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Control of water pollution from agriculture

FAO IRRIGATION AND DRAINAGE PAPER

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Food and Agriculture Organization of the United Nations

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by

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Foreword

Environmental pollution is a major global concern. When sources of water pollution are enumerated, agriculture is, with increasing frequency, listed as a major contributor. As nations make efforts to correct abuses to their water resources, there is a need to determine the causes of water quality degradation and to quantify pollution contributions from many sources. Until such time as adequate facts are made available through research to delineate causes and sources, conflicting opinions continue to flourish and programmes to control and abate pollution will be less effective and efficient in the use of limited resources.

Existing knowledge indicates that agricultural operations can contribute to water quality deterioration through the release of several materials into water: sediments, pesticides, animal manures, fertilizers and other sources of inorganic and organic matter. Many of these pollutants reach surface and groundwater resources through widespread runoff and percolation and, hence, are called "non-point" sources of pollution. Identification, quantification and control of non-point pollution remain relatively difficult tasks as compared to those of "point" sources of pollution.

FAO's mandate is to raise levels of nutrition and standards of living of people and, in implementing this mandate, it promotes agricultural development and national food security. FAO is equally committed to sustainable development and, hence, has given top priority to sustainable agricultural development. In this context, the Organization recognizes the key role of water in agricultural development and implements a comprehensive Regular Programme on Water Resources Development and Management. One of the thematic areas of this programme is water quality management which includes, among others, the control of water pollution from agricultural activities, with particular reference to non-point sources.

It is under the framework of these Regular Programme activities of the Organization that the preparation of a "guidelines" document on control and management of agricultural water pollution is initiated. The objective is to delineate the nature and consequences of agricultural impacts on water quality, and to provide a framework for practical measures to be undertaken by relevant professionals and decision-makers to control water pollution.

The Organization recognizes that the preparation of the guidelines is only the beginning in the long process of assisting Member Nations to build national capacity and implement programmes on the control of agricultural water pollution. The publication will be disseminated widely among Member Nations and relevant regional and international organizations. It is intended that this will be followed by regional and national workshops, with the mobilization of extra-budgetary sources of funds for this purpose.

The Organization recognizes the contribution of the Canada Centre for Inland Waters, Environment Canada, and the expertise of Dr E. Ongley in the preparation of this document.

Acknowledgements

This publication was prepared as a follow up to FAO's commitment to integrated water management within the framework of sustainable development and food security. This framework was strengthened following the United Conference on Environment and Development, 1992, and links with other water programmes of United Nations specialized agencies such as UNEP, WHO and the GEMS/Water Programme.

The author wishes to acknowledge the assistance of many professionals of FAO for their inspiration and cooperation in developing the framework and locating references. In particular, the wise counsel of Drs Arumugam Kandiah, Hans Wolter and Robert Brinkman of the Land and Water Development Division, is much appreciated. Dr Desmond Walling of the University Exeter, graciously reviewed the draft manuscript and provided useful comment and suggestions for improvement. Much appreciation is extended to the many others within FAO and from other agencies who also reviewed the manuscript. Thanks are also due to Mr J.G. Kamphuis for reviewing and editing the document and Ms C. Redfern for formatting and preparing the text for final printing.

The sections on data issues and integrated basin management are largely drawn from experiences gained through the author's participation in the UNEP/WHO GEMS/Water Programme in many developing countries. Material on environmental information systems reflects the author's long association with Dr David Lam and his staff at the Canada Centre for Inland Waters and Dr David Swain of the University of Guelph.

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Acronyms of institutes and programmes

CCREM	Canadian Council of Resource and Environment Ministers
ECE	United Nations Economic Commission for Europe
EEA	European Environment Agency
EEC	European Economic Community
ESCAP	Economic and Social Commission for Asia and the Pacific
FAO	Food and Agriculture Organization of the United Nations
GEMS	Global Environment Monitoring System
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Pollution
IAEA	International Atomic Energy Agency
ICWE	International Conference on Water and the Environment
OECD	Organization for Economic Cooperation and Development
OMAF	Ontario Ministry of Agriculture and Food
PLUARG	Pollution from Land Use Activities Reference Groups
RIVM	The Netherlands National Institute of Public Health
RIZA	Institute for Inland Water Management and Waste Water Treatment, The Netherlands
UFRGS	Universidade Federal do Rio Grande do Sul
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
US-EPA	United States Environmental Protection Agency
USDA	United States Department of Agriculture
WB	World Bank
WHO	World Health Organization
WWF	World Wildlife Fund

Chapter 1

Introduction to agricultural water pollution

Second only to availability of drinking water, access to food supply is the greatest priority. Hence, agriculture is a dominant component of the global economy. While mechanization of farming in many countries has resulted in a dramatic fall in the proportion of population working in agriculture, the pressure to produce enough food has had a worldwide impact on agricultural practices. In many countries, this pressure has resulted in expansion into marginal lands and is usually associated with subsistence farming. In other countries, food requirements have required expansion of irrigation and steadily increasing use of fertilizers and pesticides to achieve and sustain higher yields. FAO (1990a), in its Strategy on Water for Sustainable Agricultural Development, and the United Nations Conference on Environment and Development (UNCED) in Agenda 21, Chapters 10, 14 and 18 (UNCED, 1992) have highlighted the challenge of securing food supply into the 21st century.

Sustainable agriculture is one of the greatest challenges. Sustainability implies that agriculture not only secure a sustained food supply, but that its environmental, socio-economic and human health impacts are recognized and accounted for within national development plans. FAO's definition of sustainable agricultural development appears in Box 1.

BOX 1: FAO's DEFINITION OF SUSTAINABLE AGRICULTURAL DEVELOPMENT

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.

It is well known that agriculture is the single largest user of freshwater resources, using a global average of 70% of all surface water supplies. Except for water lost through evapo-transpiration, agricultural water is recycled back to surface water and/or groundwater. However, agriculture is both cause and victim of water pollution. It is a cause through its discharge of pollutants and sediment to surface and/or groundwater, through net loss of soil by poor agricultural practices, and through salinization and waterlogging of irrigated land. It is a victim through use of wastewater and polluted surface and groundwater which contaminate crops and transmit disease to consumers and farm workers. Agriculture exists within a symbiosis of land and water and, as FAO (1990a) makes quite clear, "... *appropriate steps must be taken to ensure that agricultural activities do not adversely affect water quality so that subsequent uses of water for different purposes are not impaired.*"

Sagardoy (FAO, 1993a) summarized the action items for agriculture in the field of water quality as:

- establishment and operation of cost-effective water quality monitoring systems for agricultural water uses.
- prevention of adverse effects of agricultural activities on water quality for other social and economic activities and on wetlands, *inter alia* through optimal use of on-farm inputs and the minimization of the use of external inputs in agricultural activities.
- establishment of biological, physical and chemical water quality criteria for agricultural water users and for marine and riverine ecosystems.
- prevention of soil runoff and sedimentation.
- proper disposal of sewage from human settlements and of manure produced by intensive livestock breeding.
- minimization of adverse effects from agricultural chemicals by use of integrated pest management.
- education of communities about the pollution impacts of the use of fertilizers and chemicals on water quality and food safety.

This publication deals specifically with the role of agriculture in the field of freshwater quality. Categories of non-point source impacts ? specifically sediment, pesticides, nutrients, and pathogens ? are identified together with their ecological, public health and, as appropriate, legal consequences. Recommendations are made on evaluation techniques and control measures. Much of the scientific literature on agricultural impacts on surface and groundwater quality is from developed countries, reflecting broad scientific concern and, in some cases, regulatory attention since the 1970s. The scientific findings and management principles are, however, generally applicable worldwide. This publication does not deal with water quality impacts caused by food processing industries insofar as these are considered to be point sources and are usually subject to control through effluent regulation and enforcement.

WATER QUALITY AS A GLOBAL ISSUE

Agriculture, as the single largest user of freshwater on a global basis and as a major cause of degradation of surface and groundwater resources through erosion and chemical runoff, has cause to be concerned about the global implications of water quality. The associated agrofood-processing industry is also a significant source of organic pollution in most countries. Aquaculture is now recognised as a major problem in freshwater, estuarine and coastal environments, leading to eutrophication and ecosystem damage. The principal environmental and public health dimensions of the global freshwater quality problem are highlighted below:

- Five million people die annually from water-borne diseases.

- Ecosystem dysfunction and loss of biodiversity.
- Contamination of marine ecosystems from land-based activities.
- Contamination of groundwater resources.
- Global contamination by persistent organic pollutants.

Experts predict that, because pollution can no longer be remedied by dilution (i.e. the flow regime is fully utilized) in many countries, freshwater quality will become the principal limitation for sustainable development in these countries early in the next century. This "crisis" is predicted to have the following global dimensions:

- Decline in sustainable food resources (e.g. freshwater and coastal fisheries) due to pollution.
- Cumulative effect of poor water resource management decisions because of inadequate water quality data in many countries.
- Many countries can no longer manage pollution by dilution, leading to higher levels of aquatic pollution.
- Escalating cost of remediation and potential loss of "creditworthiness".

The real and potential loss of development opportunity because of diversion of funds for remediation of water pollution has been noted by many countries. At the 1994 Expert Meeting on Water Quantity and Quality Management convened by the Economic and Social Commission for Asia and the Pacific (ESCAP), Asian representatives approved a declaration which called for national and international action to assess loss of economic opportunity due to water pollution and to determine the potential economic impacts of the "looming water crisis". Interestingly, the concern of the delegates to the ESCAP meeting was to demonstrate the economic rather than simply the environmental impacts of water pollution on sustainable development. Creditworthiness (Matthews, 1993) is of concern insofar as lending institutions now look at the cost of remediation relative to the economic gains. There is concern that if the cost of remediation exceeds economic benefits, development projects may no longer be creditworthy. Sustainable agriculture will, inevitably, be required to factor into its water resource planning the larger issues of sustainable economic development across economic sectors. This comprehensive approach to management of water resources has been highlighted in the World Bank's (1993) policy on water resource development.

Older chlorinated agricultural pesticides have been implicated in a variety of human health issues and as causing significant and widespread ecosystem dysfunction through their toxic effects on organisms. Generally banned in the developed countries, there is now a concerted international effort to ban these worldwide as part of a protocol for Persistent Organic Pollutants (POPs). One example of such an effort was the Intergovernmental Conference on the Protection of the Marine Environment from Land-based Activities, convened in Washington DC in 1995 jointly with UNEP (more information is included in Chapter 5).

TABLE 1
Classes of non-point source pollution (highlighted categories refer to agricultural activities)
(Source: International Joint Commission, 1974, and other sources)

Agriculture **Animal feedlots** **Irrigation** **Cultivation** **Pastures** **Dairy farming** **Orchards** **Aquaculture**	**Runoff from all categories of agriculture leading to surface and groundwater pollution. In northern climates, runoff from frozen ground is a major problem, especially where manure is spread during the winter. Vegetable handling, especially washing in polluted surface waters in many developing countries, leads to contamination of food supplies. Growth of aquaculture is becoming a major polluting activity in many countries. Irrigation return flows carry salts, nutrients and pesticides. Tile drainage rapidly carries leachates such as nitrogen to surface waters.**	**Phosphorus, nitrogen, metals, pathogens, sediment, pesticides, salt, BOD[1], trace elements (e.g. selenium).**
Forestry	**Increased runoff from disturbed land. Most damaging is forest clearing for urbanization.**	**Sediment, pesticides.**
Liquid waste disposal	Disposal of liquid wastes from municipal wastewater effluents, sewage sludge, industrial effluents and sludges, wastewater from home septic systems; **especially disposal on agricultural land**, and legal or illegal dumping in watercourses.	Pathogens, metals, organic compounds.
Urban areas Residential Commercial Industrial	Urban runoff from roofs, streets, parking lots, etc. leading to overloading of sewage plants from combined sewers, or polluted runoff routed directly to receiving waters; local industries and businesses may discharge wastes to street gutters and storm drains; street cleaning; road salting contributes to surface and groundwater pollution.	Fertilizers, greases and oils, faecal matter and pathogens, organic contaminants (e.g. PAHs[2] and PCBs[3]), heavy metals, pesticides, nutrients, sediment, salts, BOD, COD[4], etc.
Rural sewage systems	Overloading and malfunction of septic systems leading to surface runoff and/or direct infiltration to groundwater.	Phosphorus, nitrogen, pathogens (faecal matter).
Transportation	Roads, railways, pipelines, hydro-electric corridors, etc.	Nutrients, sediment, metals, organic contaminants, pesticides (especially herbicides).
Mineral extraction	Runoff from mines and mine wastes, quarries, well sites.	Sediment, acids, metals, oils, organic contaminants, salts (brine).
Recreational land use	Large variety of recreational land uses, including ski resorts, boating and marinas, campgrounds, parks; waste and "grey" water from recreational boats is a major pollutant, especially in small lakes and rivers. Hunting (lead pollution in waterfowl).	Nutrients, pesticides, sediment, pathogens, heavy metals.
Solid waste disposal	Contamination of surface and groundwater by leachates and gases. Hazardous wastes may be disposed of through underground disposal.	Nutrients, metals, pathogens, organic contaminants.
Dredging	Dispersion of contaminated sediments, leakage from containment areas.	Metals, organic contaminants.
Deep well disposal	Contamination of groundwater by deep well injection of liquid wastes, especially oilfield brines and liquid industrial wastes.	Salts, heavy metals, organic contaminants.
Atmospheric deposition	Long-range transport of atmospheric pollutants (LRTAP) and deposition of land and water surfaces. Regarded as a significant source of pesticides (from agriculture, etc.), nutrients, metals, etc., especially in pristine environments.	Nutrients, metals, organic contaminants.

[1] BOD = Biological Oxygen Demand
[2] PAH = Polycyclic Aromatic Hydrocarbons
[3] PCB = Polycyclic Chlorinated Bi-Phenyls
[4] COD = Chemical Oxygen Demand

NON-POINT SOURCE POLLUTION DEFINED

Non-point source water pollution, once known as “diffuse” source pollution, arises from a broad group of human activities for which the pollutants have no obvious point of entry into receiving watercourses. In contrast, **point source** pollution represents those activities where wastewater is routed directly into receiving water bodies by, for example, discharge pipes, where they can be easily measured and controlled. Obviously, non-point source pollution is much more difficult to identify, measure and control than point sources. The term “diffuse” source should be avoided as it has legal connotation in the United States that can now include certain types of point sources.

In the United States, the Environmental Protection Agency (US-EPA) has an extensive permitting system for point discharge of pollutants in watercourses. Therefore, in that country, non-point sources are defined as any source which is not covered by the legal definition of “point source” as defined in the section 502(14) of the United States Clean Water Act (Water Quality Act) of 1987:

> *“The term “**point source**” means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, form which pollutants are or may be discharged. This term does **not** include agricultural storm water discharges and return flows from irrigated agriculture.”*

The reference to “agricultural storm water discharges” is taken to mean that pollutant runoff from agriculture occurs primarily during storm flow conditions. However, even in the United States, the distinction between point and non-point sources can be unclear and, as Novotny and Olem (1994) point out, these terms tend to have assumed legal rather than technical meanings.

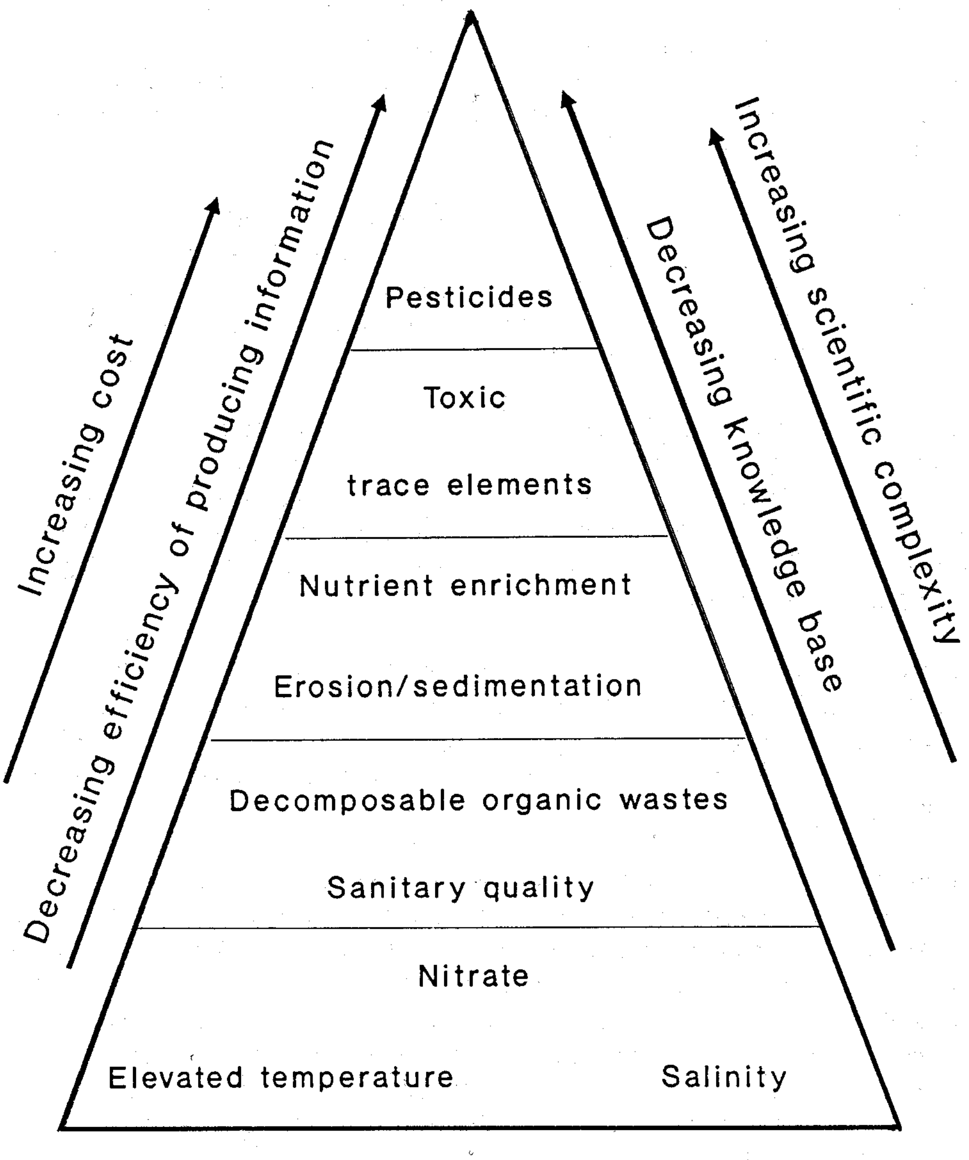
Conventionally, in most countries, **all types of agricultural practices and land use, including animal feeding operations (feed lots), are treated as non-point sources**. The main characteristics of non-point sources are that they **respond to hydrological conditions**, are **not easily measured or controlled directly** (and therefore are difficult to regulate), and **focus on land and related management practices**. Control of point sources in those countries having effective control programmes is carried out by effluent treatment according to regulations, usually under a system of discharge permits. In comparison, control of non-point sources, especially in agriculture, has been by education, promotion of appropriate management practices and modification of land use.

Classes of non-point sources

Prevention and modification of land-use practices

Table 1 outlines the classes of non-point sources and their relative contributions to pollution loadings. Agriculture is only one of a variety of causes of non-point sources of pollution, however it is generally regarded as the largest contributor of pollutants of all the categories.

FIGURE 1
Hierarchial complexity of agriculturally-related water quality problems (Rickert, 1993)



SCOPE OF THE PROBLEM

Non-point source pollutants, irrespective of source, are transported overland and through the soil by rainwater and melting snow. These pollutants ultimately find their way into groundwater, wetlands, rivers and lakes and, finally, to oceans in the form of sediment and chemical loads carried by rivers. As discussed below, the ecological impact of these pollutants range from simple nuisance substances to severe ecological impacts involving fish, birds and mammals, and on human health. The range and relative complexity of agricultural non-point source pollution are illustrated in Figure 1.

In what is undoubtedly the earliest and still most extensive study of non-point source pollution, Canada and the United States undertook a major programme of point and non-point source identification and control in the 1970s for the entire Great Lakes basin. This was precipitated by public concern (e.g. press reports that "Lake Erie was dead!") over the deterioration in water quality, including the visible evidence of algal blooms and increase in aquatic weeds. Scientifically, the situation was one of hypertrophic[1] conditions in Lake Erie and eutrophic[1] conditions in Lake Ontario caused by excessive phosphorus entering the Lower Great Lakes from point and non-point sources. The two countries, under the bilateral International Joint Commission, established the "Pollution from Land Use Activities Reference Groups" (known as "PLUARG") which served as the scientific vehicle for a ten year study of pollution sources from the entire Great Lakes basin, and which culminated in major changes both to point and non-point source control. The study also resulted in an unprecedented increase in scientific understanding of the impacts of land use activities on water quality. This work, mainly done in the 1970s and early 1980s, still has great relevance to non-point source issues now of concern elsewhere in the world.

The PLUARG study, through analysis of monitoring data of rivers within the Great Lakes, from detailed studies of experimental and representative tributary catchments, and from research of agricultural practices at the field and plot level, found that non-point sources in general, and agriculture in particular, were a major source of pollution to the Great Lakes. By evaluation of the relative contributions of point and non-point sources to pollution loads to the Great Lakes, the PLUARG study proposed a combined programme of point source control and land use modification. The two federal governments and riparian state and provincial governments implemented these recommendations with the result that the two lower and most impacted Great Lakes (Erie and Ontario) have undergone major improvements in water quality and in associated ecosystems in the past decade. A significant factor in the agricultural sector was the high degree of public participation and education. Change in agricultural practices was, in many cases, achieved by demonstrating to farmers that there were economic gains to be realized by changing land management practices.

In most industrialized countries, the focus on water pollution control has traditionally been on point source management. In the United States, which is probably reasonably typical of other industrialized nations, the economics of further increases in point source regulation are being challenged, especially in view of the known impacts of non-point sources of which agriculture has the largest overall and pervasive impact. There is a growing opinion that, despite the billions of dollars spent on point source control measures, further point source control cannot achieve major additional benefits in water quality without significant control over non-point sources. In this context, it is relevant to note that agriculture is regarded as the main non-point source issue. Table 2 presents the outcome of a study by US-EPA (1994) on the ranking of sources of water quality deterioration in rivers, lakes and estuaries.

The United States is one of the few countries that systematically produces national statistics on water quality impairment by point and non-point sources. In its 1986 Report to Congress, the United States Environmental Protection Agency (US-EPA) reported that 65% of assessed river miles in the United States were impacted by non-point sources. Again, in its most recent study, the US-EPA (1994) identified agriculture as the leading cause of water

[1] These terms refer to the levels of nutrient enrichment in water; these are described in Chapter 3.

TABLE 2
Leading sources of water quality impairment in the United States (US-EPA, 1994)

Rank	Rivers	Lakes	Estuaries
1	**Agriculture**	**Agriculture**	Municipal point sources
2	Municipal point sources	Urban runoff/storm sewers	Urban runoff/storm sewers
3	Urban runoff/storm	Hydrologic/habitat modification	**Agriculture**
4	Resource extraction	Municipal point sources	Industrial point sources
5	Industrial point sources	On-site wastewater	Resource extraction

TABLE 3
Percent of assessed river length and lake area impacted (US-EPA, 1994)

Source of pollution	Rivers (%)	Lakes (%)	Nature of pollutant	Rivers (%)	Lakes (%)
Agriculture	72	56	Siltation (sediment)	45	22
Municipal point sources	15	21	Nutrients	37	40
Urban runoff/storm sewers	11	24	Pathogens	27	
Resource extraction	11		Pesticides	26	
Industrial point sources	7		Organic enrichment DO	24	24
Silviculture	7		Metals	19	47
Hydrologic/habitat modification	7	23	Priority organic chemicals		20
On-site wastewater disposal		16			
Flow modification		13			

TABLE 4
Number of States reporting groundwater contamination (maximum possible is 50) (US-EPA, 1994)

Pollutants	No. of States	Pollutants	No. of States
Nitrates	**49**	Volatile organic substances	48
Petroleum products	46	Metals	45
Pesticides	**43**	Brine/salinity	37
Synthetic organic substances	36	Arsenic	28
Other substances	26	**Other agricultural chemicals**	**23**
Radioactive material	23	Fluoride	20
Other inorganic substances	15		

quality impairment of rivers and lakes in the United States (Table 3) and third in importance for pollution of estuaries. Agriculture also figures prominently in the types of pollutants as noted in Table 3. Sediment, nutrients and pesticides occupy the first four categories and are significantly associated with agriculture. While these findings indicate the major importance of agriculture in water pollution in the United States, the ranking would change in countries with less control over point sources. However, a change in ranking only indicates that point source controls are less effective, not that agricultural sources of pollution are any less polluting.

The ranking of agriculture as a major polluter is highlighted by the statistics of Table 3. Fully 72 % of assessed river length and 56% of assessed lakes are impacted by agriculture. These finding caused the US-EPA to declare that: "***AGRICULTURE** is the leading source of impairment in the Nation's rivers and lakes ...*".

Since the 1970s there has also been growing concern in Europe over the increases in nitrogen, phosphorus and pesticide residues in surface and groundwater. Intense cultivation and "factory" livestock operations led to the conclusion, already drawn by the French in 1980, that agriculture is a significant non-point source contributor to surface and groundwater pollution (Ignazi, 1993). In a recent comparison of domestic, industrial and agricultural sources of pollution from the coastal zone of Mediterranean countries, UNEP (1996) found that agriculture was the leading source of phosphorus compounds and sediment.

The European Community has responded with Directive (91/676/EEC) on "Protection of waters against pollution by nitrates from agricultural sources". The situation in France has resulted in the formation of an "Advisory Committee for the Reduction of Water Pollution by Nitrates and Phosphates of Agricultural Origin" under the authorities of the Ministry of Agriculture and the Ministry of the Environment (Ignazi, 1993).

Agriculture is also cited as a leading cause of **groundwater pollution** in the United States. In 1992, fully forty-nine of fifty states identified that nitrate was the principal groundwater contaminant, followed closely by the pesticide category (Table 4). The US-EPA (1994) concluded that: *"more than 75% of the states reported that **AGRICULTURAL ACTIVITIES** posed a significant threat to **GROUNDWATER** quality."*

In an analysis of wetlands, the US-EPA (1994) reported that: *"**AGRICULTURE** is the most important land use causing **WETLAND** degradation".*

Similar data are difficult to obtain or are not systematically collected and reported in other countries, however, numerous reports and studies indicate that similar concerns are expressed in many other developed and developing countries.

AGRICULTURAL IMPACTS ON WATER QUALITY

Types of impacts

As indicated in Table 5 the impacts of agriculture on water quality are diverse. The major impacts will be discussed in greater detail in subsequent chapters.

Irrigation impacts on surface water quality

United Nations' predictions of global population increase to the year 2025 require an expansion of food production of about 40-45%. Irrigation agriculture, which currently comprises 17% of all agricultural land yet produces 36% of the world's food, will be an essential component of any strategy to increase the global food supply. Currently 75% of irrigated land is located in developing countries; by the year 2000 it is estimated that 90% will be in developing countries.

In addition to problems of waterlogging, desertification, salinization, erosion, etc., that affect irrigated areas, the problem of downstream degradation of water quality by salts, agrochemicals and toxic leachates is a serious environmental problem. "It is of relatively recent recognition that salinization of water resources is a major and widespread phenomenon of possibly even greater concern to the sustainability of irrigation than is that of the salinization of soils, per se. Indeed, only in the past few years has it become apparent that trace toxic constituents, such as Se, Mo and As in agricultural drainage waters may cause pollution problems that threaten the continuation of irrigation in some projects" (Letey *et al*., cited in Rhoades, 1993).

TABLE 5
Agricultural impacts on water quality

Agricultural activity	Impacts	
	Surface water	Groundwater
Tillage/ploughing	**Sediment/turbidity**: sediments carry phosphorus and pesticides adsorbed to sediment particles; **siltation** of river beds and loss of habitat, spawning ground, etc.	
Fertilizing	Runoff of nutrients, especially phosphorus, leading to eutrophication causing taste and odour in public water supply, excess algae growth leading to deoxygenation of water and fish kills.	Leaching of nitrate to groundwater; excessive levels are a threat to public health.
Manure spreading	Carried out as a fertilizer activity; spreading on frozen ground results in high levels of contamination of receiving waters by pathogens, metals, phosphorus and nitrogen leading to eutrophication and potential contamination.	Contamination of ground-water, especially by nitrogen
Pesticides	Runoff of pesticides leads to contamination of surface water and biota; dysfunction of ecological system in surface waters by loss of top predators due to growth inhibition and reproductive failure; public health impacts from eating contaminated fish. Pesticides are carried as dust by wind over very long distances and contaminate aquatic systems 1000s of miles away (e.g. tropical/subtropical pesticides found in Arctic mammals).	Some pesticides may leach into groundwater causing human health problems from contaminated wells.
Feedlots/animal corrals	Contamination of surface water with many pathogens (bacteria, viruses, etc.) leading to chronic public health problems. Also contamina-tion by metals contained in urine and faeces.	Potential leaching of nitrogen, metals, etc. to groundwater.
Irrigation	Runoff of salts leading to salinization of surface waters; runoff of fertilizers and pesticides to surface waters with ecological damage, bioaccumulation in edible fish species, etc. High levels of trace elements such as selenium can occur with serious ecological damage and potential human health impacts.	Enrichment of groundwater with salts, nutrients (especially nitrate).
Clear cutting	Erosion of land, leading to high levels of turbidity in rivers, siltation of bottom habitat, etc. Disruption and change of hydrologic regime, often with loss of perennial streams; causes public health problems due to loss of potable water.	Disruption of hydrologic regime, often with increased surface runoff and decreased groundwater recharge; affects surface water by decreasing flow in dry periods and concentrating nutrients and contaminants in surface water.
Silviculture	Broad range of effects: pesticide runoff and contamination of surface water and fish; erosion and sedimentation problems.	
Aquaculture	Release of pesticides (e.g. TBT[1]) and high levels of nutrients to surface water and groundwater through feed and faeces, leading to serious eutrophication.	

[1] TBT = Tributyltin

FIGURE 2
Turbid irrigation return flow from a large irrigated area of southern Alberta, Canada

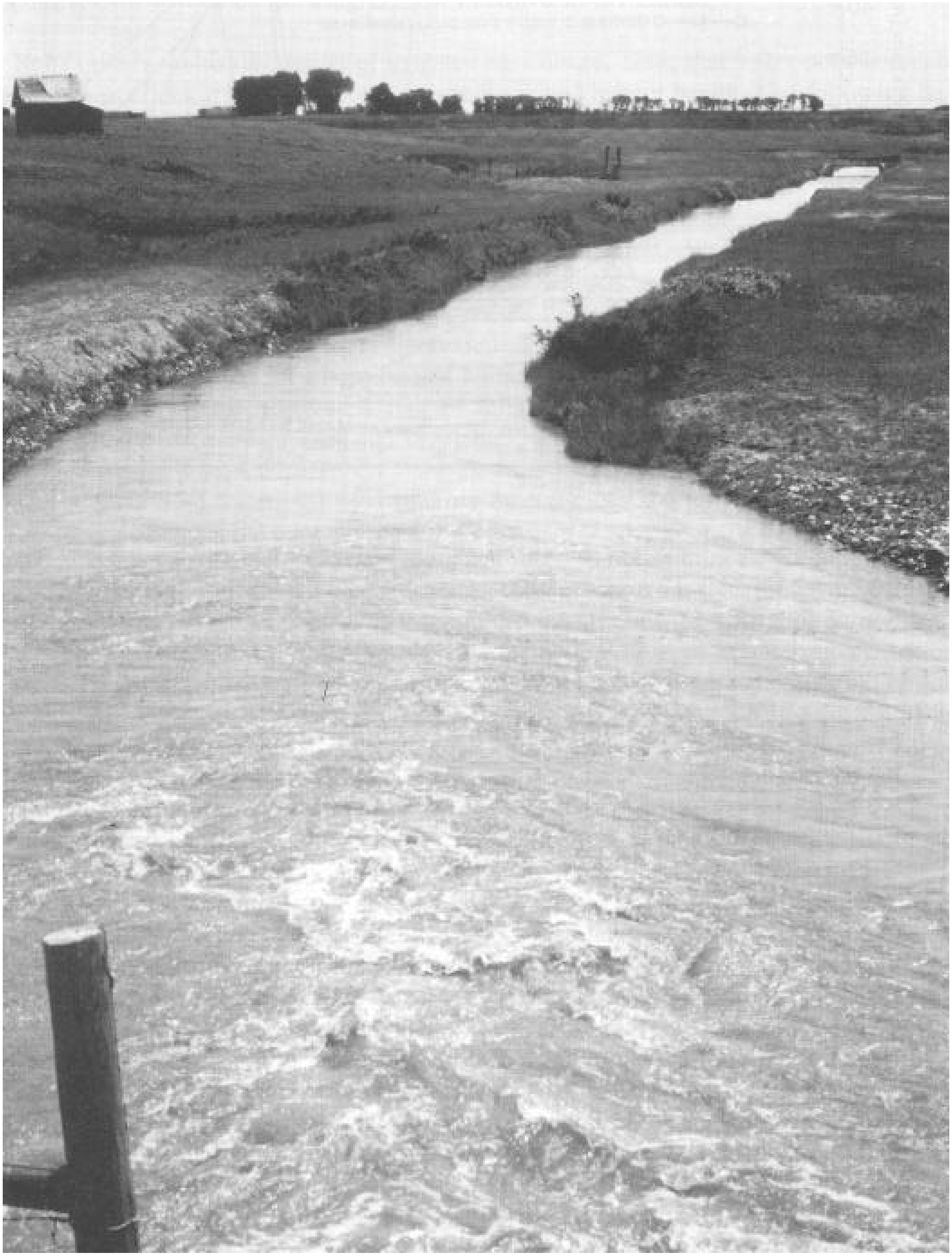
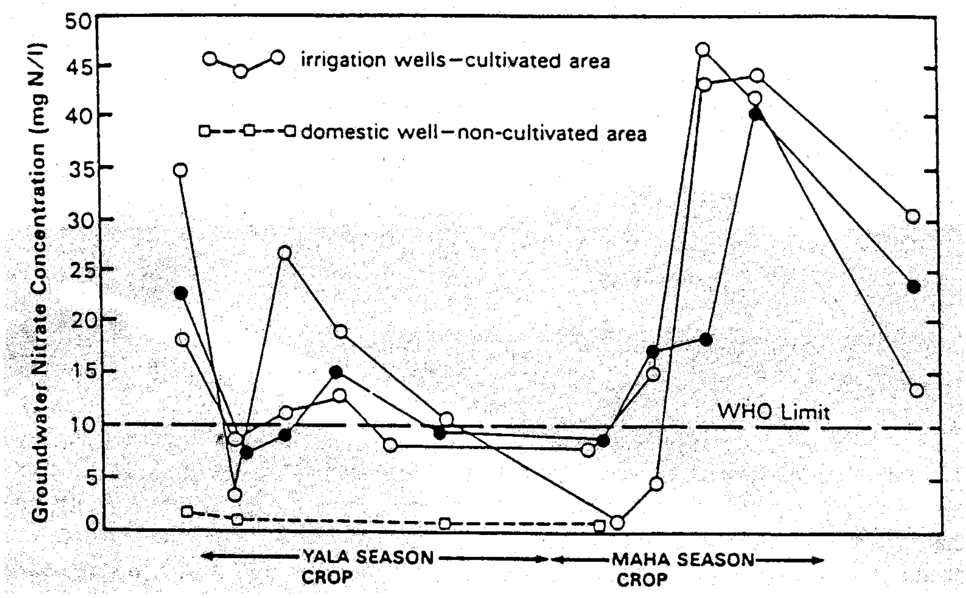


FIGURE 3
Seasonal nitrate variations in shallow sand aquifers in Sri Lanka in areas under intensive fertilized irrigation

(*Yala* refers to the dry season; *maha* refers to the rainy season)



Public health impacts

Polluted water is a major cause of human disease, misery and death. According to the World Health Organization (WHO), as many as 4 million children die every year as a result of diarrhoea caused by water-borne infection. The bacteria most commonly found in polluted water are coliforms excreted by humans. Surface runoff and consequently non-point source pollution contributes significantly to high level of pathogens in surface water bodies. Improperly designed rural sanitary facilities also contribute to contamination of groundwater.

Agricultural pollution is both a direct and indirect cause of human health impacts. The WHO reports that nitrogen levels in groundwater have grown in many parts of the world as a result of “intensification of farming practice” (WHO, 1993). This phenomenon is well known in parts of Europe. Nitrate levels have grown in some countries to the point where more than 10% of the population is exposed to nitrate levels in drinking water that are above the 10 mg/l guideline. Although WHO finds no significant links between nitrate and nitrite and human cancers, the drinking water guideline is established to prevent methaemoglobinaemia to which infants are particularly susceptible (WHO, 1993).

Although the problem is less well documented, nitrogen pollution of groundwater appears also to be a problem in developing countries.

Lawrence and Kumppnarachi (1986) reported nitrate concentrations approaching 40-45 mg N/l in irrigation wells that are located close to the intensively cultivated irrigated paddy fields. Figure 3 illustrates the variation in NO_3-N which shows a peak in the *maha* (main) cropping season when rice growing is most intensive in Sri Lanka.

Reiff (1987), in his discussion of irrigated agriculture, notes that water pollution is both a cause and an effect in linkages between agriculture and human health. The following health impacts (in descending order of health significance) which apply, in particular, to developing countries, were noted by Reiff:

- Adverse environmental modifications result in improved breeding ground for vectors of disease (e.g. mosquitos). There is a linkage between increase in malaria in several Latin American countries and reservoir construction. Schistosomiasis (Bilharziasis), a parasitic disease affecting more than 200 million people in 70 tropical and subtropical countries, has been demonstrated to have increased dramatically in the population following reservoir construction for irrigation and hydroelectric power production. Reiff indicates that the two groups at greatest risk of infection are farm workers dedicated to the production of rice, sugar cane and vegetables, and children that bathe in infested water.

- Contamination of water supplies primarily by pesticides and fertilizers. Excessive levels of many pesticides have known health effects.

- Microbiological contamination of food crops stemming from use of water polluted by human wastes and runoff from grazing areas and stockyards. This applies both to use of polluted water for irrigation, and by direct contamination of foods by washing vegetables etc. in polluted water prior to sale. In many developing countries there is little or no treatment of municipal sewage, yet urban wastewater is increasingly being used directly or recycled from receiving waters, into irrigated agriculture. The most common diseases associated with contaminated irrigation waters are cholera, typhoid, ascariasis, amoebiasis, giardiasis, and enteroinvasive *E. coli*. Crops that are most implicated with spread of these diseases are ground crops that are eaten raw such as cabbage, lettuce, strawberries, etc.

- Contamination of food crops with toxic chemicals.

- Miscellaneous related health effects, including treatment of seed by organic mercury compounds, turbidity (which inhibits the effectiveness of disinfection of water for potable use), etc.

To this list can be added factors such as the potential for hormonal disruption (endocrine disruptors) in fish, animals and humans. Hormones are produced by the body's endocrine system. Because of the critical role of hormones during early development, toxicological effects on the endocrine system often have impacts on the reproductive system (Kamrin, 1995). While pesticides such as DDT have been implicated, the field of endocrine disruption is in its infancy and data which support cause and effect are not yet conclusive. It is probably safe to conclude, however, that high levels of agricultural contaminants in food and water as are found in many developing country situations have serious implications for reproduction and human health. Box 2 presents a survey of the agricultural impacts in the Aral Sea region.

BOX 2: AGRICULTURE AND THE ARAL SEA DISASTER

The social, economic and ecological disaster that has occurred in the Aral Sea and its drainage basin since the 1960s, is the world's largest example of how poorly planned and poorly executed agricultural practices have devastated a once productive region. Although there are many other impacts on water quality in the region, improper agricultural practice is the root cause of this disaster. Virtually all agriculture is irrigated in this arid area. The Aral Sea basin includes Southern Russia, Uzbekistan, Tadjikistan, and part of Kazakhstan, Kirghiztan, Turkmenistan, Afghanistan, and Iran.

Population: 1976 = 23.5 million; and 1990 = 34 million
Area: 1.8×10^6 km^2 **% Irrigated = 65.6%** (1985)

Water Balance of the Aral Sea Basin

Perennial (average) water supply: 118.3 km^3/yr (100%)
Irrigation demand (current estimates): 113.9 km^3/yr **(96.3%)**
Consumptive use in irrigation is 75.2 km^3/yr (63.4% of available water supply)

Irrigation Expansion and Inflow to Aral Sea

Irrigation: Since 2000-3000 B.C.
1950s + -- major expansion
1985 - 65.6% of total land area

Inflow to Aral Sea: Historical: 56 km^3/yr
1966-1970: 47 km^3/yr
1981-1985: 2 km^3/yr

Salinization

Magnitude and acceleration of salinization is demonstrated in Uzbekistan

	Salinized Area	% of Total Irrigated Area
1982	12 000 km^2	36.3
1985	16 430 km^2	42.8

Public Health Impacts (Over past 15 years)

Typhoid - 29-fold increase (morbidity index up 20%)
Viral Hepatitis - 7-fold increase
Paratyphoid - 4-fold increase
Number of persons with hypertonia, heart disease, gastric and duodenal ulcers – up 100%
Increase in premature births - up 31%

Morbidity & Mortality in Karakalpakia, from 1981-1987

Liver cancers:	up 200%
Gullet cancers:	up 25%
Oesophageal cancers:	up 100%
Cancer occurrence in young persons:	up 100%
Infant mortality:	up 20% (1980-1989)

Ecological and water quality impacts

Salt content of major rivers exceeds standard by factors of 2-3.

Contamination of agricultural products with agro-chemicals.

High levels of turbidity in major water sources.

High levels of pesticides and phenols in surface waters.

Excessive pesticide concentrations in air, food products and breast milk.

Loss of soil fertility.

Induced climatic changes.

Major decline and extinctions of animal, fish and vegetation species.

Destruction of major ecosystems.

Decline in Aral Sea level by 15.6 metres since 1960.

Decline in Aral Sea volume by 69%.

Destruction of commercial fishery.

MISMANAGEMENT OF AGRICULTURE IS THE ROOT CAUSE

* Increase in irrigation area and water withdrawals.
* Use of unlined irrigation canals.
* Rising groundwater.
* Extensive monoculture and excessive use of persistent pesticides.
* Increased salinization and salt runoff leading to salinization of major rivers.
* Increased frequency of dust storms and salt deposition.
* Discharge of highly mineralized, pesticide-rich return flows to main rivers.
* Excessive use of fertilizers.

UNEP (1993) concludes that, "high mineral [salt] content in drinking waters affects the morbidity of digestive, cardiovascular and urine-secretion system organs, as well as the development of gynaecological and pregnancy-related pathology," and "... the effects of pesticides on the level of oncological [cancer], pulmonary, and haematological morbidity, as well as on inborn deformities and other genetic factors .... exposure to pesticides also has been linked to immune system deficiencies...".

(Source: UNEP, 1993. The Aral Sea)

Data on agricultural water pollution in developing countries

Data on water pollution in developing countries are limited. Further, such data are mostly "aggregated", not distinguishing the relative proportion of "point" and "non-point" sources. In Thailand, the Ministry of Public Health reported the results of pollution monitoring of 32 rivers (Table 6).

TABLE 6
Pollution of 32 rivers in Thailand (Ministry of Public Health, Thailand, 1986)

Types of pollution	No. of rivers affected out of 32 monitored
Organic waste	13
Microbial waste	20
Heavy metals	8

Pesticide consumption has strongly increased in all developing countries. In India, consumption increased nearly 50-fold between 1958 and 1975. Yet the Indian consumption in 1973-74 was reported to be averaging a mere 330 g/ha, compared to 1483 g in USA and 1870 g in Europe (Avcievala, 1991).

According to various surveys in India and Africa, 20-50% of wells contain nitrate levels greater than 50 mg/l and in some cases as high as several hundred milligrams per litre (Convey and Pretty, 1988). In the developing countries, it is usually wells in villages or close to towns that contain the highest levels, suggesting that domestic excreta are the main source, though livestock wastes are particularly important in semi-arid areas where drinking troughs are close to wells.

TYPES OF DECISIONS IN AGRICULTURE FOR NON-POINT SOURCE POLLUTION CONTROL

Decisions by agriculturalists for control of agricultural non-point source pollution can be at various scales. At the **field level**, decisions are influenced by very local factors such as crop type and land use management techniques, including use of fertilizers and pesticides. These decisions are based on best management practices that are possible under the local circumstances and are meant to maximize economic return to the farmer while safeguarding the environment. Local decisions are made on the basis of known relationships between farm practice and environmental degradation but do NOT usually involve specific assessment of farm practices within the larger context of river basin impacts from other types of sources. Decisions regarding use of waste water, sludges, etc. for agricultural application are also made using general knowledge of known impacts and of measures to mitigate or minimize these impacts. Specific recommendations are made in each chapter of this publication. However, the challenge for agriculturists is to mobilize the knowledge base and to make it available to farmers.

At the **river basin scale**, the nature of decision making is quite different. At this scale, the typical decision-making problem for non-point source control in many developing countries is that illustrated in Box 3.

BOX 3: A TYPICAL SCENARIO FOR DECISION MAKING

1. Environmental status:

HIGHLY EUTROPHIC or CONTAMINATED LAKE OR RIVER
HIGH TURBIDITY
ECOSYSTEM DYSFUNCTION
↓
↓

2. The database and institutional capability is very frequently found to be:

NO POINT OR NONPOINT SOURCE CONTROLS
LITTLE RELEVANT DATA
POOR LABORATORIES
INADEQUATE SCIENCE / KNOWLEDGE OF ISSUE
LITTLE MONEY
↓
↓

3. The usual questions in such situations are:

WHAT IS THE IMPACT OF AGRICULTURE
RELATIVE TO OTHER SOURCES ?
for
Nutrients **Sediment**
Pathogens **Salinization**
Contaminants

↓

4. Type of solution:

WHAT IS THE MOST COST-EFFECTIVE MEANS
OF REHABILITATION OR REMEDIATION?

Comprehensive Basin Management
Point Source Control versus Non-point Source Control

It is not possible in this publication to describe in detail the “tools” that are used to address this basin-scale management problem. Moreover, many of the tools are not yet systematized to the point where they are easily accessible to agricultural practitioners.

THE DATA PROBLEM

One area, however, that is well known, is the data problem. The water quality database that is available in many developing countries (and in some developed countries) is of little value in pollution management at the river basin scale nor is it useful for determining the impact of agriculture relative to other types of anthropogenic impacts.

A common observation amongst water quality professionals is that many water quality programmes, especially in the developing countries, collect the wrong parameters, from the wrong places, using the wrong substrates and at inappropriate sampling frequencies, and produce data that are often quite unreliable. Further, the data are not assessed or evaluated, and are not sufficiently connected to realistic and meaningful programme, legal or management objectives. This is not the fault of the developing countries; more often it results from inappropriate technology transfer from the developed countries and an incorrect assumption by recipients and donors that the data paradigm developed by the developed countries is appropriate in the developing countries (Ongley, 1994).

Additionally, water quality monitoring programmes, worldwide, are under severe stress as governments reduce budgets, downsize, and shift priorities. "Monitoring" has become a dirty word and governments are increasingly reluctant to pay for it. Paradoxically, the need for reliable water quality information has never been greater. Fortunately, new scientific research, together with budget realities, now makes it possible to rethink and redesign data programmes that are inherently more focused, more practical, more efficient, produce more information and less data, and which meet programme goals in measurable economic terms (see Chapter 5).

This publication is not the place to deal substantively with new monitoring (data collection) techniques; however, it is sufficient to note here that monitoring technology has changed dramatically in the past decade, to the point where significant economic and information gains can be achieved in most monitoring programmes (Chapter 5). Significant for agricultural programmes is that water quality data are rarely collected by ministries of agriculture. Nevertheless, sustainable agriculture within the framework of comprehensive basin management will require relevant and reliable data upon which to make management decisions. This will necessitate intervention by agriculturalists in existing water quality data programmes if relevant data are to be collected for agricultural management purposes.

Chapter 2

Pollution by sediments

Although agriculture contributes to a wide range of water quality problems, anthropogenic erosion and sedimentation is a global issue that tends to be primarily associated with agriculture. While there are no global figures, it is probable that agriculture, in the broadest context, is responsible for much of the global sediment supply to rivers, lakes, estuaries and finally into the world's oceans.

Pollution by sediment has two major dimensions.

One is the PHYSICAL DIMENSION - top soil loss and land degradation by gullying and sheet erosion and which leads both to excessive levels of turbidity in receiving waters, and to off-site ecological and physical impacts from deposition in river and lake beds.

The other is a CHEMICAL DIMENSION - the silt and clay fraction (<63μm fraction), is a primary carrier of adsorbed chemicals, especially phosphorus, chlorinated pesticides and most metals, which are transported by sediment into the aquatic system.

Erosion is also a net cost to agriculture insofar as loss of top soil represents an economic loss through loss of productive land by erosion of top soil, and a loss of nutrients and organic matter that must be replaced by fertilizer at considerable cost to the farmer in order to maintain soil productivity. The reader is referred to Roose (FAO, 1994a) for a detailed analysis of the social, economic and physical consequences of erosion of agricultural land and of measures that should be taken to control erosion under different types of land use, especially in developing countries. Whereas Roose is mainly concerned with the impact of erosion on agriculture, this publication is primarily concerned with agricultural erosion from the perspective of its impacts on downstream water quality.

Control of agricultural pollution usually begins, therefore, with measures to control erosion and sediment runoff. Therefore, this chapter deals with the principal mechanisms which govern erosion processes, and those measures which can be taken to control erosion. Processes discussed here also apply to fertilizer and pesticide runoff presented in the following chapters.

SEDIMENT AS A PHYSICAL POLLUTANT

Global estimates of erosion and sediment transport in major rivers of the world vary widely, reflecting the difficulty in obtaining reliable values for sediment concentration and discharge in many countries, the assumptions that are made by different researchers, and the opposing effects of accelerated erosion due to human activities (deforestation, poor agricultural practices, road construction, etc.) relative to sediment storage by dam construction. Milliman and Syvitski (1992) estimate global sediment load to oceans in the mid-20th century at 20 thousand million t/yr, of which about 30% comes from rivers of southern Asia (including the Yangtze and Yellow Rivers of China). Significantly, they believe that almost 50% of the global total comes from erosion associated with high relief on islands of Oceania - a phenomenon which has been underestimated in previous estimates of global sediment production. While erosion on mountainous islands and in upland areas of continental rivers reflects natural topographic influences, Milliman and Syvitski suggest that human influences in Oceania and southern Asia cause disproportionately high sediment loads in these regions.

Sediment, as a physical pollutant, impacts receiving waters in the following principal ways:

- High levels of **turbidity** limit penetration of sunlight into the water column, thereby limiting or prohibiting growth of algae and rooted aquatic plants. In spawning rivers, gravel beds are blanketed with fine sediment which inhibits or prevents spawning of fish. In either case, the consequence is disruption of the aquatic ecosystem by destruction of habitat. Notwithstanding these undesirable effects, the hypertrophic (nutrient rich) status of many shallow lakes, especially in developing countries, would give rise to immense growth of algae and rooted plants were it not for the limiting effect of light extinction due to high turbidity. In this sense, high turbidity can be “beneficial” in highly eutrophic lakes; nevertheless, many countries recognise that this situation is undesirable for both aesthetic and economic reasons and are seeking means to reduce both turbidity and nutrient levels. Box 4 presents the impact of sediment on coral reefs.

- High levels of **sedimentation** in rivers leads to physical disruption of the hydraulic characteristics of the channel. This can have serious impacts on navigation through reduction in depth of the channel, and can lead to increased flooding because of reductions in capacity of the river channel to efficiently route water through the drainage basin. For example, calculations by the UFRGS (1991) of erosion and sediment transport in the Sao Francisco River Basin, a large drainage system in eastern Brazil, demonstrate

BOX 4: SEDIMENT AND DESTRUCTION OF CORAL REEFS

- Sediment has been identified as a major cause of decline and destruction of coral reefs, world wide. Experts (M. Risk, pers. comm., 1995) estimate that percentages of reefs affected by siltation are:

- Central America - 100%
- Polynesia - 10%
- Asia - nearly 100%
- Worldwide - 60-70% of fringing reefs

- Studies of coral reefs in the Australia indicate that terrestrial particulate organic carbon can be transported off-shore over distances of 110 km to reef locations (Risk *et al*., 1994). Sediment is largely produced by agricultural activities and from erosion of deforested lands. Sediment production from intensive logging of the island of Madagascar have killed the fringing reefs. Observations from space described the transition of Madagascar from an island of green in a sea of blue, to an island of brown in a sea of red (sediment).

that the central portion of the river basin is now dominated by sediment deposition. This has resulted in serious disruption of river transportation, and clogs hydraulic facilities that have been built to provide irrigation water from the main river channel. The sediment largely originates from rapidly eroding sub-basins due to poor agricultural practices.

SEDIMENT AS A CHEMICAL POLLUTANT

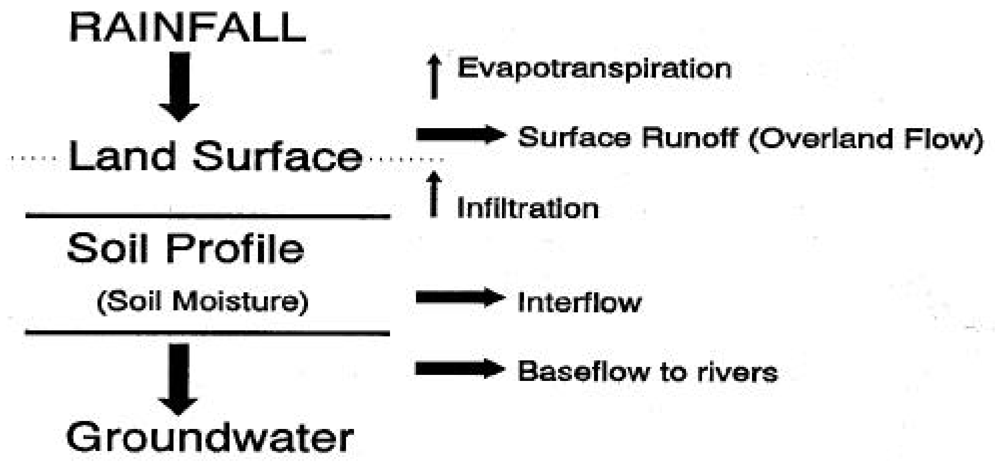
The role of sediment in chemical pollution is tied both to the particle size of sediment, and to the amount of particulate organic carbon associated with the sediment. The chemically active fraction of sediment is usually cited as that portion which is smaller than 63 μm (silt + clay) fraction. For phosphorus and metals, particle size is of primary importance due to the large surface area of very small particles. Phosphorus and metals tend to be highly attracted to ionic exchange sites that are associated with clay particles and with the iron and manganese coatings that commonly occur on these small particles. Many of the persistent, bioaccumulating and toxic organic contaminants, especially chlorinated compounds including many pesticides, are strongly associated with sediment and especially with the organic carbon that is transported as part of the sediment load in rivers. Measurement of phosphorus transport in North America and Europe indicate that as much as 90% of the total phosphorus flux in rivers can be in association with suspended sediment.

The affinity for particulate matter by an organic chemical is described by its octanol-water partitioning coefficient (K_{ow}). This partitioning coefficient is well known for most organic chemicals and is the basis for predicting the environmental fate of organic chemicals (see Chapter 4). Chemicals with low values of K_{ow} are readily soluble, whereas those with high values of K_{ow} are described as “hydrophobic” and tend to be associated with particulates. Chlorinated compounds such as DDT and other chlorinated pesticides are very hydrophobic and are not, therefore, easily analysed in water samples due to the very low solubility of the chemical. For organic chemicals, the most important component of the sediment load appears to be the particulate organic carbon fraction which is transported as part of the sediment. Scientists have further refined the partitioning coefficient to describe the association with the organic carbon fraction (K_{oc}).

Another important variable is the concentration of sediment, especially the <63 μm fraction, in the water column. Even those chemicals that are highly hydrophobic will be found in trace levels in soluble form. Where the suspended load is very small (say, less than 25 mg/l), the amount of water is so large relative to the amount of sediment that the bulk of the load of the chemical may be in the soluble fraction. This becomes an important issue in the monitoring of hydrophobic chemicals as noted in Table 17.

Unlike phosphorus and metals, the transport and fate of sediment-associated organic chemicals is complicated by microbial degradation that occurs during sediment transport in rivers and in deposited sediment. Nevertheless, the role of sediment in the transport and fate of agricultural chemicals, both for nutrients, metals, and pesticides is well known and must be taken into account when monitoring for these chemicals, and when applying models as a means of determining optimal management strategies at the field and watershed level. For this reason, models using the "fugacity" concept (uses the partitioning characteristics [Chapter 4] of chemicals as a basis for determining the environmental compartment - air, sediment,

FIGURE 4
Schematic diagram showing the major processes that link rainfall and runoff



water, biota - in which the chemical is primarily found) has proven effective in predicting the environmental pathways and fate of contaminants (Mackay and Paterson, 1991).

- *Conclusion: The role of sediment as a chemical pollutant is a function of the chemical load that is carried by sediments.*

Organic chemicals associated with sediment enter into the food chain in a variety of ways. Sediment is directly ingested by fish however, more commonly, fine sediment (especially the carbon fraction) is the food supply for benthic (bottom dwelling) organisms which, in turn, are the food source for high organisms. Ultimately, toxic compounds bioaccumulate in fish and other top predators. In this way, pesticides that are transported off the land as part of the runoff and erosion process, accumulate in top predators including man.

KEY PROCESSES: PRECIPITATION AND RUNOFF

The major characteristic of non-point source pollution is that the primary transfer mechanisms from land to water are driven by those hydrological processes that lead to runoff of nutrients, sediment and pesticides. This is important, not only to understand the nature of agricultural pollution, but also because modelling of hydrological processes is the primary mechanism by which agriculturalists estimate and predict agricultural runoff and aquatic impacts. Except where agricultural chemicals are dumped directly into watercourses, almost all other non-point source control techniques in agriculture involve control or modification of runoff processes through various land and animal (manure) management techniques.

In large parts of the world, precipitation is in the form of rain. However, in those areas where precipitation is in the form of snow, the science becomes more complex. Nevertheless, control measures, whether for areas subject to rain or snow can be easily summarized. Therefore, for the purpose of this publication, focus will be on the relationships between rainfall and runoff.

While the practice of hydrology can be quite theoretical, the principal concepts are easily understood (Figure 4).

Rainfall: The primary controlling factor is the rate (intensity) of rainfall. This controls the amount of water available at the ground surface, and is closely related to measures of energy that are used in many mathematical formulations to calculate soil detachment by rain drops. Soil detachment makes soil particles available for sediment runoff.

Soil Permeability: Permeability is a physical characteristic of a soil and is a measure of the ability of the soil to pass water, under saturated conditions, through the natural voids that exist in the soil. Permeability is a function of soil texture, mineral and organic composition, etc.. In contrast, "porosity" is the measure of the amount of void space in a soil; however, permeability refers to the extent to which the porosity is made up of interconnecting voids that allow water to pass through the soil. As an example, styrofoam is highly porous but impermeable, whereas a sponge is both porous and permeable.

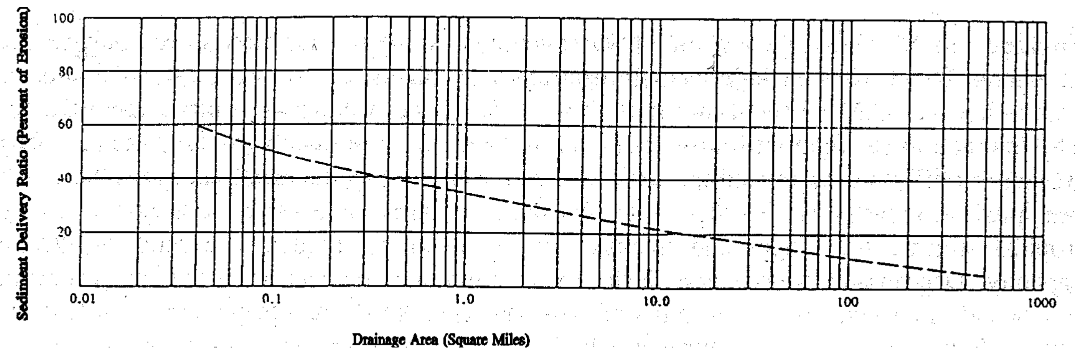
Infiltration: Infiltration rate, the rate at which surface water passes into the soil (cm/hr), is one of the most common terms in hydrologic equations for calculating surface runoff. Infiltration is not identical to permeability; it is mainly controlled by capillary forces in the soil which, in turn, reflect the prevailing conditions of soil moisture, soil texture, degree of surface compaction, etc. Infiltration will vary between and within rainfall events, depending upon factors such as antecedent soil moisture, nature of vegetation, etc. In general, infiltration rate begins at a high value during a precipitation event, and decreases to a small value when the soil has become saturated.

Surface runoff: This is the amount of water available at the surface after all losses have been accounted for. Losses include evapotranspiration by plants, water that is stored in surface depressions caused by irregularity in the soil surface, and water that infiltrates into the soil. The interaction between infiltration rate and precipitation rate mainly governs the amount of surface runoff. Intense rainstorms tend to produce much surface runoff because the rate of precipitation greatly exceeds the infiltration rate. Similarly, in areas of monsoonal rain and tropical storms, the length and intensity of precipitation frequently exceeds infiltration capacity. Destruction of protective surface vegetation and compaction of the soil, especially in tropical environments, leads to major erosional phenomena due to the amount of surface runoff (Figure 5). Except for nitrogen which is usually found in groundwater in agricultural areas, surface runoff is the primary contributor of agricultural chemicals, animal wastes, and sediment to river channels.

Interflow: (sometimes called "throughflow") Because soil horizons have different levels of permeability not all water in the soil will move downward into the groundwater. The residual water in the soil will move along the soil horizons, parallel to the ground surface. Interflow usually emerges near the bottom of slopes and in valley bottoms. Therefore, identification of these hydrologically active zones is an important part of agricultural non-point source control measures. Interflow is the mechanism which has also been linked to soil piping, a potentially destructive characteristic in some soils by which shallow "pipes" form naturally in the soil and are enlarged by interflow to the point where they collapse causing gullies in the agricultural surface.

FIGURE 6
Massive gully erosion in agricultural areas of southern Brazil

FIGURE 5
Relationship between drainage area and sediment delivery ratio (Source: USDA, 1983)



Groundwater: Groundwater is supplied by water which passes through the soil horizons into the parent material and/or bedrock underlying the soil. Groundwater tends to flow towards rivers channels where it emerges and supports stream flow during periods of little or no rain. This component of stream flow is called "base flow". The chemistry of baseflow reflects the soil and bedrock geochemistry, plus any agrochemicals that have been leached into the groundwater.

Snowmelt: The phenomenon of snowmelt greatly complicates prediction of agricultural pollution using conventional hydrologic models. Snowmelt, by itself, is not normally a major producer of surface runoff. However, the combination of spring rain and snowmelt on frozen or thawing soils can produce serious erosional problems. Snowmelt tends to contribute greatly to agricultural non-point source pollution by carrying to adjacent streams the animal wastes, sludges, and other wastes that were spread on frozen agricultural soils during the winter period. Correct management of animal wastes in regions of frozen ground has major beneficial effects on water quality.

KEY CONCEPTS

Sediment delivery ratio

The sediment delivery ratio (SDR) is commonly used in erosion and transport studies to describe the extent to which eroded soil (sediment) is stored within the basin. The SDR is defined as:

$$SDR = \frac{Measured\ Sediment\ Yield}{Gross\ erosion\ in\ the\ basin}$$

where *yield* is determined from reservoir sedimentation or from a sediment monitoring station, and *gross erosion* is estimated using an estimation techniques such as the Universal Soil Loss Equation.

The SDR is always less than 1.0 as illustrated in Figure 6, indicating that soil that is eroded at the field level tends not to travel far before it is deposited. Indeed, sediment storage in rills on fields, at field margins and at the foot of slopes is large. Storage also occurs in river channels (bed and overbank deposition), in wetlands, and in reservoirs and lakes. The SDR is highly variable, however the concept is one of the most important in the understanding of erosion and sedimentation processes and how these operate in time and space (see, for example, Walling, 1983).

Sediment enrichment ratio

The concept of the sediment enrichment ratio (SER) is quite important in understanding the impact and economic cost of chemical loss from fields. The process of surface erosion tends to be selective towards fine particles. Consequently, the particle size characteristics of material eroded at source (at the plot level) is progressively changed towards finer particles through deposition of the coarser fraction (e.g. sand-size material). Because of the chemically enriched nature of fine particles due to the large surface area of clay-size sediment, the concentration of chemicals that are associated with sediment (phosphorus, metals, organic nitrogen, hydrophobic pesticides) increases as the impoverished sand-size fraction is lost during down-field transport resulting in an increasing proportion of the chemically enriched fine (silt-clay) fraction.

TABLE 7
Agricultural non-point source models (Compiled from: Beasley and Huggins, 1981; Knisel, 1980; Lane and Nearings, 1989; Novotny and Olem, 1994; Young *et al*., 1986; Abbott *et al*., 1986)

NAME	APPLICATION	TIME SCALE	SPATIAL SCALE
A. Low to medium data needs			
Unit area loads (statistical prediction)	Sediment loss Nutrient loss	Long-term averages	10's to 100's km^2
NOTE: Statistical models use aggregated data for comparable conditions. Predictive power is low but can be useful for screening purposes or where no field data are available; or where the spatial scale is so large that field data are uneconomical.			
USLE (Universal Soil Loss Equation)	Average soil loss for specific crops, etc.	Annual	Plot/field
RUSLE/MUSLE (Revised/Modified USLE)	Average soil loss for specific crops, etc.	Annual	Plot/field
NOTE: Empirical USLE-type models have been applied to large area analysis, using remote sensing data, etc. for regional estimates of soil loss (e.g. Brazil). USLE-type models are often incorporated into more detailed hydrological models below.			
B. Data intensive modelling (process-oriented)			
ACTMO (Agricultural Chemical Transport Model)	Hydrologic processes Water quality	Event, continuous	Field
AGNPS (Agricultural Non-point Source Pollution)	Hydrology, erosion, N, P and pesticides	Event, daily, continuous	Grid cell, field scale
ANSWERS (Areal Non-point Source Watershed Environ-ment Response Simulation)	Hydrology, erosion, N P and pesticides	Single storm	Grid cell
CREAMS (Chemical, Runoff and Erosion from Agric. Management Systems)	Hydrology, erosion, N, P and pesticides	Daily, continuous	Field scale
EPIC (Erosion-Productivity Impact Calculator)	Hydrology, erosion, nutrient cycling. crop and soil management and economics	Event, daily, continuous	Field scale
HPSF (Hydrologic Simulation Program-Fortran)	Hydrology, water quality for conventional and toxic organic pollutants	Event, daily, continuous	Watershed
SHE (Système Hydrologique Européen)	Hydrology, with water quality modules	Event, daily, continuous	Watershed
SWAM (Small Watershed Model)	Hydrologic processes, sediment, nutrients and pesticides	Daily, continuous	Watershed
SWAT (Soil and Water Assessment Tool	Hydrologic processes, sediment, nutrients and pesticides	Event, daily, continuous	Simultaneous simulation for hundreds of sub-basins
SWRRB (Simulator for Water Resources in Rural Basins)	Water balance and hydrologic processes and sedimentation	Event, daily, continuous	Watershed
WEPP (Water Erosion Prediction Project)	Hydrologic processes, sediment processes	Single storm, daily, continuous	Hillslope, watershed, grid cell

The Sediment Enrichment Ratio (SER) is defined as:

$$SER = \frac{Concentration\ of\ chemical\ "X"\ in\_transported\ sediment}{Concentration\ of\ the\_chemical\ "X"\ in\ the\ soil}$$

Sediment chemistry is measured at some point downslope, e.g., at the edge of a field or in adjacent streams.

The importance of the enrichment ratio lies in the fact that there is proportionally more fine-grained sediment transported than coarse-grained sediment during surface erosion. Therefore, the sediment being transported has a finer texture than the source soil material. Because of the affinity of soil nutrients for fine sediment, this proportionally larger loss of fine material means that there is net impoverishment of the soil. As discussed in Chapter 3 (Fertilizers), this usually constitutes "mining" of the natural nutrition of the soil (often referred to as "natural capital") and which may never be replaced by the addition of fertilizer. The cost to the farmer is therefore two-fold: loss of productivity due to loss of natural nutrition in the soil; and economic cost of fertilizer which is added in the attempt to compensate for this loss.

MEASUREMENT AND PREDICTION OF SEDIMENT LOSS

Prediction models

Agriculturalists worldwide have spent much time and resources attempting to find reliable methods of predicting erosion and sediment-associated chemical runoff under different conditions of crop type, tillage practices, etc. Consequently, there is a large number of models that have been developed for the prediction of agricultural non-point source runoff of sediment, nutrients and pesticides. Many of the models permit gaming with alternative choices of land management, crop type, and fertilizer and pesticide application rates. Because all models (except unit load models) require hydrometric input and many use a sediment sub-component, it is appropriate to integrate these into a single table (Table 7), together with their principal characteristics.

In general, there are three types of models based on input data needs.

1. Simple **screening models**, such as the **unit load approach**, attempt to provide approximate answers about the likely magnitude of sediment and chemical runoff. This approach is a statistical methodology in which data on runoff of sediment, nutrients and pesticides on a unit area basis (e.g. tonnes of sediment per hectare) are collated from many studies to reflect similarities in crop type, soil and physiographic characteristics. Unlike the other types of models which are largely focused on prediction and improvement of agricultural management at the farm level, the unit load approach is mainly focused on impacts of agriculture on downstream water quality and without consideration of alternative farm management practices.

   Despite the unreliability and large margins of error (refer to Tables 8 and 14 and related text, this approach has been widely used as a cost-effective means for providing first-approximation answers for agricultural areas for which there are no data. The methodology was originally developed by McElroy *et al*. (1976) who collated a major database on unit loads. This approach was further developed into a US-EPA Screening Procedure by Mills *et al*. (1985) and which remains the most comprehensive document on the subject. Unit load data reflect conditions in the United States; application of these data to other climatic and physiographic environments should be avoided. Nevertheless, it is an approach that may be worth considering for development in other parts of the world.

2. Simple **empirical relationships**: the widely used and respected Universal Soil Loss Equation (USLE) of Wischmeier (1976) has had remarkable success at the plot level and has been incorporated into many of the complex models of Table 7. The USLE is designed as a field management tool and provides aggregated information at the storm, seasonal or annual level. Wischmeier (1976) reported that the average prediction error for annual soil loss was 12%; larger errors are to be expected for single storm events. The USLE is one way to determine erosion potential for input into the denominator of the Sediment Delivery Ratio. The USLE is detailed here because of its success and because the same type of approach has been used in Africa (Elwell and Stocking, 1982) and elsewhere (e.g. Modified USLE in Brazil by Chaves, 1991).

   The USLE is calculated as:

$$A = R \,.\, K \,.\, LS \,.\, C \,.\, P$$

where:	A	=	Calculated soil loss in t/ha for a given storm or period.
	R	=	Rainfall energy factor
	K	=	Soil erodibility factor
	LS	=	Slope-length factor
	C	=	Cropping management factor (vegetative cover)
	P	=	Erosion-control practice factor

   Each of the factors can be calculated or estimated using field data (as in the case for R and LS) and from tables or nomograms for all other factors. Novotny and Olem (1994) provide an excellent commentary on this and other methods for estimating or modelling erosion. The USLE is designed for rainfall only and does not handle snowmelt or rainfall on frozen ground. The USLE requires calibration data from standard plot experiments which are widely available in North America and, more limitedly, from other parts of the world.

   At the international level, the simplicity and effectiveness of the soil loss approach prompted an important series of experiments in Zimbabwe in the 1950s and 1960s with the primary objective of determining losses of nitrogen, phosphorus and organic carbon from the natural fertility of the soil. According to Stocking (FAO, 1986) who exhaustively analysed this database, it represented (at the time of his report) the "best such database in any developing or tropical country". This work led to the development of the SLEMSA model (Soil Loss Evaluation Model for Southern Africa) for conditions in Southern Africa (Elwell and Stocking, 1982). The value of this approach has further led FAO (1985) to develop an international network, "Network on Erosion-Induced Loss in Soil Productivity", with research partners in Africa, South America and Asia (as of 1995 - internal FAO communication).

FIGURE 7
Erosion measurement plots in the Negev Desert, Israel

Although Wischmeier (1976) has cautioned against extending soil loss models beyond field loss studies, these models are intuitively attractive for predicting erosion over large areas. It should be noted that, due to transport losses (Sediment Delivery Ratio noted above), such erosion estimates apply only to total erosion at source and do not reflect sediment loads (or sediment yield) measured at downstream locations. Such estimating techniques would, if calibrated so that the errors are known, have useful application as a screening tool for the estimation of erosion potential under conditions of similar crop, soil and topographic factors over large areas. Internationally, there appears to be little systematic information on calibration; however the Network on Erosion-Induced Loss in Soil Productivity (FAO, 1991) may eventually provide suitable information.

The most extreme example of use of the soil loss approach for large area estimation is in Brazil where the UFRGS (1991) and Carvalho (1988) used large area maps and satellite data to estimate several of the parameters of the USLE for application at regional scales. The intent was to provide generalized estimates of regional erosion potential for the entire country. While this approach has wide margins of error, it represents a method of screening for major change in erosion potential arising from combinations of agricultural land use, climate, and topography and merits further consideration, especially where plot calibration and in-river sediment monitoring data are available.

Together with the need to further develop screening level models, is the need to generate improved field data on erosion and sediment loss. Hudson (FAO, 1993b) has presented a wide range of simple field measurement techniques that are particularly useful in developing countries.

TABLE 8

Selected values for sediment loss

Location	Land use	Soil loss (t/ha/yr)	Comments
Italy	Wheat Maize Pasture	5.614 18.767 2.224	Average of 7 years' plot data from central Italy. Source: Zanchi, C. 1988. The cropping pattern and its role in determining erosion risk: experimental plot results from the Mugello valley (central Italy). In: *Sediment Budgets.* M.P. Bordas and D.E. Walling (eds.). IAHS Publication No. 174. Int. Assoc. Hydrol. Sci., Wallingford, UK.
Philippines	Reforested and agricultural	22-39.7	Sediment yield from nested catchments from 18.8 to 2041 km^2 in Luzon. Source: White, S. 1988. Sediment yield and availability for two reservoir basins in central Luzon, Philippines. In: Bordas and Walling (see above).
Morocco	Arid, grazing	25.0-59.0	Range calculated from sedimentation in three reservoirs having catchment areas from 107-780 km^2. (Source: Lahlou, A. 1988. The silting of Moroccan dams. In: Bordas and Walling (see above).
Kenya	Semi-arid grazing	79.5	Average in 1986 for seven sub-basins within a total area of 0.3 km^2. Source: Sutherland, R.A. and Bryan, R.B. 1988. In: Bordas and Walling (see above).
Bolivia	Andean arid, semi-arid	5.21-51.8	Four basins <1000 km^2 in headwaters area. Source: Guyot, J.L. *et al*. 1988. Exportation de matière en suspension des Andes. In: Bordas and Walling (see above).
United Kingdom	Agriculture	1.9 (net)	Fishpool Farm, UK, area, <1 km^2. Source: Walling, D.E. and Quine, T.A. 1992. The use of caesium-137 measurements in soil erosion surveys. In: *Erosion and Sediment Transport Monitoring Programmes in River Basins*. J. Bogen, D.E. Walling and T. Day (eds). IAHS Publication No. 210. Int. Assoc. Hydrol. Sci., Wallingford, UK.
Lesotho	Agriculture	7.8 (net)	Field measurements near Ha Sofonio, Lesource. Source: See above.

TABLE 9

Increases in sediment yield caused by land use change (Walling and Webb, 1983; Ostry, 1982)

	Land use change	Increase in sediment yield
Rajasthan, India	Overgrazing	x 4-18
Utah, USA	Overgrazing of rangeland	x 10-100
Oklahoma, USA	Overgrazing and cultivation	x 50-100
	Cultivation	x 5-32
Texas, USA	Forest clearance and cultivation	x 340
N. California, USA	Conversion of steep forest to grassland	x 5-25
Mississippi, USA	Forest clearance and cultivation	x 10-100
S, Brazil	Forest clearance and cultivation	x 4500
Westland, N. Zealand	Clearfelling	x 8
Oregon, USA	Clearfelling forest	x 39
Ontario, Canada	Conversion to agriculture	x 14

3. There is a wide variety of **deterministic and stochastic models** that attempt to simulate the physics of the erosion process. The data requirements for calibration and verification are extremely large. While such models may have certain advantages, especially in terms of the level of detail in which one can simulate alternative farm practices, these are generally unsuitable for developing countries due to their data requirements and the observation that management judgements for farm-level decisions can almost always be made on the basis of more generalized data combined with experience and common sense.

Sediment yield

Sediment yield, usually expressed as tonnes per unit area of the basin per year, is the amount of sediment measured at some point in the basin divided by the basin area. It always less than the total erosion due to sediment storage during transport, and is highly variable because of measurement difficulty, the temporal variability of hydrological processes, and changes in land management practices in the basin from one year to the next.

The values of Table 8 demonstrate not only the wide range of values in different climatic and topographic situations, but also the problem of interpreting sediment data because of spatial and time scales. As noted above, the Sediment Delivery Ratio subsumes a wide range of storage processes that operate at the field, sub-basin and basin scales. Sediment yield values are also highly variable in time, with smaller basins subject to greater variability than larger basins. Consequently, published values for sediment yield (t/ha/yr) must be interpreted with great caution. The Italian data in Table 8 are the only plot data and would appear much smaller if they were based on sediment measurements taken at the sub-basin scale. The magnitude of change in sediment yield arising from changes in agricultural land use is shown in Table 9.

Estimates of sediment yield have important economic consequences. In many developing countries the database with which to estimate reservoir life is very limited. According to White (1988) examples of predicted sediment yield in Asia tend to be between two and sixteen times lower than actual measured rates, with the consequence that actual reservoir life is greatly reduced. This is also a problem in northern Africa (Lahlou, pers. comm.). Partly this arises from the use of unreliable prediction techniques and the use of short-term data which usually fail to account for occasional but severe episodes of erosion (e.g. major storm events), and from increased land pressure after construction of the reservoir. White reports that the Magat Dam (Philippines) was constructed on the basis of a planned sediment yield of 20 t/ha/yr when, in reality, the yield was shown to be 38 t/ha/yr ? cutting the useful life of the reservoir in half! In the Republic of South Africa, off-site damage (reservoir sedimentation, water treatment, etc.) due to soil erosion was estimated in 1989 to total US$ 37.6 million annually (Braune and Looser, 1989). Because agriculture is a major contributor to sediment yield it is essential that national agricultural organizations account for off-site costs.

Scale problems

In all aspects of monitoring, modelling, or prediction of non-point source management, the scale factor is poorly understood by many practitioners. The scale factor not only pertains to the cost of collecting data for model calibration, but it is also vital to the ability to extrapolate useful management principles that will apply to larger areas. As an example, during the 1970s

TABLE 10
Influence of spatial scale on basin assessment (Ongley, 1987)

(A) SMALL AREAS (few hectare to several km^2).

? Detailed measurement of one land use or land management practice is possible.
? Data collected at catchment mouths do not necessarily represent target land use because of the influence of single phenomenon (such as gullies) or random events (specific action of one farmer, for example).
? Sediment data are more closely related to erosion at this scale than at larger scales.
? Expensive due to the number of monitoring sites necessary.
? Difficult to relate sediment and quality data to downstream receiving waters due to rapid information dilution (increasing noise) in downstream direction.
? The physics of catchment behaviour can be modelled in deterministic form.
? This scale is effective for site-specific management interventions but is too small for interventions involving general questions of land use.
? Data reveal synoptic scale effects (i.e. can resolve short-term scale effects within small areas).

(B) MEDIUM AREAS (tens to several hundreds km^2).

? Capable of representing combinations of similar land uses and/or physical information.
? Is a scale for which land use policies pertaining to diffuse sources can be effective and for which effectiveness can be assessed.
? Physico-chemical data do not relate directly to erosion or source but more to what is transported (information loss problem).
? Not a useful scale for erosion process studies, but can be used to assess overall erosional contribution to diffuse source chemistry.
? This scale inhibits dominance of site data by a specific phenomenon (e.g. one gully); this scale homogenizes phenomena so that their effects can be modelled by stochastic rather than deterministic processes.
? Deterministic models have very large data requirements at this scale.
? Is useful for determining impact of land and land-use practices on water quantity/quality, i.e. upstream impact on downstream sites.
? Data reveal seasonally variable effects.

(C) LARGE AREAS (>several hundred km^2).

? Too large to understand influence of land use or land management on downstream water quality, or role of natural physiographic units (except for macro-phenomena).
? Provides regional estimates of sediment transport but not of erosion.
? Can estimate influence on downstream receiving water bodies for physical and chemical variables.
? Can be functionally linked to medium areas but not to small areas.
? Related to behaviour of trunk rivers.
? Spatial elements are best modelled by stochastic models (excluding hydrological modelling).
? Not a useful scale for evaluating management options nor for evaluating the *a posteriori* effectiveness of management actions in upstream areas.
? Data reveal seasonally variable effects but may be substantially influenced by long-term lag phenomena.

it was assumed by many modellers who were engaged in the non-point source management programme of the North American Great Lakes, that extrapolation of cause-effect relationships from small-area studies into larger parts of the Great Lakes basin was feasible. It was found, however, that extrapolation became quite uncertain as basin area increased, for a variety of reasons.

The problem of extrapolation has not been definitively addressed in regards to levels of uncertainty. For example, although it is known that control of agricultural erosion is essential to mitigate nutrient (especially phosphorus) loss to receiving watercourses, it is unclear over what distance phosphorus runoff from agriculture has an immediate impact. The question then is, does erosion control in far upstream areas have an immediate benefit for a receiving water that may lie hundreds of kilometres downstream? Alternatively, one may adopt the position that over longer periods of time (say, scores of years) large storms will ensure that most of the eroded sediment is, in fact, transported through the river system and, therefore, one can assume a 1:1 relationship between upstream sediment production and downstream sediment transport. Research by Meade and Trimble (1974) and others shows that over longer time periods, sediment is mobilized differentially along the river basin. Contemporary sediment mobilization in the middle reaches of piedmont rivers of the United States represented sediment that was eroded several decades earlier but which had been deposited during transport into long-term storage as valley floor deposits. Table 10 presents the influence of spatial scale on basin assessment.

The essential point is that time and space scales must be recognized when preparing management plans for erosion control. While the near-term physical benefits of erosion control are likely to be felt quickly in receiving waters, sediment-associated contaminants that are stored in the river basin may take decades to finally be transported out of the basin, notwithstanding the resources spent on upstream erosion control.

RECOMMENDATIONS

These recommendations reflect two very different scales which, in turn, reflect two different types of issues. At the small scale are the recommendations which apply at the farm level and which reflect actions to be taken by the individual farmer after considering the economic costs of his alternatives. At the large scale (river basin scale) are those issues that tend to reflect policy and investment needs of states. This includes issues such as determining the net contribution of agriculture to river pollution relative to other types of polluting sources.

1. Internalizing costs

Although the control of erosion at source in rain-fed agriculture is a major factor in improving downstream water quality and associated ecological impacts, implementation of control measures will only be successful if the farmer can determine that it is in his economic interest to undertake such measures. Therefore, the economic benefits such as maintenance of soil fertility, reduced energy consumption in minimum till situations, etc., relative to economic costs of excessive fertilizer usage and loss of productivity by "mining" of soil capital, must be clearly demonstrated. This implies that agricultural agencies must use a holistic approach to the economics of farming practices.

2. Screening and estimating tools

There is an urgent need to develop simple and robust screening models for use in developing countries to determine the potential for erosion and soil loss at source (field level). The models must contain the ability to game with crop and land management alternatives. Data requirements must be relatively small and easily accessible, require no real-time calibration, and aggregate results on a seasonal or annual basis. Further calibration of the USLE (and its derivatives) and SLEMSA models are encouraged. These models must be developed from the perspective of assisting in farm-level decisions, and not from the perspective of further elaboration of the physics of erosion and sediment transport.

At the large scale, screening methods are needed to develop policy options for erosion control and land use practices at the basin scale. Soil loss models require adequate calibration so that the errors inherent in large scale use, using satellite and large scale map information, are known. Use of sediment loading data from river monitoring sites is an inadequate alternative due to the large sediment losses that occur during sediment transport from field to river.

3. Erosion control

There are no unique solutions to erosion control. Control measures depend very much on the economic situation of the farmer, the degree of importance placed on sediment erosion by environmental authorities, availability of capital, and the state of development of the country. The following control measures are those classified and recommended by the US-EPA (1993). These categories are used in many parts of the world, including developing countries. These techniques also have beneficial effects for conservation of nitrogen and phosphorus in the soil.

? **CONSERVATION COVER** *Establish and maintain perennial vegetative cover to protect soil and water resources on land retired from agricultural production.*

? **CONSERVATION CROPPING** *A sequence of crops designed to provide adequate organic residue for maintenance of soil tilth. This practice reduces erosion by increasing organic matter. It may also disrupt disease, insect and weed reproduction cycles thereby reducing the need for pesticides. This may include grasses and legumes planted in rotation.*

? **CONSERVATION TILLAGE** *Also known as reduced tillage, this is a planting system that maintains at least 30% of the soil surface covered by residue after planting. Erosion is reduced by providing soil cover. Runoff is reduced and infiltration into groundwater is increased. No-till, common in North America, is a conservation tillage practice.*

? **CONTOUR FARMING** *Ploughing, planting, and other management practices that are carried out along land contours, thereby reducing erosion and runoff.*

? **COVER AND GREEN MANURE CROP** *A crop of close-growing grasses, legumes, or small grain grown primarily for seasonal protection and soil improvement. Usually it is grown for 1 year or less.*

? **CRITICAL AREA PLANTING** *Planting vegetation, such as trees, shrubs, vines, grasses or legumes, on highly erodible or eroding areas.*

? **CROP RESIDUE USE** *Using plant residues to protect cultivated fields during critical erosion periods.*

? **DELAYED SEEDBED PREPARATION** *Any cropping system in which all crop residue is maintained on the soil surface until shortly before the succeeding crop is planted. This reduces the period that the soil is susceptible to erosion.*

? **DIVERSIONS** *Channels constructed across the slope with a supporting ridge on the lower side. By controlling downslope runoff, erosion is reduced and infiltration into the groundwater is enhanced.*

? **FIELD BORDERS AND FILTER STRIPS** *A strip of perennial herbaceous vegetation along the edge of fields. This slows runoff and traps coarser sediment. This is not generally effective, however, for fine sediment and associated pollutants.*

? **GRASSED WATERWAYS** *A natural or constructed channel that is vegetated and is graded and shaped so as to inhibit channel erosion. The vegetation will also serve to trap sediment that is washed in from adjacent fields.*

? **SEDIMENT BASINS** *Basins constructed to collect and store sediment during runoff events. Also known as detention ponds. Sediment is deposited from runoff during impoundment in the sediment basin.*

? **STRIP CROPPING** *Growing crops in a systematic arrangement of strips or bands across the general slope (not on the contour) to reduce water erosion. Crops are arranged to that a strip of grass or close-growing crop is alternated with a clean-tilled crop or fallow.*

? **TERRACING** *Terraces are constructed earthen embankments that retard runoff and reduce erosion by breaking the slope into numerous flat surfaces separated by slopes that are protected with permanent vegetation or which are constructed from stone, etc. Terracing is carried out on very* *steep slopes, and on long gentle slopes where terraces are very broad.*

Note however, that in tropical areas a number of these measures may produce situations that enhance the breeding of disease vectors as a result of ponding of water or reducing of water velocity in waterways.

Data from Chesapeake Bay (USA) installations indicate the following ranking of costs of erosion control measures (Table 11). Cost factors and rankings will vary greatly, especially in parts of the world where labour costs are less and where the economic benefit is factored into the ranking system. For example, grassed filter strips may have no economic benefit and are replaced with alternative practices such as herbaceous cover mixed with fruit trees.

TABLE 11
Annualized cost estimates for selected erosion management practices in the USA

Practice	Rank
Grassed filter strips	1 (least cost)
Cover crops	2
Strip-cropping	3
Conservation tillage	4
Reforestation of crop and pasture land	5
Diversions	6
Permanent vegetation on critical areas	7
Terraces	8
Sediment ponds and structures	9 (most cost)

Erosion in tropical areas has a unique set of problems. Marginal agricultural practices such as slash and burn on highly erodible tropical soils and tillage on steep tropical slopes lead to highly unstable situations which erode quickly during rainy seasons. Similarly, deforestation in tropical lands, either for agriculture or for timber, tends to leave a highly erodible land surface. In many tropical countries erosion from deforested areas is having a devastating influence on coastal zones including destruction of coral reefs far offshore. Poor land management practices such as overgrazing, especially on hill lands, always leads to serious erosion problems which are difficult or impossible to remedy due to the scale of damage and cost of reconstructing hill-sides. Erosion control measures for semi-arid areas are extensively described by Hudson (FAO, 1987).

While recommendations to control these abuses are self-evident, the fundamental causes lie often in national economic goals that are incompatible with environmental and water quality objectives, and in social policies that do little to contain destructive marginal agricultural practices.

Chapter 3
Fertilizers as water pollutants

EUTROPHICATION OF SURFACE WATERS

"Eutrophication" is the enrichment of surface waters with plant nutrients. While eutrophication occurs naturally, it is normally associated with anthropogenic sources of nutrients. The "trophic status" of lakes is the central concept in lake management. It describes the relationship between nutrient status of a lake and the growth of organic matter in the lake. Eutrophication is the process of change from one trophic state to a higher trophic state by the addition of nutrient. Agriculture is a major factor in eutrophication of surface waters.

The most complete global study of eutrophication was the Organization for Economic Cooperation and Development (OECD) Cooperative Programme on Eutrophication carried out in the 1970s in eighteen countries (Vollenweider *et al*., 1980). The sequence of trophic state, from oligotrophic (nutrient poor) to hypertrophic (= hypereutrophic [nutrient rich]) is shown in Table 12.

Although both nitrogen and phosphorus contribute to eutrophication, classification of trophic status usually focuses on that nutrient which is limiting. In the majority of cases, phosphorus is the limiting nutrient. While the effects of eutrophication such as algal blooms are readily visible, the process of eutrophication is complex and its measurement difficult. This is not the place for a major discussion on the science of eutrophication, however the factors noted in Table 13 indicate the types of variables that must be taken into account.

Because of the complex interaction amongst the many variables that play a part in eutrophication, Janus and Vollenweider (1981) concluded that it is impossible to develop strict boundaries between trophic classes. They calculated, for example, the probability (as %) of classifying a lake with total phosphorus and chlorophyll-a concentrations of 10 and 2.5 mg/m^3 respectively, as:

	Phosphorus	Chlorophyll
Ultra-oligotrophic	10%	6%
Oligotrophic	63%	49%
Mesotrophic	26%	42%
Eutrophic	1%	3%
Hypertrophic	0%	0%

The symptoms and impacts of eutrophication are:

- Increase in production and biomass of phytoplankton, attached algae, and macrophytes.

TABLE 12
Relationship between trophic levels and lake characteristics (Adapted from Janus and Vollenweider, 1981)

Trophic status	Organic matter mg/m^3	Mean total phosphorus[1] mg/m^3	Chlorophyll maximum[1] mg/m^3	Secchi depth[1] m
Oligotrophic	low	8.0	4.2	9.9
↓				
Mesotrophic	medium	26.7	16.1	4.2
↓				
Eutrophic	high	84.4	42.6	2.45
↓				
Hypertrophic	very high	750-1200		0.4-0.5

[1] Values are the preliminary OECD classification and are defined as the geometric mean. Secchi depth is a measure of turbidity of the water column in a lake.

TABLE 13
Parameters for measuring and monitoring eutrophication (Source: Janus and Vollenweider, 1981)

Resultant variables		Causal variables
Short-term variability: high	Short-term variability: moderate-low	
Phytoplankton biomass	Zooplankton standing crop	**Nutrient loadings** Total phosphorus
Major algal groups and dominant species	Bottom fauna standing crop	Ortho phosphates Total nitrogen
Chlorophyll-a & other phytopigments	Epilimnetic ?P, ?N, ?Si (? is difference between winter and summer concentrations)	Mineral nitrogen (NO_3+NH_3) Kjeldahl nitrogen
Particulate organic carbon and N	Hypolimnetic O_2 and ?O_2	**Nutrient concentrations** Same as above
Daily primary production rates	Annual primary production	Reactive silica Others (e.g. micro-elements)
Secchi disc visibility		

- Shift in habitat characteristics due to change in assemblage of aquatic plants.
- Replacement of desirable fish (e.g. salmonids in western countries) by less desirable species.
- Production of toxins by certain algae.
- Increasing operating expenses of public water supplies, including taste and odour problems, especially during periods of algal blooms.
- Deoxygenation of water, especially after collapse of algal blooms, usually resulting in fish kills.
- Infilling and clogging of irrigation canals with aquatic weeds (water hyacinth is a problem of introduction, not necessarily of eutrophication).
- Loss of recreational use of water due to slime, weed infestation, and noxious odour from decaying algae.

FIGURE 8
Algal bloom in a Canadian prairie lake dominated by agricultural runoff. The form on the shore is algal biomass.

- Impediments to navigation due to dense weed growth.
- Economic loss due to change in fish species, fish kills, etc.

Role of agriculture in eutrophication

In their summary of water quality impacts of fertilizers, FAO/ECE (1991) cited the following problems:

- Fertilization of surface waters (eutrophication) results in, for example, explosive growth of algae which causes disruptive changes to the biological equilibrium [including fish kills]. This is true both for inland waters (ditches, river, lakes) and coastal waters.

- Groundwater is being polluted mainly by nitrates. In all countries groundwater is an important source of drinking water. In several areas the groundwater is polluted to an extent that it is no longer fit to be used as drinking water according to present standards.

While these problems were primarily attributed to mineral fertilizers by FAO/ECE (1991), in some areas the problem is particularly associated with extensive and intensive application of organic fertilizers (manure).

The precise role of agriculture in eutrophication of surface water and contamination of groundwater is difficult to quantify. Where it is warranted, the use of environmental isotopes can aid in the diagnosis of pollutant pathways to and within groundwater (IAEA, pers. comm. 1996). RIVM (1992), citing Isermann (1990), calculated that European agriculture is responsible for 60% of the total riverine flux of nitrogen to the North Sea, and 25% of the total phosphorus loading. Agriculture also makes a substantial contribution to the total atmospheric nitrogen loading to the North and the Baltic Seas. This amounts to 65% and 55% respectively. Czechoslovakia reported that agriculture contributes 48% of the pollution of surface water; Norway and Finland reported locally significant eutrophication of surface waters arising from agriculture; high levels of usage of N and P are considered to be responsible for proliferation of algae in the Adriatic; similar observations are made in Danish coastal waters; substantial contamination of groundwater by nitrate in the Netherlands was also reported (FAO/ECE, 1991). Appelgren (FAO, 1994b) reported that 50% of shallow groundwater wells that supply more than one million rural residents in Lithuania are unfit for human consumption because of a wide range of pollutants which include pesticides and nitrogen species. In the 1960s Lake Erie (one of the North American Great Lakes) was declared "dead" by the press due to the high levels of nutrients accompanied by excessive growth of algae, fish kills, and anaerobic bottom sediments.

Although the ECE (1992) regarded livestock wastes as a point source and excluded it from calculations of the contribution of agriculture to eutrophication in Europe, their statistics indicated that livestock wastes accounted "on average" for 30% of the total phosphorus load to European inland waters, with the rest of agriculture accounting for a further 17%. The situation for nitrogen, as for phosphorus, was quite variable from country to country. Danish statistics indicated that manure contributes at least 50% of the leaching of inorganic N (Joly, 1993). Nitrogen from agricultural non-point sources in the Netherlands amounted to 71% of the total N load generated from within the Netherlands (ECE, 1992).

A study by Ryding (1986) in Sweden demonstrated how lakes which were unaffected by industrial or municipal point sources, underwent long-term change in nutrient status as a result of agricultural activities in the watershed. Over the period 1973-1981 the nutrient status of Lake Oren increased from 780 to 1000 mg/m^3 for Total-N, and from 10 to 45 mg/m^3 for Total-P. Lake transparency declined from 6.2 to 2.6 m and suffered periodic (heavy) algal blooms.

TABLE 14
Selected values for nutrient losses

Location	Land use	Phosphorus (kg/ha/yr)	Nitrogen (kg/ha/yr)	Comment (source)
Southern Ontario	Cropland Unimproved Maize, potatoes Cereals, beans. veg. & tobacco Hay, unimproved pasture Unimproved	0.415 0.08	 26.0 3.6 0.1 0.0	Sediment-associated P, mean of 14 catchments (Spires and Miller, 1978) From 11 catchments in S. Ontario (Nielsen *et al*. 1978) As above As above As above
Great Lakes Basin (N. America)	Cropland		0.2-37.1	Range reported for total N for 15 studies of stream-discharged N (not tile drains) Nielsen *et al*. 1978)
Hungary	Cropland	1.142		1984 results for 73 km^2 watershed tributary in Lake Balaton (Jolankai, 1986)
Denmark & Netherlands	Livestock/crop systems		316	Where 680 kg/N/ha are added (Joly, 1993)
USA	Cropland		64	Where livestock is not intense (Joly, 1993)
Côte d'Ivoire	Agriculture	29.0	98	Lower Côte d'Ivoire (FAO, 1994a)

TABLE 15
Relative leaching losses of nitrogen and phosphorus (% change between no fertilizer and with fertilizer) (Source: Bolton *et al*., 1970 as reported in Bangay, 1976)

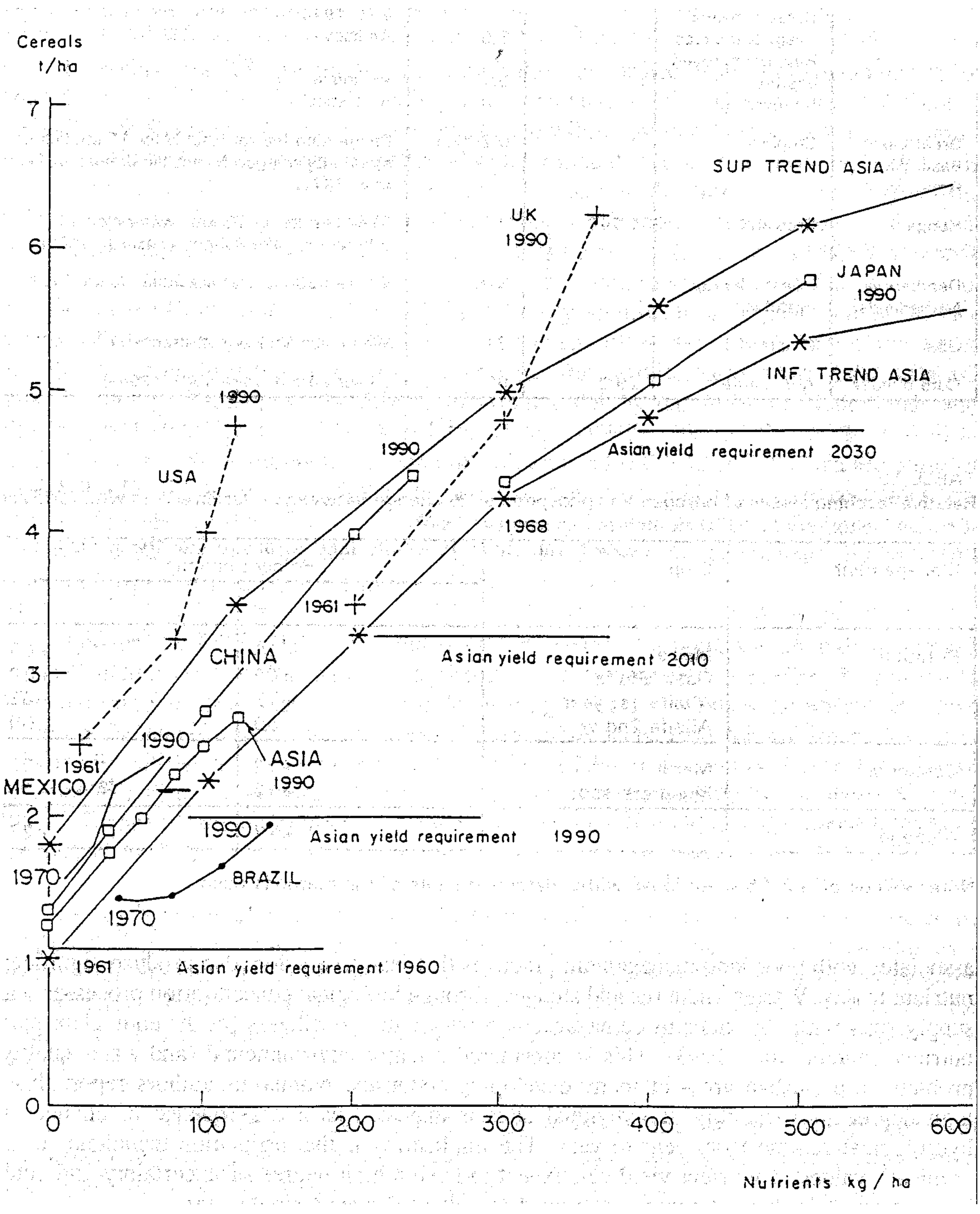
Management	Crop	Percent change	
		P	N
Rotation	Maize Oats, alfalfa Alfalfa 1st year Alfalfa 2nd yr	+10 - 05 +17 +59	+65 +33 - 08 +09
Continuous	Maize Bluegrass sod	+12 +12	+102 - 69
Average		+17	+27

Note: Values of +/- 15% are likely within detection limits of the methods used.

As noted in Chapter 1, the US-EPA regards agriculture as the leading source of impairment of that nation's rivers and lakes with nutrients ranking second only to siltation as the pollutant most affecting rivers and lakes.

The values cited in Tables 14 and 15 indicate the wide range of nutrient losses that are measured at the plot, field and sub-basin scales. Heavily fertilized crops such as maize tend to have large losses relative to non-intensive uses such as pasture. Agricultural uses associated with poor land management practices that lead to erosion also produce significant nutrient losses. Wastes, manures and sludges, through biological concentration processes, can supply soils with 100 times more hazardous products than fertilizers for the equivalent plant nutrient content (Joly, 1993). This is considered a major environmental (and water quality) problem in periurban areas of many developing countries. Numerous authors report that a high degree of variability at individual sites is expected as a consequence of changes in hydrological regime from year to year. The implication is that estimation techniques using "typical" values of

FIGURE 1
Fertilizer use development and crop yield evolution in Asian, European and Latin American countries and the United States (Source: Joly, 1993)



nutrient yield can expect to have a high degree of uncertainty and could be very much in error if estimated from data collected over a single year.

The huge increases in fertilizer use worldwide over the past several decades are well documented. Figure 9 illustrates the historical trends and predicted future needs of fertilizer use. However, fertilizer use (either mineral or organic) is not, of itself, the primary factor in downstream water quality. More important are the land management practices that are used in crop production.

There is a danger, however, in assuming that all waters have natural levels that are low in nutrients. In some areas, such as lakes located in areas of rich agricultural soils, waters have historically been highly enriched by nutrients associated with natural erosion of fertile soils. In the prairie lakes of Canada, for example, early settlers reported that the lakes were green with algae. In other parts of the world, as in Asia, ancient civilizations so profoundly impacted water quality that there are no longer "natural" levels of nutrients. In such situations the existence of eutrophication, while undeniable, must be measured against arbitrary standards that reflect water quality criteria established on the basis of societal needs for beneficial use of the water.

Organic fertilizers

The importance and, in some cases, the major problems associated with organic fertilizers, deserve special mention. Manure produced by cattle, pigs and poultry are used as organic fertilizer the world over. To this is added human excreta, especially in some Asian countries where animal and human excreta are traditionally used in fish culture as well as on soils. However, intensive livestock production has produced major problems of environmental degradation, a phenomenon which has been the subject of European and North American legislation and control. The problem is particularly acute in areas of intensive livestock production, such as in the Eastern and Southern parts of the Netherlands where the production of manure greatly exceeds the capacity of the land to assimilate these wastes.

In addition to problems associated with excessive application of manure on the land, is the problem of direct runoff from intensive cattle, pig and poultry farms. Although this is controlled in many western countries, it constitutes a serious problem for water quality in much of the rest of the world. For example, Appelgren (FAO, 1994b) reports that discharge of pig wastes from intensive pig raising in Lithuania is a major source of surface water pollution in that country. The FAO/ECE reports similar problems in the Po River of Italy. The Canadian Department of Agriculture calculated in 1978, on the basis of detailed study of several feedlot operations, that cattle feedlots and manure storage facilities contributed 0.5-13% of the total loading of total phosphorus at that time to the Canadian portion of the Lower (agricultural portion) Great Lakes (Coote and Hore, 1978).

To the typical pathways of degradation, that of surface runoff and infiltration into the groundwater, is added the volatilization of ammonia which adds to acidification of land and water. In a review of environmental impacts caused by animal husbandry in Europe, the FAO/ECE (1991) reported the following major categories of impacts:

- Fertilization of surface waters, both as a result of direct discharges of manure and as a consequence of nitrate, phosphate and potassium being leached from the soil.

FIGURE 3
The N cycle in soil (from Stevenson, 1965)

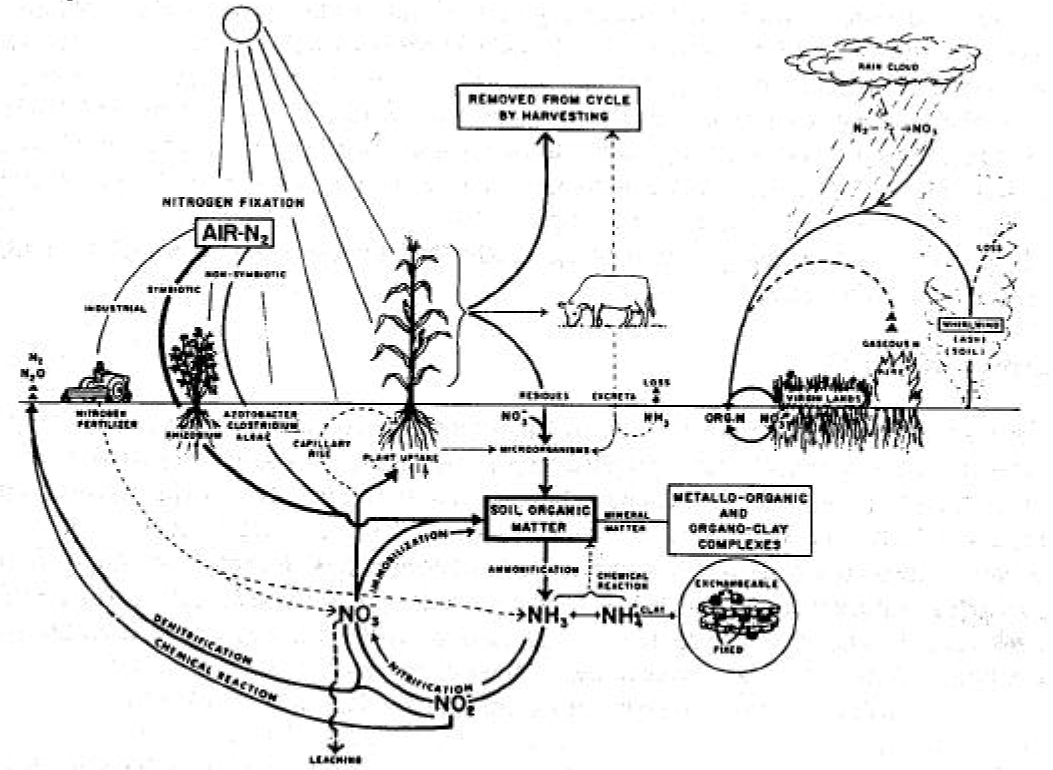


FIGURE 2
Schematic diagram of nitrogen and phosphorus losses. Arrows are proportional to loss

NITROGEN FERTILIZERS **PHOSPHORUS FERTILIZERS**

ß ß ß ß

<u>applied to land surface</u> → *Surface Runoff* ⇐ **<u>applied to land surface</u>**

leaching ⇐ ← leaching

Þ *Interflow / tile drains*

ß ß ↓

loss to groundwater loss to groundwater

- Contamination of the groundwater as a result of leaching, especially by nitrate. Phosphates are less readily leached out, but in areas where the soil is saturated with phosphate this substance is found in the groundwater more and more often.
- Surface waters and the groundwater are being contaminated by heavy metals. High concentrations of these substances pose a threat to the health of man and animals. To a certain extent these heavy metals accumulate in the soil, from which they are taken up by crops. For example, pig manure contains significant quantities of copper.

- Acidification as a result of ammonia emission (volatilization) from livestock accommodation, manure storage facilities, and manure being spread on the land. Ammonia constitutes a major contribution to the acidification of the environment, especially in areas with considerable intensive livestock farming.

ENVIRONMENTAL CHEMISTRY

The key hydrological processes that link rainfall, runoff and leaching, and which give rise to erosion and transport of chemically enriched soil particles, are important components of the environmental chemistry, transport and fate of fertilizer products. These hydrological processes are described in Chapter 2 and are not repeated here.

The environmental dynamics of nitrogen and phosphorus are well known although the detailed transformations of nitrogen that occur in soil and water are difficult to study and document. The nitrogen cycle is depicted in Figure 10.

Nitrogen is comprised of the forms: soluble organic N, NH_4-N (ammonium), NO_3-N (nitrate), NO_2-N (nitrite), and N associated with sediment as exchangeable NH_4-N or organic-N. Nitrogen cycling is extremely dynamic and complex, especially the microbiological processes responsible for mineralization, fixation and denitrification of soil nitrogen. Generally, in soils that are not waterlogged, soil N (held as protein in plant matter) and fertilizer-N are microbiologically transformed to NH_4 (ammonium) through the process of ammonification. The ammonium ion is oxidized by two groups of bacteria (*Nitrosomonas* and *Nitrobacter*) to NO_3 with an unstable intermediate NO_2 product in a process called nitrification. Urea is readily hydrolysed to ammonium. Denitrification occurs under anoxic conditions such as wetlands where NO_3 is reduced to various gaseous forms. The N cycle is largely controlled by bacteria, hence the rate of N cycling is dependent upon factors such as soil moisture, temperature, pH, etc. NO_3 is the end-product of aerobic N decomposition and is always dissolved and mobile.

From a water quality perspective, the ammonium ion (NH_4) can be adsorbed to clay particles and moved with soil during erosion. More importantly, however, NH_4 and NO_3 are soluble and are mobilized through the soil profile to groundwater during periods of rain by the process of leaching. NO_3 is also observed in surface runoff during rainfall events. Prevention of nitrogen pollution of surface and groundwater depends very much on the ability to maintain NO_3 in soil only up to the level that can be taken up by the crop, and to reduce the amount of NO_3 held in the soil after harvesting. The processes described above are depicted in Figure 11.

In contrast, the behaviour of phosphorus is quite simple. Phosphorus can exist in a variety of forms: as mineral (generally apatite) phosphorus (AP); non-apatite inorganic-P (NAIP); organic-P (OP ? bound up with carbon and oxygen in plant matter); and as dissolved soluble reactive ortho-P (SRP). The phosphorus species AP, NAIP and OP are associated with the particulate phase. In studies of phosphorus movement from agricultural lands the largest amount is sorbed onto clay materials and transported as erosion products. SRP is readily available to aquatic plants to the point where measured SRP in surface water may only represent a residual amount after most of the SRP has been taken up by plant life. Consequently, in aquatic studies, the focus is often on the sediment-associated forms of P as these tend to dominate total phosphorus flux. The NAIP fraction is considered to be available to plant roots and is rapidly solubilized under conditions of anoxia in the bottom of lakes and reservoirs. It is for this reason that lake sediments can represent a very large internal (autotrophic) load of phosphorus which is recycled into the water column during periods of bottom anoxia. This load can be so large that, without attention to lake sediment remediation, phosphorus management programmes in tributaries can be quite meaningless.

The relative losses of N and P to groundwater are illustrated in Table 15 where it is seen that P losses are generally smaller relative to the much more soluble N. Indeed, insofar as maize is the most heavily fertilized crop, the leaching of nitrogen is especially noticeable.

THE POINT VERSUS NON-POINT SOURCE DILEMMA

The dilemma in many countries is to ascertain the role of agriculture relative to the impacts of (often untreated) municipal sewage. In a large number of countries the database required to make this distinction is lacking and frustrates the development of a rational pollution abatement programme and inhibits cost-effective investment in control measures. In developing countries it makes sense that the focus should initially be on point source control; however, it has been the experience in the developed countries that point source control for nutrients has not had the desired level of environmental benefit until agricultural control measures were seriously addressed. It is significant that the trend of fertilizer usage worldwide has been one of huge increases in the past 40 years suggesting that, in the absence of major changes in land use to control fertilizer runoff in large parts of the world, one may expect that agriculture will be responsible for an ever-increasing contribution to surface water pollution.

The observations reported by Quirós (see Box 5) for the La Plata basin are indicative of the difficulty in segregating the effects of agriculture from other sources. In the Great Lakes of North America some $10 million dollars were spent between 1970 and 1980 to quantify the relative impacts of point versus non-point sources. That exercise proved enormously successful and specific policies were adopted for nutrient control in each lake basin that reflected the relative contributions from each type of source.

MANAGEMENT OF WATER QUALITY IMPACTS FROM FERTILIZERS

The investigation of eutrophication of surface water by agriculture must adopt a pragmatic management perspective. Of value to agriculture is the perspective adopted by the OECD study of eutrophication. That study focused on the following aspects:

- The qualitative assessment of the trophic state of bodies of water in terms of a few easily measured parameters.
- The dependence of this state on nutritional conditions and nutrient load.
- Translation of these results to the needs of eutrophication control for management.

The progression of these aspects is interesting in that the focus is on easily measurable **state** of the water body, followed by a determination of the extent to which the state is a product of nutrient loads, then the degree to which loads may be manipulated to achieve a desired trophic state **that is determined by water use**.

Prediction of water quality impacts of fertilizers and related land management practices is an essential element of site-specific control options and for the development of generic approaches for fertilizer control. Prediction tools are essentially in the form of models, many of which are contained in Table 7.

BOX 5: SEGREGATING AGRICULTURAL FROM INDUSTRIAL IMPACTS ON WATER QUALITY OF THE LA PLATA BASIN, SOUTH AMERICA

In his report on impacts on the fishery in the la Plata river system, Quirós (1993) provided a comprehensive summary of observed symptoms. He admitted to the difficulty in providing evidence for cause and effect in this large river system. Nevertheless, he concluded that the evidence was consistent with that of a regulated river-floodplain system impacted from toxic substances used in agriculture and industry.

Observed Symptoms

Fruit and seed eater species of the genera *Colossoma* and *Brycon* and the big catfish *Paulicea lutkenii* have practically disappeared from the commercial catch in the lower Paraná river, and also from the catches in the La Plata and Uruguay rivers.

Fish species of marine lineage of the genera *Basilichthys* and *Lycengraulis*, usually moving upstream from the estuary in winter, have practically disappeared from the commercial catches in the middle Paraná.

The commercial catches of the pelagic top predator *Salminus maxillosus* have been decreasing since the late 1940s in all the lower basin, though its commercial catch has been highly restricted.

Populations of most of the migratory fish species are severely diminished in the middle and upper Uruguay river.

Relatively high levels of agricultural pesticides and heavy metals were detected in fish tissues.

Periodic massive fish mortalities were reported in the lower Paraná delta and the La Plata river.

Low water oxygen levels and massive fish mortalities were detected in the lower Paraguay river, and discharges of high organic matter content effluents from the agricultural industry have increased in the upper basin.

The exotic *Cyprinus carpio* was the most important species in biomass in the experimental catches in the La Plata river, and its catch has been increasing in the middle Paraná.

Maximum size of catch of the big catfish of the genera *Pseudoplatystoma* has been decreasing for the last three decades in the lower middle Paraná.

The conflicting situations between recreational and commercial fishermen have been increasing, and the trophy size of *Salminus* has been decreasing at the confluence of the Paraná and Paraguay rivers, though total fishing effort seems not to have increased.

Source: Quirós (1993).

Mineral fertilizers

The response to the need to control leaching and runoff of nutrients and contamination of soils and water by heavy metals has been variable in Europe. Control measures are part of the larger issue of mineral and organic fertilizer usage. FAO/ECE (1991) summarized the types of voluntary and mandated controls in Europe that apply to mineral fertilizers as:

- Taxes on fertilizer.
- Requirement for fertilizer plans.

- Preventing the leaching of nutrients after the growing season by increasing the area under autumn/winter green cover, and by sowing crops with elevated nitrogen
- Promoting and subsidizing better application methods, developing new, environmentally sound fertilizers, and promoting soil testing.
- Severely limiting the use of fertilizers in e.g. water extraction areas and nature protection areas.

In any location where intensive agriculture and/or livestock farming produces serious risks of nitrogen pollution, Ignazi (1993) recommended the following essential steps that are taken at the farm level:

1. ***Rational nitrogen application:*** To avoid over-fertilization, the rate of nitrogen fertilizer to be applied needs to be calculated on the basis of the "crop nitrogen balance". This takes into account plant needs and amount of N in the soil.

2. ***Vegetation cover:*** As far as possible, keep the soil covered with vegetation. This inhibits build-up of soluble nitrogen by absorbing mineralized nitrogen and preventing leaching during periods of rain.

3. ***Manage the period between crops:*** Organic debris produced by harvesting is easily mineralized into leachable N. Steps to reduce leachable N includes planting of "green manure" crops, and delaying ploughing of straw, roots and leaves into the soil.

4. ***Rational irrigation:*** Poor irrigation has one of the worst impacts on water quality, whereas precision irrigation is one of the least polluting practices as well as reducing net cost of supplied water.

5. ***Optimize other cultivation techniques:*** Highest yields with minimum water quality impacts require optimization of practices such as weed, pest and disease control, liming, balanced mineral fertilizers including trace elements, etc.

6. ***Agricultural Planning:*** Implement erosion control techniques (see Chapter 2) that complement topographic and soil conditions.

Organic fertilizers

Voluntary and legislated control measures in Europe are intended to have the following benefits:

- ***Reduce the leaching of nutrients***
- ***Reducing emissions of ammonia***
- ***Reducing contamination by heavy metals***

The nature of these measures varies by country; however FAO/ECE (1991) have summarized the types of voluntary and mandated control as:

- Maximum numbers of animals per hectare based on amount of manure that can be safely applied per hectare of land.

- Maximum quantities of manure that can be applied on the land is fixed, based on the N and P content of the manure.
- Holdings wishing to keep more than a given number of animals must obtain a license.
- The periods during which it is allowed to apply manure to the land have been limited, and it is obligatory to work it into the ground immediately afterwards.
- Establishment of regulations on minimum capacity for manure storage facilities.
- Establish fertilizer plans.
- Levies (taxes) on surplus manure.
- Areas under autumn/winter green cover were extended, and green fallowing is being promoted.
- Maximum amounts established for spreading of sewage sludge on land based on heavy metal content.
- Change in composition of feed to reduce amount of nutrients and heavy metals.
- Research and implementation of means of reducing ammonia loss.

Sludge management

Sludge is mentioned here only insofar as the spreading of sludge from municipal wastewater treatment facilities on agricultural land is one method used to get rid of municipal sludge in a way that is perceived to be beneficial. The alternatives are incineration and land fill. FAO/ECE (1991) include sludge within the category of organic fertilizers but note that sludge often contains unacceptable levels of heavy metals. Pollution of water by sludge runoff is otherwise the same as for manure noted above.

ECONOMICS OF CONTROL OF FERTILIZER RUNOFF

Nutrient loss is closely associated with rainfall-runoff events. For phosphorus, which tends to be associated with the solid phase (sediment), runoff losses are directly linked to erosion. Therefore the economics of nutrient control tend to be closely tied to the costs of controlling runoff and erosion. Therefore, this will be treated briefly here. In particular, it is useful to examine the economic cost of nutrient runoff which must be replaced by fertilizers if the land is to remain productive.

The link between erosion, increasing fertilizer application, and loss of soil productivity is very direct in many countries. In the Brazilian state of Paraná where agriculture is the base of the state economy, Paraná produces 22% of the national grain production on only 2.4% of the Brazilian territory. Agricultural expansion in Paraná occurred mainly in the period 1950-1970 and was “characterized by short-term agricultural systems leading to continuous and progressive environmental degradation as a result of economic policies and a totally inappropriate land parcelling and marketing system...” (Andreoli, 1993). Erosion has led to extensive loss of top soil, large-scale gullying (Figure 4), and silting of ditches and rivers. The use of fertilizers has risen as a consequence, up 575% over the period 1970-1986 and **without** any gain in crop yields. Loss of N-P-K from an average erosion of 20 t/ha/yr represents an annual economic loss of US$242. million in nutrients.

FIGURE 4
Water-based aquaculture in the Lakes Region of southern Chile

Analysis by Elwell and Stocking (1982) of nutrient loss arising from erosion in Zimbabwe shows similar significant economic losses in African situations. Stocking (FAO, 1986), applying data collected in the 1960s by Hudson to the soil use map of Zimbabwe, calculated an annual loss of 10 million tonnes of nitrogen and 5 million tonnes of phosphorus annually as a consequence of erosion (cited by Roose in FAO, 1994a). Roose (FAO, 1994a) also cites losses of 98 kg/ha/yr of nitrogen, 29 kg/ha/yr of phosphorus, 39 kg/ha/yr of lime and 39 kg/ha/yr of magnesium from soils of lower Côte d'Ivoire as a result of erosion. This loss is so severe that compensation requires 7 tonnes of fresh manure annually, plus 470 kg of ammonium sulphate, 160 kg of superphosphate, 200 kg dolomite and 60 kg of potassium chloride per hectare per year. Roose notes that it is not surprising that the soil is exhausted after only two years of traditional agriculture. Furthermore, these losses do not take into account additional losses due to harvesting and runoff. Roose summarizes by stating that action against soil erosion is essential in order to manage what he describes as a "terrible" chemical imbalance in soils caused by soil erosion. Estimates of phosphorus loss by erosion in the Republic of South Africa (Du Plessis, 1985) are R26.4 M/yr (US$ 10.5 million).

Economic losses tend to be higher in tropical countries where soils, rainfall and agricultural practices are more conducive to erosion, and reported rates of erosion are much above average. The World Bank (1992) reported that extrapolation from test-plots of impacts of soil loss on agricultural productivity, indicates some 0.5-1.5% loss of GDP annually for countries such as Costa Rica, Malawi, Mali and Mexico. These losses do not include offsite costs such as reservoir infilling, river sedimentation, damage to irrigation systems, etc.

Soil fertility is a complex issue and nutrient loss is not necessarily nor always a consequence of erosion. Erosion and soil loss is the end member of a variety of physical, vegetative and nutrient factors that lead to soil degradation. Global patterns of fertilizer application, as reported by Joly (1993), indicate however that rapidly rising levels of fertilizer utilization are required merely to maintain soil productivity from a variety of types of loss, including losses due to erosion and, more generally, to soil degradation.

In a study of 17 agricultural sub-watersheds in the Lake Balaton district of Hungary, Jolankai (1986) measured and modelled N and P runoff from a variety of agricultural land uses. He calculated that a selection of control measures (mainly erosion control) would reduce phosphorus loss by 52.8% at a cost of US$ 2500 per ha in remediation measures (in 1986).

AQUACULTURE

Aquaculture is a special case of agricultural pollution. There are two main forms: land-based and water-based systems (Figure 12). Effluent controls are possible on land-based systems, however water-based systems present particular problems. Aquaculture is rapidly expanding in most parts of the developed and developing world, both in freshwater and marine environments. In contrast, coastal fisheries in most countries are declining.

The environmental impact is primarily a function of feed composition and feed conversion (faecal wastes), plus assorted chemicals used as biocides, disinfectants, medicines, etc. Wastage of feed (feed not taken up by the fish) is estimated to be 20% (Ackefors and Enell, 1992) in European aquaculture. Waste feed and faecal production both add substantial nutrient loadings to aquatic systems.

Additional environmental problems include risk of disease and disease transfer to wild fish, introduction of exotic species, impacts on benthic communities and on the eutrophication of water, interbreeding of escaped cultured fish with wild fish with consequent genetic change in the wild population.

Traditional integrated aquaculture systems, as in China, where sewage-fish culture is practised, can be a stabilizing influence in the entire ecosystem (Rosenthal, 1992). This is recommended, especially in developing countries where water and resources are scarce or expensive.

PROBLEMS OF RESTORATION OF EUTROPHIC LAKES

Eutrophic and hypertrophic lakes tend to be shallow and suffer from high rates of nutrient loadings from point and non-point sources. In areas of rich soils such as the Canadian prairies, lake bottom sediments are comprised of nutrient-enriched soil particles eroded from surrounding soils. The association of phosphorus with sediment is a serious problem in the restoration of shallow, enriched lakes. P-enriched particles settle to the bottom of the lake and form a large pool of nutrient in the bottom sediments that is readily available to rooted plants and which is released from bottom sediments under conditions of anoxia into the overlying water column and which is quickly utilized by algae. This phosphorus pool, known as the “internal load” of phosphorus, can greatly offset any measures taken by river basin managers to control lake eutrophication by control of external phosphorus sources from agriculture and from point sources. Historically, dredging of bottom sediments was considered the only means of remediating nutrient-rich lake sediments, however, modern technology now provides alternative and more cost-effective methods of controlling internal loads of phosphorus by oxygenation and by chemically treating sediments *in situ* to immobilize the phosphorus. Nevertheless, lake restoration is expensive and must be part of a comprehensive river basin management programme.

Chapter 4

Pesticides as water pollutants

The term “pesticide” is a composite term that includes all chemicals that are used to kill or control pests. In agriculture, this includes herbicides (weeds), insecticides (insects), fungicides (fungi), nematocides (nematodes), and rodenticides (vertebrate poisons).

A fundamental contributor to the Green Revolution has been the development and application of pesticides for the control of a wide variety of insectivorous and herbaceous pests that would otherwise diminish the quantity and quality of food produce. The use of pesticides coincides with the “chemical age” which has transformed society since the 1950s. In areas where intensive monoculture is practised, pesticides were used as a standard method for pest control. Unfortunately, with the benefits of chemistry have also come disbenefits, some so serious that they now threaten the long-term survival of major ecosystems by disruption of predator-prey relationships and loss of biodiversity. Also, pesticides can have significant human health consequences.

While agricultural use of chemicals is restricted to a limited number of compounds, agriculture is one of the few activities where chemicals are intentionally released into the environment because they kill things.

Agricultural use of pesticides is a subset of the larger spectrum of industrial chemicals used in modern society. The American Chemical Society database indicates that there were some 13 million chemicals identified in 1993 with some 500 000 new compounds being added annually. In the Great Lakes of North America, for example, the International Joint Commission has estimated that there are more than 200 chemicals of concern in water and sediments of the Great Lakes ecosystem. Because the environmental burden of toxic chemicals includes both agriculture and non-agricultural compounds, it is difficult to separate the ecological and human health effects of pesticides from those of industrial compounds that are intentionally or accidentally released into the environment. However, there is overwhelming evidence that agricultural use of pesticides has a major impact on water quality and leads to serious environmental consequences.

Although the number of pesticides in use (Annex 1) is very large, the largest usage tends to be associated with a small number of pesticide products. In a recent survey in the agricultural western provinces of Canada where some fifty pesticides are in common use, 95% of the total pesticide application is from nine separate herbicides (Birkholz, pers. comm., 1995). Although pesticide use is low to nil in traditional and subsistence farming in Africa and Asia, environmental, public health and water quality impacts of inappropriate and excessive use of pesticides are widely documented. For example, Appelgren (FAO, 1994b) reports for Lithuania that while pesticide pollution has diminished due to economic factors, water pollution by pesticides is often caused by inadequate storage and distribution of

TABLE 16
Chronology of pesticide development (Stephenson and Solomon, 1993)

Period	Example	Source	Characteristics
1800-1920s	Early organics, nitro-phenols, chlorophenols, creosote, naphthalene, petroleum oils	Organic chemistry, by-products of coal gas production, etc.	Often lack specificity and were toxic to user or non-target organisms
1945-1955	Chlorinated organics, DDT, HCCH, chlorinated cyclodienes	Organic synthesis	Persistent, good selectivity, good agricultural properties, good public health performance, resistance, harmful ecological effects
1945-1970	Cholinesterase inhibitors, organophosphorus compounds, carbamates	Organic synthesis, good use of structure-activity relationships	Lower persistence, some user toxicity, some environmental problems
1970-1985	Synthetic pyrethroids, avermectins, juvenile hormone mimics, biological pesticides	Refinement of structure activity relationships, new target systems	Some lack of selectivity, resistance, costs and variable persistence
1985-	Genetically engineered organisms	Transfer of genes for biological pesticides to other organisms and into beneficial plants and animals. Genetic alteration of plants to resist non-target effects of pesticides	Possible problems with mutations and escapes, disruption of microbiological ecology, monopoly on products

agrochemicals. In the United States, the US-EPA's National Pesticide Survey found the 10.4% of community wells and 4.2% of rural wells contained detectible levels of one or more pesticides (US-EPA, 1992). In a study of groundwater wells in agricultural southwestern Ontario (Canada), 35% of the wells tested positive for pesticides on at least one occasion (Lampman, 1995).

The impact on water quality by pesticides is associated with the following factors:

- Active ingredient in the pesticide formulation.
- Contaminants that exist as impurities in the active ingredient.
- Additives that are mixed with the active ingredient (wetting agents, diluents or solvents, extenders, adhesives, buffers, preservatives and emulsifiers).
- Degradate that is formed during chemical, microbial or photochemical degradation of the active ingredient.

In addition to use of pesticides in agriculture, silviculture also makes extensive use of pesticides. In some countries, such as Canada, where one in ten jobs is in the forest industry, control of forest pests, especially insects, is considered by the industry to be essential. Insecticides are often sprayed by aircraft over very large areas.

Irrigated agriculture, especially in tropical and subtropical environments, usually requires modification of the hydrological regime which, in turn, creates habitat that is conducive to breeding of insects such as mosquitoes which are responsible for a variety of vector-borne diseases. In addition to pesticides used in the normal course of irrigated agriculture, control of vector-borne diseases may require additional application of insecticides such as DDT which have serious and widespread ecological consequences. In order to address this problem, environmental management methods to control breeding of disease vectors are being developed and tested in many irrigation projects (FAO, 1984).

HISTORICAL DEVELOPMENT OF PESTICIDES

The history of pesticide development and use is the key to understanding how and why pesticides have been an environmental threat to aquatic systems, and why this threat is diminishing in developed countries and remains a problem in many developing countries. Stephenson and Solomon (1993) outlined the chronology presented in Table 16.

NORTH-SOUTH DILEMMA OVER PESTICIDE ECONOMICS

As noted above, the general progression of pesticide development has moved from highly toxic, persistent and bioaccumulating pesticides such as DDT, to pesticides that degrade rapidly in the environment and are less toxic to non-target organisms. The developed countries have banned many of the older pesticides due to potential toxic effects to man and/or their impacts on ecosystems, in favour of more modern pesticide formulations. In the developing countries, some of the older pesticides remain the cheapest to produce and, for some purposes, remain highly effective as, for example, the use of DDT for malaria control. Developing countries maintain that they cannot afford, for reasons of cost and/or efficacy, to ban certain older pesticides. The dilemma of cost/efficacy versus ecological impacts, including long range impacts via atmospheric transport, and access to modern pesticide formulations at low cost remains a contentious global issue.

In addition to ecological impacts in countries of application, pesticides that have been long banned in developed countries (such as DDT, toxaphene, etc.), are consistently found in remote areas such as the high arctic. Chemicals that are applied in tropical and subtropical countries are transported over long distances by global circulation. The global situation has deteriorated to the point where many countries are calling for a global convention on “POPs” (Persistent Organic Pollutants) which are mainly chlorinated compounds that exhibit high levels of toxicity, are persistent, and bioaccumulate. The list is not yet fixed; however, “candidate” substances include several pesticides that are used extensively in developing countries.

FATE AND EFFECTS OF PESTICIDES

Factors affecting pesticide toxicity in aquatic systems

The ecological impacts of pesticides in water are determined by the following criteria:

- **Toxicity:** Mammalian and non-mammalian toxicity usually expressed as LD_{50} (“Lethal Dose”: concentration of the pesticide which will kill half the test organisms over a specified test period). The lower the LD_{50}, the greater the toxicity; **values of 0-10 are extremely toxic** (OMAF, 1991).

Drinking water and food guidelines are determined using a risk-based assessment. Generally, Risk = Exposure (amount and/or duration) x Toxicity.

Toxic response (effect) can be **acute** (death) or **chronic** (an effect that does not cause death over the test period but which causes observable effects in the test organism such as cancers and tumours, reproductive failure, growth inhibition, teratogenic effects, etc.).

- **Persistence:** Measured as half-life (time required for the ambient concentration to decrease by 50%). Persistence is determined by biotic and abiotic degradational processes. Biotic processes are biodegradation and metabolism; abiotic processes are mainly hydrolysis, photolysis, and oxidation (Calamari and Barg, 1993). Modern pesticides tend to have short half lives that reflect the period over which the pest needs to be controlled.

- **Degradates:** The degradational process may lead to formation of “degradates” which may have greater, equal or lesser toxicity than the parent compound. As an example, DDT degrades to DDD and DDE.

- **Fate (Environmental):** The environmental fate (behaviour) of a pesticide is affected by the natural affinity of the chemical for one of four environmental compartments (Calamari and Barg, 1993): solid matter (mineral matter and particulate organic carbon), liquid (solubility in surface and soil water), gaseous form (volatilization), and biota. This behaviour is often referred to as “partitioning” and involves, respectively, the determination of: the soil sorption coefficient (K_{oc}); solubility; Henry's Constant (H); and the n-octanol/water partition coefficient (K_{ow}). These parameters are well known for pesticides and are used to predict the environmental fate of the pesticide.

An additional factor can be the presence of impurities in the pesticide formulation but that are not part of the active ingredient. A recent example is the case of TFM, a lampricide used in tributaries of the Great Lakes for many years for the control of the sea lamprey. Although the environmental fate of TFM has been well known for many years, recent research by Munkittrick *et al.* (1994) has found that TFM formulation includes one or more highly potent impurities that impact on the hormonal system of fish and cause liver disease.

Human health effects of pesticides

Perhaps the largest regional example of pesticide contamination and human health is that of the Aral Sea region (Box 2). UNEP (1993) linked the effects of pesticides to "the level of oncological (cancer), pulmonary and haematological morbidity, as well as on inborn deformities ... and immune system deficiencies".

Human health effects are caused by:

* Skin contact: handling of pesticide products

* Inhalation: breathing of dust or spray
* Ingestion: pesticides consumed as a contaminant on/in food or in water.

Farm workers have special risks associated with inhalation and skin contact during preparation and application of pesticides to crops. However, for the majority of the population, a principal vector is through ingestion of food that is contaminated by pesticides. Degradation of water quality by pesticide runoff has two principal human health impacts. The first is the consumption of fish and shellfish that are contaminated by pesticides; this can be a particular problem for subsistence fish economies that lie downstream of major agricultural areas. The second is the direct consumption of pesticide-contaminated water. WHO (1993) has established drinking water guidelines for 33 pesticides (Annex 1). Many health and environmental protection agencies have established "acceptable daily intake" (ADI) values which indicate the maximum allowable daily ingestion over a person's lifetime without appreciable risk to the individual. For example, in a recent paper by Wang and Lin (1995) studying substituted phenols, tetrachlorohydroquinone, a toxic metabolite of the biocide pentachlorophenol, was found to produce "significant and dose-dependent DNA damage".

Ecological effects of pesticides

Pesticides are included in a broad range of organic micro pollutants that have ecological impacts. Different categories of pesticides have different types of effects on living organisms, therefore generalization is difficult. Although terrestrial impacts by pesticides do occur, the principal pathway that causes ecological impacts is that of water contaminated by pesticide runoff. The two principal mechanisms are bioconcentration and biomagnification.

Bioconcentration: This is the movement of a chemical from the surrounding medium into an organism. The primary "sink" for some pesticides is fatty tissue ("lipids"). Some pesticides, such as DDT, are "lipophilic", meaning that they are soluble in, and accumulate in, fatty tissue such as edible fish tissue and human fatty tissue. Other pesticides such as glyphosate are metabolized and excreted.

Biomagnification: This term describes the increasing concentration of a chemical as food energy is transformed within the food chain. As smaller organisms are eaten by larger organisms, the concentration of pesticides and other chemicals are increasingly magnified in tissue and other organs. Very high concentrations can be observed in top predators, including man.

The ecological **effects** of pesticides (and other organic contaminants) are varied and are often inter-related. Effects at the organism or ecological level are usually considered to be an early warning indicator of potential human health impacts. The major types of effects are listed below and will vary depending on the organism under investigation and the type of pesticide. Different pesticides have markedly different effects on aquatic life which makes generalization very difficult. The important point is that many of these effects are chronic (not lethal), are often not noticed by casual observers, yet have consequences for the entire food chain.

- Death of the organism.
- Cancers, tumours and lesions on fish and animals.
- Reproductive inhibition or failure.

- Suppression of immune system.
- Disruption of endocrine (hormonal) system.
- Cellular and DNA damage.
- Teratogenic effects (physical deformities such as hooked beaks on birds).
- Poor fish health marked by low red to white blood cell ratio, excessive slime on fish scales and gills, etc.
- Intergenerational effects (effects are not apparent until subsequent generations of the organism).
- Other physiological effects such as egg shell thinning.

These effects are not necessarily caused solely by exposure to pesticides or other organic contaminants, but may be associated with a combination of environmental stresses such as eutrophication and pathogens. These associated stresses need not be large to have a synergistic effect with organic micro pollutants.

Ecological effects of pesticides extend beyond individual organisms and can extend to ecosystems. Swedish work indicates that application of pesticides is thought to be one of the most significant factors affecting biodiversity. Jonsson *et al.* (1990) report that the continued decline of the Swedish partridge population is linked to changes in land use and the use of chemical weed control. Chemical weed control has the effect of reducing habitat, decreasing the number of weed species, and of shifting the balance of species in the plant community. Swedish studies also show the impact of pesticides on soil fertility, including inhibition of nitrification with concomitant reduced uptake of nitrogen by plants (Torstensson, 1990). These studies also suggest that pesticides adversely affect soil micro-organisms which are responsible for microbial degradation of plant matter (and of some pesticides), and for soil structure. Box 6 presents some regional examples of ecological effects of pesticides.

Natural factors that degrade pesticides

In addition to chemical and photochemical reactions, there are two principal biological mechanisms that cause degradation of pesticides. These are (1) microbiological processes in soils and water and (2) metabolism of pesticides that are ingested by organisms as part of their food supply. While both processes are beneficial in the sense that pesticide toxicity is reduced, metabolic processes do cause adverse effects in, for example, fish. Energy used to metabolize pesticides and other xenobiotics (foreign chemicals) is not available for other body functions and can seriously impair growth and reproduction of the organism.

Degradation of Pesticides in Soil: "Many pesticides dissipate rapidly in soils. This process is mineralization and results in the conversion of the pesticide into simpler compounds such H_2O, CO_2, and NH_3. While some of this process is a result of chemical reactions such as hydrolysis and photolysis, microbiological catabolism and metabolism is usually the major route of mineralization. Soil micro biota utilize the pesticide as a source of carbon or other nutrients. Some chemicals (for example 2,4-D) are quite rapidly broken down in soil while others are less easily attacked (2,4,5-T). Some chemicals are very persistent and are only slowly broken down (atrazine)" (Stephenson and Solomon, 1993).

Process of Metabolism: Metabolism of pesticides in animals is an important mechanism by which organisms protect themselves from the toxic effects of xenobiotics (foreign chemicals) in their food supply. In the organism, the chemical is transformed into a less toxic form and either excreted or stored in the organism. Different organs, especially the liver, may be

BOX 6: REGIONAL EXAMPLES OF ECOLOGICAL EFFECTS

In Europe, the European Environment Agency (EEA, 1994) cites a study by Galassi et al. that closely links toxicity of Po River water to the zooplankton daphnia magna, to runoff of agricultural pesticides.

In the Great Lakes of North America bioaccumulation and magnification of chlorinated compounds in what is, on global standards, a relatively clean aquatic system, caused the disappearance of top predators such as eagle and mink and deformities in several species of aquatic birds.

The World Wide Fund for Nature (WWF, 1993) reports that a significant amount of an estimated 190 000 tons of agricultural pesticides plus additional loadings of non-agricultural pesticides that are released by riparian countries bordering the North Sea, eventually are transported into 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.

involved, depending on the chemical. Enzymes play an important role in the metabolic process and the presence of certain enzymes, especially "mixed function oxygenases (MFOs) in liver, is now used as an indicator that the organism has been exposed to foreign chemicals.

PESTICIDE MONITORING IN SURFACE WATER

Monitoring data for pesticides are generally poor in much of the world and especially in developing countries. Key pesticides are included in the monitoring schedule of most western countries, however the cost of analysis and the necessity to sample at critical times of the year (linked to periods of pesticide use) often preclude development of an extensive data set. Many developing countries have difficulty carrying out organic chemical analysis due to problems of inadequate facilities, impure reagents, and financial constraints. New techniques using immunoassay procedures for presence/absence of specific pesticides may reduce costs and increase reliability. Immunoassay tests are available for triazines, acid amides, carbamates, 2,4-D/phenoxy acid, paraquot and aldrin (Rickert, 1993)

Data on pesticide residues in fish for lipophilic compounds, and determination of exposure and/or impact of fish to lipophobic pesticides through liver and/or bile analysis is mainly restricted to research programmes. Hence, it is often difficult to determine the presence, pathways and fate of the range of pesticides that are now used in large parts of the world. In contrast, the ecosystemic impacts from older, organochlorine pesticides such as DDT, became readily apparent and has resulted in the banning of these compounds in many parts of the world for agricultural purposes.

Table 17 indicates why older pesticides, together with other hydrophobic carcinogens such as PAHs and PCBs, are poorly monitored when using water samples. As an example, the range of concentration of suspended solids in rivers is often between 100 and 1000 mg/l except during major runoff events when concentrations can greatly exceed these values. Tropical rivers that are unimpacted by development have very low suspended sediment concentrations, but increasingly these are a rarity due to agricultural expansion and deforestation in tropical countries. As an example, approximately 67% of DDT is transported in association with suspended matter at sediment concentrations as low as 100 mg/l, and

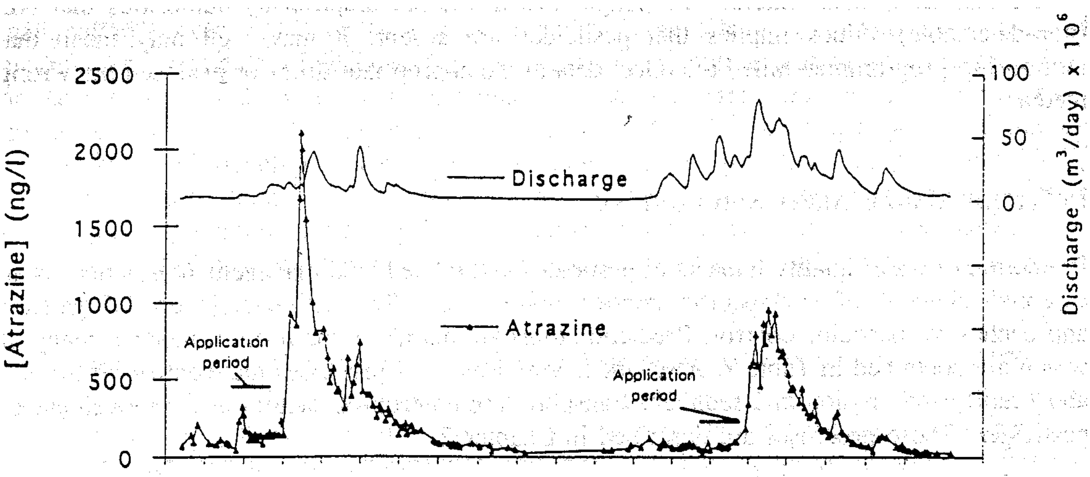
TABLE 17
Proportion of selected pesticides found in association with suspended sediment (After Ongley *et al.*, 1992)

Pesticide	log K_{ow}	% of chemical load at different concentrations (mg/l) of suspended sediment			
		mg/l = 10	mg/l = 100	mg/l = 1000	mg/l = 10000
Aldrin	5.5	15	55	90	100
Atrazine	2.6	0	0	2	20
Chlordane	6.0	30	75	95	100
DDT	5.8	20	67	93	100
Dieldrin	5.5	15	55	90	100
Endrin	5.6	18	57	90	100
Endosulfan	3.6	0	0	21	57
Heptachlor	5.4	13	48	88	100
Lindane	3.9	0	2	30	80
Mirex	6.9	75	95	100	100
Toxaphene[1]	3.3	0	0	12	47
Trifluralin	5.3	12	45	87	100
2,4-D	2.0[2]	0	0	0	4

increases to 93% at 1000 mg/l of suspended sediment. Given the analytical problems of inadequate detection levels and poor quality control in many laboratories of the developing countries, plus the fact that recovery rates (part of the analytical procedure) can vary from 50-150% for organic compounds, it follows that monitoring data from water samples are usually a poor indication of the level of pesticide pollution for compounds that are primarily associated with the solid phase. The number of NDs (Not Detectable) in many databases is almost certainly an artifact of the wrong sampling medium (water) and, in some cases, inadequate analytical facilities and procedures. Clearly, this makes pesticide assessment in water difficult in large parts of the world. Experience suggests that sediment-associated pesticide levels are often much higher than recorded, and NDs are often quite misleading. Some water quality agencies now use multi-media (water + sediment + biota) sampling in order to more accurately characterize pesticides in the aquatic environment.

Another problem is that analytical detection levels in routine monitoring for certain pesticides may be too high to determine presence/absence for protection of human health. Gilliom (1984) noted that the US Geological Survey's Pesticide Monitoring Network [in 1984] had a detection limit of 0.05 ? g/l for DDT, yet the aquatic life criterion is 0.001 ? g/l and the human health criterion is 0.0002 ? g/l ? both much less that the routine detection limit of the programme. ND (not detectible) values, therefore, are not evidence that the chemical is not present in concentrations that may be injurious to aquatic life and to human health. That this analytical problem existed in the United States suggests that the problem of producing water quality data that can be used for human health protection from pesticides in developing countries, must be extremely serious. Additionally, detection limits are only one of many analytical problems faced by environmental chemists when analysing for organic contaminants.

FIGURE 13
Occurrence of atrazine, a widely used herbicide, in surface water is limited to the period immediately after application (Reproduced with permission from Schottler *et al.* 1994, copyright American Chemical Society)



Even when one has good analytical values from surface water and/or sediments, the interpretation of pesticide data is not straight forward. For example, the persistence of organochlorine pesticides is such that the detection of, say, DDT may well indicate only that (1) the chemical has been deposited through long range transport from some other part of the world, or (2) it is a residual from the days when it was applied in that region. In North America, for example, DDT is still routinely measured even though it has not been used for almost two decades. The association of organochlorine pesticides with sediment means that the ability of a river basin to cleanse itself of these chemicals is partly a function of the length of time it requires for fine-grained sediment to be transported through the basin. Geomorphologists now know that the process of erosion and transport of silts and clays is greatly complicated by sedimentation within the river system and that this fine-grained material may take decades to be transported out of the river basin. For sediment-associated and persistent pesticides that are still in use in some countries, the presence of the compound in water and/or sediments results from a combination of current and past use. As such, the data make it difficult to determine the efficacy of policy decisions such as restrictive use or bans.

Pesticide monitoring requires highly flexible field and laboratory programmes that can respond to periods of pesticide application, which can sample the most appropriate medium (water, sediment, biota), are able to apply detection levels that have meaning for human health and ecosystem protection, and which can discriminate between those pesticides which appear as artifacts of historical use versus those that are in current use.

For pesticides that are highly soluble in water, monitoring must be closely linked to periods of pesticide use. In the United States where there have been major studies of the behaviour of pesticide runoff, the triazines (atrazine and cyanazine) and alachlor (chlorinated acetamide) are amongst the most widely used herbicides. These are used mainly in the spring (May). Studies by Schottler *et al.* (1994) indicate that 55-80% of the pesticide runoff occurred in the month of June (Figure 13). The significance for monitoring is that many newer and soluble pesticides can only be detected shortly after application; therefore, monitoring programmes that are operated on a monthly or quarterly basis (typical of many countries) are unlikely to be able to quantify the presence or determine the significance of pesticides in surface waters. Pesticides that have limited application are even less likely to be detected in surface waters. The danger lies in the presumption by authorities that ND (non-detectable) values implies that pesticides are absent. It may well only mean that monitoring programmes failed to collect data at the appropriate times or analysed the wrong media.

PESTICIDE MANAGEMENT AND CONTROL

Prediction of water quality impacts of pesticides and related land management practices is an essential element of site-specific control options and for the development of generic approaches for pesticide control. Prediction tools are mainly in the form of models, many of which are contained in Table 7. Also, the key hydrological processes that control infiltration and runoff, and erosion and sediment transport, are controlling factors in the movement of pesticides. These processes are described in Chapter 2.

The European experience

The Netherlands National Institute of Public Health and Environmental Protection (RIVM, 1992) concluded that "groundwater is threatened by pesticides in all European states. This is obvious both from the available monitoring data and calculations concerning pesticide load, soil sensitivity and leaching... It has been calculated that on 65% of all agricultural land the EC standard for the sum of pesticides (0.5 ? g/l) will be exceeded. In approximately 25% of the area this standard will be exceeded by more than 10 times..."

In recognition of pesticide abuse and of environmental and public health impacts the European countries have adopted a variety of measures that include the following (FAO/ECE, 1991):

- Reduction in use of pesticides (by up to 50% in some countries).
- Bans on certain active ingredients.
- Revised pesticide registration criteria.
- Training and licensing of individuals that apply pesticides.
- Reduction of dose and improved scheduling of pesticide application to more effectively meet crop needs and to reduce preventative spraying.
- Testing and approval of spraying apparatus.
- Limitations on aerial spraying.
- Environmental tax on pesticides.
- Promote the use of mechanical and biological alternatives to pesticides.

Elsewhere, as for example Indonesia, reduction in subsidies has reduced the usage of pesticides and has increased the success of integrated pesticide management programmes (Brinkman, pers. comm., 1995).

Pesticide registration

Pesticide control is mainly carried out by a system of national registration which limits the manufacture and/or sale of pesticide products to those that have been approved. In developed countries, registration is a formal process whereby pesticides are examined, in particular, for mammalian toxicity (cancers, teratogenic and mutagenic effects, etc.) and for a range of potential environmental effects based on the measured or estimated environmental behaviour of the product based on its physico-chemical properties. Most developing countries have limited capability to carry out their own tests on pesticides and tend to adopt regulatory criteria from the developed world. As our knowledge of the effects of pesticides in the environment accumulates, it has become apparent that many of the older pesticides have inadequate registration criteria and are being re-evaluated. As a consequence, the environmental effects of many of the older pesticides are now recognized as so serious that they are banned from production or sale in many countries.

A dilemma in many developing countries is that many older pesticides (e.g. DDT) are cheap and effective. Moreover, regulations are often not enforced with the result that many pesticides that are, in fact, banned, are openly sold and used in agricultural practice. The dichotomy between actual pesticide use and official policy on pesticide use is, in many countries, far apart.

Regulatory control in many countries is ineffective without a variety of other measures, such as education, incentives, etc. The extent to which these are effective in developed versus developing countries depends very much on (1) the ability of government to effectively regulate and levy taxes and (2) on the ability or readiness of the farming community to understand and act upon educational programmes. The fundamental dilemma remains one of accommodating local and short term gain by the farmer (and manufacturer and/or importer) by application of an environmentally dangerous pesticides, with societal good by the act of limiting or banning its use.

There is now such concern over environmental and, in some instances, human health effects of excessive use and abuse of pesticides, that there is active discussion within many governments of the need to include a programme of pesticide reduction as part of a larger strategy of sustainable agriculture. In 1992, Denmark, the Netherlands and Sweden were the first of the 24 member states of the OECD to embark upon such a programme. The Netherlands is the world's second largest exporter of agricultural produce after the United States. In contrast, wood preservatives in the forest sector account for 70% of Swedish pesticide use with agriculture using only 30%. As noted above, the lack of baseline data on pesticides in surface waters of OECD countries, is a constraint in establishing baseline values against which performance of the pesticide reduction programme can be measured.

Box 7 presents information on EXTOXNET, a pesticide-toxicology network which is available on INTERNET.

The Danish example

In 1986 the Danish Government initiated an Action Plan for sustainable agriculture which would prevent the use of pesticides for two purposes (WWF, 1992):

BOX 7: PESTICIDE INFORMATION

One source of current information on pesticides is through the EXtension TOXicology NETwork operated by the University of Oregon on the Internet. EXTOXNET provides information on:

? What is the EXTension TOXicology NETwork?
? Pesticide Information Profiles
? Toxicology Information Briefs
? Toxicology Issues of Concern
? Factsheets
? News about Toxicology Issues
? Newsletters
? Resources for Toxicology Information
? Technical Information
? Mailing Groups
? Search ALL Extoxnet areas for keywords
? Search ALL Extoxnet areas for partial words

email access:	almanac@sulaco.oes.orst.edu (request extoxnet catalogue)
GOPHER access:	gopher to -- sulaco.oes.orst.edu choose option #3 -- Or. Ext. Ser. Projects and Programs then choose option #4 -- EXTOXNET
WWW access:	URL - http://www.oes.orst.edu:70/1/ext choose -- EXTOXNET

- Safeguard human health - from the risks and adverse effects associated with the use of pesticides, primarily by preventing intake via food and drinking water.

- Protect the environment - both the non-target and beneficial organisms found in the flora and fauna on cultivated land and in aquatic environments.

The objective was to achieve a 50% reduction in the use of agricultural pesticides by 1997 from the average amount of pesticides used during the period 1981-85. This was to be measured by (1) a decline in total sales (by weight) of the active ingredients and, (2) decrease in frequency of application. While the World Wide Fund for Nature (WWF, 1992) report that by 1993, sales of active ingredients had been reduced by 30%, the application frequency had not declined.

The Danish legislation included the following components although, by 1993, not all had achieved comparable success.

- **Reassessment of active ingredients:** Reassessment reflects improved scientific knowledge of pathways, fate and effects of pesticides. By 1993, 80% of the 223 active ingredients had been reassessed. Fewer than 40% had been approved and about 15% are restricted to specific types of application (WWF summary of Danish Environmental Protection reports).

- **Promotion of organic agriculture:** The legislation included funding to promote conversion of traditional agriculture to organic agriculture which, by definition, does not use pesticides.

- **Excise tax on pesticides:** The Danish Institute of Agriculture concluded that, "A tax on pesticides can be designed and implemented in such a way that it will reduce the use of pesticides without distorting or dramatically worsening the economic situation in the agricultural sector." Funds raised by the tax were to be directed back to the agricultural sector. Studies reported by the Institute of Agriculture suggested, however, that pesticide taxes alone would not produce the requisite reduction during the lifetime of the plan.

- **Certification of pesticide users:** All farmers and commercial sprayers must hold application certificates. Certification includes education in pesticide issues.

- **Records of pesticide application:** Commencing 1 August 1993, individual farmers were required to maintain records of pesticide application.

- **Approval of spraying equipment:** This measure gives the Ministry of Agriculture some control of types of spraying equipment used in Denmark. New computer controlled sprayers permit continuous monitoring of pesticide dose by the farmer and reduces excessive application.

The Danish Government is considering the following additional components as part of the regulatory process:

- ***Maximum limits on the environmental load of pesticides*:** The intent is to produce an index which equates the quantity used of a pesticide with its known ecological effects. The concept is, however, difficult to implement as noted by the WWF, "... there is no direct relationship between the pesticide-load index and the environmental effects - direct or indirect - of pesticides, since these are the result of a complex interaction between many different factors." Nevertheless, the concept has certain management and regulatory value and may be possible, initially, with a few common pesticides.
- ***Prohibiting the use of pesticides within 10 m of lakes, watercourses, wetlands, and conservation areas*:** This would achieve some level of pesticide protection for aquatic systems in the same manner that buffer strips are widely used to reduce the effects of sedimentation.
- ***Prohibiting the use of pesticides within a specified distance from private gardens and properties containing fields that are cultivated without the use of pesticides.***
- ***Prohibiting the use of pesticides within 10 m of a drinking-water reservoir.***

The Swedes have had considerable success in achieving pesticide reduction targets. WWF (1992) credits their success to the following factors.

- Setting of targets with achievable goals and using multiple measures of reduction.
- Lead role played by the Environment Ministry and Chemicals Inspectorate.
- Active support of farmers organizations which realize the economic and environmental advantages of reduced pesticide usage.
- A strong research and development base that provides credible support for new pesticide initiatives.
- Certification of new machinery and routine testing of farm sprayers at government-regulated test centres.

- Re-evaluation and re-registration of pesticides which has resulted in 338 products being removed from the market.

Pesticides and water quality in the developing countries

Use of pesticides in developing countries is extremely variable, from nil in large parts of Africa, to extremely heavy dosage in intensive agricultural areas of Brazil and plantations of Central America. In their review of the limited research literature on pesticide use and impacts in Africa, Calamari and Naeve (1994) conclude that, "The concentrations found in various aquatic compartments, with few exceptions are lower than in other parts of the world, in particular in developed countries which have a longer history of high pesticide consumption and intense use. Generally, the coastal waters, sediments and biota are less contaminated than inland water environmental compartments, with the exception of a few hot spots."

The Brazilian State of Paraná is typical of developing countries undergoing rapid expansion of agriculture, and illustrates the dilemma of pesticide monitoring. Andreoli (1993) reports that Brazil, in general, had become the world's third largest user of "agrotoxic" substances by 1970, only exceeded by France and the United States. However, Andreoli states that less than 15% of active ingredients marketed in Brazil are analysed owing to the lack of methodology, equipment and financial resources. Yet, in a major study of 17 agrotoxic substances (including 11 organochlorine pesticides) over the period 1976 and 1984 in the Paraná River basin, 91.4% of *in situ* [presumably ambient] samples contained at least one In the Pirapó sub-basin 97.2% of ambient water supply samples and fully 100% of samples from springs showed pesticide residues. Andreoli also notes that studies of "intoxication" in 1985 showed a predominant effect from organophosphate pesticides, with the most serious effects influencing persons between the ages 15 and 25.

The International Code of Conduct on the Distribution and Use of Pesticides, formulated and being implemented by FAO (Box 8) is very relevant to pesticide pollution control and environmental protection in general.

The problems of pesticide management in developing countries is somewhat different than those of the developed countries. These are summarized as:

- Inadequate legislation and enforcement of pesticide regulations, including importation, use and disposal.

- Gifts of pesticides from donors that encourage inefficient use and abandonment of older quantities of the same pesticide.

- Stockpiling of pesticides, especially in countries with unstable governments, leading to abandonment of stockpiles in situations of insurrection and civil war. Examples exist where such a situation led to severe groundwater contamination and public health crises due to dumping of pesticides by untrained civilians.

BOX 8: INTERNATIONAL CODE OF CONDUCT ON THE DISTRIBUTION AND USE OF PESTICIDES

This Code of Conduct, adopted by FAO and its member countries in 1985, recognises that: *"In the absence of an effective pesticide registration process and of a governmental infrastructure for controlling the availability of pesticides, some countries importing pesticides must heavily rely on the pesticide industry to promote the safe and proper distribution and use of pesticides. In these circumstances foreign manufacturers, exporters and importers, as well as local formulators, distributors, repackers, advisers and users, must accept a share of the responsibility for safety and efficiency in distribution and use."*

Prior Informed Consent (PIC) is an important component of the Code of Conduct. Under PIC, *"pesticides that are banned or severely restricted for reasons of health or the environment are subject to the Prior Informed Consent procedure. No pesticide in these categories should be exported to an importing country participating in the PIC procedure contrary to that country's decision ..."*. Implementation of PIC is carried out jointly by FAO and the International Register of Potentially Toxic Chemicals (UNEP/IRPTC) and included 127 countries in December, 1994.

Pesticides currently (1994) under national review under PIC are:

Aldrin	DDT	Dieldrin
Dinoseb	Fluoroacetamide	HCH (mixed isomers)
Chlordane	Cyhexatin	EDB
Heptachlor	Chlordimeform	Mercur Compounds

FAO, 1990b.

- Storage and handling is a major problem, including leakage from old barrels and deliberate dumping of surplus pesticide mixtures into water courses following application.

- Destruction of old stores of pesticides (due to deterioration of the active ingredient) is financial prohibitive (estimated at US$ 5000 per tonne) especially as stocks must be moved to a developed country for destruction. Consequently, old barrels deteriorate with leakage into surface and groundwater and/or dumping of stocks.

- Lack of training of users in pesticide handling and application, leading to improper application with environmental and public health consequences.

- Use of pesticides for inappropriate purposes, such as killing of trash fish.

- Use of old pesticide drums for drinking water, cooking, etc.

Chapter 5

Summary and recommendations

Specific actions recommended for the control of sediment, fertilizer and pesticide impacts on water quality have been enumerated in each respective chapter. In this concluding chapter are discussed a selection of issues pertaining to water quality which have over-arching implications for agriculture. Some, such as internalization of all environmental costs, represent a significant challenge to the way in which agricultural agencies pursue agricultural practices. Others reflect the interaction between agriculture and other national development priorities and reflect public policy issues that are of national significance.

In his analysis of impacts of agriculture on water quality in the Brazilian state of Paraná in which agricultural expansion has had major impacts on water quality, Andreoli (1993) summarized a series of institutional and substantive lessons from that state into the following observations that have general application.

- The environmental impacts on water resources [in general] caused by agricultural activities cannot be disassociated from the agricultural impacts in production areas themselves. They require monitoring, and preventive measures should always be systemically integrated.

- It is necessary to develop and implement water resource monitoring systems with a prior definition of indicators, parameters, tolerance limits, frequency and sampling points, combining this information with quantity data.

- Data and information generated should be properly treated in the sense of disseminating them as much as possible in order to heighten awareness and mobilization of the public sector and of society with respect to agriculture's impact on the environment.

- Attempts should be made to exchange information and to pursue horizontal cooperation among countries, in order to promote the exchange of information and experiences.

- In the prevention systems proposed, solutions to causes should be looked for, seeking to match the agricultural model to the socio-economic needs of the population within environmental limits and vocations.

- Besides treating water quality related problems, there is evidence of other problems generated by conflicts in use, particularly the need to integrate quality management with the quantity of water within a comprehensive, decentralized and participatory management system, reconciling regional development with environmental protection.

- The cooperation of fiscalizing and monitoring agencies dealing with agrotoxic substances is urgent, with the capacity for control structures, seeking the development of biological indicators (enzymes, AMES test, biotesting, bioindicators) of residues and of anatomy and pathological damages caused by agrotoxic substances.

NECESSITY TO INTERNALIZE COSTS AT THE FARM LEVEL

Ultimately, any strategy to reduce agricultural impacts on water quality will only be successful if it is implemented at the farm level. Therefore, implementation of control measures at the farm level will only be successful and sustainable if the farmer can determine that it is in his economic interest to undertake such measures. Therefore, the economic benefits from such factors as implementation of erosion control measures to maintain soil fertility, capital costs associated with improved manure handling and distribution, etc., must be clearly seen to be offset by reduced energy consumption in minimum till situations, improvement in soil fertility by improved manure handling and erosion control, reduced fertilizer costs, etc.. This implies that agricultural agencies must use a holistic approach to the economics of farming practices. There are abundant examples from both developed and developing countries that indicate that this approach is equally applicable to all farmers who have a long-term interest in their land.

In cases where particularly serious pollution of surface and/or groundwater (such as creation of a groundwater recharge reserve) creates conflicts over water rights and beneficial uses, mitigation is often addressed by a mixture of regulatory and voluntary measures. These measures may involve change in agricultural use or land management practice, or may take land entirely out of production. Where the cost-benefit is not in the farmer's favour, compensation becomes an important issue. While compensation is a well established legal recourse in developed countries, appropriate compensation for land owners in cash or kind should be considered as part of pollution mitigation programmes in developing countries. The situation in the former Soviet republics is particularly unique; the conversion of public agricultural land to private ownership requires new administrative, compensatory, and infrastructure costs to achieve water quality protection. In some countries, the costs of social disruption of landless farm labourers needs to be factored into the overall compensatory package.

INTEGRATED NATIONAL WATER QUALITY MANAGEMENT

The need for integrated water resources management has been widely accepted as a necessary national policy goal (ICWE, 1992; United Nations, 1992, World Bank, 1993; FAO 1994c). From the agriculturist's perspective, only an integrated approach permits the evaluation of the role of agriculture in a national water resource management programme, and protects against disjointed, inefficient and inequitable policy decisions for water quality remediation. The disastrous environmental situation in many Eastern European countries as well as in some rapidly industrializing countries, provides ample evidence for the types of policy actions that need to be taken to deal cost-effectively with the role of agriculture within the larger framework of water quality management.

The example of Lithuania is instructive (FAO, 1994b). The following seventeen issues form the basis for the water quality policy that is proposed in Lithuania. Clearly, ***agriculture*** is but one of the concerns that comprise the mix of water quality policy issues. Also, the emphasis on piggeries can be replaced by other types of intensive animal farming in other countries.

1. ***Unsafe groundwater supplies in rural areas.***
2. ***Need for identification/definitions of water protection areas.***
3. ***Waste from pig complexes is discharged directly into watercourses; lack of appropriate technology for handling of waste from pig complexes.***
4. ***Conflicting views on (a) intensive agriculture, and (b) water quality protection from nutrient and chemical pollution.***
5. Groundwater pollution from municipal waste water in Karst areas.
6. Policy issues related to the use of surface water are linked with pollution and dilution requirements during periods of low flow.
7. ***Conflicting functions of (a) licensing and (b) quality control of pesticides, carried out by the same agency.***
8. Financing and implementation of municipal waste treatment to EC-HELCOM (Helsinki Commission) recommended standards.
9. Collection/treatment of industrial/urban rainwater runoff.
10. Poorly managed solid waste dumping sites.
11. Consideration of step-wise, time-targeted implementation of industrial effluent standards.
12. Need to consider economic and social consequences of effluent standards and water quality objectives.
13. Industry to have access to clean technology for safe disposal of waste.
14. Inefficient and operational problems of combined industrial and municipal waste water treatment.
15. ***Viability of irrigation is questionable; alternative methods for disposal of slurry waste from pig complexes have to be identified.*** [Note: refers to use of irrigation to dispose of slurry waste from pig complexes.]
16. Water protection and general environmental health policies are not consistent and need to be adapted to general policies of extended private initiative and responsibility.
17. Responsibility, ownership and mechanisms for certification, accreditation and control of water quality laboratories including main objectives (environmental, hygienic, law enforcement and scientific purposes) need to be defined.

Missing from this list is improved ***pest management*** and ***fertilizer management***, particularly from the context of efficient use of animal wastes and the environmental (including water quality) and public health benefits from a more optimal use of pesticides. In other countries with different climatic and topographic characteristics, additional policy elements would include:

- erosion control
- aquaculture impacts
- deforestation impacts
- wetlands management
- pesticide management and control (importation, manufacture, sales and application, and disposal)
- irrigation management
- rice/fish culture management

ASSESSMENT METHODOLOGY

In Chapter 1 it was noted that a typical dilemma in managing water quality in river basins was the difficulty in determining the extent to which agriculture contributes to the overall water quality problem. Therefore, recommendations for assessment of impacts of agriculture on water quality fall into two spatial categories ? one is at the farm level, the other is at the river basin level. Assessment and decision-making at these two scales are fundamentally different.

At the **farm level**, assessment and decisions are those that can be implemented by the farmer. While the net benefits may be felt at larger scales, the objective is to implement decisions that are practical and which are economically advantageous for the farmer. At the **river basin scale** the user is a regional or national agency which must assess the contribution of agriculture to the larger problem of river pollution, and the management alternatives both for point and non-point sources that could be implemented in different parts of the basin that would have the greatest impact at the least cost. Therefore, basin-scale assessment is essential for the development of rational and cost effective remediation and control programmes which are usually driven by national policies on water pollution. The tools for agricultural impact assessment are well known, however, they need to be systematized into a general methodology and integrated with modern environmental chemistry and take advantage of new advances in the field of information technology. The methodology needs to be developed at two levels of detail: (a) at the screening level in which a rapid assessment can be made and which provides approximate levels of predicted impacts based on easily accessible information; and (b) at a detailed level for use in detailed studies for the purpose of developing remediation options.

At the **small scale** (field, small catchment) it is important to be able to predict the nature of agricultural runoff and associated loss of nutrients, sediments and pesticides, so that agriculturalists can predict the probable impact of different crop and land management options. Table 13 identifies a selection of models that are used for agricultural assessment purposes. It is recommended that one or more screening models be adapted for use in developing countries for the purpose of estimating erosion and chemical loss at the plot or field level, and for “gaming” with alternative land use options relative to erosion and potential for chemical runoff. Appropriate screening models should not require excessive data, should integrate over seasons, and be easily transportable from one region to another. Such models will require selective calibration by national agricultural agencies to ensure reliability.

At the **large scale** (sub-basin, basin, regional) there is an urgent need to develop simple methods for making estimates of erosion at the basin scale, as has been discussed more fully in Chapter 2. Also at the basin scale there is a need to develop a systematic methodology that permits evaluation of water quality impacts of agriculture relative to other types of polluting sources. One possibility is a combination of the “rapid assessment” methodology of the World Health Organization (Economopoulos, 1993) in which point sources can be rapidly inventoried and assigned to pollutant categories together with a non-point source assessment methodology (a screening type of model), both operated within a georeferenced expert system.

ENVIRONMENTAL CAPACITY

GESAMP (1986) defines environmental (also known as receiving, absorptive or assimilative) capacity as "the ability of a receiving system or ecosystem to cope with certain concentrations or levels of waste discharges without suffering any significant deleterious effects" (Cairns, 1977, 1989). All activities, including agriculture have some level of impact on water quality; the issue is whether the impact exceeds thresholds which society deems unacceptable for social, economic or cultural reasons. Scientifically, much is already known ? rates of uptake, dilution, losses through volatilization, etc. However, determination of the threshold values requires not only scientific input, but also socio-economic and cultural inputs. According to GESAMP, this works well within an interactive environmental management strategy (Barg, 1992).

For agriculture, there is need to determine what the environmental capacity is for different types of runoff products in the local context. Determination of acceptable threshold values could be systematized through use of an expert system in which the database includes all relevant scientific characteristics; the decision on the threshold value are evaluated as a series of options that are filtered through the knowledge (input) of local circumstances.

THE DATA PROBLEM IN WATER

(a) Data Programmes: It was noted in Chapter 1 that, typically, the data which are needed for such an assessment are not often available from conventional water quality monitoring programmes. However, there are new techniques in environmental chemistry and toxicology which permit much more cost-effective determination of the nature and source of water quality problems than is possible with conventional physico-chemical measurements that are carried out in most water quality programmes. Applegren (FAO, 1994b), in his assessment of water resource policy needs in Lithuania, a country which is probably typical of many other former Soviet republics, identified the need for strengthened water quality monitoring and a water resources database.

The framework for cost-effective improvements in water quality measurement is as follows:

- Reduce fixed site monitoring networks and **expand the survey approach** to water quality measurement (Rickert, 1993).

- **Achieve a better balance between water sampling (traditional) and other media** such as suspended sediment sampling. Note that hydrophobic contaminants such as organochlorine compounds including many older pesticides, PAHs and PCBs are often found only at trace levels in water but can be easily determined on solids. It follows that management judgements about presence/absence/toxicity and environmental and/or human health impacts of aquatic chemistry are frequently grossly in error if analysis is made only on water samples.

- **Use of "Environmental Effects Monitoring" (EEM) to reduce the amount of analytical chemistry and to increase environmentally relevant information for decision-making**. Commonly, EEM involves in-stream assessments using biological survey techniques. The rationale is based on the fact that, if aquatic contamination exists, it will be evident in biota (Reynoldson and Metcalfe-Smith, 1992; Reynoldson *et al*., 1995; US-EPA, 1989). Canada and the United States have agreed on the use of biologically-based objectives for the management of water quality of the Great Lakes. These techniques are very useful in developing countries insofar as the measurements require training in biology (usually good in developing countries) and is labour intensive rather than capital intensive. EEM reduces reliance on high-end analytical chemistry with its large capital costs and lengthy training. EEM can involve many other types of biological measures such as fish health, fecundity, immune suppression, etc. Many of these tests are simple and are low cost.

- Except where specific chemical measures are justified, make use of modern screening techniques that provide economical indicators of chemical presence and/or impact. Screening techniques are designed to provide quick information which guides the decision on where more detailed (and expensive) chemistry is needed. Screening techniques eliminate the "menu" approach to environmental chemistry wherein laboratory analysis is restricted, for reasons of cost, to a predetermined set of chemical parameters. Experience has shown that such lists frequently have little value in studies of environmental contamination. Screening tools include the following types of activities:

- Standardized laboratory bioassays (Keddy *et al*., 1994)
- Immunoassay tests (Bushway *et al.*, 1988; Thurman *et al*., 1990)
- Measures of fish health such as red/white blood cell ratio, slime on body and gills, etc.
- Use of enzyme measures to determine whether fish have been exposed to toxic chemicals (e.g. MFO induction [Mixed Function Oxidases])
- Measure of total chlorine (an indicator of total chlorinated compounds).
- TIE (Toxicity Identification Evaluation).

(b) Mobilizing Data: It is essential that agriculturalists can determine the impacts of agriculture on water quality at the medium and large scales relative to other potential sources of water quality degradation. This requires that conventional monitoring data for nutrients, salinity, and suspended sediment need to be integrated into a single information system that permits analysis of basin or sub-basin trends in water quality and sediment transport relative to point and non-point sources and gross indicators of land use, topography, soils and climate. That this is not done in most countries reflects inter-agency and institutional problems and the lack of suitable software. Measures of data reliability must be established and confidence levels established for interpretive activities. Analysis of existing data rapidly leads to identification of data gaps, of unreliable parameters, and of parameters which have no useful function and which can be eliminated from monitoring programmes.

WATER QUALITY INDICES FOR APPLICATION TO AGRICULTURAL WATER QUALITY ISSUES

Water Quality Indices refer to two or more parameters that indicate the "healthiness" of water. In some cases, indices reflect ecosystem behaviour; in other cases, they indicate conditions of the aquatic environment (e.g. toxicity). These indices are generally designed to determine potential for ecosystem dysfunction, and to provide insight into pollution sources and management decisions for source control. Indices tend to be mainly used for descriptive purposes and are not often used directly for water quality management at the field level. The need is for indices that permit rapid assessment of **impact** of agricultural runoff and which can be used to make judgements on levels of impacts in space and time as a basis for management decisions concerning the need for controls. There is also potential to develop indices which link water quality impacts to economic factors relative both to upstream sources and downstream consequences, as a way to evaluate the economic impacts of agricultural runoff.

Currently, water quality indices are of the following types:

(a) Numerical Indices based on conventional water chemistry: There are commonly a half dozen indices that combine various chemical measures of water quality into an integrated index. These commonly include a mixture of nutrients, microbiology, dissolved oxygen and, occasionally, metals. Generally, these are used as descriptive tools for assessing river reaches. The more successful indices use a limited number of parameters (e.g. a eutrophication index would use nutrients and dissolved oxygen or BOD) and describe one type of water pollutant impact (e.g. eutrophication). The most complete recent reference is a report (in Dutch) produced for RIZA (Netherlands) on chemical indices (RIZA, 1994).

(b) Effects Indicators/Indices: There are a wide variety of "effects" indicators which are often combined into an index. These generally are some measure of biological reaction to aquatic pollutants. Many of these are used as "screening" tools (as noted above) which can help managers resolve spatially and causally, the nature and intensity of the pollutant impact. These indicators include:

Bioassay: Usually a scoring system based on the performance of a number of standardized lab assays using pollutant-sensitive species that are indicative of various trophic levels (e.g. bacteria, algae, invertebrates, vertebrates). Bioassay tends to focus on toxicity impacts (Keddy *et al*., 1994).

Biotic Indices: There are a variety of standardized biotic indices that are commonly used in Europe for water quality assessment and management. Generally, these indices are developed from benthic assemblages in rivers and streams. The index represents the nature of benthic response, mainly to organic pollution (domestic and municipal wastes). These have not been very successful for toxics assessment. There have been many reviews of biotic indices (Reynoldson and Metcalfe-Smith, 1992; Metcalfe-Smith, 1994).

Ecosystem indicators: Increasingly, there is interest in indicators that describe how parts of ecosystems respond to physical and chemical stress. Indicators can include a range of ecological measurements (fish, benthic organisms, habitat, etc.). This technique has proven useful as a means of establishing norms against which managers can measure success of remediation measures (US-EPA, 1989). This approach has also been used in the United Kingdom, Canada, and Australia (Reynoldson *et al*. 1995)

Other Effects Indices: There are a wide range of indices that are used to assess nutrient and/or toxic stress. Many of these use fish as a useful surrogate for impacts on humans. These indices include:

- measures of fish health using histological (e.g. red/white cell ratio) and pathological measures (size and appearance of organs).

- presence/absence of contaminant metabolites in fish bile, liver, etc.
- presence of enzymes as part of detoxification process in organisms (e.g. measures exposure of fish to toxic chemicals).

(c) Other Chemical Indicators: These are integrating (and usually simplifying) chemical measures of groups of compounds. An example is the mapping of chlorine residuals as a measure of total chlorinated material in the water column in a river basin. "Hot spots" within the basin indicate potential problem areas. The objective of such indicators is to use simple, inexpensive measures to determine whether problems may exist and to guide decisions on priorities for further (and expensive) chemical analysis.

General Note: Many of these techniques are lower in capital equipment requirements and higher in useful information than conventional water chemistry, and are capable of implementation by developing countries which typically have good capacity for biology but much less for advanced environmental chemistry. Such indices do require a shift in the "data paradigm" which continues to be dominated by the (western) chemical approach to water quality assessment.

ECONOMIC ANALYSIS OF COST OF WATER POLLUTION ATTRIBUTED TO AGRICULTURE

Because agricultural water pollution is of a non-point source nature, the quantification of pollutants and their impacts is more difficult than for point sources. However, the world's ever-increasing demand for dwindling supplies of good-quality freshwater requires that countries adopt a holistic approach to water resource management. Pollution control is now so expensive that decisions on resource management priorities should be guided by knowledge of the cost of water pollution to the various economic sectors. That cost is in two parts: the first is the direct cost (e.g. treatment) of meeting minimum water quality standards required for various uses; the second is the cost of lost economic opportunity because of inadequate water quality. Examples include: reduced production due to excessive salinity in irrigation water, and loss of fish production due to reproductive and growth impairment caused by toxic chemicals. It is only by knowing both direct and indirect costs, and by assigning these costs to the various economic sectors (including agriculture) that the true cost both caused by and absorbed by agriculture, can be evaluated relative to other sectors.

INFORMATION TECHNOLOGY AND DECISION MAKING

An often cited benefit of information technology is the ability to electronically access data, text, graphics, etc. from an infinite number of locations in the world. An example for pesticide information was provided in Chapter 4. The hardware and software (e.g. World Wide Web on the Internet) is now reliably dedicated to such tasks to the point where information overload is now a problem. Nevertheless, while this type of information technology is the best known aspect of the information revolution, it is only one side of the information technology equation. The second side deals with the problems created by this ease of access. This includes the frequent absence of quality control and other meta-data which are needed to describe the characteristics of the data/information, and the immense problem of what to do with such large amounts of information when it is received and how to use it for decision-making purposes. Indeed, the challenge is no longer that of accessing information but one of integrating information in a systematic manner for the purpose of making management judgements about particular projects and problems in agriculture in general, and the management of water quality in particular.

Information technology is now conventionally used in the following ways:

a. **Information Systems:** systems that inform users about what information exists and where to find it. These may be internal to an agency or mounted on the Internet through an agency's Home Page. As part of these systems, hypertext permits instant (Internet) access to information sources no matter where that information may be located in the world.

b. **Integrating Software:** software that contains an integrated set of "tools" (map editors, statistics, graphics, expert system shells, etc.) which permit the user to access, assemble and use data, models, text, imagery, video, models, etc. for any purpose defined by the user. While some geographic information systems (GIS) have some of this capability, fully developed systems, such as Environment Canada's RAISON Software, are designed specifically for such tasks.

c. **Advisers:** special computer programs that are designed to provide advice to users. This can range from simple situations that are captured in the software and presented to the user, up to programs which use the full range of information technologies such as Expert Systems (knowledge base), neural networks (self-learning), fuzzy logic (uncertainty), etc. and which are increasingly being used in complex decision-support software. While these advanced technologies are invisible ("transparent") to the user, they often permit analysis of uncertainty in the decision process which can be very beneficial to the user. The technology of "advisors" uses much of the same techniques as information systems insofar as the advisor may lead the user to information sources that may be held anywhere on the Internet. Other "advisors" are quite self-contained and rely only on input of appropriate data by the user. An example of each is provided below.

   One particular role of advisors is in the field of **screening tools**. As in the example below (**EXPRES**), a screening tool provides a consistent approach to making first-approximation judgements, usually with limited information. Screening tools, whether they be based on information systems or on biological and chemical measurements as noted earlier in this Chapter, assist the user to decide if greater attention to the issue is merited. For example, a screening tool could be used which permits a first rapid assessment of the potential for developing an irrigation scheme. The screening tool provides a first estimate of the potential (including potential impacts) and identifies those aspects which remain unclear and which require further investigation in order to provide an improved decision. The screening tool is especially useful for the non-expert and, in many instances, can save time and money by eliminating the need to send irrigation professionals with different types of expertise to every possible site. Alternatively, the screening tool can assist a single expert by providing the knowledge base of other experts as part of the database contained within the computer program.

   Advisers can also lead to significant savings in labour in situations where agencies must routinely respond to technical issues. By capturing the experts' knowledge about these issues on a computer, routine responses can often be handled by a secretary thereby freeing up the time of expensive professionals.

Examples of Advisers in Water Quality: The following two examples demonstrate two types of advisers that reflect problems of water quality in agriculture. The first, a manure management system known as the **"Manure Wizard"**, is an information system which not only assists in making a decision, it also permits the user to explore the sources of information that pertain to the recommended decision. The second, **EXPRES**, is a self-contained program which permits the user to explore the potential for contamination of shallow groundwater by pesticides through the use of models and pesticide databases that are built into the software.

(a) Manure Wizard

Manure management at the farm level is mainly driven by problems of water quality impacts. Manure management is often complex, involving decisions about manure chemistry, animal types, quantitative prediction, economics of manure handling, different options for disposal, spreading on land under different conditions of soil, slope and crop types, etc.. Because manure management has significant pollution potential as well as significant costs at the farm level for containment and disposal, the **Manure Wizard** provides the farmer with as much information as is needed to make an informed decision about his options. This Advisor, developed at the University of Guelph (Canada) for Agriculture Canada allows the farmer to interrogate the information system about any aspect of manure management under different types of agricultural conditions that are found in Ontario. The system contains relevant text as well as the ability to connect the user, via the Internet, to other sources of documentary information. The Adviser contains a "knowledge base" which helps the farmer arrive at an appropriate and cost-effective solution for manure management. The knowledge base consists of informed judgement from professionals in this field, which is captured as part of the database, and then applied to the particular problem of the user. The Advisor, once developed, provides comprehensive and systematic information for decision-making to the farmer, and requires no computer skills on the part of the user.

Figure 14 illustrates the first two "screens" (i.e. computer images) that appear in the Manure Wizard. Each screen leads the user through a series of questions and provides guidance on those issues relevant to manure management. Using "hypertext" linkages, the user can interrogate specific words, titles, phrases or issues that appear on the screen. Hypertext then immediately transfers the User to the relevant section of the Advisor or automatically connects the user to an external information source.

(b) EXPRES: The **EX**pert system for **P**esticide **R**egulatory **E**valuations and **S**imulations), was developed by the National Water Research Institute of Environment Canada (Crowe and Mutch, 1994) as a tool for quickly evaluating the potential for contamination of shallow groundwater by agricultural pesticides. Typically, this type of issue is answered by a detailed knowledge of the soil (often through drilling of cores), measurement of slope, pesticide chemistry, etc.. This type of investigation is expensive and there was a need to develop a screening technique which would allow non-experts to estimate the potential for groundwater contamination without having to go to the expense and trouble of drilling wells, making field measurements, hiring consultants, etc.

The **EXPRES** expert system consists of a "knowledge base" (informed judgement by experts) in this field, and which is captured as part of the database, a database of pesticide and other relevant information, and three pesticide assessment models. Using the user's available data and study objectives, **EXPRES** selects the most appropriate model, assists the

FIGURE 14
Example of the first two "screens" of the Manure Wizard. These guide the user through a series of questions designed to assist the user in making a decision for the most cost-effective and beneficial way to manage animal wastes (Source: University of Guelph, Canada)

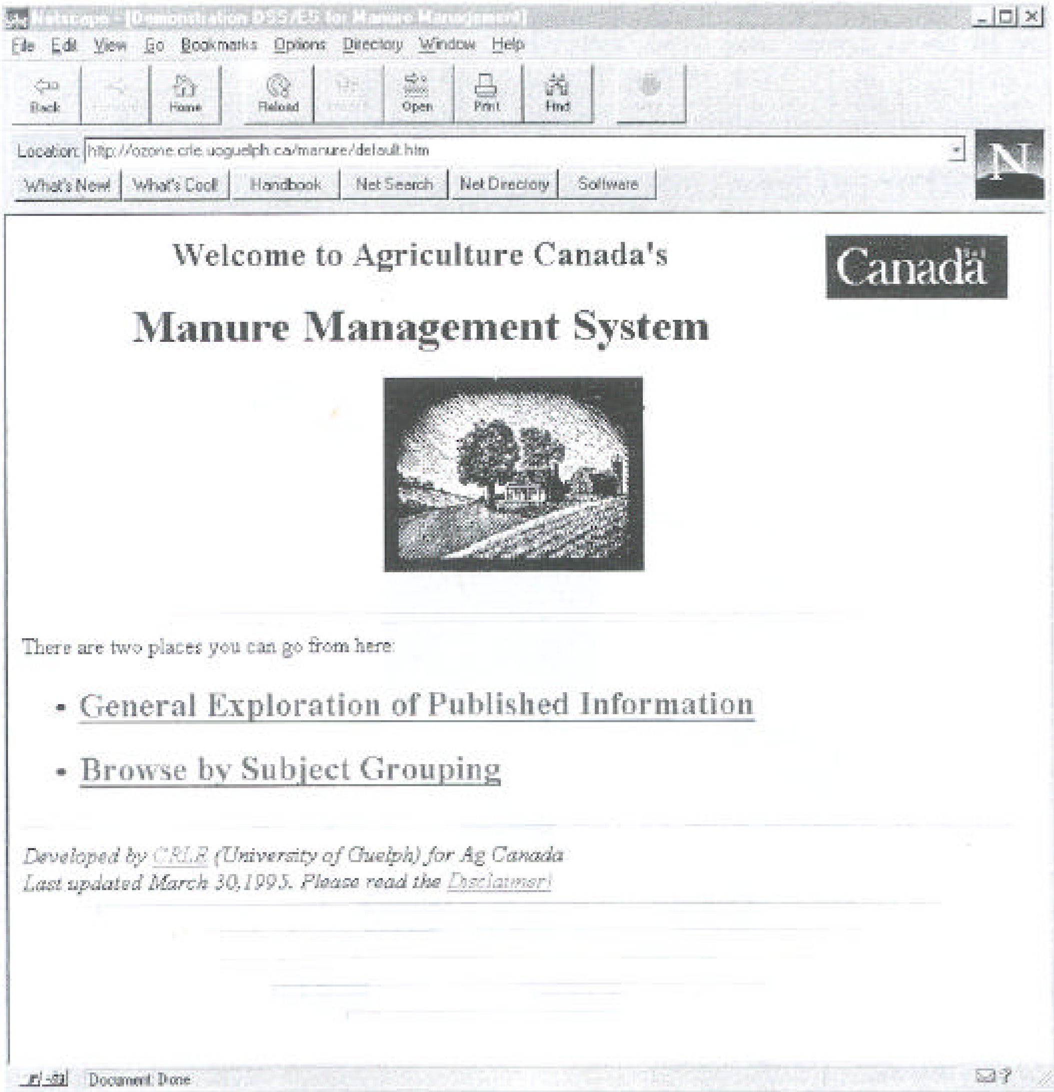


FIGURE 14 cont'd

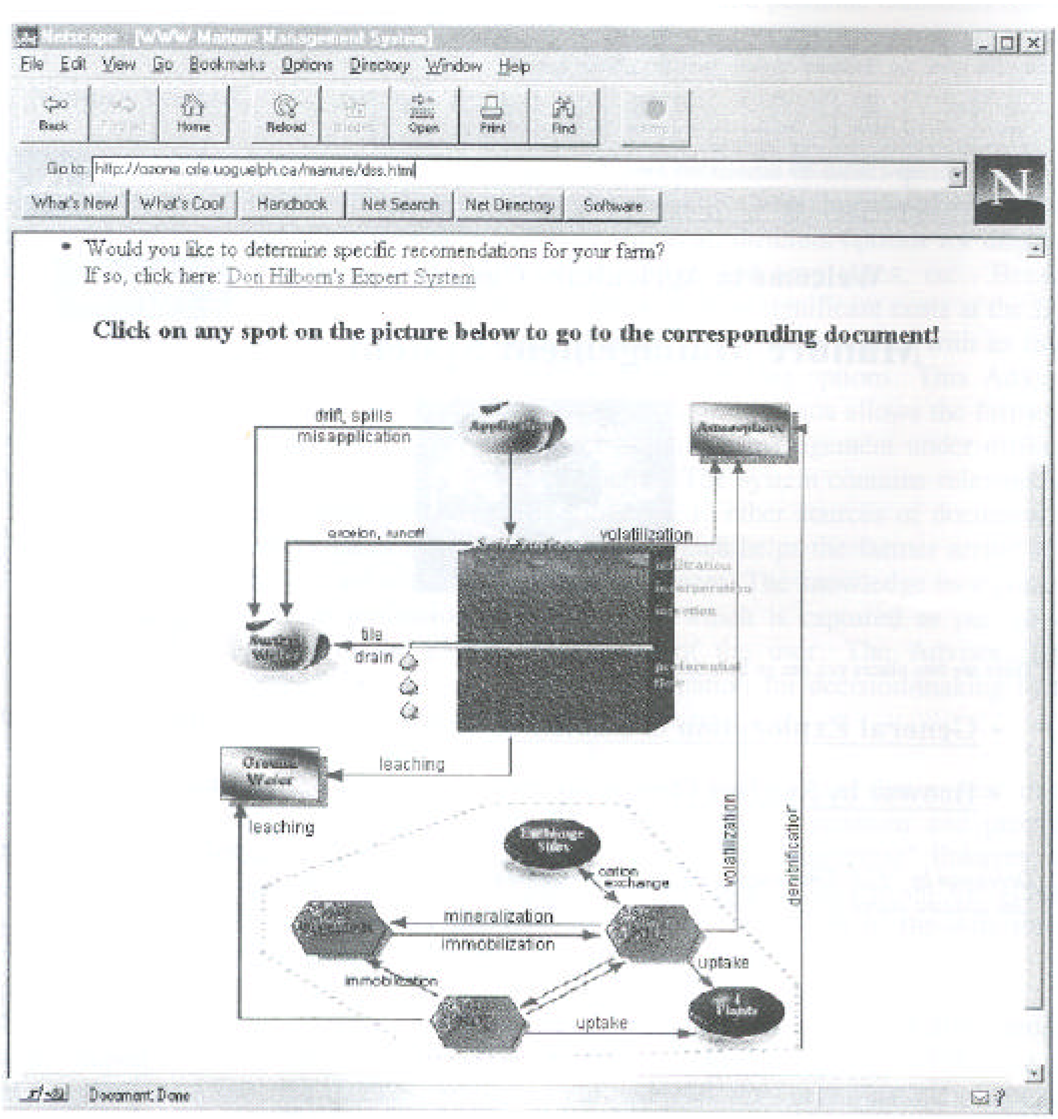
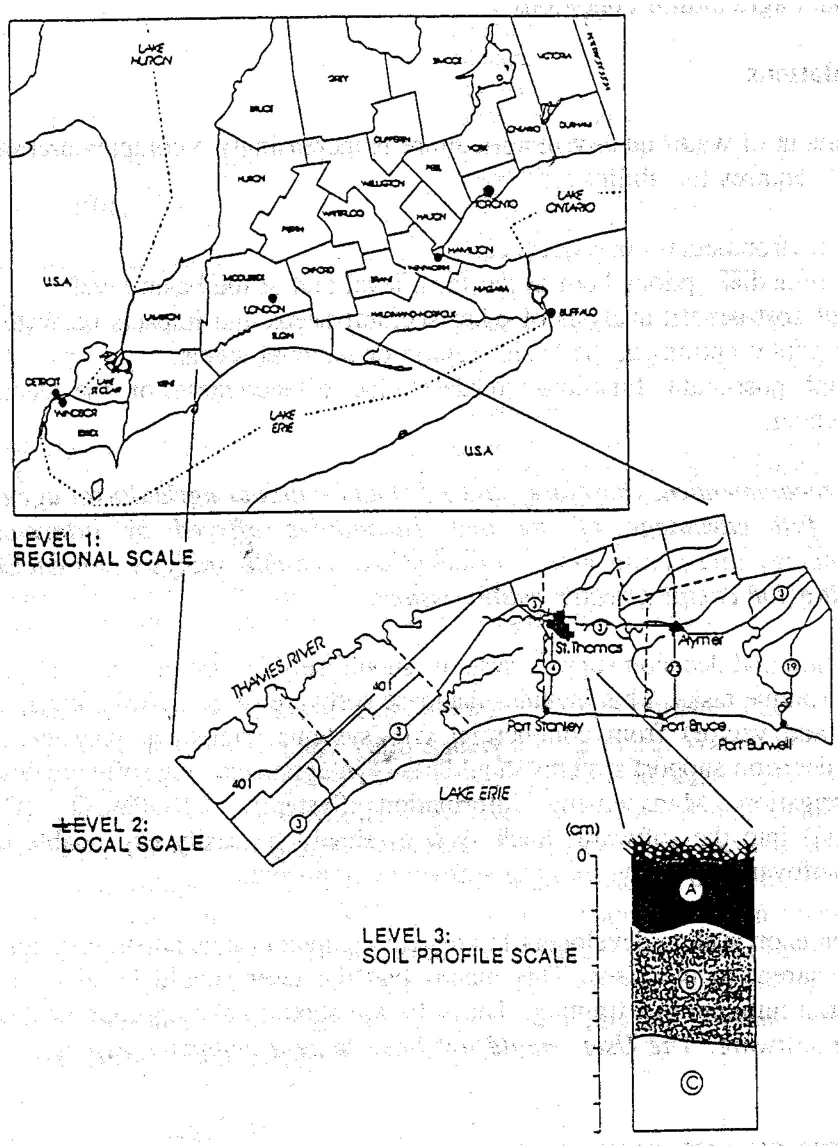


FIGURE 15
Different geographical scales that can be addressed with the EXPRES regional assessment adviser (From Crowe and Booty, 1995; printed by permission of Kluwer Academic Publishers)



user in construction of an input data set, initiates the assessment, and aids in the interpretation of the results. **EXPRES** can review pesticide and site properties, assess the potential for leaching to groundwater relative to other possible pesticides, make quantitative predictions on the distribution and migration rates of the pesticide, and evaluate the processes and factors that control the fate of pesticides in the subsurface.

EXPRES has been expanded into a regional assessment tool (Figure 15) by Crowe and Booty (1995) with three different scales of application ? soil profile scale, local scale, and regional scale. The most detailed analysis is at the soil profile scale, whereas the larger scales are used as screening tools by regulators to determine the relative potentials for groundwater contamination and the need for groundwater monitoring.

Advisers tend to be designed for specific sets of conditions. Both **EXPRES** and the **Manure Wizard** are designed for application under humid temperate conditions and agricultural systems found in Canada; nevertheless, they can be adapted to include other types of climatic and agricultural conditions.

Recommendations

The management of water quality in agriculture is increasingly a complex and multi-sectoral problem that requires the ability to:

- predict environmental consequences;
- analyse remedial options both at the farm level and at the basin level;
- carry out cost-benefit analysis of other sectoral needs and impacts on water quality;
- identify policy options at the basin, region or national levels;
- carry out post-audit functions to determine effectiveness of the decisions, once implemented.

> It is recommended, therefore, that FAO and national agricultural agencies take full advantage of the new capabilities offered by information technology that permit more consistent and reliable analysis and decision-making for complex water quality issues.

Information and decision-support systems should rely on commercial and public domain products for routine tasks. This includes database software (e.g. dBASE, etc.), existing GIS files (raster and vector) from commercial GIS systems, statistical packages etc. Where appropriate, decision-support systems should easily integrate existing software (such as SIMIS [Scheme Irrigation Management Information System], CROPWAT [Crop Water Requirements]) into the software. Such systems should be easily expandable (adding new tasks to the software) by using existing software components.

The onus is on system developers to create a computer decision-support software which is quite transparent to the User. This means that the User should be able to operate the program with a minimum of training. The software should have appropriate "HELP" tools built into the software. ***The User should not have to be a computer expert.***

USE OF WATER QUALITY OBJECTIVES

Water quality objectives and guidelines are widely used to determine the suitability of water quality for designated uses, including agricultural use. The impacts of agriculture on water quality, therefore, are a determinant in whether or not water is suitable for a downstream use, including downstream withdrawals for irrigation. Water quality objectives are widely used for regional water quality assessment and planning purposes, and for environmental reporting.

There is a tendency amongst developing countries to adopt water quality objectives and guidelines developed by western water quality agencies. The Canadian Water Quality Guidelines (CCREM, n.d.), for example, are widely cited. Calamari and Naeve (1994) note that the use of water quality criteria that are developed in temperate ecosystems should be used with care in African situations due to the large differences in chemical behaviour (toxicity, persistence and accumulation rates) in these different climate conditions. The same

TABLE 18
Candidate pesticides for the proposed international POPs protocol

PESTICIDES	**Others[1]**
Aldrin	Acrylonitrile
Atrazine	Aramite
Chlordane	**Dioxins**
Chorpicrin	**Furans**
1,2-Dibromoethane	Lead compounds
1,2-Dichloroethane	Cadmium compounds
Dieldrin	Captafol
DDT (+DDD + DDE)	Chlordecone (Kepone)
Endrin	Chlordimeform
Fluoroacetic acid & derivatives	Chloroform
Heptachlor	Crimidine
Hexachlorobenzene	Isobenzan
Lindane (Hexachlorocyclohexane)	Isodrin
Mirex	Kelevan
Nitrofen	Morfamquat
Pentachlorophenol	2,4,5-T
Polychlorinated terpenes	**Poly-chlorinated biphenyls (PCBs)**
Quintozene	Selenium compounds
Toxaphene	

[1] Chemicals not currently used in Western Europe but identified as requiring control if they were in use. Highlighted compounds are those commonly referred to as the "Dirty Dozen"

point can be made for Asian and many Latin American countries. Water quality objectives/ guidelines/criteria also reflect, explicitly or implicitly, societal values and willingness to accept risk, especially for water quality objectives linked to public health. All these considerations suggest that water quality objectives developed in advanced countries may not be appropriate for developing countries. This issue is much larger than that of agricultural impacts on water quality, however the level of impact of agriculture in many developing countries is sufficiently large that agricultural agencies should have some involvement in the development of water quality objectives that are appropriate for those countries and which are realistic in terms of the ability to assess agricultural impacts on water quality for the purpose of meeting water quality objectives.

FAO AND THE POPS AGENDA

Global contamination by Persistent Organic Pollutants (POPs) has achieved international prominence (Table 18). The importance of these chemicals in the context of non-point sources of pollution was brought out in the following fora: 1995 UNEP Governing Council; ongoing ECE negotiations on long-range transport of atmospheric pollutants (LRTAP); the 1995 adoption of a Global Plan of Action for the Prevention of Pollution of the Marine Environment by Land Based Activities; and a Nordic initiative to achieve a POPs protocol.

The implications for agriculture are that a substantial number of the candidate chemicals on the POPs list are agricultural pesticides (Table 18), some of which are still widely used in developing countries. The chemicals listed in Table 18 are taken from European, Canadian and ECE lists of pesticides that are banned or that have been identified as requiring major reductions in use due to documented environmental and/or public health consequences.

BOX 9: POPS STATEMENT INCLUDED IN THE WASHINGTON DECLARATION
ON PROTECTION OF THE MARINE ENVIRONMENT
FROM LAND-BASED ACTIVITIES

Para. 17: Acting to develop, in accordance with the provisions of the Global Programme of Action, a global, legally binding instrument for the reduction and/or elimination of emissions, discharges and, where appropriate, the elimination of the manufacture and use of the **persistent organic pollutants** identified in decision 18/32 of the Governing Council of the United Nations Environment Programme. The nature of the obligations undertaken must be developed recognizing the special circumstances of countries in need of assistance. Particular attention should be devoted to the potential need for the continued use of certain persistent organic pollutants to safeguard human health, sustain food production and to alleviate poverty in the absence of alternatives and the difficulty of acquiring substitutes and transferring of technology for the development and/or production of those substitutes.

The agricultural sector will face significant challenges in accommodating worldwide bans or serious restrictions on certain pesticide formulations. These challenges include cost-effective alternatives, national regulations, and enforcement of importation, manufacturing and use of banned agro-chemicals. Because, at the time of writing, it is difficult to foresee what the final outcome of the various POPs initiatives will be, this recommendation deals only with the role that FAO may have to play in the negotiations that may lead to an international POPs protocol. FAO is the principal source of impartial information, both on the science and chemistry of pesticides used in agriculture that will be needed by many developing countries to effectively participate in the POPs negotiations, and on provision of informed advice to developed countries of the economics and efficacy of pesticide use in the developing world. FAO is in the position of playing an important and highly visible role as mediator and broker to the POPs process.

PESTICIDES IN DEVELOPING COUNTRIES

Quite separate from the POPs agenda is the problem of pesticide use in developing countries and countries with economies in transition. The history of pesticide abuse is legend. The environmental, water quality, and public health consequences are well known. While the "Prior Informed Consent" programme of FAO and IRPTC (International Register of Potentially Toxic Chemicals) is an important step, the abuse and misuse of agricultural chemicals remains a major problem in many countries, especially in Latin America, Asia and eastern Europe. There are no easy answers or recommendations, however the issue is so important both for public health and the environment, with large off-site economic costs, that FAO needs to develop a specific action plan in the field of pesticide use. The action plan needs to include assessment, education, demonstration, chemical replacement, storage and destruction.

Actions by national governments, such as reduction or elimination of price subsidies, can have significant beneficial effects through reduced pesticide use. Combined with training in integrated pest management, reduced pesticide use can achieve both ecological (including water quality) and economic advantages at the local level.

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Annex 1

Pesticide inventory

This Annex provides general information for a broad range of agricultural pesticides. Readers must consult the original sources for detailed information, especially for drinking water guidelines. Different values for concentrations in drinking water and in fish and shellfish tissue reflect different criteria and methods used to calculate these values. Guidelines for fish are for edible parts (e.g. fillets). Concentration values for drinking water and fish and shellfish tissue are not available for many pesticides. The primary source for this Annex is Reference #1 below: unless otherwise indicated, information and values come from this source.

(1) US Environmental Protection Agency, 1990. National Pesticide Survey: Survey Analytes. In: "National Survey of Pesticides in Drinking Water Wells, Phase 1 Report, Office of Water, Office of Pesticides and Toxic Substances, EPA570/9-90-015, Washington DC
(2) Nowell, L.H. and Resek E.A. 1994. National standards and guidelines for pesticides in water, sediment, and aquatic organisms: Application to water-quality assessments. Volume 140 of "Reviews of Environmental Contamination and Toxicology", Springer-Verlag, Heidelberg, Germany, Volume 140. (Refer to this source for comprehensive discussion; guidelines for aquatic life, etc.).
(3) World Health Organization, 1993. Guidelines for drinking water quality; Volume 1: Recommendations. World Health Organization, Geneva,Second Edition.
(4) Misc. sources, including product literature, etc.

Pesticide	Common or Trade Name	Type	Principal Use	Drinking Water Level (? g/l)	Fish & Shellfish Tissue (mg/kg)
Acifluorfen	Blazer Carbofluorfen Tackle RH-620	Herbicide	Controls weeds and grasses in soybeans, groundnuts, rice, and other large seeded legumes	-----	
Alachlor	Lasso	Herbicide	Controls annual grasses and weeds in maize, soybeans, and groundnuts	2.0 20. (3)	
Aldicarb	Temik	Insecticide Acaricide Nematocide	Controls insects, nematodes, and mites on cottom, sugar beets, potatoes, and ornamentals	10. (1,3)	
Aldicarb sulfone	Standak Aldoxycarb	(Degradate)	(See Aldicarb)	40.	
Aldicarb sulfoxide	(See Aldicarb)	(Degradate)	(See Aldicarb)	10.	

Pesticide	Common or Trade Name	Type	Principal Use	Drinking Water Level (? g/l)	Fish & Shellfish Tissue (mg/kg)
Aldrin	HHDN Octalene	Insecticide	Controls soil insects	0.03 (3)	0.3 (2)
Ametryn	Gesapax	Herbicide	Controls weeds in pineapple, sugarcane, bananas, plantains, maize, and potatoes	---	
Atraton	Gesatamin	Herbicide	Formerly an experimental herbicide	---	
Atrazine	AAtrex	Herbicide	Controls cerain weeds in maize, sorghum, sugarcane, pineapple, and citrus fruits	3.0 2.0 (3)	
Atrazine, deethylated	(See Atrazine)	(Degradate)	(See Atrazine)	---	
Barban	Carbyne	Herbicide	Controls weeds in wild oats, wheat, lentils, peas, sugar beets, barley and clover	---	
Baygon	Propoxur Unden Blattanex	Insecticide	Controls cockroaches, flies, mosquitos, and turf insects	---	
Bentazon	Basagran	Herbicide	Controls broadleaf weeds in soybeans, rice, maize, groundnuts, beans, peas, and mint	30. (3)	
Bromacil	Borea Hyvar Uragan	Herbicide	Controls weeds and brush in non-crop areas, and controls weeds in citrus and pineapple	---	
Butachlor	Machete	Herbicide	Controls annual grasses and weeds in seeded, transplanted rice and other crops	---	
Butylate	Sutan	Herbicide	Controls grassy weeds and nut grass in maize	---	
Carbaryl	Sevin	Insecticide	Controls insects in forests lawns, ornamentals, shade trees, and rangeland	---	
Carbofuran	Furadan Caraterr	Insecticide Acaricide Nematocide	Controls insects, mites, 40. nematodes on maize and other crops	5. (3)	
Carbofuran, 3-hydroxy-	(See Carbofuran)	(Degradate)	(See Carbofuran)	---	
Carbofuran, phenol	(See Carbofuran)	(Degradate)	(See Carbofuran)	---	
Carbofuran, phenol, 3-keto-	(See Carbofuran)	(Degradate)	(See Carbofuran)	---	
Carboxin	D-735 DCMO Vitavax	Fungicide	Controls smuts on barley, oats, wheat, and seedlings	---	
Chloramben	Amiben Vegiben	Herbicide	Controls weeds in soybeans, groundnuts, sunflowers, and maize	---	

Pesticide	**Common or Trade Name**	**Type**	**Principal Use**	**Drinking Water Level (? g/l)**	**Fish & Shellfish Tissue (mg/kg)**
Chlordane	Gold Crest C-100	Insecticide	Controls termites in homes and controls other insects such as fire ants around underground cables	2. 0.2 (3)	0.3 (2)
Chlordecone (2) (Kepone)					0.3 (2)
Chlorobenzilate	Akar Benzilian	Acaricide	Controls mites on citrus, cotton, and vegetables	---	
Chloroneb	Terraneb	Fungicide	Controls snow mold, and systematic seedling diseases of cotton, beans, and soybeans	---	
Chlorothalonil	Bravo Daconil	Fungicide	Controls fungus on beans, carrots, celery, maize, conifers, and groundnuts	---	
Chlorotoluron (3)				30. (3)	
Chlorpropham	Chloro IPC CIPC Furloe Sprout NP	Herbicide	Controls weeds in alfalfa, lima beans, and snap beans	---	
Cyanazine	Bladex Fortrol	Herbicide	Controls annual grasses and broadleaf weeds in fallow croplands	---	
Cycloate	Ro-Neet	Herbicide	Controls annual broadleaf weeds and grasses	---	
2,4-D	2,4 Dichloro- phenoxyacetic acid Aqua Kleen	Herbicide	Controls weeds in wheat, maize, and barley	70. 30. (3)	
Dalapon	Dowpon Ded-Weed	Herbicide	Controls growth of grasses such as quackgrass, bermuda grass, and some perennials	200.	
2,4-DB	Butyrac Embutox	Herbicide	Controls broadleaf weeds in alfalfa, soybeans, and groundnuts	90. (3)	
DCPA	Chlorthal-dimethyl Dachtal	Herbicide	Controls annual grasses in turf, ornamentals, fruit and vegetables	---	
DCPA acid metabolites	(See DCPA) Dachtal acid metabolites	(Degradate)	(See DCPA)		
4,4-DDD	TDE Rothane	Insecticide	Controls mosquitoes and spiders	---	5. (2)
4,4-DDE	(See 4,4-DDD)	(Degradate)	(See 4,4-DDD)	---	5. (2)
4,4-DDT	(See 4,4-DDD)	(See 4,4-DDD)	(See 4,4-DDD)	2. (3)	5. (2)
Diazinon	Spectracide Basudin AG-500	Soil Insecticide	Controls insects such as cut worms, wireworms, and maggots on fruit, vegetables and tobacco	---	

Pesticide	Common or Trade Name	Type	Principal Use	Drinking Water Level (? g/l)	Fish & Shellfish Tissue (mg/kg)
Dibromochloro- propane (DBCP)	Nemafume Fumazone Nemagon	Soil Fumigant	Controls nematodes on berries, citrus, melons, and nuts	0.2 1. (3)	
Dicamba	Banvel D Banfel Compound B Mediben	Herbicide	Controls broadleaf weeds in maize, sorghum, grains, and asparagus	---	
Dicamba, 5-hydroxy-	-----	Herbicide (Degradate)	Controls annual and perennial broadleaf weed species in asparagus, cereals, grain and maize	---	
3,5-dichlorobenzoic acid	Dalapon	Herbicide	Controls perennial grasses	---	
1,2-dichloropropane	Propylene Dichloride 1,2-DCP	Soil Fumigant	Controls nematodes in soil (Contaminant of a registered active ingredient)	5. 20. (3)	
cis-1,3 dichloropropene	Telone II	Nematocide	Controls nematodes in soil	20. (3)	
trans-1,3 dichloropropene	(See cis-1,3-dichloropropene)	(See cis-1,3-dichloropropene)	(See cis-1,3-dichloropropene)	---	
Dichlorprop	Maizeox RK	Herbicide	Controls polygonum persicaria, galium, and aparine in cereals and pastures	100. (3)	
Dichlorvos	Herkol Nogos Nuvan Phosvit Vapona	Insecticide with fumigant action	Controls mosquitos, flies, aphids, and spider mites on fuits and vegetables	---	
Dieldrin	Heod Dielorex Octalox	Insecticide	Controls soil insects such as locusts	---	
Dinoseb	DNBP Dinitro Premerge	Herbicide	Controls potato vines and dessicating seed crops	7.	
Diphenamid	Dymid Enide	Herbicide	Controls annual grasses and broadleaf weeds in groundnuts, tobacco and alfalfa	---	
Disulfoton	Dysyston Dithiodemeton Di-syston Ditio-systox	Insecticide	Controls insects and mites on seeds	---	
Disulfoton sulfone	(See Disulfoton)	(Degradate)	(See Disulfoton)	---	
Disulfoton sulfoxide	(See Disulfoton)	(Degradate)	(See Disulfoton)		
Diuron	DCMU Karmex	Herbicide	Controls broadleaf and --- grassy weeds in wheat, barley, and bananas		

Pesticide	Common or Trade Name	Type	Principal Use	Drinking Water Level (? g/l)	Fish & Shellfish Tissue (mg/kg)
Endosulfan I	Thiodan Cyclodan Malix	Insecticide Acaricide (Degradate)	Controls a variety of insects such as mites on cereals, coffee, cotton, fruit, oilseeds, potatoes, and tea.	---	
Endosulfan II	(See Endosulfan I)	(Degradate)	(See Endosulfan I)	---	
Endosulfan sulfate	(See Endosulfan I)	(Degradate)	(See Endosulfan I)	---	
Endrin	Nendrin	Insecticide	Controls insects on cotton, small grains, and grasshoppers in noncrop areas	2.	0.3 (2)
Endrin aldehyde	(See Endrin)	(Degradate)	(See Endrin)	---	
EPTC	EPTAM	Herbicide	Controls weeds in beans, potatoes and maize	---	
Ethoprop	Mocap Prophos Ethoprophos	Nematocide Insecticide	Controls nematodes and insects on bananas, cabbage, and maize	---	
Ethylene dibromide (EDB)	Bromofume Nephis	Insecticide	Controls insects in soil and is an additive in leaded gasoline	0.05	
Ethylene thiourea (ETU)	ETU	Breakdown product of EBDC Fungicides	EDBC controls fungus on roses and other flowers, potatoes, tomatoes, lettuce and apples	---	
Etridiazole	Koban Terrazole	Soil Fungicide	Controls diseases of turf, beans, maize, cotton, sorghum	---	
Fenamiphos	Nemacur Inemacury	Insecticide Nematocide	Controls nematodes and insects on cotton, groundnuts, soybeans, vegetables and fruit	---	
Fenamiphos sulfone	(See Fenamiphos)	(Degradate)	(See Fenamiphos)	---	
Fenamiphos sulfoxide	(See Fenamiphos)	(Degradate)	(See Fenamiphos)	---	
Fenarimol	Bloc Rimidin Rubigan	Fungicide	Protects against powdery mildew on apples, grapes and roses	---	
Fenoprop (3)				9. (3)	
Fluometuron	Cotoron	Herbicide	Controls annual grasses, and broadleaf weeds	---	
Fluridone	Sonar	Herbicide	Controls annual grass and weeds in cotton fields	---	
Glyphosate (4)	Roundup	Herbicide	Nonselective broad spectrum herbicide used on cereals, beans and other crops (4)	700. (2)	
alpha-HCH	(See gamma-HCH)	(See gamma-HCH)	(See gamma-HCH) (Contaminant of a registered active ingredient)	---	

Pesticide	Common or Trade Name	Type	Principal Use	Drinking Water Level (? g/l)	Fish & Shellfish Tissue (mg/kg)
beta-HCH	(See gamma-HCH)	(See gamma-HCH)	(See gamma-HCH) (Contaminant of a registered active ingredient)	---	
delta-HCH	(See gamma-HCH)	(See gamma-HCH)	(See gamma-HCH) (Contaminant of a registered active ingredient)	---	
gamma-HCH (Lindane)	gamma BHC Lindane	Insecticide	Controls leafhoppers in lowland rice, and beetles in wood (is a Contaminant in a registered active ingredient)	0.2 2. (3)	
Heptachlor	Velsicol 3-chlorochlorene	Insecticide	Controls insects on maize, alfalfa, hay and vegetables (is a Contaminant in a registered active ingredient)	0.4 0.03 (3)	0.3 (2)
Heptachlor epoxide	(See Heptachlor)	(Degradate)	(See Heptachlor)	0.2 0.03 (3)	0.3 (2)
Hexachlorobenzene	Anti-Carie HCB	Fungicide	Controls fungus on wheat	1. (1,3)	
Hexazinone	Velpar	Herbicide	Controls selective weeds in conifers, sugarcane, pineapple, and pecans	---	
Isoproturon (3)				9. (3)	
Linuron	Afalon	Herbicide	Controls weeds in field maize, carrots, celery, and potatoes	---	
MCPA (3)				2. (3)	
Mecoprop (3)				10. (3)	
Merphos	Folex	Defoliant	Acts as cotton defoliant	---	
Methiocarb	Mesurol Draza	Insecticide	Controls insects on cherries, and acts as a bird repellant on cherries	---	
Methomyl	Lannate Nudrin	Insecticide	Control a broad-spectrum of insects on agricultural and ornamental crops	---	
Methoxychlor	Malate	Insecticide	Controls insects on fruit and shade trees	400. 20. (3)	
Methyl paraoxon	E-600 Mintacol	Insecticide	Controls a variety of insects	---	
Metolachlor	Dual Primext	Herbicide	Controls weeds in woody ornamentals, sunflowers and maize	10. (3)	
Metribuzin	Sencor Sencorex Lexone	Herbicide	Controls grass and broadleaf weeds in soybeans, wheat, barley, peas and lentils	---	
Metribuzin DA	(See Metribuzin)	(Degradate)	(See Metribuzin)	---	

Pesticide	Common or Trade Name	Type	Principal Use	Drinking Water Level (? g/l)	Fish & Shellfish Tissue (mg/kg)
Metribuzin DADK	(See Metribuzin)	(Degradate)	(See Metribuzin)	---	
Metribuzin DK	(See Metribuzin)	(Degradate)	(See Metribuzin)	---	
Mevinphos	Phosdrin	Insecticide Acaricide	Controls mites, beetles, grasshoppers, cutworms and leafhoppers on a broad range of vegetables and fruit	---	
MDK 264	Van Dyke-264	Synergist	Acts as a synergist for pyrethrin, allethrin, and rotenone	---	
Mirex (2)					0.1
Molinate	Ordram	Herbicide	Controls germinating broad-leaves and watergrass in rice	6. (3)	
Napropamide	Devrinol	Herbicide	Controls annual grasses and broadleaf weeds	---	
Neburon	Kloben	Herbicide	Controls weeds and grasses in nursurey, ornamentals	---	
4-Nitrophenol	----	Fungicide Breakdown product of parathion insecticides	Degradate of parathion pesticides, controls a variety of insects such as aphids and mosquitoes on pears	---	
Norflurazon	Zorial Evital Solicam	Herbicide	Controls insects on cotton, stone fruits, nuts, and cranberries	---	
Oxamyl	Vydate DPX-1410	Insecticide	Controls insects, mites, and nematodes on crops and fruits	200.	
Pentachlorophenol (PCP)	Dowicide 7	Fungicide Insecticide Defoliant Herbicide	Protects timber from fungal rot and insects	200. 9. (3)	
Pebulate	Tillam	Herbicide	Controls annual grasses, nut sledge, and broadleaf weeds in sugar beets, tobacco and tomatoes	---	
Pendimethalin (3)				20. (3)	
Permethrin	Ambush Perthrine	Insecticide	Controls a broad range of insects in cotton	20. (3)	
Picloram	Tordon	Herbicide	Controls broadleaf and woody plants in pastures and rangeland	500.	
Prometon	Gesagram	Herbicide	Controls perennials, broadleaf weeds, and grasses in non-crop areas	---	
Prometryn	Gesagard Caparol	Herbicide	Controls weeds in cotton, peas, carrots, and vegetables	---	

Pesticide	Common or Trade Name	Type	Principal Use	Drinking Water Level (? g/l)	Fish & Shellfish Tissue (mg/kg)
Pronamide	Kerb	Herbicide	Controls weeds and grass in lettuce, legumes, and trees	---	
Propachlor	Bexton Ramrod	Herbicide	Controls grasses and certain broadleaf weeds	---	
Propanil	Rogue	Herbicide	Controls weeds in rice and and potatoes	20. (3)	
Propazine	Gesomil Milogard Primatol P	Herbicide	Controls annual broadleaf weeds and grasses in sorghum	---	
Propham	IPC Beet-Kleen	Herbicide	Controls weeds in alfalfa, lettuce, spinach, sugar beets, lentils, and peas	---	
Pyridate (3)				100. (3)	
Simazine	Princep Aquazine Gesatop Weedex	Herbicide	Controls annual grasses and weeds in crops, especially maize, and fruit such as citrus, asparagus, and nuts	1. 2. (3)	
Simetryn	Gy-bon	Herbicide	Controls broadleaf weeds in rice	---	
Stirofos	Gardona Tetrachlorvinphos	Insecticide	Controls insects on maize, cotton, vines, and fruit	---	
Swep	SWEP	Herbicide	Controls weeds on rice, maize, peas, and groundnuts	---	
2,4,5-T (Trichloropheno-xyacetic acid)	Weedone	Herbicide	Controls woody plants in industrial areas	9. (3)	
Tebuthiuron	Graslan Spike	Herbicide	Controls vegetative weeds in non-crop and rangeland	---	
Terbacil	Sinbar	Herbicide	Controls annual and perennial weeds in sugar can, alfalfa, apples, peaches, citrus, pecans and mint	---	
Terbufos	Counter	Insecticide	Controls soil insects and nematodes on maize, vegetables, and sorghum	---	
Terbutryn	Igram Preban	Herbicide	Controls weeds in winter wheat and barley	---	
Toxaphene (2) (2)					5.
2,4,5-TP (Trichlorophenol)	Silvex	Herbicide	Controls weeds and brush in rangeland, sugar cane, and rice	50.	
Triademefon	Bayleton	Fungicide	Controls mildew and rusts on vegetables, cereals, coffee, and fruit	---	

Pesticide	**Common or Trade Name**	**Type**	**Principal Use**	**Drinking Water Level (? g/l)**	**Fish & Shellfish Tissue (mg/kg)**
Tricyclazole	Beam Bim Blascide	Fungicide	Controls fungus in seeded rice	---	
Trifluralin	Treflan	Herbicide	Controls annual grasses, weeds in soy beans, cotton, and vegetables	20. (3)	
Vernolate	Vernam	Herbicide	Controls broadleaf and grassy weeds	---	