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NUTRIENT, BACTERIAL, AND VIRUS CONTROL AS RELATED TO GROUND-WATER CONTAMINATION

UNITED STATES · ENVIRONMENTAL PROTECTION AGENCY

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NUTRIENT, BACTERIAL, AND VIRUS CONTROL AS RELATED TO GROUND-WATER CONTAMINATION

by

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate, and management of pollutants in ground water; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective, and provide adequate protection for the American public.

William C. Galegar
Director

ABSTRACT

A general introduction provides something of the history of ground-water, its present use, and the means by which it can become contaminated. A priority listing of sources of ground-water contamination is presented for four geographical areas of the United States.

Phosphorus is discussed in terms of its fate in soil systems. The fate of organic and inorganic nitrogen compounds is also discussed giving consideration to sorption and biological utilization and degradation. Criteria important to the survival and transport of bacteria and viruses is presented along with information concerning indicator organisms in the subsurface environment.

CONTENTS

ACKNOWLEDGMENT

The need for this report was conceived by Mr. Edmond P. Lomasney, Regional Representative, Office of Research & Development, EPA Region IV, Atlanta, Georgia. He guided its development to conform with the needs of that Region.

Since its original preparation in December 1974, this report has been widely accepted and acclaimed, as can be shown by the continued and increasing requests for copies. The Robert S. Kerr Environmental Research Laboratory acknowledges with appreciation such favorable response which has resulted in this publication of "Nutrient, Bacterial, and Virus Control as Related to Ground-Water Contamination."

INTRODUCTION

GENERAL

For those associated with the development and protection of ground water, the most worrisome problem has traditionally been a lack of knowledge on the part of those outside their fraternity. This is exemplified in understanding the movement and fate of nutrients, bacteria, and viruses in the subsurface environment.

As early as the 17th century, John Ray, the English naturalist, and René Descartes, a French mathematician and philosopher, made astoundingly accurate observations concerning the mysterious movement of underground water. In 1856 Henry Darcy established a mathematical base for the laminar flow of ground water in its porous environment.

Yet, in 1861 an Ohio court ruled, "Because the existence, origin, movement and course of such waters, and the causes which govern and direct their movement are so secret, occult and concealed that an attempt to administer any set of legal rules in respect to them would be, therefore, practically impossible."

In more recent years there has been an increasing awareness of the value of underground water in terms of the Nation's water resources and the importance of protecting these waters from contamination.

GROUND-WATER USE

Estimates vary but it is certain that this Country's recoverable ground water exceeds all surface sources by something in the neighborhood of one order of magnitude. Approximately 20 percent of the total national water demands are met by ground water. It accounts for more than 85 percent of the public water supply in several States and furnishes the total or partial water supply for over 30 of the Nation's 100 largest cities. It is estimated that more than 50 percent of the national population and more than 95 percent of the rural population receive their drinking water from ground-water resources.

GROUND-WATER POLLUTION

The implication of allowing ground-water resources to become polluted cannot be overstated. Air pollution has a residence time usually measured in hours, while in streams and rivers it is considered in terms of days. Even in surface reservoirs where pollution residence is measured in months, the implications fall far short of ground-water reservoirs where pollutants are likely to remain for decades or perhaps centuries. Consequently, the restoration of a contaminated ground-water resource is lengthy and expensive at best and difficult, if not impossible, at worst.

The very core of understanding the fate of pollutants in the sursurface environment is a complete understanding of the subsurface environment as a pollution receptor. This environment is a horrendously complex area in which the geologic matrix varies greatly in both the vertical and horizontal directions. In this zone there exists tremendous surface areas available for the sorption of pollutional parameters. These surfaces provide long retention periods during which time many physical, chemical, and biochemical alterations may take place in an environment where nutrients, moisture, temperature, pH, oxidation-reduction potential, and the numbers and species of biological life vary markedly within only short distances. The dilemma is compounded with the realization that the parent pollutant as well as its myriad of degradation products must be accounted for in their movement through this complex environment.

Contamination of ground water rarely occurs in a dramatic fashion. Therefore, continuous monitoring near a suspected source of contamination can produce a false sense of security while, in fact, the clandestine movement of pollutants is relentlessly proceeding. The diffuse and diverse nature of ground-water pollution further compounds the problems of control and abatement.

There are three basic mechanisms by which ground water can become contaminated. The first occurs only after pollutants have traversed the soil-vegetation matrix overlying and providing a measure of protection for subsurface waters. The second can occur when pollutants are directly introduced to ground water, as through well disposal or construction of waste disposal facilities (landfills, septic tank laterals, lagoons, etc.), within the water table itself. The third results from hydraulic or chemical alterations which allow polluting substances to move within or between aquifers.

Four reports have been completed (1, 2, 3, 4) which, among other things, presented by priority the major ground-water pollution problems within those parts of the Country covered. Table 1 presents the ten most prevalent problems as excerpted from those reports.

It can be seen from Table 1 that many of the most prevalent ground-water pollution problems portend the addition of nutrients, bacteria, and viruses to ground-water supplies. These are the pollutional parameters with which this report will specifically deal.

Table 1. PRIORITY SOURCES OF GROUND-WATER POLLUTION

	Southwest	South Central	Northeast	Northwest
1.	Natural Leaching	Natural Pollution	Septic Tanks and Cesspools	Septic Systems
2.	Irrigation Return Flow	Oil Field Brine	Buried Pipelines and Storage Tanks	Sewage Treatment Plant Discharges
3.	Sea Water Encroachment	Well Construction	Highway Deicing Salts	Irrigation Return Flow
4.	Solid Wastes	Overpumping	Landfills	Dry Land Farming
5.	Disposal of Oil Field Brines	Irrigation Return Flow	Surface Impoundments	Abandoned Oil Wells and Test Wells
6.	Animal Wastes	Land Application of Wastes	Spills and Surface Discharges	Brine Injection
7.	Accidental Spills--Hazardous Materials	Solid Wastes	Mining Activity	Disposal Wells
8.	Water from Fault Zones and Volcanic Origin	Evapotranspiration from Native Vegetation	Petroleum Exploration and Development	Surface Impoundments
9.	Evapotranspiration from Native Vegetation	Animal Wastes	Salt Water Intrusion	Mine Drainage and Mine Tailings
10.	Injection Wells for Waste Disposal	Waste Lagoons	River Infiltration	Urban and Industrial Landfills

NUTRIENTS IN GROUND WATER

For purposes of this report, phosphorus and the compounds of nitrogen will be used to describe categorically the potential of ground-water contamination by nutrients. A dissertation covering all of the materials that might serve as a nutrient to all forms of life would be quite beyond the scope of this writing. Nevertheless, phosphorus and nitrogen serve well to describe the fate of such substances in the subsurface due to their diverse behavior in this environment.

PHOSPHORUS

The fate of phosphorus in the subsurface environment is dependent upon two factors. The first is concerned with the residual phosphorus concentration in the soil solution which is controlled by the solubility of naturally-occurring phosphate minerals. The second factor is the soil's capacity to sorb phosphorus and the kinetics of this reaction. Generally, phosphorus compounds entering the subsurface environment do not present a great threat to ground-water quality. At least this could not be considered a high priority in the protection of ground-water quality.

In the presence of iron, aluminum, manganese, and calcium cations phosphorus compounds become relatively insoluble mineral components of the soil matrix. These reactions are dependent upon a number of factors among which pH is one of the most important in the subsurface environment. Figure 1 (5) provides a qualitative description of the fate of phosphorus compounds in soils versus pH. With some knowledge of the type of soil encountered and pH, it is possible to make some judgment as to the fate of phosphorus in this environment. Two additional factors must be considered when phosphorus compounds are introduced to the soils. There must be adequate time for these reactions to take place, and care must be taken that the sorptive capacity of the soil is not exceeded. In a great many cases these limitations should not present particular difficulties with respect to ground-water contamination. There are, however, circumstances where consideration should be given to assure that adequate soil types and depths are available to provide sufficient time and sorptive capacity.

There are cases where impermeable rocks lie near the surface with very thin soil cover. The application of phosphorus-containing wastes in these types of geology could result in the contamination of nearby streams. Fractured rocks under similar conditions could allow phosphorus compounds to travel considerable distances in the ground water to discharge to surface waters or to reach water supply wells.

The ability of soils to sorb phosphorus is often measured in terms of the equilibrium isotherms of Langmuir or Freundlich (6). Although these equations

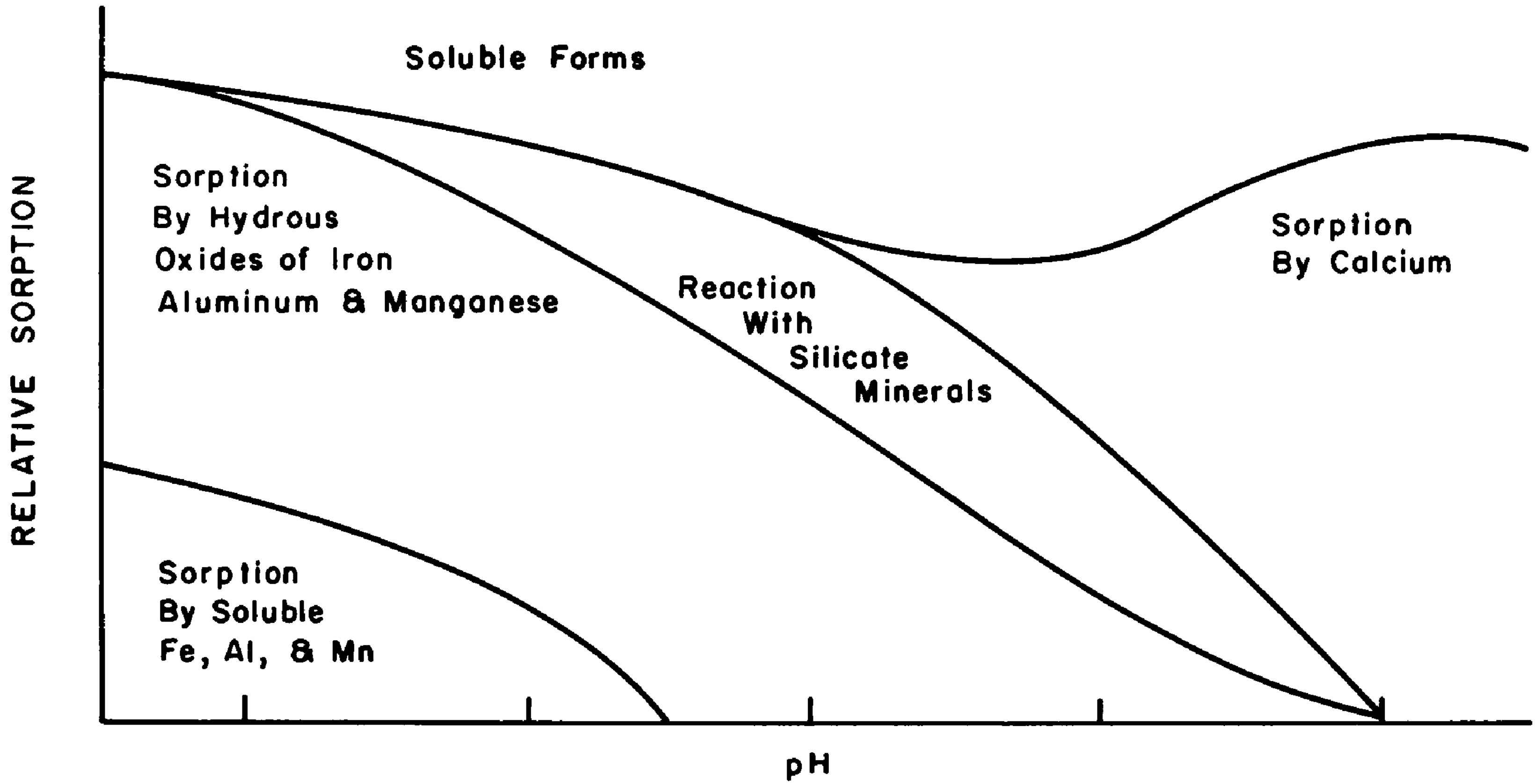

Figure 1: Fate of phosphorus compounds in soils.

assume that equilibrium is reached instantaneously, they can be helpful for many purposes. Non-equilibrium models (7) may be necessary when considering the long-term sorptive capacity of soils in large projects such as the application of wastes to the soil by spray irrigation or soil infiltration.

NITROGEN

Many sources of potential ground-water contamination contain organic and inorganic forms of nitrogen. It is generally believed that the organic fraction is bound either by sorption on the soil matrix or is incorporated in the cellular material of the resident biological community. Of course, these are kinetic reactions wherein microbial utilization, sorption, and degradation are continuing processes until eventual stabilization is reached.

These are extremely complex reactions which are further complicated by being in an environment which is itself complex. The subsurface environment changes radically within only short distances either vertically or horizontally. These changes in the soil matrix, its moisture content, the availability of nutrient material, oxygen, and the numbers and species of biological life probably keep organic compounds and their degradation products in a continual and lethargic state of flux.

There has been little research concerning the movement of organic nitrogen compounds in the subsurface environment. It can only be postulated that if these compounds or their products of degradation do move to great extents through the unsaturated zone such movement would likely be very slow. Once they have reached the saturated zone or water table their potential to contaminate wells or other points of discharge would be entirely speculative.

Most concern and, therefore, most research on the fate of nitrogen compounds in the subsurface environment is directed toward nitrate and nitrite ions. Usually this concern is associated with methemoglobinemia in infants and ruminants. In addition, there is evidence that high nitrate water can cause chemical diarrhea in humans and a number of maladies in livestock, including thyroid problems, rickets, enteritis, arthritis, and general poor health. That nitrate and particularly nitrite might react in the human stomach with secondary amines (from cooked food) to form nitrosamines, some of which are highly carcinogenic, is a possibility currently under investigation by various research groups.

An abundance of recent literature suggests that the nitrate problem in ground water is more widespread than was previously noted. As might be expected, many reports of local contamination have been related to septic tanks, irrigation practices, animal feedlots, and the land disposal of wastes, only to name a few. There have also been reports of nitrate contamination well over 100 mg/l in remote pasture areas where they could not be attributed to the activities of man. The most probable source of this natural nitrate is the degradation of vegetation accompanied by climatic and land use patterns which allow its concentration below the normal root zone.

In many instances the presence or absence of ground-water nitrates is paradoxical. Nitrates can be found where least expected and be in low concentrations or missing in areas where they would seem most likely to exist in high quantities. As mentioned above, very high natural concentrations can be found if the correct combination of climatic and land use patterns exists (8). Organic nitrogen may be converted by microbial processes to ammonia, which can be lost to the atmosphere by vaporization, retained by the soil, or oxidized, principally by chemoautotrophic bacteria, to nitrite and finally nitrate. The oxidative process may be essentially reversed under anaerobic conditions by facultative and obligately anaerobic chemoorganotrophic bacteria, provided nutrients and organic matter sufficient for the matabolic activities of these microbes are present. This is called denitrification and results in the conversion of nitrate to nitrogen gas which usually finds its way to the atmosphere.

Although denitrification provides a means for nitrate removal and has been used as such for surface waters, it is not presently known if this is a feasible technique for in situ ground water. Those cases where nitrate has been reduced in ground water have resulted more from good fortune rather than a planned control program.

Control measures are associated in operations where waste is applied to the land. Spray irrigation, for example, is based on the premise that the nutrient uptake by plants will be efficient under a proper hydraulic and nutrient loading, generally in the neighborhood of two inches per week during the growing season. Soil infiltration systems count on denitrification by loadings sufficient to create an anaerobic environment within the soil matrix. These loadings are about 2-3 feet per week with proper rest periods between applications to prevent biological growths from plugging the soil. The proper use of septic tank systems must rely on an installation density low enough to limit the amount of nitrates entering ground water. Work is under way now at Texas A&M to determine the allowable septic tank density for various geologic conditions.

Once an aquifer is contaminated only dilution, proper aquifer selection, or well construction can be used with assurance to control the concentration of nitrates in drinking water. Although nitrates can be removed from wastewater by algae ponds, ion exchange, ammonia stripping, microbial denitrification, and electrodialysis, these techniques are generally not feasible in many instances. The prevention of ground-water contamination would seem to be the most economical course. The most interesting and promising new technology for identifying the source of nitrate contamination makes use of the stable isotope ratios of nitrogen. The technique has been used to differentiate between natural and several man-made sources of nitrate contamination in ground water.

BACTERIA AND VIRUSES

The pollutional potential of bacteria and viruses in ground water is essentially equatable to their time of survival and the distances they might traverse during this time. The time of survival and the distance traveled is dependent on the organisms' abilities to overcome various environmental obstacles.

Some factors affecting the survival of bacteria and viruses in surface aquatic environments are relatively unimportant in soil and ground waters.

Bacteria and viruses are generally tolerate of the pH, temperature, and osmotic conditions existing in soil and non-saline ground-water aquifers.

Other factors are important, however. The survival of bacteria is enhanced by increased soil moisture and organic matter which can serve as a food source.

The survival of bacteria can be altered by predators such as protozoa. Some soil organisms produce antibiotics such as actinomycin and streptomycin which kill susceptible bacteria. The action of bacteriophages on bacteria in water and soil reduce the survival time of susceptible bacteria.

As in other environments, the ability of different organisms to survive in ground water will vary. Coliforms were chosen as indicators of fecal pollution in surface waters because of their ability to survive longer than most enteric pathogens. However, some preliminary studies indicate that the lack of demonstrable coliform levels in ground waters may not preclude the presence of pathogens, especially viruses.

The removal of bacteria and viruses by passage through soil is now thought to be primarily due to adsorption onto the soil particles, as well as physical removal by filtration.

Bacteria and viruses vary greatly in size and shape. This variance obviously affects their mobility in the sense of their physical filterability. Figure 2 provides a graphical comparison of several microorganisms ranging from an amoeba and bacterial to the poliomyelitis virus, a size differential of over three orders of magnitude.

In highly fractured limestone or basaltic geology, it is conceivable that many microorganisms could travel great distances provided they were in an environment conducive to their survival. In consolidated sands only the smaller viruses could be expected to travel any appreciable distance without being physically filtered.

The factors affecting adsorption by soils of bacteria and viruses are not very well understood. The type of soil is important--a soil such as clay with a large surface area per unit of volume being best.

Bacteria and viruses may survive for long periods after being adsorbed. This is potentially important since the adsorption may be reversible.

Generally, it has been assumed that within reasonable distances microorganisms will be removed from waters percolating or moving through consolidated or unconsolidated media such as sands, loams, or clays, but the validity of this assumption requires further investigation, particularly in the case of viruses. In fractured rocks both bacteria and viruses may travel for great distances.

Although certain speculations have been made here, there has not been a sufficient amount of knowledge accumulated on the survival of bacteria and

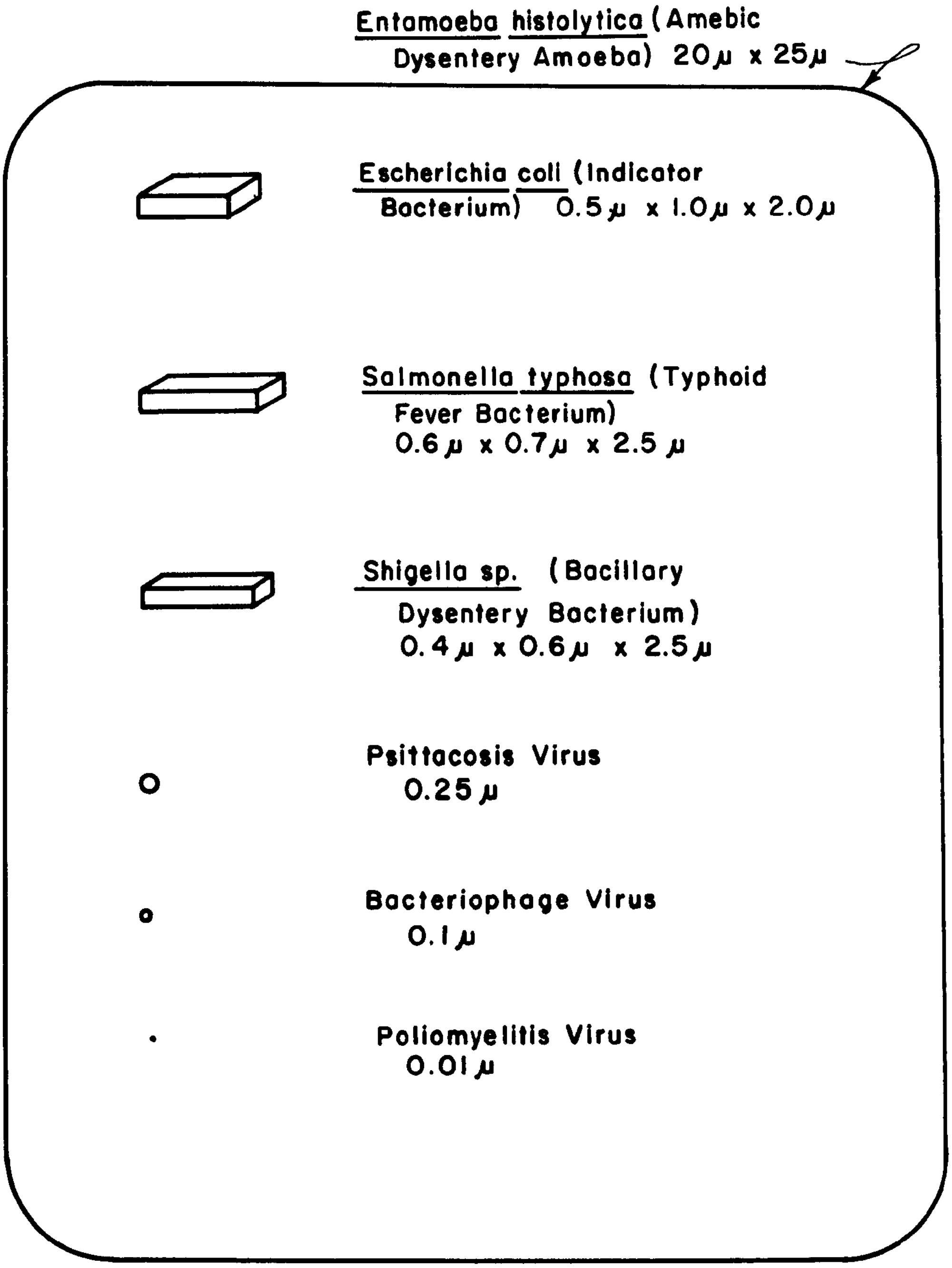

Figure 2. Size comparison of microorganisms.

particularly viruses in ground water. Increased stresses on this environment such as the application of wastes to the land and lagoons and landfills of one nature or another will undoubtedly require additional knowledge now or in the near future.

SOURCES OF EXPERTISE

The following are offered as direct sources of information for the subjects contained herein. They are not suggested as the sole source or necessarily the world's leading authorities. They are, however, researchers working in the areas described who possess the current state-of-knowledge on the subjects themselves and who through their associations can provide additional references which should provide sufficient information in answer to the most detailed questions.

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16. ABSTRACT

A general introduction provides something of the history of ground-water, its present use, and the means by which it can become contaminated. A priority listing of sources of ground-water contamination is presented for four geographical areas of the United States.

Phosphorus is discussed in terms of its fate in soil systems. The fate of organic and inorganic nitrogen compounds is also discussed giving consideration to sorption and biological utilization and degradation. Criteria important to the survival and transport of bacteria and viruses is presented along with information concerning indicator organisms in the subsurface environment.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Ground Water, Pollution, Bacteria, Phosphorus inorganic compound, Viruses	Nutrients	13B

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