

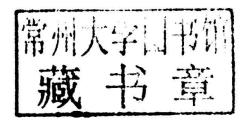
## Encyclopedia of Nanotechnology in Water and Wastewater Treatment

VOLUME 2: TREATMENT OF MICROPOLLUTANTS IN WATER AND WASTEWATER

Editor

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# Encyclopedia of Nanotechnology in Water and Wastewater Treatment

#### **Preface**

Urban waste waters are increasingly contaminated with organic substances such as biocides, endocrine disrupting compounds (EDCs), personal care products (PCPs) and pharmaceutical substances. These contaminants, with their known or potential harmfulness for aquatic ecosystems and human health, have become a major issue for the Water Utilities. Various studies over recent years have shown that treated municipal wastewater contributes significantly to water pollution from micropollutants. This contamination can be minimized by upgrading current wastewater treatment plants to include an additional treatment step. Through improved methods of chemical analysis, micropollutants, e.g. pharmaceuticals and endocrine disrupting compounds are increasingly being detected in our water bodies. In most cases these enter the wastewater after being excreted in urine and faeces. In the sewage plant, a part of the substances is eliminated via sorption and biological degradation. The rest is discharged with the treated effluent. In surface water and during bank infiltration further elimination is observed but some micropollutants persist, acting as wastewater tracer in groundwater and are also detected in drinking water. Water supply, urban drainage and wastewater treatment systems were originally designed to solve conventional problems (supply of potable water, flood protection and sanitation) and water quality research has mainly focused on organic matter and nutrients.

Activated carbon is a material used to filter harmful chemicals from polluted water. Is looks like tiny granules of black sand. As polluted water or air flows through an activated carbon filter, chemicals sorb or stick to the surface and within the pores of the granules. Most tap water filters and fish tank filters at home contain activated carbon and work the same way. Activated carbon filters are often used as part of a pump and treat system to clean up polluted groundwater. Activated carbon filters are also used to remove unwanted tastes,

odours, radon, and some man-made volatile organic contaminants from drinking water. The efficiency of the unit depends on the type of activated carbon installed, the filter bed depth, the type of contaminants in the water and their concentration, and the contact time between the water and the carbon filter. Activated carbon filters do not adsorb every type of contaminant equally well. Carbon filters are easy to install and maintain, and operating costs are usually limited to filter replacement. Depending on the type and concentration of the contaminant being removed, some carbon filters may require special hazardous waste handling and disposal, which can be costly. Other filter types are available including charcoal and ceramic materials that treat the water similarly, through the adsorption of the contaminant onto the filter. The solid material used in an activated carbon filter is a specialized carbon manufactured for these purposes. Contaminants adhere to the surface of these carbon granules or become trapped in the small pores of the activated carbon.

This book describes possible measures for eliminating trace organics in waste and drinking water treatment. These include on the one hand, permanent measures at the source such as an ecolabel for pharmaceuticals and personal care products as well as the separate treatment of strongly polluted wastewater, e.g. in hospital or industry.

-Editor

### **Contents**

	Preface	vii
1.	Introduction to Water Pollution  Water Quality as a Global Issue • Classes of Non-Point Sources • Agricultural Impacts on Water Quality • Public Health Impacts • Pollution by Sediments • Sediment as a Chemical Pollutant	1
2.	Fertilizers as Water Pollutants  Pesticides as Water Pollutants • Environmental Impact of Pharmaceuticals and Personal Care Products • Environmental Persistent Pharmaceutical Pollutant • Nanofiltration	41
3.	Managing Micro-Pollutants  Wastewater • Elimination of Organic Micropollutants in Wastewater Treatment Plants • Sewage Treatment • Sewage Sludge Treatment • Activated Sludge	98
4.	Advanced Oxidation Process  Aerated Lagoon • Aerobic Treatment System • API Oil-Water Separator • Anaerobic Lagoon • Some Other Common Pathogens (and Their Symptoms)	145
5.	Aerobic Granulation  Bioretention • Cesspit • Coarse Bubble Diffusers • Dark Fermentation • Dissolved Air Flotation • Distillation	165
6.	Batch Distillation  Continuous Distillation • Overhead System Arrangements • Laboratory Scale Distillation • Azeotropic Distillation • Desalination • EcocyclET Systems	182

311

Index

7.	Electrocoagulation  Electrodeionization • Expanded Granular Sludge Bed Digestion  • Facultative Lagoon • Fenton's Reagent • Fine Bubble Diffusers  • Froth Flotation • Imhoff Tank • Lamella Clarifier • Maceration (Sewage)	224
8.	Retention Basin • Reverse Osmosis • Remineralisation and pH Adjustment • Rotating Biological Contactor • Sand Filter • Sedimentation (Water Treatment)	
9.	Sequencing Batch Reactor  Septic Tank • Stabilization Pond • Trickling Filter • Ultrafiltration (Industrial) • Ultraviolet Germicidal Irradiation • Upflow Anaerobic Sludge Blanket Digestion • Vacuum Evaporation	283
	Bibliography	309

## Chapter 1

#### Introduction to 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 (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 recognised 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 evapotranspiration, 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 utilised) 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 Landbased Activities, convened in Washington DC in 1995 jointly with UNEP.

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

Agriculture		
Animal feedlots	Runoff from all categories of agriculture	Phosphorus, nitrogen,
Irrigation	leading to surface and groundwater pollution.	metals, pathogens,
Cultivation	In northern climates, runoff from frozen	sediment, pesticides, salt,
Pastures	ground is a major problem, especially where	BOD1, trace elements (e.g.
Dairy farming	manure is spread during the winter.	selenium).
Orchards	Vegetable handling, especially washing in	
Aquaculture	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.	
Forestry	Increased runoff from disturbed land. Most	Sediment, pesticides.
	damaging is forest clearing for urbanization.	
Liquid waste	Disposal of liquid wastes from municipal	Pathogens, metals, organic
disposal	wastewater effluents, sewage sludge, industrial	compounds.
	effluents and sludges, wastewater from home septic	
	systems; especially disposal on agricultural	
	land, and legal or illegal dumping in watercourses.	
Urban areas		
Residential	Urban runoff from roofs, streets, parking lots, etc.	Fertilizers, greases and oils,
Commercial	leading to overloading of sewage plants from	faecal matter and pathogens,
Industrial	combined sewers, or polluted runoff routed directly	organic contaminants (e.g.
	to receiving waters; local industries and businesses	PAHs <sup>2</sup> and PCBs <sup>3</sup> ), heavy
	may discharge wastes to street gutters and storm	metals, pesticides, nutrients,
	drains; street cleaning; road salting contributes to	sediment, salts, BOD, COD4,
	surface and groundwater pollution.	etc.
Rural sewage	Overloading and malfunction of septic systems	Phosphorus, nitrogen,
systems	leading to surface runoff and/or direct infiltration to	pathogens (faecal matter).
m .	groundwater.	
Transportation	Roads, railways, pipelines, hydro-electric corridors,	Nutrients, sediment, metals,
	etc.	organic contaminants,
		pesticides (especially
		herbicides).
Mineral extraction	Runoff from mines and mine wastes, quarries, well	Sediment, acids, metals, oils,
	sites.	organic contaminants, salts
		(brine).
Recreational land	Large variety of recreational land uses, including	Nutrients, pesticides,
use	ski resorts, boating and marinas, campgrounds,	sediment, pathogens, heavy
	parks; waste and "grey" water from recreational	metals.
	boats is a major pollutant, especially in small lakes	
	and rivers. Hunting (lead pollution in waterfowl).	
Solid waste disposal	Contamination of surface and groundwater by	Nutrients, metals, pathogens
	leachates and gases. Hazardous wastes may be	organic contaminants.
	disposed of through underground disposal.	100
Dredging	Dispersion of contaminated sediments, leakage	Metals, organic
	from containment areas.	contaminants.
Deep well disposal	Contamination of groundwater by deep well	Salts, heavy metals, organic
	injection of liquid wastes, especially oilfield brines	contaminants.
	and liquid industrial wastes.	
Atmospheric	Long-range transport of atmospheric pollutants	Nutrients, metals, organic
deposition	(LRTAP) and deposition of land and water surfaces.	contaminants.
D	Regarded as a significant source of pesticides (from	
	agriculture, etc.), nutrients, metals, etc., especially	
	in pristine environments.	I .

<sup>&</sup>lt;sup>1</sup>BOD =Biological Oxygen Demand

<sup>&</sup>lt;sup>2</sup> PAH = Polycyclic Aromatic Hydrocarbons

<sup>&</sup>lt;sup>3</sup> PCB = Polycyclic Chlorinated Bi-Phenyls

<sup>&</sup>lt;sup>4</sup> 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 water courses. 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 a non-point sources. Themain 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.

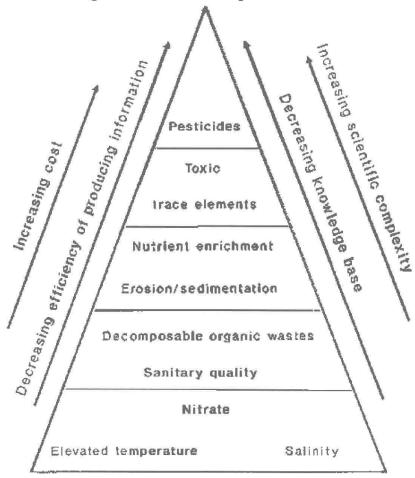


Figure: Hierarchical complexity of agriculturally-related water quality problems (Rickert, 1993)

#### 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 conditions in Lake Erie and eutrophic 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 realised 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 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.

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