Pergamon

Wat. Sci. Tech. Vol. 39, No. 3, pp. 1–13, 1999.

0273–1223/99 $19·00 + 0·00

PII: S0273-1223(99)00027-X

DIFFUSE POLLUTION FROM AGRICULTURE – A WORLDWIDE OUTLOOK

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ABSTRACT

Until the 1950s most farming was carried out on smaller family farms that used organic fertilizers and essentially their waste production was easily assimilated by soils and receiving water bodies. The period post 1950 has seen a worldwide shift to larger monocultural, intensively operated farm units. The farm yields have increased dramatically, however, to sustain the increasing yields and productivity farms are using large quantities of chemical fertilizers and pesticides. At the same time, deforestation has occurred on a large scale since the 1950s and the deforested land has been converted to agricultural (mostly in developing countries) and urban (both developed and undeveloped countries) land uses. Also, a massive shift of population from rural areas to the cities has occurred in developing countries since the 1950s. Surface and groundwater quality degradation due to agricultural practices and conversion of land to agriculture can be categorized as follows: a) degradation due to land use conversion from native lands to agriculture; b) increased erosion and soil loss due to agricultural practices; c) chemical pollution by fertilizers and pesticides; and d) pollution from animal operations. Abatement of agricultural diffuse sources of pollution can and must be conducted in the context of moving toward sustainable agriculture. Some trends toward sustainable agriculture are already emerging in the US and Europe.

KEYWORDS

Agricultural pollution; worldwide pollution; sustainability; diffuse pollution; pollution externalities; eutrophication; organic chemicals

INTRODUCTION

Until the 1950s most farming was carried out on smaller family farms that used organic fertilizers and essentially their waste production was easily assimilated by soils and receiving water bodies. The period post 1950 has seen a worldwide shift to larger monocultural, intensively operated farm units. The farm yields have increased dramatically, however, to sustain the increasing yields and productivity farms are using large quantities of chemical fertilizers and pesticides. At the same time, deforestation has occurred on a large scale since the 1950s and the deforested land has been converted to agricultural (mostly in developing countries) and urban (both developed and undeveloped countries) land uses.

Also, for thousands of years people have been drawing water from rivers and groundwater to irrigate crops for growing more food. Presently on a global scale, agriculture uses about 70 percent of all freshwater supplies, which makes it the largest user of freshwater resources (Ongley, 1996). Inadequate drainage has resulted in salinization of soil and irrigation return flow, and subsequent use of chemicals has made the irrigation return flow a pollution hazard. The countries that are most affected are predominantly in arid and semi-arid regions. In western Asia, the major water quality problem is salinity caused by widespread irrigation. It has been estimated that about 20 percent of the world=s 250 million hectares of irrigated land are salt affected (Commission on Sustainable Development, 1997).

Figure 1 shows the land use modification process and its causal relationship to pollution. The land use shifts are caused by population pressures, local and regional economy, tourism and recreation pressures, international trade and others. Pollution is usually caused by a failure of the economical and political system to recognize the cost of the environmental damage caused by pollutant discharges (Novotny and Olem, 1994).

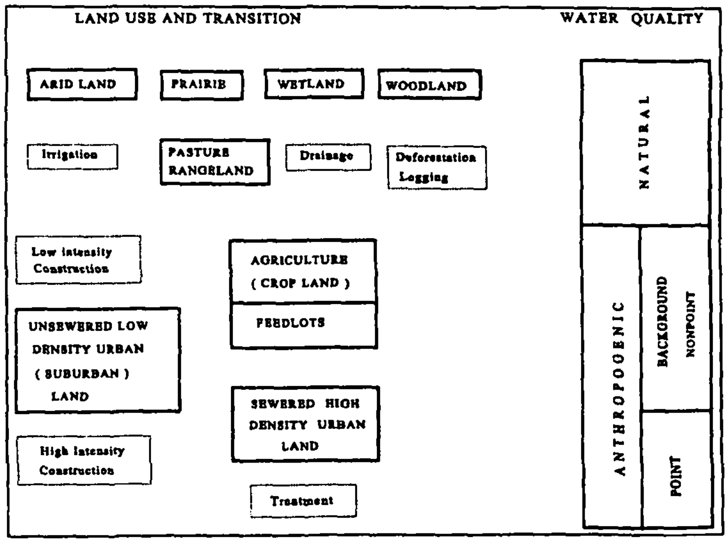

Figure 1. Land use changes and pollution.

<u>Population shift</u>

Population is affecting and will continue to affect economic activities and pollution. The mid-range projection from the United Nations is that the world population will grow from 5.7 billion in 1995 to about 8.3 billion in 2025. One of the consequences of the population increase is the shift of poor populations from rural to urban areas. Much of the population increase will be in rapidly growing urban areas of developing countries, many of which are already experiencing serious water stresses and severe diffuse pollution problems.

As the productivity of farms has been increasing, farmers' profits have decreased to the point that a typical family farm cannot be economically viable. In developing countries, this trend is combined with population growth problems. For example, population growth in Thailand during the 1940s was less than 1 percent and increased to 3.2 percent during the 1950s (Niemczynowicz, 1996). On a worldwide basis, the growth of the urban population in the period 1975-1990 was two and a half times greater than that for the total population (Table 1). It is clear that a massive shift of population from rural areas to the cities has occurred since the 1950s.

Niemczynowicz attributes the population shift to increased agricultural production, especially in developing countries, by introduction of new crops, irrigation, and new agricultural routines. He also pointed out that these methods and techniques did not always take into account local soils and climatic conditions as well as

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social structure. After an initial growth of agricultural production and productivity, a decline has been noticed in many areas of the world because of erosion, salinization, water logging and desertification. These adverse impacts have resulted in a loss of arable land. To compensate for the loss of top soil and loss of fertility, more chemical fertilizers and pesticides are needed. This creates a vicious cycle. As more, often marginal, land is converted by deforestation to agriculture, as more fertilizer is used to sustain higher yields of monocultural crops, more top soil and natural nutrients are lost from the soils, resulting in a decline of productivity. For example, in arid areas of west and central Africa carbon content in soils has decreased by more than 50 percent; which has reduced the productivity by about 50 percent and the need to use fertilizers is now five times higher than in some advanced countries (Niemczynowicz, 1996).

Thus the attempt to increase agricultural productivity in many developing countries has to some degree backfired and resulted in a massive migration of population from rural to urban areas. A large part of this new population lives in slums, poverty and without adequate sanitation. The growth of megacities in the developing countries represents a massive diffuse pollution problem that, to some degree, can be attributed to the failure of rural agriculture to feed and economically sustain the rural population.

Table 1. Annual percent growth of population in the period 1975-1990 (geometric increase). Data from Niemczynowicz (1996) and United Nations (1989)

	percent growth/year
Total population increase	1.75
More developed regions	0.64
Less developed regions	2.12
Urban areas	
More developed regions	1.58
Less developed regions	5.27

In spite of the large shift of population from rural to urban areas, agriculture in developing countries, for example in India, consists mostly of small family farms that use relatively small amounts of fertilizers and pesticides when compared with developed countries. Agriculture is always linked with animal husbandry and there is a large number of cattle, however, concentrated animal operations with a large number of heads are rare (Agrawal, 1999).

ENVIRONMENTAL CONSEQUENCES OF AGRICULTURE

Surface and groundwater quality degradation due to agricultural practices and conversion of land to agriculture can be categorized as follows.

Degradation by land use conversion

There are four types of native (pre-agricultural) lands: prairies (step), wetland, forest and arid lands (desert). In order to use these lands they must be converted (Fig. 1). The conversion activities include slash burning followed by ploughing (prairie, forest), drainage (wetlands), and irrigation (arid lands). Each conversion process produces pollution and pollutant loads during the conversion that are typically several orders of magnitude higher than the background loads from the original native lands. The most damaging activity is deforestation. Table 2 shows the increase of sediment yields in watersheds converted to agriculture.

In developing countries, deforestation is driven by population growth, limited soil fertility and land tenure inequities (Sanchez, 1992). Eighty percent of tropical deforestation is caused by non-traditional shifting cultivation, i.e. small farmers clear and burn a few hectares of land a year, mainly to grow food. When the fertility of the soil so reclaimed is exhausted the farmer clears another area and the previously cultivated land is left to reforest. The fields created by shifting cultivation in tropical forests have typically low yields, therefore, more land is required. For example, under shifting cultivation, upland rice growing farms in Peru and the Amazonian regions, created by deforestation, will yield about 1 ton per hectare of crops while conventional farming would produce rice yields of about 11 tons per hectare.

Table 2. Increases in sediment yield caused by land use change (after Walling and Webb, 1983 - original references are listed in Novotny and Olem, 1994)

	Land-use change	Increase in sediment yield
Rajasthan, India	Overgrazing	x 4 - 18
Utah, US	Overgrazing of rangeland	x 10 - 100
Oklahoma, US	Overgrazing and cultivation	x 50 - 100
	Cultivation	x 5 - 32
Texas, US	Deforestation and cultivation	x 340
N. California, US	Conversion of steep forest to grassland	x 5 - 25
Mississippi, US	Deforestation and cultivation	x 10 - 100
South Brazil	Deforestation and cultivation	x 4500
Oregon, US	Deforestation (clear cutting)	x 39
Ontario, Canada	Agriculture	x 14

[1] Compared to undisturbed forested land in the same area.

Shifting cultivation with subsequent reforestation may be possible in humid tropical countries. Traditional shifting cultivation, with low population densities and without excessive soil erosion, allows forest to grow back over 20 or 30 years (Sanchez, 1992). However, in countries with relative high population densities, lower precipitation, and farming on higher, sloping, erosive lands, e.g. Haiti, Ethiopia and several other African countries, deforested land has lost most of the top soil and return to forest has not occurred. From history it is known that land deforested in the Middle Ages by Venetians in the mountainous Dalmatian region of Croatia has not returned to forest.

In addition to soil loss, conversion of native lands to agriculture changes soil chemistry, which may lead to a significant loss of chemicals. For example, conversion of prairies into arable land and drainage of wetlands triggered nitrification of large amounts of organic nitrogen stored in the native soils and released large quantities of nitrate into groundwater, and subsequently into the base surface flow (Kreiter and Jones, 1975). Deforestation and conversion of deforested lands to agriculture, and erosion of agricultural lands, are the main pollution problems in developing tropical and subtropical countries.

Increased erosion and soil loss

With the exception of arid lands, soil loss by erosion from fields is at least an order of magnitude higher than the background loads. A publication by Clark *et al.* (1985) is an authoritative treatise on the impact of erosion and sedimentation on the environment in general and water quality in particular. Soil erosion is the major cause of diffuse pollution and sediment is also the most visible pollutant. The environmental impacts of excessive erosion and sedimentation caused by agriculture can be listed as follows (Goldman *et al.*, 1986):

- Effects of excessive sediment loading on receiving waters include deterioration or destruction of aquatic habitats. Excessive deposition of sediments in slow moving reaches and impoundments blankets the bottom fauna, "paves" the bottom of the streams, and destroys fish spawning areas. Sediment can destroy spawning areas, food sources and also directly harm fish and other aquatic wildlife.

- Excessive sedimentation causes a rapid loss of storage capacity in reservoirs and accumulation of bottom deposits that inhibit normal biological life. In many parts of the world, reservoirs built on sediment laden streams have been filled in a matter of years, sometimes before the full function of the reservoir was achieved.

- Nutrients carried by sediment can stimulate algal growths and, consequently, accelerate the process of eutrophication. Phosphates and, to a lesser degree, ammonia from fertilizer applications and pollution discharges are adsorbed by soils and suspended sediment.

- Sediment - especially its fine fractions - is a primary carrier of other pollutants such as organic components, metals, ammonium ions, phosphates, and many organic toxic compounds. For example, persistent organochlorine compounds, such as aldrin and dieldrin pesticides, have low solubilities in water but are readily adsorbed by suspended sediment.

- Turbidity from sediment reduces in-stream photosynthesis, which may lead to reduced food supply and habitat.

Many fields are found in flood plains. Silt generated by excessive erosion tends to clog drainage canals and further encourages seasonal flood plain farming. High concentrations of salts in the agricultural seasonal floods encourage growth of weeds after the floods have passed (Agrawal, 1997).

Chemical pollution by fertilizers and pesticides

Much has changed since the period before the 1970s when many members of an agricultural community would have denied that agriculture might be causing pollution and environmental degradation (Novotny and Chesters, 1981). Indeed, the most rapid adverse changes in environmental degradation occurred in the developed countries and countries of the former Soviet block after 1950 and accelerated in the 1970s and 1980s. Streams and lakes in agricultural areas, which before the 1960s were reasonably clean, are now suffering from excessive algal growths and eutrophication caused by discharges of nutrients from fields and animal operations. Groundwater that was previously safe for drinking is now unsuitable for human consumption due to a high nitrate content and contamination by organic chemicals, many of them carcinogenic. The most severe water quality changes caused by excessive application of agricultural chemicals have occurred in Central Europe, Belgium, the Netherlands, the United Kingdom and in some parts of North America.

In the agricultural sector, pesticide use has increased both in industrialized and developing countries. In India, pesticide use has increased nearly 50-fold between 1958 and 1975, yet the Indian consumption in 1973-1974 was reported to be averaging about 330 g/ha, compared to 1.48 kg/ha in USA and 1.87 kg/ha in Europe (Avcievala, 1991; quoted in Ongley, 1996). The greatest use of these chemicals is in Western Europe. A further increase was noticed between 1975 and 1990. If expressed in kg/ha, in 1993 the Netherlands used about 20 kg/ha of organic chemicals, Belgium 12 kg/ha, France 6 kg/ha and Germany 4 kg/ha, respectively. Fumigation of soils (particularly in potato growing areas) accounts for the highest use of organic chemicals in the Netherlands (Salomons and Stol, 1995).

In the same period, use of industrial fertilizers has also increased exponentially, resulting in high levels of nitrates in groundwater and, subsequently, in the surface base flow of streams draining agricultural areas. Use of chemical fertilizers in Western Europe between 1950 and 1980 has increased by an order of magnitude. For example, the use of nitrogen fertilizers in the United Kingdom has increased from about 100,000 tons in 1950 to 1.6 x 10^6 tons in 1980. Figure 2 shows historical trends in the use of industrial fertilizers in several countries. Again, using the United Kingdom as an example (a similar trend can be also expected in Scotland) the use of fertilizers has increased from about 200 kg/ha in 1961 to 400 kg/ha in 1990 (Ongley, 1996). In the Czech Republic, use of fertilizers increased from about 180 kg/ha in 1975 to 250 kg/ha in 1985-1989. As shown in Fig. 3, use of fertilizers was reduced dramatically after the "velvet" revolution in 1989 (Czechoslovak Academy of Sciences, 1992).

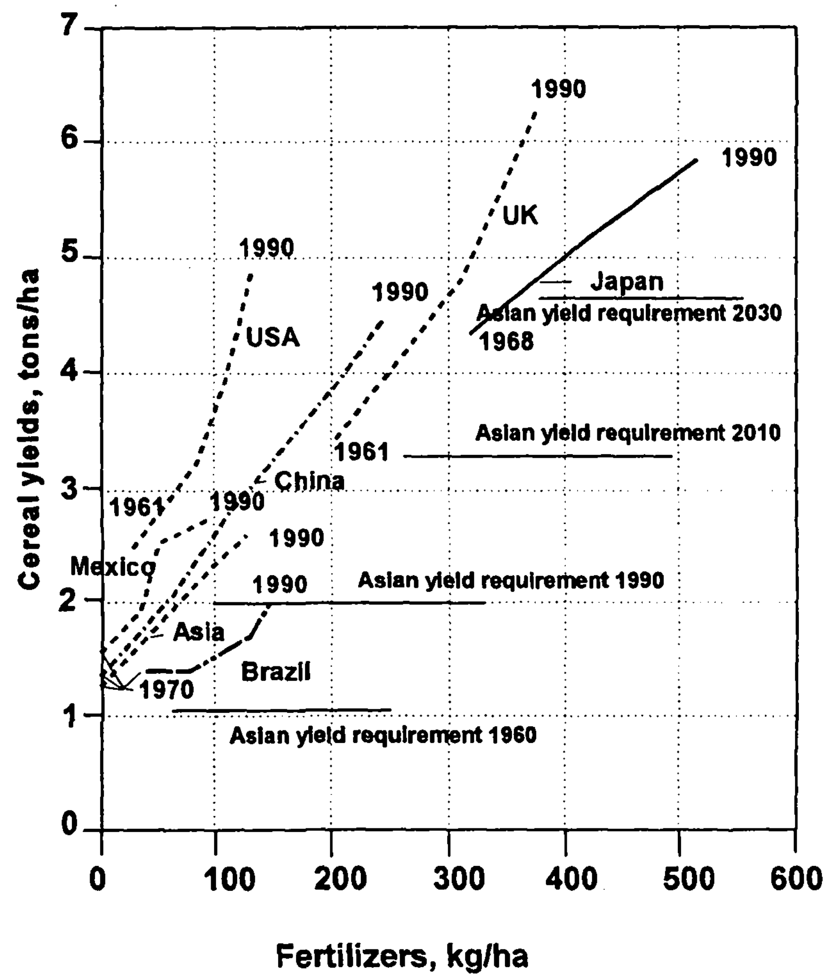

Figure 2. Fertilizer uses and crop yield evolution in Asian, European and American countries, and in the United States (sources: Joly, 1993; Ongley, 1996).

Sources of nutrients from agriculture can be categorized as livestock sources and emissions from fields. Livestock wastes accounted on average for 30 percent of the total phosphorus load in European inland waters, and the rest of agriculture accounted for an additional 17 percent (ECE, 1992). Wastes from concentrated livestock operations (feedlots) are considered as point source pollution. On the other hand, nitrogen from agricultural nonpoint sources in the Netherlands amounted to 71 percent of the total N generated from within the state (ECE, 1992).

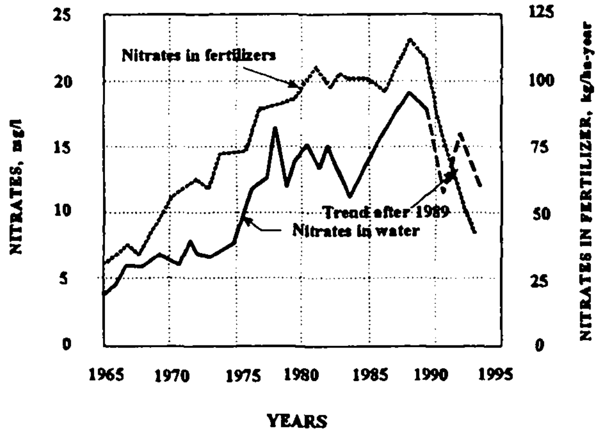

Figure 3. Relation of nitrate concentration (as NO_3^-) in groundwater and base flow in Vltava River (Czech Republic) and fertilizer use in the watershed (source: Czech Academy of Sciences, 1992).

Pollutants exist in soils in two phases: (1) as a part of soil particulate matter (adsorbed on soil particles, precipitated or as a part of soil organic particulates), and (b) dissolved in pore water of the soil (sediment). More than 99 percent of most pollutants (with the exception of nitrate) are stored in particulate form. Less than 1 percent is dissolved, however, the dissolved fraction is important because it represents the fraction that is bioavailable to organisms. The pollutants associated with particulates can be moved by erosion. Dissolved pollutants can be leached by diffusion and move with water either into surface or groundwater runoff.

It has been pointed out by Salomons and Stol (1995) that soils have a capacity to retain many pollutants in their far less environmentally damaging (particulate) form. This is especially evident for phosphates, hydrophobic organic chemicals, ammonium, and metals. However, this capacity is limited and has been reached, even exceeded in many parts of the world. The capacity of soil to retain and adsorb pollutants depends on its composition and redox status. The most important component is the soil organic matter, followed by pH, clay content, soil moisture and cation exchange capacity. These parameters are called Acapacity controlling parametersA (Salomons and Stol, 1995).

At some point, the soil becomes saturated by the pollutant and larger quantities are released in dissolved form into groundwater and the base flow of surface waters. The first indication that the soil retention capacity has been exhausted for some pollutants in some parts of the world is the dramatic increase of nitrate pollution of European and Asian (e.g. India, China) ground and surface waters as shown in Fig. 3. Well aerated agricultural soils have a lower retention capacity for nitrogen that is readily nitrified to mobile nitrate forms. As long as the soil retention capacity is not exhausted, the result is a net accumulation of pollutants in the soils that is being noticed worldwide. Net accumulation of nutrients in soils on a worldwide basis is about 3.1 kg/ha-year. In the agricultural areas of the European Community it is 18 kg/ha-year for nitrogen and 12 kg/ha-year for phosphorus, respectively (UNEP, 1992). In the Netherlands, the annual load of phosphate, defined as application minus crop uptake, has been in the order of 150-450 kg/ha-year in corn growing areas subjected to high loads of organic manure from animal operations (Salomons and Stol, 1995). Since most of the phosphorus is retained by soil, the lifetime of such overloaded soils before they become saturated will be only a few years.

Pollution from animal operations

Pollution from animal operations can be divided into that from pastures and that from concentrated animal operations (feedlots). Dairy farming is different from cattle grazing for meat where cattle are scattered in pastures. Milking operations of dairy farms require that several times daily the cows are gathered in a concentrated area for milking. These barnyards, though small (typically less than one hectare) produce very high pollution loads. Studies of loads from barnyards located in Wisconsin, Michigan and Ontario by Moore *et al.* (1979) provide information on the loads of nutrients. For example, phosphorus production by one dairy cow or heifer is 18 kg/year. Of that amount, a significant portion may reach the receiving water bodies. This load depends on the proximity of the farm to the watercourse and on the pollution attenuation during overland flow. The phosphorus load produced by one cow is equivalent to 18-20 humans (Novotny *et al.*, 1989).

The nutrient load (phosphorus and nitrogen) is not the only problem associated with barnyard runoff. Runoff from animal operations, if it is not controlled, can severely affect receiving water bodies. The most obvious impact is the depletion of dissolved oxygen caused by a high BOD of the runoff. The BOD concentrations of barnyard runoff exceed that of sewage by two orders of magnitude. Typical concentrations in barnyard runoff are given in Table 3. The runoff also carries pathogenic organisms, including the protozoa *Cryptosporidium*.

In developing countries, animals are kept by farmers in small numbers on farms and typically allowed to roam freely on pastures, in the nearby countryside, in the water bodies and even in urban areas.

Table 3. *Typical concentration of pollutants in feedlot runoff, pasture and domestic sewage*

	Pollutant concentration, mg/l				
	BOD_5	COD	Total N	Total P	Source
Feedlot runoff	1,000-11,000	30,000-40,000	920-2,100	290-380	Loehr (1972)
Grazed pasture	NA	NA	4.5	7	Robins (1985)
Untreated sewage	160	235	30	10	Novotny *et al.* (1989)

WATER QUALITY IMPACTS

In most developed countries point source pollution has been controlled, however, discharge of untreated sewage still overwhelms receiving water bodies in developing countries. Consequently, in less developed countries, control of agricultural pollution, in spite of its adverse consequences in rural areas, is not a priority.

In the United States, water quality degradation is judged in terms of impairment of the designated beneficial uses of the water body. The beneficial uses include *water supply, contact and non-contact recreation, fish and wildlife propagation.* Other, less demanding uses, are navigation, industrial uses, irrigation and others. Disposal of waste into receiving water bodies is not a beneficial use. This concept of protecting certain uses could be modified even in less developed countries. For example, in India, there is a culture of living on the river with dominating in-stream uses of bathing, washing and cattle wading. Furthermore, rivers are sacred and used for religious bathing and disposal of ashes for burial. In this case, such uses of rivers may be substituted for the uses common in developed countries. Water quality standards have been developed in most countries to protect the beneficial uses.

Discharges of contaminated runoff and subsurface flows from agricultural areas conflict with the beneficial uses. As pointed out by Ongley (1996), with the exception of the US, very few countries keep systematic statistics on water quality impairment that would differentiate between point and non-point sources.

In the United States, the 1990 water quality inventory (US EPA, 1992) reported that agriculture accounts for about 55 percent of the pollution problems in water bodies where the designated uses have not been met. The second and third largest problems were hydrological habitat modification such as channel straightening, and discharges of stormwater runoff. Municipal and industrial point sources accounted for only about 25 percent of the water quality problems.

Siltation was the most frequently reported cause of water body degradation, which was affecting 36 percent of impaired length of rivers. Nutrients, the second cause of water body degradation, affect 28 percent of degraded river lengths and most of this degradation was attributed to agricultural fertilizer use. Both siltation by sediments and degradation by nutrients are predominantly from diffuse sources. Organic enrichment/dissolved oxygen depletion was linked to sewage treatment plant discharges and feedlots.

A worldwide evaluation of ecological effects of pesticide use on water quality was carrie out by Ongley (1996). Typically, monitoring for pesticides is poor, especially in developing countries. As pointed out, generally the use of pesticides in developing countries is much smaller than in industrialized countries with intensive agriculture. Therefore, most water quality problems have been noticed in Europe and North America.

In Europe, the European Environment Agency (EEA,1994) cited a study by Galassi *et al.* that linked toxicity of the Po River in Italy (measured by *Daphnia magna*) to runoff from agricultural areas contaminated by pesticides. Surface and groundwater contamination in the Po River valley by atrazine is widespread.

The World Wide Fund for Nature (WWF, 1993) reports that a significant amount of the estimated 190,000 tons of agricultural pesticides, plus additional loadings of non-agricultural pesticides, released by countries bordering the North Sea, are eventually transported to the North Sea by a combination of riverine, groundwater and atmospheric processes. WWF further reports that the increased rate of disease, deformities and tumours in commercial fish species in highly polluted areas of the North Sea and coastal waters of the United Kingdom since the 1970s is consistent with effects known to be caused by exposure to pesticides (Ongley, 1996).

In tropical humid countries, rainfall and stream flow pattern vary extremely. During humid monsoon periods, rivers carry very high loads of silt, nutrients, organics and even heavy metals washed off during floods.

SUSTAINABLE AGRICULTURE

Definition of sustainable agricultural development

To abate agricultural pollution, industrialized countries of North America and Western Europe have developed many so-called Best Management Practices (BMPs). These practices include soil conservation, nutrient management, feedlot runoff collection and abatement, use of wetlands, taking polluting lands out of production and subsidizing farmers for such practices. Such practices will not be discussed herein.

It has become evident that worldwide application of BMPs developed in, and applicable to, developed countries may not be possible, at least not in the near future. Many BMPs are applied *a posteriori* (e.g. wetlands, ponds), which means that they are designed to remove pollutants from polluted runoff. Installation of such practices requires economic means that may not be available to farmers, and some kind of regulation that would enforce their application. Diffuse pollution is an externality (Novotny, 1988) which cannot be overcome without governmental intervention and, in some countries, international financial assistance. The problem of diffuse pollution from agriculture must be looked upon as a loss of resources (top soil, fertilizers) and as an overuse and misuse of land. Recognizing dangers to present and future generations caused by some past and present agricultural practices, misuse and overuse of land, and damaging land use conversions, it was recognized that sustainable agriculture is the urgent goal and that the diffuse pollution problem may only be resolved in the framework of approaching and achieving sustainable agriculture.

The Food and Agriculture Organization (FAO) of the United Nations in the *Strategy on Water for Sustainable Agricultural Development* (FAO, 1990), and the United Nations Conference on Environment and Development have highlighted the challenge for securing food for the future in a sustainable way. The definition of sustainable agricultural development was stated by FAO as:

> *Sustainable development is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for the present and future generations. Such sustainable development in the agriculture, forestry and fisheries sectors conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable.* (FAO, quoted in Ongley, 1996).

<u>Addressing root cause problems</u> - <u>a possible global solution</u>

There are strong and complex linkages between land use policies and practices, the macroeconomics of production and economic incentives, land degradation, and impairment of water resources. In solving the problems of pollution from agriculture there is a need to distinguish between the root causes of pollution and its symptoms. For example, eutrophication is a symptom of anthropogenically enhanced input of nutrients from agricultural lands, but the root cause is poor land management practice that may reflect economic subsidies for fertilizers (UNEP, 1997), failure to internalize the external cost of pollution and lack of enforceable pollution control laws.

Since overburdening receiving waters with waste fertilizers and pesticides from agriculture usually results in a diminished use or even loss of the water resource for other beneficial uses, society must balance its needs. Many surface and ground water bodies, which have been used for water supply, have lost their utility due to pollution from agriculture. For example, many cities and villages in the Po River valley cannot use their wells and surface water, and drinking water has to be brought by tankers overlarge distances at a great cost due to agricultural pollution. The same situation has occurred in the Czech Republic where surface water supply sources are heavily contaminated by nitrates and by-products of hyper-eutrophication attributed to agricultural pollution. A similar situation exists in New York State where diffuse sources of pollution are degrading the trophic status and downgrading the water quality of reservoirs supplying water for the City of New York. A very expensive (in 10^9 dollars) water treatment scheme should be installed to make the water suitable for water supply.

The question is whether the increase of agricultural production caused by overuse of fertilizers and pesticides justifies such great economic loss of water resources to society. The externality is the problem. Upstream users of land - farmers, land developers - do not feel the economic impact of their action on the downstream users - e.g. people who must use water from other sources because the quality of their source of water, either a groundwater aquifer or surface water reservoirs, has been rendered unsuitable. The farmers respond to their economic realities and factors, i.e. they want to make at least some profit or even just survive during harsh economic situations, which can be accomplished by increased yields. They are also responding, in some cases, to government policies of subsidies for fertilizers and irrigation water price controls and subsidies, and other government actions to promote food production. Without some intervention in the farmers= economic reasoning, a water quality problem in a water body far downstream will not influence the farmers' decision on how many chemicals they will use on their land or how they will dispose of their animal wastes (obviously, the same is true for any other upstream user detached from the water body where their waste discharges, land development and production processes cause a problem).

The problem of pollution externality has been the subject of many economic studies (see Novotny, 1988, for citations) and will not be covered in detail in this presentation. Generally, externality can be overcome by the following economic/legislative instruments:

a) government intervention, e.g. by imposing limits or bans on using certain lands for agricultural purposes, or on use of fertilizers and pesticides as well as mandatory and enforced water quality standards; and

b) using economic instruments such as fees for pollution discharges or subsidies, e.g. for implementation of Best Management Practices.

Experience in the US and elsewhere suggests that imposing standards and mandatory BMPs on the agricultural sector is very difficult and often legally and politically impossible. Also, in the US, there is a reluctance by present legislative bodies to call for new taxes that could be used to finance incentives to farmers to install BMPs. In developing countries, environmental regulations are either weak or non-existent and existing regulations are not enforced.

New emerging watershed approaches may provide some answers to these dilemmas. A watershed is a geographical unit that combines both polluters and those who suffer from pollution and whose benefits from beneficial uses of the receiving water bodies are denied by pollution and impairment of the water body integrity. Often, the users of the water resources (i.e. those who use them for drinking water supply, recreation, fishing, etc.) would be willing to pay some kind of fee to restore and retain their benefits. In addition, if the BMPs provide economic and/or health benefits to the farmers as well, which is the optimum situation, farmers may be willing to share the cost.

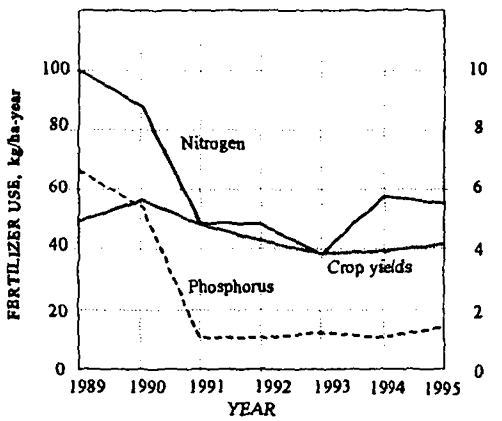

Figure 4. Fertilizer applications in Czech Republic (after Holas, 1997).

Figure 4 shows one possible scenario. Clearly, the high use of fertilizers in the Czech Republic before 1989 was primarily due to government subsidies to agricultural co-operatives which kept the cost of fertilizers artificially low. The adjustment of fertilizer prices to reflect their market value (not yet including the cost of the pollution externality) has resulted in a dramatic reduction of fertilizer use. When farmers and their co-operatives in the Czech Republic significantly reduced the application rates of fertilizers, for example, nitrogen by 50 percent and phosphorus by more than 70 percent, there was only a minimal drop in the crop yield. If this experience was applied to other areas of the world it would significantly reduce the cost of farming due to lower costs for fertilizers but could potentially result in a small (a few percent) loss of income to the farmers. A reduction of yields may slightly increase the market price of the crops which would reduce the loss to the farmer, however, such increases are not certain because in many countries there is an overproduction of crops and prices are not elastic enough to increase proportionally to the reduction in production. In this case, the level of the subsidy from the beneficiaries of improved water quality to the farmers would equal the loss of income due to decreased yields minus the cost savings on the fertilizers.

Consequently, nutrient management must be a part of watershed management. Shuyler (1984) in the special issue of the *Journal of Soil and Water Conservation* devoted to nutrient management, pointed out that in most cases, the nutrient management plan will call for a reduction of present application rates because, today, fields are overfertilized and crops are overproduced at a great cost to the environment and users of water resources.

Examples of such watershed approaches are emerging. A proposal has been made in the Czech Republic whereby users of drinking water in Prague who get their water from the Želivka Reservoir, which is heavily polluted and eutrophic due to agricultural discharges of nutrients, may be willing to provide economic incentives to farm co-operatives and individual farmers in the watershed for reduction of fertilizer use and installation of BMPs (Holas, 1997). Similar approaches should be implemented in the watersheds of the New York drinking water reservoirs that are also suffering from excessive eutrophication, and where water treatment is resulting in large costs (more than \$ 10^9) to the users of drinking water in the city. In Wisconsin, a special fund was created by the legislature, using a fee attached to annual licence plate renewals for automobiles, which provides 75 percent cost-sharing to farmers on installation of BMPs in watersheds that have a diffuse pollution problem. A similar fund was established in Florida from land transaction fees used for watershed management.

Some transfers of benefits must be carried out on an international scale. For example, users of the Black, Baltic and North Seas (tourist, recreation and fishing industries), through the European Community institutional structure, could provide incentives for implementation of BMPs in agriculture, including nutrient management, to farmers in upstream countries who are remote and will not enjoy the benefits of the water quality improvement.

Restoration of eroded and deforested soils in developing countries is another problem that must be addressed. A methodology for reforesting bare lands with no top soils, using effluent sludge and bacterial biofertilization, was developed by the National Environmental Engineering Research Institute (NEERI) in Nagpur, India. The reforested land grows teak, shishum and other valuable cash trees. Harvesting these valuable woods, after a decade of growth, could easily recover the cost of reforestation and bring economic benefits (Juwarkar, 1996).

In conclusion, it can be stated that traditional approaches which have been successfully used to control point sources of pollution in most advanced countries are inoperative for control of pollution from agriculture. A watershed approach involving economic benefit transfers and incentives and advancing toward sustainable agriculture, both locally and globally, is the solution that must be implemented in the next few decades.

ACKNOWLEDGMENT

Presentations of this paper were made on April 9, 1997 by Brian D'Arçy at the conference on *Diffuse Pollution and Agriculture* in Edinburgh, Scotland and by the author at the International Workshop on *Integrated Management of Water Quality - The Role of Agricultural Diffuse Pollution Sources* on May 11, 1997 in Teolo, Veneto Region, Italy.

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