TO z
SUM (ef_avg * sarea * 100 / 10 ^ 9) FOR permafrost TO zp
SUM (ef_avg * sarea * 150 / 10 ^ 9) FOR ("O" $ sunit) TO X
? ""
? "Average assessed methane emission from soils: "+STR(zp+z)+" Tg/year"
? "That from soils on permafrost: "+STR(zp)+" Tg/year"
? "That from soils of mires: "+STR(X)+" Tg/year"
? ""
SET TALK ON
*: EOF: UNMAP.ACT
```

```
*:*****************************************************
*:
*:        Program: H:\ANDY\SOILS\AREA.PRG
*:
*:         System: UNMAP
*:         Author: Andrei B. Rozanov
*:      Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/12/94     15:18
*:
*:      Called by: UNMAP.PRG
*:
*:          Calls: SPERM.PRG
*:               : SHOT.PRG
*:
*:           Uses: RUSSIA.DBF
*:               : SOILS.DBF
*:
*:      CDX files: RUSSIA.CDX
*:               : SOILS.CDX
*:
*:      Documented 10/18/94 at 16:03 FoxDoc  version 2.10
*:*****************************************************
   ********************************
   * WETLAND SOIL AREAS FOR RUSSIA *
   ********************************
   CLOSE DATABASES
   USE russia IN A
   USE soils IN B
   SELECT soils
  ╔═DO WHILE NOT EOF()
  ║   sol = sunit
  ║ ┌─IF permafrost
  ║ │   DO sperm
  ║ ├─ELSE
  ║ │   DO shot
  ║ └─ENDIF
  ╚═ENDDO
   RETURN
   *: EOF: AREA.ACT
```

```
*:*****************************************************
*:
*:        Program: H:\ANDY\SOILS\SPERM.PRG
*:
*:         System: UNMAP
*:         Author: Andrei B. Rozanov
*:      Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/12/94     14:28
*:
*:      Called by: AREA.PRG
*:
*:      Documented 10/18/94 at 16:03 FoxDoc  version 2.10
*:*****************************************************
    **********************************
    * PERMAFROST SOIL AREA SUBROUTINE *
    **********************************
    SELECT russia
    SUM dsa TO A FOR sol $ dsc AND '1' $ SUBSTR(phases,7)
    SUM s1a TO B FOR sol $ s1c AND '1' $ SUBSTR(phases,7)
    SUM s2a TO C FOR sol $ s2c AND '1' $ SUBSTR(phases,7)
    SUM s3a TO D FOR sol $ s3c AND '1' $ SUBSTR(phases,7)
    SUM s4a TO E FOR sol $ s4c AND '1' $ SUBSTR(phases,7)
    SUM s5a TO F FOR sol $ s5c AND '1' $ SUBSTR(phases,7)
    X=A+B+C+D+E+F
    SELECT soils
    REPLACE sarea WITH X
    SKIP 1
    RETURN
    *: EOF: SPERM.ACT
```

```
*:******************************************************
*:
*:        Program: H:\ANDY\SOILS\SHOT.PRG
*:
*:         System: UNMAP
*:         Author: Andrei B. Rozanov
*:      Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/12/94     14:27
*:
*:      Called by: AREA.PRG
*:
*:      Documented 10/18/94 at 16:03 FoxDoc  version 2.10
*:******************************************************
    *************************************
    * NONPERMAFROST SOIL AREA SUBROUTINE *
    *************************************
    SELECT russia
    SUM dsa TO A FOR sol $ dsc AND NOT '1' $ SUBSTR(phases,7)
    SUM s1a TO B FOR sol $ s1c AND NOT '1' $ SUBSTR(phases,7)
    SUM s2a TO C FOR sol $ s2c AND NOT '1' $ SUBSTR(phases,7)
    SUM s3a TO D FOR sol $ s3c AND NOT '1' $ SUBSTR(phases,7)
    SUM s4a TO E FOR sol $ s4c AND NOT '1' $ SUBSTR(phases,7)
    SUM s5a TO F FOR sol $ s5c AND NOT '1' $ SUBSTR(phases,7)
    X=A+B+C+D+E+F
    SELECT soils
    REPLACE sarea WITH X
    SKIP 1
    RETURN
    *: EOF: SHOT.ACT
```

```
*:******************************************************
*:
*:       Program: H:\ANDY\SOILS\COMU.PRG
*:
*:        System: UNMAP
*:        Author: Andrei B. Rozanov
*:     Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/12/94     16:04
*:
*:     Called by: UNMAP.PRG
*:
*:          Uses: WETS.DBF
*:              : SOILS.DBF
*:              : RUSSIA.DBF
*:              : WL.DBF
*:
*:       Indexes: SNUM  (tag in RUSSIA.CDX)
*:
*:     CDX files: SOILS.CDX
*:              : RUSSIA.CDX
*:
*:     Documented 10/18/94 at 16:03 FoxDoc  version 2.10
*:******************************************************
   ***********************************************
   * Copy Mapping Units containing CH4-generating*
   *        soils to WL temporary database       *
   ***********************************************
   CLOSE DATABASES
  ┌─IF FILE("WETS.DBF")
  │   DELETE FILE wets.dbf
  └─ENDIF
   USE soils IN A
   USE russia IN B
   SELECT B
   COPY STRUCTURE TO wl
   USE wl IN C
   SELECT soils
  ╔═DO WHILE NOT EOF()
  ║   i = sunit
  ║  ┌─IF NOT permafrost
  ║  │   SELECT wl
  ║  │   APPEND FROM russia FOR i $ dsc
  ║  │   APPEND FROM russia FOR i $ s1c
  ║  │   APPEND FROM russia FOR i $ s2c
  ║  │   APPEND FROM russia FOR i $ s3c
  ║  │   APPEND FROM russia FOR i $ s4c
  ║  │   APPEND FROM russia FOR i $ s5c
  ║  │   SELECT soils
```

```
║ │   SKIP 1
║ ├─ELSE
║ │   SELECT wl
║ │   APPEND FROM russia FOR i $ dsc AND SUBSTR(phases,7) = "1"
║ │   APPEND FROM russia FOR i $ s1c AND SUBSTR(phases,7) = "1"
║ │   APPEND FROM russia FOR i $ s2c AND SUBSTR(phases,7) = "1"
║ │   APPEND FROM russia FOR i $ s3c AND SUBSTR(phases,7) = "1"
║ │   APPEND FROM russia FOR i $ s4c AND SUBSTR(phases,7) = "1"
║ │   APPEND FROM russia FOR i $ s5c AND SUBSTR(phases,7) = "1"
║ │   SELECT soils
║ │   SKIP 1
║ └─ENDIF
╚═ENDDO
 SELECT wl
 INDEX ON snum UNIQUE TAG snum ADDITIVE
 COPY TO wets
 RETURN
 *: EOF: COMU.ACT
```

```
*:******************************************************
*:
*:        Program: H:\ANDY\SOILS\SAF.PRG
*:
*:         System: UNMAP
*:         Author: Andrei B. Rozanov
*:      Copyright (c) 1994, Andrei B. Rozanov
*:  Last modified: 10/17/94     10:55
*:
*:      Called by: UNMAP.PRG
*:
*:           Uses: CH4.DBF
*:               : CH4TMP.DBF
*:               : WETS.DBF
*:
*:        Indexes: SNUM                   (tag in RUSSIA.CDX)
*:
*:      CDX files: CH4TMP.CDX
*:
*:     Documented 10/18/94 at 16:03 FoxDoc  version 2.10
*:******************************************************
  * Calculating CH4 area factors for Mapping Units
  CLOSE DATABASES
  USE ch4 IN A
┌─IF FILE("CH4TMP.DBF")
│   DELETE FILE ch4tmp.dbf
└─ENDIF
  COPY STRUCTURE TO ch4tmp
  USE ch4tmp IN A
  DELETE FILE ch4.dbf
  USE wets IN B
  SELECT A
  APPEND FROM wets
  GO TOP
╓═DO WHILE NOT EOF()
║   X = dsa/area
║   REPLACE dsaf WITH X
║   X = s1a/area
║   REPLACE s1af WITH X
║   X = s2a/area
║   REPLACE s2af WITH X
║   X = s3a/area
║   REPLACE s3af WITH X
║   X = s4a/area
║   REPLACE s4af WITH X
║   X = s5a/area
║   REPLACE s5af WITH X
║   SKIP 1
```

```
└═ENDDO
  SELECT ch4tmp
  INDEX ON snum UNIQUE TAG snum ADDITIVE
  COPY TO ch4
  RETURN
  *: EOF: SAF.ACT
```

```
*:*****************************************************
*:
*:      Program: H:\ANDY\SOILS\CH4EM.PRG
*:
*:       System: UNMAP
*:       Author: Andrei B. Rozanov
*:    Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/18/94     12:00
*:
*:    Called by: UNMAP.PRG
*:
*:        Calls: ADATA.PRG
*:             : STAT.PRG
*:
*:         Uses: CH4STAT.DBF
*:             : STATMP.DBF
*:             : EMISSION.DBF
*:
*:      Indexes: ID_N     (tag in CH4TMP.CDX)
*:
*:    CDX files: STATMP.CDX
*:
*:    Documented 10/18/94 at 16:03 FoxDoc  version 2.10
*:*****************************************************
   **********************************
   * Processing CH4 emission factors *
   **********************************
   CLOSE ALL
   USE ch4stat
   COPY TO statmp
   CLOSE DATABASES
   DELETE FILE ch4stat.dbf
   USE statmp
   APPEND FROM emission
   INDEX ON id_n UNIQUE TAG id_n ADDITIVE
   COPY TO ch4stat
   CLOSE DATABASES
   DELETE FILE statmp.dbf
   DELETE FILE statmp.cdx
   * Calculate data availability
   DO adata
   * Calculate emission factors' statistics
   DO STAT
   RETURN
   *: EOF: CH4EM.ACT
```

```
*:*******************************************************************
*:
*:      Program: H:\ANDY\SOILS\ADATA.PRG
*:
*:       System: UNMAP
*:       Author: Andrei B. Rozanov
*:    Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/17/94      9:53
*:
*:    Called by: CH4EM.PRG
*:
*:         Uses: SOILS.DBF
*:             : CH4STAT.DBF
*:
*:    CDX files: SOILS.CDX
*:
*:    Documented 10/18/94 at 16:03          FoxDoc  version 2.10
*:*******************************************************************
   CLOSE DATABASES
   USE soils IN A
   USE ch4stat IN B
   SELECT soils
  ╓═DO WHILE NOT EOF()
  ║   i = sunit
  ║  ┌─IF permafrost
  ║  │   SELECT B
  ║  │   COUNT TO ob FOR (i $ soil_unit) AND ch4stat->permafrost
  ║  │   COUNT TO ax FOR (i $ soil_unit) AND ((end_date - start_date) > 365) AND permafrost AND ch4stat->permafrost
  ║  │   COUNT TO ay FOR (i $ soil_unit) AND (((end_date - start_date) < 366) AND ((end_date - start_date) > 90)) AND ch4stat->permafrost
  ║  │   COUNT TO az FOR (i $ soil_unit) AND (((end_date - start_date) < 91) AND ((end_date - start_date) > 31)) AND ch4stat->permafrost
  ║  │   COUNT TO ah FOR (i $ soil_unit) AND (((end_date - start_date) < 32) AND ((end_date - start_date) > 0)) AND ch4stat->permafrost
  ║  │   COUNT TO AS FOR (i $ soil_unit) AND ((end_date - start_date) = 0) AND ch4stat->permafrost
  ║  │   COUNT TO un FOR (i $ soil_unit) AND (NOT (end_date - start_date) >= 0) AND ch4stat->permafrost
  ║  │   SELECT A
  ║  │   REPLACE annual WITH ax
  ║  │   REPLACE seasonal WITH ay
  ║  │   REPLACE monthly WITH az
  ║  │   REPLACE weekly WITH ah
  ║  │   REPLACE individual WITH AS
  ║  │   REPLACE unknown WITH un
  ║  │   REPLACE observatns WITH ob
  ║  │   SKIP 1
```

```
|| ├─ELSE
|| |   SELECT B
|| |   COUNT TO ob FOR (i $ soil_unit) AND (NOT ch4stat->permafrost)
|| |   COUNT TO ax FOR (i $ soil_unit) AND ((end_date - start_date) > 365) AND (NOT ch4stat->permafrost)
|| |   COUNT TO ay FOR (i $ soil_unit) AND (((end_date - start_date) < 366) AND ((end_date - start_date) > 90)) AND (NOT ch4stat->permafrost)
|| |   COUNT TO az FOR (i $ soil_unit) AND (((end_date - start_date) < 91) AND ((end_date - start_date) > 31)) AND (NOT ch4stat->permafrost)
|| |   COUNT TO ah FOR (i $ soil_unit) AND (((end_date - start_date) < 32) AND ((end_date - start_date) > 0)) AND (NOT ch4stat->permafrost)
|| |   COUNT TO AS FOR (i $ soil_unit) AND ((end_date - start_date) = 0) AND (NOT ch4stat->permafrost)
|| |   COUNT TO un FOR (i $ soil_unit) AND (NOT (end_date - start_date) >= 0) AND (NOT ch4stat->permafrost)
|| |   SELECT A
|| |   REPLACE annual WITH ax
|| |   REPLACE seasonal WITH ay
|| |   REPLACE monthly WITH az
|| |   REPLACE weekly WITH ah
|| |   REPLACE individual WITH AS
|| |   REPLACE unknown WITH un
|| |   REPLACE observatns WITH ob
|| |   SKIP 1
|| └─ENDIF
╚═ENDDO
  RETURN
  *: EOF: ADATA.ACT
```

```
*:*****************************************************************
*:
*:        Program: H:\ANDY\SOILS\STAT.PRG
*:
*:         System: UNMAP
*:         Author: Andrei B. Rozanov
*:      Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/18/94     13:51
*:
*:      Called by: CH4EM.PRG
*:
*:           Uses: SOILS.DBF
*:               : CH4STAT.DBF
*:
*:      CDX files: SOILS.CDX
*:
*:      Documented 10/18/94 at 16:03               FoxDoc  version 2.10
*:*****************************************************************
    * Calculating emission factors' statistics
    PUBLIC i, wav, tot, num, werr, wstd
    CLOSE DATABASES
    USE soils IN A
    USE ch4stat IN B
    SELECT A
  ╔═DO WHILE NOT EOF()
  ║   i = sunit
  ║  ┌─IF NOT permafrost
  ║  │  SELECT B
  ║  │  SUM (mg_d_a * n_obs) FOR ((i $ soil_unit) AND (NOT ch4stat->permafrost)) TO tot
  ║  │  SUM n_obs FOR (i $ soil_unit) AND (NOT ch4stat->permafrost) TO num
  ║  │ ┌─IF num > 0
  ║  │ │  wav = tot / num
  ║  │ │  SELECT A
  ║  │ │  REPLACE ef_avg WITH wav
  ║  │ │  SKIP 1
  ║  │ ├─ELSE
  ║  │ │  SELECT A
  ║  │ │  SKIP 1
  ║  │ └─ENDIF
  ║  ├─ELSE
  ║  │  SELECT B
  ║  │  SUM (mg_d_a * n_obs) FOR ((i $ soil_unit) AND (ch4stat->permafrost)) TO tot
  ║  │  SUM n_obs FOR (i $ soil_unit) AND (ch4stat->permafrost) TO num
  ║  │ ┌─IF num > 0
  ║  │ │  wav = tot / num
  ║  │ │  SELECT A
```

```
║  │  │    REPLACE ef_avg WITH wav
║  │  │    SKIP 1
║  │  ├─ELSE
║  │  │    SELECT A
║  │  │    SKIP 1
║  │  └─ENDIF
║  └─ENDIF
╙═ENDDO
  RETURN
  *: EOF: STAT.ACT
```

```
*:*******************************************************************
*:
*:        Program: H:\ANDY\SOILS\FACTS.PRG
*:
*:         System: UNMAP
*:         Author: Andrei B. Rozanov
*:      Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/18/94     14:00
*:
*:      Called by: UNMAP.PRG
*:
*:           Uses: SOILS.DBF
*:               : CH4.DBF
*:
*:      CDX files: SOILS.CDX
*:
*:      Documented 10/18/94 at 16:03               FoxDoc  version 2.10
*:*******************************************************************
   ************************************************
   * Insert calculated Emission Factors into CH4.DBF *
   ************************************************
   CLOSE DATABASES
   USE soils IN A
   USE ch4 IN B
   SELECT A
 ╓═DO WHILE NOT EOF()
 ║    i = sunit
 ║    ae = ef_avg
 ║  ┌─IF permafrost
 ║  │    SELECT B
 ║  │    GO TOP
 ║  │  ╓═DO WHILE NOT EOF()
 ║  │  ║      REPLACE dscef_avg WITH ae FOR (i $ dsc) AND ("1" $ SUBSTR(phases,7))
 ║  │  ║      REPLACE s1cef_avg WITH ae FOR (i $ s1c) AND ("1" $ SUBSTR(phases,7))
 ║  │  ║      REPLACE s2cef_avg WITH ae FOR (i $ s2c) AND ("1" $ SUBSTR(phases,7))
 ║  │  ║      REPLACE s3cef_avg WITH ae FOR (i $ s3c) AND ("1" $ SUBSTR(phases,7))
 ║  │  ║      REPLACE s4cef_avg WITH ae FOR (i $ s4c) AND ("1" $ SUBSTR(phases,7))
 ║  │  ║      REPLACE s5cef_avg WITH ae FOR (i $ s5c) AND ("1" $ SUBSTR(phases,7))
 ║  │  ╙═ENDDO
 ║  ├─ELSE
 ║  │    SELECT B
 ║  │    GO TOP
```

```
║ │ ╔═DO WHILE NOT EOF()
║ │ ║    REPLACE dscef_avg WITH ae FOR (i $ dsc) AND (NOT "1" $ SUBSTR(phases,7))
║ │ ║    REPLACE s1cef_avg WITH ae FOR (i $ s1c) AND (NOT "1" $ SUBSTR(phases,7))
║ │ ║    REPLACE s2cef_avg WITH ae FOR (i $ s2c) AND (NOT "1" $ SUBSTR(phases,7))
║ │ ║    REPLACE s3cef_avg WITH ae FOR (i $ s3c) AND (NOT "1" $ SUBSTR(phases,7))
║ │ ║    REPLACE s4cef_avg WITH ae FOR (i $ s4c) AND (NOT "1" $ SUBSTR(phases,7))
║ │ ║    REPLACE s5cef_avg WITH ae FOR (i $ s5c) AND (NOT "1" $ SUBSTR(phases,7))
║ │ ╚═ENDDO
║ └─ENDIF
║   SELECT A
║   SKIP 1
╚═ENDDO
  RETURN
  *: EOF: FACTS.ACT
```

```
*:**********************************************************************
*:
*:        Program: H:\ANDY\SOILS\EFMU.PRG
*:
*:         System: UNMAP
*:         Author: Andrei B. Rozanov
*:      Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/18/94     14:02
*:
*:      Called by: UNMAP.PRG
*:
*:           Uses: CH4.DBF
*:               : CH4E.DBF
*:
*:      Documented 10/18/94 at 16:03               FoxDoc  version 2.10
*:**********************************************************************
   *****************************************
   * CH4 Emission factors ofr Mapping Units *
   *****************************************
   CLOSE DATABASES
   USE ch4
  ╔═DO WHILE NOT EOF()
  ║   z = dsaf * dscef_avg + s1af * s1cef_avg + s2af * s2cef_avg + s3af * s3cef_avg
+ s4af * s4cef_avg + s5af * s5cef_avg
  ║   REPLACE ef_avg WITH z
  ║   SKIP 1
  ╚═ENDDO
  ┌─IF FILE("CH4E.DBF")
  │   DELETE FILE ch4e.dbf
  └─ENDIF
   COPY TO ch4e FIELDS snum, faosoil, ef_avg
   RETURN
   *: EOF: EFMU.ACT
```

```
*:******************************************************************
*:
*:       Program: H:\ANDY\SOILS\ANNUAL.PRG
*:
*:        System: UNMAP
*:        Author: Andrei B. Rozanov
*:     Copyright (c) 1994, Andrei B. Rozanov
*: Last modified: 10/18/94     14:06
*:
*:     Called by: UNMAP.PRG
*:
*:          Uses: SOILS.DBF
*:
*:     CDX files: SOILS.CDX
*:
*:     Documented 10/18/94 at 16:03                FoxDoc  version 2.10
*:******************************************************************
   CLOSE DATABASES
   USE soils
  ╔═DO WHILE NOT EOF()
  ║  ┌─IF permafrost
  ║  │   REPLACE ch4annual WITH (ef_avg * sarea * 100 / 10 ^ 9)
  ║  │   SKIP 1
  ║  ├─ELSE
  ║  │   REPLACE ch4annual WITH (ef_avg * sarea * 150 / 10 ^ 9)
  ║  │   SKIP 1
  ║  └─ENDIF
  ╚═ENDDO
   *: EOF: ANNUAL.ACT
```

APPENDIX 4

Methane Emissions (Gg) from Livestock Enteric Fermentation in Russia

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4, DAIRY	CH_4, NON-DAIRY	CH_4, SWINE	CH_4, SHEEP, GOATS	CH_4, HORSES
Adigei Republic	144.7	56.7	77.3	79.0	6.1	4.6	4.9	0.1	0.6	0.1
Altai Kray	2042.9	710.9	778.1	1592.8	149.4	57.6	74.6	1.2	11.3	2.7
Amur oblast	442.3	168.4	392.5	25.1	14.9	13.6	15.3	0.6	0.2	0.3
Arkhangelsk oblast	356.5	142.6	179.9	102.1	9.0	11.6	12.0	0.3	0.7	0.2
Astrakhan oblast	354.3	117.6	56.0	1301.1	32.4	9.5	13.3	0.1	9.2	0.6
Bashkortostan Republic	2354.7	847.5	1004.1	2150.8	192.8	68.6	84.4	1.5	15.3	3.5
Belgorod oblast	871.3	316.2	880.4	381.0	23.4	25.6	31.1	1.3	2.7	0.4
Bryansk oblast	812.2	297.6	540.1	39.7	34.7	24.1	28.8	0.8	0.3	0.6
Buryat Republic	549.6	190.1	264.3	1262.7	75.7	15.4	20.1	0.4	9.0	1.4
Checheno-Ingush Republic	291.3	132.2	65.9	708.5	10.8	10.7	8.9	0.1	5.0	0.2
Chelyabinsk oblast	1168.7	440.7	523.5	783.7	59.1	35.7	40.8	0.8	5.6	1.1
Chita oblast	782.4	262.5	309.4	3248.6	82.4	21.3	29.1	0.5	23.1	1.5

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4, DAIRY	CH_4, NON-DAIRY	CH_4, SWINE	CH_4, SHEEP, GOATS	CH_4, HORSES
Chuvash Republic	520.9	205.7	482.4	394.4	23.7	16.7	17.7	0.7	2.8	0.4
Daghestn Republic	742.8	291.6	38.0	3278.3	17.7	23.6	25.3	0.1	23.3	0.3
Gorno-Altai Republic	186.2	74.5	18.4	1157.7	77.5	6.0	6.3	0.0	8.2	1.4
Irkutsk oblast	800.5	291.5	569.7	307.6	45.7	23.6	28.5	0.9	2.2	0.8
Ivanovo oblast	371.6	151.8	207.6	164.6	2.6	12.3	12.3	0.3	1.2	0.0
Kabardino-Balkarian Republic	310.0	110.4	126.8	418.9	24.0	8.9	11.2	0.2	3.0	0.4
Kaliningrad oblast	459.3	171.1	263.2	47.1	4.2	13.9	16.1	0.4	0.3	0.1
Kalmyk-Khalm-Tangch Republic	353.5	126.2	100.2	2963.0	20.6	10.2	12.7	0.2	21.0	0.4
Kaluga oblast	516.1	210.3	201.9	118.3	6.4	17.0	17.1	0.3	0.8	0.1
Kamchatka oblast	61.7	21.6	78.5	1.6	3.2	1.7	2.2	0.1	0.0	0.1
Karachai-Cherkess Republic	252.5	92.6	26.3	721.9	18.9	7.5	9.0	0.0	5.1	0.3
Karelia Republic	125.0	45.9	108.8	63.1	1.2	3.7	4.4	0.2	0.4	0.0
Kemerovo oblast	719.7	306.5	705.4	122.4	40.3	24.8	23.1	1.1	0.9	0.7
Khabarovsk Kray	214.7	91.1	391.7	9.6	4.6	7.4	6.9	0.6	0.1	0.1

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4, DAIRY	CH_4, NON-DAIRY	CH_4, SWINE	CH_4, SHEEP, GOATS	CH_4, HORSES
Khakass Republic	257.8	90.7	144.0	1491.9	28.2	7.3	9.4	0.2	10.6	0.5
Kirov oblast	984.9	363.6	439.9	319.9	13.1	29.5	34.8	0.7	2.3	0.2
Komi Republic	175.4	71.0	146.9	51.8	7.9	5.8	5.8	0.2	0.4	0.1
Kostroma oblast	325.9	140.3	136.3	171.2	4.5	11.4	10.4	0.2	1.2	0.1
Krasnodar Kray	1778.1	587.7	2966.9	829.6	51.2	47.6	66.7	4.5	5.9	0.9
Krasnoyarsk Kray	1302.0	471.8	922.8	741.9	77.0	38.2	46.5	1.4	5.3	1.4
Kurgan oblast	1011.4	350.3	478.4	593.4	49.1	28.4	37.0	0.7	4.2	0.9
Kursk oblast	992.7	349.7	764.0	419.0	38.2	28.3	36.0	1.1	3.0	0.7
Leningrad oblast	548.0	229.6	626.1	69.1	4.1	18.6	17.8	0.9	0.5	0.1
Lipetsk oblast	634.1	244.0	571.3	302.0	20.3	19.8	21.8	0.9	2.1	0.4
Magadan oblast	42.9	17.0	71.4	0.2	1.3	1.4	1.5	0.1	0.0	0.0
Mari-El Republic	321.6	121.3	309.0	162.1	5.3	9.8	11.2	0.5	1.2	0.1
Mordovian SSR	629.2	222.7	292.9	310.9	16.8	18.0	22.8	0.4	2.2	0.3
Moscow oblast	1172.5	484.4	733.6	155.2	7.6	39.2	38.5	1.1	1.1	0.1
Murmansk oblast	41.7	17.2	131.2	2.7	0.1	1.4	1.4	0.2	0.0	0.0

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4, DAIRY	CH_4, NON-DAIRY	CH_4, SWINE	CH_4, SHEEP, GOATS	CH_4, HORSES
Nizhni Novgorod oblast	1215.6	459.6	649.4	379.3	18.9	37.2	42.3	1.0	2.7	0.3
North-Ossetian SSR	175.2	67.2	189.3	141.1	5.7	5.4	6.0	0.3	1.0	0.1
Novgorod oblast	317.3	135.8	203.2	81.8	6.3	11.0	10.2	0.3	0.6	0.1
Novosibirsk oblast	1578.4	589.6	569.3	1066.0	95.2	47.8	55.4	0.9	7.6	1.7
Omsk oblast	1598.2	572.2	622.0	902.2	93.4	46.3	57.5	0.9	6.4	1.7
Orenburg oblast	1697.9	616.9	552.0	2007.5	95.2	50.0	60.5	0.8	14.3	1.7
Oryel oblast	644.8	224.8	447.1	193.9	22.6	18.2	23.5	0.7	1.4	0.4
Penza oblast	812.2	308.8	496.3	458.2	28.1	25.0	28.2	0.7	3.3	0.5
Perm' oblast	861.4	336.5	498.2	242.8	22.1	27.3	29.4	0.7	1.7	0.4
Primorski Kray	368.0	139.9	313.0	18.1	7.7	11.3	12.8	0.5	0.1	0.1
Pskov oblast	530.3	228.3	292.3	175.3	17.2	18.5	16.9	0.4	1.2	0.3
Rostov oblast	1963.9	676.3	1985.7	3657.6	57.7	54.8	72.1	3.0	26.0	1.0
Ryazan' oblast	832.3	329.7	368.4	315.6	19.2	26.7	28.1	0.6	2.2	0.3
Sakha (Yakutia) Republic	419.1	149.5	119.4	0.4	209.1	12.1	15.1	0.2	0.0	3.8
Sakhalin oblast	95.6	35.8	177.6	1.2	0.5	2.9	3.3	0.3	0.0	0.0

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4, DAIRY	CH_4, NON-DAIRY	CH_4, SWINE	CH_4, SHEEP, GOATS	CH_4, HORSES
Samara oblast	970.8	370.4	832.9	721.1	37.6	30.0	33.6	1.2	5.1	0.7
Saratov oblast	1542.8	586.4	841.4	2600.8	61.4	47.5	53.6	1.3	18.5	1.1
Smolensk oblast	725.4	289.6	345.5	146.0	17.2	23.5	24.4	0.5	1.0	0.3
Stavropol Kray	1015.2	351.2	963.2	6030.7	50.1	28.4	37.2	1.4	42.8	0.9
Sverdlovsk oblast	823.2	335.2	641.9	228.0	28.3	27.2	27.3	1.0	1.6	0.5
Tambov oblast	725.0	300.7	752.1	450.0	27.4	24.4	23.8	1.1	3.2	0.5
Tatarstan Republic	1570.7	578.8	1032.0	1384.4	77.7	46.9	55.5	1.5	9.8	1.4
Tomsk oblast	335.4	133.7	305.8	82.6	19.2	10.8	11.3	0.5	0.6	0.3
Tula oblast	632.8	246.0	410.6	155.1	12.5	19.9	21.7	0.6	1.1	0.2
Tuva Republic	200.4	73.6	59.4	1146.6	39.7	6.0	7.1	0.1	8.1	0.7
Tver' oblast	837.8	358.4	320.2	307.2	19.1	29.0	26.8	0.5	2.2	0.3
Tyumen' oblast	865.2	326.9	513.8	334.7	50.9	26.5	30.1	0.8	2.4	0.9
Udmurt Republic	662.2	249.0	463.0	277.5	19.3	20.2	23.1	0.7	2.0	0.3
Ulyanovsk oblast	679.6	247.7	536.2	476.1	21.4	20.1	24.2	0.8	3.4	0.4

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4, DAIRY	CH_4, NON-DAIRY	CH_4, SWINE	CH_4, SHEEP, GOATS	CH_4, HORSES
Vladimir oblast	439.6	173.0	251.5	113.4	3.8	14.0	14.9	0.4	0.8	0.1
Volgograd oblast	1438.7	481.9	1140.7	2804.9	47.8	39.0	53.6	1.7	19.9	0.9
Vologda oblast	587.4	249.4	283.0	201.7	9.5	20.2	18.9	0.4	1.4	0.2
Voronezh oblast	1267.6	498.7	1223.9	1166.0	42.0	40.4	43.1	1.8	8.3	0.8
Yaroslavl' oblast	469.5	202.7	162.4	165.1	5.1	16.4	14.9	0.2	1.2	0.1
Total Russia Federation	54923.1	20559.3	35687.8	55497.4	2594.9	1665.3	1924.4	53.5	394.0	46.7

APPENDIX 5

Methane Emissions (Gg) from Manure Management in Russia

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4 DAIRY	CH_4 NON DAIRY	CH_4 SWINE	CH_4 SHEEP & GOATS	CH_4 HORSES
Adigei Republic	144.7	56.7	77.3	79.0	6.1	0.3	0.4	0.3	0.0	0.0
Altai Kray	2042.9	710.9	778.1	1592.8	149.4	4.3	5.3	3.1	0.9	0.2
Amur oblast	442.3	168.4	392.5	25.1	14.9	1.0	1.1	1.6	0.0	0.0
Arkhangelsk oblast	356.5	142.6	179.9	102.1	9.0	0.9	0.9	0.7	0.1	0.0
Astrakhan oblast	354.3	117.6	56.0	1301.1	32.4	0.7	0.9	0.2	0.7	0.1
Bashkortostan Republic	2354.7	847.5	1004.1	2150.8	192.8	5.1	6.0	4.0	1.2	0.3
Belgorod oblast	871.3	316.2	880.4	381.0	23.4	1.9	2.2	3.5	0.2	0.0
Bryansk oblast	812.2	297.6	540.1	39.7	34.7	1.8	2.1	2.2	0.0	0.1
Buryat Republic	549.6	190.1	264.3	1262.7	75.7	1.1	1.4	1.1	0.7	0.1
Checheno-Ingush Republic	291.3	132.2	65.9	708.5	10.8	0.8	0.6	0.3	0.4	0.0
Chelyabinsk oblast	1168.7	440.7	523.5	783.7	59.1	2.6	2.9	2.1	0.4	0.1
Chita oblast	782.4	262.5	309.4	3248.6	82.4	1.6	2.1	1.2	1.8	0.1
Chuvash Republic	520.9	205.7	482.4	394.4	23.7	1.2	1.3	1.9	0.2	0.0

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4 DAIRY	CH_4 NON DAIRY	CH_4 SWINE	CH_4 SHEEP & GOATS	CH_4 HORSES
Daghestn Republic	742.8	291.6	38.0	3278.3	17.7	1.7	1.8	0.2	1.8	0.0
Gorno-Altai Republic	186.2	74.5	18.4	1157.7	77.5	0.4	0.4	0.1	0.6	0.1
Irkutsk oblast	800.5	291.5	569.7	307.6	45.7	1.7	2.0	2.3	0.2	0.1
Ivanovo oblast	371.6	151.8	207.6	164.6	2.6	0.9	0.9	0.8	0.1	0.0
Kabardino-Balkarian Republic	310.0	110.4	126.8	418.9	24.0	0.7	0.8	0.5	0.2	0.0
Kaliningrad oblast	459.3	171.1	263.2	47.1	4.2	1.0	1.2	1.1	0.0	0.0
Kalmyk-Khalm-Tan gch Republic	353.5	126.2	100.2	2963.0	20.6	0.8	0.9	0.4	1.6	0.0
Kaluga oblast	516.1	210.3	201.9	118.3	6.4	1.3	1.2	0.8	0.1	0.0
Kamchatka oblast	61.7	21.6	78.5	1.6	3.2	0.1	0.2	0.3	0.0	0.0
Karachai-Cherkess Republic	252.5	92.6	26.3	721.9	18.9	0.6	0.6	0.1	0.4	0.0
Karelia Republic	125.0	45.9	108.8	63.1	1.2	0.3	0.3	0.4	0.0	0.0
Kemerovo oblast	719.7	306.5	705.4	122.4	40.3	1.8	1.7	2.8	0.1	0.1
Khabarovsk Kray	214.7	91.1	391.7	9.6	4.6	0.5	0.5	1.6	0.0	0.0

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4 DAIRY	CH_4 NON DAIRY	CH_4 SWINE	CH_4 SHEEP & GOATS	CH_4 HORSES
Khakass Republic	257.8	90.7	144.0	1491.9	28.2	0.5	0.7	0.6	0.8	0.0
Kirov oblast	984.9	363.6	439.9	319.9	13.1	2.2	2.5	1.8	0.2	0.0
Komi Republic	175.4	71.0	146.9	51.8	7.9	0.4	0.4	0.6	0.0	0.0
Kostroma oblast	325.9	140.3	136.3	171.2	4.5	0.8	0.7	0.5	0.1	0.0
Krasnodar Kray	1778.1	587.7	2966.9	829.6	51.2	3.5	4.8	11.9	0.5	0.1
Krasnoyarsk Kray	1302.0	471.8	922.8	741.9	77.0	2.8	3.3	3.7	0.4	0.1
Kurgan oblast	1011.4	350.3	478.4	593.4	49.1	2.1	2.6	1.9	0.3	0.1
Kursk oblast	992.7	349.7	764.0	419.0	38.2	2.1	2.6	3.1	0.2	0.1
Leningrad oblast	548.0	229.6	626.1	69.1	4.1	1.4	1.3	2.5	0.0	0.0
Lipetsk oblast	634.1	244.0	571.3	302.0	20.3	1.5	1.6	2.3	0.2	0.0
Magadan oblast	42.9	17.0	71.4	0.2	1.3	0.1	0.1	0.3	0.0	0.0
Mari-El Republic	321.6	121.3	309.0	162.1	5.3	0.7	0.8	1.2	0.1	0.0
Mordovian SSR	629.2	222.7	292.9	310.9	16.8	1.3	1.6	1.2	0.2	0.0
Moscow oblast	1172.5	484.4	733.6	155.2	7.6	2.9	2.8	2.9	0.1	0.0
Murmansk oblast	41.7	17.2	131.2	2.7	0.1	0.1	0.1	0.5	0.0	0.0

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4 DAIRY	CH_4 NON DAIRY	CH_4 SWINE	CH_4 SHEEP & GOATS	CH_4 HORSES
Nizhni Novgorod oblast	1215.6	459.6	649.4	379.3	18.9	2.8	3.0	2.6	0.2	0.0
North region	1286.0	526.1	849.8	421.4	27.7	3.2	3.0	3.4	0.2	0.0
North-Ossetian SSR	175.2	67.2	189.3	141.1	5.7	0.4	0.4	0.8	0.1	0.0
Novgorod oblast	317.3	135.8	203.2	81.8	6.3	0.8	0.7	0.8	0.0	0.0
Novosibirsk oblast	1578.4	589.6	569.3	1066.0	95.2	3.5	4.0	2.3	0.6	0.2
Omsk oblast	1598.2	572.2	622.0	902.2	93.4	3.4	4.1	2.5	0.5	0.2
Orenburg oblast	1697.9	616.9	552.0	2007.5	95.2	3.7	4.3	2.2	1.1	0.2
Oryel oblast	644.8	224.8	447.1	193.9	22.6	1.3	1.7	1.8	0.1	0.0
Penza oblast	812.2	308.8	496.3	458.2	28.1	1.9	2.0	2.0	0.3	0.0
Perm' oblast	861.4	336.5	498.2	242.8	22.1	2.0	2.1	2.0	0.1	0.0
Primorski Kray	368.0	139.9	313.0	18.1	7.7	0.8	0.9	1.3	0.0	0.0
Pskov oblast	530.3	228.3	292.3	175.3	17.2	1.4	1.2	1.2	0.1	0.0
Rostov oblast	1963.9	676.3	1985.7	3657.6	57.7	4.1	5.2	7.9	2.0	0.1
Ryazan' oblast	832.3	329.7	368.4	315.6	19.2	2.0	2.0	1.5	0.2	0.0

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4 DAIRY	CH_4 NON DAIRY	CH_4 SWINE	CH_4 SHEEP & GOATS	CH_4 HORSES
Sakha (Yakutia) Republic	419.1	149.5	119.4	0.4	209.1	0.9	1.1	0.5	0.0	0.3
Sakhalin oblast	95.6	35.8	177.6	1.2	0.5	0.2	0.2	0.7	0.0	0.0
Samara oblast	970.8	370.4	832.9	721.1	37.6	2.2	2.4	3.3	0.4	0.1
Saratov oblast	1542.8	586.4	841.4	2600.8	61.4	3.5	3.8	3.4	1.4	0.1
Smolensk oblast	725.4	289.6	345.5	146.0	17.2	1.7	1.7	1.4	0.1	0.0
Stavropol Kray	1015.2	351.2	963.2	6030.7	50.1	2.1	2.7	3.9	3.3	0.1
Sverdlovsk oblast	823.2	335.2	641.9	228.0	28.3	2.0	2.0	2.6	0.1	0.0
Tambov oblast	725.0	300.7	752.1	450.0	27.4	1.8	1.7	3.0	0.2	0.0
Tatarstan Republic	1570.7	578.8	1032.0	1384.4	77.7	3.5	4.0	4.1	0.8	0.1
Tomsk oblast	335.4	133.7	305.8	82.6	19.2	0.8	0.8	1.2	0.0	0.0
Tula oblast	632.8	246.0	410.6	155.1	12.5	1.5	1.5	1.6	0.1	0.0
Tuva Republic	200.4	73.6	59.4	1146.6	39.7	0.4	0.5	0.2	0.6	0.1
Tver' oblast	837.8	358.4	320.2	307.2	19.1	2.2	1.9	1.3	0.2	0.0
Tyumen' oblast	865.2	326.9	513.8	334.7	50.9	2.0	2.2	2.1	0.2	0.1

Administrative region	CATTLE, th. heads	DAIRY CATTLE, th. heads	SWINE, th. heads	SHEEP, GOATS, th. heads	HORSES, th. heads	CH_4 DAIRY	CH_4 NON DAIRY	CH_4 SWINE	CH_4 SHEEP & GOATS	CH_4 HORSES
Udmurt Republic	662.2	249.0	463.0	277.5	19.3	1.5	1.7	1.9	0.2	0.0
Ulyanovsk oblast	679.6	247.7	536.2	476.1	21.4	1.5	1.7	2.1	0.3	0.0
Vladimir oblast	439.6	173.0	251.5	113.4	3.8	1.0	1.1	1.0	0.1	0.0
Volgograd oblast	1438.7	481.9	1140.7	2804.9	47.8	2.9	3.8	4.6	1.5	0.1
Vologda oblast	587.4	249.4	283.0	201.7	9.5	1.5	1.4	1.1	0.1	0.0
Voronezh oblast	1267.6	498.7	1223.9	1166.0	42.0	3.0	3.1	4.9	0.6	0.1
Yaroslavl' oblast	469.5	202.7	162.4	165.1	5.1	1.2	1.1	0.6	0.1	0.0
Total Russian Federation						126.5	140.5	146.2	30.6	4.2