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ANALYSIS AND CONTROL OF NONPOINT NITRATE POLLUTION OF MUNICIPAL WATER SUPPLY SOURCES

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ABSTRACT

An exploratory study was carried out as a collaborative effort between IIASA and several external institutions. The study was aimed at generating a methodological outline of a multidisciplinary approach to the problem in order to provide practical prospects for dealing with nitrate pollution of water resources caused by agricultural activities. Main ideas of the methodological outline and a related Task Force Meeting are summarized.

NITRATE POLLUTION OF WATER RESOURCES: SOURCES AND CONTROL

The initial step in developing options for control of nonpoint nitrate pollution of municipal water supply sources is the analysis of the physical system to be controlled. The interactions of various components of the system, such as the water resources of a region, or the inputs and outputs of nitrogen to and from the water resources system, need to be identified. Then a control system can be outlined.

Nitrogen and Water Resources

When considering a regional water resource system, the amount of nitrate present in water supply abstraction is determined by the amount of nitrogen lost from the system as regional outflow. However, it is basically controlled by the various processes taking place in the nitrogen cycle, particularly by the interaction of water with the soil-plant system. Consequently, the system to be controlled has been divided into three generalized parts: surface water, groundwater, and the soil-plant system.

There is a tremendous variety of nitrogen sources in the environment contributing to water pollution. However, among the major sources of nitrogen to water supplies, chemical fertilizers are the dominant cause of the recent rapid increase in nitrate concentrations in water resources.

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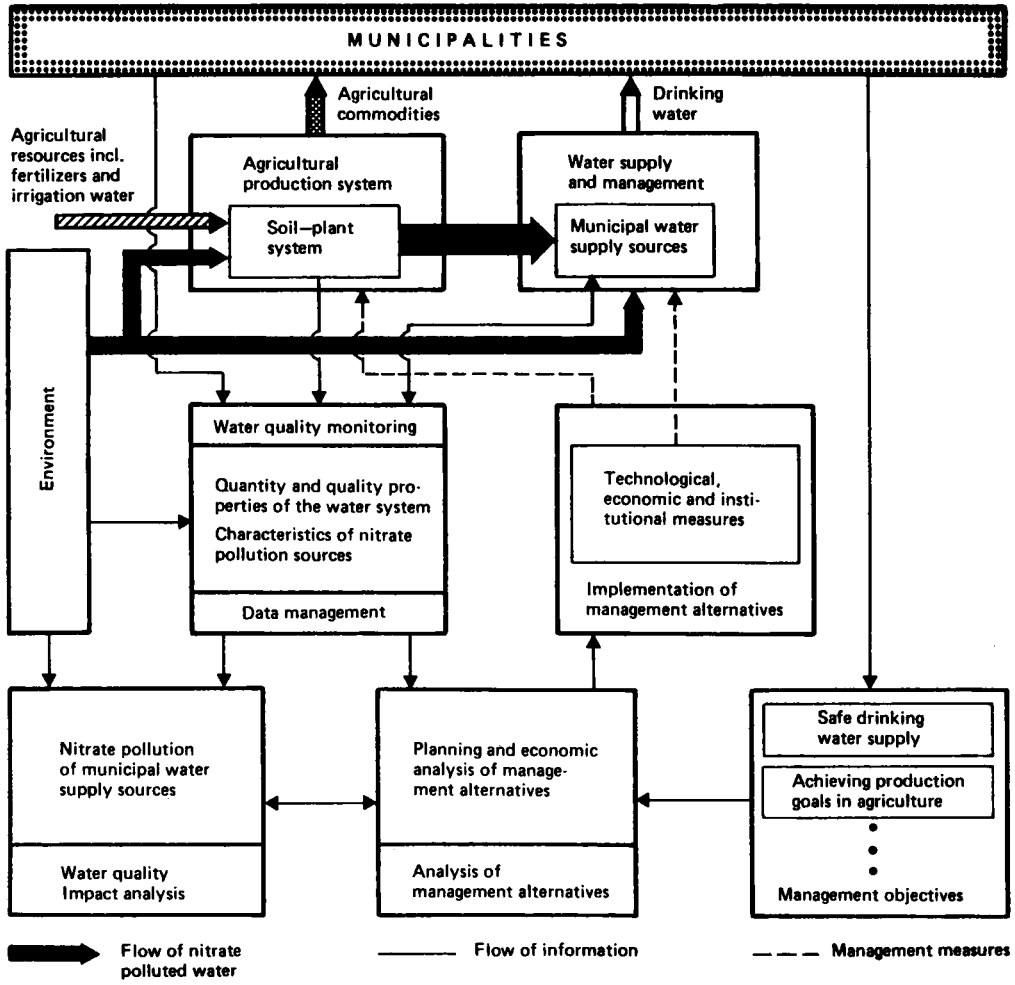
Although the contribution of agricultural fertilizers to water pollution depends very much on specific climatic, soil, and land use conditions in a region, there is abundant evidence confirming Golubev's (1980) findings. He concluded from a global survey that water pollution by nitrates is of more concern on a nationwide basis for countries of Western and Central Europe with dense populations and the highest levels of fertilizer application. However, the nitrate problem is also important on a regional basis in large countries, such as the USA and the USSR, which have lower fertilizer loads and are less densely populated.

The relative importance of water supply sources (rivers, lakes, reservoirs, and aquifers) generally depends on the natural conditions of a given region. It is important to note that for those countries identified as having a particularly high potential for nitrate pollution, groundwater resources play a key role in drinking water supply. Moreover, Golubev (1980) proved that the hazard of nitrate leaching is particularly high for these countries because of their general climatic features. Often, the effect of this natural situation is compounded by the use of supplemental irrigation, a factor which intensifies agricultural crop production.

Because of the above situation, groundwater resources deserve special attention, especially as there is an important difference between groundwater and surface water pollution and their respective management strategies. While the decision to purify river water is made with the knowledge that water quality can be restored relatively quickly after having removed the pollution source, the same does not apply to lakes, reservoirs, or particularly to aquifers where pollutants may be retained for decades or even centuries. Nevertheless, examination of the effects of fertilizer nitrate water pollution in a regional context usually requires a conjunctive consideration of the groundwater and surface water resources of a region.

Outline of a Control System

The physical system considered so far is now ready to be fit into a more general management system for the control of nitrate pollution in municipal water supply sources. As seen from the preceding analysis, the major concern in outlining such a system is controlling nonpoint pollution sources in agriculture, such as organic and inorganic fertilizer, with most importance given to the latter. Hence, the system must provide a framework for the analysis of the various factors affecting regional water resources management, considering the interests of the competing users of soils and waters. In order to understand how water supply and management is influenced by increasing nitrate concentrations in water resources and how to ensure a safe drinking water supply, management must link land use and water supply development. The framework for analysis carried out in the study therefore followed the concept of a decision making process based on the control system shown in the following Figure.



THE SYSTEM FOR CONTROL OF NONPOINT NITRATE POLLUTION OF MUNICIPAL WATER SUPPLY SOURCES

METHODS OF ANALYSIS

To answer the question of how water supply and management are influenced by increasing nitrate concentrations in water resources and how a safe drinking water supply can be ensured, requires coordinating goals of the agricultural production sector with public decisions regarding land use and water supply development, and the surface water and groundwater systems. Therefore, water pollution control management must be based on an effective planning procedure. Water quality monitoring, water quality impact modeling, and joint physical-economic modeling of management alternatives should form an integrated system of analysis. In order that strategic planning decisions for pollution control are taken in time, the analysis must meet the following information requirements:

- identification of the relative importance of nitrogen sources and those supply sources most at risk from nitrate pollution,
- predictions of likely future levels of nitrate concentration in supply sources,
- identification of implications of water supply development plans through assessment of the physical and economic effects of the chosen management alternatives.

The tools applied in the analytical process must be capable of matching both the ability of data to yield information with confidence and matching the expectations of the decision makers. Hence, the study did not mainly focus on methods for detailed analysis of the physical, chemical, and biological processes constituting the behavior of nitrogen in water resources. It was rather intended to show how such means as monitoring and modeling can support the decision making process in nitrate water pollution control management with particular reference to nonpoint source pollution.

As to groundwater quality, for example, the study revealed the need for implementing monitoring programs in a way which considers both ambient trend and source monitoring, but stresses the latter. In developing a monitoring strategy attention is to be paid to the two dimensions of monitoring, its purposes and activities. Purposes such as routine or special monitoring require carrying out coordinated activities such as network design, sample collection, laboratory analysis, data handling, and data analysis.

When aiming at monitoring in its broadest sense, an important part is played by mathematical analysis and modeling, which focus on the evaluation of the infiltration potential of nitrogen into soil as well as the mobility of nitrogen in the unsaturated zone and the attenuation of nitrate in the saturated zone of the groundwater systems. While there is a need for complex distributed parameter models of the advection-dispersion type in detailed studies of pollutant migration from point sources, there is also a need for simpler conceptual and operational nonpoint source pollution models for use in regional size problems. Lumped parameters have been successfully used in modeling nonpoint source pollution of

groundwater systems when spatially averaged concentration values are an appropriate output, as is often the case in planning and management.

From the viewpoint of resource economy and planning, it can be said that water pollution control must be coordinated with water resource development and land use planning. Integrated land use water quality modeling is needed for planning both optimal natural resource allocation in agriculture and nonpoint nitrate pollution control. Since the scope of such clearly needed analytical tools is usually not restricted to the farm level, but is concerned with the agricultural economy of river basins, the problem is dealt with at the level where policies are implemented.

TOPICS FOR FUTURE RESEARCH

Pollution of municipal water supplies by nitrogen compounds is and will remain to be a real world problem for the years to come. There are three topics of particular interest to future research:

1) The health hazard issue of nitrogen compounds in water and food
2) Agricultural activities as an important nitrogen pollution source
3) The "nitrogen problem" in municipal water supply and management.

The Health Hazard Issue

The exact nature of the human health problems are not yet well understood nor documented, as witnessed by the variation of standard limits set in national regulations. There is still the need for establishing consistent criteria for safe (low risk) limits of nitrogen compounds, in particular nitrates, in drinking water and food. More toxicological and/or epidemiological studies are needed to dispel uncertainties by accounting for such factors as size and susceptibility of population exposed, number of water systems involved, relative dose in water compared with total burden, positive response of nitrate in carcinogenic, teratogenic, and mutagenic tests, etc.

Agriculture

There is the need for documenting the sources of nitrogen compounds from agriculture under various conditions of agricultural production (climate, soil type, cropping pattern, fertilizer type and technology of application, etc.). The aim should be to derive cause-effect relationships between agricultural practices and the generation of nitrogen compounds leaving the agricultural system. Hence, technological changes in agricultural production need to be evaluated in terms of fertilizer use and environmental impacts. Based on this, policies to be used to encourage better agricultural management practices have to be identified and evaluated in terms of tradeoffs between agricultural production and pollution control.

Water Supply and Management

To deal with the "nitrogen problem" from the point of view of water supply and management requires taking into account all sources of nitrogen (agriculture, industry, households, atmosphere, etc.) as well as all types of nitrogen compounds (organic nitrogen, ammonia, nitrite, nitrate) contributing to water pollution. Because of the variety of municipal water supply sources (rivers, lakes, reservoirs, aquifers) the "nitrogen problem" therefore becomes a multiple pollution source-constituent-resource problem. Since it can only be controlled by conjunctive water resource management, sufficient attention must be paid to pollution of groundwater which is of the greatest long-term concern.

Any pollution changes in time and space, as well as the total nitrogen balance need to be understood, i.e., there is a need to analyze water quality data in different settings to document trends and eventually correlate trends with pollution activities. After having proved the standard limits to be likely exceeded, water treatment technologies (structural, nonstructural) have to be identified and evaluated. Policies for implementing them need to be designed through analyzing the tradeoffs between water treatment technologies and pollution source controls.

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