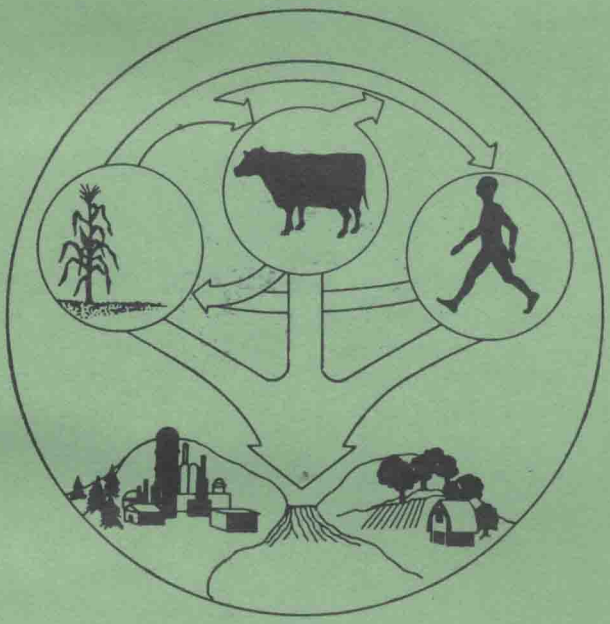
NITROGEN AND PHOSPHORUS

Food Production – Waste – The Environment



NITROGEN AND PHOSPHORUS
Food Production, Waste and the Environment

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（内部交流）

A Report of an Interdisciplinary Research Project

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氮和磷

«粮食生产、废物和环境»

本书是由各方面协作进行的综合性研究项目的总结。以氮和磷为中心，以纽约州中部水域为对象，经过四年研究取得的资料。探讨了氮和磷在土壤中、河流中及湖泊中的动态，以及这些养分在耕作时的管理与保肥、使用合成肥料与粪肥的经济问题等。书中有数据、有分析、有结论、文字清晰。读者对象：农业、土肥、环保、水生生物科学工作者。

目次如下：①环境中的氮和磷，②湖泊对磷的反应，③人类活动对福尔河中磷与硝酸盐转移的影响，④土地上氮和磷的流动，⑤农业生产中降低磷损失的经济分析，⑥管理动物废料以控制养分，⑦三个水域的社会研究，⑧氮和磷的估量与管理。书后有附录和索引。

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PREFACE

> "Once the raindrop touches the surface of the earth or its appurtenances—such as rocks, trees, roofs, fences, haystacks, animals—it meets, almost immediately, abundant dust or dirt, including matter organic and inorganic, soluble and insoluble, living and lifeless. As it rolls over the dusty rock alone or as a trickling stream, it naturally dissolves some substances and sweeps on others mechanically—its departure from purity increasing as it proceeds."
>
> Sedgwicks' *Principles of Sanitary Science and Public Health*, 1935

Man has always managed his surroundings for his own ends. In the past these have often been immediate rather than long-term. As a result, excessive exploitation of resources has sometimes been accompanied by the production of waste for which disposal was inadequate. Attitudes are now changing, and the need to conserve vital resources and the desire to protect the environment are increasingly expressed.

More stringent policies are now being applied to easily identified causes of environmental deterioration; industry, mining, and urbanization. Furthermore, a more knowledgeable appreciation of pollution and its causes has led to control policies that now include agriculture. In this respect, the aphorism of an early pioneer in the subject, "the rain to the river and the sewage to the soil" is an oversimplification of today's problems. Rain-induced flows of water whether as runoff from urban or rural areas may themselves become contaminated. Furthermore sewage or manure disposed on land can eventually enrich natural waters through leaching or runoff. This, for the eventual uses of such waters, may constitute pollution. Such less discernible non-point sources come within the province of the Federal Water Pollution Control Amendment Act of 1972. This legislation may place agriculture under significant and possibly severe constraints.

What is important for farming, if the requirements of the new

legislation are to be realistically met, is that these effects must be quantified to provide a basis for proper assessment and control. In some cases, such as in food processing plants, or intensive animal units, the wastes are discharged at a point and are therefore more easily measured. But, in general, material "lost" from farming is diffuse in origin and its measurement is extremely difficult.

Coupled with the desire to preserve the environment is the objective of maximizing the efficiency of agricultural production. Given the current high costs of food and its world-wide scarcity, aims to increase production may differ from, and even be incompatible with, environmental objectives. Unfortunately the flow of water over and through the soil may remove large amounts of nutrients in soluble or particulate form. Thus the enrichment of natural waters represents a loss in potential productivity to the farmer. On the other hand, control measures may themselves be expensive and increase the cost of food production.

The studies described in this report deal with the interwoven issues of maintaining agricultural efficiency and protecting the environment. This was done by considering especially the substances nitrogen and phosphorus, both of primary economic and environmental importance. Sources of nitrogen and phosphorus found in streams and lakes have been identified. Estimates of the quantities involved have been made and their effects on lakes have been assessed with regard to management alternatives. Management of manure from treatment to direct disposal on land, and the application of fertilizer have been studied. The economic consequences of applying controls to reduce nutrient losses from farm land have also been estimated. Finally, social issues, such as public attitudes toward pollution and the efficacy of institutions responding to such attitudes, have been examined in a comprehensive sociological investigation.

To confine the investigations within reasonable limits, the group chose to primarily consider specific problems in central New York. However, many of the conclusions, such as the significance of sources of nitrogen and phosphorus, their effects, the management of animal wastes, and the economic consequences of control, have broader significance, as emphasized in Chapter 8.

To fully deal with these issues requires thorough studies of many aspects of the watershed: topography, climate, nature of the soils, geology, plant characteristics, hydrology, and the inhabitants and their activities. All these subsume the physical, chemical, bio-

logical, economic, social and engineering components of processes which are fundamental to understanding and managing the flows of nitrogen and phosphorus. Unfortunately, it is not advisable to simplify investigation by considering problems in complete isolation. Admonition of this difficulty is given by the public health inspector—perhaps apocryphal—who was quite unmoved by the rustic charms of a village that boasted neither proper sanitation nor water supply excepting a highly favored well. Upon his directive, a complete sewage system was installed, eliminating all the primitive sanitary arrangements. Unfortunately, it also eliminated the well which dried up and never yielded another drop.

Considerable efforts were made in the investigation described in this report to consider all the major ramifications of nutrient flows in agricultural watersheds. To this end, the members of the research team represented several academic disciplines—agricultural economics, agricultural engineering, agronomy, limnology, sociology, and systems analysis, all from the College of Agriculture and Life Sciences at Cornell University. The cooperative nature of this interdisciplinary venture was ambitious. As described in the Postscript to this report, occasional disagreements and different viewpoints between disciplines proved to be a sharp catalyst from which the whole group, and the investigators themselves, benefited.

This report describes a cooperative investigation and in this sense, it is a group report. In a joint effort such as this, it is difficult to properly and fairly acknowledge credit for all the work done. Throughout the investigations there was a vigorous exchange of ideas and suggestions. Also each chapter was reviewed in detail by the group as it progressed through various stages. However, for reference, major contributors to individual parts of the report are indicated at the end of each chapter.

The report has been written for both the interested layman and the scientific community. Problems discussed are also of current interest to administrators and policy makers responsible for the management of our natural resources.

To achieve readability and clarity, a serious effort has been made to clarify terms used and to ensure consistency throughout the report. To this end, a glossary is provided at the end of the report in addition to definitions within the main text. There are difficulties. A topical subject such as the environment, in which there is popular as well as technical interest, rapidly acquires a polysyllabic vocabulary liable to abuse. Such usage is illustrated by

Sir Bruce Fraser who describes a small girl pointing to her baby brother and shouting, "Mummy! Johnny's polluted his environment again" (Fraser, 1973).

The problem is not made easier when there is scientific confusion over the terms and their meaning. An important example is the term "biologically available phosphorus," which defines that fraction of total phosphorus most available to plants. Considerable care was taken in this study to distinguish this fraction from other forms of phosphorus discussed in the literature. Unfortunately, the group cannot claim to have fully resolved the ambiguity subsumed in the word phosphorus.

As will be clear from the report, it is easier to raise questions than to give their answers. Much work remains to be done. It is hoped that the following chapters will provoke and stimulate interest in the problems discussed. The group would welcome correspondence on the report or matters arising from it. Where questions concern an individual chapter, it is suggested that correspondents write to the principal author of the chapter concerned.

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CONTENTS

1

Nitrogen and Phosphorus in the Environment

Chapter 1

NITROGEN AND PHOSPHORUS IN THE ENVIRONMENT

Now from all parts of swelling kennels flow
And bear their trophies with them as they go,
Filth of all hues and odors seem to tell
What streets they sailed from by their sights and smell;
Sweepings from butchers' stalls, dung, guts and blood,
Drowned puppies, stinking sprats, all drenched in mud,
Dead cats and turnip tops come tumbling down the flood.

—Jonathan Swift (1667–1745), describing effects of a heavy shower on the streets of London.

INTRODUCTION

The investigations described in this book have two main themes. The first is to assess the effects of man's activities, especially in rural areas, on the circulation of nitrogen and phosphorus. Included in this assessment are economic and sociological factors related to management and policy. The second theme is to consider management of nitrogen and phosphorus which maintains desired levels of agricultural production without degrading the environment.

These themes reflect two concerns of primary importance for modern man: to conserve resources and to maintain or improve the quality of the environment. In the United States, preservation and improvement of the environment has become a major national goal, as embodied in the 1972 Amendments to the Federal Water Pollution Control Act, PL 92–500.

This chapter introduces the investigations in this book by briefly describing a) why the problems investigated are important, b) what the causes and effects of the problems appear to be, and finally c) how the investigators approached the study of these problems.

The nitrogen and phosphorus contained in fertilizers and animal

and human wastes are actual or potential resources. However, as described in later chapters, the use of fertilizer under certain conditions can adversely affect the quality of ground and surface waters. Similarly, the disposal of organic wastes may affect the environment by degrading the quality of water resources, or that of the air (by the release of ammonia and other odor-producing gases). Water and air are both resources, and in this sense, preservation of the environment and conservation of resources are one.

The use of chemical fertilizers is a relatively recent development, but as Klein (1962) states, the "disposal of human wastes and other organic refuse without creating a nuisance has been a problem since time immemorial." Some ancient societies were strict in their sanitary codes, as illustrated by the Mosaic injunction to "turn back and cover that which cometh from thee" in the soil (Deut. 23:13). Given sufficient available land, disposal in this manner is potentially useful. If plant residues, and the wastes from animals and humans consuming the plants, are all returned to the original soil, then a closed cycle is preserved and nutrient additions are unnecessary since none are lost.

The use of excrement to increase the growth of plants has a long history. Sir John Russell (1971) cites a 12th century Moor living in Seville who gave explicit directions for the making of compost from organic waste. The Moor recommended the addition of blood, especially human blood, for best results. Also, the Englishman Plot (1677) highly recommended "old rags" discarded by men and women which were "well sated with urinous salts contracted from the sweat and continued perspirations attending their bodies." Apparently farmers preferred garments discarded by the poor because of their greater perspirations. Farm workers were less enthusiastic because of the fear of smallpox. The Chinese, in particular, for centuries maintained high levels of soil fertility by using their wastes. William Hinton (1970) reported that in pre-revolutionary China, a farmer's most valued possession was the contents of his privy. Farm workers were required to use their master's privy while at work, and peasants were known to locate their privies near frequently travelled paths hopeful that passersby would leave "deposits."

In Western societies, this tradition was broken as man increasingly congregated in large cities. Contents of chamber pots were often simply hurled through upstairs windows to the obvious peril of persons in the street below. Following the industrial revolution, wastes were increasingly discharged into rivers, a process acceler-

ated by the installation of sewers in many cities in the 19th century. Outbreaks of waterborne diseases such as cholera and typhoid in major cities were frequent, and development of methods of water and wastewater treatment were primarily intended to control such diseases.

As wastewater treatment plants were more widely installed in the first half of the 20th century, and epidemics became less frequent, more attention was given to the problem of organic pollution in rivers. Since World War II, the adoption of biological treatment in sewage works has become general in the United States. This reduces easily degradable organic substances to inorganic compounds before discharge into surface waters. These compounds may serve as nutrients, and as Sawyer (1965) states, as a "result, aquatic areas have often become fertilized beyond desirable levels."

This trend in the management of wastewater has promoted several questions over the past two decades. First, there is the shift in concern from organic to inorganic substances in surface waters. Some justification for this is given by a U.S. Environmental Protection Agency (1974) study of trends in the quality of the nation's major waterways. The study showed that whereas the waterways are improving with respect to coliform bacteria, oxygen demand and dissolved oxygen, there were general increases in the recorded concentrations of nitrate-nitrogen and total phosphorus.

Second, the reduction in gross pollution from industrial and domestic wastes has transferred attention from substances in point source discharges to those originating from non-point sources such as farm land. In 1967, a Task Group sponsored by the American Water Works Association reported that "the quantity of nitrogen and phosphorus in rural runoff appears to be greater than that contributed in domestic wastes. Agricultural runoff is the greatest single contributor of nitrogen and phosphorus to water supplies" (Task Group Report, 1967). Estimates of contributions of nutrients from various sources, provided by the Task Group, indicate that up to about 60% of the nitrogen and 40% of the phosphorus in water supplies might originate from agricultural land. Other published evidence has suggested that agriculture is a major source of contaminants in rivers. For example, the U.S. Department of Agriculture (1955) estimated that approximately 1 billion tons of sediment were transported within the United States to sea every year, a large part of which was attributed to agriculture.

A third question concerns the effect of the nutrients on receiving waters. In a survey conducted by the Task Group cited above,

it was found that more than half the surface waters in the United States used as water supplies were apparently affected by problems caused by excess nutrients (Task Group Report, 1966). The enrichment of these waters produced unwanted algae and state health departments indicated that 43% of impounded water supplies were sufficiently affected to require the application of chemicals such as copper sulfate. In California, more than 95% of surface waters impounded for water supply were treated with algicidal chemicals as a matter of routine.

Fourth, another major issue is the very rapid increase in the use of phosphorus in detergents since World War II. It was estimated in 1967 that 13% of all manufactured phosphatic compounds were used as "builders" to improve the effectiveness of detergents (Task Force, 1967). As a result, the amount of phosphorus discharged in wastes to surface waters has approximately doubled. Since 1972, controls have been imposed on the use of phosphatic detergents in Canada and in some parts of the United States. Although it is premature to reliably assess the effects of such prohibitions, it is believed that the effect of reduction of this one source of phosphorus is potentially greater than that of any other single source of phosphorus in surface waters (Vallentyne, 1974).

Finally, a fifth question concerns the loss of resources that the discharge of nutrients to surface water represents and means for their conservation. For example, as Sawyer (1965) has argued, the "trend of man to live in urban rather than rural areas has caused a tremendous dislocation of phosphorus distribution within the environment. Because of the custom of using water as a carrier for human wastes much of the phosphorus, as well as other fertilizing elements removed from the soil, is transferred to rivers, streams and lakes."

As the magnitude of such losses has become more evident, so has the possibility of recovering part of the nutrients been considered. Apart from recovering nutrients during treatment, another technique to recover or at least reduce their loss is to apply the wastewater to land, rather than discharge it into rivers (Sullivan *et al.*, 1973). In a sense, it is foreseeable that management of wastewater intended to recycle nutrients would constitute a return to ancient methods in principle if not in practice.

The dual problems of conservation and water quality were central to the investigations described in this book. As will be outlined later, effects of inorganic forms of nitrogen and phosphorus on surface waters were quantified, sources of the nutrients were identi-