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Abstract
The Poland Agriculture and Water Quality Protection project, in operation since 1992, has identified several problems for the country's agricultural sector. This report focuses on the effects of agricultural production on water quality. These effects result primarily from the introduction into water sources of chemicals used to assist production, such as plant protection agents and fertilizers. The report also outlines five proposals for actions to change the present structure of agriculture in Poland.

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THE EFFECTS OF AGRICULTURE ON WATER QUALITY: A POLISH PERSPECTIVE

Agriculture is often seen as a natural system that can be maintained if practices such as using mineral fertilizers or pesticides are abandoned. Such a view is erroneous, because agriculture is a food-producing industry and, as do all industries, requires an investment of materials that, when not consumed in the production process, may become dispersed and cause perturbations in the environment.

Agriculture is not itself a natural system, but it strongly affects the natural systems surrounding it, especially the amount and quality of soil and surface water. Agricultural activities have primarily occupied the areas with the best soil and most favorable water conditions. It has caused destruction of the natural plant cover, removed most native animals, and disturbed the microclimate and hydrologic regime.

Agricultural production practices can be divided into plant and animal production activities. Plant production requires enormous amounts of water—from 200 to 500 liters per kg of dry product mass—and high mineral inputs. Plant products provide animal nutrition elements such as carbohydrates, lipids and proteins, and industrial raw materials, primarily fibers.

An average of 4 to 8 tons of organic dry mass is produced per hectare of arable land per year with an input of about 100 kg nitrogen, 15 kg phosphorus, and 100 kg potassium. Not all of this organic matter produced can be used directly in the form of grain, potato tubers, beets, or green fodder. Some of the mass-form byproducts of production, such as straw from cereals, are usually recycled into production on the farm or returned to the soil. The amount of usable organic mass depends on natural conditions and inputs, primarily fertilizers. The environmental effects of fertilizer used in agricultural plant production depend on the amount used and on the farmer's skill in using appropriate application timing and rates. Fertilizer not used up in production may be dispersed into the environment.

The main agricultural product in developed countries (and in Poland) is animal protein. About 90 percent of the mass of plant material from fields and meadows is used in animal production as fodder or litter. It is for this purpose that almost all plant products are collected and processed on the small surface of Polish farms.

This paper discusses the effects of agricultural production on water quality. These effects primarily result from chemicals used to assist production, such as plant protection agents and fertilizers, into water. This paper specifically addresses the effects of water contamination from fertilizer, primarily nitrogen.

Feeding the World Population

The task of agriculture is to feed the increasing number of people in the world. Food should also be cheap and readily available. The agricultural production area is not increasing, and thus the surface area per person to be fed is getting smaller (Tables 1 and 2).

Table 1. Agriculture capacity to produce nutrients and nutrition of the human population

Agricultural management system	Culture or era	Yield of cereals	World population	Hectares per capita
		Tons per ha	millions	ha
Hunting and collecting	Paleolithic		7	
Wandering economy [management]	Neolithic	1	35	40.0
Transition economy	500- 1450 AD.	1	900	1.5
Beginning of rational animal breeding	Late 18th century	2	1800	0.7
Fertilizers and pesticides usage	20th century	2	4200	0.3

Only intense and rational agricultural production can provide sufficient food. In addition to improved biological crop species enhancement, nitrogen fertilizer is the main and indispensable factor increasing agricultural production. In the second half of the 20th century the increase in fertilizer use to increase agricultural production has been so great that it has practically abolished hunger throughout much of the world. Such a high level of artificial nitrogen production has been achieved that it has surpassed the amount of biologically bound nitrogen in agricultural systems. In addition, the amount of synthetic nitrogen present in industrial products (explosives, plastics, drugs) and released during burning of raw materials for energy corresponds to the amount of nitrogen bound biologically by natural and forest systems. This creates a high nitrogen potential in the environment that causes the eutrophication of the environment and is a danger to the water and air quality (Table 3).

Table 2. Agricultural production, cereal yields, and consumption of mineral fertilizer over the last 180 years in Germany

Year	Number of persons fed by 1 ha of agricultural land	Production of cereal equivalent/person, tons	Yield of cereal equivalent /ha, tons	Mineral fertilizer consumption kg N+P2O5 + K2O/ha
1800	0.8	0.91	0.73	0
1875	1.3	0.92	1.2	3.1
1900	1.6	1.14	1.84	15.6
1925	2.1	1.09	2.28	43.9
1950	3.3	0.91	2.98	101.9
1975	4.6	0.95	4.43	233.5
1978	4.5	1.03	4.63	255.8

Table 3. Global sources of nitrogen fixation, 1992

Source	Million tons
Biological	
Agricultural land	89
Other continental	49
Oceanic	20 - 120
Industrial	
Commercial fertilizers	93
Other industrial products	21
Burning of natural resources	21
Wood burning and decomposition	10 - 200
Atmosphere	
Atmospheric lightning	20

Only a small amount of nitrogen used as an input in agricultural production is used in food production. The rest remains in the soil or is dispersed to other systems in the environment. The path of nitrogen from agricultural production to the consumer has been analyzed in Germany (Table 4). In order to feed one person, about 40 kg of nitrogen have to be introduced, of which about 10 kg are present in the food produced. During processing of these products, half of this nitrogen returns to agriculture or is lost. A single individual buys foods containing about 7 kg of nitrogen. Of this amount 1.5 kg of nitrogen ends up in trash dumps or sewers as waste or spoiled food. Each of us consumes 4.5 kg of nitrogen and excretes the same amount. Part of the nitrogen consumed by the average individual ends up in community sewage; the rest is dispersed in the environment through other pathways. In Poland, about 230,000 tons of nitrogen from produced food is dissipated into the environment. More than 20 tons of phosphorus are also lost.

Table 4. Nitrogen pathway from crop production to human consumption

Pathway	N kg/ha	N kg/per capita
Total agricultural input	218	42.9
Agricultural market products	51	10.0
Animal products	28	5.5
Plant products	23	4.5
Products purchased by the population	28	5.6
Food actually eaten	22	4.1

Agricultural Production

Nitrogen Balance

Only a small amount of the nitrogen introduced into agriculture is used in production; the rest is dispersed in the environment. An easy method of estimating nitrogen loss in production is by calculating a nitrogen balance. This may be the balance for the whole farm, for a field in plant production, or for animal feeding operations. All three types of balance may be used to predict water contamination from nitrogen compounds, but they only address a very small area. So, to predict the contamination scale for a country or region, the balance must be prepared on a similar scale.

Before discussing the nitrogen balance in Polish agriculture, it is worthwhile to examine the nitrogen balance in Danish agriculture in 1950 and 1980. In 1950, Danish agriculture was very intensive while nitrogen mineral fertilizer use was very small. In 1980, the maximum artificial fertilizer use in this country was noted. In 1950 the main sources of nitrogen in plant production were cultures of legumes, which provided three times more nitrogen than mineral fertilizers. Another important source of nitrogen was imported fodder. The nitrogen excess, its losses, exceeded 80 kg of nitrogen per hectare, even though small quantities of mineral fertilizers were used (Table 5). Thirty years later the proportions of the nitrogen balance had significantly changed. The primary nitrogen source was artificial fertilizers followed by imported fodder. The amount of nitrogen from rainfall had also increased. Cultivation of legumes had, to a large extent, been abandoned. The amount of nitrogen in plant products had decreased but it had increased in animal products. This is a reflection of the food habits of wealthier societies who consume large amounts of animal protein. Finally, the nitrogen excess had increased to about 180 kg of nitrogen per hectare annually, which seriously endangers water quality (Table 5).

Table 5. Nitrogen balance in Danish agriculture

Source	1950	1980
	(kg N/ha/year)	
Total inputs	102	217
Commercial fertilizers	20	130
Imported fodder	17	62
Atmospheric precipitation	5	15
Biological fixation	60	10
Outputs with products	19	30
Animal	7	20
Plant	12	10
Nitrogen surplus	83	187

Currently, the nitrogen balance in Poland shows a smaller excess than in the 1980s, when the price of artificial fertilizers was maintained at artificially low levels. In 1993 the main sources of nitrogen were mineral fertilizers, the use of which reached the lowest point after Poland's political system changed. The next most important nitrogen source is rainfall, which annually brings in almost 20 kg of nitrogen per hectare (Table 6).

Table 6. Balance of nitrogen, phosphorus, and potassium in Polish agriculture, 1993

Balance component	Nitrogen kg N/ha	Phosphorus kg P/ha	Potassium kg K/ha
Total inputs	74.8	6.3	14.3
Commercial fertilizers	36.6	5.2	14.3
Imported fodder	6.4	1.1	1.3
Microbiological fixation	16.4	-	-
Atmospheric precipitation	17.0	-	-
Outputs	10.7	1.97	3.44
Plant products	6.95	1.18	3.44
Small grain	3.95	1.18	2.72
Potatoes	0.29	0.04	0.29
Sugar beets	1.74	0.23	1.17
Rapeseeds	0.85	0.19	0.26
Fruits and vegetables	0.11	0.01	0.13
Animal products	3.78	0.79	0.72
Meat	1.82	0.42	0.17
Milk	1.93	0.37	0.55
Eggs	0.03	0.003	0.002
Surplus	64.1	4.3	10.9

Low mineral fertilizer use is responsible for low yields in Polish agriculture and results in three times less nitrogen per hectare in its marketed products than in those from Danish agriculture. Moreover, nitrogen primarily is found in plant products, indicating that Polish society consumes relatively little animal protein. Low nitrogen doses are given through application of mineral fertilizers in Poland compared with very high levels in Denmark. The percentages of nitrogen applied that are present in marketed plant materials are 29 percent for Poland and 23 percent for Denmark, indicating that intensification of inputs relative to production only slightly increases nitrogen losses per product mass.

The observed nitrogen excess in Poland was 64 kg per hectare in 1993, or about 1.2 million tons for the entire country. This equals material losses of 1.2 trillion new zlotys although nobody counts the material losses resulting from dispersion of nitrogen in the environment. Excess phosphorus and potassium remain in the soil, increasing their productive potential. This increase of soil phosphorus currently does not constitute a significant danger to the environment, but an excessive increase in soil phosphorus is undesirable because erosion transports considerable amounts of this element into the water where its environmental effects are much greater.

The Fate of Lost Nitrogen

The excess of nitrogen in the balance equation is nitrogen that was not used in production and could be dispersed into the environment by evaporation into the atmosphere or leaching into ground or surface water.

Escape of Ammonia

In agriculture in which animal production dominates, the greatest nitrogen losses occur from ammonia evaporation, primarily from animal excrement. Animal production is based on the transformation of plant protein into animal protein. But only a part of the plant protein taken up by the animals with fodder is digested by them and used in body mass or milk production. The rest is excreted as undigested plant protein or the products of its transformation (Table 7). Agricultural animals produce relatively large amounts of excrement (Table 7). For example, a farm containing 27 large conversion units (eg., 18 milk cows and their calves or 200 pigs) produces as much excrement as a settlement with 400 inhabitants, and five such farms produce as much excrement as a small town with 2,000 inhabitants. In such a town, it is evident that a sewage processing plant should be built. The question then arises: What should be done on farms in order to mitigate the danger from the accumulation of large amounts of excrement, which, according to the standards of the European Union, should be stored for nine months?

Table 7. Nutrients excreted with animal wastes, per year

Animal	Nitrogen (kg N/animal)	Phosphorus (kg N/animal)	Potassium (kg N/animal)	Dry matter (kg N/animal)
Dairy cows	68.0	10.0	95.0	2000
Hogs	18.0	5.5	8.0	500
Sheep	10.0	1.8	20.0	350
Geese	0.6	0.2	0.4	25
Laying chickens	0.3	0.2	0.2	12
Humans	4.5	0.5	1.1	134

A considerable amount of the nitrogen in animal excrement is in the form of the ammonium ion or substances that are easily transformed to ammonia or ammonium ions. In the feces of farm animals, about 25 percent of the nitrogen is ammonium, and more ammonium is formed during fermentation of farm manure or liquid manure. In urine, about 90 percent of the nitrogen is in urea, which is quickly hydrolyzed to ammonia. The animals excrete 50 to 70 percent of the nitrogen consumed but unassimilated with the urine. Therefore, during storage and use of animal excrement as fertilizer, the nitrogen contained in urea poses the greatest problem.

The annual nitrogen emission for various farm animals has been calculated (Table 8). A single cow excretes almost 30 kg of ammonia per year. Excretion by other animals depends on their size. About 10 percent of ammonia losses occur in the places where the animals are housed. Further ammonia evaporation occurs during storage of the excrement as liquid manure, farm manure, or dung. The highest losses, however, occur while the manure is used as fertilizer.

The magnitude of ammonia emissions depends on the surface from which they are evaporated. Rapid removal of excrement from buildings, in airtight containers, and immediate mixing with soil before spreading on the field, greatly reduces ammonia emissions.

On Polish farms, the liquid manure/farm manure system is most often used for storage. However, on most farms this storage, especially of dung, favors ammonia emission. Containers for dung, in general, are small capacity and are not tight. Frequent removal of dung, often onto soil that is frozen or covered with snow, favors excessive ammonia emission. Plant production also favors ammonia emission. A small amount of ammonia is emitted by growing plants, but a much larger quantity comes from mineral fertilizers containing urea or the ammonium ion.

Table 8. Ammonia emission factors used in Poland

Animal	Factor NH_3 /animal/year
Dairy cows	27.8 kg
Other cattle	12.5 kg
Hogs	5.1 kg
Sheep and goats	1.9 kg
Poultry	0.26 kg
Horses	12.5 kg

Decreased fertilization and fewer farm animals in Poland led to decreased nitrogen emissions in 1992 compared with the 1980s (Table 9). The nitrogen losses from this source amount to 35 percent of the excess nitrogen in farming.

Table 9. Ammonia emissions from agricultural sources in Poland

Source	Ammonia emission			Percent of emission
	1985	1990	1992	1992
		thousand tons per year		
Dairy cows	154	137	118	28.4
Other cattle	69	64	50	12.0
Pigs	90	99	113	27.2
Sheep	9	8	4	1.0
Horses	18	12	11	2.6
Poultry	16	12	10	2.4
Animal Total	356	332	306	73.6
Commercial fertilizers	147	151	73	17.5
Crops	38	38	37	8.9
Agriculture Total	541	521	416	100
Industry	20	20	15	

In the atmosphere, ammonia interacts with acids, primarily the aerosols of sulfuric acid and nitric acid, with an average yield of 30 percent per hour of ammonia concentration in the air. This large ammonia reactivity with acids has serious environmental consequences, because the NH_4^+ is not removed efficiently as dry precipitation, and, without removal, it may migrate over large distances. After falling to the ground, the ammonia is bound by ions as the NH_4^+ cation, which together with the NH_4^+ aerosol from precipitation, takes part in the nitrification process. As a result of this process, two protons are formed from one ammonia molecule:

$$NH_4^+ + 2O_2 \Rightarrow NO_3^- + 2\,H^+ + 2\,H_2O.$$

Atmospheric ammonia thus is an agent that strongly acidifies the environment. An ammonia molecule causes the same amount of acidification as an SO_2 molecule from the atmosphere and two times more than a nitrogen dioxide molecule. The acidification of Poland's environment as a result of ammonia emission from agriculture is twice larger than that caused by nitrogen oxide emissions and about half of that caused by sulfur dioxide emissions (Table 10). Much attention has been devoted to the problem of limiting sulfur emissions during energy production, and nitrogen oxide from communication. A considerable amount of money has also been devoted to this goal, whereas nitrogen emissions in farming have been largely ignored.

Table 10. Share of ammonia emission in environmental acidification and eutrophication in Poland

	Sulfur oxides		Nitrogen oxides		Ammonia	
Recalculations	**1985**	**1992**	**1985**	**1992**	**1985**	**1992**
			(kg N/ha/year)			
Recalculated on SO_2	4300	2817				
Recalculated on NO_2			1500	1130		
Recalculated on NH_3					541	416
Recalculated on N			456	344	444	342
Recalculated on protein	134.2	87.9	32.6	24.6	63.6	48.9
			(percent)			
Share in acid precipitation	58.2	54.5	14.2	15.2	27.6	30.3

Denitrification and Escape of Nitrous Oxide

Denitrification takes place in the soil (and water) when anaerobic conditions occur and easily oxidized organic matter and nitrates are present. The main product of denitrification is molecular nitrogen,

$$5\ C_6H_6O_6 + 24\ NO_3^- + 24\ H^+ \Rightarrow 30\ CO_2 + 42\ H_2O + 12\ N_2,$$

and nitrous oxide is the byproduct,

$$C_6H_6O_6 + 6\ NO_3^- + 6\ H^+ \Rightarrow 6\ CO + 9\ H_2O + 3\ N_2O.$$

This side reaction, which should arouse uneasiness for environmental protection, releases nitrous oxide into the atmosphere and contributes to two processes of global importance: destruction of the ozone layer and the greenhouse effect, based on a global increase of average atmospheric temperature.

The concentration of nitrous oxide in the atmosphere is currently 0.31 ppb and increases at a rate of about 0.25 percent annually. Nitrous oxide, in addition to freon and other halocarbons, is responsible for destruction of the ozone layer. Moreover, this compound in the atmosphere has the greatest potential for absorbing radiation in the infrared range and at wavelengths that are not absorbed by other atmospheric contaminants. Nitrous oxide contributes 6 to 8 percent of the increase in global temperature from the greenhouse effect.

Denitrification is a natural microbiological process. In the natural circulation of biomass the process removes excess nitrogen entering the system both from biochemical nitrogen fixation and mineral fertilizers. Currently, the yield of denitrification depends to a large extent on the mass of industrially bound nitrogen. This industrial synthesis is responsible for the excess nitrous oxide in the atmosphere. In agricultural production, denitrification is undesirable from an economic viewpoint because it causes nitrogen losses. There is little current awareness of the extent of this loss. Losses from denitrification are estimated to be a few to a few dozen percent of nitrogen excess in farming. Denitrification is the most intense on permanently green arable land.

Leaching of Nitrogen Compounds into Surface and Groundwater

Mechanisms connected with leaching nitrogen compounds, mainly nitrates from arable land, are well known, but it is much more difficult to estimate the magnitude of such losses and the resulting nitrogen loadings into groundwater.

Nitrogen compounds reach surface water directly due to surface flow and water and wind erosion. The results of such mechanisms have been measured to some extent in Western countries, but we know little about the situation in Poland with respect to the load of nitrogen and phosphorus reaching surface water from these events.

Surface flow transfers dissolved forms of nitrogen and phosphorus and also sweeps along light floating organic material, such as the remains of plants and organic fertilizers. The highest risk to water quality is from the flow from the surface of animal courtyards and runways, because large amounts of animal excrement are washed away from these places. Such flows contain not only large amounts of nitrogen and phosphorus, but also fecal bacteria. Similar contaminants are carried by surface flow from arable land onto which organic fertilizers have been applied without mixing them with the soil. The observed contamination of surface water with coliform bacteria may be due to flow originating from farms.

The amount of nitrogen transported from agriculture into surface water constitutes about 50 percent of its total load. The estimation of these amounts is rather complicated because it is difficult to estimate the origin of nitrogen in a stream. In England, calculation coefficients are often used (Table 11) for estimating the amount of nitrogen brought in to surface water from animal production. The use of these coefficients for the number of animals in Poland would indicate that 140,000 metric tons of nitrogen reach surface water from animal sources. This would constitute 12 percent of the nitrogen excess in agriculture. These data do not include the amount of nitrogen introduced by plant production.

Water and wind erosion move lighter soil material enriched with organic matter, nitrogen and phosphorus, and sometimes fecal bacteria, if animal excrement were applied to the field as fertilizer before erosion. Erosion also contaminates water with a soil suspension. The materials of the sediment and suspension undergo chemical changes in the stream or container: organic matter is decomposed, forming simpler nitrogen and phosphorus compounds that are water soluble.

Table 11. Coefficients of nitrogen export from animal production to surface water used as in the UK

Animal	Nitrogen in animal waste	Coefficient of nitrogen export	Nitrogen export to surface water
	kg N/animal/year	Percent	kg N/animal/year
Dairy cow	70.2	16.1	11.3
Pig	18.7	14.5	2.7
Sheep	8.9	17.0	1.5
Horse	76.8	16.1	12.4
Poultry	0.3	15.3	0.046

The greatest danger, however, is nitrogen leaching beyond the plant rhizosphere. This process depends on the pathways of the nitrogen cycle in the soil, the decomposition of waste, and the amount of water seeping through to the soil water. Nitrogen content in soil is, in general, high. In arable soils it is generally in the range of 2 to 4 tons nitrogen per hectare and in mineral meadow soils, 3 to 6 tons nitrogen per hectare. Even more nitrogen is present in peat soils. Mineral nitrogen occurs as nitrates and the ammonium ion. The total content of these two forms in the soil profile generally varies from 20 to 200 kg per hectare. However, the main mass of nitrogen in the soil is as organic compounds with various stabilities. Soil organic material composed mainly of humus materials is highly stable. From the plant nutrition and nitrogen leaching viewpoint, a greater importance can be ascribed to the soil organic material that easily undergoes changes, especially oxidation. The soil also contains plant remains and a small amount of living microorganisms. This part of the soil organic material strongly affects nitrate leaching. Organic fertilizers introduced into the soil also take part in these processes.

Nitrates are introduced into the soil with saltpetre fertilizers. Other forms of fertilizer nitrogen, such as ammonium salts or urea, are quickly nitrified to nitrates in the soil. The fate of nitrogen released from organic fertilizers is similar, only their release is slower. Nitrogen from fertilizers, particularly when applied in the spring, is quickly taken up by plants that are in an intense growth stage; the remainder is bound by soil microfauna and deposited in soil organic materials. In August, after cereals have been harvested and uptake by the remaining crops has decreased, mineralization of nitrogen in the soil is intensified. The plants cannot take up the entire amount of released mineral nitrogen; thus, the amount of nitrates in the soil increases. This coincides with excess rainfall and its seepage into groundwater. Therefore, leaching of the bulk of the nitrate mass occurs in late autumn and winter when increased nitrate concentration in the soil coincides with renewal of groundwater. The most effective strategies for limiting nitrate leaching try to limit the nitrate content in the soil during nonvegetative seasons.

Nitrate leaching beyond the rhizosphere depends on the amount in the soil profile and on the extent of the seepage. The amount of leached nitrates depends more on their content in the soil, and their concentration in groundwater, than on the extent of the seepage.

A distinctly lower rainfall in Poland, compared to Western Europe, renews less groundwater. On the average, about 100 mm seep into Poland's groundwater, whereas in Denmark, the Netherlands, Ireland, and Normandy, the annual renewal rate is 300 mm. Therefore, in Poland, an annual leaching rate of 10 to 20 kg of nitrate nitrogen endangers the quality of drinking water (Table 12) because of its much higher concentration. Observation and model experiments have shown that, in Poland, 5 to 20 kg NO_3 -N per hectare are leached from cereal cultivation, up to 50 kg from rapeseed and sugar beet cultivation, and, in general, less than 10 kg NO_3-N per hectare from permanently green arable land. These amounts of leached nitrates are a serious danger to groundwater quality.

Table 12. Nitrate concentration in groundwater as related to nitrate leaching and percolation

Nitrate leached	Percolation		
kg N/ha/year	100 mm	200 mm	400 mm
		mg NO_3-N/dm^3	
		mm/year	
10	10[a]	5	2.5
20	20	10[a]	5.0
50	50	25	12.5
100	100	50	25
200	200	100	50

[a]Highest accepted concentration according to Polish standard.

Nitrates leached from the rhizosphere move to deeper layers relatively slowly. Under Polish conditions, the rate of this movement is 0.5 to 1 m annually. Higher doses of nitrogen fertilizer have been used in Poland for only 20 years, which may be the reason why a greater contamination of groundwater with nitrates is not observed. However, this slow movement is responsible for making the decrease of nitrate concentration in subterranean waters a slow process also.

About 30 percent of the 1.2 million tons of excess nitrogen in agriculture can be expected to end up in surface water, often causing contamination. We must, however, keep in mind that leaching of nitrates beyond the rhizosphere and transport of nitrates into surface water are natural processes that also affect natural ecosystems, including the protected national parks. Agricultural practices, however, result in much larger amounts of nitrogen compounds affecting surface and groundwater systems, thus perturbing the natural balance.

The Effect of Agricultural Production on Water Quality

Nitrogen compounds lost in agricultural production directly reach water as a result of erosion and surface flow and leaching into groundwater, but also indirectly from ammonia emission. This causes water contamination in the immediate vicinity of agricultural activities. In the first place, nitrogen compounds contaminate drinking water from the farm's own sources. This water is consumed by farm families. Observations within the "Polish Agriculture and Water Quality Protection" (PAWQP) project indicate that drinking water from domestic sources on farms in demonstration catchments is contaminated with nitrates in more than 50 percent of the cases (Table 13). The nitrate contamination is accompanied by phosphorus, potassium, and chloride contamination (Table 14). Both dug and drilled wells were examined, some to a depth of 40 m. Water samples from drilled wells were contaminated with nitrates less frequently than those from dug wells. The main source of water contamination in wells is animals, which is demonstrated by a very high potassium concentration in the water.

Table 13. Drinking water quality from farmers' wells: percent of samples in various nitrate concentration ranges

Voivodship	Number of samples	Concentration range (mg NO_3-N/dm^3) <5	5-10	10-20	20-40	>40
Lomza	102	26.5	3.9	23.5	31.4	14.7
Nowy Sacz	87	58.6	18.4	13.8	8.0	1.1
Ostrolecka	727	36.6	12.2	12.0	23.8	15.4
Szczecin	213	18.3	12.2	14.1	22.5	32.9

Table 14. Nutrient concentration in farmers' wells from the Szczecin area

Village and house number	Nutrient concentration, mg/dm^3 NO_3-N	NH_4-N	P	K	Cl
Debica No. 1	10.5	0.01	0.50	80	43
Debica No. 2	24.6	0.03	1.60	126	65
Warnice No. 1	16.1	0.11	0.02	2.71	60
Warnice No. 2	0.6	0.86	0.01	23.1	129
Nieborowo No. 1	78.9	0.06	2.85	105	61
Nieborowo No. 2	4.0	0.56	1.90	546	67
Turze No. 1	147.0	0.06	0.01	670	496
Turze No. 2	3.7	0.59	0.10	1813	1166
Wierzbno No. 1	369.0	0.09	0.71	307	269
Wierzbno No. 2	98.0	0.03	3.89	671	601

Maintaining proper cleanliness on the farm and its surroundings has a considerable effect on the purity of groundwater. Within the scope of the PAWQP project, systematic investigations are being performed on groundwater below the stockyard on several dozen test farms. Results from two farms with the best economic conditions have been compared. The first farm produces milk, and all production from meadows and fields is used as fodder for cows. On the average, nitrogen fertilizer is used at a rate of 80 kg N per hectare, and an additional 20 kg N per hectare is bought with fodder from outside the farm. The hygiene on the farm is average and cleanliness leaves a lot to be desired. On the second farm, high-quality hogs are produced. Nitrogen fertilizer is applied at a rate of 110 kg

N per hectare, on the average, but 140 kg per hectare is bought with fodder from outside the farm. The hygiene on the farm is impeccable and cleanliness is excellent. On the first farm, groundwater is weakly contaminated with nitrates, more strongly with ammonia, and very strongly with phosphorus and potassium (Table 15). We assume that large amounts of organic substances pass into the groundwater with fertilizer components and undergo denitrification under conditions that reduce nitrates; thus, they are not present in the water. On the second farm, the main contaminant is nitrates, formed by nitrification of the ammonia that is emitted in large amounts, and is absorbed into the ground. Here nitrates cannot undergo denitrification, since animal excrement is not in contact with the soil.

Table 15. Nutrient concentration in groundwater below farmstead

	Dairy farm				Pig farm			
Sample date	NO_3-N mg/dm³	NH_4-N mg/dm³	P mg/dm³	K mg/dm³	NO_3-N mg/dm³	NH_4-N mg/dm³	P mg/dm³	K mg/dm³
01.07.93	12.0	1.90	10.5	628	1.7	1.40	0.04	3.6
10.09.93	0.5	4.08	10.2	554	39.3	0.20	0.01	3.0
05.12.93	0.3	0.05	5.2	618	140.0	0.11	0.02	7.5
18.02.94	11.6	1.97	28.0	1246	47.4	0.04	0.06	29.2
12.04.94	31.8	0.46	37.3	641	36.7	0.12	0.03	7.3

The water contaminants from the stockyard and the entire farm are transported to surface water or to deeper layers of groundwater. Since January 1995, WIOS in Torun, in collaboration with the BAAP project sponsored by the Swedish government, has been analyzing the water from the Ciechocinska Stream. This stream collects water from a typical agricultural catchment. Along several sections of this stream, the water is strongly contaminated with nitrates and is unsuitable for drinking (Table 16).

Table 16. Nitrate concentration in stream Struga Ciechocinska

	Sampling dates		
Sampling point	**January 24, 1995**	**February 28, 1995**	**March 28, 1995**
Mileszewka 0.4 km.	3.89	6.25	5.48
Mileszewka 1.5 km.	10.7	8.0	10.5
Mileszewka 1.7 km.	1.5	6.1	4.9
Mileszewka 6.1 km.	8.9	10.2	7.7
Mileszewka 9.4 km.	11.5	10.0	8.0

Thus, farms devoted to animal production are a sort of local source of water contamination. On these farms a large amount of fodder is accumulated and, after the animals are fattened, there is also a considerable amount of animal excrement. Such a system is not closed; part of the organic materials will be transported to the surrounding environment and eventually contaminate the water. How much is actually transported into the water depends on the quality of buildings and equipment, technology used, farmyard cleanliness, and, of most importance, the expertise and awareness of farmers.

The Effect of Nitrogen Components from Atmospheric Precipitation on the Environment

On the average, 12 to 25 kg of nitrogen per hectare are transported into the soil with precipitation in Poland. In samples of atmospheric precipitation collected throughout Poland, the concentration of ammonia and ammonium ion varies, but within the range of 0.5 to 3 mg/dm^3 NH_4 -N. This constitutes about 50 percent of the concentration of nitrogen compounds (NH_4 -N and NO_3 -N) in precipitation. The load of nitrogen from dry precipitation has not been estimated. Practically all ammonia in precipitation is derived from agricultural production and nitrates (nitrogen oxide) from energy production, industry, and transportation.

The amount of nitrogen introduced by precipitation does not pose a significant problem in arable lands and is, in fact, an extra nitrogen source for farming during the present crisis of fertilizer use in the country. These amounts, however, do pose a serious threat to surface water, natural terrestrial ecosystems, and water of the Baltic Sea, resulting in eutrophication and acidification. The Baltic Sea environment is particularly sensitive to nitrogen deposition by precipitation, but this nitrogen source also contributes to acidification of forest systems and to the eventual destruction of forest communities (Table 17). Therefore, the emission of nitrogen oxides from energy production, industry, and transport should be limited, as should emission of ammonia from animal production.

Table 17. Observed and accepted values of nitrogen input from atmosphere to natural ecosystems in Europe

System	Nitrogen input from atmosphere	
	Observed	Accepted (maximum)
	(kg/ha/yr N)	
Protected natural objects (high peat heath land)	<10 - 30	10
Woodland	10 - 200	15 - 20
Baltic and North Sea	10	5
Estuaries	9 - 15	3 - 7

Summary

Within the Poland Agriculture and Water Quality Protection project, in operation since 1992, under an agreement between the Ministry of Agriculture and Food Economy and the U.S. Environmental Protection Agency (USEPA), the following problems have been identified for agriculture and water quality.

- There is a low degree of awareness among farmers concerning the need to protect water quality and of the consequences of drinking contaminated water from domestic sources.
- Drinking water from most domestic sources on farms is contaminated with nitrates and other fertilizer components, posing a serious threat to the health of the farm families, especially young children.
- The main source of water contamination on farms is the lack, in 95 percent of them, of appropriate facilities for storing solid and liquid animal excrement.
- The methods and times of using animal excrement as fertilizers do not, in most cases, correspond to standards of the European Union.
- Agricultural advisory services have no action program to address limiting the negative effects of agriculture on the environment, especially water quality.
- The current programs related to agricultural policy and restructuring of agriculture do not address the need to limit the negative effects of agriculture on the environment.

- There is no appropriate agency responsible for limiting the negative effects of farming and village areas on the environment in the Ministry of Agriculture and Food Economy; there is also no such unit in the Ministry of Environmental Protection, Natural Resources, and Forestry.

- No studies have been conducted about how Polish legislation should be fit to the European Union standards for limiting the negative effects of farming on the environment, especially on water quality.

- Governments of other countries and various international institutions conduct various agricultural projects in Poland with the aim of making farmers and local and central decision makers aware of the danger to water quality due to production, but these activities are not being coordinated by Polish scientists or government officials.

Agricultural production in Poland is now in crisis from underinvestment on individual farms. This has led to reduced use of fertilizer and a need to import food. The development of larger specialized farms, which may be able to compete with Western European farmers, is currently being promoted. Therefore, we may expect an increase in the use of fertilizers and increased animal production. Agricultural policy recommends a far-reaching restructuring of agriculture. Unfortunately, within this restructuring, the necessity for limiting the negative effect of farming on water quality has been ignored.[2]

Also ignored in the restructuring programs is the fact that the Polish government must conform to the Helsinki agreements about the protection of the Baltic Sea environment, the need to make Polish agriculture conform to the standards of the European Union, and from legal regulations. These put considerable pressure on agriculture. The structural reforms now being undertaken in Polish agriculture must include the requirements for environmental protection, especially the protection of water resources. In this situation, correcting the changes already introduced must also be undertaken. In the future, omitting questions of environmental protection may turn out to be very expensive, and the current investments may be unnecessary or misplaced.

It is possible to limit water contamination from agricultural production to a large extent. Appropriate technologies and systems of agricultural production have been developed and tested. They may be introduced on farms that are economically sound. But presently, the main danger is underinvestment on farms, lack of farmer expertise, and poor hygiene and cleanliness on farms. The cheapest and most effective method of improvement is to educate farmers about the need for environmental protection without incurring any economic losses for the farmer.

Another important matter is including environmental protection in programs of agricultural policy and implementing actions designed to change the present structure of agriculture in Poland.

Proposals for Action

1. Develop a system of agricultural education to address limiting the negative effects of farming on the environment, especially on the quality of water.
2. Develop a system of subventions from the national budget for building facilities for storage of animal waste in farms, and include provisions for these activities in the national budget and in the development of appropriate legal regulations in this field.
3. Encourage farmers to rationally apply fertilizers on the basis of chemical analysis of the soil and plants, and develop an appropriate system of economic stimuli in this field.
4. Make management of animal waste more efficient, and introduce legal regulations in this field.
5. Develop a program for increasing the area of permanent green arable land, managed intensively, as the best way of protecting streams and containers from contamination from farming and other sources.

ENDNOTES

1. These very simple mineral compounds (also nitrates and orthophosphates) are responsible for excessive eutrophication of water. The first symptom of this process is more intense, long-lasting blooming of phytoplankton.
2. In the complex program of restructuring of the Torun and Wroclaw provinces (end - 1996) these problems are treated very seriously, even as priorities.