A Comparative Analysis of Negative Soil- and Water-related Environmental Effects Linked to Agricultural Production

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Summary:

This report presents an analysis of soil and water related environmental effects linked to agricultural production in the net exporting countries Australia, New Zealand and USA, and the net importing countries Japan, Norway and Switzerland.

The study has been based on the following indicators:

General features of the selected countries.

Pesticide use, finding and concentration of pesticides in surface water and groundwater.

Fertiliser use and nitrogen balance.

Soil erosion, extent and rates of water erosion, risk of wind erosion.

Water resources, agricultural withdrawals and water use efficiency.

Water quality, nitrogen and phosphorous concentrations in surface water and groundwater.

For soil erosion the overall tendency is a net environmental deterioration by expanding agricultural production in the net exporting countries as compared with the net importing country Norway. For agricultural withdrawals of water an expansion of agriculture in the net exporting countries may result in a net environmental detorioration versus the net importing countries Norway and Switzerland. For surface water and groundwater quality the effect of trade liberalisation is more uncertain.

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Preface

This report presents a comparative study of soil and water related agri-environmental indicators in Australia, New Zealand, USA, Japan, Norway and Switzerland. The Ministry of Agriculture selected these countries based on whether they are net exporters or net importers of agricultural products. The countries were therefore divided into two groups: Net Exporting Countries and Net Importing Countries. The countries studied also represent different levels of support or subsidies to the agricultural sector. Japan, Norway and Switzerland are characterised by high subsidy levels, while Australia, New Zealand and USA are characterised by lower agricultural subsidies.

The report has been written by Arne Grønlund, Tor-Gunnar Vågen, Olav Prestvik and Arnor Njøs, Centre for Soil and Environmental Research (Jordforsk).

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1 SUMMARY

Objectives

This report presents an analysis of soil and water related environmental effects linked to agricultural production in 6 countries; the net exporting (NE) countries Australia, New Zealand and USA, and the net importing (NI) countries Japan, Norway and Switzerland.

General features of the selected countries

The NI-countries are more mountainous, have more limited land resources capable of agriculture, a lower share of agricultural land to total land area and less agricultural and arable land per capita than the selected NE-countries. Because of the higher share of agricultural land to total land area, the environment in the NE-countries is expected to be more influenced by agricultural activities.

Pesticides

The average consumption of pesticides per hectare arable land and permanent crops shows the following ranking between the selected countries: Japan > Switzerland > Australia ≈ New Zealand ≈ USA > Norway. The trends for the period 1990-1996 indicate a reduction of total pesticide use in the NI-countries but not in the NE-countries (New Zealand and USA). The total consumption of pesticides gives limited information about the impact of pesticides on the environment. Some crops, which require large quantities of pesticides, are not grown in all the countries included in this study.

The reports on decisions on import of pesticides according to the Prior Informed Concept (PIC) indicate that main NE-countries are less restrictive than some of the NI-countries.

Monitoring data on pesticides in water have been available only for USA and Norway. Similar patterns have been found in the two countries: pesticides are detected in most of the samples from streams and about half of the samples for ground water and farm wells. A majority of the most frequently detected compounds in USA are considered to be harmful and are not permitted in Norway.

Fertilisers

The NI-countries have a significantly higher fertilisation rate and nitrogen surplus per hectare agricultural land than the NE-countries. The nitrogen surplus per total land area, which should be considered as a more relevant indicator of the risk for impact on surface water, is lower in Australia, New Zealand and Norway than in USA, Japan and Switzerland.

There are relatively small differences in fertilisation rates for wheat and no differences in the efficiency of nitrogen for wheat between the counties where relevant data has been available. Norway and Switzerland have higher phosphorous efficiency for wheat than USA. For rice, Japan has lower nitrogen application rate and higher nitrogen efficiency than USA, but higher phosphorous application rate and lower phosphorous efficiency.

Soil erosion

Few data on soil erosion are available for other countries than USA. From Japan and Switzerland comparable data on erosion rates have not been available for this study.

A considerable part of the agricultural land in Australia, New Zealand, USA and Norway is affected by water erosion. In Norway only cropland is affected, while in the NE-countries also a substantial part of the pasture is reported to be erosive. The reported data for cropland indicate the highest mean water erosion rates in USA and no significant differences between Australia and Norway.

Wind erosion constitutes a problem in all the NE-countries included in the study, but affects only minor areas in Norway.

Water resources

New Zealand and Norway have the highest amounts of water resources per capita and the lowest withdrawal in per cent of total resources of the selected countries. USA and Japan have the highest withdrawals, and Norway and Switzerland the lowest withdrawals annually for agricultural consumption.

Crop water requirement and water use efficiency have been calculated for Australia, USA, Japan and Norway. Due to winter growing, Australia has the lowest crop water requirement for wheat. The water use efficiency, in which also the yield is taken into account, is highest for Japan and Norway and lowest for USA.

Water quality

Salinisation is a major water quality problem in parts of Australia and USA.

The reported data indicate the following ranking in nutrient concentration in streams:

Nitrogen: Switzerland > Austalia ≈ USA > New Zealand ≈ Norway.

Phosphorous: Australia ≈ USA > Switzerland > New Zealand ≈ Norway.

The levels of nitrogen and phosphorous in streams in USA minimally affected by agriculture are higher than the concentrations in streams in Norway representing the central agricultural areas.

The available data give no significant indications as to differences in nitrate concentrations in ground water between the countries. Because agriculture is the main source of nitrate to groundwater, it is expected that the NE-countries, which have a larger share of agricultural land to total land, have a larger part of their groundwater resources influenced by nitrate leaching.

Possible environmental effects due to liberalisation of food trade

Liberalisation of food trade normally leads to a reduction in negative environmental effects on soil and water in countries where production is reduced, and likewise an increase in negative effects where production is expanded. A net reduction in negative environmental effects occurs when the reduction of negative environmental effects in countries with reducing production is larger than the increase of negative effects in countries with expanding agriculture production.

Agri-environmental indicators are used to evaluate possible environmental effects resulting from changes in agricultural production of the NE- and NI-countries. The results of the analysis do not indicate that a shift in production from NI to NE countries would lead to an overall/total reduction of negative environmental effects of agriculture.

2 INTRODUCTION

2.1 Objectives of the study

This report presents a comparative study of selected environmental indicators in Norway, Switzerland, Japan, Australia, New Zealand and USA. These countries provide different levels of support or subsidies to the agricultural sector. Countries like Australia, New Zealand and USA are named Net Exporting Countries (NE-countries) and are traditionally characterised by low agricultural subsidies, while Japan, Norway and Switzerland, named Net Importing Countries (NI-countries), are characterised by high subsidy levels.

The objectives of the study are:

- Analyse the use of pesticides (total amounts used and disaggregated per specific production and in relation to degree of toxicity; pesticide residues in ground water, drinking water and lakes and rivers).
- Analyse the water pollution of nitrogen and phosphorus (animal densities; use of fertiliser; eutrophication; nitrate and phosphorous levels in groundwater, drinking water and lakes and rivers).
- Provide data on soil erosion based on available data on erosiveness, land use and erosion control measures.
- Provide data on water use and salinisation in agriculture.

2.2 Environmental impacts of agriculture

Agricultural production can have both positive and negative effects on the environment. This study includes only the negative effects on soil and water.

Environment is considered as what is outside or around an actual system, such as the individual, the family, the farm, the village or the city. An expanding farm intrudes on its environment by changing the land use from more "natural" to more industrial, thereby reducing the environment and/or the original quality of the environment. Agricultural production is an industry considered to have a general negative effect on the environment, because it tends to reduce the spatial range of environment.

Soil degradation can be caused by decomposition of organic matter, soil compaction, water erosion, wind erosion, contamination by pesticides, salinisation and desertification. Agricultural practices, such as grazing or tillage, tend to increase soil erosion. Soil tillage further tends to increase the mineralisation of soil organic matter, thereby increasing nutrient losses to the watercourses. Thus agriculture in itself, by the use of land for food production, decreases "the quantity and quality of environment".

The stresses on water resources caused by the agricultural sector are overuse of groundwater for irrigation and losses of phosphorous, nitrogen, organic substances and pesticides to surface water and groundwater. These environmental effects are generally results of interactions between soil properties, climate and management practices. In Table 1 the relationships between some of the predominant environmental effects related to soils and water and the causes of these effects are presented.

Soil quality is significant for water quality due to the soils' ability to absorb, buffer, and transform chemical flows, retain and store floodwaters, support plant growth and renew quality water supplies. Soil erosion has traditionally been the most widely used indicator of soil quality, but during recent years there has been an increased recognition of the fact that improving and protecting soil quality is much broader concept than soil erosion alone. Loss of soil organic matter, compaction, acidification, increased heavy metal content from atmospheric deposition, increased pesticides content in soil due to agricultural management practices and loss of soil biodiversity have received increasing attention as important indicators of soil quality.

Pollution of water (groundwater, rivers, lakes and coastal areas) caused by erosion, nutrient load and pesticide residues, is considered to be the most serious environmental concern in several regions. The impact of pollution on water depends both on the intensity of the agricultural production (amounts of fertiliser and pesticides per area unit, livestock density) and the extensity, expressed as the proportion of the total land area that is cultivated within a catchment or a region. Thus, water quality may be damaged in regions with high proportions of agricultural land, even when the intensity and loads per area unit are low or moderate.

Table 1. The relationships between various environmental problems (stresses) and soil conditions, climate and management practice.

Environmental problem	Soil/terrain	Climate	Management
Soil erosion	Silty soils, low organic matter contents, poor structure, low permeability, long and steep slopes	Heavy rain intensity, thawing, snow melting	Intensive soil tillage, removal of vegetation strips, overgrazing
Pesticides contamination	Coarse texture, low organic matter content, cracks (low absorption and water-holding capacity)	Low temperature – droughts	Pesticide inputs – large amounts and frequency, high toxicity, persistence and mobility
Nutrient loads	Low productivity, high natural drainage, binding and water-holding capacity	Heavy rain intensity	High fertiliser input, nutrient surplus, high livestock density, artificial drainage
Water consumption	Low water-holding capacity	Water deficit, high evapotranspiration	Irrigation, no drainage system
Salinisation	High ground water level, high capillary conductivity	Water deficit, high evapotranspiration	Irrigation (high salinity of irrigation water)

OECD is developing agri-environmental indicators within a framework differentiating between driving forces, state and responses. The driving forces include causes or *pressures* that influence the farmers' practice. The farmers' different practices influence the *state* of the environment in different ways. State indicators cover emissions from agriculture and the consumption of natural resources used by agriculture. The third group, the *response* indicators, reflect how farmers, consumers and government react to changes in the environment.

Most of the indicators used in this study are among the agri-environmental indicators proposed by the OECD. Agricultural use of pesticides, fertilisers and water belong to *driving force* indicators, while soil erosion and water quality belong to the *state* indicators.

2.3 Environmental impacts of agricultural trade liberalisation

It is a common assertion that governmental interventions like subsidies to the agricultural sector may lead to environmental damage. This assertion is based on the following assumptions:

- subsidised input factors, for example fertilisers and pesticides, may cause increased consumption of these factors and an increased risk of pollution
- product price support will reduce the ratio between the price of the inputs and the products, and therefore will have the same effect as subsidised input factors
- support in the form of direct payment per unit area (”area support”), may encourage cultivating marginal areas vulnerable to erosion and nutrient leaching.

On the other hand, subsidies used to encourage certain measures, e.g. soil erosion protection measures and catch crops to reduce nitrogen leaching, may lead to improvement of the environment.

In the case of lower prices as a consequence of trade liberalisation, a decline in production is expected. The input of fertilisers, pesticides and irrigation water are likely to be reduced. This may lead to reduced impact on water quality and resources. Some marginal areas may be abandoned, which may result in both positive and negative environmental effects.

In countries where production is expanded, the opposite effects are expected. The application of agro-chemicals and irrigation water are likely to be increased and more land will be used for agricultural production. The environmental effects of the expanded production depend on factors such as the initial level of production, intensity, share of land area under cultivation, quality of new land to be cultivated, e.g. risk of erosion or salinisation, water quality and resources.

The overall environmental effects should be evaluated on the sum of changes in the importing and exporting country. It is evident that an importing country with a low percentage of cultivated land as related to total land would gain little in the environmental dimension by increased food import as compared to a country with a high ratio of cultivated land to total land.

Environmental impact of trade liberalisation on transport, landscape, biodiversity and greenhouse gas emission has not been included in this study.

It has also been suggested that the economic growth from trade liberalisation may raise social demand for environmental quality and stimulate environmental friendly policy (Erwin 1997, OECD 1999). Assessments of such effects are beyond the scope of this study.

3 GENERAL FEATURES OF THE SELECTED COUNTRIES

3.1 Topography and climate

The countries selected for the study represent a wide range of climatic and topographic conditions. The NI-countries are smaller than the NE-countries, except for New Zealand, and are generally characterised by a mountainous and steep topography.

3.1.1 Australia

Australia is the lowest continent in the world with an average elevation of only 330 metres. The highest peak on the continent is Mount Kosciuszko, which is 2229 metres. Almost 40 % of Australia's land area have an elevation of 200 to 500 metres. Temperatures on the continent are highly variable, but the north and north-west are generally warmest, while the south and south-eastern parts are relatively cooler. Rainfall in Australia is also highly variable (Figure 2), although the continent as a whole has an average annual rainfall of only 165 mm. Rainfall intensities are high in the tropical parts of the country, and the rainfall pattern is concentric around the extensive arid zone of the continent.

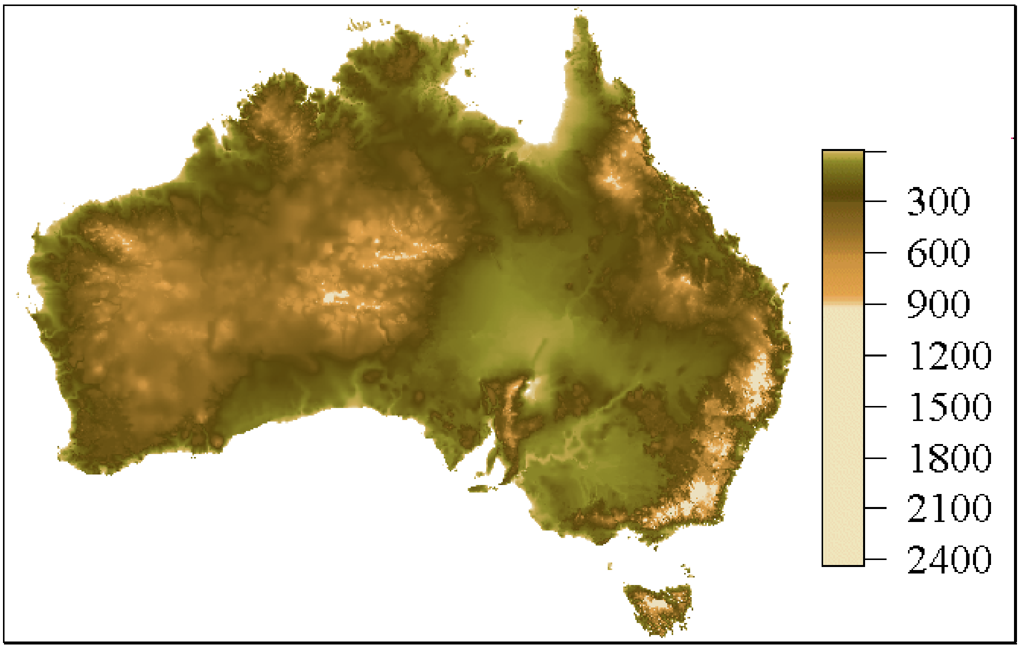

Figure 1. Topographical map of Australia, based on 1 km elevation grid data. Source: USGS, GTOPO-30.

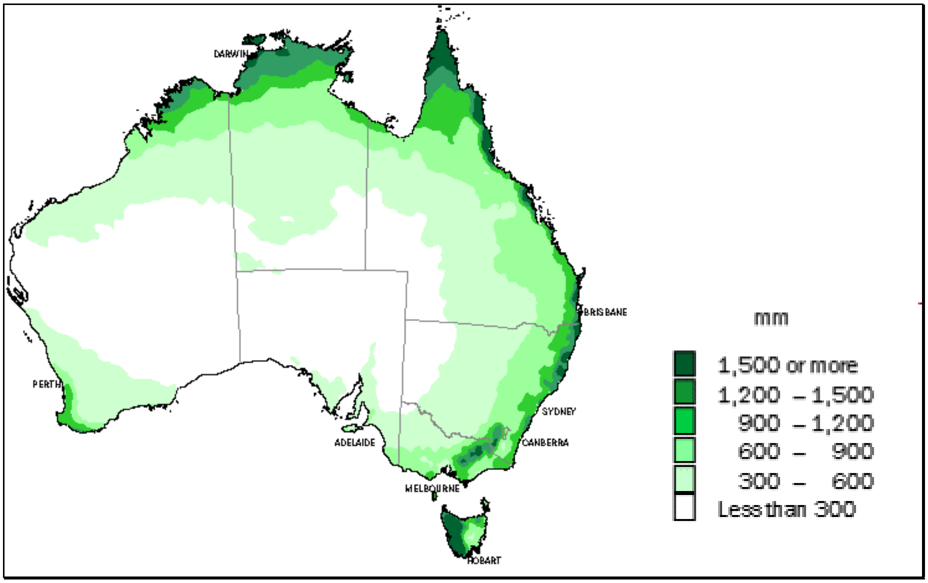

Figure 2. Median annual rainfall for Australia (mm). Source: Australian Bureau of Meteorology.

3.1.2 New Zealand

New Zealand is characterised by a mountainous topography, with the principal mountain range on the North Island stretching along the east of the island. The principal mountain range of the South Island stretches along the western side of the island (Figure 3). The climate is temperate with mild, wet winters and warm, dry summers. Rainfall (Figure 4) is generally moderate to abundant, with an average annual rainfall of 1245 mm, and rainfall distribution is largely influenced by the topography.

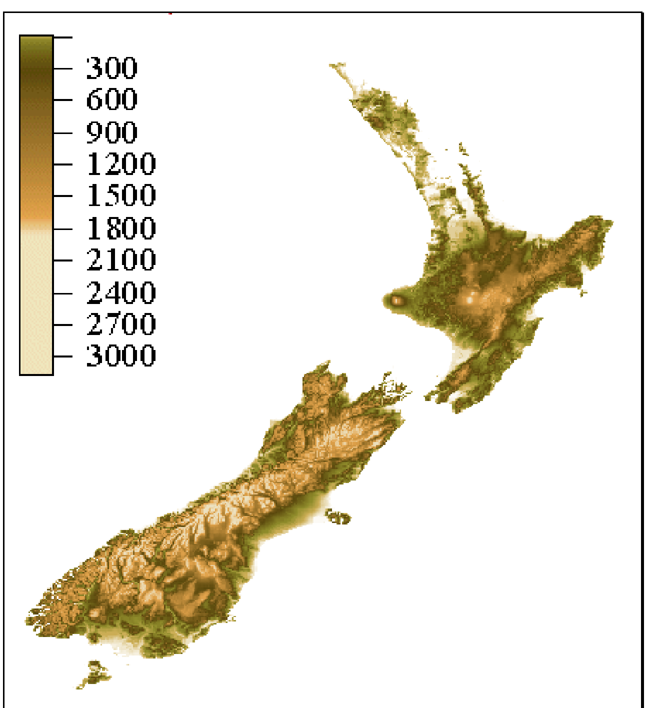

Figure 3. Topographical map of New Zealand, based on 1 km elevation grid data. Source: USGS, GTOPO-30.

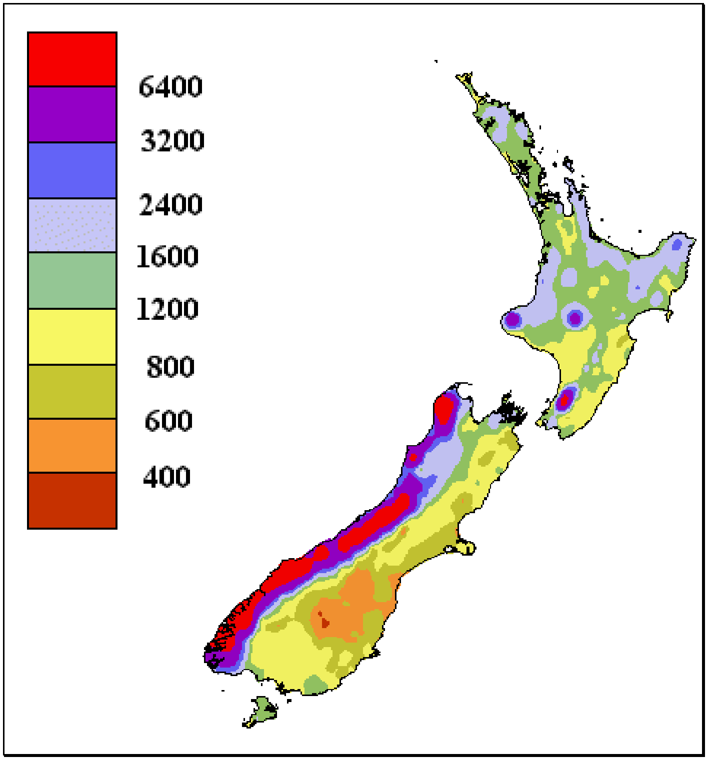

Figure 4. Rainfall distribution map showing average annual precipitation for New Zealand. Source: National Institute of Water and Atmospheric Research.

3.1.3 USA

Two inland mountain ranges run north to south and parallel the coasts: Rocky Mountains (Pacific) and Appalachian Mountains (Atlantic).

Temperatures vary seasonally, with the greatest extremes in the north-central plains. Although the US experiences wide climatic variation, the precipitation pattern may be depicted as comparatively humid coasts separated by a progressively less humid (east to west) interior. Rainfall generally declines westward from the humid eastern zone, where precipitation is usually < 1000 mm.

Corn (maize) is typically cultivated in the Midwest, mainly in Ohio, Indiana, Illinois, Iowa, Wisconsin, Minnesota and Michigan. Wheat is concentrated in drier areas to the west of the main corn region, and can be found in Kansas-Nebraska-Oklahoma, as well as in the north-western states, such as the Dakotas, Montana and Washington. Cotton is grown in the southern states. Major irrigation areas are naturally found in the drier areas west of the Mississippi River (with California's intensively cultivated areas of vegetables and fruit as a noteworthy area, in the cotton areas), in the lower Mississippi Valley, in the wheat growing region and in horticultural areas in the south-east and east.

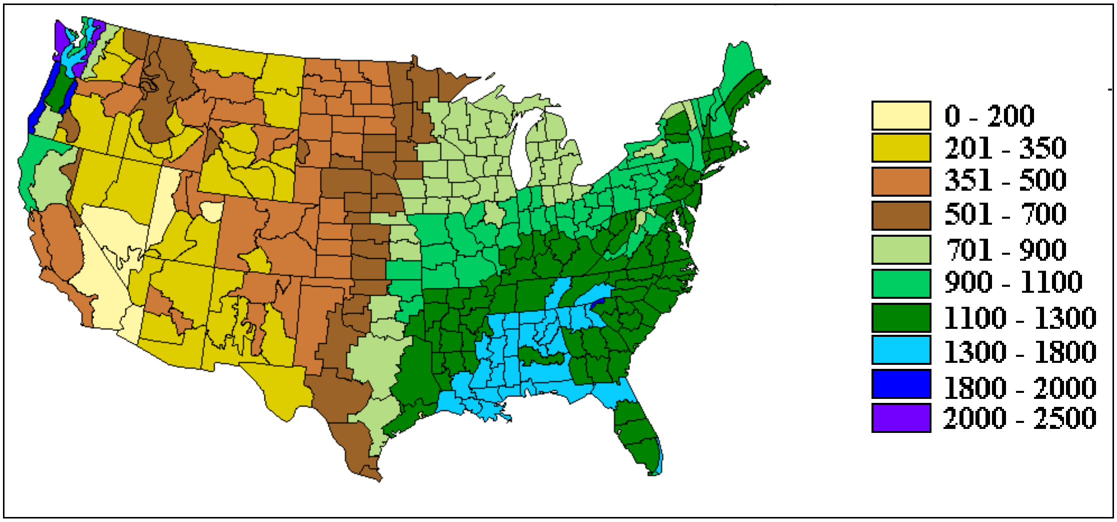

Figure 5. Average annual precipitation for the US. Source: National Climatic Data Center.

3.1.4 Japan

The Japanese archipelago stretches in a narrow arc 3 800 km long. The four main islands are Honshu, Hokkaido, Kyushu, and Shikoku. The climate varies from tropical in the south to cool temperate in the north with rainfall ranging from 1000 to 2500 mm per year, and a mean annual rainfall of 1800 mm. The island is part of a long chain of mountains running from Southeast Asia to Alaska, and it therefore has a mountainous topography with mountains accounting for approximately 71 % of the total land area.

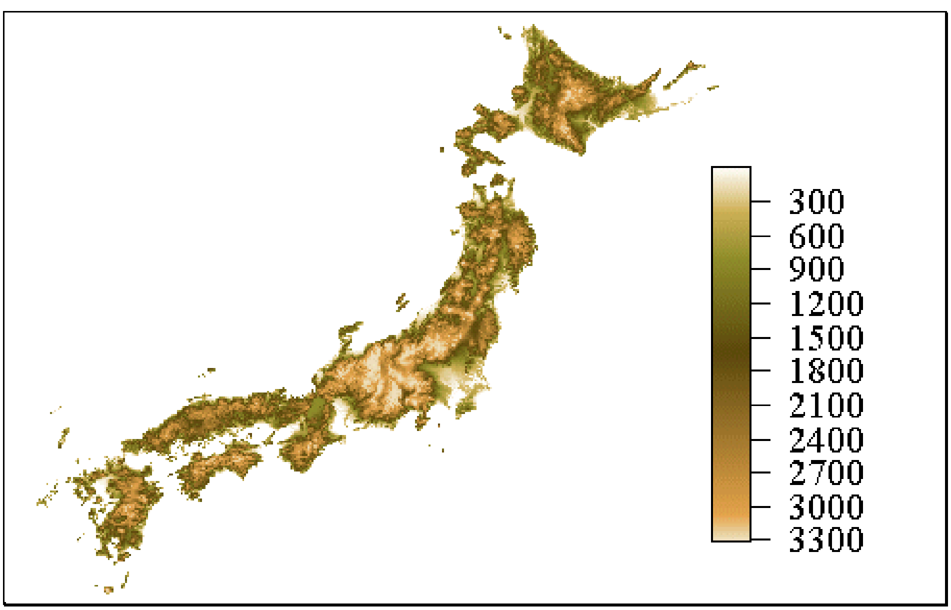

Figure 6. Topographical map of Japan, based on 1 km elevation grid data. Source: USGS, GTOPO-30.

3.1.5 Norway

Norway is characterised by mountainous topography with steep valleys and incised fjords. Large areas have sparse soil cover over the bedrock. Low temperatures and short cropping seasons restrict the agricultural production. The mean annual precipitation is about 1400 mm, ranging from 300 to more than 3000 mm. The most productive agricultural areas are in the lowlands around Oslo, Stavanger and Trondheim.

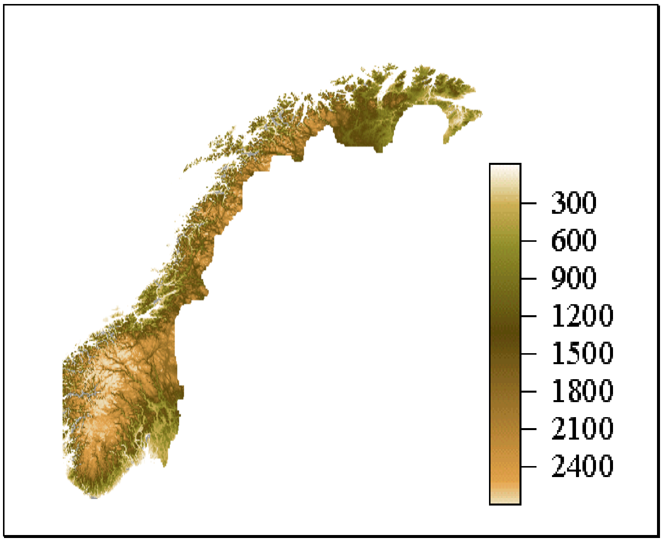

Figure 7. Topographical map of Norway, based on 1 km elevation grid data. Source: USGS, GTOPO-30.

3.1.6 Switzerland

Switzerland has a very mountainous topography with altitude differences of more than 4000 metres and two mountain systems, the Alps and the Jura covering 70 % of the country. Between these two mountain ranges lies the hilly Swiss plateau. Switzerland's climate and precipitation vary according to elevation. In the plateau and lower valleys, temperatures are moderate, while higher elevations have average lower temperatures and greater precipitation, mostly as snow.

3.2 Land use and population

Land use in the selected countries is presented in Table 2. The land use categories have been defined by FAO (1999):

- Total land area includes inland waters.
- Arable land is land under temporary crops, temporary meadows for mowing or pasture, land under gardens and land temporarily fallow (less than five years).
- Permanent crops are land cultivated with crops that occupy the land for long periods and includes land under flowering shrubs, fruit trees, nut trees and vines.
- Permanent pasture is land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land). The dividing line between this category and the category "Forests and woodland" is rather indefinite. In the year 1995 and onward there is no data for this category.
- Agricultural area is a category used up to 1994 and includes the sum of *arable land*, *permanent crops* and *permanent pastures*.
- Forests and woodland include land under natural or planted stands of trees, whether productive or not. This category includes land from which forests have been cleared but that will be reforested in the foreseeable future, but it excludes woodland or forest used only for recreation purposes.

The NI-countries have a significantly lower share of agricultural land in per cent of total land area and a lower area of agricultural land (both arable and total agricultural) per capita than the NE-countries (Table 2 and Table 3). This indicates that the land resources suitable for cultivation are more limited in the NI- countries.

Table 2. Land use in the selected countries (1994). Source: FAO.

	Land use, 1000 ha

Cate-gory	Country	Total land area, 1000 km^2	Arable land	Perma-nent cropland	Perma-nent pasture	Agri-cultural land	Forest and woodland	Arable land in % of total area	Agric. land in % of total land area
	Australia	7 713	47 000	200	414 500	461 500	145 000	6	60
NEC	New Zealand	271	1 534	1537	13 536	15 070	7 667	6	56
	USA	9 364	178 950	2050	239 250	418 200	295 990	19	45
	Japan	378	3 999	423	661	4 660	25 000	11	12
NIC	Norway	324	901	0	129	1 030	8 330	3	3
	Switzerland	41	410	24	1 147	1 557	1 186	10	38

Table 3. Population and agricultural land per capita (1994). Source: FAO.

		Population	Ha agricultural land per capita	
Category	Country	(1000)	Arable land	Total agric. land
	Australia	17 529	2.68	26.33
NEC	New Zealand	3 451	0.44	4.37
	USA	258 233	0.69	1.62
	Japan	123 653	0.03	0.04
NIC	Norway	4 312	0.21	0.24
	Switzerland	6 938	0.06	0.22

The share of agricultural land to total land area is used by the OECD as a key indicator for agriculture. The larger the share of total area used for agriculture, the larger the potential impact on the environment. Land use information is used for interpretation of other environmental indicators, e.g. nitrogen balance and erosion risk.

3.3 Crops and yields

Areas and yields for cereal crops are presented in Table 4. Switzerland has the highest yield for all crops but rice, followed by New Zealand, Norway and Japan, while Australia and USA have the lowest yield. The rice yield is highest in Australia and about the same in USA as in Japan.

Table 4. Crops and yields (average for 1994-98). Source: FAO.

Category	Country	Areas, 1000 ha					Yields, tons/ha				
		Wheat	Rice	Rye	Barley	Oats	Wheat	Rice	Rye	Barley	Oats
NEC	Australia	9986	135	33	3 073	963	1.8	8.4	0.6	1.7	1.5
	New Zealand	49			77	11	5.5			4.9	4.2
	USA	24947	1 259	154	2 590	1 241	2.6	6.6	1.7	3.1	2.1
NIC	Japan	156	2 012		59	1	3.4	6.5		3.6	1.9
	Norway	65		4	170	97	4.5		3.7	3.7	3.8
	Switzerland	100		5	52	8	6.2		6.1	6.1	5.5

3.4 Conclusion

Compared to the NE-countries, the selected NI-countries are more mountainous with limited land resources suitable for agricultural use. Moreover, the NI-countries have a lower share of agricultural land to total land area and less agricultural and arable land per capita.

Because of the higher ratio of agricultural land to total land area, the environment in the NE-countries is expected to be more influenced by agricultural activities.

The NI-countries have higher yield per ha than Australia and USA for most of the cereal crops compared in the study. The yield rates in New Zealand are about the same as in the NI-countries.

4 PESTICIDES

There is a significant awareness of the possible negative effects of pesticide use on human health and the environment. In addition to the risk of hazardous residues in the products and potential hazards to other non-targeted organisms, there is considerable concern regarding development of resistance among insects, fungi and other organisms.

The objective of governmental policies has for a long time been to reduce the health and environmental impacts caused by pesticides. Especially in the developing countries there is a great emphasis on reducing the risks to farm workers, farmers and other farm families associated with pesticide handling and use. Many governments have aimed at encouraging the use of integrated pest management (IPM) methods and at reducing agriculture's heavy dependence on chemical inputs. To a growing degree consumers not only seem to be aware of the possibility of pesticide residues in food, but also of the impacts of agricultural pesticides on the environment.

The UN Conference on Environment and Development, Rio 1992, recommended increased international co-ordination in the field of chemical safety. In 1995 the Inter-Organization Programme for the Sound Management of Chemicals (IOMC) was established by UNEP, ILO, FAO, WHO, UNIDO and the OECD. The work with pesticides in IOMC is coordinated with the activities of the OECD Pesticide Forum.

In 1997 a study of possible additional EU policy instruments concluded that taxation of pesticides, which had until then been practised only in Denmark, Norway and Sweden, would be a cost effective instrument. Norway has imposed environmental levies over many years. From 1999 the Norwegian levies on pesticides are based on a calculated area-dose fee level. This level is differentiated according to potential health and environmental hazards of the product.

4.1 Limitations in using total amount of pesticides as an environmental indicator

For several reasons, a comparison of the total amounts of pesticides applied, or trends in total amounts of pesticides applied, does not give a correct idea of differences in negative impacts of pesticides on the environment:

- The countries, and regions within a country, may have introduced quite different measures to reduce harmful effects from the use of pesticides. As the OECD Pesticide Forum has revealed, there is a common goal for the different countries to reduce the risks connected to agricultural pesticide use.
- The need for controlling weeds, fungae and insects varies with crops and climatic conditions. Generally, a warmer climate requires greater uses of pesticides than a colder climate to maintain agricultural productivity. Grapes and cotton, which are not grown in all the countries included in this study, are among the crops that usually require the greatest application of pesticides. Few countries have reliable data concerning pesticide use on specified crops.
- The possible harmful effects of pesticides varies with the toxicity, mobility and persistence of the substance. Small amounts of a dangerous pesticide may have greater negative effects on the environment than greater application of a less harmful chemical.
- The use of pesticides should be evaluated together with other environmental impacts of agriculture. For instance, the use of glyphosate and other weed killing chemicals may be preferable compared to weed control by ploughing and harrowing, which leaves the soil more exposed to erosion forces.

In spite of the facts mentioned above, the most common statistical data for impacts of pesticides on the environment are amounts of pesticides applied. This is mainly due to lack of data for pesticide's impact on the *state of the environment.* Some OECD countries are working to develop *pesticide risk indicators* which will be more policy relevant as to environmental impacts than total pesticide use.

The work of the Swedish National Chemical Inspectorate using pesticide risk indicators shows that the trend of the risk indicator closely follows the trend in total pesticide use. Arie Oskam and Rob Viftingschild in their chapter "Towards Environmental Pressure Indicators for Pesticide Impacts" (in Brouwer and Crabtree 1999) suggest that "*pesticide intensity*", which may be expressed by the quantity of active substance of pesticides applied per hectare land, is a good indicator for emissions of chemicals to the environment. The detections of the US Geological Survey of pesticides in streams and rivers seems to confirm this. As to the level of residues from pesticides in products, “pesticide efficiency”, i.e. quantity of active substance of pesticide per unit crop product, seems to be more related to residue levels.

USDA (1997) has analysed the risk from different groups of pesticides. For herbicides, chronic risk and acute risk indicators varied proportionally with the quantity of active ingredients applied. Insecticides account for more than 90 per cent of the total acute risk and more than 50 per cent of the chronic risk of total pesticides.

4.2 Use of main groups of pesticides in the selected countries

The total pesticide use in the selected countries is presented in Table 5. The data for Australia are collected from FAO and represent data for 1992. The data for USA are the mean of the five years 1991-1995 referring to the FAO statistics supplied with data from US Environmental Protection Agency (EPA). In the case of Japan, only data on total pesticide use have been available. The figures in are mean values for the period 1991-1993 from OECD Environmental Data Compendium 1997. The OECD Environmental Performance Review Japan (1995) states a total pesticide use of 14.6 kg active ingredient per hectare, while the same review for 1990 states about 18 kg of active ingredients per hectare. The data on total use of pesticides in New Zealand agriculture are means of the four years 1993-1996 according to the OECD Data Compendium 1997. The distribution of the different categories is from personal communication with Dr Jack Richardson, AGCARM Inc, Wellington. The OECD Environmental Performance Review of New Zealand (1993) stated a pesticide use of 4.3 kg active ingredients per hectare arable land (area with permanent crops not included) in the early 90’s. The data for Norway are means of the five-year period 1993 to 1997. Other national sources and international reviews state 0.7-0.8 kg active ingredient of pesticides used per hectare arable land in Norway. The data comprise the years 1993 to 1997. OECD Environmental Performance Review Switzerland (1995) states 3.7 kg active ingredients of pesticides per hectare of arable land are used in Switzerland.

Table 5. Total active ingredients of pesticides used in the early 90's.

Category	Country	Tons				kg/ha arable land & perm. crops			
		Total	Herbi-cides	Fungi-cides	Insecti-cides	Total	Herbi-cides	Fungi-cides	Insecti-cides
NE-countries	Australia	120000	18031	94193	7430	2.3	0.34	1.7	0.16
	New Zealand	3603	2162	829	310	2.3	1.4	0.54	0.20
	USA	416549	203292	21772	45820	2.3	1.1	0.12	0.26
NI-countries	Japan	65023	n.a.*	n.a.	n.a.	15	n.a.	n.a.	n.a.
	Norway	803	566	164	18	0.89	0.63	0.18	0.02
	Switzerland	1815	645	927	213	4.1	1.5	2.1	0.48

* n.a. = no data available

The trend in use of pesticides in the selected countries is presented in Table 6. In Norway, Switzerland and Japan pesticide use has been reduced in the period 1990-1996. In USA and New Zealand the data show no significant reduction. For Australia data is accessible only for the year 1992.

Table 6. Tons of active ingredients of agricultural pesticides according to OECD Environmental Data Compendium, FAO Database and US Environmental Protection Agency.

Category	Country	1990	1991	1992	1993	1994	1995	1996
NE-countries	Australia	n.a.*	n.a.	119654	n.a.	n.a.	n.a.	n.a.
	New Zealand	n.a.	n.a.	n.a.	3490	3515	3904	3499
	United States	378636	370918	380564	367863	415118	410583	n.a.
NI-countries	Japan	68330	65650	64920	64500	n.a.	n.a.	n.a.
	Norway	1196	770	781	767	860	930	706
	Switzerland	2283	2056	2022	1936	1921	1827	1747

* n.a. = no data available

Targets to reduce the amount of pesticides applied are set by many countries. The European Union has the aim to reduce pesticide use per unit agricultural land. The Department of Agriculture of the United States of America has announced the goal of having 75 % of US cropland under integrated pest management systems by the year 2000, which is expected to lead to a reduction in pesticides applied.

World pesticides sales data is compiled annually by Agranova Alliance Page (earlier Allan Woodburn Associates). The sales in 1996 were US$ 30 560, which is an increase of 5.5 % from the year before. 1996 is the third consecutive year that pesticide sales have risen.

4.3 Use of selected harmful pesticides

The potentially greatest environmental risk arises from those chemicals that are

- *applied in large quantities*
- *mobile in the ecosystems*
- *persistent*
- *highly toxic*

The relative risk of one pesticide compared to another can be characterised by multiplying the quantity used of the pesticide with the degree of harm the chemical may do to the environment.

Oskam and Vijftigschild in Brouwer and Crabtree (1999) have ranked some pesticides used in California for environmental and health risks. The five highest ranked pesticides were *methomyl, parathion, aldicarb, carbofuran* and *mevinphos*[1].

All five above are insecticides; methomyl, aldicarb and carbofuran are carbamates, which are toxic for fish in small amounts. None of the five pesticides above are any longer on the list of registered pesticides in Norway. In USA aldicarb, carbofuran and mevinphos are on the list of federally registered restricted use pesticides, and methomyl and parathion are registered as restricted in some states.

4.3.1 Procedure for Certain Hazardous Chemicals and Pesticides in International Trade

After a period with a voluntary international program known as the Prior Informed Consent (PIC), a convention was finalised in 1998 that gives importing countries, especially developing countries, the power to decide which chemicals they want to receive. The pesticides on the current list of hazardous substances subject to the PIC procedure are presented in Table 7. A summary of the decision on import of pesticides on the voluntary PIC list for the selected countries are presented in Table 8.

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[1] *Methomyl* was used on many crops in 1992. The largest amounts were used on cotton, sweet corn, lettuce, apples, alfalfa, corn, peanuts, tomatoes, sorghum and grapes. The estimated total quantity in 1992 was 1.7 millions pounds a year.

Parathion was used on cotton, corn, alfalfa, wheat and grains, rice, soybeans, sunflower, peaches and other crops. Ethyl parathion consumption in 1992 was estimated at 2 million pounds and methyl parathion at 8.7 million pounds. According to EPA (1997) the use of methyl parathion in 1995 was about 4-7 million pounds. In 1999 EPA estimates the application of methyl parathion to be between three and four million pounds annually.

Aldicarb was used especially on cotton and peanuts, but also on sugar beets, citrus and tobacco, with an annual consumption of about 4.2 million pounds on these crops according to USGS estimates for 1992. In 1998 aldicarb still was the most widely used insecticide on upland cotton.

Of c*arbofuran* nearly half of the consumption was used on corn, but it was also used on alfalfa, sorghum, potatoes, rice, cotton, tobacco and other crops, with a yearly estimated amount of 4.7 million pounds to these crops in 1992.

Mevinphos was used mainly on vegetables, with an estimated annual quantity of 185 000 pounds in 1992.

Table 7. Pesticides Subject to the PIC Procedure.

Chemical	Relevant CAS Number(s)	Category	Date
2,4,5-T	93-76-5	Pesticide	1997
Aldrin	309-00-2	Pesticide	1991
Binapacryl	485-31-4	Pesticide	1999
Captafol	2425-06-1	Pesticide	1997
Chlordane	57-74-9	Pesticide	1992
Chlordimeform	6164-98-3	Pesticide	1992
Chlorobenzilate	510-15-6	Pesticide	1997
DDT	50-29-3	Pesticide	1991
Dieldrin	60-57-1	Pesticide	1991
Dinoseb and dinoseb salts	88-85-7	Pesticide	1991
1,2-dibromoethane(EDB)	106-93-4	Pesticide	1992
Fluoroacetamide	640-19-7	Pesticide	1991
HCH (mixed isomers)	608-73-1	Pesticide	1991
Heptachlor	76-44-8	Pesticide	1992
Hexachlorobenzene	118-74-1	Pesticide	1997
Lindane	58-89-9	Pesticide	1997
Mercury compounds(incl. inorganic mercury cpds., alkyl mercury cpds., and alkyloxyalkyl and aryl mercury cpds.)		Pesticide	1992
Pentachlorophenol	87-86-5	Pesticide	1997
Toxaphene	8001-35-2	Pesticide	1999
Methamidophos (Soluble liquid formulations of the substance that exceed 600 g active ingredient / l)	10265-92-6	Severely Hazardous Pesticide Formulation	1997
Methyl-parathion [emulsifiable concentrates (EC) 50%, 60% active ingredient and dusts containing 1.5%, 2% and 3% active ingredient]	298-00-0	Severely Hazardous Pesticide Formulation	1997
Monocrotophos (Soluble liquid formulations of the substance that exceed 600 g active ingredient / l)	6923-22-4	Severely Hazardous Pesticide Formulation	1997
Parathion [all formulations - aerosols, dustable powder (DP), emulsifiable concentrate (EC), granules (GR) and wettable powders (WP) - of this substance are included, except capsule suspensions (CS)]	56-38-2	Severely Hazardous Pesticide Formulation	1997
Phosphamidon (Soluble liquid formulations of the substance that exceed 1000 g active ingredient / l)	13171-21-6 [mixture, (E) & (Z) isomers) 23783-98-4 [(Z)-isomer] 297-99-4 [(E)-isomer]	Severely Hazardous Pesticide Formulation	1997

Table 8. Summary of decisions on import of pesticides under the voluntary PIC.

NE-countries	Australia	No restriction for parathion and methyl parathion. Specific approval of import of lindane.
	New Zealand	The registration for (ethyl-) parathion has been withdrawn, but methyl parathion is still imported.
	United States	No decisions reported.
NI-countries	Japan	Decisions for only a few substances have been reported
	Norway	None of the pesticides on the PIC list are allowed to be imported
	Switzerland	Import of parathion is permitted.

4.3.2 Methyl bromide

Methyl bromide is used as a pre-plant soil fumigant for tomatoes, strawberries, vegetables and other crops. In the Montreal Protocol for the Protection of the Ozone Layer, the countries agreed in limiting the use of methyl bromide, which contributes to depletion of the ozone layer. All six countries reported less use of methyl bromide in 1995 compared to 1991. However, in Australia the consumption seemed to be higher in 1996 and especially in 1997 than in 1995. Japan has reported great difficulties in finding substitutes for methyl bromide. In the Annual Report 1996, the Japanese Division of Pesticides reports that 30-45 % of the amount of methyl bromide used in soil fumigation in Japan is lost to the atmosphere.

Table 9. Consumption of methyl bromide (tons) reported to the Methyl Bromide Phaseout. Source: UNEP.

Category	Country	1991	1995	1996	1997
NE-countries	Australia	799	496	631	1031
	New Zealand	135	128	97	n.a.*
	United States	23414	22262	21118	20772
NI-countries	Japan	9163	8713	8188	7908
	Norway	11	9	10	n.a.
	Switzerland	43	24	22	n.a.

* n.a. = no data available

4.3.3 Atrazine

Atrazine is the pesticide with the largest quantity applied in the US. One spraying of atrazine in corn gives weed control during the whole season. The quantity yearly used in US has been about 70 million pounds over many years until 1995. In 1997, 69 % of the 62.2 million acres of corn in ten US states was sprayed with atrazine, and in 1998, 67 % of the corn fields in ten surveyed states were sprayed. The application rate is about one pound per acre (approx. 1 kg/ha). Atrazine is a possible carcinogen. It is persistent in the soil and has a high potential to leach through porous soils. Atrazine and its metabolites are the most frequently found pesticide residues in surface water and ground water. The Maximum Contaminant Level (MCL) in drinking water is 3 ppb.

4.3.4 Endosulfan

The moderately persistent insecticide endosulfan is used on cotton, fruits, forage crops and other crops. Endosulfan is dangerous to agricultural workers if not used properly, and it is harmful to fish and other aquatic organisms when drifting spray or storm run-off finds its way into rivers. In Australia only licensed spraying contractors are allowed to use endosulfan after 30 June 1999. The National Registration Authority of Australia says that endosulfan may be further restricted or withdrawn if reductions in its release to the environment are not achieved.

A problem with endosulfan is that under dry conditions and late in the growing season residues of the chemical may persist in plant materials for a longer period than earlier expected. In Australia residues of between 3 and 10 mg endosulfan per kilogram of stubble are registered four to six months after application. The maximum residue level (MRL) for stock feeds in Australia is 0.3 mg endosulfan per kilogram of hay, silage fodder crops and pasture. More than 0.5 mg/kg of endosulfan in the total diet of cattle can cause residues in cattle meat to exceed the 0.2 mg/kg Australian MRL for fat of meat. The international MRL for endosulfan in meat is 0.1 mg/kg.

4.4 Detection of emissions of pesticides to the environment

In "Trends in the Potential for Environmental Risk from Pesticide Loss from Farm Fields" Kellogg et al. (1999) estimate a total mass loss at an average of about 5 % of the amount of pesticides applied. Mass loss through adsorbtion to soil particles seems to have increased through the 1990's.

4.4.1 USA

Pesticides in surface waters in USA

A study of pesticides in surface water was conducted on a random sample of 149 streams in a 10-state region of the Midwest in 1991 (Goolsby et al. 1991). Although this study was regional rather than national in scope, approximately three-quarters of all preemergent herbicides used in the United States are applied to row crops in the study region. The results of the mentioned study suggest that detectable concentrations of atrazine, one of the most commonly used herbicides for weed control in corn and sorghum production, occurred year-round in a majority of the streams sampled. During the first runoff after application in 1989, a majority (52 %) of the streams sampled had atrazine concentrations exceeding 3 μg/L (micrograms per litre), the EPA MCL recommended for drinking water (Figure 8). The atrazine concentrations increased by as much as two orders of magnitude during the spring and early summer period following herbicide application, and then decreased to preapplication levels by autumn during low streamflow conditions. Because of the random design of the sampling, these results are believed to be typical of streams throughout the study region.

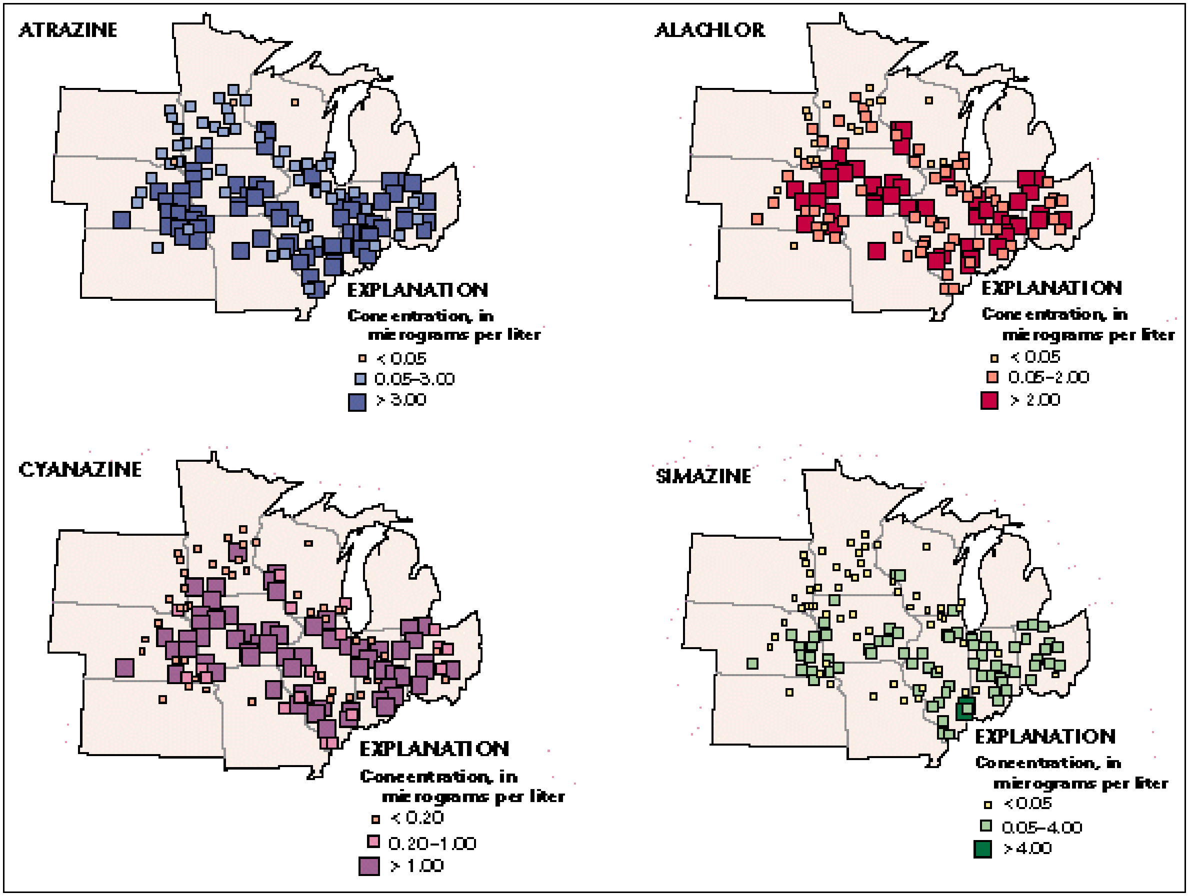


Figure 8. Concentrations of selected herbicides collected during the first runoff after application in the spring of 1989 in streams that drain agricultural areas in a 10-State area in the Midwest. Source: USGS.

The US Geological Survey (1998) presented results from data collection during 1992-1996 including analyses of 76 pesticides and 7 selected pesticide degradation products in about 8 200 samples of groundwater and surface water in 20 of the nation's major hydrologic basins. The studies are not designed to produce a statistically representative analysis of national water quality conditions, but to target specific watersheds and shallow groundwater areas that are influenced primarily by a single dominant land use (agricultural or urban) that is important in the particular area. A summary of the detections is presented in Figure 9. More than 95 % of all samples collected from streams and rivers contained at least one pesticide, compared to about 50 % for groundwater. Most detections in streams were greater than 0.01 µg/L, and more than half were greater than 0.05 µg/L. Compared to streams, groundwater generally had a greater proportion of detections below 0.05µg/L in all land use and hydrologic settings. The 20 most frequently detected compounds in streams mainly influenced by agriculture are presented in Table 10. Among these 20 compounds, only 7 are permitted in Norway.

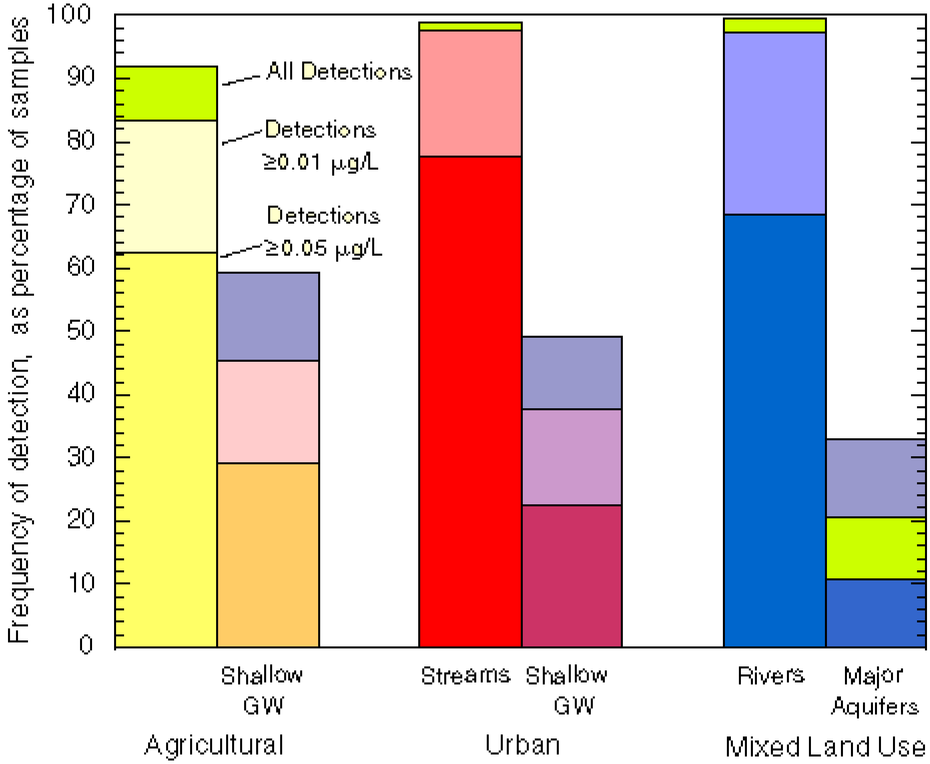


Figure 9. Summary of detections of one or more pesticides in USA. Source: USGS.

Table 10. The 20 most frequently detected compounds in streams mainly influenced by agriculture. Source: US Geological Survey.

Compound	% findings		
	All	>=0,01 µg/L	>=0,05 µg/L
Atrazine	77	66	38
Metolachlor	73	53	27
Simazine	62	45	17
Atrazine, deethyl (E)	53	36	15
Alachlor	36	27	11
Prometon	35	26	9
Cyanazine	28	25	13
EPTC	25	14	5
DCPA	22	10	4
Trifluralin	18	7	1
Diazinon	17	11	3
Tebuthiuron	16	8	1
Chlorpyrifos	16	10	2
Metribuzin	14	8	2
Carbofuran (E)	12	11	5
2,4-D	12	--	11
Pendimethalin	11	7	2
Carbaryl (E)	11	7	2
Triallate	9	4	1
Diuron	8	--	8

Larson, S. J. 1999 summarises the results of the data of pesticides in streams and rivers collected by the US Geological Survey. The amounts of the herbicides *atrazine, metolachlor* and *cyanazine* recorded in streams represent about 1 per cent of the amounts of the herbicides applied in agriculture in the drainage basins. Other herbicides like *EPTC* and *trifluralin*, which are more volatile than atrazine, metolachlor and cyanazine and are incorporated into the soil when applied, usually have loads in streams representing 0.01 to 0.1 per cent of the quantities applied in the drainage basins. The commonly detected insecticides *carbaryl* and *carbofuran* showed loads of about 0.1 per cent of the amount used in the basins.

In a few cases the concentrations of the pesticides in stream water were above their criteria values for drinking water. The herbicides *alachlor, atrazine, cyanazine* and *HCH* and the insecticide *diazinon* were the compounds most often detected at concentrations greater than the maximum contaminant level (MCL).

The concentration of one or more pesticides exceeded the aquatic-life criterion values in the majority of the sites examined. Even where insecticide levels are much lower than herbicide levels in streams, insecticides may be more important in terms of potential effects on aquatic life. In addition to *diazinon,* the insecticides *chlorpyrifos, azinphos-methyl* and *malathion* occurred frequently above aquatic-life criterion.

Pesticides in groundwater

In the late 1970s pesticides in groundwater were registered for the first time in USA. The US Geological Survey recently published a report of selected herbicides detected in groundwater in two sampling series between 1991 and 1995 (Barbash et al. 1999). Standards for drinking water were exceeded at very few of the sites sampled, and all the exceedances involved *atrazine* alone.

For the most frequently used pesticides in agriculture the frequencies of detection of the pesticides were positively correlated with agricultural use of the corresponding area.

In the two sampling series, 19.7 and 13.8 %, respectively, of the sites sampled had two or more detections of the herbicides of interest.

In some cases the most frequently detected pesticide compounds were transformation products rather than parent compounds. This was the case especially for the less persistent herbicides. Furthermore, the water quality criteria for drinking water has been established for some of the pesticides in use, and only for each separate compound, not for the combination of different pesticides.

4.4.2 Norway

Monitoring of pesticides in surface water and groundwater has been included in the Agricultural Environmental Monitoring Programme since 1995. The sampling has been located in areas affected by agriculture with regular use of pesticides. The analysed compounds (Table 11) make up 46 % of the total used pesticides.

Table 11. Least detectable level of the analysed pesticides in Norway. Source: Agricultural Environmental Monitoring Programme.

Compounds	**Least detectable level, µg/l**
Bentazon, 2,4-D, Dicamba, Dichlorprop, MCPA, Mekoprop	0.02
Aklonifen, Atrazine, Cypermetrin alfa, Diazinon, Dimetoat, Esfenvarelat, Fenitrotion, Fenpropimorf, Fluazinam, Lindana, Metribuzin, Penkonazol, Simazine, Vinklozolin	0.05
Azinfosmetyl, DDT, Endosulfan, Fenvarelat, Iprodion, Klorfenvinfos, Linuron, Metalaksyl, Metamitron, Permetrin, Pirimikarb, Proklorax, Propaklor, Propikonazol, Tebukonazol, Terbutylazin, Tiabendazol, Fluroksypyr, Yoksynil	0.1

One or more pesticides have been detected in 70 % of the samples from streams and 48 % of the samples from farm wells. Twelve per cent of the findings in streams had concentrations above the environmental risk index (ERI), which is the level for harmful effects on aquatic organisms. In 17 % of the findings in farm wells, the concentration exceeded the recommended level of 0.1 µg/l for a single pesticide, but none exceeded the level for human health risk. The most frequently detected compounds in streams in Norway are presented in Table 12.

Table 12. The 20 most frequently detected compounds in small streams in Norway strongly influenced by agriculture. Source: Agricultural Environmental Monitoring Programme.

Compound	% findings	% exceeding ERI
Glyphosate	82	0
Bentozan	47	0
ETU	30	3
Metribuzin	23	6
MCPA	22	0
Diklorprop	18	0
Mekoprop	14	0
Matalaksyl	13	0
Simazin	11	0
2,4-D	7	0
Linuron	5	5
Propikonazol	4	4
Propaklor	4	1
Metamitron	4	1
Klorfenvinfos	3	3
Lindane	2	0
Aklonifen	<1	1
Azifosme5tyl	<1	1
Fenpropimorf	<1	1
Diemetoat	<1	1

4.5 Conclusion

The average consumption of pesticides per hectare arable land and permanent crops shows the following ranking among the selected countries: Japan > Switzerland > Australia ≈ New Zealand ≈ USA > Norway. The trends for the period 1990-1996 indicate a reduction of total pesticide use in the NI-countries (Japan, Norway and Switzerland) but no reduction in the NE-countries (New Zealand and USA). For different reasons the total consumption of pesticides gives limited information about the impact of pesticides on the environment. More information on the use of pesticides is wanted. Comparisons among countries are difficult because some crops, which require large quantities of pesticides, are not grown in all the countries included in this study.

The reports on decisions on import of pesticides according to the Prior Informed Consent (PIC) indicate that main food exporting countries are less restrictive than at least some of the net importing countries. The growing awareness as to consumers of pesticide residues and other aspects of pesticide use, however, may result in reduced pesticide use also in the exporting countries.

Monitoring data on pesticides in water are only available for USA and Norway. Similar patterns have been found in the two countries. Pesticides are detected in most of the samples from streams and about half of the samples for groundwater and farm wells. Notwithstanding, the results are not directly comparable. None of the sampling systems give statistically representative analysis of water quality as a whole. USA has generally higher finding frequencies than Norway, but this may partly be a result of a lower least detectable level in USA (<0.01 in USA and 0.02-0.1 in Norway). However, a majority of the most frequently detected compounds in USA are considered to be harmful and are not permitted in Norway.

5 NUTRIENTS

5.1 Fertiliser use

Fertiliser use will naturally vary within and between the countries studied due to differences in crops, soils, nutrient status and use of animal manure. The data on fertiliser use has mainly been collected from the following sources:

- FAO
- European Fertiliser Manufacturers Association (EFMA)
- International Fertiliser Industry Association (IFA)
- International Fertiliser Development Corporation (IFDC)
- The Fertiliser Institute
- OECD
- Australian Bureau of Statistics (ABS)
- USDA
- World Resources Institute (WRI)

The availability of data varies greatly between the different countries, and USDA has the most comprehensive database covering a 30-year period. The methods used in sampling the data also vary somewhat between the different sources, and there are therefore substantial variations for some of the crops when comparing data from the different sources.

Table 13. Fertiliser use per hectare. Mean for 1993-96. Source: FAO-database.

		Kg fertilisers per ha arable land + permanent cropland		Kg P_2O_5 per ha agricultural land
Category	Country	N	P_2O_5	
NEC	Australia	14	19	2
	New Zealand	42	126	23
	United States	61	24	10
NIC	Japan	126	151	131
	Norway	121	35	31
	Switzerland	141	56	15

Table 13 shows that the NI-countries have a higher rate of fertiliser application per hectare than the NE-countries. The application rates are expressed as kg/ha arable land + permanent cropland, because most of the fertilisers are applied to these two area categories. The phosphorous application rate is also expressed per ha agricultural land because in some countries, especially in New Zealand, a substantial part of the phosphorous fertilisers are applied to permanent pasture.

Particularly Australia has a low average application rate. However, there are some variations within the groups. Switzerland has a lower phosphorous application than New Zealand, even if the rate is expressed per hectare agricultural land.

The trend in nitrogen and phosphorous application rates, illustrated in Figure 10, shows that the difference between the NI-countries and the NE-countries has not been significantly changed since 1961.

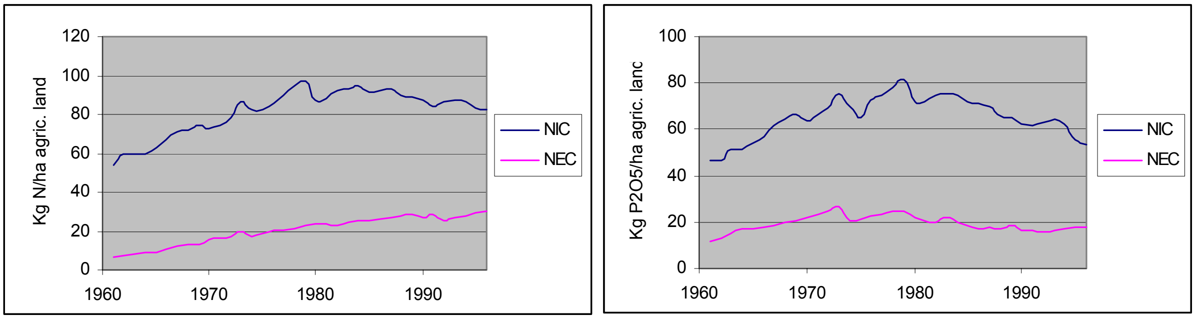


Figure 10. Trends in N and P applications per ha. Source: FAO-database.

5.2 Nutrient balances

The nutrient balance measures the differences between nutrient inputs and outputs in an agricultural system. It gives an indication of the sustainability of the cropping systems in terms of inputs vs. outputs, but also provides important information about potential environmental effects e.g. of excessive use of fertilisers and low yields.

The balances for the selected countries, calculated by the OECD (2000 forthcoming), are presented in Table 14. These balances are based on the surface balance principle, which is calculated as the differences between the total quantity of nitrogen inputs entering the soil and the quantity of nitrogen outputs leaving the soil annually. The annual total quantity of inputs includes nitrogen in inorganic or chemical fertilisers, net livestock manure nitrogen production, biological nitrogen fixation, atmospheric nitrogen deposition, nitrogen from recycled organic matter and nitrogen in seeds and planting materials. The annual total quantity of outputs includes nitrogen in crops and fodder removed by harvesting or pasture.

Table 14 shows that the NE-countries, especially Australia, New Zealand and USA, have a significantly lower nitrogen surplus per hectare agricultural land than the NI-countries have, even though the decrease from 1985-87 to 1995-97 seems to have been larger in the NI-counties. A comparison of the nitrogen balance between countries is complicated by the fact that permanent pasture, which is occasionally fertilised, is included in the agricultural area. On the other hand, a calculation of the nitrogen balance by dividing the total balance on the arable land would have resulted in too high surpluses in Australia and New Zealand for example, because some fraction of the nitrogen fertiliser is applied to permanent pasture.

The nitrogen balance per unit agricultural land cannot be considered to give an adequate expression of the total load of nitrogen to a catchment or a country. The nitrogen balance per unit total land area should therefore be a more relevant indicator of the overall risk for impact on surface waters. Table 15 shows that Norway in particular, but also New Zealand and Australia, have a significantly lower nitrogen surplus per unit total area than USA, Japan and Switzerland. Even if the atmospheric deposition, which is deposited on all areas, is excluded from the calculation, this pattern will not be significantly changed.

For an assessment of the nitrogen surplus per produced unit, the balance should be expressed in per cent of nitrogen in output. The lower the nitrogen surplus in per cent of output, the higher the efficiency of nitrogen is as a production factor. Table 15 shows that the differences between the country categories is less distinct when comparing the balances in per cent of output. Japan appears to have the highest surplus both per hectare and in per cent of output, while New Zealand has the lowest. Between the other countries the differences are rather small. It should be noted that the surplus in New Zealand, 2 % of the output, is improbably low, because some losses through leaching and gas emission are unavoidable. The extremely low numbers should be explained either as an underestimation of the biological nitrogen fixation or a net mineralization of soil organic matter and a depletion of the organic nitrogen pool in the soil.

Comparisons of nitrogen balances in per cent of output between countries should be done with care. Differences between countries may also be explained by crops with different nutrient requirements and efficiencies.

Table 14. Nitrogen balance calculations for the study countries. Source: OECD (2000 forthcoming) “Environmental Indicators for Agriculture: Volume 3 - Methods and Results”.

Category	Country	N input (1000 tons)		N output (1000 tons)		N balance (1000 tons)		N balance (kg/ha agr. land)	
		1985-87	1995-97	1985-87	1995-97	1985-87	1995-97	1985-87	1995-97
NEC	Australia	8527	8780	5295	5505	3232	3275	7	7
	New Zealand	3598	3454	3531	3370	67	84	5	6
	USA	27923	30538	17114	17497	10809	13041	25	31
NIC	Japan	1466	1275	690	601	776	674	145	135
	Norway	198	206	129	131	69	75	72	73
	Switzerland	242	216	151	156	92	61	80	53

Table 15. **Nitrogen balance per total area and as per cent of output.**

		N balance (kg/ha total land area)		N balance in % of output	
		1985-87	1995-97	1985-87	1995-97
Net Exporting Countries	Australia	4	4	61	59
	New Zealand	2	3	2	2
	USA	12	14	63	75
Net Imorting Countries	Japan	21	18	112	112
	Norway	2	2	53	57
	Switzerland	22	15	61	39

5.3 Fertiliser use on specific crops

Table 16 shows the nitrogen and phosphorous application rates for wheat and rice for some of the selected countries. Due to a lack of data for fertiliser use on specific crops for Australia and New Zealand, these countries are not included. The differences are smaller than the differences in mean application (Table 13).

Based on the application rates and annual mean yields for specific crops, the nutrient efficiency, defined as kg applied N and P_2O_5 per ton yield, can be calculated. Table 16 indicates no differences between USA, Norway and Switzerland in nitrogen efficiency for wheat. The efficiency for phosphorous is lower in USA than in Norway and Switzerland. Japan has a higher nitrogen use efficiency but a distinctly lower phosphorous efficiency for rice than USA. It also appears that Switzerland has the highest nitrogen and phosphorous efficiencies in general, due to high yields.

Table 16. Fertiliser applications per ha and fertiliser use efficiency for wheat and rice. Source: The Fertiliser Institute and FAO-database.

Category	Country	kg N/ha		kg P_2O_5/ha		kg N/ton yield		kg P_2O_5/ton yield	
		Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice
NEC	USA	74	147	37	12	29	22	14	2
	Japan		83		97		13		15
NIC	Norway	122		42		27		9	
	Switzerland	170		44		27		7	

5.4 Conclusion

The NI-countries have a significantly higher fertilisation rate and nitrogen surplus per hectare agricultural land than the NE-countries. The nitrogen surplus per total land area, which should be considered as a more relevant indicator for the risk of impact on surface water, is substantially lower in Australia, New Zealand and Norway than in USA, Japan and Switzerland.

Between the countries where data on the use on fertilisers to specific crops have been available, there are small differences in phosphorous application rates for wheat and no differences in the efficiency of nitrogen for wheat, expressed as kg N/ton yield. Norway and Switzerland have higher phosphorous efficiency for wheat than USA. For rice, Japan has lower nitrogen application rate and higher nitrogen efficiency than USA, but higher phosphorous application rate and lower phosphorous efficiency.

NAFTA and the environment

There is currently a discussion in North America on whether the NAFTA trade agreement benefits the environment or not. In the central parts of USA and in western Canada there is a concentration of cattle feeding causing some environmental impacts. The report *"Issue Study 2. Feedlot Production of Cattle in the United States and Canada: Some Environmental Implications of the North American Free Trade Agreement"* points out that:

"... aggregate environmental consequences [of fed cattle expansion due to NAFTA] – for water quality and quantity, pesticide and fertilizer use, soil erosion and biodiversity – all occur due to site-specific management decisions. ... better targeting of technology and environmental management can significantly reduce many of these site-specific impacts. ... "

The study asserts that the different US soil conservation programs from the 1950s to the early 1990's in many respects were means of transferring income to farmers, rather than being focused on the roughly 10 percent of US cropland, pasture or rangeland suffering from severe degradation. The study also concludes that the criticised expansion of the cattle feedlot sector in the US mid-west has not caused any large environmental impacts. The situation in Alberta is severe water-pollution problems. If the beef cattle producers and the industry do not voluntarily carry out initiatives, others will have to initiate increasing regulatory controls. Manure application rates of up to 500 tons per acre have been reported, while long-term applications of manure from feedlots should be limited to 14 tons per acre per year to avoid leaching of nitrates to groundwater.

The beginning of the end of a subsidised beef production in Canada was when the provincial government of Alberta started to pay producers to counteract relatively high feed-grain prices in the region in the mid-80s caused by artificially low rail freight rates when transporting grain out of the prairie and into export markets. Since all of these subsidies were taken away, the comparative advantage of the area has lead to an expansion in cattle-feeding. Other factors that have stimulated the growth of this sector are:

- Availability of irrigation water at attractive producer costs (in US the application rate of water to grain corn is reported to be more than 1 acre-foot per acre as a mean).
- Reduction of tensions in the beef and cattle trade between Canada and the United States
- Lower feed-grain prices in southern Alberta compared to northern Alberta
- A dry, comfortable climate.

The final conclusion of the report states:
"There is nothing about comparative advantage in trade terms that guarantees that environmental protection will be actively pursued".

6 SOIL EROSION

6.1 General introduction

Soil erosion includes both water erosion and wind erosion and has been the most widely used indicator of soil quality for at least the last 50 years. Water erosion is the most extensive and widespread erosion form and can be divided into:

- sheet erosion - the removal of a fairly uniform layer of soil by rain and runoff
- rill erosion - the formation of small channels as a result of surface runoff
- gully erosion – formed as rills or furrows get deeper and develop into gullies
- mass movement erosion – e.g. landslides
- streambank erosion – which is a special case of rill erosion located to streambanks.

Some soil erosion by water is inevitable, but it becomes a threat when the annual rates of erosion exceed the rates at which new soil can be formed. Especially in USA, there has been a lot of focus on measuring soil erosion, and the soil loss tolerance factor (T) has been developed and is generally regarded to be the best standard for evaluating soil erosion. However, such T-factors are not used in other countries than USA, and in some cases very little research has been done to actually quantify erosion losses. Thus, some of the countries base themselves on estimates of soil erosion (e.g. Australia) most commonly using the Universal Soil Loss Equation (USLE). The validity of such estimates based on the USLE is very much up for debate, and based on recent research and more appropriate and advanced soil erosion models, the USLE cannot automatically be applied over entire landscapes (e.g. in catchments).

Wind erosion physically removes the lighter, less dense soil constituents such as organic matter, clay, silt and fine sand. Thus it removes the most fertile part of the soil and lowers soil productivity. Generally, wind erosion is a problem especially in semiarid and arid areas, and it is a major cause of soil degradation in arid and semiarid areas world-wide.

The countries in the study most affected by wind erosion problems are Australia and USA and to some extent New Zealand. Some wind erosion problems have also been reported from the other countries, but are not discussed in this report.

During the past 100 years, farming has changed substantially, especially in industrialised countries, from cultivation with draught animals (e.g. horses) to the use of sophisticated technology. These changes have also led to less diversified cropping systems, and an increase in the cultivation of single crops (monocropping) and uniformity of landscape, i.e. large, coherent units of farm operations. This loss of diversity, which included crop rotations, has resulted in substantial increases in soil erosion losses in many parts of the world.

6.2 Australia

Land clearing for agricultural and other uses is generally regarded to be one of the major factors leading to increased soil erosion problems in Australia. Since the European settlement, almost 70 % (90 % in the south and south-east) of the native vegetation has been removed or significantly modified. Land clearing is still occurring at relatively rapid rates throughout Australia's main agricultural areas (Figure 11), and total land clearing is still occurring at a rate of more than 400 000 ha/year (Table 17).

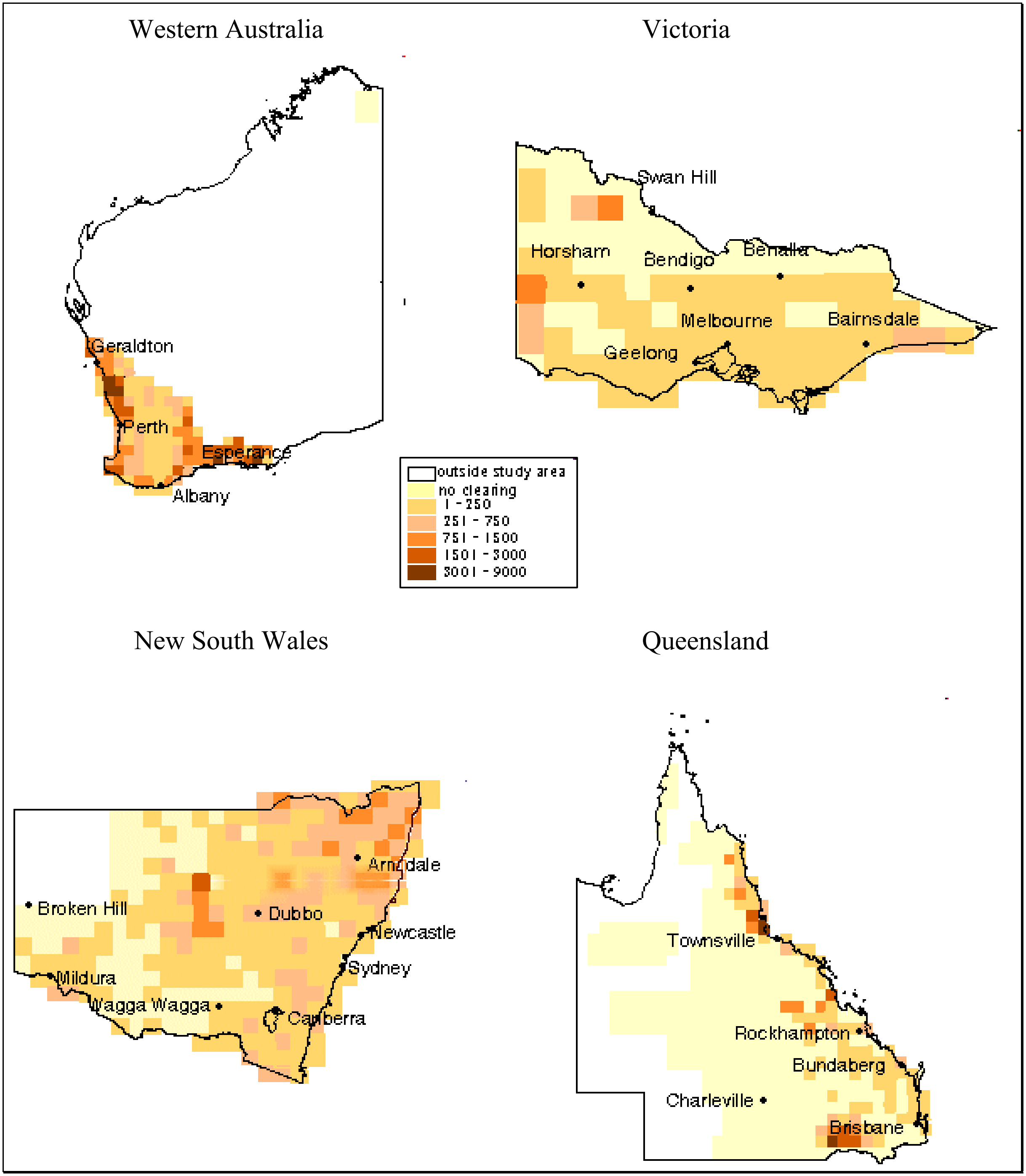


Figure 11. Decrease in area of woody vegetation due to clearing (number of hectares cleared in each 277 000-hectare region) for cropping in Western Australia, Victoria, New South Wales and Queensland. Source: Bureau of Rural Sciences.

Table 17. Rates of land clearing in Australia by state (ha/year). Source: National Greenhouse Gas Inventory 1997.

State	Period	
	1987 - 88	1991 - 95
New South Wales	150 000	150 000
Victoria	10 438	1 828
Queensland	500 000	*262 000
West Australia*	31 908	8 000
South Australia	4 471	**
Tasmania	6 000	4 000
North Territory	16 280	**
TOTAL	719 097	425 828

* Updated - Qld Dept of Natural Resources, State-wide Landcover and Trees Study, Oct 1997
** SA and NT report negligible land clearing

Data on soil erosion rates are not available for Australia as a whole, and the vast size of the Australian continent would make such data very coarse and of limited value in this study. The focus in this study has therefore been on the state of Western Australia, and on the Murray-Darling Basin area (parts of South Australia, Victoria, New South Wales, and Queensland).

Western Australia

Current data on soil erosion rates are not available for Western Australia. However, some previous measurements suggest that approximately 750 000 ha of the state's area is affected by soil erosion (Western Australia Department of Environmental Protection, 1998). According to more recent findings these figures significantly underestimate the area affected by soil erosion by water, but no research has apparently been done to quantify these problems. The largest pressures leading to erosion are agricultural practices, which increase the exposure and vulnerability of soils. These pressures include the removal of protective vegetative cover through grazing, cultivation, compaction and chemical changes to the soil, such as salinisation or increased water repellence.

The Murray-Darling Basin

The Murray-Darling is Australia's largest river system. It drains parts of the states of Queensland, New South Wales, Victoria and South Australia, and it is the most important area of Australia in terms of agricultural production and natural resources in general. Due to its importance for Australia, an initiative on the Murray-Darling Basin was launched in 1987, and this has become the worlds largest integrated catchment program.

The topography within the Murray-Darling Basin is generally relatively flat, resulting in extremely low gradients for the rivers in the basin, and low runoff from most of the catchment area. Thus, 86 % of the catchment area contributes virtually no runoff to the river systems, except during floods. The largest contributions to runoff are supplied from the catchments draining the Great Dividing Range to the south-east and south.

The relatively rapid rates and continuous land clearing (Table 17) after European settlement has led to great changes in land use in Australia in general, and the Murray-Darling Basin area has been the location of some of the most extensive and dramatic changes in vegetation cover in the country. The major ones being the clearing of eucalyptus woodland and shrubland in the drier areas and their replacement by crops and pastures, notably in what has long been known as the wheat-sheep belt that stretches from south-east Queensland through New South Wales and northern Victoria into South Australia. Grazing lands currently occupy the largest areas in the basin (Table 18). The largest soil erosion problems within the basin are found along the Great Dividing Range, where rainfall is relatively high and the topography is steep (Figure 12).

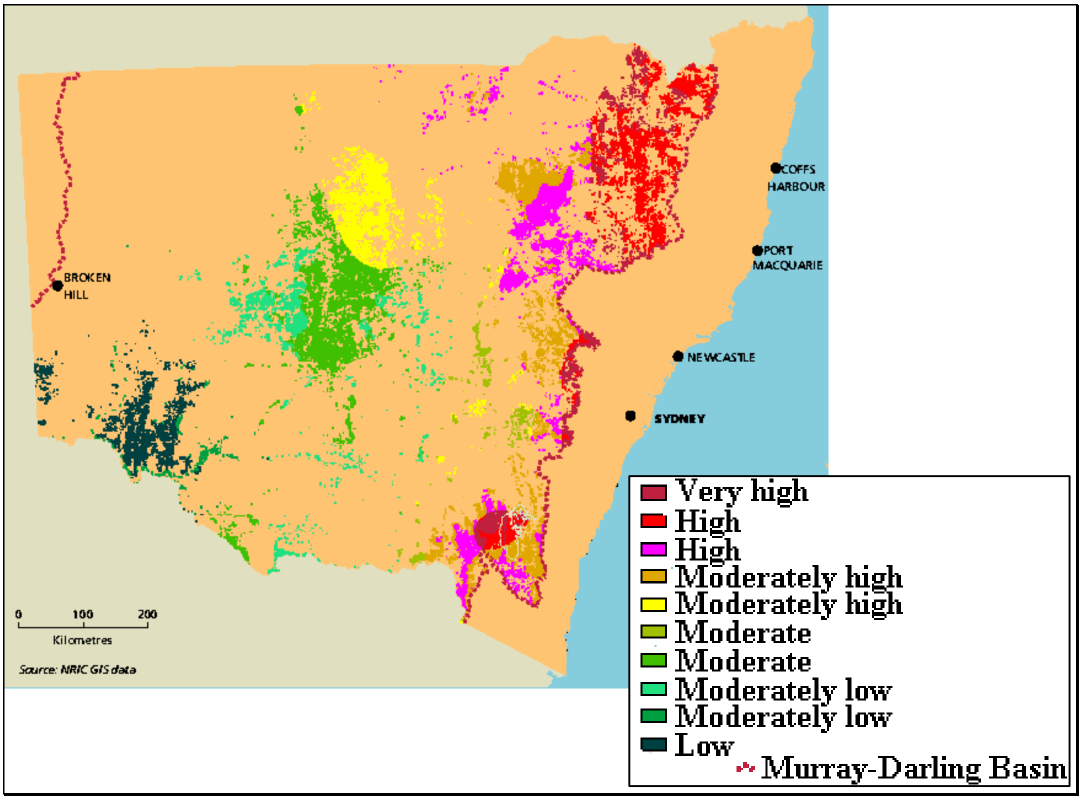


Figure 12. Water erosion risk map for south-eastern Australia. The Murray-Darling Basin is delineated with the dotted red lines. Source: Rosewell and Edwards, 1988.

Victoria is one of the most productive agricultural areas in Australia, and produces 15 % of Australia's grains, mainly cereals (wheat, barley and oats), pulses and oilseeds. These crops are grown in rotations on 4.5 million hectares of the state, shown as "broadacre cropping areas" on the map in Figure 13. Water erosion from cropland in Victoria is estimated to affect 1 million ha (Figure 13 and Figure 14), most of this area is within the Basin. Another 4.8 million ha (about 5 %) of grazing land is affected and most of this is also within the Basin.

In New South Wales 15 million ha of cultivation land and 16.3 million ha of grazing land (14 % and 15 %, respectively) are subject to water and wind erosion. The Office of the Commissioner for the Environment has estimated the annual erosion rates (in tons per hectare) for different land uses in New South Wales as:

Pasture	0.3
Winter-cropping	1.5
Summer-pasture	8.1

However, these estimates are very coarse and are only intended to give an indication of the relative erosion rates between different land use practices.

Table 18. Major land uses in the Murray-Darling Basin. Source: Department of Resources and Energy, Canberra.

Land use	Approx, area (million ha)	Percentage of total area
Unused	8.8	8.3
Conservation purposes	1.9	1.8
Forests	3.3	3.1
Grazing:		
- arid	22.9	21.7
- monsoon	26.4	25.0
- semi-arid	18.8	17.8
- sub-humid	15.3	14.5
- humid	3.4	3.2

- total grazing	86.8	82.1
Crops	4.6	4.4
Urban	0.2	0.2
Total	105.6	100.0

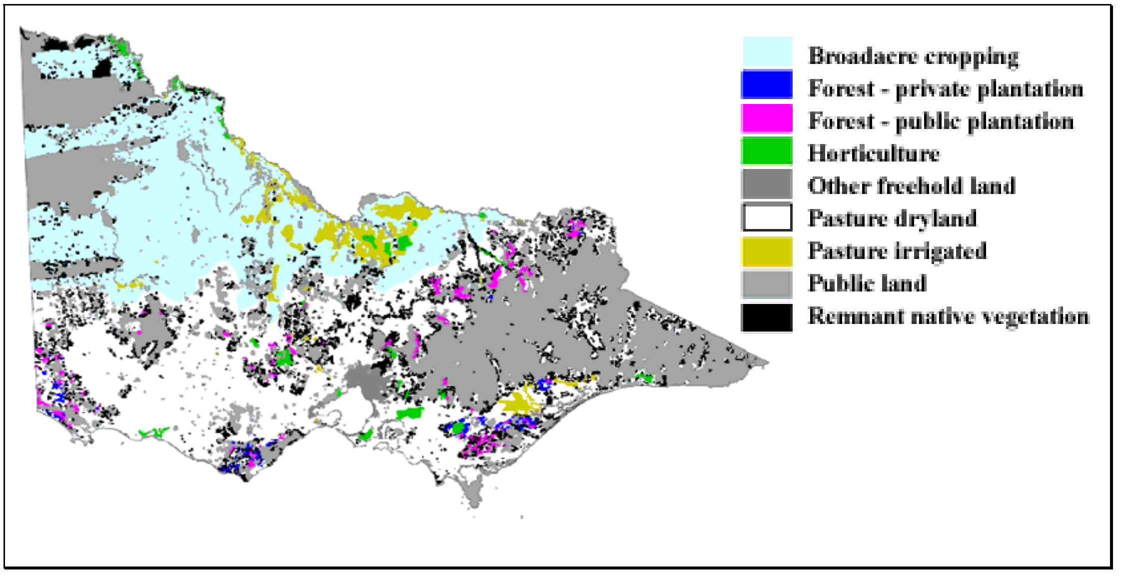


Figure 13. General land use in the state of Victoria. Source: Victoria Department of Natural Resources and Environment.

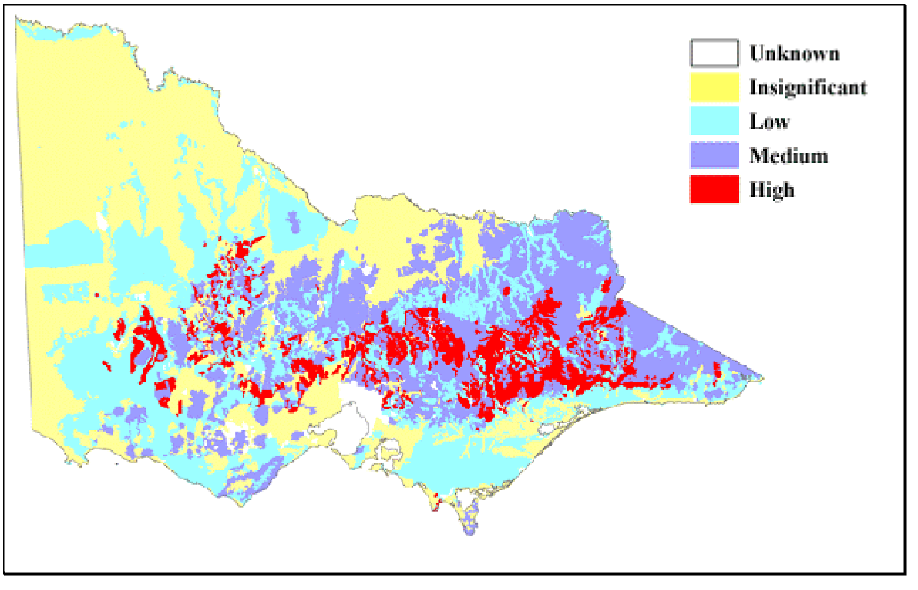


Figure 14. Susceptibility to water erosion in the state of Victoria. Source: Victoria Department of Natural Resources and Environment.

Parts of South Australia, Victoria, New South Wales, and Queensland are quite seriously affected by wind erosion (Figure 15).

The Murray-Darling Basin area experiences serious wind erosion problems, particularly in the drier areas with predominantly sandy soils. The problems in the basin are largely caused by overgrazing, frequent cultivation, and leaving the land fallow. The drier parts of the basin include many of the grain growing areas, the wheat-sheep belt, such as the light sandy and loamy soils on the Central and South-Western Slopes of New South Wales, the Mallee lands in western Victoria and adjoining areas of South Australia and New South Wales, as well as the arid and semi-arid rangelands of western New South Wales and Queensland. In Victoria, an estimated 2.6 million ha (2.5 % of the basin) of cropland is potentially subject to wind erosion, while in New South Wales, grazing lands are mainly affected with the total area at risk being 21.3 million ha (20 % of the basin). Figure 15 shows areas that are susceptible to erosion by wind in the state of Victoria.

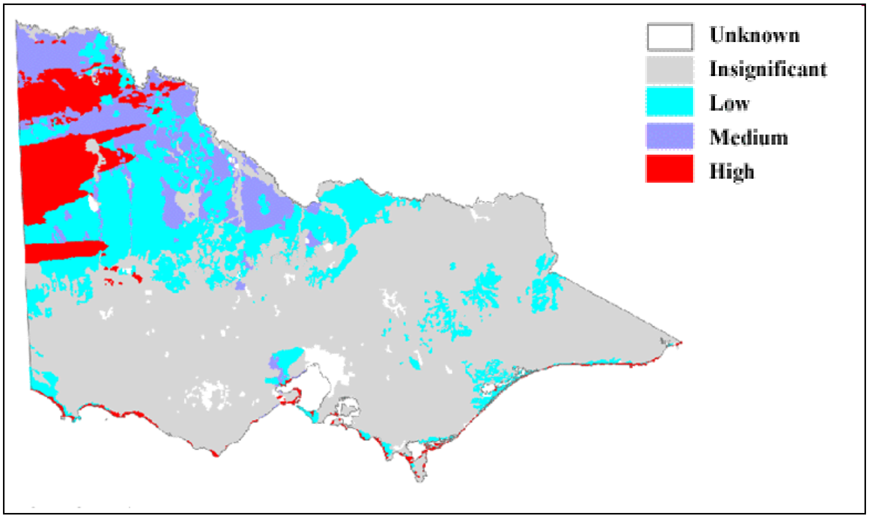


Figure 15. Susceptibility to wind erosion in the state of Victoria. Source: Victoria Department of Natural Resources and Environment.

6.3 New Zealand

Soil erosion is a problem in large parts of New Zealand because of deforestation and steep topography. It is estimated that 5.5 million ha currently under pasture (about 40 % of total pasture) are unsustainable in their present land use (Eyles 1993, Maclaren 1996). Eyles (1983) has estimated the extent of erosion in New Zealand (Table 19).

Table 19. Estimates of per cent area affected by soil erosion in New Zealand. Source: Eyles (1993).

Erosion type	North Island	South Island	New Zealand
Sheet	18.6	55.0	39.0
Wind	4.6	19.0	12.0
Total surface erosion	23.3	74.0	52.0

Average rates of soil erosion are not known for New Zealand. However, a recent survey of the extent of soil erosion, reported by the Ministry of the Environment (1998), indicates that 68 % of the farmland is erodible, and that severe to extreme erosion affects nearly 10 % of the country. The distribution of the main forms of erosion reported in New Zealand is illustrated in Figure 16.

The main cause of the soil erosion problems seen in parts of New Zealand today is the conversion of areas under indigenous forest to pasture that occurred at the end of the 1800's. Once started, the weak bedrock and extreme precipitation resulted in very high gully development rates. Soil and water conservation practices have been applied to approximately two thirds of the agricultural areas on the North Island, but the extent of such practices is not known on a national scale. Surveys have also indicated that most of the measures implemented are rather inefficient, and that about 55 % of the erodible agricultural areas of the North Island are not receiving adequate treatment, resulting in severe soil erosion in some areas.

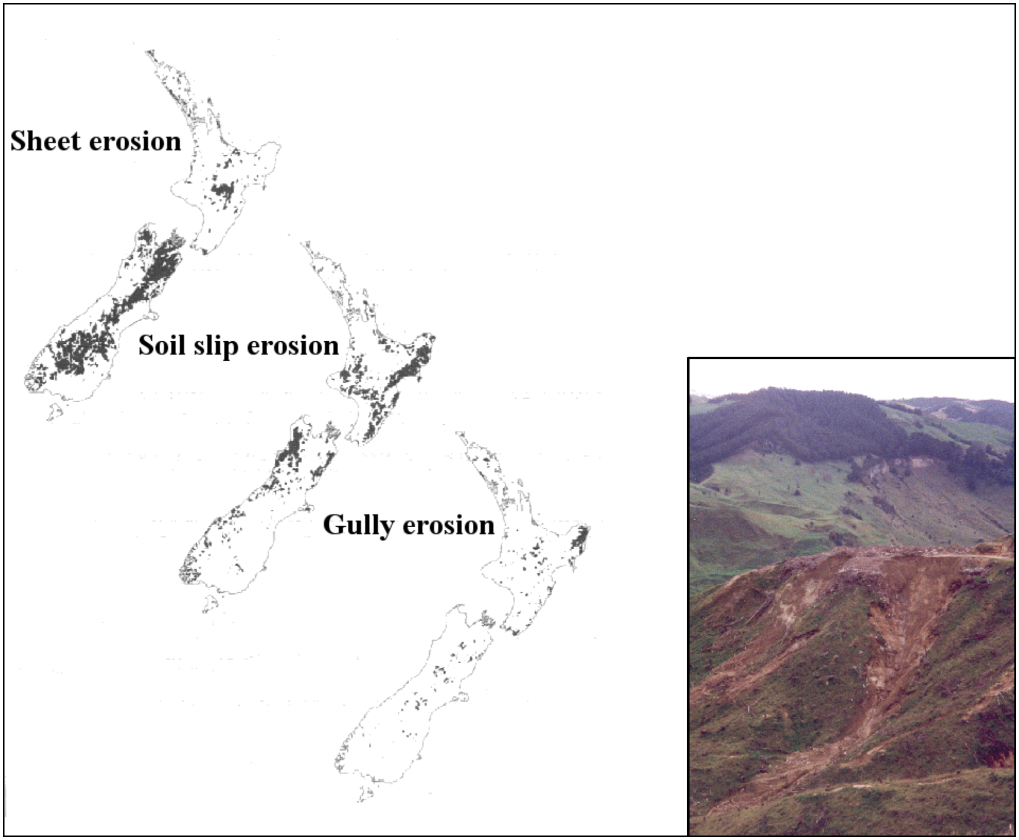


Figure 16. Geographical distribution of the main types of soil erosion in New Zealand. The picture shows an example of soil slip (landslide) erosion in Mohaka forest. Source: New Zealand Land Resource Inventory 1975-79 (Landcare Research).

6.4 USA

Water erosion

Soil erosion has long been considered as a great soil quality problem in USA. As an example, Iowa State has lost half (15 to 20 cm) of the original topsoil during the last 100 years of cultivation.

USA is by far the most advanced country in the world with regards to soil erosion research and documentation. Data series are available for the past 20 to 30 years, while for several others of the countries included in the study such data is hardly available at all. Estimates of water and wind erosion in USA (Table 20) indicate that both the extent of highly erodible cropland and the rates of erosion have decreased from 1982 to 1992. Nearly 30 % of the croplands are considered to be highly erodible. Highly erodible cropland areas are often typical of the corn and soybean region, in the wheat region, but also in other areas, e.g. the cotton areas.

Table 20. Estimates of extension and rates of water erosion (USLE) and wind erosion (WEC) in USA. Source: USDA.

	1982			1992		
	% of cropland	Tons/ha		% of cropland	Tons/ha	
		USLE	WEC		USLE	WEC
Cropland (excluding conservation program)	100.0	10.1	8.4	100.0	7.7	5.9
Highly erodible Cropland	29.7	18.8	16.6	27.6	14.3	12.8
Cultivated	24.6	21.7	19.8	21.7	17.1	16.3
Non-Cultivated	5.1	4.9	2.0	5.9	4.2	1.0
Non-Higly erodible Cropland	70.3	6.4	4.9	72.4	5.2	3.5
Cultivated	62.4	6.9	5.4	63.4	5.9	3.7
Non-Cultivated	7.9	1.0	0.2	9.0	1.0	0.2

Average annual rates of sheet and rill erosion (in tons per ha) from different land uses are estimated at (USDA, 1992):

Grazed forest land	10.4
Forest land	3.0
Rangeland	7.7
Pastureland, including native pasture	6.4
Cultivated cropland	12.6
All cropland	11.8

Due to the vast size of the country, soil erosion data for USA as a whole become very coarse and of limited value in assessment e.g. the effects of agricultural development on soil erosion during the past decades. However, on a national scale such aggregated data can be of use as an overview of areas affected by soil erosion problems (Figure 17).

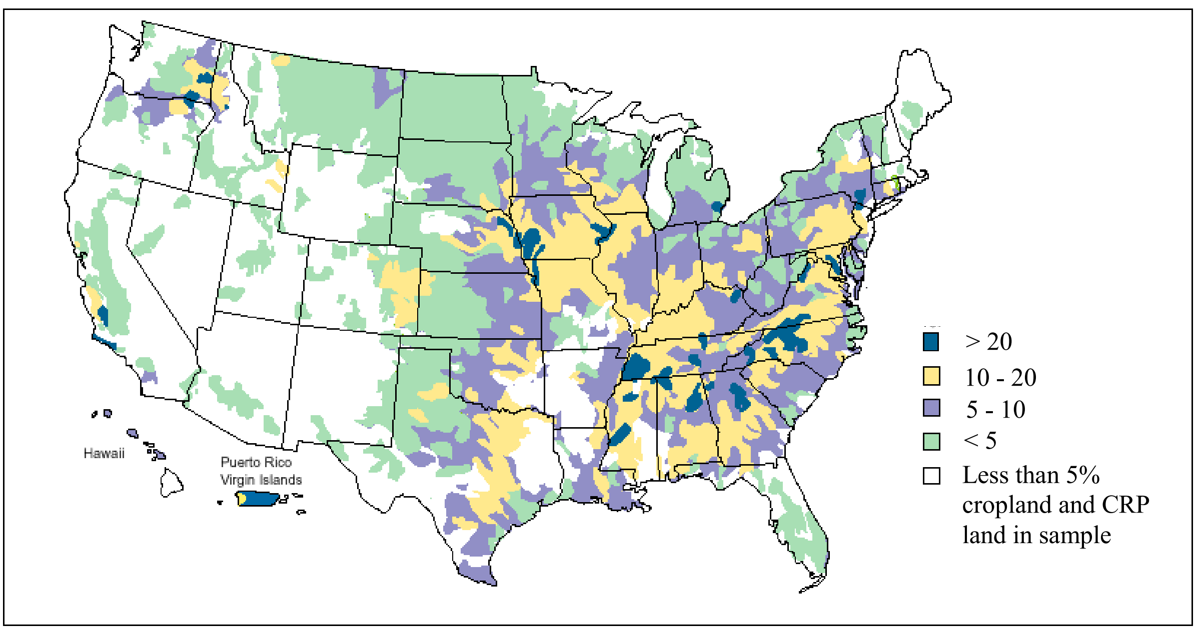


Figure 17. Average annual soil erosion by water (tons/ha/year) on cropland and Conservation Reserve Program land, 1992. Source: USDA.

Wind erosion

Wind erosion in USA is most widespread on agricultural land in the Great Plains states. It is normally calculated based on the Wind Erosion Equation (WEQ) model, which has been designed to predict long-term average annual soil losses. Results are normally expressed in tons/acre/year, but have been recalculated here to tons/ha/year (Figure 19).

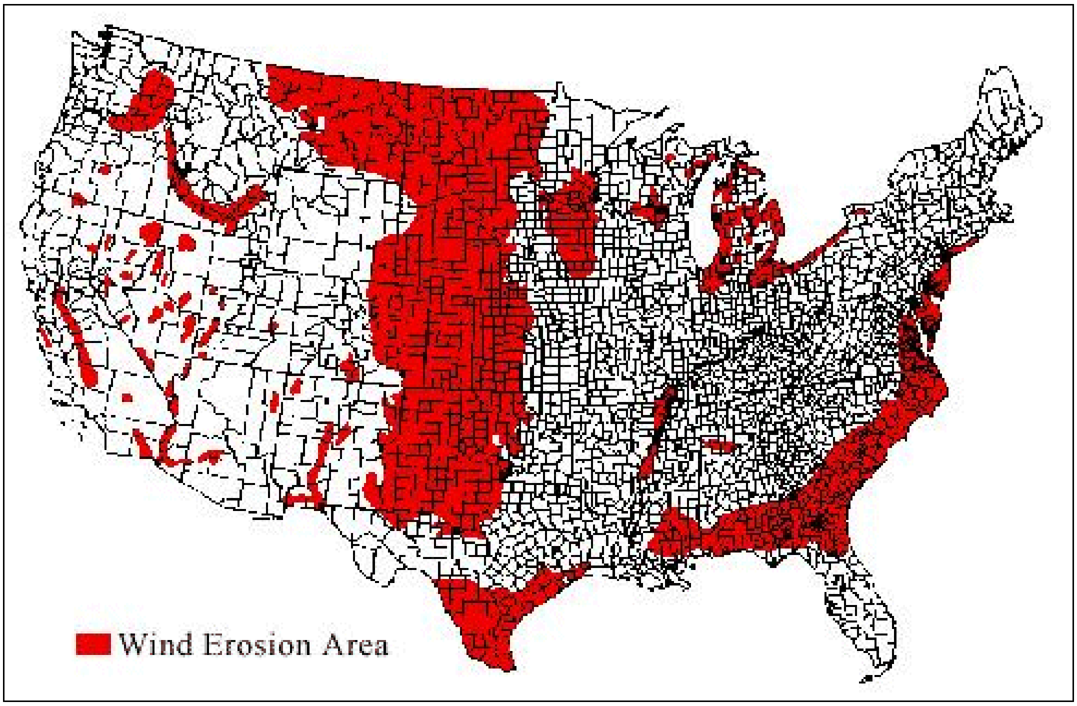


Figure 18. Map showing areas affected by wind erosion in USA. Source: USDA.

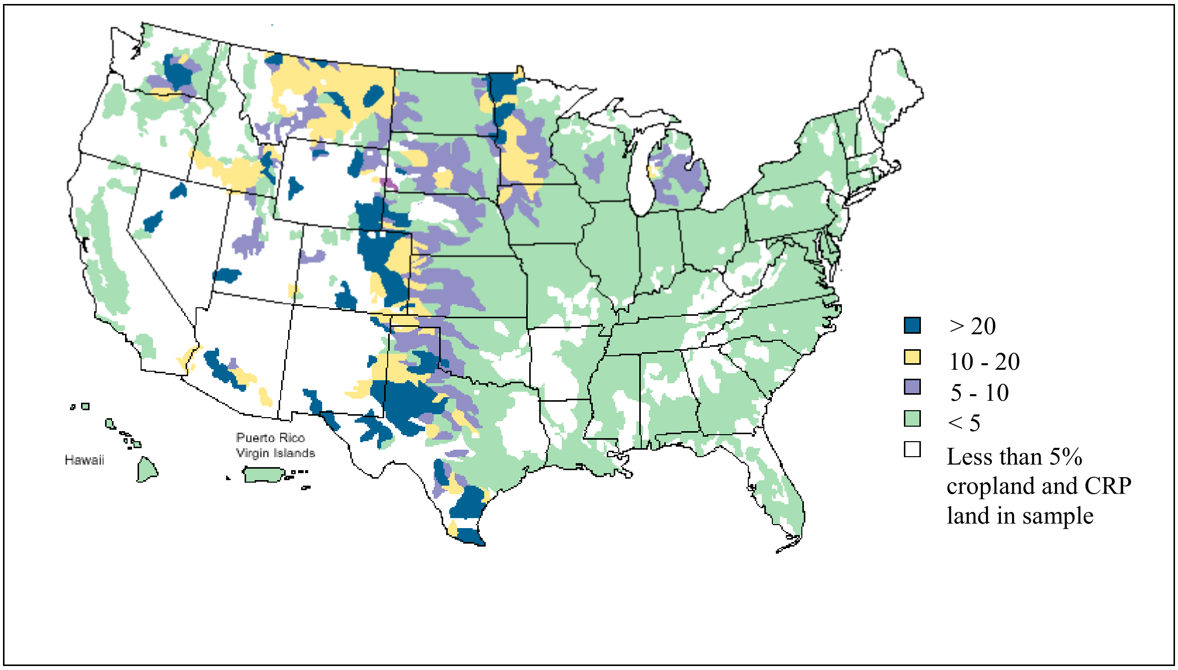


Figure 19. Average annual soil erosion by wind (tons/ha/year) on cropland and Conservation Reserve Program land, 1992. Source: USDA.

6.5 Japan

Due to the high annual rainfall and steep topography of Japan, water control is very important to prevent major floods and serious soil erosion. Thus, the focus in Japan has been on flood-control, rather than soil erosion as such. Since paddy fields can temporarily store a lot of water, they have generally been regarded to be effective in controlling floods, and soil erosion is virtually non-existent or very low in well-established paddy fields. During the past decade, increasing concern has mounted in Japan due to trade liberalisation, which has had strong impacts on Japanese agriculture. One such impact is the increasing abandonment of arable fields, which has occurred since the 1980s (NIAES, 1996). The area of rice terraces on slopes steeper than 1/20 was 419 000 ha in 1983 and has decreased to 363 000 ha in 1994 due to abandonment. This again has led to the deterioration of paddy fields in some areas, including deterioration of embankments and consequently increased soil erosion.

6.6 Norway

Most of the erosion in Norway occurs in autumn, winter and spring, in periods with heavy rain, snow melting and freezing/thawing. Occasionally, very intensive summer showers may cause erosion if they occur before complete coverage of the plant canopy. Only small areas are affected by wind erosion.

Sheet erosion by water is calculated for some areas dominated by cereal production by means of soil map units and the USLE calibrated to Norwegian weather conditions (Table 21). The annual mean potential sheet erosion is estimated at 1.8 tons/ha[2].

Subsidies are granted to avoid tillage in the autumn. The higher the erosion risk, the higher the support rate per hectare. As a consequence, stubble fields constitute a larger share of the high and very high risk areas than of the low and moderate risk areas. The actual sheet erosion is calculated at 1.2 tons per hectare and year as a mean value for the cereal areas.

The results from the Agricultural Environmental Monitoring Programme indicate that about 1.2 tons erosion materials, including rill and gully erosion material, is transported from cereal areas to streams on an annual basis. Because of sedimentation of eroded material on the land surface, the total average erosion rate in cereal areas is larger, probably 2-3 tons per hectare. For meadow and permanent grassland, which constitute about 60 % of the agricultural land, the erosion risk is almost negligible because of relatively high organic matter contents and protection of the vegetation cover. As a consequence, about 70 % of the agricultural area are assumed to have an average annual erosion of less than 1 ton per ha, about 20 % between 1 and 5 tons and about 10 % more than 5 tons per ha.

[2] Potential erosion is the erosion calculated provided autumn ploughing and no specific erosion control practice.

Table 21. Calculated sheet erosion by water in Norway, based on data from Norwegian Institute of Land Inventory and reports form the Ministry of Agriculture.

Land use	Erosion risk	% of area	Potential erosion (tons/ ha/year) Class interval	Potential erosion (tons/ ha/year) Mean	Tillage system (% of cereal area) Autumn tillage	Tillage system (% of cereal area) Stubble	Actual erosion, (tons/ ha/year)
Cereals and other cash crops	All	40		1.8	69	31	1.2
	Low	9	<0.5	0.3	87	13	0.3
	Moderate	22	0.5-2	0.9	72	28	0.7
	High	7	2-8	3.8	47	53	2.2
	Very high	2	>8	10.4	43	57	5.6
Grassland	Low	60		<0.5			<0.5

6.7 Conclusion

The comparison between the countries studied is complicated because of few available data on soil erosion for other countries than USA. From Japan and Switzerland comparable data on erosion rates have not been available for this study. A summary of the reported extent and rates of erosion in Australia, New Zealand, USA and Norway is presented in Table 22. A considerable part of the agricultural land is affected by water erosion in all these countries. In Norway only cropland is affected, while in the NE-countries also a substantial part of the pasture is reported to be erosive. The reported data for cropland indicate the highest mean water erosion rates in USA and no significant differences between Australia and Norway.

Wind erosion makes up a problem in all the NE-countries included in the study, but affects only minor areas in Norway.

As a whole, the NE-countries seem to be more affected by soil erosion than Norway. The contrast is greatest on pasture where erosion is almost negligible in Norway.

Table 22. Summary of extent and rates of erosion.

	% of agricultural land subject to erosion		Annual mean erosion, tons/ha	
	Cropland	Pasture	Cropland	Pasture
Australia				
Victoria	20	5	n.a.*	n.a.
New South Wales	14	15	1.5	0.3-8
New Zealand	n.a.	50-70	n.a.	n.a.
USA	27-30	n.a.	8-12	6
Norway	15-25	<1	2	<0.5

* n.a. = no data available

7 WATER RESOURCES

7.1 Water withdrawals

The availability of water is a substantial limiting factor for the health and welfare of the global population. In order to meet the demand from the growing world population, there will be pressure to use more water to produce food. Therefore, there is an increasing attention on water withdrawals and the efficiency of water use in agriculture.

In accordance to Aeuckens (1998), as much as 70 % of the water used in Australia is used for irrigated agriculture. Even though only 4 % of the pasture areas are irrigated, pasture constitutes 57 % of the irrigated areas. Of the areas used for cereals, which constitute 15 % of the irrigated area, 2 % are irrigated. It is fundamental to the long-term future of Australia's irrigated agricultural industry that water recourses are managed in an ecologically sustainable manner.

According to the Ministry of Agriculture and Forestry in New Zealand, agricultural use of water is estimated of about 350 million cubic metres for livestock farming, and more than one billion cubic metres for irrigation of pasture and agricultural and horticultural crops. Irrigation comprises around 57 % of all withdrawals and livestock around 18 %. A total of 257 000 ha agricultural land (165 000 ha pasture, 65 000 ha arable land and 27 000 ha horticultural land) is annually irrigated, which constitutes about 1.7 % of the total agricultural area. Although water used in agriculture is only a small part of the 300 billion cubic metres of water available annually, the combined agricultural, urban and industry use can place pressure on particular groundwater aquifers and surface water resources during summer low flows and/or drought periods.

Land use change from relatively extensive sheep and cattle farming systems to dairy farming is likely to lead to substantial increases in water use in New Zealand. The intensification of farming is leading to increasing demands for irrigation water, for example in the Northland region, and this may lead to a conflict in the use of water.

In USA, agriculture is by far the biggest water consumer, largely due to an expansion in the area of irrigated crops (USDA 1998). USA as a whole has adequate water supplies, but an abundance of water in the aggregate belies increasingly limited supplies in many areas. Irrigated cropland is an important part of the US agricultural sector, contributing about 40 % of the total value of crops on just 15 % of the total cropland harvested. Most irrigation water withdrawals occur in the arid western states where irrigated production is concentrated. Combined irrigation withdrawals in the four largest withdrawal states (California, Idaho, Colorado and Montana) exceeded nearly half of total US irrigation withdrawals in 1990.

Irrigated agriculture affects water quality in several ways including higher chemical-use rates associated with irrigated crop production, increased field salinity and erosion from applied water, accelerated pollutant transport with drainage flows, degradation due to increased deep percolation to saline formations, and greater in-stream pollution concentration due to reduced flows. Surface return flows and drainage from irrigation are main sources of water pollution in rivers, lakes, streams and estuaries nation-wide. According to recent estimates, irrigated cropland in the West accounts for 89 % of quality-impaired river mileage and irrigated agriculture accounts for more than 40 % of the pollution in lakes with impaired water quality (USDA 1998).

In Japan irrigation has a long history. Existing irrigation facilities were developed some hundred years ago. Rice cultivation is the major use of the irrigation facilities (Nakasima 1998).

According to FAO there are large methodological discrepancies between countries in the compilation of information about water resources. There is generally a need to distinguish between internally renewable water resources (IRWR) and total renewable water resources (TRWR). IRWR is the part of a country's water resources which is generated from endogenous precipitation. It is computed by summing surface water flow and groundwater recharge and subtracting their common part. TRWR is computed by summing IRWR and external flow, and is a measure of the maximum theoretical amount of water available to a country without any technical, economic or environmental considerations.

Table 23. Annual internally renewable water resources, annual withdrawals and sectoral withdrawals in the countries studied. Source: World Resource Institute.

	Annual IRWR (1995)	Annual withdrawals	Sectoral withdrawals (%, 1987)	Agricultural withdrawals

Cate-gory	Country	Total km^3	Per capita m^3	Year	km^3	%	Do-mestic	Indus-try	Agri-culture	in % of total resources
	Australia	343	18596	1985	15	4	65	2	33	1,3
NEC	New Zealand	327	88859	1991	2	1	46	10	44	0,4
	USA	2459	8983	1990	467	19	13	45	42	8,0
	Japan	547	4344	1990	91	17	17	33	50	8,5
NIC	Norway	384	87691	1985	2	1	20	72	8	0,1
	Switzerland	43	5802	1991	1	3	23	73	4	0,1

Annual internally renewable water resources and withdrawals for the selected countries, reported by World Resource Institute (1999) are presented in Table 23. New Zealand and Norway have the highest amounts of water resources per capita and the lowest annual withdrawal in per cent of total resources. USA and Japan have the highest annual withdrawals, both total and agricultural. Norway and Switzerland have distinctly lower annual withdrawals for agricultural consumption than the other countries. The national report for water resources from Australia indicates that the withdrawals for agriculture may be too low for this country.

7.2 Crop water requirement

In the early 1970's, FAO developed a practical procedure to estimate crop water requirements, which has become a widely accepted standard, in particular for irrigation studies. However, this procedure has been modified a number of times due to advances in research. A consultation of experts organised by FAO in 1990 recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculation of the various parameters. Revised procedures were therefore developed by FAO in cooperation with an international working group to estimate crop evapotranspiration based on the Penman-Monteith approach. These revised procedures are included in the CROPWAT model, which is used in this study for calculations of potential crop water requirements for selected parts of the 7 countries studied (Table 24). The model results are based on wheat cropping, and are intended to be used for comparisons of relative differences in precipitation, effective rain during the growing season, and crop water requirements. The selected climate stations generally fall within areas where wheat is a major agricultural crop. Sufficient climatological data to run the model was not available for Switzerland and New Zealand, and these countries are therefore not included in Table 24.

In Australia, wheat is grown in the winter period. Normal sowing dates are in May-June, and the sowing date was accordingly set to the 5th of June when calculating CWR. Fallowing is generally widely practised in Australian wheat production areas, meaning that the soil is kept bare of plant growth for about 8 – 10 months before the crop is sown. This practice is generally considered to conserve soil moisture and to accelerate mineralisation (and hence the availability) of soil nitrogen, and it has been reported to reduce the incidence of some cereal diseases by eliminating host weed species.

Table 24. Calculated crop water requirements (CWR) for wheat in selected parts of the study countries.

Country	State/ Province	Climate Station	Mean Annual Precipitation (mm)	Rain during cropping season (mm/period)	Crop water requirement (mm/period)
Australia	WA	Coolgardie	2678	97	234
	Victoria	Bendigo	549	244	244
	NSW	Naradhan	455	163	228
USA	Iowa	Des Moines	840	436	361
	Ohio	Columbus	933	395	458
	Kansas	Wichita	750	399	431
		Concordia	727	414	414
Japan		Maebashi	1147	685	342
		Asahikawa	1157	486	294
Norway		Ås	785	333	322
		Lillehammer	545	274	323

Rain during the cropping season can only be considered as an indicator of the plant available water. The true value should be the initial content of available water in the soil, plus the rain during the cropping season minus interception, evaporation and surface runoff.

Due to low temperatures during the cropping season the selected regions in Australia have the lowest calculated CWR for wheat, followed by Japan and Norway. USA has the highest CWR; most of the stations indicate higher CWR than 400 mm.

7.3 Water use efficiency

Water use efficiency in this context is defined as water requirement per kg unit yield. Calculations of water use efficiency are presented in Table 25. The calculation is based on arithmetical mean values for crop water requirement for the selected stations and the mean wheat yields for the countries. The calculated WUE is highest for Japan and Norway (lower values for water consumption). USA has the lowest efficiency due to high crop water requirement and low yield.

Table 25. Water use efficiency for wheat based on calculated values for water crop requirement and mean yield.

Country	Crop water requirement, mm	Mean wheat yield, kg/ha	Water use efficiency, tons water/kg yield
Australia	237	1.8	1.3
USA	416	2.6	1.6
Japan	318	3.4	0.9
Norway	322	4.5	0.7

7.4 Conclusion

Of the selected countries, New Zealand and Norway have the highest amounts of water resources per capita and the lowest withdrawal in per cent of total resources. USA and Japan have the highest withdrawals, both total and agricultural. Norway and Switzerland have the lowest annual withdrawals for agricultural consumption: only 0.1 % of the total water resources at disposal are used in agriculture.

Crop water requirement and water use efficiency are calculated for Australia, USA, Japan and Norway. Due to winter growing, Australia has the lowest crop water requirement for wheat. The water use efficiency, in which also the yield is taken into account, is highest for Japan and Norway and lowest for USA.

8 WATER QUALITY

8.1 General introduction

Agricultural production affects water quality through nitrate in surface water and groundwater, phosphorous in surface water, contamination with pesticides, sedimentation of aquatic environments and salinisation.

The assessment of water quality is largely impeded by two principal factors; the scarcity of nationally assembled reliable data, and the complexity in measuring water quality. This complexity depends on the following factors:

- Timing of the measurement: Periodically (e.g. at the beginning of a storm or after a storm) or continually?
- Location of the measurement: E.g. just below the water's surface or on the streambed?
- Sampling strategy (random sampling, point sampling with fixed intervals, volume proportional sampling).
- The length of time series: 3, 5, 10, 20 years?
- Measured parameters and indicators (concentrations or total quantities, biological, chemical and physical indicators).
- The source of the pollutant(s): E.g. point sources or diffuse sources, from farm fields or urban areas?

This complexity in measuring water quality leads to a variety of different measurement schemes which are often difficult to compare, thus leading to a set of data which is not compatible. However, some general things can be said about these issues, including the links between soil quality and water quality, and the effects of sediments and erosion on water quality.

Sediments are a result of soil erosion, and silt and other suspended solids from agricultural and non-agricultural sources are generally regarded to be the leading cause of impairment of rivers and streams, and a major cause for low visibility of lakes, reservoirs and estuaries. Sediments transport nutrients, pesticides, pathogens, and various toxic substances into surface waters.

Concern has been mounting about the increases in nitrogen losses from agricultural areas to the environment. A primary concern in this regard is the leaching of nitrate into groundwater, and potential effects on humans and ruminant animals. Nitrate is readily leachable in most soils, but the transport capacity of different soils vary substantially. Thus there is a high spatial variability in nitrate leaching to groundwater. The Environmental Protection Agency (EPA) has established a 10 mg/l (as nitrogen) standard as the maximum concentration of nitrate in drinking water. Nitrate losses can be reduced principally through improved fertiliser application techniques, and it is crucial that nitrogen fertilisers are applied in phase with crop demands and that realistic yield goals are set.

Phosphorus is another major pollutant when entering surface waters in substantial amounts, and it can accelerate eutrophicaton, leading to increased growth of algae and aquatic weeds. Although nitrogen and carbon are also associated with increased eutrophicaton, most attention has been focused on phosphorus. Unlike nitrate, phosphorus is strongly sorbed in the soil and losses are therefore generally related to soil erosion and sediment delivery to streams and lakes. Nonpoint sources of phosphorus include runoff from uncultivated land (soil erosion, animal excreta, plant residues), runoff from cultivated land (soil erosion, fertiliser loss, manure, plant residues, sewage sludge), runoff from urban areas (soil erosion, septic tanks, domestic waste), and atmospheric deposition (wet and dry deposition). In addition to runoff losses, some phosphorus is also lost by particulate transport through soil macropores.

8.2 Australia

8.2.1 Eutrophication and surface water quality

8.2.1.1 <u>Western Australia</u>

Eutrophication is mainly a problem in the south-western parts of Western Australia, where many estuaries and wetlands are nutrient enriched. The effects of eutrophicaton have generally increased since the 1970s, and include:

- Algal blooms in rivers and wetland systems, and a decline in water quality.
- Loss of important habitats and some ecosystem functions.

Quantitative data on rates and degrees of eutrophicaton (e.g. trends in nutrient concentrations) are limited and the processes behind the current eutrophicaton problems in the state are therefore poorly understood.

Another problem, which is leading to rapid declines in water quality in Western Australia, is salinisation. The problems related to salinisation occur in the same parts of the state as the eutrophicaton problems, and severely alter aquatic ecosystems and reduce biodiversity and the supply of potable water. Table 26 shows the proportion of catchment cleared and the salinity expressed as the concentration of total soluble salts (TSS) for representative rivers in WA. According to the classification of water in terms of salinity (Table 27), most of the rivers should be classified as moderately saline. Most rivers in the south-west have had lower salinity levels since 1990, compared to the preceding five years, largely due to higher rainfall. Reforestation has led to significant reductions in groundwater levels and in the amount of salt transported by streamflow in experimental catchments (Bell et al. 1987). Reductions have also been observed in the salt input to Wellington Reservoir following the reforestation of about 10 per cent of the total cleared land in the catchment (7000 ha in the highest salt-yielding portion of the catchment).

Table 26. Salinity in representative rivers for affected areas of the state of Western Australia. Source: Water and Rivers Commission.

	Proportion of Catchment Cleared (% in 1986)	Current Salinity (mg TSS/l)	Salinity increase since 1965 (mg TSS/l/y)
Frankland River	56	2760	74
Kent River	40	2087	58
Greenough River	50	4908	*
Blackwood River	85	1760	58
Collie River	24	790	24
Murray River	75	2260	93

* Insufficient data

Table 27. ***Classification of waters in terms of salinity.*** **Source: Rhoades et al. (1992).**

Type of water	Electrical conductivity (dS/m)	Total soluble salts (TTS) g/l	Water class
Drinking and irrigation water	<0.7	<0.5	Non-saline
Irrigation water	0.7±2.0	0.5±1.5	Slightly saline
Primary drainage water and groundwater	2.0±10.0	1.5±7.0	Moderately saline
Secondary drainage water and groundwater	10.0±20.5	7.0±15.0	Highly saline
Very saline groundwater	20.0±45.0	15.0±35.0	Very highly saline
Seawater	>45.0	>35.0	Brine

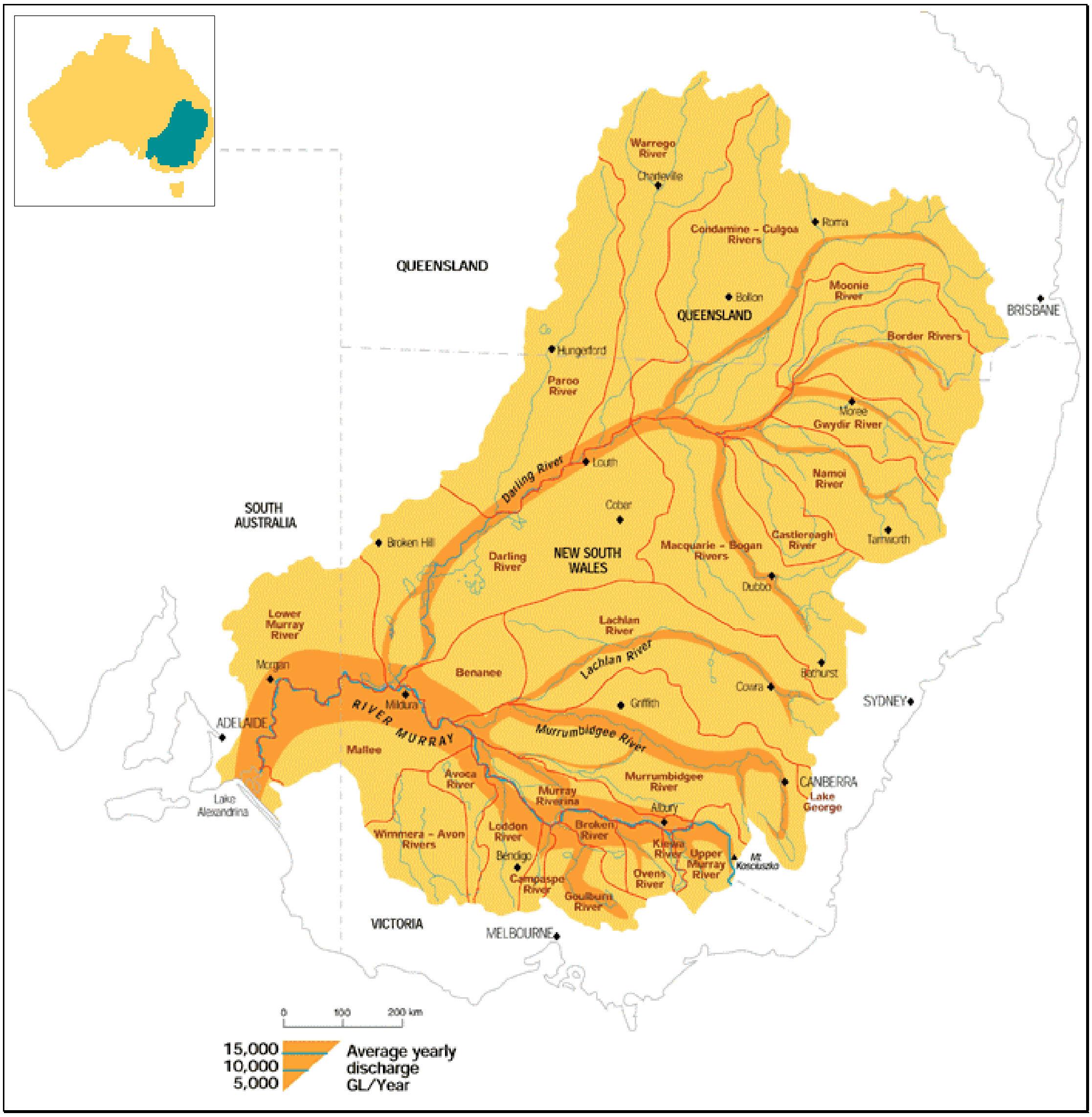


Figure 20. Major river catchments within the Murray-Darling Basin, and average yearly discharge. Source: Murray-Darling Basin Management Committee.

8.2.1.2 <u>The Murray-Darling Basin</u>

The Murray-Darling river has a mean annual discharge of 400 m^3/sec (about 13 billion m^3 per year), which is very low compared to other large rivers with similar catchment size (Table 29). Water quality in the Murray-Darling Basin area's rivers is highly variable, partly due to the low rates of streamflow and the fact that during periods with low flow, groundwater can make up a larger proportion of total flow to streams. Studies have indicated that the natural quality of the water in the basin area is not high, with naturally high turbidity levels. However, in parts of the catchment area, water quality deterioration as a consequence of human intervention has been significant, particularly in intensively farmed areas.

The Murray-Darling Basin is a naturally saline environment in terms of its soils, geology, surface water and groundwater, especially in the western parts of the catchment area. The most comprehensive information available on river water salinity is for the River Murray. There is a very marked downstream increase in salinity levels (Figure 21). In the South Australian sections of the river, relatively steady inflows of saline groundwater with salinity levels up to 50 000 mg/l TSS have been reported. These problems have been exacerbated during recent years due to rising groundwater tables and drainage flows from irrigation areas, and problems have also emerged in the extensive areas of dryland farming. Quite recent research indicates that salinity levels have increased significantly in numerous rivers of the basin (Allison and Schonfeldt, 1989).

Table 28. Total point and diffuse source nutrient inputs to streams in the Murray-Darling Basin. Source: GHD (1992)

Category	Nutrient Loads, tons per year					
	Dry Year		Average Year		Wet Year	
	Total P	Total N	Total P	Total N	Total P	Total N
Point sources	650	3 900	750	4 400	900	5 300
Diffuse sources	250	1 600	950	6 700	4 300	28 000
Ratio point/diffuse sources	2.6	2.4	0.8	0.7	0.2	0.2

In the state of Victoria alone, about 260 000 ha farming land is presently suffering significant damage from soil salinisation. Of this total, 140 000 ha are located in Victoria's northern irrigation districts and a further 120 000 ha of non-irrigated (dryland) grazing and cropping land throughout the state is also affected. The salinity problems are mainly caused by a clearing of more than half of all the deep-rooted native trees and shrubs that once grew in the State.

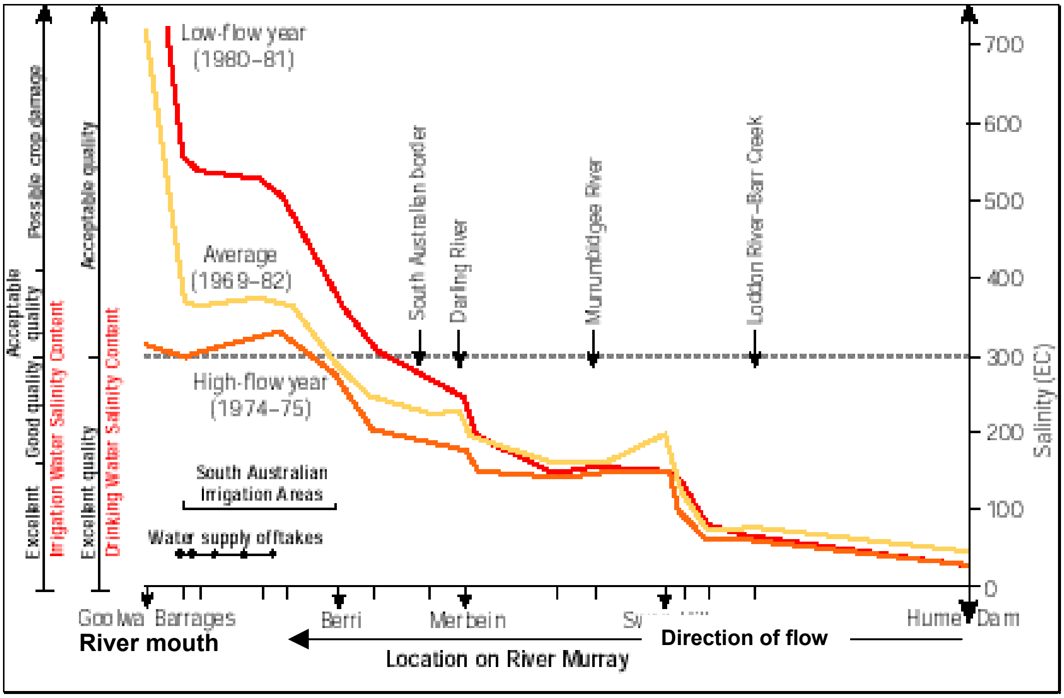


Figure 21. Salinity levels in the River Murray. Downstream towards left. Source: Murray-Darling Basin Management Committee.

Table 29. A selection of some of the worlds largest river systems which are comparable to the Murray-Darling in size. Source: Encyclopaedia Britannica

River system	Length (km)	Catchment area (km^2)	Mean annual discharge (m^3/sec)
Murray-Darling	3 780	1 057 000	400
Nelson (North America)	2 575	1 072 000	2000
Indus	2 900	1 166 000	5000
Danube	2 850	816 000	7000
Zambesi	3 500	1 330 000	7000

The contributions of different sources to eutrophicaton of rivers and streams within the MD Basin area vary between dry, average, and wet years (Table 28), with point sources as the dominant sources in dry years, while diffuse sources dominate during wet years. Overall, however, the diffuse sources are by far the most important.

The total annual load is estimated at 11 100 tons nitrogen and 1 700 tons phosphorous for an average year. Based on a mean annual discharge of 13 billion m^3, the mean concentration can be calculated to about 1 mg nitrogen/litre and 0.13 mg phosphorus/litre. Total phosphorus concentrations are high throughout much of the basin, particularly in New South Wales, largely due to soil erosion. Several reservoirs within the basin have had recent algal blooms, especially during periods of low flow, and it has been reported that reducing the potential for low flows greatly reduces the possibilities of algal blooms (Jones 1994).

8.2.2 Groundwater

8.2.2.1 <u>Western Australia</u>

Groundwater is a significant source of water supplies in Western Australia. The largest bodies of groundwater in the state are found in extensive deposits of sand or sandstone, which cover 40 % of Western Australia (Figure 22) and may be as much as 20 kilometres thick. The Canning Basin has the largest amount of stored groundwater. Quantitative data on groundwater pollution are limited for Western Australia, but studies have indicated potential environmental impacts for waterways and wetlands that receive groundwater flow, particularly in the coastal area between Geraldton and Augusta where more than 80 % of the population live.

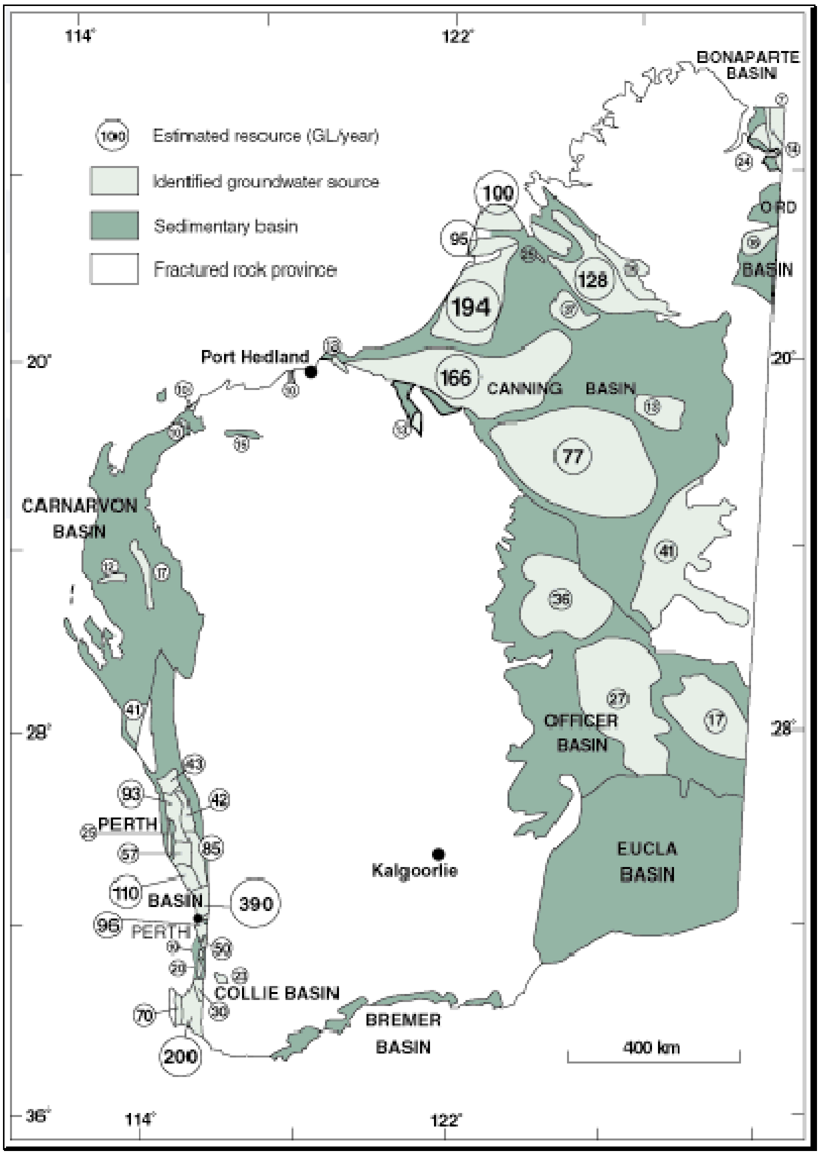


Figure 22. Location and estimated renewable yields (gigalitres/year of groundwater with Total Dissolved Salt (TDS) contents of less than 1500 mg/l) of major known groundwater sources in Western Australia. Source: Allen et al. (1992).

8.2.2.2 <u>The Murray-Darling Basin</u>

As already mentioned in previous sections, salinisation problems in the basin are largely groundwater-induced, due to rising groundwater tables. However, although the general trend in the basin seems to be that groundwater tables are rising, several parts of the basin also have had a lowering of the groundwater tables during the beginning of the 1990's (**Figure 23**). An important factor in these groundwater trends is climatic variations, and observations of rainfall records back to the 1940's suggest that conditions across central and eastern parts of the region have become significantly wetter. This at least in part can explain the increase in groundwater levels observed in some areas of the basin. It should be kept in mind that the measurements of groundwater trends in the basin are generally strongly biased by the nature of the groundwater monitoring program. For instance, the bulk of monitoring is sited in salinity affected areas. Further, most of the monitoring occurs where there is some degree of salinity treatment being practiced.

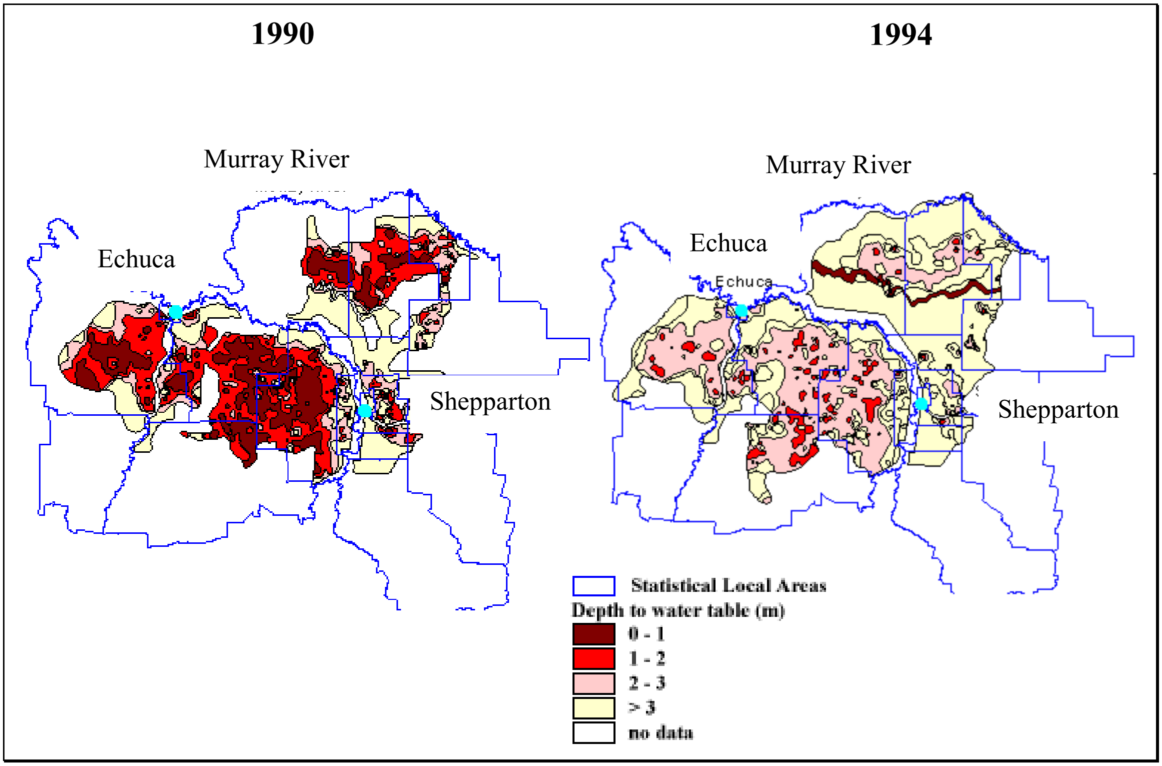


Figure 23. Depth to groundwater table in parts of the Murray-Darling Basin area in 1990 and 1994. Source: Victoria Department of Natural Resources.

8.3 New Zealand

Agriculture outranks other sources of pressure on water quality largely because of the scale of pastoral farming (Ministry of Environment 1998). Yearly nitrogen (in tons/year) loads to surface waters in New Zealand are estimated at (source: Cooper 1992):

Non-point sources	
Agriculture	100 000
Native forest	15 000
Exotic forest	7 000
Point sources	
Agriculture	7 000
Sewage/urban	2 400
Pulp and paper	800

The total load from agriculture is estimated at 107,000 tons N/year.

National water quality data are rather limited, despite the fact that water is the most monitored feature in the New Zealand environment. Several surveys have been reported, where local authorities have been asked to identify and rank the pressures on water quality locally. Pollution of surface waters from point sources has been reported to decrease significantly during the past years due to a general decrease in the number of point sources and improved waste treatment processes. In a review of data on the nutrient state of 177 lakes in New Zealand, Smith et al. (1993) concluded that at least 10 % of the lakes were eutrophic or hypertrophic. Most (>90 %) of the eutrophic lakes are on the North Island. The largest of the eutrophic lakes, Wairarapa on the North Island and Ellesmere on the South Island, both have predominantly agricultural catchments. The Ministry of Environment (1998) has presented the following values for nutrient concentrations in 77 monitored rivers in New Zealand (in mg/l):

	Median	**Range**
Dissolved reactive phosphorous	0.004	0.002-0.02
Nitrate-nitrogen(NO_3-N)	0.1	0.01-0.6
Ammoniacal nitrogen (NH_4-N)	0.009	0.003-0.015

Pastoral agriculture is the main source of pressure on water quality in New Zealand (Ministry of Agriculture and Forestry 1998). Data on nitrate concentration in groundwater is currently being updated and has not been available for this study.

8.4 USA

8.4.1 Eutrophication and surface water quality

Potential nitrogen fertiliser loss from farm fields is high in the corn and soybean area in the Mississippi Basin, along the cotton growing region and horticulture areas in the south and east, and in the intensive horticulture areas in California. The Mississippi River, with a catchment of more than 3 million km^2, carries an enormous amount of nitrogen into the Mexican Gulf.

Smith et al. (1993) conducted a study of water quality in the USA, using data from altogether 1400 monitoring stations throughout the country. From these 1400 stations, 313 to 424 (depending on the indicator used) stations met their criteria and were included in the analysis. The report presented monitored water quality data for each indicator by major land use (Appendix 1). Indicators included in the study were dissolved oxygen, fecal coliform bacteria, dissolved solids, dissolved nitrite plus nitrate, total phosphorous and suspended sediments. The data presented by Smith et al. (1993) on nitrate and phosphorus losses to surface waters are presented in Appendix 2 (Figure 30, Figure 31, Figure 32 and Figure 33) in this report. Trends in suspended sediments show the same development as for phosphorus during the period from 1982 to 1992.

Much of the geographic variation in yields of nitrate, total phosphorus, and suspended sediment results from differences in land use. For example, yields in the Ohio, Tennessee and Upper Mississippi regions are the result of extensive agricultural activity and relatively high population density. In agricultural areas, nitrate, total phosphorus, and suspended sediment yields were reported to be highest in areas under corn and soybean cultivation (Smith et al. 1993). Yields were lowest in areas under wheat cultivation and moderate to high in areas dominated by mixed agriculture (wheat, corn and soybeans). The differences in yield result from factors such as fertiliser composition and application rates, tillage practices, climate, and soil characteristics that have an influence on either nutrient and suspended sediment availability or on runoff.

Compared to nitrogen, a smaller proportion of phosphorus (originating mostly from livestock wastes or fertilisers) was lost from watersheds to streams. The annual amounts of total phosphorus and total nitrogen measured in agricultural streams were equivalent to less than 20 % of the phosphorus and less than 50 % of the nitrogen that were applied annually to the land. This is consistent with the general tendency of phosphorus to attach to soil particles and move with runoff to surface water (US Geological Survey 1999).

US Geological Survey (1999) has published the following background concentrations of nutrients in streams (in mg/l):

Total nitrogen	1.0
Nitrate N	0.6
Ammonia N	0.1
Total phosphorous	0.1

The samples are collected from undeveloped areas considered to be minimally affected by agriculture, urbanisation and associated land uses.

In a study reported by Mueller (1995), nitrate concentrations from agricultural, agricultural/ urban and urban sites were greater than 0.7 mg N/l in more than 50 % of the samples. The nitrate concentrations from these sites were not significantly different from each other, but were higher than concentrations from other sites. The phosphorous concentrations were greater than 0.1 mg/l in more than 50 % of the samples from agricultural, agricultural/urban and urban sites. The phosphorous concentrations exceeded 0.2 mg/l in less than 25 % of samples from agricultural sites, but in more then 50 % of samples from urban sites.

8.4.2 Groundwater

Nitrate contamination of groundwater occurs in patterns based on "input" factors (population density and nitrate contribution from fertiliser, manure, and atmospheric deposition) and "aquifer vulnerability" factors (soil drainage characteristic and woodland/cropland ratio in agricultural areas). Areas with high nitrogen inputs, well-drained soils, and low woodland to cropland ratios have the highest potential for contamination of groundwater. In Figure 24, a compilation of the patterns of risk for nitrate contamination is presented.

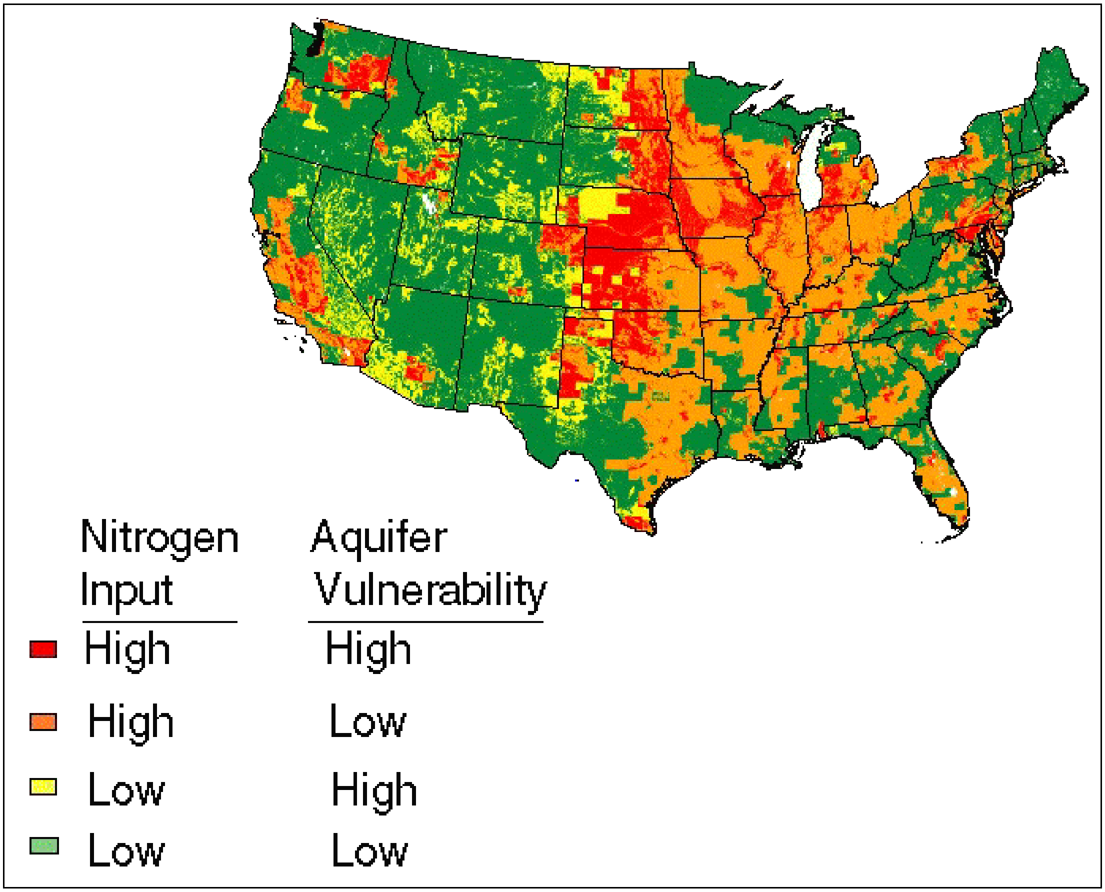


Figure 24. Risk for groundwater contamination from nitrate in the US. Source: Nolan et al. 1997.

Nitrate concentrations of shallow groundwater (<100 feet below the land surface) under different land use settings have been reported by Mueller et al. (1995). The results (presented in Table 30) show that the nitrate concentrations in groundwater beneath agricultural land were significantly higher than in samples from other land use settings, and they exceeded the USEPA drinking water standard of 10 milligrams per liter (as nitrogen) in 21 % of the samples.

Table 30. Nitrate concentrations in groundwater in USA beneath different land-use setting. Source: Mueller et al. (1995).

Land use setting	Number of wells	Nitrate concentration (as N)	
		Median (mg/l)	% of samples exceeding drinking water standard
Forest Land	625	0.1	3.0
Rangeland	224	1.5	8.5
Agricultural Land	2 012	3.4	21.2
Urban Land	454	1.8	7.0

8.5 Japan

No data for water quality for Japan has been available for this study. According to Nakasima (1998), irrigation for paddy-field rice cultivation has so far never caused salinity.

8.6 Norway

8.6.1 Eutrophication and surface water quality

The mean concentrations of nitrogen and phosphorous at the river mouth five major rivers in Southern Norway in 1997 are presented in Table 31. Although the rivers represent the most agriculturally intensive part of Norway, the share of agricultural area to total land area is low. As a consequence, the concentrations of nutrients are very low. As indicated in Figure 25, the nutrient concentrations in the five catchments are highly correlated with the share of agricultural area of the total catchment area.

Table 31. Mean concentrations (at the river mouth) of total nitrogen and total phosphorous in major rivers in Southern Norway in 1997. Source: Norwegian Institute of Water Research (1998).

	Total catchment area, km^2	% agricultural area	Concentration, mg/l		
			Total P	Total N	NO_3-N
Glomma	41918	5.8	0.020	0.58	0.39
Drammenselva	17034	3.6	0.005	0.45	0.29
Numedalslågen	5577	3.5	0.009	0.43	0.23
Skienselva	10772	1.9	0.005	0.32	0.20
Otra	3738	0.8	0.002	0.27	0.14

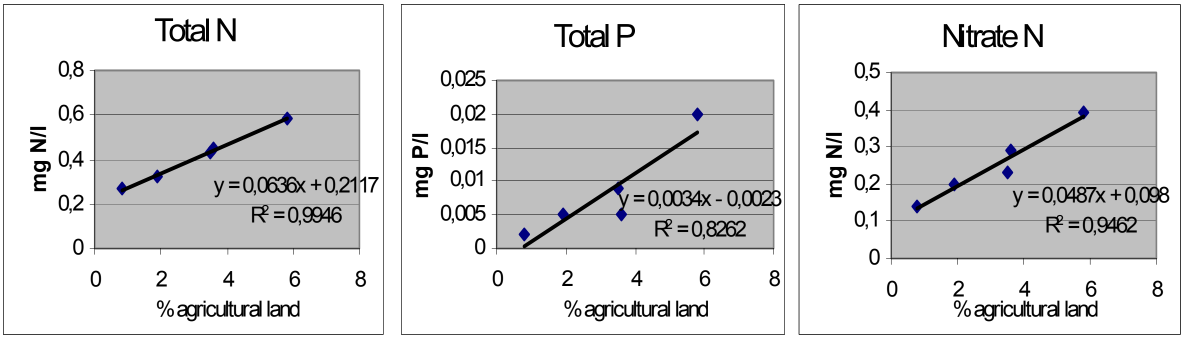


Figure 25. Correlations between % agricultural land in catchments and nutrient concentrations in rivers in Norway.

8.6.2 Groundwater

The mean concentration of nitrate-N in groundwater in 668 samples from areas affected by agriculture is 3 mg/l. Four per cent of the samples exceeded 11 mg NO_3-N/l, which is the maximum recommended level for drinking water. All of these samples were found in Solør on a location with well drained fluvial sand.

Table 32. Nitrate concentration of groundwater in areas affected by agriculture in Norway. Source: Compilation of data on groundwater quality in Norway, by Jens Kværner (personal communication).

Locality	Years	No. of samples	Mean conc. mg NO_3-N/l	Max. conc. mg NO_3-N/l	% of samples with NO_3-N> 11 mg/l
All		668	3	24	4
Solør	1980-92	264	4	24	14
Rena	1991-92	100	2	7	0
Ås	1986-92	68	1		0
Rakkestad	1986-87	64	2		0

Lindesnes	1981-87	7	1	2	0
Fana	1981-87	4	3	4	0
Overhalla- Trøndelag	1981-87	7	3	6	0
Jeløy	1975-82	9	3		0
Horten Tønsberg	1979-81	22	3		0
Moss- Rygge	1975-82	20	2		0
Stensengbekken	1973-79	103	5		0

Note: Most of the data series are old (10-20 years), but because of small changes in nitrogen fertilisation rates, small changes in NO_3-concentration of groundwater are expected.

8.7 Switzerland

The crucial problem for Swiss agriculture as far as water quality is concerned is the trend for increasing nitrogen contents of drinking water in crop growing areas. Nitrogen and phosphorous inputs in surface waters also have a certain ecological significance. In addition, herbicides have been found in groundwater, but a thorough assessment of the situation is not possible at the present stage. The nitrogen leaching from agricultural areas in Switzerland has been calculated at 37 000 tons nitrogen/year (24 kg/ha agricultural area) in 1994, of which 8 % to surface water and the rest to groundwater. As a result of an agricultural reform, the leaching is expected to be reduced to 23 000 tons in 2002.

Nitrate concentrations in major Swiss rivers have increased somewhat during the last decades, largely due to increased use of fertilisers and high livestock densities in some areas (Figure 26). The increases are particularly evident in intensively farmed areas. Phosphate concentrations in surface waters have decreased substantially in some rivers during the last 10 to 15 years (Figure 27). This is partly due to improved wastewater treatment systems, but probably mainly due to the ban on phosphate in textile detergents, which was imposed in 1986.

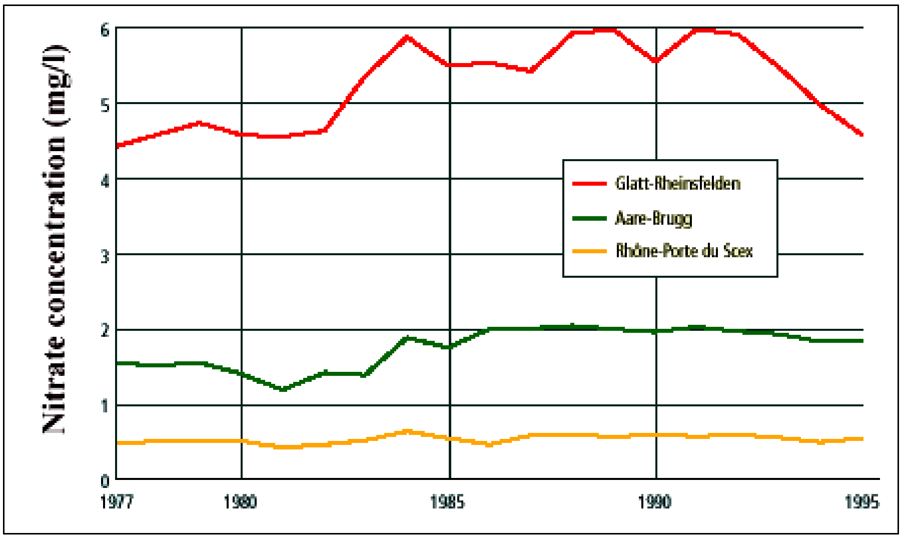


Figure 26. Nitrate concentrations in three major Swiss rivers. Source: Swiss Agency of the Environment, Forests and Landscape.

According to Pfefferli and Zimmermann (1998), the key issue associated with water quality in Switzerland is the nitrogen content of groundwater. Average values for groundwater of the gravel beds of the central region range between 20 and 35 mg NO_3/l. The maximum tolerated level of 40 mg NO_3/l is exceeded in some agricultural areas. Around 75 per cent of nitrate leaching into groundwater originates from soils used for agricultural purposes. For running water and groundwater the set target is 25 mg/l NO_3-N for nitrate.

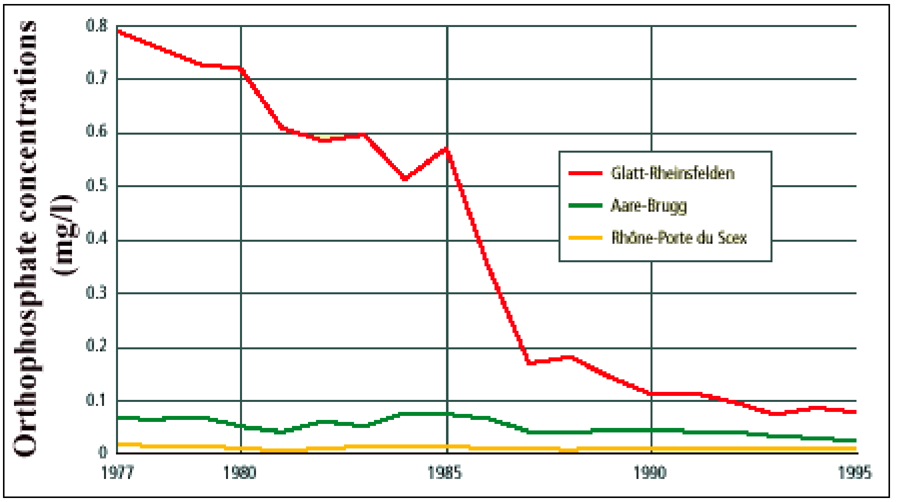


Figure 27. Orthophosphate concentrations in three major Swiss rivers. Source: Swiss Agency of the Environment, Forests and Landscape.

The severity of water pollution in Switzerland greatly depends on the population density in the catchment areas (Figure 28), as well as on land use in general. For the river Glatt, the ratio of population density to discharge quantity is six times that of the Swiss average. This results in a significantly higher phosphorous load than in other areas.

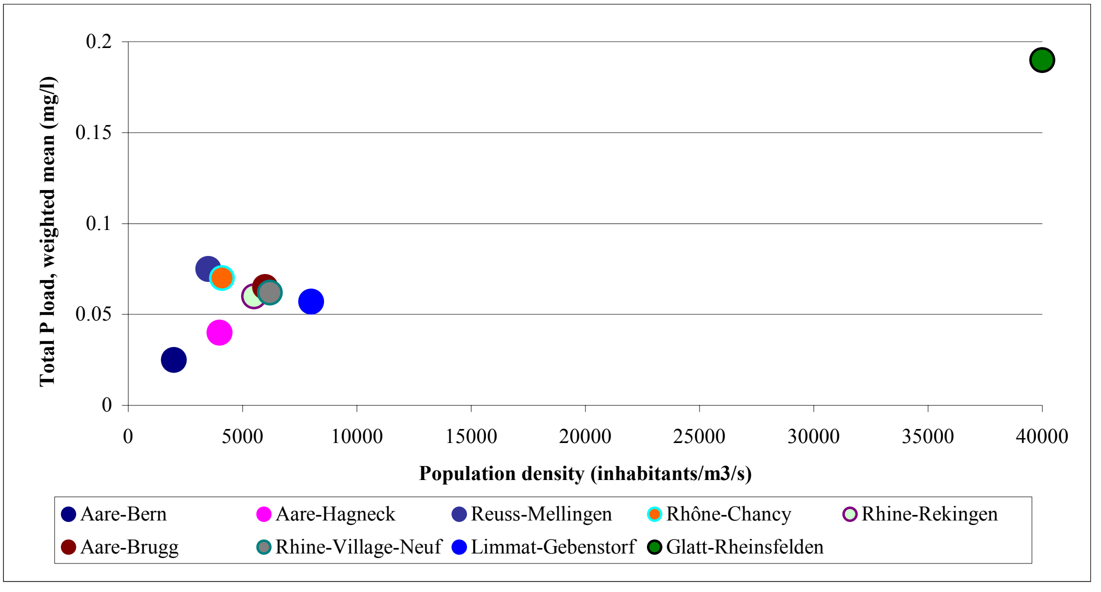


Figure 28. Total P load in major Swiss rivers. Source: Swiss Agency of the Environment, Forests and Landscape.

8.8 Conclusion

The shortage of water of good quality is becoming an important issue especially in the arid and semi-arid zones. For this reason the availability of water resources of marginal quality, such as drainage water and saline groundwater, has become an important concern. Salinisation is a major water quality problem in parts of Australia and USA, leading to a drastic deterioration of the quality of water supplies to urban areas and for livestock and domestic purposes. In addition to its effects on the quality of water supply, salinisation leads to a serious deterioration of soil quality and reduced yields. In Australia, the salinisation problems are largely caused by land clearing, which has altered the water balance, and irrigation and rising groundwater levels have brought the salt closer to the surface (Figure 29). Irrigation with saline water requires a comprehensive analysis even beyond the area where water is applied, and the problem should therefore be treated beyond the scope of the irrigation scheme, taking into consideration the groundwater and downstream surface water resources of the river basin.

Table 33. Summary of nutrient concentrations in streams.

Category	Country/region	Total nitrogen	Nitrogen as ammonia	Nitrogen as nitrate	Phosphorous
NEC	Australia Murray Darling	1			0.13
	New Zealand		0.01	0.01-0.6	0.002-0.02
	USA Background values Agricultural/urban (median)	1	0.1	0.6 0.7	0.1 0.1
NIC	Norway (agricultural areas)	0.3-0.6		0.15-0.4	0.002-0.02
	Switzerland			0.5-5	0.01-0.1

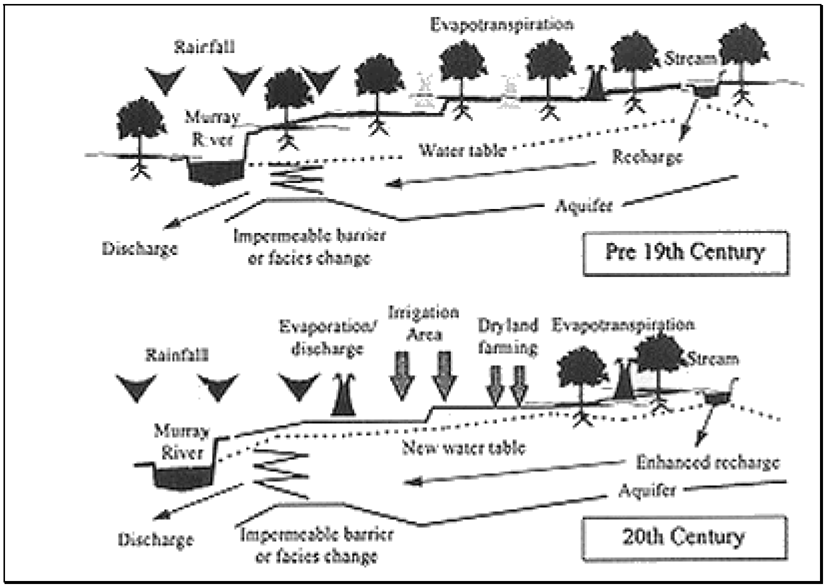


Figure 29. Impact of changes in vegetation (e.g. land clearing) and development of irrigation on groundwater tables.

The reported data indicate the following ranking for nutrient concentration in streams:

Nitrogen: Switzerland > Austalia ≈ USA > New Zealand ≈ Norway.

Phosphorous: Australia ≈ USA > Switzerland > New Zealand ≈ Norway.

In USA the reported background levels of nitrogen and phosphorous in streams minimally affected by agriculture are higher than the concentrations in streams in Norway representing the central agricultural areas.

Because of insufficiently harmonised data on nitrate concentration in groundwater, only a verbal comparison between the countries is meaningful:

- In New Zealand the pastoral agriculture is reported to represent a pressure on groundwater quality, but few data on nitrate content have been available for this study.
- The concentration of nitrate has exceeded 10 mg nitrogen in 21 % of the samples from shallow groundwater beneath agricultural land in USA.
- The maximum tolerated level of 50 mg NO_3/l (11mg N) is exceeded in 4 % of the samples from agricultural areas in Norway.
- About seventy-five per cent of the NO_3 leaching into groundwater in Switzerland originates from agriculture. The maximum tolerated level of 40 mg NO_3/l is exceeded in some agricultural areas.

The nitrate concentration of the groundwater beneath agricultural areas depends on the cultivation system, nitrogen surplus, water balance and soil properties. As a consequence, great variation within the countries is expected. The available data give no significant indications as to differences between the countries.

Because agriculture is the main source of nitrate to groundwater, it is expected that the NE-countries, which have a larger share of agricultural land to total land, have a larger part of groundwater resources influenced by nitrate leaching.

9 POSSIBLE ENVIRONMENTAL EFFECTS DUE TO LIBERALISATION OF FOOD TRADE

9.1 Conditions for beneficial effects of trade liberalisation

Agricultural production inevitably results in negative effects on the environment. In general, the global effects depend on the quantity of food produced and the total area needed or used to produce this food. Increased food production, or increased area of cultivation, is normally expected to cause some negative effects on soil and water, while corresponding decreases may reduce such effects. Thus, transfer of production from one country to another, e.g. due to trade liberalisation, might also be accompanied by a corresponding transfer of negative environmental effects. Whether there is a global positive or negative effect depends on the conditions of the two countries and the potential for expansion without negative environmental effects. The main success factors for expanding production without harmful effects on soil and water are:

- sufficient precipitation to cover crop demand, or sufficient water resources available for irrigation, or high water use efficiency
- low or moderate initial production intensity
- low share of agricultural land to total land area
- low population density
- available land resources suitable for expansion of agriculture
- tolerable levels of nutrients and pesticides in surface water and groundwater.

If a country does not meet one or more of these conditions, harmful effects of increased production are expected. One condition necessary for a net positive effect of trade liberalisation on soil and water is that the environmental improvement in the importing country due to reduced production is larger than the environmental deterioration in the exporting country due to expanded production.

In Table 34 to Table 37 indicators are used to describe environmental changes resulting from changes in agricultural production of the NE- and NI-countries. In general, if the indicators point to a less harmful environmental influence of agricultural production in a NE-country as compared to a NI-country, trade liberalisation is likely to result in a net environmental improvement. In the opposite case trade liberalisation may result in a net environmental deterioration.

9.2 Soil erosion

The differences in erosion risk between the NE-countries and NI-countries are presented in Table 34. The data on rates of water erosion of cropland indicate a larger erosion risk in USA than in Norway, but no significant differences between Norway and Australia. The indicators for water erosion in pastures and the indicators for wind erosion point to larger erosion risk in all of the NE-countries than in Norway. As a consequence, trade liberalisation resulting in reduced agricultural production in Norway and expanded production in the NE-countries is not likely to result in net reduced soil erosion. On the contrary, the indicators suggest that net increased erosion may be more likely.

Table 34. Differences in soil erosion risk between the NE-countries and the NI-countries.

Indicator	NI-countries with declined production	NE-countries with expanded production		
		Australia	New Zealand	USA
Extent of water erosion on cropland	Japan	n.a.*	n.a.	n.a.
	Norway	0	n.a.	0
	Switzerland	n.a.	n.a.	n.a.
Rates of water erosion on cropland	Japan	n.a.	n.a.	n.a.
	Norway	0	n.a.	-
	Switzerland	n.a.	n.a.	n.a.
Extent of water erosion on pasture	Japan	n.a.	n.a.	n.a.
	Norway	-	-	n.a.
	Switzerland	n.a.	n.a.	n.a.
Rates of water erosion on pasture	Japan	n.a.	n.a.	n.a.
	Norway	-	n.a.	-
	Switzerland	n.a.	n.a.	n.a.
Wind erosion	Japan	n.a.	n.a.	n.a.
	Norway	-	-	-
	Switzerland	n.a.	n.a.	n.a.

Explanation:
+ Better environmental state in the NE-country
- Poorer environmental state in the NE-country
0 No significant difference in the environmental state
*n.a. = no data available

9.3 Water resources

The differences in agricultural water withdrawals in per cent of total water resources and water use efficiency between the NE-countries and the NI-countries are presented in Table 35. Most of the differences indicate a poorer condition in the NE-country than in the NI-country. Japan has agricultural water withdrawals similar to USA but larger than Australia and New Zealand. On the other hand, the calculated water use efficiency is higher in Japan than in Australia and in USA. The data on water withdrawals and water use efficiency give no indication that a reduced production in a NI-country and an expanded production in a NE-country will result in less stress on water resources.

Table 35. Differences in agricultural water withdrawals and water use efficiency between the NE-countries and the NI-countries.

Indicator	NI-countries with declined production	NE-countries with expanded production		
		Australia	New Zealand	USA
Agricultural withdrawals in % of total water resources	Japan	+	+	0
	Norway	-	-	-
	Switzerland	-	-	-
Water use efficiency	Japan	-	n.a.*	-
	Norway	-	n.a.	-
	Switzerland	n.a.	n.a.	n.a.

Explanation:
+ Better environmental state in the NE-country
- Poorer environmental state in the NE-country
0 No significant difference in the environmental state
*n.a. = no data available

9.4 Water quality

The differences in indicators for water quality between the NE-countries and the NI-countries are presented in Table 36 and Table 37. Japan and Switzerland have a larger nitrogen surplus per total area than the NE-countries. The nutrient concentrations in surface water indicate better conditions in New Zealand than in Switzerland. Australia and USA seem to have a lower nitrogen concentration but a larger phosphorous concentration in surface water than Switzerland. None of the indicators for surface water quality point to better conditions in the NE-countries than in Norway. As a conclusion, the indicators suggest that a reduced production in Switzerland and an expanded production in New Zealand may possibly result in a net improvement of surface water quality, while the effect of an expansion in Australia and USA is more uncertain. A reduction of production in Norway and an expanded production in the NE-countries is not likely to result in a net improvement in surface water quality. Because of lack of data on nutrient concentrations in Japan, no conclusion can be drawn about possible effects on surface water quality due to changed production.

Table 36. Differences in indicators for surface water quality between the NE-countries and the NI-countries.

Indicator	NI-countries with declined production	NE-countries with expanded production		
		Australia	New Zealand	USA
Pesticides in surface water	Japan	n.a.*	n.a.	n.a.
	Norway	n.a.	n.a.	0
	Switzerland	n.a.	n.a.	n.a.
Nitrogen surplus per total area	Japan	+	+	+/0
	Norway	0/-	0	-
	Switzerland	+	+	0/+
Nitrogen concentrations in streams	Japan	n.a.	n.a.	n.a.
	Norway	-	0	-
	Switzerland	+	+	+
Phosphorous concentrations in streams	Japan	n.a.	n.a.	n.a.
	Norway	-	0	-
	Switzerland	-	+	-

Explanation:
+ Better environmental state in the NE-country - Poorer environmental state in the NE-country 0 No significant difference in the environmental state
*n.a. = no data available

Only a few conclusions about the groundwater quality can be drawn due to the lack of data. Compared to the NE-countries (Table 37), it cannot be ruled out that the higher nitrogen surplus in per cent of output in Japan is associated with denitrification and emission of N_2 gas as well as nitrate pollution of groundwater. The apparently lower nitrogen surplus in per cent of output in New Zealand may at least partly be explained by a possible underestimation of the nitrogen input, as suggested in 5.2 Nutrient balances. Comparable indicators for groundwater quality are only available for USA and Norway. These indicators do not suggest that a reduction of production in Norway and an expanding production in USA will result in a net improvement of groundwater quality.

Table 37. Differences in indicators for groundwater quality between the NE-countries and the NI-countries.

Indicator	NI-countries with declined production	NE-countries with expanded production		
		Australia	New Zealand	USA
Pesticides in groundwater	Japan	n.a.*	n.a.	n.a.
	Norway	n.a.	n.a.	0
	Switzerland	n.a.	n.a.	n.a.
Nitrogen surplus in % of output	Japan	+	+	+
	Norway	0	+	0/-
	Switzerland	0/-	+	-
Nitrogen concentrations in groundwater	Japan	n.a.	n.a.	n.a.
	Norway	n.a.	n.a.	-
	Switzerland	n.a.	n.a.	n.a.

Explanation:

+ Better environmental state in the NE-country

- Poorer environmental state in the NE-country

0 No significant difference in the environmental state

*n.a. = no data available

9.5 Conclusion and final comments

The indicators used in this study, pesticide and fertiliser use, soil erosion and water resources and water quality, may vary greatly within an individual country. A net environmental improvement is likely to be gained from a reduced production in a region in a NI-country with intensive production or high risk of erosion and water damage, and an expanded production in a region in a NE-country with less intensive initial production or less erosion and water damage. This may probably be the case even if the relevant soil and water resources are more stressed as a whole in the NE-country where production is expanded. However, if the average agri-environmental conditions in a NI-country are better than in a NE-country, it is more likely that a domestic transfer, from strongly stressed regions to less stressed regions within the NI-country, may lead to environmental improvements.

The indicators for erosion suggest that a trade liberalisation resulting in reduced agricultural production in Norway and expanded production in the NE-countries may result in net increased soil erosion. The water withdrawals and calculated water use efficiency indicate that a reduced production in the NI-countries and an expanded production in the NE-countries in most cases may result in more stress on water resources. The indicators suggest less significant differences in surface water and groundwater quality, and the effect of trade liberalisation is therefore more uncertain.

Because of the restricted availability of relevant data, the list of indicators is not complete for all the countries included in this study. Moreover, some of the indicators, e.g. for erosion and water quality, are based on data not standardised or harmonised between the countries. It should also be emphasised that indicators in general only give an indication as to the state of the environment, not a true environmental description. The conclusions in this report should therefore be considered as highly preliminary.

10 NEEDS FOR FURTHER RESEARCH AND ANALYSIS

A more complete assessment of the environmental impacts of agricultural trade liberalisation requires more research and analysis of data from statistics and environmental monitoring and survey. This study has revealed a lack of comparable data on pesticides, soil erosion and water quality. Further analysis should include the following aspects:

1. Pesticides

Total consumption of pesticides gives limited information on the environmental impact of pesticide use. Development and harmonisation of pesticide risk factors based on quantity, toxicity, persistence and mobility in soil should be given priority. Moreover, some crops, which require large pesticide applications because of high exposure to pests are not grown in all of the NI-countries. Comparison of pesticide use on specific crops should therefore be relevant, in particular those crops whose production is likely to be transferred as a consequence of trade liberalisation, e.g. cereals and fruits.

2. Soil erosion

Erosion data are sparse for countries other than USA. Analysis based on more relevant data from monitoring and survey of the extent and rates of water and wind erosion should be undertaken, and soil erosion models should be further developed and harmonised.

3. Water quality

There is a need for analysis of groundwater quality based on data from the monitoring of nitrate concentrations. The data series should be better harmonised regarding analysis and presentation (mean values, medians, percentiles, etc.).

4. Land resources

A condition for an environmentally successful transfer of agricultural production is access to agricultural land of high quality. More data of suitable land resources in the NE-countries, e.g. land with high productivity and low risk of erosion and salinisation, should be compiled.

5. International co-operation

A substantial restriction for this study has been the lack of available of data e.g. on pesticide use, fertilisation to specific crops, soil erosion and water quality in the individual countries. International co-operation could lead to better access to national data series.

11 REFERENCES

Allen A.D., Laws A.T., Commander D.P., (1992) A review of the major groundwater resources in Western Australia, Report to Kimberley Water Resources Development Office, December 1992.

Allison, G.B. & Schonfeldt, C.B. (1989): "Sustainability of water resources of the Murray-Darling Basin". 12th Invitation Symposium: Murray-Darling Basin - a resource to be managed. Preprint No. 8: 149-161. Australian Academy of Technological Sciences and Engineering, Melbourne.

Aspelin, A. L.1997: Pesticide Industry Sales And Usage. 1994 and 1995 Market Estimates. United States Environmental Protection Agency.

Auckens, V. and members of the Commonwealth Department of Primary Industries and Energy, Land and Water Resources Division, Camberra. 1998. A Strategic Framework for the Reform of Australia's Water Industry. OECD Workshop on the Sustainable Management of Water in Agriculture: Issues and Policies. The Athens Workshop.

Barbash, J. E. et al 1999: Distribution of Major Herbicides in Ground Water of the United States. U. S. Geological Survey Water-Resources Investigations Report 98-4245.

Bell, R. W., Loh, I. C. & Borg, H. (1987) The effect of non-valley reforestation on water quality and quantity in the Padbury Reservoir catchment and its regional implications. Report No. WS 24, Water Authority of WA: Perth, WA.

Bergman, L. and Pugh, D.M. (eds) 1994: Environmental Toxicology, Vol. 8. Kluwer Academic, Dordrecht.

Brouwer, F. and Crabtree, B. (ed.) 1999: Environmental Indicators and Agricultural Policy. CAB International, Wallingford, United Kingdom.

Cooper, A.B. 1992. Rural impacts on water resources. IIR Wastewater Management, Treatment and Technology Conference, Auckland. 19–20.

Ervin, D. 1997. Agriculture, Trade and the Environment: Anticipating the Policy Challenges. OECD General Distribution Document OECD/GD(97)171, Paris.

Eyles, G. O. 1983. The distribution and severity of present soil erosion in New Zealand. New Zealand Geographer 39 (1), 2-28.

Eyles, G. O. 1989. Making our land resources more sustainable. Forestry investment seminar, Flock House, 10 July 1993. Landcare Research, Palmerston North.

FAO 1999. Statistical Database. http://apps.fao.org/cgi-bin/nph-db.pl?subset=agriculture.

GHD (1992): An Investigation of Nutrient Pollution in the Murray-Darling River System. Gutteridge Haskins & Davey for the Murray-Darling Basin Commission, Canberra.

Goolsby, D.A., Thurman, E.M., and Kolpin, D.W. 1991. Geographic and temporal distribution of herbicides in surface waters of the upper midwestern United States, 1989-90, in Mallard, G.E., and Aronson, D.A., eds, U.S. Geological Survey toxic substances hydrology program--Proceedings of the technical meeting, Monterey, Calif., March 11-15, 1991: U.S. Geological Survey Water-Resources Investigations Report 91-4034, p. 183-188.

Jones, G. (1994): River flow and blue-green algal blooms. Seeking Solutions No.21. Division of Water Resources, CSIRO, Canberra.

Kellogg, R. L. et al. 1999. Trends in the Potential for Environmental Risk from Pesticide Loss from Farm Fields. Poster presentation, Chicago, Illinois.

Larson, S. J., Gilliom, R.J., and Capel, P.D., 1999, Pesticides in Streams of the United States--Initial Results from the National Water-Quality Assessment Program U.S. Geological Survey Water-Resources Investigations Report 98-4222, 92 p. At URL: http://water.wr.usgs.gov/pnsp/rep/wrir984222/

Maclaren, J. P, 1996. Environmental Effects of Planted Forest in New Zealand. Fri bulletin No. 198. New Zealand Forest research institute.

Mueller, D. K., Hamilton, P. A., Helsel, D. R., Hitt, K. J. And Ruddy, B. C. 1995. Nutrients in Ground Water and Surface Water in the Uniated States - An Analysis through 1992. U.S. Geological Survey. Water-Resources Investigations Report 95-4031.

New Zealand Ministry of Agriculture and Forestry, 1998. The Impact of Policy Reforms on Water Quantity and Quality Issues. OECD Workshop on the Sustainaable Management of Water in Agriculture: Issues and Policies. The Athens Workshop.

Holtan, G. Berge, D., Holtan, H. And Hopen, T. 1998. Oslo and Paris Commissions. (OSPAR). Annual report on direct and riverine inputs to Norwegian coastal waters during the year 1997. A. Principles, results and discussion. B. Data report.SFT Report 750/98. NIVA report O-90001/Serial no 3952-98. 101 p.

NIAES (1996). Annual Report 1996 of the Japanese National Institute of Agro-Environmental Sciences.

Nolan, B.T., Ruddy, B.C., Hitt, K.J., and Helsel, D.R. 1997. Risk of nitrate contamination in groundwaters of the United States--A national perspective: Environmental Science and Technology, v. 31, no. 8, pages 2229-2236.

OECD 1999. Domestic and International Environmental Impacts of Agricultural Trade Liberalisation. Joint Working Party of the Committee for Agriculture and the Environment Policy Committee. COM/AGR/CA/ENV/EPO(99)72.

OECD (2000 forthcoming) Environmental Indicators for Agriculture: Volume 3 -- Methods and Results".

Pfefferli, S. and Zimmermann, A. 1998. Swiss Agri-environmental Policy and Water Quality. OECD Workshop on the Sustainaable Management of Water in Agriculture: Issues and Policies. The Athens Workshop.

Pujol, JL and Dron, D. (1999). Agriculture, monde rural et envrionnement: qualité oblige. Report to the minister of Regional Planning and the EnvironmentForecasting and Strategy Unit. French Ministry for Regional Planning and the Environment.

Rhoades, J.D., Kandiah, A., Mashali, A.M. (1992). The use of saline waters for crop production. FAO Irrigation and Drainage Paper No. 48, Rome, 133 pp.

Rowland, Ph. et al 1997: The Environment and Food Quality. Australia: State of the Environment Technical Paper Series. State of the Environment Reporting. http://www.environment.gov.au/epcg/soe/soe_env/tech_papers/envfood.pdf

Smith, C.M., Wilcock R.J., Vant W.N., Smith D.G., and Cooper, A.B. 1993. Towards Sustainable Agriculture: Freshwater Quality in New Zealand and the Influence of Agriculture. (MAF Policy Technical paper 93/10.) Ministry of Agriculture and Fisheries: Wellington, New Zealand.

Smith, R., R. Alexander, and K. Lanfear. (1993). Stream water quality in the conterminous United Sates: Status and trends of selected indicators during the 1980s. *In* National Water Summary 1990-91: Hydrologic Events and Stream Water Quality. Water Supply Pap. 2400. U.S. Geo. Surv., Washington, DC.

URL: http://ca.water.usgs.gov/pnsp/rep/wrir984245/

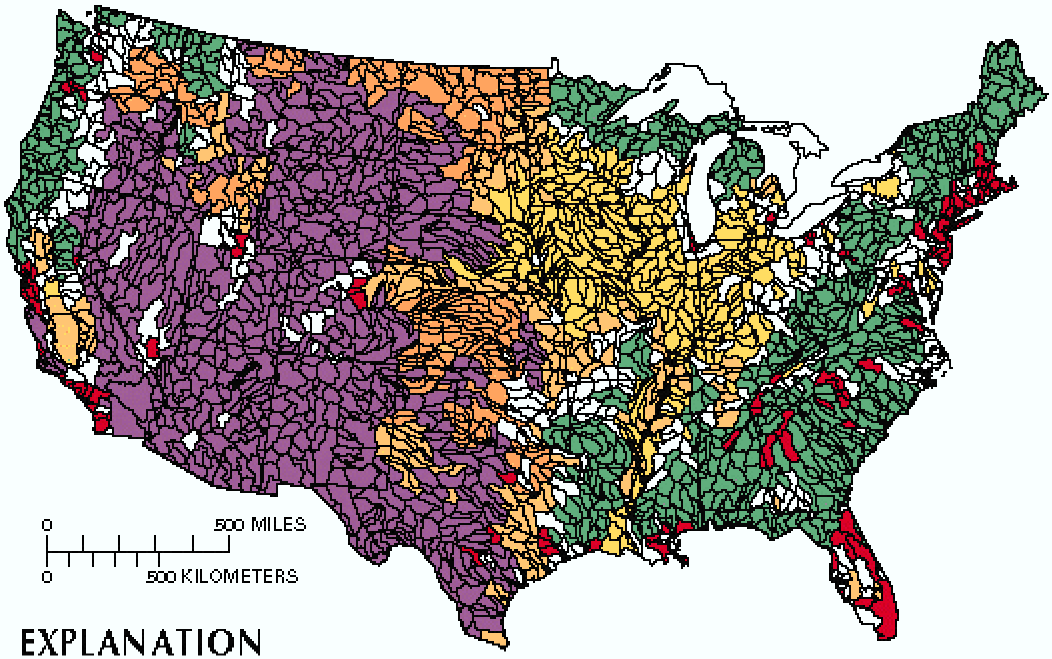
US Environmental Protection Agency: Methyl Bromide Use Background Document (Internet) http://www.epa.gov/spdpublc/mbr/background.html

Western Australia Department of Environmental Protection (1998). State of the Environment Report, Land, Erosion.
URL: http://www.environ.wa.gov.au/pubs/soe/soe16.htm

World Resource Institute 1999. World Resources 1998-99. Environmental change and human health. Environmental Data Tables, Chapter 12, Fresh Water.
URL: http://www.wri.org/wr-98-99/pdf/wr98_wa.pdf

12 APPENDIXES

12.1 Appendix 1. Land use classification for USA.



EXPLANATION

—— Boundary of hydrologic cataloging unit

LAND USE SHOWN ON MAP	CRITERIA FOR DETERMINING LAND USE (Land cover, in percent; crop type, in percent; population density, in persons per square mile; total water withdrawals for domestic use, in million gallons per day)
AGRICULTURE Wheat	Land cover: >40 crop and pasture, <40 forest, <10 urban. Crop type: >50 wheat, <20 corn and soybeans
Corn and soybeans	Land cover: >40 crop and pasture, <40 forest, <10 urban. Crop type: >50 corn and soybeans, <20 wheat
Mixed	Land cover: >40 crop and pasture, <40 forest, <10 urban. Crop type: <50 wheat and corn and soybeans
URBAN	Land cover: <30 crop and pasture. Population: >100. Total water withdrawals for domestic use: >6
FOREST	Land cover: >50 forest, <40 agriculture, <10 urban
RANGE	Land cover: >50 range and barren land, <40 agriculture, <40 forest, <10 urban
OTHER	All land cover not meeting any of the above criteria

Source: Smith et al. (1993).

12.2 Appendix 2. Nutrient concentration of stream water in USA.

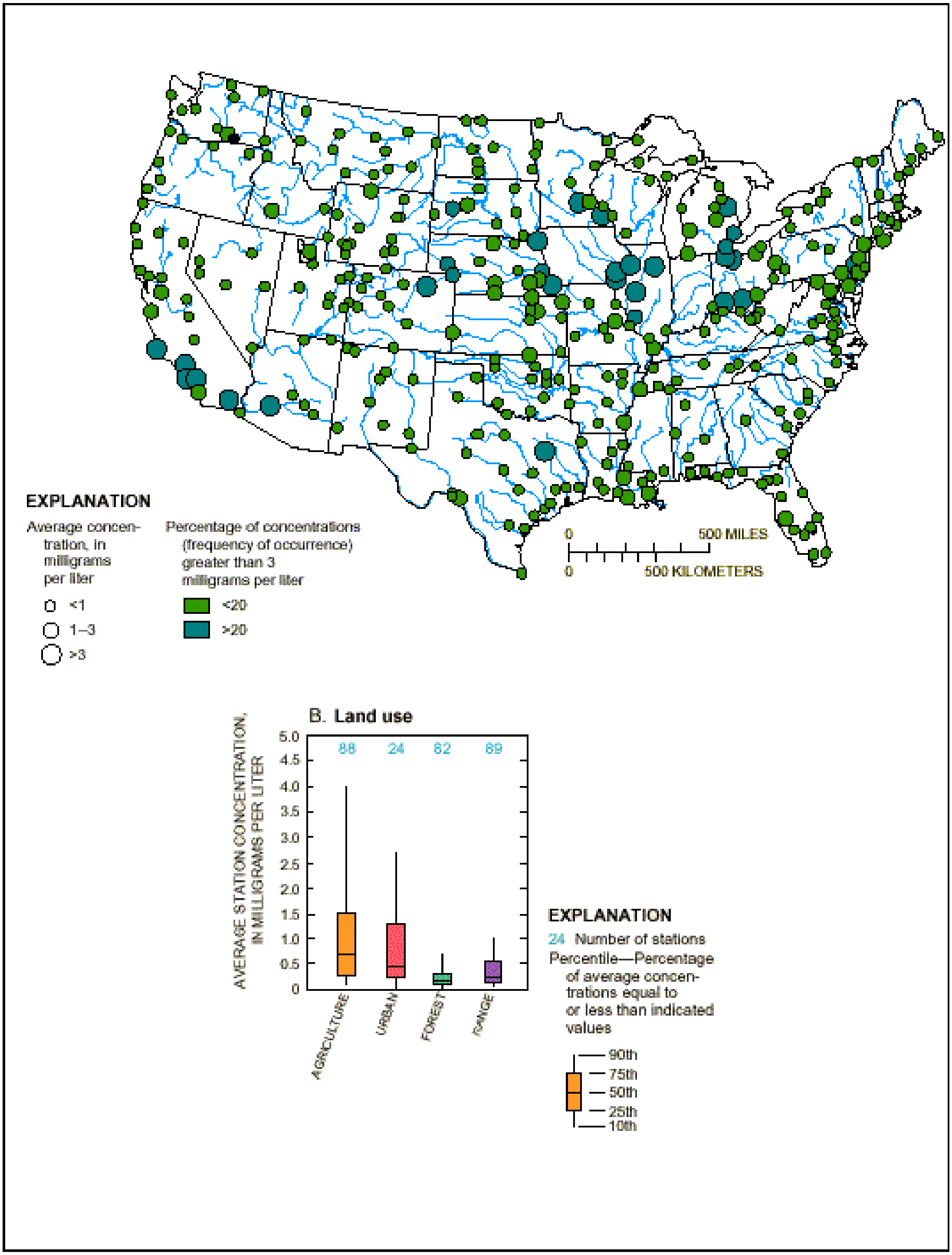


Figure 30. Concentration of nitrate (nation-wide and by land use) in stream water, 1980 to 1989 (Smith et al. 1993).

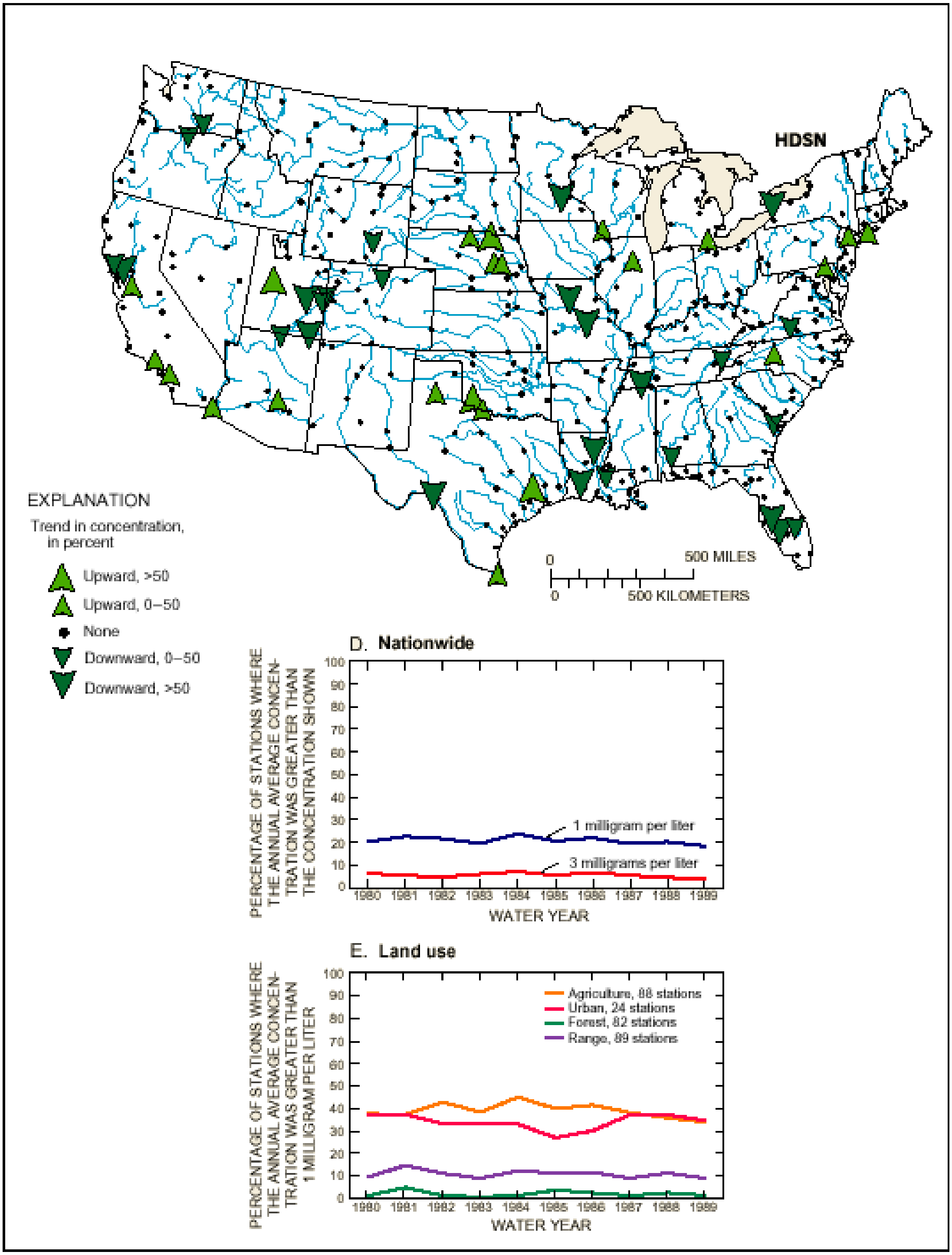


Figure 31. Trends of nitrate concentration (nation-wide and by land use) in stream water, 1980 to 1989 (Smith et al. 1993).

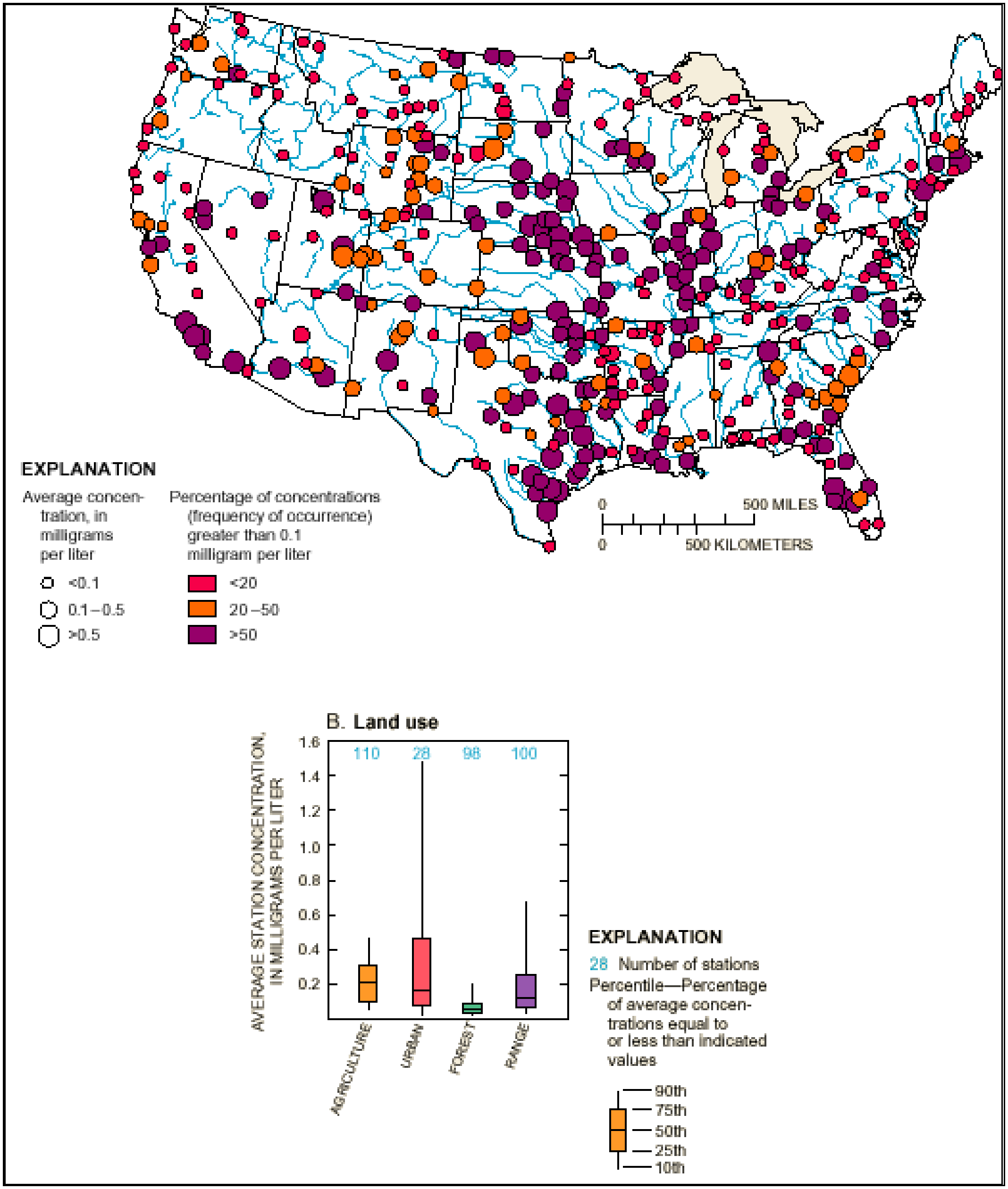


Figure 32. Concentrations (nation-wide and by land use) of total phosphorus in stream water, 1982 to 1989 (Smith et al. 1993).

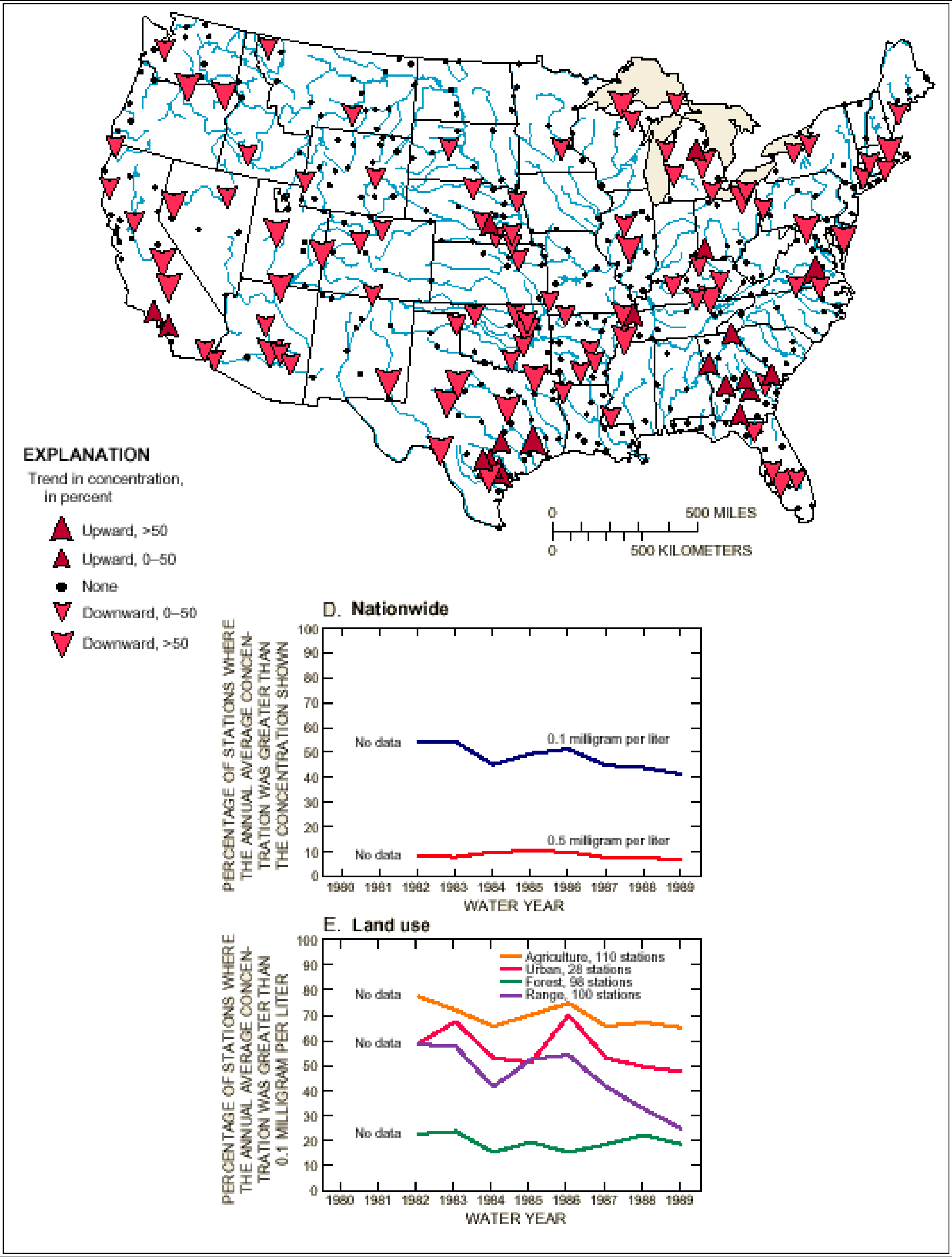


Figure 33. Trends (nation-wide and by land use) of total phosphorus in stream water, 1982 to 1989 (Smith et al. 1993).