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**NON POINT SOURCE POLLUTION
STATE OF THE ART**



**NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (UTTARANCHAL)**

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PREFACE

For about a century engineers and scientists have been concerned with municipal and industrial pollution, which was easy to locate and control. The other pollution, originating on farms and urban streets went unnoticed. However, during recent years, the non-point source of water pollution is being recognized of greater importance than point sources. This is due in part to the continuing efforts to reduce pollution from point sources over the past few decades, as well as recognition that non-point sources, such as storm water, may contain harmful contaminants. In rural areas, nutrients and pesticides are released in surface and ground water and may degrade the quality of drinking water and cause various health problems to humans. Nutrients and pesticides, particularly, are of major concern because of high toxicity and eutrophication problems. Nutrients and pesticides are transported from cropland either by being adsorbed onto eroded soil particles or dissolved in runoff water. This has increased the need to identify and quantify major sources of nutrients and pesticides deposited within the river system.

Keeping the above points in mind, the report entitled 'Non-point source pollution – State-of-the-art' has been prepared by Dr. C. K. Jain, Sc. 'E1' and Dr. Imran Ali, Sc. 'B' under the work programme of Environmental Hydrology Division for the year 2000-2001.


(K S RAMASASTRI)

DIRECTOR

CONTENTS

	Page No.
ABSTRACT	i
1.0 INTRODUCTION	1
2.0 POLLUTION SOURCES	8
3.0 NPS POLLUTION PARAMETERS	10
3.1 Sediment	11
3.2 Dissolved Oxygen	12
3.3 Nutrients and Eutrophication	13
3.4 Metals and other Toxic Chemicals	15
3.5 pH and Acidity Problems	18
4.0 SURFACE WATER PROBLEMS	23
5.0 GROUND WATER PROBLEMS	31
6.0 POLLUTION CONTROL	39
6.1 Nutrient Control	40
6.2 Pesticides Control	42
6.3 Watershed Management Planning	42
7.0 CONCLUSION	44
REFERENCES	45

ABSTRACT

Non-point source (NPS) pollution originates from diffuse land areas that contribute pollutants to surface and ground water bodies. Sediments, nutrients and pesticides can enter surface water bodies through runoff, and nutrients and pesticides can enter ground water through leaching. Modern agriculture has relied, among other things, on heavy use of fertilizers and pesticides. This has largely occurred without any serious regard to the environmental consequences, especially pollution of both surface and ground water resources. Chemicals (fertilizers and pesticides) applied in agro-ecosystems invariably enter the hydrological cycle, causing contamination of surface water and ground water resources. Nutrients and pesticides, particularly, are of major concern because of eutrophication and toxicity problems. Nutrients and pesticides are transported from cropland either by being adsorbed onto eroded soil particles or dissolved in runoff water. This has increased the need to identify and quantify major sources of nutrients and pesticides deposited within the river system. In this report a review on several aspects of NPS pollution, including effects and extent of pollution in surface and ground water bodies, pollution control measures, monitoring and modelling, and management options is presented.

1.0 INTRODUCTION

During recent years, non-point sources of water pollution have been recognized as being of greater importance than point sources. This is due in part to the continuing efforts to reduce pollution from point sources over the past two decades, as well as recognition that non-point sources, such as storm water, may contain harmful contaminants.

With ever increasing global population, there has been an increased pressure to maximise farm production to meet food and fibre requirements. Modern agriculture has relied, among other things, on heavy use of fertilizers and pesticides. This has largely occurred without any serious regard to the environmental consequences, especially pollution of water resources. While the problem is being recognised and systematically studied in the western countries (Strebel et al., 1989; Fried, 1991; Frink, 1991; Goodrich et al., 1991, USEPA, 1992, Cooper, 1993, Spalding and Exner, 1993), this is less so in developing countries where agricultural pollution is usually complicated by urban and industrial pollution (Duda, 1993.)

The human activities combined with changes in land use pattern like urbanisation, deforestation, agricultural and mining practices greatly influence the quality of river water. The influence of urbanisation on the water quality depends mainly on the nature of generated industrial effluents, domestic sewage and surface runoff from urban and rural areas.

In rural areas, nutrients and pesticides are released in surface and ground water and may degrade the quality of drinking water and cause various health problems to humans. Nutrients and pesticides, particularly, are of major concern because of high toxicity and eutrophication problems. Nutrients and pesticides are transported from cropland either by being adsorbed onto eroded soil particles or dissolved in runoff water. This has increased the need to identify and quantify major sources of nutrients and pesticides deposited within the river system. The assessment of non-point source pollution is a perfect example of a spatially and temporally complex, multidisciplinary environmental problem that exists over multiple scales.

Non-point sources of pollution account for more than 50% of the total water quality problems, and they are being recognized and investigated nationally and internationally. In many areas, non-point pollution, such as runoff from cropland, urban storm water, strip mining and runoff from construction sites are becoming major water quality problems (Alexander, 1976). Agriculture is often considered as the largest contributor to non-point source pollution of both surface and subsurface systems. It is mainly responsible for degrading the river water quality by generating runoff from animal husbandry units, which contain predominantly organic compounds from the use of mineral fertilizers and chemical pesticides. In this context, processes in soils associated with nitrogen and phosphorous losses to waters receive much attention.

It is more difficult to control non-point source pollution than point sources. Even though stringent controls may be placed on industrial and municipal sewage discharges, environmental water quality may not improve to the extent expected. This may be due to the diffuse pollution caused by agriculture or by urban runoff. In order to identify non-point source pollution and its relationship with land use activities, a geographical information system may be used to relate data associated with land use (e.g. cropping intensity, vegetation clearance and soil erosion information). Water quality data are entered in order to estimate the effects of agricultural activities on water quality so that pollution control policies can be devised.

The factors influencing the non-point source surface water pollution include soil erosion and sedimentation and erosion of stream banks, washing out nutrients and organic material from livestock wastes and agricultural land, storm runoff from urban areas and atmospheric deposition. Adsorption to the surface of sediment particles provides a mechanism for transport of many contaminants derived from agricultural fertilizers, pesticides and industrial wastes. Deposition of sediments carrying such load in the channel or on the flood plain can have detrimental consequences for ecology and agricultural activities. The sediment released into the river system can promote channel instability and cause bed degradation.

In most cases the sources and concentrations of non-point source pollutants are the

result of land use interactions with the transport system. It is a source transport problem in which the hydrologic cycle provides the transport processes to move pollutants from the source to ground water, a stream, or a reservoir. Non-point sources can be urban, industrial, or agricultural pollutants that are distributed over the surface. The mode of transport is the flow of water across the soil surface and in stream channels and reservoirs or the flow of water through the soil profile.

The problem of non-point pollution does not only involve the traditional pollution parameters such as suspended sediment, biochemical oxygen demand (BOD) and dissolved oxygen (DO). Some of the most serious non-point pollution problems do not have a parallel in the traditional point source oriented environmental pollution control area. These problems include nutrients (nitrogen and phosphorous), PCB (polychlorinated biphenyl) contamination, acid rain and pesticides contamination of surface water and ground-water bodies and aquatic biota.

The fluxes of C, N, P and S induced by excessive human activities have begun to exceed the natural fluxes in many parts of the world. The effects are increased production of organic matter replacing the algae at the base of important food chains with less desirable species, increasing areas of anoxia and added loading of heavy sediments with organic carbon (Bolin et al., 1983). In recent years exponential growth in population and fragmentation of farm families have caused a reduction in land holding size, consequently forcing the farmers towards intensive cultivation (Rai and Sharma, 1995) leading to enhanced soil and nutrient loss.

Levels of dissolved inorganic nitrogen and phosphorous in the aquatic environment have increased significantly due to the wide-spread use of fertilizers, detergents and industrial chemicals containing N and P. In addition, there is increased transport in the weathering cycle of organic carbon due to deforestation and land-use changes. Human activity has drastically enhanced the quantity of nutrients transported by rivers from land to ocean. According to Wollast (1983), the increase of the dissolved nitrogen flux in rivers represents 30% of the nitrogen fixed annually by man during combustion processes and fertilizer production. For phosphorous the increase is only 15% of the total phosphorous mined annually. The increased biological activity due to the entry of N and P in rivers had led in some cases to anoxia and consequent fish mortalities.

To understand the nitrogen and phosphorous concentrations in surface waters one should always take into account factors such as current and historic nutrient inputs to agricultural land from fertilization and atmospheric deposition, soil type, hydrology, historical land-use and climatic conditions. Preferential flow also plays an important role in the subsurface losses of nutrients in many soils, especially after longer periods of drought.

Precipitation, erosion, entrainment from flood plains, chemical weathering, slope run-off and leaching are the main sources for carbon, nitrogen, phosphorous and sulphur in the rivers. The processes are such that species of these elements are mostly in the oxidized state (CO_2 , NO_3 , PO_4 , SO_4). The river composition itself is determined by various weathering regimes, the involvement of the flood plains, the character of the vegetation in the basin, hydrographic situations and the occurrence of episodic floods. Oxidation of the elements to their oxides by aerobic respiration facilitates their easy transport in the dissolved state.

Various pathways are employed in the transport of N and P into a river system. Depending on the pH and temperature of soils, NH_4^+ and NO_3^- ions are produced in the watershed through ammonification and nitrification of organic matter and mobilized into rivers through run-offs. The weathering of apatitic rocks is the major natural source of PO_4^{3-} . Rain is a source of dissolved N and S. N, P and S from fertilizer application, sewage and non-point source run-off contribute significant quantities of dissolved species of N, P and S near human habitation.

The growth of terrestrial and aquatic plants depends on the availability and continued supply of N and P. The sources of these nutrients are varied and include the soil, domestic/industrial effluent, agricultural inputs and atmospheric deposition. Modern high yielding crops generally require the addition of fertilizers, which can be inorganic or organic form. Annual uptake efficiencies by crops are relatively poor, approximately 50 and 20% for N (Nielsen et al., 1987) and P (Holford and Doyle, 1993) respectively. The fertilizer application rates have increased over the last two-three decades (World Fertilizer Consumption Statistics, 1992). This has resulted in the possibility of increased NO_3 -N losses from terrestrial systems into water courses through surface runoff and/or by

leaching through the soil profile (Vinten et al., 1991). The relative contribution of individual sources and processes to N and P losses vary spatially and temporally, being greatly influenced by climatic and management factors

As per the National Water Quality Inventory Report, non-point agricultural pollution significantly affects water quality in 68% of drainage basins in the United States (National Water Quality Inventory, 1978). It has been reported that agricultural pollution contributes 60% of the BOD, 64% of suspended solids and 76% of total phosphorous discharged into the water resources (Duda and Johnson, 1985).

In the Great Lakes region (Sonzogni et al., 1978; Pluarg, 1978), phosphorous contribution from non-point sources represents roughly 50% of the total load to Lakes Superior, Huron and Erie and exceeds municipal and industrial point sources. The balance is due to atmospheric fallout and shoreline erosion. Phosphorous is the limiting nutrient controlling eutrophication of most of the Great Lakes. Over 90% of lead loading to Lakes Superior, Michigan, Huron and Ontario originate from non-point sources. In addition, the International Joint Commission research (PLUARG, 1978) has found that diffuse sources including atmospheric inputs account for major loading of PCBs and organic chemicals to the lakes.

The magnitude of loadings from various areas varies considerably depending on the hydrological activity of the area. The loading of sediment may vary from zero to few kilograms per hectare per year from forest lands and pastures on permeable soils or some low density suburban residential areas and parks, to several hundred tons per hectare per year from construction sites, mining or congested non-maintained urban centers. A large amount of nutrients and organic chemicals are lost to surface water from animal feedlot operations. The loading of various constituents exhibit seasonal variations, e.g., the highest loading from agricultural lands can be expected in spring after plowing, and the lowest, in fall and winter. Loadings are also subject to meteorological factors, high intensity storms generate the highest pollution.

Some hazardous pollutants are almost uniquely generated from non-point sources and

their contribution from point sources is negligible, for example, pesticides and PCBs. Pesticide contamination of surface waters originate from the use of agricultural chemicals to control weeds and pests, whereas PCB contamination can be traced to PCB containing products primarily in use in urban areas. The example of PCBs shows how a chemical component, which represents only a minor point source problem, could contaminate the environment and become a most serious non-point pollution hazard.

Biotic and abiotic activities of a diverse variety enacted on the stage of land basins are integrated by rivers. They provide media for the operation of the aquatic fluxes of dissolved and particulate organic and inorganic materials. The load carried by the rivers exhibit a wide spectrum of physical and chemical characteristics. These materials enter the rivers through diverse pathways and are utilized, modified and stored by the complex chemistry of inter-phase reactions maintaining a dynamic equilibrium that sustains the living systems in the river basins.

Several articles discussed the urgent need for and the problems associated with controlling non-point sources of water pollution from agricultural activities. Cooney (1997) discussed U.S. EPA's past efforts at controlling NPS runoff from farm operations, particularly from animal-feeding operations, and U.S. EPA's probable future course of action, targeting both large and small farm enterprises.

Several articles evaluated economic aspects of controlling NPS pollution. Randhir and Lee (1997) used a multiyear regional risk programming model to evaluate impacts of different environmental policies on cropping systems, use of fertilizer and pesticide, NPS pollution, farm income and risk. Policies had varied effects on pollutant loads and involved tradeoffs between water quality and economic considerations. Boggess *et al.* (1997) evaluated the economic impacts of three water-quality programs designed to reduce phosphorus runoff from dairy manure into Florida's Lake Okeechobee. Direct impacts included reductions in milk production and the number of dairy cows in affected areas. Dairies that remained in production experienced increased costs, however, these costs were offset by increased milk production.

Haruvy *et al.* (1997) developed and applied a linear programming-based optimization model to the southern region of Israel to evaluate the conflicting interests between farmers and the state, assuming farmer's prime motivation is production with high profits, while public concern is over groundwater protection. Linear programming was also used to evaluate the economic and environmental impacts of applying European Community guidelines for waste application on U.K. dairy farms (Rigby, 1997). The author concluded that farms were affected differently based upon how the limits were imposed and discussed the implications of these results on controlling waste application. Schleich and White (1997) used linear programming to design the most cost-effective strategy to achieve politically specified phosphorus and total suspended solids reduction goals for the Fox-Wolf river basin in northeast Wisconsin.

Wallace *et al.* (1997) presented an example of a point-NPS trading framework developed to help a discharger comply with load allocation constraints in the Minnesota River. The main pollutant of concern was carbonaceous biochemical oxygen demand, but other pollutants such as nutrients and sediment were also a problem and thus were included in the framework. Hoag and Hughes-Popp (1997) compared the theory of pollution credit trading and its application in the Tar-Pamlico nutrient-trading program in North Carolina, where point-NPS trading is possible. The article evaluated transaction costs, number and relative discharge of participants, abatement costs, enforcement costs, trading ratio, and loading limits and identified factors that encourage or discourage trades.

2.0 POLLUTION SOURCES

The sources of pollution may be classified into point sources and non-point sources. Generally, point sources of pollution are those sources emitted to a watershed at a specific point. They usually can be directly measured and their impact can be assessed. Common point sources include municipal and industrial pollutants discharged directly to a stream. The non-point (diffuse) sources are those sources discharged to a watershed in a way that they depend upon the vagaries of the hydrologic cycle to transport them to the stream system. Many water bodies receive significant pollution load from sources related to use of the land by man and to natural processes occurring in the watershed. The term non-point sources define these sources of pollution. Nutrients, pesticides, bacteria, heavy loads of organic matter and sediments are generally considered non-point source pollutants.

There are several general characteristics that describe non-point source pollution (Adamkus, 1976):

- Non-point source discharges enter surface waters in a diffuse manner and at intermittent intervals that are related mostly to the occurrence of meteorological events.
- Pollution arises over an extensive area of land and is in transit overland before it reaches surface waters.
- Non-point sources generally cannot be monitored at their point of origin, and their exact source is difficult or impossible to trace.
- Elimination or control of pollutants must be directed at specific sites.
- In general, the most effective and economical controls are land management techniques and conservation practices in rural zones and architectural control in urban zones.
- Compliance monitoring for non-point sources is carried out on land rather than in water.

- Non-point source pollutants cannot be measured in terms of effluent limitations.
- The extent of non-point pollution is related, at least in part, to certain uncontrollable climatic events, as well as geographic and geologic conditions, and may differ greatly from place to place and year to year.
- Non-point sources are derived from consecutive operations on extensive units of land, as opposed to industrial activities that typically use repetitive operations on intensive (small) units of land.

Rural Non-point Sources: These sources are mostly related to agricultural activities. Agricultural pollutants have their origin in fertilizer use and pesticide applications, and generally, the primary causes are agricultural methods of disturbing soils by tillage (agricultural lands) or logging (silvicultural lands). Several other factors also affect pollution loading: soil type, climate, management practices and topography. Land uses that produce the most pollution per unit area are animal feedlot operations and farming on steep slopes. Forested lands and pastures, on the other hand, produce the least amount of pollution, that is approaching background levels. The impact of pollution on receiving waters depends on the distance of the source from the nearest concentrated flow-stream-and on the processes taking place during the overland flow phase of the pollutant's transport.

Urban Non-point Sources: Urbanization and related hydrologic modifications may cause increased pollution loading that are significantly above the original or background levels. The sources of urban non-point pollutants varies considerably, ranging from urban bird and net population, street litter accumulation, tire wear of vehicles, abrasion of road surfaces by traffic, street salting practices and construction activities. Urban non-point pollution may contain many dangerous contaminants such as lead, zinc, asbestos, PCBs, oil and grease.

3.0 NPS POLLUTION PARAMETERS

Non-point source (NPS) pollution can affect all surface and ground water bodies. Even some small water stream in a protected park area may have signs of non-point pollution caused by construction, roads, atmospheric inputs and waste disposal by visiting public. Evaluation of the effects of non-point pollution on surface water quality may differ from the traditional approach designed mainly for point sources. The difference can be summarised as follows:

S.No.	Point Source	Non-point Source
1.	Fairly steady flow and quality. Variability ranges less than one order of magnitude.	Highly dynamic in random in intermittent intervals. Variability ranges more than several orders of magnitude.
2.	The most severe impact during a low flow summer period.	The most severe impact during or following a storm event.
3.	Enter receiving water at identifiable points.	Point of entry often cannot be identified or defined.
4.	Primary parameters of interest include BOD, dissolved oxygen, nutrients and suspended solids.	Primary parameters of interest include sediment, nutrients, toxic substances, pH (acidity) and dissolved oxygen.

A typical non-point pollution load to surface water is a response of the drainage area to a storm event. It has a limited duration, lasting from a fraction of an hour to 2 days. However, some inputs from soil and ground water zones last longer. The magnitude of the non-point pollution load depends on many uncontrollable factors, primarily the rain volume, intensity and quality, duration of the preceding dry period and others.

Water quality problems associated with non-point source pollution can be divided into several categories:

1. Sediment
2. Dissolved oxygen and biodegradable organics
3. Nutrients and eutrophication
4. Toxic chemicals and metals
5. pH and acidity

3.1 Sediment

Sediment from non-point sources is the most widespread pollutant of surface water. Sediment, especially its finer fraction, cuts down light penetration and, thus, greatly reduces algae production. The turbidity caused by the sediment also has deleterious effects on benthic biota and fish, and impairs most of the major beneficial uses of water.

In rivers and streams, sediment either moves as suspended sediments or is transported as bed load. The suspended portion is called washout, while bed load is the portion that moves at or near the bottom in an erratic movement along the streambed. The bed load portion of the sediment transport eliminates suitable habitats for aquatic life. The concentration of suspended sediment in streams and rivers are highly variable and are influenced by several factors including rainfall duration and intensity, soil condition, topography, geology, vegetation cover and disturbing activities taking place in the watershed. Sediment concentration may vary from a few milligrams to more than ten thousand milligrams per liter. Most freely flowing rivers demonstrate significant day-to-day variations in concentration of suspended solids. The suspended load may vary with different reaches of a stream, particularly when the bed is resuspended or deposited due to changes in the hydraulic conditions.

The question of how much suspended sediment is harmful to surface waters is still unanswered, and standards are only available for turbidity. However, detrimental effects of sediment loads on the ecosystems can be characterized, and the importance of each effect outlined. Suspended sediment alters aquatic environment, primarily by inhibiting light, changing heat radiation,

blanketing the stream bottom and retaining organic materials and other substances that create unfavourable conditions for benthic organisms. Sedimentation of the stream bottom concern both organisms living in the bottom of the receiving water as well as higher organisms that depend upon bottom organisms for food. It has been long recognized that sediment deposition is primarily harmful to fish eggs burried in the bottom. Heavy concentrations of solids may also interfere with the gill movement of fish to affect circulation.

Increasing turbidity reduces the light penetration, which in turn limits the primary productivity by limiting the column of water in which light intensity is sufficient (about 1% of incident light) for the rate of photosynthesis to exceed the respiration rate. Since photosynthetic organisms form the base of the food web, any significant change in their population would have a widespread effect on the organism depending upon them for food.

The surface of particulate matter may act as substrate for bacteria and other microorganisms, thus changing their habitat. Sediment also traps nutrients, phosphorous in particular, and other toxic materials, which may be buried with the sediment in places of sediment deposition. Nutrient release and possible release of toxic materials may follow when resuspension of bottom materials occurs during periods of high flow or local scour.

Sediment deposition in reservoirs limits their useful lifetime. Similarly, many navigation waterways must be continuously dredged to keep the navigation channels passable, a process that is greatly polluting water by resuspending sediments and associated pollutants and nutrients. Soil loss, which is the primary source of sediment, contains organic matter, nutrients and often significant amount of pesticides, toxic metals and PCBs. Furthermore, processes taking place in the sediment layers may also, under different environmental conditions, release large amounts of nutrients back into the water.

3.2 Dissolved Oxygen

Dissolved oxygen (DO) concentration of surface water is the primary parameter on which suitability of water is judged. The DO standard is also the major parameter for the determination of waste assimilative capacity. The dissolved oxygen problem caused by non-point sources such as runoff from manure application, animal feedlots, and urban storm or combined sewers, can be devastating to the receiving water. The problem is not limited to runoff discharges containing high amount of organics, e.g., feedlot runoff. Large amounts of relatively 'clean' storm water may resuspend bottom deposits and increase their oxygen demands by several orders of magnitude.

The basic concept of the oxygen balance in streams was proposed by Streeter and Phelps (1944) and was later summarized by Phelps (1944). This concept, which is primarily used for evaluation of the point source impact on water quality, is still in use with some modifications. However, the original model, which assumes a point sewage discharge from a single source, cannot be used without modification for non-point source evaluation. Smith and Eilers (1978), Meadows et al. (1978), and Wanielista (1978) among other attempted to modify the Streeter-Phelps model for evaluation for non-point source impact on receiving streams.

The most important task in the dissolved oxygen analysis of non-point pollution effects on receiving water is determining the design flow, appropriate coefficients and stream characteristics and temperature conditions.

3.3 Nutrients and Eutrophication

Although many elements and chemical compounds are essential for plants and algal growth, only nitrogen and phosphorous are considered the limiting nutrients controlling their growths. On the average, about 50% of phosphorous and an even greater proportion of nitrogen originate from non-point sources.

The studies under taken by the National Eutrophication Survey in the early 1970s

clearly indicated that nation wide there is a distinct correlation between general land use and nutrient concentrations in streams. Streams draining agriculture watersheds had on the average considerably higher nutrient concentrations than those draining forested watersheds. The nutrient concentrations were proportional to the percentage of land in agricultural and urban land use (Omernik, 1977).

The nutrient problem is especially important for lakes, reservoir and estuaries. In these water bodies, the classical dissolved oxygen concept may not work in evaluating the waste assimilative capacity and the production of organic matter by phytoplankton and large plants-macrophytes-may greatly exceeds the BOD contributions from point sources, runoff and tributaries. Oxygen levels are also affected by photosynthesis and respiration and BOD concentrations are affected by the planktonic organisms and their residues.

The production of organic matter in lakes and reservoirs depends on the trophic state of the impoundment. Many lakes and reservoirs have experienced accelerated eutrophication in the last few decades. The term eutrophication is usually associated with excessive growths of autotrophic organisms, primarily planktonic algae (phytoplankton) and aquatic weeds (macrophytes). Eutrophication is not synonymous with pollution, however. A body of water may experience excessive algal growths if it receives pollutants containing certain kinds of nutrients, primarily phosphorus and nitrogen. The eutrophication process takes place in a surface water body in which organic mass production nourished by nutrients exceeds its loss by respiration, decay and outflow. In today's context, eutrophication refers to the natural and artificial addition of nutrients to bodies of water and to the effect of these added nutrients on water quality (Rohlich, 1969).

The process of eutrophication and trophic states of surface waters has recently attained much public attention. Lakes Erie and Ontario and portions of Lakes Michigan and Huron have been deteriorating rapidly due to accelerated production of organic matter with consequent limitation on their beneficial uses. Many other lakes and reservoirs have become highly eutrophicated in the last few decades as a result of increased nutrient loadings from intensive farming operation and urban developments. Eutrophication problems in some reservoirs occurred after a few years of operation.

During investigations of eutrophication problems in Madison, Wisconsin lakes, Sawyer (1947) noted that algal blooms occurred when concentrations of inorganic nitrogen (NH_4^+ , NO_2^- , NO_3^-) and inorganic phosphorous exceeded respective values of 0.3 mg N/L and 0.01mg P/L. It should be noted that due to the uptake of nutrient by algae, very low concentrations would be measured during the productive summer period, therefore, the critical nutrient concentrations should be evaluated during the spring overturn.

3.4 Metals and other Toxic Chemicals

Almost any element in the earth's crust can potentially be found at least in trace quantities, in surface water bodies. Most of these elements originate from natural sources. However, increased industrialization and urbanization have raised the levels of the trace metals in surface waters, especially the levels of toxic, sometimes improperly called 'heavy' metals (Chapman, 1978).

The periodic table includes over 90 elements from Hydrogen to trans-uranians and all but 20 can be classified as metals. As many as 59 of these elements can be considered 'heavy metals' (Chapman, 1978). However, only 17 of the heavy metals (Co, Bi, Ni, Cu, Zn, Sn, Se, Te, Pd, Ag, Cd, Pt, Hg, Tl, Pb, Sb) are considered both very toxic and relatively accessible. Of these 17 toxic metals, nine (Ag, Cd, Cu, Hg, Ni, Pb, Sb, Sn, Zn) are being mobilized into the environment by man at rates greatly exceeding those of natural geological processes (Chapman, 1978; Weiss et al., 1969).

Most likely each of these nine metals occurs naturally in water to some extent, and all organisms are naturally exposed to some level. In addition, some metals including Cd, Cu and Zn have known biochemical roles and others may be required as trace elements by the cell.

Since any metal may have a positive biological role, it follows that the total absence of a metal may be detrimental, that some concentrations may be optimal, and that some

concentrations will be toxic. The toxicity levels will depend on the type of the metal, its biological role and on the type of the organism and its ability to regulate its body concentrations of the metal. The general ranking of toxicity of metals in the aquatic environment is as follows:

Metal	Ag, Cd, Hg	> Cu	> Ni, Pb, Zn	> Sb	> Sn
Toxic level	10^{-8} M	10^{-7} M	10^{-6} M	10^{-5} M	10^{-4} M

PLUARG, in studying the impact of pollution of the Great Lakes, determined that the following elements should be considered potentially hazardous and requiring further attentions:

1. Mercury, lead
2. Arsenic, cadmium, selenium
3. Copper, zinc, chromium, vanadium

The ranking is based on environmental potential or an existing hazard to the Great Lakes. The elements of concern and their environmental hazard may change for other geographical locations. The following Table lists some toxic metals, their non-point sources and recommended stream criteria.

Some toxic metals that can be found in surface waters

Metal	Non-point source	Alleged effects	Recommended drinking water standard	EPA criteria for aquatic life
Arsenic	Pesticides, soil	Chronic, cumulative, carcinogenic, cardiovascular effects	50 µg/lit	0.04 mg/lit
Cadmium	Soil, industrial pollution	Arteriosclerosis, cancer, itai-itai disease	10 µg/lit	0.01-1.2 µg/lit
Chromium	Industrial pollution	Cancer, ulceration	50 µg/lit	0.29 µg/lit
Lead	Transportation, industrial pollution	Cumulative, plumbism	50 µg/lit	0.1-3 µg/lit
Mercury	Soil, industrial pollution, fungicides	Methylated cause Minamata disease	2 µg/lit	0.0005 µg/lit
Zinc	Soil	Taste problem	5 µg/lit	47 µg/lit

There are tremendous amounts of organic chemicals (pesticides and polychlorinated biphenyls, PCBs) that can be potentially dangerous to the aquatic environment. The amount and nature of pesticides reaching surface waters from agricultural lands are primarily functions of the persistence of the compound used, intensity and length of time pesticides have been applied, and transport mechanisms from the area of application to receiving waters (Chesters and Simsiman, 1974). The contamination of surface waters by pesticides and other organic chemicals can have a great impact on humans, commercial fishing, fish propagation and survival of aquatic species in general.

Many organic chemicals, including chlorinated hydrocarbons, are potentially carcinogenic. Some of the potentially dangerous chemicals such as persistent pesticides and PCBs have become a part of the environment and can travel by air, water and with the sediment. Many of them, for example DDT and most PCBs, are highly insoluble, hydrophobic (water repellent) substances and travel mostly with air aerosols and aquatic particulate matter.

PCBs have the wide industrial use since the 1930s. The chemical properties that make PCBs desirable industrial materials are their excellent thermal stability, their strong resistance to both acidic and basic hydrolysis and their general inertness. Despite their overall use and known toxic effects, their presence in the environment and in surface waters in particular was not discovered until the late 1960s in Sweden and the United States (Anon, 1976).

In aquatic environments, PCBs are highly hydrophobic and travel solely with sediments. In addition to the industrial source, PCBs can be found in the air particulate matter, soil, urban dust and bottom sediments of many surface water bodies. In most of the cases the entry of PCBs into the environmental systems, including surface waters, can be considered a known point source. The total annual world wide loss of PCBs into the environment has been estimated to be of the order of 1.5 to 2×10^3 tones/year into the atmosphere, 4 to 5×10^3 tones/year into fresh and coastal waters and 1.8×10^3 tones/year dumps and landfills (Nisbet and Sarofin, 1972).

Data gathered by the National Water Monitoring Program of the Environmental Protection Agency indicated that occurrence of PCBs in surface waters and bottom sediments is widespread throughout the major drainage basins of the United States. Median residue levels of the positive detection's for the years 1971 to 1974 ranges between 0.1 to 3 $\mu\text{g/L}$ for unfiltered water samples and from 1.2 to 160 $\mu\text{g/kg}$ for bottom sediments. The highest levels were found in basins east of the Mississippi River (Dennis, 1976).

3.5 pH and Acidity

The pH is one of the primary indicators used for the evaluation of surface water quality and suitability for various beneficial uses. Most aquatic biota is sensitive to pH variations. Fish kills and reduction and change of other aquatic species result when the pH is altered outside their tolerance limits. Most of the aquatic species prefer a pH near neutral but can withstand pH in the range of about 6.0 to 8.5.

The toxicity of other toxic components can also be altered if the pH is changed. The solubility of many metals as well as other compounds (ammonia) is affected by the pH, resulting in increased toxicity in the lower pH range. Change of the pH and acidity of surface waters resulting from non-point inputs can occur mainly from two sources of acidity: (1) acid mine drainage water, and (2) acid precipitation. Both sources have similar origins. Acid mine drainage is a result of mine water being in contact with sulfur-bearing minerals, while acidity of precipitation is caused primarily by atmospheric sulfur. Oxidation of these sulfuric compounds in surface or atmospheric water produces sulfuric acid, when then dissociates to H^+ and SO_4^{2-} ions.

Acid rain, which is defined as rain with a pH less than 5.6, is a result of sulfuric and nitrate emissions from urban, industrial and electric utility burning operations that use sulfur-and-nitrogen containing fuel (primarily coal or, to a lesser degree, low-quality oil). Lethal and sublethal effects of acid rain or acid mine drainage have been noticed both in the United States and in Europe (Beamish and Harvey, 1972; Almer et al., 1974; Likens and Borman, 1974; Likens et al., 1979).

Undesirable "oligotrophication" (a severe loss of productivity by the low pH conditions) and fish kills are the most visible and dangerous consequences of acidification. Loss of natural fish populations due to acidic rain and snow input in New York's Adirondack Mountains and in many pristine lakes of North America and Scandinavia has been documented and widely publicized. The damage to the fish populations of these lakes was brought about by both a long-term decreases of pH and short-term pH shocks by runoff from large storms and snowmelt.

Many watersheds and surface water systems have a natural ability to neutralize the excess acidity. During the overland flow, rain and snowmelt water dissolves calcium and magnesium-containing rocks (limestone and dolomite) or soils, and it is enriched by mineral and organic salts such as phosphates and humates. These constituents often provide enough buffering capacity to maintain the pH of surface waters within acceptable ranges. At this time, rain acidity does not seem to have a great adverse effect on larger water bodies such as the Great Lakes that have elevated hardness and salinity contents.

The ability of surface waters to neutralize acidic inputs depends primarily on the carbonate (CO_3^{2-}) and bicarbonate (HCO^-) content that is expressed as alkalinity. However, many North American and Scandinavian lakes are particularly sensitive to acid inputs. These lakes have watersheds underlain by siliceous hard rocks such as granite, some gneisses, quartzite and quartz sandstone. These materials are highly resistance to weathering and produce waters that contain very low concentrations of neutralizing components (alkalinity less than 30 mg CaCO_3/L). When acid rain falls on such watersheds the acids are not neutralized during the overland flow, and streams and lakes become acidified (Likens et al., 1979).

As reported by Likens et al. (1979), acidification of thousands of fresh water lakes and streams in Southern Norway has affected fish population in an area of 33,000 km^2 . In addition to damages to fish population, other adverse effects can be attributed to acidification. Bacterial decomposition is reduced at a lower pH, nitrification does not exist in low pH waters, and changes occur at all levels of the food web.

Biological Availability of Pollutants: A significant portion of pollutants from non-point sources is carried by (or is a part of) suspended solid loads. Most of the pollutants in the particulate form, however, are not readily available to the initiators of the food chain—the aquatic algae and green photosynthetic organisms. On the other hand, most of the dissolved pollutants can be readily picked up by the algae, contaminate their tissues, and initiate the food web process. By biomagnification, concentrations of the pollutants in higher trophic levels can increase by several orders of magnitude. Thus, assessing the effect of non-point pollution on aquatic biota requires an understanding of the biological availability of different pollutants entering the water bodies.

The biologically available forms of pollutants, primarily nutrients, toxic metals, and organic chemicals, are those that are dissolved or can be extracted from the sediment by desorption, dissolution or elutriation. Therefore, the adsorption-desorption and precipitation-dissolution reactions are the primary driving mechanisms determining the availability of a pollutant (Armstrong et al., 1979). These reactions can be affected by various environmental factors including pH, temperature and presence or absence of some organic compounds or inorganic catalysts.

Availability of Phosphorus: Almost 75% of the total phosphate input to the Great Lakes is in particulate form. However, only dissolved phosphate is available to algae and determines the rate of eutrophication. Consequently, the biological availability of phosphorous in suspended sediments (particulate P) is determined by the rate and extent of conversion to dissolved inorganic phosphate (Armstrong et al., 1979). The inorganic forms tend to control the phosphate concentrations in solution through adsorption-desorption and precipitation-dissolution reactions. Particulate organic P can release dissolved organic P to solution but dissolved organic P must be converted to inorganic P before it becomes available.

The factors controlling the availability of particulate P in suspended sediments include (Armstrong et al., 1979):

1. The forms and amounts of phosphorous in the particulate fraction,
2. The residence time of the particle in the lake water,

3. The phosphorous status of the algal population,
4. The solution phosphate concentration maintained by the algal or other phosphorous sinks, and
5. Other factors such as pH.

Nitrogen Availability: The quantities of nitrogen in suspended sediment range from 0.02 to 10% and represent mostly nitrogen from eroded soils and sewage sludge. Nitrogen in aquatic environments can exist as organic N (particulate and dissolved), ammonia (dissolved or adsorbed on sediments), nitrite and nitrate N, and dissolved nitrogen gas, N_2 . Due to the fast conversion of nitrite form to nitrate by nitrobacter, nitrites can be found only in trace quantities. Dissolved atmospheric N_2 is of little relevance.

Available nitrogen is defined as that fraction of the total N that can be readily or moderately assimilated by either phytoplankton (small photosynthetic aquatic organisms) or macrophytes (larger rooted or floating aquatic plants). The most important of these are the inorganic nitrogen and simple hydrolyzable organic compounds containing free amino or amide groups. The inorganic nitrogen forms in solution (ammonium and nitrate) are considered directly available, while organic forms are made available through conversion to inorganic nitrogen by mineralization. Ammonia can exist either as fixed by soil and organic particles or as exchangeable ammonium. Fixed ammonia is considered unavailable (Armstrong et al., 1979).

Simple organic compounds can undergo rapid ammonification to ammonia and further by nitrification to nitrate. The process of mineralization of aquatic organic nitrogen is somewhat similar to that occurring in soils. Measured available nitrogen in sediments of the Great Lakes tributaries ranged from 52 to 73% (mean values) of the total nitrogen in the suspended sediments. The available nitrogen was measured as exchangeable ammonium, nitrate and a portion of hydrolyzable organic nitrogen (Armstrong et al., 1979).

Toxic Metals and Organics Availability: The availability of these compounds is determined mainly by precipitation-dissolution reactions (metals) and adsorption-desorption

processes (organics). Precipitation is strongly affected by the pH of the water; therefore more metallic ions can be dissolved, and hence they become more available, at lower pH values. Investigations also indicate that humic acids, for example, from decaying leaf sediments in forest areas, increase dissolution of toxic metals by decreasing the pH and by formation of toxic metal-humic acid complexes (Bolter, and Butz, 1977). Availability of heavy metal to first trophic level organisms can be measured as the fraction extracted by a hydroxylamine hydrochloride reagent or by a chelating cation exchange resin (Armstrong et al., 1979).

Schneider et al. (1979) reported increased mercury content in fish in Ontario lakes as a result of the decrease in pH due to acid precipitation inputs. Mean values of the available metal fractions for the Great Lakes tributaries (Armstrong et al., 1979) ranged from 25 to 45% of the sediment total toxic metal content (Cu, Pb and Zn).

Many pesticides and organic chemicals, including the most dangerous ones, can be readily adsorbed-fixed-by suspended sediment. In the particulate form they are not readily available and are not taken up by algae and macrophytes (Chesters and Simsiman, 1974). The adsorption-desorption process and general desorptivity of the chemical then determines the extent of availability of the organic pollutants to aquatic organisms. However, not much is known about the process and further research is necessary.

4.0 SURFACE WATER PROBLEMS

During recent years non-point sources of pollution are being recognized as a major source of pollution to surface waters. Unpaved roads resulting from rapid development during the past few decades is the main cause of erosion and increased sedimentation of the aquatics ecosystem (MacDonald et al., 1997). Mwedera and Saleem (1997) studied the effect of cattle grazing on infiltration, runoff and soil loss during a rainy season on a natural pasture in the Ethiopian highlands and reported that soil trampling and reduced vegetative cover increased surface runoff and soil loss (particularly on upper slopes) and reduced infiltration (particularly on tilled soils and soils with high silt content).

Deletic and Maksimovic (1998) studied water quality of storm runoff at two experimental catchments, in Belgrade, Yugoslavia, and Lund, Sweden. The results indicate that the antecedent dry weather period length has only a minor effect upon road sediments wash-off, but it has an influence upon conductivity. The "first-flush effect" of suspended solids appears only in a limited number of events. Cross-correlation coefficients of rainfall, overland flow, and water quality were calculated for each event, taking into account the time lag between observed characteristics. These coefficients showed that suspended solids loading rate is influenced by rainfall intensity and overland-flow rate.

Barrett et al. (1998) studied water quality of highway runoff in the Austin, Texas, by monitoring runoff at three locations on the MoPac Expressway. The daily traffic volumes, surrounding land uses, and highway drainage system types were different at each site. The concentrations of constituents in runoff at all sites were similar to median values compiled in a nationwide study of highway runoff quality. The pollutant loads discharged from the pipe draining the swale were lower than those observed at the sites where runoff drained directly from the pavement. A first flush effect (i.e., higher pollutant concentrations at the beginning of an event) was evident during selected events, but was generally limited to a small volume. The overall effect was negligible when all monitored events were considered.

Wu et al. (1998) monitored three highway segments typical of urban, semi-urban and rural settings in the Piedmont region of north Carolina to characterize the respective runoff constituent concentrations and pollutant discharge or export loading. Runoff from the impervious bridge deck (Site I) carried total suspended solids (TSSs) concentrations and loading that are relatively higher than typical urban highways, whereas nitrogen and phosphorous loading are similar to agricultural runoff. Site II included a pervious roadside shoulder with traffic volume equal to that of a Site I. Site III was a non-urban highway having lower traffic counts and imperviousness due to the presence of a roadside median. The existing roadside shoulder and median appeared to attain at least 10-20% hydrologic attenuation of peak runoff discharges, more than 60% reduction of event mean concentration of TSSs, and attenuation of the first - flush concentration for most pollutant constituents. Bulk precipitation data collected at the bridge deck site indicated that 20 % of TSS loading, 70 - 90 % of nitrogen loading, and 10-50% of other constituent exports from the roadway corridors might have originated from atmospheric deposition during dry and wet weather condition. The long - term highway pollutant loading have been derived to provide a basis for comparing highway runoff with other categories of non-point sources (NPSs).

France (1997) reported 60% reduction in litterfall as a result of riparian clear-cutting of forest stands surrounding 10 northwestern Ontario lakes, decreasing the protective ground surface cover and retention of organic duff. It was further reported that the erosion of sandy loam can be twice as great under litter-fall conditions representative of clear-cut compared with forested shorelines. Castillo et al. (1997) studied impacts of vegetation removal on runoff and soil erosion in a semiarid area of Spain. The observed increase in surface runoff and soil loss was attributed to a progressive deterioration of soil physical properties with no evidence of vegetation recovery. Clayton and Megahan (1997) studied natural surface erosion and factors that control erosion rates in central Idaho on forested soils. Regression equations were also developed to predict summer, winter and annual erosion rates as a function of site variables and summer rain-storm intensities.

Rai and Sharma (1998) made comparative assessment of runoff characteristics under different land use patters within a Himalayan watershed. It is reported that large quantity of

sediments leaves the Himalayan through its rivers. These rivers are charged with sediments depending on the types of land use in the watersheds. Land use/cover change and hydrology was studied in a watershed in the Sikkim Himalaya. The land use change from forest and agro-forestry to open agriculture has increased by 11% from 1988 to 1992. During the same period substantial areas of dense forest has been converted to open mixed and degraded forests as a result of high pressure on natural resources. Stream flow was highest in rainy season and lowest in summer season in all the streams in all the three years (1994-1997) of the study. The water quality of streams from different micro watersheds varied significantly between streams and seasons. Sediment and nutrient loss was estimated in micro watersheds and soil loss from total watershed ranged from 4.18-8.82 t ha⁻¹yr⁻¹ during the three-year period of study. The annual total nitrogen loss estimated at the watershed outlet was at the rate of 33kg ha⁻¹, organic carbon 267 kg ha⁻¹ and total phosphorous 5 kg ha⁻¹. This study suggests that the upland micro watersheds can be hydro ecologically sustainable only if good forest cover and dense forests with large cardamom-based agro-forestry are maintained.

Several studies on the nutrient levels in surface waters from agricultural watersheds have been conducted in Pennsylvania, Maryland, Delaware, North Carolina, Colorado, Denmark and Wisconsin (Owens et al., 1997). Increased nitrogen concentration were correlated with a greater portion of cropland area in sever Chesapeake Bay watersheds (Jordan et al., 1997a,b) whereas phosphorus concentrations did not correlate with the land use. Sediments in agricultural drainage basins were reported to be enriched with phosphorus in Delaware's Inland Bays (Sallade and Sims, 1997a,b). Water-quality degradation was related to land-use changes and storm events in an Appalachian mountain watershed (Bolstad and Swank, 1997) and in the Upper Colorado River Basin (Spahr and Wynn, 1997). Long-term monitoring databases were analyzed to determine relationships between land uses and nutrient concentrations in the Albemarle-Pamlico drainage basin in Virginia and North Carolina (McMahon and Woodside, 1997) and in the upper-midwestern United States (Mueller et al., 1997). Both studies indicated the importance of agricultural land-use and management practices to nutrient levels in surface waters. Stream bank erosion was the major source of particulate phosphorus on suspended sediment in a Danish lowland stream (Kronvang et al., 1997).

David et al. (1997) reported that about 49% of the inorganic nitrogen pool in a corn and soybean field in Illinois, was leached through drain tiles and seepage, and the concentrations of nitrate in the tiles were synchronous with the nearby river. In contrast Lindau et al. (1997) reported that concentrations of nitrogen species in surface and drain water from a Louisiana sugarcane field were low and that a forested wetland adjacent to the field received only a small fraction of the nitrogen applied to the field.

Durand et al., (1999) studied major solute concentrations in overland flow water in an agricultural field of Brittany (Western France). Two storm events were monitored in detail to examine the short time-scale process. It is concluded that vegetated buffer strips designed to reduce the sediment load only, and not the amount of overland flow, will have little effect on the transfer of dissolved pollutants to the water courses.

Heathwaite and Johnes (1996) studied contribution of nitrogen and phosphorous from agricultural catchments by evaluation of the chemical composition of these nutrients in agricultural runoff for both surface and subsurface flow pathways. A range of land uses (grazed and ungrazed grassland, cereals, roots) in intensive agricultural systems was studied at scales from hill slope plots (0.5 m²) to large catchment (>300km²). By fractionating the total nutrient load it was possible to establish that most of the phosphorous was transported in the unreactive (particulate and organic) fraction via surface runoff. The form of nitrogen load varied with land use and grazing intensity. High loads of dissolved inorganic nitrogen (with >90% transported as NH₄-N) were recorded in surface runoff from heavily grazed land. In subsurface flow from small (2km²) sub-catchments and in larger (>km²) catchments, organic nitrogen was found to be an important secondary constituent of the total nitrogen load, comprising 40% of the total annual load.

In an another publication, Heathwaite et al. (1996) studied the role of nitrogen and phosphorous as key nutrients determining the trophic status of water bodies. Data are reported for water bodies undergoing eutrofication and acidification, especially water bodies receiving increased nitrogen inputs through the atmospheric deposition of nitrogen oxides. The paper primarily focuses on results from North America and Europe, particularly for the UK where a wide range of data

exists. Few nutrient loading data have been published on water bodies in less developed countries; however, some of the available data are presented to provide a global perspective. It is reported that in general, N and P concentrations have increased dramatically (>20 times background concentrations) in many areas and causes vary considerably, ranging from urbanization to changes in agricultural practices.

Johnes and Heathwaite (1997) modeled the impact of agriculture on nitrogen and phosphorous loading on the surface waters of two contrasting agricultural catchments. Sensitivity analysis was conducted to isolate the key controls on nutrient export in the modified model. The model was validated against long-term records of water quality, and was found to be accurate in its predictions and sensitive to both temporal and spatial changes in agricultural practice in the catchment. The model was then used to forecast the potential reduction in nutrient loading on Slapton Ley associated with a range of catchment management strategies. The best practicable environmental option (BPEO) was found to be spatial redistribution of high nutrient export risk sources to areas of the catchment the greatest intrinsic nutrient retention capacity.

Ohruai and Mitchell (1998) studied spatial patterns of N dynamics in two small-forested watersheds in Japan. These two watersheds were characterized by steep slopes (>30°) and high stream nitrate drainage rates (8.4 to 25.1 kg N ha⁻¹yr⁻¹) that were greater than bulk precipitation N input rates (7.5 to 13.5 kg N ha⁻¹yr⁻¹). Both stream discharge rates and NO₃⁻ concentrations in deep unsaturated soil at the near-stream zones were positively correlated to NO₃⁻ concentration in stream water. These relationships, together with high soil NO₃⁻ contents at the near-stream zones, suggest that the near-stream zone was an important source of NO₃⁻ to stream water. Nitrate flux from these near-stream zones was also related to the drainage of cations (K⁺, Ca⁺², and Mg⁺²). The steep slope of watersheds resulted in a small saturated, area that contributed to the high NO₃⁻ production (nitrification rates) in the near-stream zone.

Water-quality impacts of animal waste-management practices were evaluated for poultry litter in Oklahoma (Sharpley, 1997), dairy pastures in Australia (Nash and Murdoch, 1997), and cattle grazing in Great Britain (Haygarth and Jarvis, 1997). Bacteria concentrations in surface

water were related to cattle grazing, flow and season in Arkansas (Edwards et al., 1997a,b). Water-quality impacts of poultry and swine-waste lagoon spills were characterized in North Carolina (Mallin et al., 1997).

Surface waters in agricultural watersheds were monitored for pesticides in Arkansas (Senseman et al., 1997), Nebraska (Ma and Spalding, 1997), Idaho and Wyoming (Clark, 1997), California (Domagalski et al., 1997), and France (Garmouma et al., 1997). Metolachlor, atrazine, norflurazon, cyanazine, simazine, isoproturon, EPTC and organophosphate pesticides were detected at varying concentrations in these studies. Several studies were conducted to evaluate pesticide pollution impacts of specific management practices, including herbicide applications to cropland in Indiana (Zhang et al., 1997), herbicide applications to turf grass in Georgia (Hong and Smith, 1997), herbicide applications to vineyards in France (Lennartz et al., 1997), and herbicide and insecticide applications to wheat in Great Britain (Turnbull et al., 1997). Obenshain et al. (1997) analyzed 3 years of water, soils, and vegetation data to develop a correlation between soil type, herbicide type, and herbicide persistence in the environment, thereby developing a method to estimate pollution potential of roadside herbicide application areas.

Several studies have also been reported on the fate of pesticides in the aquatic environment. Nine alachlor metabolites were identified in river water after 28 days of incubation with the parent compound, although little actual metabolism occurred in the study (Mangiapan et al., 1997). Vink and Van Der Zee (1997) studied the transformation of four pesticides in natural waters ranging from field ditches to lakes. The smaller water bodies were much more effective in degrading the pesticides than larger ones and previous exposures through past applications also enhanced degradation. The relative effect of hydroxy radicals and direct photolysis of atrazine was altered by the presence of dissolved organic matter with more direct photolysis (Torrents et al., 1997). A survey of Mediterranean estuaries and tributaries found no evidence of significant contamination by 10 common fungicides (Readman et al., 1997).

Laroche et al. (1996) used model HSPF to study transport of pesticides on 78 ha watershed in the province of Quebec, Canada. Pesticide concentrations were measured at the outlet

of the watershed from February to November 1993. This short period of time allowed calibration of the pesticide component but precluded verification. Variations of atrazine concentration were well simulated by hydrological Simulation Program FORTRAN (HSPF), with simulated concentrations in the same range as observed values, and with peak concentrations occurring at the same time.

Surface water-quality impacts of urban and industrial land uses were monitored in Texas (Characklis and Wiesner, 1997), Utah (Farrell-Poe et al., 1997), North Carolina (Line et al., 1997), South Africa (Jagals, 1997), and Singapore (Chui, 1997). Results from these studies indicated that urban land uses contribute varying levels of metals, bacteria, sediment, nutrients and organic chemicals to surface waters. Line *et al.* (1997) showed that metals concentrations in runoff from industrial sites varied significantly for various categories of businesses. Regarding sources of nutrients in urban areas, Linde and Watschke (1997) reported that, on an average, 11% of applied phosphorus and 2% of applied nitrogen were detected in runoff from turf grass plots, whereas 14% of phosphorus and 3% of nitrogen were detected in leachate.

In order to develop a monitoring program for the Santa Monica Bay, Calif, watershed, Wong et al. (1997) developed a land use runoff model using a geographic information system (GIS) coupled with an empirical runoff model. The GIS/model has simple data requirements as compared to more complex models that require routing information, and it is useful for predicting receiving water loading on an annual basis or for single - storm events. The approach can also be used to graphically present model results in simple ways that provide better insight to managers and planners in evaluating pollution sources and control strategies. The GIS/model was used to locate monitoring stations in the most economical way. The model predictions can be used to improve the evaluation of best management practices to control pollutant discharges. Receiving water pollutant contribution from point and non-point sources can be compared to develop more economical strategies for overall pollutant minimization.

Bouraoui and Diallaha (1996) developed a non-point source pollution management model (Answers-2000) to simulate long-term average annual runoff and sediment yield from agricultural watersheds. The model is based on the event-based Answers model and is intended for

use without calibration. The physically based Green-Ampt infiltration equation was incorporated into Answers-2000 to improve estimates of infiltration. An evapotranspiration sub-model was added to permit long term, continuous simulation. The model was validated without calibration using data from the field size P2 and P4 water set in Watkinsville, Ga. Additional validation with limited calibration was done on the Owl Run watershed in Virginia. Model predictions on cumulative sediment yield were within 12% and 68% of observed values. Predicted cumulative runoff volumes ranged from 3%to35% of observed values. Predictions of sediment yield and runoff volume for individual storms were less accurate, but generally within 200% of observed values. In a practical application the use of model in agricultural non-point source pollution control planning was demonstrated.

5.0 GROUND WATER PROBLEMS

There is wide concern in developed countries that ground water resources are deteriorating in the long term, both in quantity and quality. Ground water pollution is of major concern mainly because of the implications for human health when it is used for drinking water. Many of the most serious sources of health risk, such as bacterial and viral infection and toxic metals, do not have a specific agricultural origin. However, nitrates, as a cause of methaemoglobinaemia, and pesticides, with a suspected disturbingly wide array of health effects, has a largely agricultural origin and is a cause of major concern.

Concentrations of nitrogen in ground water are an important concern because a large number of people use ground water as a source of their drinking water supply. In addition, much of the nitrogen entering our streams and lakes comes from nitrate in ground water. When urea is applied as a deicing agent during the winter, large concentrations of ammonium is observed at all soil depths, however, over time, the ammonium gets oxidized to nitrate, which leaches into the ground water (Swensen and Singh, 1997). Chakka and Munster (1997a) reported that ammonium and nitrate applied to a corn crop did not reach into the nearby River (probably due to high nitrogen concentrations in the ground water), whereas atrazine is detected in the ground water 24 days after the second application. Bruckler et al. (1997) reported nitrate losses of 97 kg/ha on fields producing salad crops during the spring and summer and 199 kg/ha of nitrate during the fall and winter. Less drainage and greater uptake/immobilization of nitrogen by perennial crops led to greater nitrate losses under row crops, nitrate-nitrogen losses were 32 mg/L under continuous corn, 24 mg/L under com-soybean rotation, 3 mg/L under alfalfa, and 2 mg/L under Conservation Reserve Program land (Randall et al., 1997). Brandi-Dohrn et al. (1997) found that cereal rye crops planted after summer crops reduced leaching losses of nitrate from 48 kg N/L to 32 kg N/L (sweet corn, winter-fallow), from 55 kg N/L to 21 kg N/L (broccoli, winter-fallow), and from 103 kg N/L to 69 kg N/L (sweet com, winterfallow).

A study involving the partitioning of nutrients between surface and subsurface flow

for applied hog manure documented that runoff accounted for 36% of the total Kjeldahl nitrogen losses, 67% of the ammonium-nitrogen losses, 42% of the nitrate-nitrogen losses, 63% of the total phosphorus losses and 27% of the ortho-phosphorus losses (Gangbazo et al., 1997). Stout et al. (1997) showed that intensive grazing systems have the potential to increase leaching losses of nitrate-nitrogen (1.17 g/m control, 1.68 g/m feces, 22.0 g/m spring-applied urine, 24.0 g/m summer-applied urine, and 31.5 g/m fall-applied urine). Shallow ground water wells demonstrated that nitrate concentrations were highly correlated to past nitrogen application rates, the field with heavy manure application rates had the highest nitrate concentrations (Kitchen et al., 1997). Through the development of nitrogen and water mass balances, Vizearra et al. (1997) showed that animal manure and fertilizer application in the lower Fraser River Basin of British Columbia, Canada, caused most of the nitrate in ground water recharge. In a study of mobile phosphorus leaching losses, dissolved organic phosphorus constituted 70% of the total phosphorus regardless of whether phosphorus was applied as animal waste or fertilizer (Chardon et al., 1997).

Nolan et al. (1997) prepared National maps of ground water vulnerability to nitrate contamination for the United States using different input parameters (population density and the amount of nitrogen contributed by fertilizer, manure and atmospheric sources) and aquifer vulnerability (soil drainage characteristics and the ratio of woodland acres to cropland acres in agricultural areas). Nitrate concentrations in drinking water wells in Maryland were found higher in areas with corn and broiler production and septic systems than areas with other land uses (Lichtenberg and Shapiro, 1997). Domestic well water quality in Nebraska demonstrated that 3-39% of the wells were contaminated with nitrate, 8-26% with bacteria, and about 4% with pesticides, depending on the region (Gosselin et al., 1997). Richards (1997) identified numerous factors that contributed to nitrate and pesticide contamination of drinking water wells.

In England and Wales 125 ground water source supplying 1.8 M people had nitrate concentrations in 1983 or 1984 exceeding 50 mg/L (Department of the Environment Report, 1986), 105 of these sources exceeded 50 mg/L in 1984 compared with 90 ground water sources in 1980 and 60 sources in 1970. Areas in East Anglia and the Midlands are most affected where nitrates are rising in about 100 source.

Unfortunately very little efforts have been made in India to carry out well-planned primary field studies to assess the impact of non-point source pollution. Agarwal et al. (1999) have reviewed the status of diffuse agricultural nitrate pollution of ground water in India and reported that nitrate levels in ground water over vast agricultural areas can be correlated with intensive irrigated agriculture, corresponding use of nitrogenous fertilizers and ground water development. It is further reported that diffuse agricultural pollution has already endangered the safety of potable ground water for future generations in both rural and urban areas. Chemical and bacterial treatment of ground water for nitrate removal relies on advanced technology and is considered costly even in developed world.

Some cases of high nitrate in ground waters in India have been reported by Handa (1975), Kumar (1983) and Kakar (1985). In a preliminary study of 2500 ground water samples (2000 from dug wells and 500 from deep tube wells) from different parts of India, the incidence of high nitrate was conjectured to be due to pollution of some sort, either from human or animal sources or from irrigation return flows from agricultural fields dressed with chemical fertilizers (Handa, 1975). Nitrate in deep waters was only 1-2 mg/L whereas in shallow water it was up to 100 mg/L in humid areas and up to 1000 mg/L in arid and semi-arid regions.

A rapid reconnaissance of nitrate in shallow ground waters was done by CGWB (Handa, 1986). The study reported average concentration of nitrate in well waters (mostly from dug wells) from several states, namely Andhra Pradesh, Bihar, Delhi, Gujarat, Himachal Pradesh, Jammu and Kashmir, Madhya Pradesh, North Eastern India, Orissa, Punjab, Tamil Nadu, Uttar Pradesh and West Bengal with the exclusion of Goa, Karnataka, Kerala, Maharashtra and Rajasthan (Agarwal et al., 1999). However, there was no discussion regarding the possible sources of pollution in different regions, i.e. whether from point sources emissions (urban sewage/industrial effluents) or non-point sources.

Bulusu and Pande (1990) carried out ground water quality survey in selected districts in 17 states of India including Rajasthan and Karnataka but excluding north-eastern states, Goa and

Kerala and reported high nitrate concentration (above the WHO limit of 45 mg/L nitrate for potable water) in 1290 out of 4696 samples without referring to specifically either urban/industrial or agricultural sources. However, high nitrate levels reported in 73% of samples from Nagpur metropolitan city, for instance, may be due to urban sewage and industrial sources. High nitrate content (45 to more than 600 mg/L) in shallow and deep tube wells due to seepage from industrial effluents and urban sewage has also been reported from around Jodhpur city in Rajasthan (Mathur and Ranganathan, 1990) and Lucknow city in Uttar Pradesh (Singh et al., 1991). In Bangalore district (Karnataka) 18% of the samples, representing 1475 km² were found to contain more than 50 mg/L nitrate, the maximum being 200 mg/L (Tamta et al., 1992). Diffuse ingress of seepage of nitrogen-bearing effluents were the cause in all these cases.

Khanna et al. (1994) carried out analyses of ground water samples obtained from shallow dug wells located in Sirsa, Hissar, Mahendragarh, Bhiwani and Rohtak districts and reported that 57% of the samples contained more than 45 mg/L of nitrate, maximum being 300 mg/L. In these rural districts, the source could be due to diffuse pollution related to agricultural return flows. Bhide (1990) has studied nitrate pollution of Indian urban solid waste capable of affecting water table aquifers by leaching. This would also essentially diffuse pollution, though not agricultural. The study by Mehta et al. (1990) attributing to high nitrate levels in dug well waters of Ganjan district (Orissa) was the first to directly implicate agricultural diffuse pollution. Gupta (1992) also seems to conjecture that high nitrate levels in ground water of Udaipur district (Rajasthan) could be due to a five-fold increase in the use of N-fertilizers in the district during the decade 1979-89, thus blaming agricultural diffuse pollution. In the study by NEERI (Bulusu and Pande, 1990), high nitrate content in 41% of samples from village around Nagpur metropolitan city and 49% of samples from Gulbarga district (Karnataka) might also reflect contributions from agricultural sources.

Loague and Corwin (1998) made regional scale assessment of non-point source ground water contamination. It is reported that at the regional scales associated with NPS agrochemical applications there are staggering data management problems in assessing potential ground water vulnerability. Geographical information system (GIS) is a timely tool that greatly facilitates the organized characterization of regional-scale variability. The strengths and weakness

of using GIS in regional-scale vulnerability assessments (owing to both data and model errors) have also been discussed. A regional GIS-driven integrated assessment approach is discussed, which is based upon cost-benefit analysis, and incorporates both physical and economic factors that can be used in a regulatory decision process. Takarate et al. (1999) studied the effect of hydrology, vegetation and substrate on spatial and temporal variations of nutrient concentrations in the ground water of a flood plain.

Monitoring of pesticides and nitrate in a shallow aquifer in central South Dakota indicated that nitrate is transported primarily through matrix flow, whereas the movement of pesticides is controlled primarily by geological and chemical characteristics of the medium and pesticides (Bhatt, 1997). Using O-18, nitrate and potassium concentrations in an assessment of ground water quality in the Delhi area of India, Datta et al. (1997) showed that fertilizer caused high nitrate concentrations. In Niger, 10% of the wells are contaminated with nitrate with the major source of the nitrate coming from latrines rather than nitrogen fertilizers (Girard and Hillaire-Marcel, 1997). Bromide was used as a tracer for nitrate in a deep Vertisol in the semiarid tropics, 40% of the bromide leached beyond the 100-cm zone (Patra and Rego, 1997). Kanwar, et al. (1997) found that when they used chloride tracer as the nitrate surrogate and fluorescent dye as a surrogate for atrazine, the chloride tracer did well as a surrogate for nitrate, but the fluorescent dye was not a good surrogate for chloride. In another similar study, Schub et al. (1997) tracked tracers (bromide, chloride, and fluorescent dyes) and nitrate and reported that, after precipitation events, elevated concentrations of tracers and nitrate were spatially variable. On sandy Coastal Plain soils, on-site wastewater treatment systems contaminated the ground water with both viruses and bacteria. Sandy soils and high water tables increased the likelihood of contamination by organisms, whereas the distance from the leachfield line decreased the survivability of the organisms (Scandura and Sobsey, 1997).

Over recent years there has been a considerable rise in the number of reported incidents of pesticides contamination in ground water due to excessive use of pesticides in agricultural activities. Milde et al. (1982) reported occurrence of 22 different pesticides in 34 locations in the USA and Europe. Atrazine is the most widely reported with concentrations up to 7

$\mu\text{g/L}$. In Britain the most extensive survey of pesticides in surface waters and ground waters has taken place in the Anglian region where the herbicide usage on cereals has been the greatest. Croll (1988) reports that while ten different pesticides are found frequently in surface waters, they are less frequently detected in underground waters.

Milde et al (1982) state that the main factors influencing the contamination potential of any pesticide are molecular structure, formulation, metabolism, water solubility, adsorption by soil, the retardation factor and resistance to chemical and biochemical degradation. The time, quantity and frequency of application, as well as the local hydrogeological and meteorological conditions will all affect the quantity of any pesticides reaching the water table.

Steenvoorden (1976) reported that the organo-chlorine pesticides are long-lived, have a low solubility and exhibit chronic toxicity to all life forms. They are strongly adsorbed by soil and are unlikely to be found at depth. The organo-phosphorous compounds exhibit a wide range of solubilities but have a low mobility, equal to the organo-chlorines. They do, however, degrade more rapidly with a persistence of 0.1% after 15 years, compared with 3-20% for the organo-chlorines.

Kolpin et al. (1997) found that 70% of all 106 municipal wells sampled were contaminated with pesticides and that the different types of aquifers affected pesticide leaching differently. Wells in alluvial deposits had the greatest number of pesticide detections and bedrock land forms had the least. Juracek and Thurman (1997) tested atrazine in the root zone of 60 dry land and irrigated fields and found no significant buildup of atrazine below the root zone indicating low possibility of ground water contamination with pesticides. Kolpin et al. (1997) used ground water pesticide data from 1982 and compared it with current data to determine changes in pesticide concentrations. The data indicated that atrazine concentrations have declined, whereas alachlor concentrations have increased. A study in Missouri found that site-to-site variability was a far more important determinant in the leaching properties of atrazine and alachlor than was the rate of herbicide application, the fields that had the least amount of pesticide application had the greatest amount of leaching (Blanchard and Donald, 1997). When natural springs in the Canadian prairie were tested for herbicides, researchers found that 23% of the samples tested positive for trace levels

of the herbicides, atrazine, picloram, and 2,4-D (Wood and Anthony, 1997).

Numerous workers have studied the processes affecting the movement of pesticides into ground water. Sorption of pesticides on different types of colloids and subsequent movement of these colloids through the soil profile was studied, and the researchers found almost no increase in the transport of atrazine (Seta and Karanthanasis, 1997). When fluxes of pesticides from a stream bed were measured, it was found that pesticide fluxes for atrazine were two to five orders of magnitude greater in the stream bed than fluxes of atrazine through agricultural fields (Squillace et al., 1997). Guo et al. (1997) found that it is the concentration of organic matter in the soil profile that affects the transport of atrazine through the soil profile. Kolpin (1997) studied the effects of land use on concentrations of agricultural chemicals and reported that the concentrations of atrazine and nitrate were positively correlated to the amount of irrigated land area and that alachlor was inversely related to the amount of highly erodible land. Troiano et al. (1997) used statistical methods for assessing ground water contamination and reported that canonical variates analysis apportioned more land areas as being vulnerable to ground water contamination than principal components analysis.

Moreau and Mouvet (1997) determined the sorption and desorption properties of soil from two depths and underlying aquifers for atrazine, deethylatrazine and hydroxyatrazine. Sorption decreased and desorption increased with depth, with hydroxyatrazine having the strongest, least reversible binding and deethylatrazine having the opposite. Aquifer solids had little or no sorption capabilities. Sorption of two relatively polar herbicides, metamitron and thiazafuron, was determined for natural soil clays and model pure clays (Cox et al., 1997). Sorption was inversely related to the cation exchange capacity of the clay and organic matter was less important for thiazafuron than for metamitron. Phosphate significantly reduced 2,4-D adsorption compared with acetate on montmorillonite and increasing the $Al(OH)_x$ loading on the clay surface also increased binding (Sannino et al., 1997). Adsorption of diuron and isoproturon on undispersed soil occurred primarily during the first day but continued for more than 2 weeks (Gaillardon, 1997). Partial replacement of the pore water increased desorption but with diminishing effects over time.

Chiang et al. (1997) conducted sorption studies for butachlor, thiobencarb and

chlomethoxyfen on nine soils and found sorption to be highly correlated with soil organic matter content. They also verified two previously reported equations to predict sorption based on the water solubility of each compound. Novak et al. (1997) had similar observations with atrazine and successfully used landscape position and the resulting effects on soil properties to more accurately predict atrazine sorption compared with soil maps. The sorption and mobility of four pesticides in two Malaysian soils were tested under varying conditions (Cheah et al., 1997). Temperature, pH, and pesticide mixtures did not affect adsorption, and leaching was found only for 2,4-D and lindane in the lighter soil under high water flux.

Rodriquez and Harkin (1997) studied persistence of atrazine residues in sub-soils and aquifer sediments and reported degradation rates under different conditions. Half-lives of 1-5 years were found in sub-soils and no measurable degradation occurred in the aquifer sediments. Rapid degradation (< 10 day half-life) was found for surface soils, particularly if the pH was above 7.7 (Vanderheyden et al., 1997). Subsoils varied in degradation capacity, ranging from nearly none to nearly as effective as surface soils. Atrazine dissipation in surface and subsurface soils was determined by laboratories in four countries with a wide variation of degradative capability (Issa et al., 1997).

Endosulfan was reported to dissipate to 3-8% after 4 weeks in subtropical Indian soils, and very little downward movement for either the parent or the two major metabolises was detected (Kathpal et al., 1997). Chlorpyrifos dissipated more rapidly under air-dry conditions compared with more moist conditions (Awasthi and Prakash, 1997).

Reducing application rates has been found to be an important aspect to prevent ground water contamination in many areas. Hanson et al. (1997) determined that varying rates of 0.56-4.48 kg atrazine/ha did not change relative movement of either the parent compound or two of its metabolises and that absolute differences were directly proportional to the rate of application.

6.0 POLLUTION CONTROL

Concern over non-point source pollution in integrated water quality management has been growing recently. Such sources are likely to be more critical in developing countries including India, where agriculture and rural habitats are still dominant. The term pollution control refers to regulation of pollutants from individual outfalls or non-point sources including urban developing lands, feedlots, agricultural areas and other pollution generating land uses. The purpose of all pollution control should be (Patrick, 1975):

1. To protect the capacity of surface water to assimilate pollution without damage or impairment of their use,
2. To protect shellfish and wildlife,
3. To preserve or restore the aesthetic and recreational values of surface waters,
4. To protect the humans from adverse water quality conditions.

Water quality management deals with all aspects of water quality problems for all beneficial uses of water or lands from which pollution originates, whereas pollution control is mostly understood as the safe disposal of wastewater and their treatment. Water quality and pollution are determined by comparing measured physical, chemical, biological, microbiological and radiological parameters to a set of standards and criteria.

The water quality standards used presently by water pollution engineers and scientists as well as pollution abatement authorities throughout the world are either stream standards or effluent standards. The effluent standards, which determine how much pollution can be discharged from municipal and industrial wastewater sources, are of lesser importance in non-point source pollution control and management. Performance standards, an equivalent of effluent standards to control pollution from lands, have been used by some local authorities to control pollution from subdivisions, construction areas or mining. The stream standards can be related to the protection of aquatic habitat and biota and/or to intended downstream use of water.

6.1 Nutrient Control

The control of nutrients is an important issue throughout the world, both from a public health perspective and to keep natural waters free from eutrophication. The most widely used water quality standard for nitrate is the 50 mg/L limit adopted by WHO as a precautionary level to safeguard babies from the risks of contracting methaemoglobinaemia (WHO, 1993). Most national authorities regard the 50 mg/L concentration as a realistic target in relation to eutrophication and, therefore, programmes aimed at controlling eutrophication often use this value as an EQS. Whereas there are techniques available to remove nitrate from drinking water after it has been abstracted, the eutrophication problem is universally dependent on the control of nitrate sources.

There is an added and unexpected health implication related to eutrophication, particularly in lakes. In a number of countries in the world, the phenomenon of excessive growth of blue-green algae has caused concern where recreational pursuits take place on the lakes and also where the water is withdrawn for public supply. This is due to the recognition that such algae produce a number of toxins, which, if ingested, can cause liver damage. There are a number of well-documented cases where animals are known to have died as the result of drinking water heavily laden with these algae (e.g. Australia, South Africa, UK) and, for this reason alone, nutrient control is justified.

The reduction of nitrogen and phosphorous from agriculture relies upon changes to farming practices because they give rise to diffuse sources. Ploughing of grassland and other crops, particularly during autumn, leads to the release of large quantities of soil nitrogen and, therefore, a general move towards permanent pasture regimes assists in lowering nitrate leaching. When this is not possible, the use of short-term rotational crops to take up nitrogen followed by their harvesting and subsequent removal from the catchment is helpful. Animal wastes should be used carefully, avoiding overuse and direct runoff into water courses, but wherever possible they should be used in place of synthetic fertilisers. Spreading of cattle manure and liquid sludge should be banned during

the time when aquifers are replenished by rains. A manuring season should be prescribed for main crops depending on monsoon and crop patterns in different regions. The use of biofertilizers and green manures should be encouraged and research need to be undertaken to improve their quality and efficiency. Use of all types of fertilisers should be carefully controlled and matched to crop requirements.

One of the most important aspects of controlling phosphorous inputs from agriculture is the need to prevent erosion from field surfaces. Phosphates tend to bind to soil particles which, washed from fields into watercourses, become a source of phosphate in suspended form and in deposited sediments. Sediments act as a long-term source of phosphate by releasing it (i.e. by redissolution) under certain environmental conditions. Physical removal of the sediment layer, in order to remove the bound phosphate from the catchment, has been tried in a number of locations around the world. Some success has been achieved in lowering phosphate levels in the Norfolk Boards in England by a combination of the diversion of effluents containing phosphorous out of the area, phosphorous stripping at sewage treatment works, and by the dredging of 1 m of sediment. Concentrations below the target of $100 \mu\text{g l}^{-1}$ of phosphorous were reached (RCEP, 1992).

In addition to agricultural sources, phosphate occurs in sewage effluents as a result of its use as detergent (creating optimum conditions in the wash water for the surfactant to operate). Sodium tripolyphosphate is commonly used, this compound breaks down to orthophosphate which can be used as a nutrient source by aquatic plant. Control of phosphate at source is not yet practiced and removal relies on 'stripping' of the orthophosphate from the sewage works effluent by chemical treatment. Swage works can remove 40% of incoming phosphate, but removal of at least 90% is often required to bring about a change in the trophic state of a receiving water body. Reductions in the polyphosphate content of some detergents may also help in controlling phosphate. The importance of phosphate is recognized by the EC Urban Wastewater Treatment Directive by the inclusion of phosphate limits for discharges to eutrophic waters (2 mg/L for population between 10,000 and 100,000 and 1 mg/L for population greater than 100,000).

6.2 Pesticides Control

Pesticides represent a particularly difficult area of pollution control activity, not only because the environmental effects in relation to aquatic flora and fauna are important but because human health issues have a very important bearing upon the nature of the control applied. There are several thousands of formulations of insecticides, herbicides and fungicides in common use and, therefore, the potential for water pollution is very high. There are also very stringent limits for water used for public supply and, consequently, the control of pollution by pesticides is quite crucial.

Many pesticides in water are derived from agricultural use and it is therefore difficult to regulate their input to water bodies. Regulation can only take place by prevention, i.e. by indirect controls on their manufacture, storage and use. Approval for the use of pesticides is granted in the UK by the government, following expert assessment of safety and the environmental risks. The active ingredients in pesticides are approved by the European Union and placed on an approved list. This Directive allows authorisation provided the pesticides is not expected to occur in ground water at concentration above 0.1 µg/L. Further controls are also placed on products by Directives such as that on Classification, Packaging and Labelling of Dangerous Substances.

6.3 Watershed Management Planning

The watershed management essentially relates to soil and water conservation by proper land use, protecting deterioration of soil, increasing and maintaining soil fertility, reducing soil erosion, conserving water for drinking and other farm uses, increasing the availability of basic resources and achieving the optimum productivity of land uses (Sharma et al., 1992). Rai et al. (1994) has described the traditional conservation practices and relationship with land use in Mamlay watershed in the Sikkim Himalaya. It was observed that the agricultural land area has considerably increased over the past 40 years (Sharma et al., 1992; Rai et al., 1994). The soil without tree cover on steep upland farming systems such as associated with more intensive agricultural practices is vulnerable to soil erosion and reduced fertility (Rai and Sharma, 1995).

In several countries, including the UK, Canada and the USA, the process of

catchment or watershed planning has been introduced. Catchment management plans are designed to cover a catchment of a river and its tributaries and any associated ground water flows. Catchment management plans are designed to be strategic in approach and to take into account regional and national policies and all activities likely to have an impact on the watercourse. As a result of the plan the main polluting sources may be identified and solutions agreed which can be achieved with available resources and to a time scale agreed by all concerned.

to have an impact on the watercourse.

7.0 CONCLUSION

Non-point source pollution from agricultural activities is a world-wide problem, as it has been responsible for contamination of surface water as well as ground water. The magnitude of the problem is a complex function of many physical, chemical and biological interactions in relation to soil type, management practices and climatic conditions. As progress has been made in reducing pollutant loading from point sources, the relative importance of non-point sources has increased. Such sources are likely to be even more critical in developing countries including India, where agriculture and rural habitats are still dominant. A number of special features of the Indian scene need to be considered to tackle the problem of non-point source pollution. These include: (i) extremely varying rainfall and stream flow pattern; (ii) still largely traditional agricultural practices with average application of fertilizers and pesticides and significant areas under farming or only marginal irrigation; (iii) a very large cattle population, with agriculture almost always linked with animal husbandry; and (iv) a culture of living close to the river with dominating instream uses of bathing, washing, cattle wading, waste disposal, etc. and large scale floodplain farming. The review of literature clearly indicates the need to address the problems of non-point source pollution and to manage it as carefully as point source of pollution. Catchment management plans may be designed to cover catchments of different river systems and their tributaries and associated ground water flows. The plans should be strategic in approach and should take into account regional and national policies and all activities likely to have an impact on the watercourse.

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DIRECTOR

K S RAMASASTRI

COORDINATOR

K K S BHATIA

DIVISIONAL HEAD

C K JAIN

STUDY GROUP

C K JAIN, Sc. 'E1'

IMRAN ALI, Sc. 'B'

SUPPORTING STAFF

BABITA SHARMA, JRA

BEENA PRASHAD, JRA