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 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).

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

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) × 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_20, $C0_2$, 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 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.

BOX 6: REGIONAL EXAMPLES OF ECOLOGICAL EFFECTS

In Europe, the European Environment Agency (EEG, 1994) cites a study by Galas 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.

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 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.

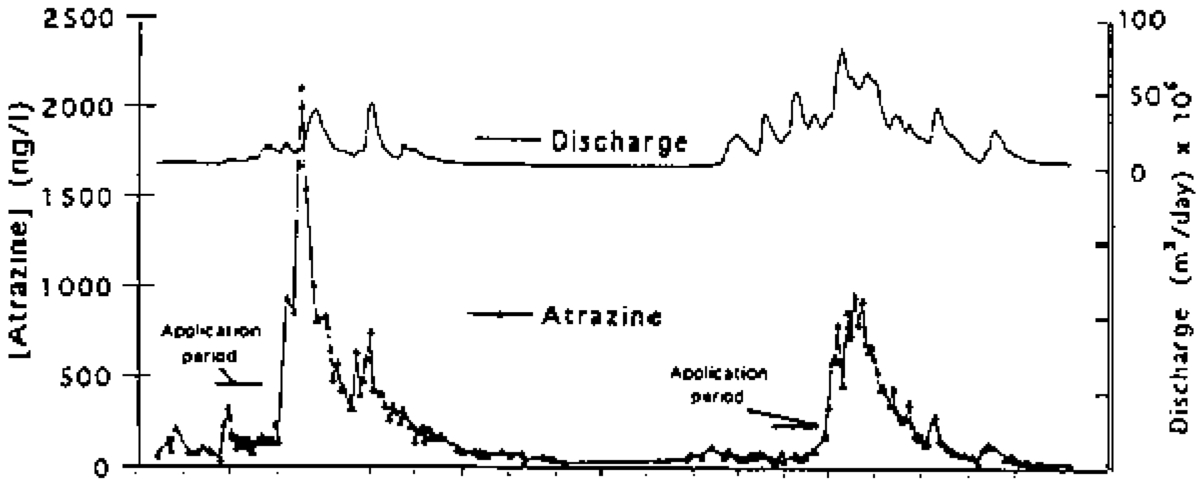
TABLE 17: **Proportion of selected pesticides found in association with suspended sediment** (After Ongley *et al.*, 1992)

Pesticide	**log Kow**	**% 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

[1] Toxaphene mixture.
[2] Range is 1.5-2.5.

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 μg/l for DDT, yet the aquatic life criterion is 0.001 μ g/l and the human health criterion is 0.0002 μ 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; μ 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):

- 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.

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

• **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.

- 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.

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

FAO, 1990b.