Proceedings of a Workshop on Water Quality and Land Use Activities, September 11 and 12, 1973, University of Guelph, Guelph, Ontario

International Joint Commission. International Reference Group on Great Lakes Pollution From Land Use Activities

J.D. Wiebe

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PROCEEDINGS
OF A WORKSHOP ON
WATER QUALITY
AND
LAND USE
ACTIVITIES

SEPTEMBER 11 AND 12, 1973
UNIVERSITY OF GUELPH,
GUELPH, ONTARIO

Sponsored by the
INTERNATIONAL REFERENCE GROUP ON GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES, A REFERENCE GROUP OF THE INTERNATIONAL JOINT COMMISSION.

J. D. WIEBE, EDITOR
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PREFACE

LAND USE AND WATER QUALITY

J.D. Wiebe

The determination of the governments of Canada and the United States of America to restore and enhance the Water Quality of the Great Lakes resulted in the signing of the Great Lakes Water Quality Agreement of 1972. Recognizing that non point sources contribute a substantial amount of the contaminants contributing to pollution of the Great Lakes, the Agreement calls upon the International Joint Commission to conduct a study on the pollution of the Great Lakes System from agriculture, forestry and other land uses.

In response to this reference, the International Joint Commission in November of 1972 established the International Reference Group on Pollution of the Great Lakes from Land Use Activities and charged the Group with the development and implementation of a study to answer the specific questions posed by the governments in their request to the Commission.

The Reference Group appointed by the Commission consists of 18 persons, 9 Canadian and 9 American. The Canadian contingent represents the Federal Departments of Environment and Agriculture and the Ontario Provincial Departments of Environment, Agriculture and Natural Resources. The United States members represent the U.S. Department of Agriculture, the U.S. Environmental Protection Agency and agencies from seven Basin states.

This workshop was organized with the intent of drawing upon the varied expertise and knowledge of scientists from a variety of disciplines in order to provide the Group with expert advice and to assist the Reference Group in the refinement of its study plan.

Thanks are extended to Guelph University for the provision of facilities, to Mr. E. Brubacker of the Ontario Ministry of Agriculture and Food for his assistance in the preparations for this workshop, to Mr. P. Chamut, Ms. P. Bonner, Mr. D. Brannen and staff of the IJC Great Lakes Regional Office for their assistance in the transcription and publication of the proceedings.
and to Mrs. H. Hetherington of the Environmental Quality Coordination Unit at the Canada Centre for Inland Waters for her aid in handling correspondence and in the typing of manuscripts.

Ed. Note

The discussion sections are edited versions of the proceedings and not necessarily verbatim accounts.
INTRODUCTION

Dr. M.G. Johnson
Canadian Co-Chairman

International Reference Group on Great Lakes Pollution from Land Use Activities

I would like to welcome you to this Workshop on Land Use and Water Quality and to thank not only the participants for having come but also the University of Guelph for providing these excellent facilities.

The purpose of this two day workshop is two-fold. First, the Land Use Activities Reference Group established by the International Joint Commission in late 1972, would like to learn more about the work and the findings of specialists in the field of land use-water quality relationships. Secondly, we are hopeful that the aims of the Reference Group, now engaged in the preparation of its detailed study plan, will be conveyed, in an informal way, to those of you on whom we are dependant for advice and direct assistance with the preparation and implementation of the plan. Our objective is to encourage this two-way flow of ideas in a workshop format of modest and manageable size. For that reason we had rather stringent guidelines on the attendance. We attempted to level off the attendance at sixty participants, and I think this will be achieved fairly closely.

It goes without saying that the particular tasks assigned to the Land Use Activities Reference Group encompass a much broader area of understanding than any one person possesses. This became apparent quite early in the deliberations of that group and we must give credit to Bill Marks of Michigan for first making the proposal for an event of this type. Therefore, the job over the next two days is to attempt to broaden our knowledge of the relationship between water quality and land use activities.

My job in the two day workshop is simply to introduce to you the four session chairman who will carry a half-day program each on the four topics which were selected from a list of several at the last meeting of the Land Use Activities Reference Group in Rochester. First I would like to introduce to you Dr. Bill Weingard, President of the University of Guelph. Dr. Weingard has been President here for seven years. He continues to teach metallurgy by offering a course to students in the School of Engineering. However, he is not an outsider to environmental studies. The University and
the Colleges within the University here, over the past several years, attempted
to assess the scope, the nature, and the form of their environmental studies
programs. Dr. Weingard has personally been in the front line of environmental
studies in that not too long ago he served as a committee member of the
Ontario Committee of Inquiry looking into the possible impact on the environ-
ment of a large fertilizer-producing plant in the estuary of the Grand River.
WELCOME

Dr. W. Weingard
President
University of Guelph

Good morning Ladies and Gentlemen. I know you are going to discuss an important topic, Water Quality and Land Use Activities. It is a complicated topic, and one about which we are not yet able to write down all the do’s and don’ts. This was brought home very clearly to me when, shortly after I arrived in Guelph as a metallurgical engineer, I was brought into the Provincial Committee of Inquiry on pollution in the Port Maitland area about which I knew very little. I knew what a cow looked like and I knew that soil was that stuff that you dug in your garden, and I knew what fertilizer was, but to walk into all this cold and suddenly find yourself a member of an Official Committee of Inquiry was a real jolt. Fortunately, however, most of the experts that we called were from the University of Guelph and so I got my training riding back and forth to the Committee hearings surrounded by Guelph faculty as they gave me a three week crash course on these matters. It built up a considerable interest and one that I don’t suppose I will ever lose. It sensitized me in my early days here to the significance of the problem. Approximately a year ago now, this University did what very few Universities have been capable of doing today, which was the setting down on paper of their aims and objectives, the function of the University, what they were going to specialize in, what their research was going to be about and so on. This document is more than the general platitudes that one can always take half an hour and write down. It is fairly specific and it’s a source of some pride to me that one of the things that this University will concentrate its resources in will be the environment. As Murray has said, many, many departments in this University are operating in these areas now and we intend to emphasize them even more. One of our problems is that we have so many people working on the environment that it is hard to organize it into a single concentrated task. It’s nice to have a little group working on the environment if you have only ten people at the University interested. But what you do when you have 350 faculty members interested, is quite another organizational problem. I’ve read the study plan to assess great lakes water quality as it may be affected by land use activities and it is a comprehensive plan; it is an important plan and I’m certainly glad it is an international one. In the Great Lakes we all know that only an
international approach is going to work. I hope that over the two days you evolve better understandings than we have now. I hope also that you enjoy the University of Guelph. I'm sorry that you aren't staying in our residence, but we happen to be full at the moment with a waiting list of a couple of hundred, but despite that, I hope you will enjoy some of the hospitality of the University. This is a University dedicated to both scholarship and to the public good, and one which is quite hardworking and sensitive, where everybody is pretty keen and where we all happen to like each other. That, in my experience, is pretty unusual in a University. I hope you feel some of that spirit while you are here and that we make you welcome. I wish you a successful two day workshop. Thank you.
SESSION 1

FATE OF PESTICIDES & FERTILIZERS APPLIED TO LAND AND CROPS

Chairman: Dr. R. R. Parizek, Professor of Geology, Pennsylvania State University
SESSION

FATE OF PESTICIDES APPLIED TO LAND AND CROPS

Chairman: Dr. R. F. Parker
Professor of Entomology, University of Wisconsin
FATE OF FERTILIZERS AND PESTICIDES
APPLIED TO CROP LAND

R.F. Holt

ABSTRACT

The bulk of the chemicals transported by water off agricultural land is attached to or is an integral part of the sediment. A small but significant portion, in terms of eutrophication, is dissolved in runoff water and an appreciable amount of the N and P comes from leaching of dessicated vegetation. Deep incorporation of fertilizers into the soil effectively prevents soluble nutrient losses in runoff water. Conservation practices that prevent or delay runoff from a watershed can increase ground water if low, and decrease surface runoff. Pesticide losses in runoff water are low but volatilization losses may be high.

1 Contribution from the North Central Region, Agricultural Research Service, USDA, Morris, Minn., in cooperation with the Minnesota Agricultural Experiment Station, St. Paul, Minn.

2 Soil Scientist, USDA, Morris, Minn. and Professor, University of Minnesota.
Our program at Morris, Minnesota, has been looking at the contribution of agricultural practices to the quality of runoff water for a number of years. I would like to present a general outline of what I consider to be the problems associated with water quality as influenced by agricultural practices with specific reference to fertilizers and pesticides.

A logical starting point for the discussion of water quality is the hydrologic cycle in which the water falls onto the land, runs off into streams, lakes and oceans and is evaporated back into the atmosphere to fall again. Problems arise primarily because some of the chemicals which create undesirable conditions in surface waters will track this hydrologic cycle only part way, while others may track the cycle completely but at a different rate than the water itself, thus resulting in an accumulation of chemicals at certain locations in the cycle. This is a natural process and leads to the formation of eutrophic waters through the accumulation of nutrients (primarily nitrogen and phosphorus) in lakes and streams. Subsequently, the well nourished waters support plant growth, and lakes in various stages of plant take-over are observable in forested as well as agricultural areas. The millions of acres of peat bogs throughout the northern United States and Southern Canada attest to this natural process. Bogs are a reservoir of nutrients held as an integral part of the vegetation. One might speculate that the formation of peat bogs represents a process which has been effectively removing nutrients from surface waters for ages.

Observation of lakes surrounded by agricultural land or under urban influence frequently shows evidence of accelerated nutrient build up. Many times this accumulation of nutrients can be traced to a specific source such as a sewage treatment plant or a livestock operation that drains directly into a lake. These sources are relatively easy to identify and can be rather simply (although sometimes expensively) controlled.

A major problem as yet not completely understood and for which there is no simple solution, involves the delivery of chemicals to surface waters from non point sources. Fertilizers and pesticides applied to the surface soil are vulnerable to loss with runoff and erosion from watersheds. We know that the bulk of the chemicals (nutrients and pesticides) carried off the land are associated with the solid particles (sediment). Man can and does influence the erosion from agricultural land.

Table 1 indicates the average annual soil loss from a Barnes loam soil in western Minnesota with a 6 percent slope that has been farmed up and down hill. Continuous corn will average about four times as much soil loss as a corn-oats-hay rotation. While these represent values obtained from small (13.3 by 72.6 ft) natural runoff plots, the relative potential for sediment delivery from agricultural lands is probably correct. Therefore, the use of a soil conserving rotation will reduce the soil loss and the delivery of nutrients associated with the soil.
Table 1

Eight-year average annual soil losses
(Barnes loam-6% slope)

<table>
<thead>
<tr>
<th>Cropping treatment</th>
<th>Soil loss Tons/A/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallow</td>
<td>17.5</td>
</tr>
<tr>
<td>Continuous corn</td>
<td>7.8</td>
</tr>
<tr>
<td>Rotation corn</td>
<td>3.4</td>
</tr>
<tr>
<td>Rotation oats</td>
<td>2.2</td>
</tr>
<tr>
<td>Rotation hay</td>
<td>0.0</td>
</tr>
</tbody>
</table>

The quantity of nutrients carried as part of the sediment will vary with type of soil as well as level of management. Pounds of nitrogen and phosphorus associated with average soil loss (2-year average) from a Barnes loam for different cropping treatments are shown in Table 2. A corn-oats-hay rotation effectively reduces the sediment nutrient delivery. However, the reduction may not necessarily be in proportion to the decrease in soil loss.

Table 2

Average (2-year) annual nitrogen and phosphorus loss with sediment

<table>
<thead>
<tr>
<th>Cropping treatment</th>
<th>Crop</th>
<th>N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
<td>57</td>
<td>0.30</td>
</tr>
<tr>
<td>corn</td>
<td>corn</td>
<td>12</td>
<td>0.10</td>
</tr>
<tr>
<td>corn</td>
<td>corn</td>
<td>4</td>
<td>0.09</td>
</tr>
<tr>
<td>oats</td>
<td>oats</td>
<td>5</td>
<td>0.03</td>
</tr>
<tr>
<td>alfalfa</td>
<td>alfalfa</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
because a higher level of management can lead to a higher nutrient loss per ton of soil loss. An example of the effect of high level management on nutrient losses associated with sediment is given in Table 3. The rotation provided a fourfold advantage over continuous corn in terms of soil loss, but the higher management level and subsequent higher nitrogen and phosphorus loss per ton of soil significantly reduced the effectiveness of the rotation in terms of nutrient delivery associated with the sediment. This raises a question as to what should be considered an allowable soil loss based on nutrient delivery, because 4 tons per acre (the traditional allowable loss for Barnes loam) would deliver more nutrients under high level management than 6 tons under poorer management. The erosion process is selective and eroded soil will invariably contain higher quantities of nutrients and organic matter than the soil from which it was derived. This emphasizes the necessity for effective soil conserving practices for maintaining surface water quality.

### Table 3

| Cropping treatment          | Soil Loss T/A | Lbs of N/ton soil loss | Lbs of N/loss/A | Lbs of P/ton soil loss | Lbs of P/loss/A |
|-----------------------------|---------------|------------------------|----------------|------------------------|----------------|----------------|
| Continuous corn             | 9.44          | 7.03                   | 66.4           | 0.09                   | 0.85           |
| Corn-oats-hay rotation      | 2.21          | 14.26                  | 31.5           | .39                    | .86            |

Good conservation practices can tie down or trap essentially all of the sediment that might leave the land surface and prevent its entering surface water supplies. If this is done, what then is the quality of the water which flows off land? In other words, what are the concentrations of dissolved nutrients in runoff water from land in different crops? Table 4 presents average concentrations of total dissolved nitrogen and phosphorus in runoff water from various crops. The total dissolved nitrogen values averaged from under two to just over four parts per million while total dissolved phosphorus ranged from under one-tenth to about one part per million. These concentrations must be used in conjunction with total volume of flow in order to determine the quantity of nutrients in runoff.

Measurement of runoff in west central Minnesota has shown that the major portion comes from snowmelt and consequently, the concentrations
Table 4

Average (2-year) concentration (ppm) of total dissolved nitroben (N) and phosphorus (P) in runoff from crops.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Snowmelt Runoff</th>
<th>Snowmelt Total N</th>
<th>Snowmelt Total P</th>
<th>Rainfall runoff</th>
<th>Rainfall Total N</th>
<th>Rainfall Total P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in.</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
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<tr>
<td>Fallow</td>
<td>7.9</td>
<td>2.66</td>
<td>0.07</td>
<td>2.52</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Continuous corn</td>
<td>6.3</td>
<td>3.26</td>
<td>0.15</td>
<td>3.47</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>Rotation corn</td>
<td>2.7</td>
<td>2.92</td>
<td>0.22</td>
<td>2.20</td>
<td>0.88</td>
<td></td>
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<tr>
<td>Rotation oats</td>
<td>6.8</td>
<td>4.17</td>
<td>0.20</td>
<td>1.97</td>
<td>0.53</td>
<td></td>
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<tr>
<td>Rotation alfalfa</td>
<td>11.5</td>
<td>3.61</td>
<td>0.53</td>
<td>2.19</td>
<td>0.41</td>
<td></td>
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</tbody>
</table>

associated with snowmelt assume major importance. Total dissolved phosphorus was highest (0.56 lb per acre per year) from rotation alfalfa and lowest (0.12 lb per acre per year) from fallow. Native prairie which we have been studying has contributed about 0.09 lb per acre per year and a forested watershed about 0.13 lb per acre per year of total dissolved phosphorus to surface runoff. All of the phosphorus leaving the alfalfa plot was associated with snowmelt runoff, an observation that led to an investigation of the influence of freezing on the leachability of phosphorus from plants. Fresh green alfalfa and bluegrass were either leached immediately with water or frozen and then leached. As indicated in Table 5, the freezing process releases relatively large amounts of nitrogen and phosphorus from green vegetation. Similar increases were found by drying the vegetation. It appears then that plants can represent an appreciable source of soluble nutrients for surface runoff waters.

Our studies in western Minnesota have indicated that the application of fertilizers to cropped land is not well correlated with total delivery of nutrients in runoff (Table 6). Continuous corn, which received the highest amounts of nitrogen and phosphorus, contributed some of the lowest amounts of those elements to the runoff water. The rotation hay, which received no fertilizer during the year of measurement, contributed some of the highest levels of nutrients to runoff water. This was apparently due to the leaching of the dessicated alfalfa by spring snowmelt runoff as indicated in the preceding paragraph.
### Table 5

Estimated soluble P and N losses based on leaching losses.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pound per acre loss of</th>
<th>Ortho P</th>
<th>Org. P</th>
<th>Total P</th>
<th>Total N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh green-leached</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Frozen-leached</td>
<td>0.47</td>
<td>0.11</td>
<td>0.58</td>
<td>1.85</td>
<td></td>
</tr>
<tr>
<td>Bluegrass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh green-leached</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Frozen-leached</td>
<td>0.22</td>
<td>0.05</td>
<td>0.27</td>
<td>0.12</td>
<td></td>
</tr>
</tbody>
</table>

### Table 6

Nitrogen and orthophosphate in runoff water from various crops and fertilizer treatments.

<table>
<thead>
<tr>
<th>Cropping treatment</th>
<th>Fertilizer N applied</th>
<th>Av. total dissolved N lbs/A/in 7 yrs.</th>
<th>Fertilizer ortho P applied</th>
<th>Av. dissolved ortho P lbs/A/yr.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>lbs/A/yr</td>
<td>lbs/A/in 7 yrs.</td>
<td>lbs/A/yr.</td>
</tr>
<tr>
<td>Fallow</td>
<td>40</td>
<td>3.48</td>
<td>26</td>
<td>0.05</td>
</tr>
<tr>
<td>Continuous corn</td>
<td>700</td>
<td>0.70</td>
<td>182</td>
<td>0.06</td>
</tr>
<tr>
<td>Rotation corn</td>
<td>154</td>
<td>1.08</td>
<td>125</td>
<td>0.07</td>
</tr>
<tr>
<td>Rotation oats</td>
<td>154</td>
<td>0.67</td>
<td>125</td>
<td>0.01</td>
</tr>
<tr>
<td>Rotation alfalfa</td>
<td>154</td>
<td>3.10</td>
<td>125</td>
<td>0.21</td>
</tr>
</tbody>
</table>

The influence of fertilizer incorporation methods on runoff water quality has been investigated (Table 7). Incorporation of broadcast fertilizer (150 lbs per acre N as ammonium nitrate and 35 lbs per acre P as superphosphate (0-46-0)) by plowing under resulted in no greater concentration of
N or P in the runoff water than was found for the unfertilized control. Ammonium nitrate and total P concentrations increased 3 to 4 fold over the control when the fertilizer was disked into the rough plowed surface; concentrations increased 16 to 30 fold when fertilizer was unincorporated on the disked surface. Apparently, the downward mobility of the nitrate prevented any significant increase in nitrate levels of the surface runoff water.

Table 7

Effects of different fertilizer incorporation methods on the concentration of nutrients in runoff water

<table>
<thead>
<tr>
<th>Method</th>
<th>NH\textsubscript{4}-N ppm</th>
<th>NO\textsubscript{3}-N ppm</th>
<th>Total P ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plowed and disked, no fertilizer</td>
<td>0.13</td>
<td>0.40</td>
<td>0.04</td>
</tr>
<tr>
<td>Fertilizer broadcast on oat stubble, plowed and disked</td>
<td>0.13</td>
<td>0.40</td>
<td>0.04</td>
</tr>
<tr>
<td>Plowed, fertilizer broadcast and disked</td>
<td>0.40</td>
<td>0.44</td>
<td>0.18</td>
</tr>
<tr>
<td>Plowed and disked, fertilizer broadcast on disked surface</td>
<td>2.00</td>
<td>0.48</td>
<td>1.28</td>
</tr>
</tbody>
</table>

A practice such as terracing can materially change the pathway that water follows as it moves in a watershed. Studies by Agricultural Research Service scientists at Treynor, Iowa, indicate the magnitude that water flow can be changed by level terraces on deep permeable soils (Table 8). Increasing downward movement of water and subsequent increased subsurface flow would be expected to improve the quality of water with respect to the less mobile elements such as phosphorus, but may increase the levels of the mobile nitrate ion.

Application of pesticides to agricultural lands presents another source of chemical contamination of surface waters. Pesticides in general have a strong affinity for soil materials and their movement into surface waters is largely associated with soil erosion. An excellent study by Agricultural Research Service scientists in Ohio partitioned the pathways of dieldrin losses from an agricultural watershed in the year of application. Runoff water and crop uptake
Table 8

Surface and groundwater flow from unterraced and level terraced land

<table>
<thead>
<tr>
<th></th>
<th>Surface flow</th>
<th>Groundwater flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inches</td>
<td>inches</td>
</tr>
<tr>
<td>Unterraced land</td>
<td>10.7</td>
<td>3.3</td>
</tr>
<tr>
<td>Level terraced land</td>
<td>2.5</td>
<td>10.6</td>
</tr>
</tbody>
</table>

appear to be minor in accounting for dieldrin loss. Largest losses were associated with volatilization during spray application (25%), volatilization from the soil and vegetation (2.9%) and loss with sediment transport (2.2%). It is worthwhile to note that while losses of dieldrin in runoff waters are low (the concentrations on the water average about 1 to 2 parts per billion), the federal water quality standards for dieldrin for fish and aquatic life set the 48-hour median tolerance level at about 0.3 parts per billion.

Soil conservation practices are effective in preventing the movement of chemicals attached to soil particles into surface water. However, appreciable amounts are transported in the solution phase. This presents a problem which is not readily resolved for non point sources such as agricultural watersheds.

**DISCUSSION**

*Mr. M. Tellekson:* With irrigation and the fact that so much drainage goes into ground water, did this change the flow regime of the stream; in other words did you have a higher base flow throughout the year?

*Dr. R. Holt:* Yes, the base flow is higher. The total stream flow was the same; what we had done was reroute the flow through the soil. The main point was, I guess, that under those circumstances I had anticipated lower phosphate levels, and also higher nitrate levels.

*Mr. M. Tellekson:* That was my second question. Would you care to postulate why you have those higher phosphate levels?
Dr. R. Holt: Well, I hate to postulate, but what I’m saying is that the levels are higher in absolute terms and I don’t have any figures on the total phosphate delivery in this system. Normally I don’t feel, at least in western Minnesota, that calcareous soils would come to equilibrium with phosphorus levels quite up to that level. This is based on general observation.

Mr. R. Carter: From your studies, are there any recommendations that you can give to farmers or to this group on how to maintain optimum productivity on the farm economically? Do the practices which result in optimum productivity also optimize the loss of nutrients, or are the two compatible?

Dr. R. Holt: Well, I think we are going to have to develop systems that are compatible. I think that’s our major goal, it’s got to be systems which utilize or recycle, as much as possible, all the nutrients, so that effectively the only thing we’re losing off the land is that which we are selling in the crop or going off in the beef steak. I think our ultimate goal has got to be to develop systems which will recycle the nutrients, on the land, in the farming operation.

Dr. R. Parizek: I’m sure that a good many of the studies going on now are aimed at this. Perhaps not all in one operation, but certainly phases of it are under investigation. One of the things that concerns me, as far as agriculture goes, is that once these nutrients have entered a lake it’s of concern certainly to the limnologists, and of concern certainly to the people who want to use that lake for its aesthetic values but unless we’re growing a crop in there then it becomes academic to agriculture. Our goal is to keep that material on the land and in use, on the land.

Mr. S. Salbach: In your talk you mentioned repeatedly the concentrations of nutrients in surface waters. I wanted to just get this clarified. Do you in fact measure it in surface waters; that is water that is drained from the surface of the soil, or is it a combination of surface and ground water?

Dr. R. Holt: In our studies it has primarily been the surface water because that’s the only thing that we were collecting.

Mr. S. Salbach: Before dilution?

Dr. R. Holt: Yes. It’s not perhaps the ideal way of doing it, but an easy way of getting at it, as a first start.

Dr. J. Frank: Dr. Holt, in Illinois we are trying to convince farmers that there is an optimum rate of fertilization, mainly in N but also in P, that can be used to sustain optimum crop production. Through the education process or through the regulatory process this has not been very well accepted. We have many people fighting us; hybrid corn people saying that some day we will need 400 pounds N per acre and on and on. The only deterrent that there’s been is the cost of N fertilizer. From your presentation here you’ve shown a low
correlation between the amount of N or P applied and the carry of this in surface runoff. I don’t know what duration your studies were over, but is it an exercise in futility to try and keep this to a reasonable level – say 200 – 250 pounds N per acre for 150 bushels of corn – or is it, through freezing of vegetative matter and leaching, going to get in there anyway? Do you think longer terms studies would indicate that there is a more positive correlation?

Dr. R. Holt: I think some studies that have been carried out are going to high rates of nitrogen. Under those circumstances generally the information I have seen indicates that when you get above somewhere around 150 pounds of nitrogen, at least in western Minnesota, you run the danger of appreciable movement of nitrogen below the root zone of the crop. Again, the studies have been carried on in western Minnesota and I would not want to postulate what would happen in Illinois. But I think that there is a danger in putting too much nitrogen on in fertilizer; I think it should be tailor made to what the crop can possibly utilize.

Dr. D. Dodge: You might be interested to know that the Ontario Government is now working with the agriculturists and others interested in improving the fertility of the soil, by harvesting plants growing under aquatic conditions, and recycling them back to the fields as a soil conditioner. They add significant amounts of phosphate and nitrogen and they are quite available to the crops. We are running a small experiment right now on the Kawartha Lakes where we are donating aquatic weeds to the farmers just to get rid of them and they are waiting in line to take them off our hands. So there is a possibility that some of this material could be returned.

Dr. R. Holt: I would wonder about the economic potential of this kind of operation. Is this something you feel might be economical?

Dr. D. Dodge: Well, it could be in a sense that somewhere along the line the people of Ontario are going to have to pay a certain amount of subsidy. But if the objective of the program is to free the recreational areas of the rather undesirable aquatic growth and at the same time contribute the material back to the field, then in the end run it looks pretty good. There’s some competition from the cattle industry, for instance, to use this material; as I say, it looks like good mulch for seeding purposes as well.

Dr. R. Frank: How is the vegetation harvested?

Dr. D. Dodge: It’s harvested with a mechanical harvester which actually mows the material and receives it and takes it up through a series of conveyors and puts it on a barge and then it is taken up through a conveyor on trucks. And then they have an option of mulching it for a short period of time or taking it directly out to the field.
Dr. J. Frank: You talk about weedy type plants rather than smaller scale life such as plankton.

Dr. D. Dodge: Yes, we’re talking about macrophytes rather than phytoplankton.

Dr. R. Holt: You’re handling a lot of water, aren’t you?

Dr. Dodge: There’s a lot of water, but in some instances this is also beneficial in terms of irrigating the soil at the same time. But you can mulch it for a very short period of time and it dries quite readily. This material will be available if the group is interested in having it. The first study is being done now, and it’s a study that’s in co-operation with the fisheries. We are determining what effect the removal of the aquatic vegetation is going to have on the fish life, mechanically as well as behaviourally.

Mr. C. Schenk: Two questions: First, with respect to ploughing and diskig, when you plough the fertilizer under, does this have an effect on crop productivity as compared to the other method? And secondly, what sort of mechanisms do you have in play in Minnesota to get such practices in the general farming system? Do you have extension services or these kinds of things?

Dr. R. Holt: Yes, to answer your question about productivity. Ploughing under, however, is a practice which has been carried on to an appreciable extent. We do have a problem in Minnesota; I don’t know what the situation is here. They seem to do better with fall ploughing, but when you do fall ploughing, you leave yourself wide open to sediment losses and so the trend now has been to try and educate the people into perhaps some form of no-till systems. And this immediately opens up another can of worms in terms of how are you going to handle the amendments that you put on the land, under a no-till system? I guess the best method is deep incorporation, and I think that this is another area which we are probably going to have to look at.

Dr. J. Konrad: In your terraced vs. unterraced experiments, do you notice any increase in the amount of ponding on the terrace?

Dr. R. Holt: Yes, we have. It’s been one of the problems on the level terraces.

Dr. J. Konrad: And could this possibly be an explanation then for the increased mobility of the phosphorus?

Dr. R. Holt: Yes, this is one of the things that I didn’t mention, but this is one thing that I think that we should be looking at. Do we have a system or a situation where we have some anaerobic condition developing and therefore an increase in mobility of phosphorus?
Dr. G. Chesters: Contrary to general belief, I think you said losses of nitrogen from rotation fields were higher than from continuous fields using a great deal more fertilizer.

Dr. Holt: Dissolved in surface runoff, yes.

Dr. G. Chesters: I think you said that the reason for this was freezing, which I presume is due to cell destruction.

Dr. R. Holt: Well, this is what we suspect.

Dr. G. Chester: What are you recommending as management practices to conserve that loss?

Dr. R. Holt: I wish I had a recommendation right now. I suspect if it goes against the maintenance of your alfalfa, certainly a late fall cutting would help. In our area, we need that late fall growth to build up the reserves in the alfalfa so that we don’t get excessive winter kill. So you pose a real problem. How to handle this. Do you have any suggestions?

Dr. G. Chesters: Do you mean this is a hoax you’ve been perpetuating all these years? Every class I ever heard of tells you the reverse of this. Why did it take so long to find that out?

Dr. R. Holt: I think one of the answers to that is nobody ever really looked much at phosphorus; they always assumed it was so low that it was never of any real concern. And it wasn’t until they started looking at lakes and the streams and the extremely low level of phosphate that was needed to cause conditions which could increase the fertility of lakes to the level where you had undesirable growth that we did become concerned with phosphorus.

Dr. G. Chesters: Do you know where you get these high phosphorus levels? What do you suggest happens to the soil that it can’t support that level?

Dr. R. Holt: I’m not really sure, but I suspect that anaerobic conditions by which some of the iron phosphates could be reduced could be one possibility.

Dr. R. Parizek: I have a question concerning the change in land use. As you go from a rural farming economy into an urban sprawl, is there any evidence that we still face a nutrient problem because of change in land use activities compared to the agricultural section? With urban sprawl, landscaping and housing, does the problem go away? Certainly with construction, it goes up for a brief period.

Dr. Holt: For a brief period yes, and also the levels of nutrient supplied on a lawn or small lot basis is certainly higher than that applied on agricultural land; plus total runoff is greater because you have more concrete. You’ve got less permeability, so you’ve increased your runoff and you’ve probably increased
the level of your nutrients. So I think your situation is as bad or probably worse under the urban sprawl.

Dr. R. Parizek: So the fact we've gone away from agriculture doesn't solve our problem. Are there data that you are aware of, or studies of this type that we can get some data from, that relate to this?

Dr. R. Holt: There are some projected in terms of sediment delivery.

Mr. R. Carter: You are saying that there are certain background or natural levels of nutrients; phosphorus and nitrogen. From forested areas or at least where there is no application of nutrients, you still find that there is a nutrient input. Would you expect to quantify this on a per acre or per pound or ton per acre basis and say that this is natural level? Also, in our concerted efforts to reduce the contribution from the non-point sources on agricultural lands, can we expect to go below that which we would expect to come off forested land? Or is this the lower limit?

Dr. R. Holt: I think a number of years ago I kind of had that as a goal; to identify the natural level and then this is what we would anticipate to keep agriculture to. I think I was a little bit idealistic because it is not that simple.

Dr. B. Ellis: Dr. Holt, can I comment on this? I think it's a mistake to try to take the forested land and use this as your control because many times the soils underneath the forested land are far different from the soils you're farming. I specifically refer to Michigan, which I don't think is too far different from Minnesota. In our northern Michigan forest lands we have soils with a pH running around 5, and there the solid phase that Gord Chesters spoke about will support a level of about .02 ppm phosphorus in solution. This keeps it very low, but if you move down to a great podzolic area or if you go to Illinois to these nice fertile soils with pH's that are naturally running 5, 6 or 7, the level supported in solution gets a lot higher, under any circumstance, and so you just can't take the agriculture land and say I'll compare this with forestry control. You could never reach it, and it was never reached before we got here.

Mr. M. Tellekson: Well, one of the tasks that is going to have to be addressed in Work Group D is the definition of this natural condition. Do you have any ideas on that Dr. Holt? What would you consider a natural condition; how would we go about defining that or suggesting a way to define it?

Dr. R. Holt: From what Boyd just said, I don't think we are going to. This is kind of skirting the question, but we have taken a look at natural prairie conditions thinking, well maybe, the natural prairie condition in western Minnesota could give us some insight as to where a person might put a natural control. Here again, we have a situation under those conditions that you get
no runoff from anything except snowmelt. At least we haven’t found any yet. The prairie as it developed, developed such a thick mulch that even a two or three inch rainfall over a rather short period causes virtually no runoff, so what you’ve done is you’ve changed the pathway in which the water reaches your surface water supply. And so again you bring on the problem of different soil types. To try and put your finger on what natural level is, is asking I think quite a lot.
FATE OF FERTILIZER APPLIED TO LAND AND CROPS

Boyd G. Ellis

ABSTRACT

Studies of nutrient losses associated with tile drainage from agricultural areas demonstrated that nutrient losses are correlated with degree of run-off, with most of the nitrogen and phosphorus loss occurring during the spring months. Nitrogen losses ranged from 3.1 to 16.7 lbs of N per acre per year, and phosphorus loss was approximately 0.1 lbs. per acre per year. The nitrogen cycle in soil, and factors affecting the transformation and movement of phosphorus in soil are discussed. The need for soil testing to verify fertilizer requirements, and the timely application of correct quantities of fertilizers is advocated to control loss of fertilizer nutrients.

1Professor, Department of Crop and Soil Science, Michigan State University.
Before beginning a discussion of loss of fertilizer nutrients to drainage waters, I would like to question the view that many people today have — that natural waters were clean and pure in "the good old days". Our natural waters have always contained nutrients. Our muck soils today are really lakes and swamps that grew biological organisms, aged and died without the help of man — eutrophication is not new. What is new is man's contribution to this process. Some sources of nutrients are easy to pinpoint and others are much more difficult to define precisely. Nutrients coming from agricultural watersheds are in the latter category. Under these circumstances it is easy to suggest that fertilizers are a major source of pollution, but it is much more difficult to prove.

**NUTRIENT CONTENT OF AGRICULTURAL DRAINAGE**

One must be convinced that some of the fertilizer nutrients applied to soils will ultimately find their way into drainage waters. The question is "does a significant quantity of nutrients from fertilizers enter our drainage water"? To answer this question we collected samples from tile drainage lines and small streams from agricultural watersheds. Data from this study (Erickson and Ellis, 1971) are given in Table 1. I should emphasize that these seven sites were selected to include normal farms with good management practices including moderate to heavy fertilization, but not excessive fertilization. Nitrate nitrogen losses ranged from 3.1 to 16.7 pounds of nitrogen per acre per year. The loss of phosphorus was approximately 0.1 pound per acre per year except from the Muck Farm which lost 1.3.

It should be pointed out that the losses were well correlated with the loss of water. Thus, most of the nitrogen and phosphorus loss occurred during the spring months. The high loss of nutrients from the Muck Farm is worthy of comment. A large quantity of water is removed from a muck soil during the growing season. Although the loss of 16.7 pounds of N as NO₃ per year may seem high, the surprising thing is that the concentration of nitrate nitrogen did not exceed 2 ppm N. This is from a heavily fertilized muck soil. The organic soil would not be expected to impede the movement of nitrate down through the profile. Consequently, we concluded that the lower than expected nitrate values were due to reduction of the nitrate in the saturated zone near the tile drainage lines (in this farm the drainage lines are submerged in water). This reduction of nitrate apparently ceases when the temperature becomes cold. We measured nitrate nitrogen contents of the water surrounding the tile lines in February and found it to be 25 ppm N. The practice of letting the water table of an organic soil rise in the non-farming season and only
Table 1
Concentration and total loss of N and P from agricultural watersheds in Michigan.
(from Erickson and Ellis, 1971)

<table>
<thead>
<tr>
<th>Location</th>
<th>Predominate soil type</th>
<th>Nutrient concentrations</th>
<th>Total Nutrient Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>Ferden Farm</td>
<td>Sims sandy clay loam</td>
<td>8.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Davis Farm</td>
<td>Sims clay loam</td>
<td>7.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Hey Farm</td>
<td>Montcalm and McBride sandy loam</td>
<td>11.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Muck Farm</td>
<td>Deep Muck</td>
<td>2.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Deer Creek</td>
<td>Gray-Brown Podzolic</td>
<td>4.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Sloan Creek</td>
<td>Gray-Brown Podzolic</td>
<td>3.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Montcalm Creek</td>
<td>Montcalm and McBride sandy loam</td>
<td>1.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>

*Measured as soluble orthophosphate.

Volume measurement was not made.

Measured for eight months.
draining the soil for farming purposes is not only good from the conservation standpoint, but it also reduces the amount of nitrate nitrogen in the drainage water.

Although relatively unimportant from a pollution standpoint, Erickson and Ellis (1971) point out that the major nutrients lost from agricultural drains are calcium and magnesium. Since most of our lakes and streams are hard water systems at the present time, additional calcium and magnesium will not increase the rate of eutrophication.

For three of the farms studied, the annual rate of fertilization could be determined accurately. These data and the comparison to the quantity of nutrients lost are given in Table 2.

Table 2

Total nutrients added in fertilizer and lost in drainage water. (Erickson and Ellis, 1971)

<table>
<thead>
<tr>
<th>Location</th>
<th>Added Each Year</th>
<th>Lost 1969</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Ferden Farm</td>
<td>80</td>
<td>35</td>
</tr>
<tr>
<td>Davis Farm</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>Muck Farm</td>
<td>50</td>
<td>15</td>
</tr>
</tbody>
</table>

From the Ferden Farm, nutrients in the drainage water were only 14% nitrogen, one-third of 1% phosphorus and 12% of the potassium when compared to the quantity added as fertilizer. At the Davis Farm, nutrients equivalent to 20% of the nitrogen, less than one-quarter of 1% of the phosphorus and less than 5% of the potassium reached the drainage water. Although the nutrient loss from the Muck Farm appears high, analysis of water samples from natural, unfertilized muck in the same area (see Table 3) indicated that the nutrient content of the water was not increased by farming or fertilization.
Table 3

Additional analysis of water in and around Muck Farm, 1970. (Erickson and Ellis, 1971).

<table>
<thead>
<tr>
<th>Location</th>
<th>N-NO$_3$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>– ppm</td>
<td></td>
</tr>
<tr>
<td>Outside of Farm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>8.7</td>
<td>0.249</td>
</tr>
<tr>
<td>Low</td>
<td>0.34</td>
<td>0.027</td>
</tr>
<tr>
<td>Mean</td>
<td>1.87</td>
<td>0.131</td>
</tr>
<tr>
<td>By Pump House</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.8</td>
<td>0.52</td>
</tr>
<tr>
<td>North Farm Drain</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.94</td>
<td>0.056</td>
</tr>
<tr>
<td>South Farm Drain</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.95</td>
<td>0.045</td>
</tr>
</tbody>
</table>

NEED FOR FERTILIZATION OF AGRICULTURAL CROPS

Before going further, we must ascertain if we really need to use fertilizer on agricultural crops. Even though the data given above show that little of the added fertilizer is lost through drainage, if the fertilizer is not really needed then the risk of any loss would not be necessary. I feel strongly that modern agriculture without fertilizer use is not feasible. Data from long-time fertility trials both in the United States and Europe (for example, the Morrow plots in Illinois and the Broadbalk plots at Rothamsted, England) show conclusively that growth of crops with no fertilization leads to very low yields after a few years. It was estimated by Ellis and Kilmer (1968) that one-half of the agricultural production in the United States is due to the use of fertilizers. In the face of expanding populations and increased food cost we cannot afford to farm without the use of fertilizer.

We then must strive to make the best possible use of fertilizers with the minimum loss of nutrients to the environment. To do this, a basic understanding of the chemistry and cycles of nitrogen and phosphorus in soils must be gained.

NITROGEN CYCLE

A nitrogen cycle given by Wolcott (1972) illustrates the complex nature of nitrogen in a soil system. The first important point is that nitrogen added to
an aerobic soil, either as inorganic fertilizer or an organic material, will convert to nitrate nitrogen (see Fig. 1). The nitrate nitrogen will be absorbed by a biological organism or move with the soil water into drainage water. If a saturated zone is encountered and if sufficient carbon is present, the nitrate nitrogen may be denitrified to nitrogen gas. It has been suggested that the nitrogen cycle has a weak link in that addition of artificially fixed nitrogen places undue stress on the nitrogen system. But I would suggest that a weaker link is created by farming, collecting nitrogen in a crop and shipping it a long distance (i.e. to a large city or a large feedlot) with no provision for returning the nitrogen to the land. Instead, it may be discharged into our waterways or leached from feedlots. To bring the nitrogen cycle back into balance, the waste may be returned to the land or the nitrogen in waste materials may be denitrified and artificially fixed nitrogen returned to the land.

An example of a system designed to produce maximum denitrification is that of Erickson, et. al. (1972) where a barriered landscape water renovation system (BLWRS) is utilized to denitrify the nitrogen in animal waste. The effectiveness of this system is shown in Table 4. In addition to nitrogen removal, phosphorus was effectively removed during the first eighteen months of operation. This appears to have been removed by adsorption mechanisms and should operate only for a limited time before higher levels of phosphorus will appear in the drainage water.

Table 4

The average Analysis of Waste Applied to the BLWRS and Effluent from the BLWRS (from Erickson, et. al., 1972)

<table>
<thead>
<tr>
<th></th>
<th>Swine Waste</th>
<th>Swine Effluent</th>
<th>Dairy Waste</th>
<th>Dairy Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
<td>mg/l</td>
</tr>
<tr>
<td>Org + NH₃-N</td>
<td>650</td>
<td>2</td>
<td>300</td>
<td>3</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>10</td>
<td>6</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>PO₄-P</td>
<td>20</td>
<td>0.02</td>
<td>40</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Figure 1. Pathways of nitrogen transformation in soil.
PHOSPHORUS IN SOILS

It is easy to obtain data confirming the fact that we are applying more phosphorus in fertilizer than we are removing by crop production. In 1968 about 115 million pounds of phosphorus was applied as fertilizer and approximately 65 million pounds removed in crops in Michigan. This leaves an excess of 50 million pounds or about 8.4 pounds phosphorus per acre. This excess is not great on the average, but we must watch it carefully.

Many people consider that excess phosphorus is precipitated in the soil as either iron, aluminum or calcium phosphates. However, it was pointed out by Ellis (1973) that precipitation will not account for low phosphate levels found in soils if the soil pH is greater than 6 (see Fig. 2). We must depend upon adsorption rather than precipitation reactions and soils have a definite adsorption capacity that can be exceeded.

Table 5

Movement of phosphorus from fertilizers applied to lawns surrounding Gull Lake
(from Shields, et. al., 1973)

<table>
<thead>
<tr>
<th>Depth</th>
<th>Site Number</th>
<th>Site Number</th>
<th>Site Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>feet</td>
<td>19</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>0-1</td>
<td>128</td>
<td>266</td>
<td>240</td>
</tr>
<tr>
<td>1-2</td>
<td>21</td>
<td>197</td>
<td>192</td>
</tr>
<tr>
<td>2-3</td>
<td>5</td>
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</table>

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Fertilizer</th>
<th>N</th>
<th>P</th>
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<tbody>
<tr>
<td></td>
<td>lbs/1000 sq. ft. per year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>45-0-0</td>
<td>5.2</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>23-7-7</td>
<td>7.8</td>
<td>1.04</td>
</tr>
<tr>
<td>16</td>
<td>13-13-13</td>
<td>1.3</td>
<td>0.56</td>
</tr>
</tbody>
</table>
Figure 2. Quantity of total phosphorus in solution as a function of pH.
MOVEMENT OF PHOSPHORUS IN SOILS

It has been observed that lawns which are over-fertilized with phosphorus will lead to movement of phosphorus in soils. The data in Table 5 (Shields, et. al., 1973) show that the soil profiles have been saturated to the ground water table in two of the three locations. In the third location, little movement has been observed. Movement of phosphorus is well correlated to use of phosphorus fertilizer on these lawns. The data collected in this area indicated that 75% of the lawns had been over-fertilized to the point of producing movement of phosphorus, suggesting that this may commonly occur in lawns.

Preliminary data have suggested that we can find agricultural soils that have been fertilized with phosphorus to the point of producing movement of phosphorus. In no case have we found movement of phosphorus in agricultural soils to the ground water table. But in some counties as many as 10% of the samples tested are very high — sufficiently high to suspect movement of phosphorus.

CONTROL OF FERTILIZER NUTRIENTS

For many years we have depended upon soil tests to delineate soils low in phosphorus. But the same soil test procedures can detect soils which have an excess of phosphorus. We should be using these procedures to determine if fertilizer phosphorus should not be applied. In fact, I feel that phosphorus fertilizer should not be applied to either lawns or articultural soils until a prior soil test verifies the need for fertilization.

Nitrogen is a relatively mobile nutrient in soils. With this nutrient we must exercise care to apply the correct quantity and to make the applications only when there is an actively growing crop. If necessary, the use of cover crops will reduce the quantity of nitrate nitrogen lost between fall and spring.

LITERATURE CITED


DISCUSSION

Mr. R. Carter: I’m not totally familiar with all our farms, but on all of our feedlots in Indiana, the method of disposal is land application. We do have a requirement for so many pounds per acre and they’ve got to have so many acres to put it on. Also they are not supposed to put it on when the ground is frozen. One thing I’m not sure of is whether or not they have to have a crop cover on which to apply!

Dr. B. Ellis: Let me make some general comments about this, and there may be others who know more about this subject. As far as applying animal waste to soil, the principal thing is how often and how much you apply. I can give you some ranges. I can tell you that you can put on 30 tons per acre per year of animal manure and not have any difficulties. We’ve done this for more than ten years now in Michigan State and the soils handle it beautifully with no problem. I can also tell you that if you put on 300 tons in one application you’re in a bit of trouble. We have data on this, Kansas has data on this, but that’s a pretty big gap in between and it really hasn’t been defined that closely, that I know of. I’m sure that you can go a bit higher than the 30 tons per year, but whether you could go to 100 tons successfully year after year, I don’t know. Soil has a good ability to break down organic materials, get rid of the BOD load; it has a pretty good ability to handle the nutrients off the manures. You will find on application of manures that a couple of things happen. First, potassium levels are likely to go very high. This may not be a pollution problem, but it’s there. Second, phosphorus will go up. The soil seems to be able to handle much of the nitrogen, at least at a 30 ton rate, and not do too bad. In fact it seems to have some beneficial effects on the soil structure. I should
try to clarify one point. Most of the nitrogen that you put in from animal manures is not in the soluble form when you put it on. It does have to undergo a conversion before it’s released into a form that is either leached or is taken up. Data from one of our experiments show about 650 parts per million of N in the organic form, and only about 10 ppm in the nitrate form, initially. If the temperatures are warm, the soil will undergo conversion very rapidly. Under those conditions I would think it would be imperative to have a crop growing. However, if you are saying that, okay, I want to go out and put this on early in the organic form, and only about 10 ppm in the nitrate form, initially. If the is going to be slower and you might get by not having a vigorously growing crop. I think it’s getting pretty guessy.

Mr. M. Tellekson: I had a question regarding the optimum application rate which you always qualify by saying “economically”. Is there an optimum application beyond which you couldn’t get any more growth from a soil, or does it just keep on going up, the more you apply the more you get?

Dr. B. Ellis: No. The reason why I hedged on the economic issue has to do with when you get into potatoes and specialty crops. If you go to corn, for example, and start plotting corn production against phosphorus added to the soil, you’ll find that once you pass 25 to 50 pounds of available P, you’ll get no more increase-period. I’ve seen data in Kansas on this; we’ve got data in Michigan on it and I’m sure there’s lots on it in other places. I hedge a little when I get into specialty crops because many times they have had so darn much of everything put on, that it’s difficult to tell where you’re at. I have seen data that would indicate little increase beyond 100 pounds per acre phosphorus, but occasionally you’ll hit a year where you seem to see some increase. Rarely is it an economical increase. And that’s why I was hedging on the top end. I wouldn’t hedge on the corn, I wouldn’t hedge on wheat even, but when you get into potatoes particularly and perhaps, sugar beets or vegetable crops, than I start hedging, that maybe, maybe you’ll get a response at higher levels.

Mr. M. Tellekson: In other words with a certain type of soil, in any one state the farmer should be able to tell what would be the outcome by what he put on it.

Dr. B. Ellis: Particularly for phosphorus. I think we’re there in most of our states right now. Between the optimum and the trouble point there is such a range that really there is no need for overfertilizing under those circumstances for phosphorus. Nitrogen is a little harder to control because how much of it you lose depends on how much water moves through the soil and several other things; so this is a little harder to control to the point of getting no loss. You certainly can put it on only at the time when the crop is growing, but if you happen to get ten inches of rain that week after you’ve put it on you’re likely to move it down to a fairly deep depth.
Mr. M. Tellekson: What type of a time frame are you talking about, with nitrates and phosphates moving down through the soil; one week?

Dr. B. Ellis: I'll refer this to Dr. Holt.

Dr. R. Holt: Well, we found that putting the nitrogen on the surface as ammonium nitrate during a storm at the rate of 2.5 inches an hour, the resulting runoff within the first hour wouldn't wash the nitrate off; it moved down faster.

Dr. B. Ellis: But how deep would it go in that first hour?

Dr. R. Holt: We really didn't measure the depth within the front; I suppose it would be from 8 inches to a foot. It can leave fairly rapidly. My only experience on measuring nitrogen was under a lawn situation. There, we caught a heavy rain after an application and it took about a week and a half to find it in the ground water. That was a distance of about three and a half feet.

Dr. S. Walesh: I'm interested in the runoff with respect to urban areas, lawns in particular. I am surprised to find that fertilizers are applied to lawns at greater rates than applied to agricultural lands. Are there other places where studies have been conducted in this area, that we might get some background?

Dr. B. Ellis: I haven't looked into that specifically, however, one of my colleagues did a fairly detailed study on this. It is written up now, but has not been published yet. Also we've studied this around some lakes. You can answer this yourself though without having to go through much scientific data. My first reflection when I saw this coming off of the lawns was that I just couldn't believe that there would be that much phosphorus. And then I sat down and started to calculate what the average homeowner would have done in the past twenty years if he wanted to maintain a pretty good lawn. The clue is that nitrogen is what is necessary to maintain nice green vigorous grass, and if you are working with a blue grass such as we have in most of Michigan it takes about 6 pounds of N per acre per year. If you're not taking off clippings, you really don't need to apply much phosphorus; it goes back in the clippings. In fact one turf man told me that he couldn't get a response to phosphorus on a fifteen pounds per acre test. So, there's a very low requirement for phosphorus, and yet if you think back to the period 1950 to 1960, what did you apply as a lawn fertilizer? You bought 12-12-12, 10-10-10 always carrying phosphorus; by 1965 it had gotten up to 12-6-6 or something like that, still carrying phosphorus; and finally a couple of years ago in a real effort to improve the environment they got as high as 23-7-7. Still carrying phosphorus! And in most of the situations it's absolutely not needed on a lawn. So if you sit down and calculate how many pounds have been applied on an annual basis by a lawn owner over the past 25 years it turns out to be a staggering amount of phosphorus and it's not removed. This shook me because before I started on this study down at the lake, you know I gave them a big spiel about how nitrate
would move and phosphorus wouldn’t. I spent a year working and had to go back and tell them that phosphorus was moving.

Dr. R. Parizek: How available is that phosphorus, if it erodes with the sediment and ends up in our lakes? Are we talking about phosphorus that can be picked back out?

Dr. B. Ellis: I wish I knew. You know when you move a sediment to the lake with phosphorus on it you have to say, is this really available or is this bound sufficiently tight that very little comes off it. There was one study at Michigan State that indicated that algae can get if off the solid adsorbed phases. But then again, down at the bottom of a fifty foot lake there are not too many algae. So then you start wondering if under reducing conditions, or if the oxygen levels get low, does it come back into solution. We’ve tried to measure this a couple times, but it’s a very difficult thing to get a good handle on. The published work on this, that is, perhaps the best is the work by Patrick. It would indicate that if you get the Redox or Millivolts low, yes, the phosphorus does come back into solution. I think if you go to the Far East and start looking at their literature on phosphorus levels in paddy soils, you start to come to the conclusion that if you flood these things phosphorus levels increase. We have done this on Michigan soils and if you flood our soils the extractable phosphorus increases, so I would guess, yes, it’s somewhat more available but it’s probably not totally available. Somebody else may want to comment on that.

Dr. D. Bouldin: I want to comment on the lawn thing. We are doing a little bit of work on that in Long Island and we’re comparing potatoes with lawns, among other things. I have a little difficulty documenting this I guess, not that I want to publish it, but I think by and large you would have to conclude that lawns are more of a pollution hazard than potato fields because of the very things that you’ve pointed out. The amount of phosphorus and nitrogen accumulated over a period of time plus the fact you’re removing very little. At least in potato fields you’re removing 100 pounds of N. With lawns you’re removing practically nothing and by and large they’re putting more nitrogen and phosphorus on lawns than they are on potato fields. I might also comment on the sediment thing. Under reduction it’s very true that the phosphorus concentration does increase if you have anaerobic water. By and large you’ll have an aerobic layer on top of that anaerobic zone and so it becomes a very important question of the transport of phosphorus from the anaerobic zone through the aerobic surface layers to the water column. So it becomes a transport problem.

Dr. B. Ellis: We actually did this study on six lakes. I was interested in seeing whether the sediment on the bottom of the lakes looked like agricultural sediments. We selected, with Bill Mark’s colleagues help, six lakes that varied in quality, sampled the sediments at various depths and measured the phosphorus
in them. We also measured the phosphorus in solution above them. The one conclusion that was inevitable was that the sediments did not look like agricultural sediments. They had no relation to the agricultural mineral soils in the area; they looked like precipitated calcium aluminum phosphates. The second conclusion that we had to come to was that we could not predict from what was on the bottom of the lake what was in solution. There seemed to be no real way of telling from the sediment composition what would be in the solution above. But there was a pretty strong correlation between the organic matter content of the solution phase and the phosphorus level.

Dr. G. Chesters: Boyd spent a rather lengthy period of time talking about the need to define these different background levels in different soil types, and I think Mr. Tellekson went so far as to say we have to determine these background levels. In terms of maintaining water quality, why do we have to determine these background levels; other than as a purely academic exercise?

Dr. B. Ellis: Well, in my opinion, I would say that rather than determining the precise background level, what we have to determine is what we can live with in our water systems. What is the level of input we can live with? Now, the academic reason for determining the background level is, as I'm sure you're aware, that when the legislatures say you will have zero discharge you have to know what zero discharge really is, because you can't take it lower than it was originally. Okay, it's up to you to go off and regulate it so as to get it down to an acceptable level and if 50% of it is non-regulatable because it's natural and to get down to the required level, you've got to remove 75% of it, somebody is going to be beating his head against a wall.

Mr. R. Carter: I think you have to know what is controllable and what isn't in order to do an effective job without spinning your wheels on regulation.

Dr. B. Ellis: I think whenever you talk about percentage removal in regulation that you are in a most precarious situation. I think in fact (Bill correct me if I'm wrong), our state requires 80% or 90% phosphate removal. Somebody asked me how do you accomplish this. The simplest way is to set up a stream to your municipal plant and dump in fertilizer.

Mr. R. Carter: Well, I wasn't really talking about percentage removal. I am talking about, you've got so many pounds going in and you've got to get down to a certain pound level.

Dr. B. Ellis: Okay, but the critical point is what level do you have to get down to? That doesn't really have to have a bearing to the natural level. Now, granted you can't say you have to get it lower than what it was to begin with, but the level that you should be determining is the level you can live with, not how much do I think I can get down to if I really tighten the controls.

Mr. R. Carter: I think we have to have both.
Dr. B. Ellis: Oh, I’m sure you have to have the second one because if you don’t somebody obviously is going to say we’ll have zero discharge and we’re going to have nothing but water in our water.

Mr. M. Tellekson: It becomes a legal problem and I think that is well illustrated by the recent court decisions regarding air pollution. Areas in the United where the court ruled that even though the standards call for a certain level in an area, if the air quality is better there now, then the standards don’t apply. You have to maintain the present quality. I think it also becomes a very real problem when you start your load allocations on streams. But another point I wanted to make, you mentioned the study on the six lakes. One of the problems that we have to address in the Reference Group is the so-called fate of the pollutants that come from a stream out into a lake. What happens to the pollutants out there? Is that information published, that you alluded to?

Dr. B. Ellis: It is in a thesis. I could send you a copy of it if you wish. I think Dr. Chesters and his group have far more information on lakes, than we have. Right, Gordon?

Dr. G. Chesters: I don’t.

Dr. B. Ellis: Your group, I said.

Dr. G. Chesters: I suspect Harris has.

Dr. B. Ellis: Yes, I’m sure Harris probably has the most information on lakes that’s floating around. And I’d be glad to furnish you with this if you would like it, but I think you might find much more from them.

Dr. J. Konrad: There have been several recent reviews on the type of work being discussed published in the Journal of Environmental Quality, first quarter issue this year, both on N and P.

Mr. W. Richardson: I’ve been involved a little bit with the tributary input program and one of the problems that has come up is the definition of input from bedload versus erosion. I was wondering if you have any recommendations or suggestions as to how to measure this? When and the frequency?

Dr. B. Ellis: Dr. Holt, I’m quite sure is our expert on erosion.

Dr. R. Holt: You’re concerned with how do you measure the sediment?

Mr. W. Richardson: Right. We measured the water column, but according to your paper it seems that most of it is in the sediment that might be carried out and this may come off during very infrequent periods. Most of it might come off during storms.

Dr. R. Holt: Generally we’ve gone to sediment samplers — automated sediment samplers — in order to pick up the sediment. It’s a matter of analyzing the
sediment for what you want to find out, and you have to pick for analysis that which you think is going to become available if that sediment gets into a water body somewhere. We’ve been using the ammonium chloride extraction method for phosphorus and also have run total nitrogen on the samples.

Mr. W. Richardson: How do you quantify the amount of material coming downstream in pounds?

Dr. R. Holt: We measure the total flow and at periodic intervals we take samples of the sediment, and so a combination of total flow and sediment integrated over the flow period gives us the total discharge of sediment.

Mr. W. Richardson: This isn’t just the suspended material in the water component, is it? Does it include the heavier material that is transported during high flow?

Dr. R. Holt: Well, we really don’t get into that which is suspended where heavier materials are concerned.

Mr. W. Richardson: What about material which is just transported during flood period? You wouldn’t have a regular sampling program, would you?

Dr. R. Holt: We would be sampling during the flood period, as well. We would probably, if the turbulence is great enough so that this heavy material is within the flow that we’re sampling, be picking that up along with the other. Generally the heavier materials, the sands etc., will not be carrying too much anyway.

Dr. B. Ellis: I found the most intriguing thing to decide is which is sediment and which is water. This sounds ridiculous when you first state it, but when you start thinking, where do I make my division, do I cut it off at 2 microns and anything greater than that is sediment and anything less than that is water, but you know darn well that you’ve got stuff in that water that’s sediment. So then you get down to a tenth micron. It’s a tough decision to make. Most of us end up making do with what we can filter rapidly or based on time.

Dr. R. Parizek: We’re heading in the direction of research needs from both speakers. It looks like going from an agricultural economy into an urban sprawl may make our problem quite serious with regard to nutrient generation. When we measure things in experimental plots or small watersheds where the soil water and the groundwater system are responding, the streams possibly now reflect what is in the groundwater reservoir and yet, when you look at larger watersheds the groundwater flow rates may be quite slow. We might not yet have seen the full impact of prolonged agricultural activity or prolonged urban activity on water quality in these streams. Can you make any comments on this; do you think that the groundwater is getting worse and has not yet fully arrived in the streams, hence, any measurement of surface discharges
today may underestimate the problem we face in another five or ten years? Or have we waited long enough that by now it should be showing there?

**Dr. B. Ellis:** I think this is going to depend on the specific local situation. Certainly, some of our practices that have caused erosion in the past, for example, may never get to a stream. We have to remember that if you sat down at the bottom of the watershed and you measured the amount of the erosion down the hill, that there might not be a stream at the bottom of the hill. And if somebody allows this erosion to go on, then puts in a practice that stops it, there might be no impact on the stream at all. On the other hand, when you start asking about loading up an area with nutrients, for example the potato plots I talked about, I’ve little doubt in my mind that at the present time we haven’t contributed much phosphorus from that area to either the streams or the groundwater. But I also know that we are getting pretty close to thin ice. In some of these cases we’re going to be hitting water in a couple more feet, and if we continue our practices for another five years—maybe ten, depending on what the figure is, but for a few more years—then it is going to become serious. And this can be true of urban areas as well. We are just tidying up a fairly large study around Houghton Lake, and one of the conclusions that is inescapable is that many of these soils have reached their capacity; in fact, in some cases you can find phosphorus moving through the soils at levels in solution that stagger you. I found one that had 35 parts per million in solution flowing directly from the septic system to the dyke. All the way, no absorption at all, the capacity had been met and it was just flowing right straight out over. And there was another one where some people in the Water Resources Commission put up a sand point well, I think out in the lake about ten or fifteen feet off of a dock, and could pump water with 1 to 5 ppm in it from down under the sand. Again trackable right back to a septic system that just let it go and fanned out, but again in a situation where it was loaded. So in answer to your question, yes, if you exceed these levels long enough you could see more impact later.

**Dr. R. Parizek:** The problem is that any measurements we’d make on major rivers today may be underestimating the full scale of a problem that’s lurking in the watershed.

**Dr. B. Ellis:** It could well be underestimating. I don’t think you can really guess at this unless you know the specific area. For example, I think in most of our northern areas in Michigan we are not underestimating; we’re probably in good shape, but if you get into an area running around the tablelands, yes, it’s probably underestimating.

**Mr. J. Neil:** As a soil scientist can you calculate the holding capacity accurately in soil, knowing its composition?
Dr. B. Ellis: I can calculate it. If you hadn't had said accurately I could have answered with an unqualified yes. We have worked for several years in the laboratory on this and we have come to the conclusion that we can make at least a ball park estimate with the Langmuir adsorption isotherm; it gives us pretty good information. Remember the slide I showed you with the potato field. My estimate in the lab was that when we exceeded about 240 pounds, give or take a little bit, that we were going to get movement, and that has generally applied. Generally when we get above these values we get movement. We now have a half a dozen field sites. We had those ten, but they were all the same soil type. Now we have a half a dozen on different soil types. This at least lends some validity to the idea that we can predict it. On the Blowers experiment that I have showed you, our systems science group have built a computer model based on the adsorption isotherm. It predicts at what point in the profile we should find the phosphorus and to date it's holding up real well. We did have to make one correction in it during our first attempt to use the isotherm. That attempt just failed out. Then we got looking at it, saying, well you know 40 parts per million is awfully high, it will stay in when we have an anaerobic holding pit, but as soon as it hits the surface with a lot of calcium and aerobic conditions it ought to precipitate as di-calcium phosphate. So we did two things, we went back and corrected the program to take out that precipitation and went back and measured the soil and sure enough we found accumulation in the top inch of soil. So I think, yes, we can make a fairly close prediction, but when you get me out of my home soils, I'm not sure how widely applicable it is. I could even find a few that it seems to fail on.

Mr. J. Neil: I'd just like to ask one more question. Do you feel that the holding capacity of the soil relevant to nutrient movement downwards relates to the distance to groundwater so that if your water course or groundwater is down twenty feet, the soil has twice as much capacity as if the groundwater is at ten feet?

Dr. B. Ellis: This depends on the soil, for example, if I take a podzol soil in Northern Michigan, I find that the surface layer has a moderate holding capacity, the b horizon has a rather large holding capacity, and the c horizon is somewhat intermediate. Another example, a Warsaw loam. Are you familiar with that term? It's a good prairie soil that tends to be kind of peculiar. It's set out in the middle of Michigan near Kalamazoo where it hadn't ought to be. You know, we're not in the prairie soil region. But here sets a nice big block of this soil, and if you look at the top, from about three to three and a half feet, it's a beautiful fine textured nice soil with a high absorbing capacity for phosphorus. Underneath it is a gravel layer that absorbs absolutely nothing. You just have to look at the individual soils, if they have an absorbing capacity down to that depth I think it can be utilized. I looked at one that had absorbed phosphorus down to 45 feet before it finally hit the water. This was from a
place in Michigan where for their municipal plant, quote, “they had a nice pothole that they poured everything into for many many years, and it just disappeared” unquote and of course over many years it saturated down to the groundwater which is 45 feet down.

Dr. M. Johnson: What is the state of the art and the feasibility of using slow release nitrogen fertilizers in agriculture?

Dr. B. Ellis: That’s a good question. You know there was a good push on slow release fertilizers back, almost fifteen years ago I guess, and in some cases they seem to have an applicability — particularly on lawns, mainly because it keeps the lawn owner from applying this fertilizer three or four times a year. I did some work on this once, in a greenhouse experiment where I set up a leaching system with different types of fertilizers. I came to the conclusion that it depends a lot on rainfall, because you could take the slow release fertilizer and let it go for a period, and if it released enough and then you got a big rain, it moved. On the other hand, if your rainfall happened to match your release pattern just right, you could give it all up, no problem. I would venture a guess that economically they will turn out to be less practical than other solutions.
FATE OF INSECTICIDES APPLIED TO LANDS AND CROPS

J.R.W. Miles

ABSTRACT

The London Research Institute of Agriculture Canada has investigated the distribution of insecticide residues in streams and ditches draining agricultural, urban and resort areas in Ontario. Analyses for parent insecticides and metabolites have been conducted in soil, water, bottom mud and fish. The highest residues in fish were found in the resort area—fish from agricultural and urban streams contained less than tolerance levels. Insecticide residues in all the water samples were very low, averaging below 50 parts per trillion. The significance of chronic exposure of biota in streams to these low levels of insecticides has not been fully investigated. Transport of insecticides by streams into the receiving lakes has been quantitated by combining the analytical data with water discharge data developed by Environment Canada.

1Agriculture Canada, Research Institute, London, Ontario.
The data presented here are from recent work of the soil insect section of the Research Institute, Agriculture Canada, London, Ontario. We have analyzed for insecticide residues resulting from spray applications to field crops, tobacco, orchards, vineyards, vegetable muck and even urban and resort areas, which should include the terminal residues from many insecticides. Because of the varied insect problems, the number of insecticides recommended or in use in these different cultures is large indeed. Without gas chromatography we would not be able to analyze samples of unknown history from areas with such widely varying insecticide use patterns.

In 1963 the electron capture detector became available for use with gas chromatographs, and since that time we have learned a great deal about the persistence and degradation of the organochlorine insecticides. Recently, other detectors have enabled us to analyze for residues of organophosphorus insecticides with greater sensitivity and precision. In 1964 our laboratory initiated a soil survey for insecticide residues in a number of farms in Ontario. A summary of the results is shown in Table 1.

Table 1
Chlorinated Hydrocarbon Residues in Soil in Relation to Crop Grown 1964

<table>
<thead>
<tr>
<th>Crop</th>
<th>DDT and Related Chemicals ppm</th>
<th>Cycloidiene Insecticides ppm</th>
<th>Total Residue ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar beets</td>
<td>0.4</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Forage and pasture</td>
<td>5</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>1.2</td>
<td>0.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Cereals</td>
<td>1.4</td>
<td>0.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Greenhouse vegetables</td>
<td>1.5</td>
<td>0.8</td>
<td>2.3</td>
</tr>
<tr>
<td>Tobacco</td>
<td>3.2</td>
<td>0.6</td>
<td>3.8</td>
</tr>
<tr>
<td>Vegetables</td>
<td>9.5</td>
<td>1.6</td>
<td>11.1</td>
</tr>
<tr>
<td>Orchards</td>
<td>61.8</td>
<td>61.8</td>
<td></td>
</tr>
</tbody>
</table>

We returned to the farms with greatest soil residue levels and planted crops to see if they would pick up residues greater than the accepted tolerances. The only instance of a residue greater than tolerance was with dieldrin in carrots and this residue was 0.11 ppm compared to a tolerance of 0.10 ppm! So
in general the levels of insecticide residues in soil were not resulting in undue residues in crops. The survey was repeated in 1966 and 1969. There was a slight increase in residues in 1966 and a slight decrease in 1969 to approximately the same levels as were found in 1964. This survey will be carried out again in 1974, which should indicate the trend since the banning of DDT, aldrin and dieldrin usage.

To examine the runoff from these soils into streams and water systems, we first chose a drainage ditch which drains a 1500 acre vegetable muck area at Erieau, Ontario. This muck area is below the level of Lake Erie and is surrounded by dykes. Individual farms are tile drained. The water in the sumps from the tile drains is automatically pumped into the drainage ditch which is pumped into Lake Erie by a diesel-powered pump capable of delivering 40,000 gallons per minute. Samples of soil, bottom mud and fish were taken periodically from April through October and analyzed for insecticide residues. The most significant residue was DDT and its metabolites, although measurable amounts of dieldrin and endosulfan were also found. The averages of the DDT results are presented in Table 2.

<table>
<thead>
<tr>
<th>Erieau Marsh</th>
<th>Total DDT</th>
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<tr>
<td>Soil (1969)</td>
<td>38.2 ppm</td>
</tr>
<tr>
<td>Water (1970)</td>
<td>43.0 ppt</td>
</tr>
<tr>
<td>Bottom Mud (1970)</td>
<td>0.22 ppm</td>
</tr>
<tr>
<td>Fish (1970)</td>
<td>0.76 ppm</td>
</tr>
</tbody>
</table>

If we can speak of a magnification from one medium to another, we find a 5130 times magnification factor from water to mud, and a 17,600 times factor from water to the fish. The concentration of DDT in water, coupled with the pumping data indicated a transfer into Lake Erie of maximum of 0.12 lb total DDT per month. This occurred in April when pumping was at a maximum.

In Table 3 are presented the averages for similar data from Big Creek, Norfolk County, Ontario, which drains 280 square miles of chiefly tobacco farms.

Magnification from water to bottom mud in Big Creek was 4,120 times, and from water to fish was 53,000 times! The 16 parts per trillion total DDT
concentration in water, when combined with stream flow data supplied by Water Survey of Canada, indicated an average transfer from Big Creek into Lake Erie of 0.11 pound total DDT per week during the April through October sampling period. When the weekly DDT concentrations were plotted against weekly rainfall there was some correlation of peaks, indicating that the greatest concentrations resulted from erosion of contaminated soil by rain (Figure 1).

Table 3

<table>
<thead>
<tr>
<th></th>
<th>Total DDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Creek</td>
<td></td>
</tr>
<tr>
<td>Soil (1969)</td>
<td>3.4 ppm</td>
</tr>
<tr>
<td>Water (1970)</td>
<td>16.0 ppt</td>
</tr>
<tr>
<td>Bottom mud (1970)</td>
<td>0.066 ppm</td>
</tr>
<tr>
<td>Fish (1970)</td>
<td>0.85 ppm</td>
</tr>
</tbody>
</table>

Even the peak concentrations in Figure 1 are very small, being in the low parts per trillion. How significant are these low levels of insecticide in water? In Table 4 are listed the drinking water standards for insecticides. But if fish are grown in water containing insecticides at these concentrations, the residues in the fish would exceed Food and Drug tolerances. Using a theoretical magnification of 10,000 times from water to fish, Ettinger and Mount (Environmental Science and Technology 1,203-5, 1967) arrived at the "Maximum Reasonable Stream Allowances" shown in column 2 of Table 4. The authors suggest that fish grown in water containing insecticides at these concentrations will be safe to eat. But in some fish samples we have calculated magnification factors up to 1 million, so from our work it would appear that Ettinger and Mount's allowances are too high. And their standards do not take into account

[Figure 1 diagram]
Table 4

<table>
<thead>
<tr>
<th>Raw and Drinking Water Standards for Biocides</th>
<th>Maximum Reasonable Stream Allowances</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppb</td>
<td>ppb</td>
</tr>
<tr>
<td>Aldrin</td>
<td>17</td>
</tr>
<tr>
<td>Chlordane</td>
<td>3</td>
</tr>
<tr>
<td>DDT</td>
<td>42</td>
</tr>
<tr>
<td>Dieldrin</td>
<td>17</td>
</tr>
<tr>
<td>Endrin</td>
<td>1</td>
</tr>
<tr>
<td>Heptachlor</td>
<td>18</td>
</tr>
<tr>
<td>Heptachlor epoxide</td>
<td>18</td>
</tr>
<tr>
<td>Lindane</td>
<td>56</td>
</tr>
<tr>
<td>Methoxychlor</td>
<td>35</td>
</tr>
</tbody>
</table>

the possible chronic effect of these low levels of insecticides on organisms and animals living in the water. The Environmental Protection Agency in the U.S. has suggested 50 parts per trillion as the environmental level for these insecticides.

In 1971 we compared insecticide levels in water, bottom mud and fish of Big Creek (Norfolk County), the Thames River, and the Muskoka River, (all in Ontario, Canada). As shown in Figure 2, Big Creek (280 sq. miles) drains an agricultural area (tobacco); the Thames River, an urban-agricultural area (City of London, population 200,000, plus 1200 square miles of dairy cattle country); and the Muskoka River drains 1700 square miles of resort area (biting-fly control). DDT use in the Big Creek area was restricted to cutworm control on tobacco in January 1970. DDT use in the urban-agricultural area was subject to the provincial ban of 1970. In the resort area, DDT had been used extensively for biting-fly control until 1966 when this use was discontinued. Insecticide residues found in the water of the three streams are shown in Table 5.

Table 5

<table>
<thead>
<tr>
<th>Residues in water pp10^12 (U.S. ppt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total DDT  dieldrin  γ-chlordane  endosulfan</td>
</tr>
<tr>
<td>---------------------------------------</td>
</tr>
<tr>
<td>Big Creek  11-79  3-41  &lt; 1- 2  &lt; 1-11</td>
</tr>
<tr>
<td>Thames R.  10-73  3-32  &lt; 1-21  &lt; 1- 3</td>
</tr>
<tr>
<td>Muskoka R.  8.57  3-11  —  —</td>
</tr>
</tbody>
</table>

The highest values of DDT and dieldrin occurred during spring runoff; from early summer through autumn the lower values would represent the norm. Dieldrin and the other cyclodiene insecticides were less in the Muskoka River, reflecting the mainly DDT-use-pattern for biting-fly control.

In Table 6 are listed the residues found in bottom mud of the three streams.

<table>
<thead>
<tr>
<th></th>
<th>Total DDT</th>
<th>Dieldrin</th>
<th>γ-chlordane</th>
<th>Endrin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Creek</td>
<td>14-22</td>
<td>0.7-4.5</td>
<td>&lt; 0.1-3</td>
<td>&lt; 0.2-0.3</td>
</tr>
<tr>
<td>Thames R.</td>
<td>2-4</td>
<td>0.3-0.6</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Muskoka R.</td>
<td>9-22</td>
<td>0.6-1.4</td>
<td>&lt; 0.1-2</td>
<td>&lt; 0.3-0.3</td>
</tr>
</tbody>
</table>

The low residue levels in the Thames River bottom mud reflect the low insecticide usage in the urban-agricultural area, but the residues in the agricultural and resort stream mud are about equal. A different situation exists with the residues in fish as shown in Table 7.

<table>
<thead>
<tr>
<th></th>
<th>Total DDT</th>
<th>Dieldrin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Creek (agricultural)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>brown trout</td>
<td>1.27</td>
<td>0.03</td>
</tr>
<tr>
<td>rainbow trout</td>
<td>0.42</td>
<td>0.01</td>
</tr>
<tr>
<td>rock bass</td>
<td>0.49</td>
<td>0.03</td>
</tr>
<tr>
<td>bluegill</td>
<td>0.45</td>
<td>0.03</td>
</tr>
<tr>
<td>Thames River (urban-agricultural)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>carp</td>
<td>0.03</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>bass</td>
<td>0.04</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Muskoka River (resort area)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sucker</td>
<td>1.98</td>
<td>0.01</td>
</tr>
<tr>
<td>lake trout</td>
<td>2.5-16.6</td>
<td>0.01-0.04</td>
</tr>
<tr>
<td>cisco</td>
<td>2.9-19.8</td>
<td>0.01-0.03</td>
</tr>
</tbody>
</table>
Insecticide residues were negligible in fish from the urban-agricultural stream. From the agricultural stream, residues were higher, but DDT was still well below the 5 ppm accepted tolerance. Residues were very high in some of the lake trout and cisco from the resort area stream, in fact the 19.8 ppm in cisco represents about one million times magnification factor from the average concentration of DDT in the water to the concentration in fish.

We have combined the concentrations of insecticides in water with stream flow data to calculate the transport of total-DDT by these three streams and in Figure 3 we show the weekly transport of DDT through the sampling period of April to October.

![Figure 3](image)

Although the transport by all three streams is very similar from July-October, great differences exist in the spring period when largest flow and greatest concentration of residues occur. In examining this figure it should be noted that the flow of the Muskoka River is about twice that of the Thames. In Table 8 are presented these transport data averaged over the whole sampling season and also adjusted for drainage area in the third column. Although DDT usage in the resort area presumably ceased in 1966, the resort area stream is a greater contributor of DDT to the Great Lakes than is either the agricultural or the urban-agricultural stream. It is difficult to compare such diverse areas. Insecticides in the agricultural area were probably incorporated into the soil and may be slow to discharge into a stream. The Muskoka River drains a Pre-Cambrian area with little or no true soil. The insecticides would have been applied on or near water and over the rocky land resulting in more rapid transfer of DDT to the aquatic ecosystem.
Recently we have been examining insecticide residues in the Holland Marsh which comprises about 6000 acres of deep muck just southwest of Lake Simcoe in the basin of the Schomberg River. The area is dyked and its drainage ditch is pumped into the river canal by pumps with capacity in excess of 100,000 gallons of water per minute. Combining the pumping data with the concentration of insecticides in the water results in the weekly transport rates shown in Figure 4.

Average transports of insecticides from the Holland Marsh in 1972 compared to Big Creek are shown in Table 9.
Table 9
Average Transport of Insecticides lb/week
April – October 1972

<table>
<thead>
<tr>
<th></th>
<th>Holland Marsh</th>
<th>Big Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total-DDT</td>
<td>0.26</td>
<td>0.09</td>
</tr>
<tr>
<td>dieldrin</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>diazinon</td>
<td>0.11</td>
<td>0.06</td>
</tr>
<tr>
<td>parathion</td>
<td>0.04</td>
<td>–</td>
</tr>
<tr>
<td>ethion</td>
<td>0.05</td>
<td>–</td>
</tr>
<tr>
<td>endrin</td>
<td>&lt; 0.01</td>
<td>–</td>
</tr>
<tr>
<td>$\alpha$-endosulfan</td>
<td>&lt; 0.01</td>
<td>–</td>
</tr>
<tr>
<td>$\beta$-Brlane</td>
<td>–</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Note that diazinon is next to DDT in the amount transported from the Holland Marsh. Diazinon is 40,000 times as soluble in water as DDT and this relation is typical of the newer replacements for the organochlorine insecticides. Although in general the replacement insecticides are more biodegradable than the organochlorines, their high solubility in water may present us with different ecological problems. However, analysis of fish from Lake Simcoe (the receptor of Holland Marsh effluent) in 1972 showed no DDT residues greater than 0.6 ppm (tolerance 5 ppm) and no organophosphorus residues were detected in the fish.

To summarize, based on the standards available to us, the levels of insecticides we have found in streams and drainage systems in Ontario are very small. We have not found any average concentration of insecticide in water greater than the "maximum reasonable stream allowances" for growing fish safe to eat. But we do not know the significance of chronic exposure of biota in streams to these low levels of insecticides in water. Insecticide residues in streams should be further investigated by biologists to determine the ecological significance of the low levels of insecticides we are finding by chemical analysis.

DISCUSSION

*Mr. J. Neil:* I should point out that there have been no hard chemicals used in Ontario since 1969/70, except for dieldrin and aldrin. What we're looking at here are residues.
Mr. J. Miles: Right, however, there is still in certain soils, depending on the practice, up to 40 parts per million of DDT, and less, of course, but still appreciable levels of dieldrin in the soils which contribute to this water contamination.

Mr. J. Neil: I think you'll agree that for the Land Drainage Reference Group purposes this is a fact of life at the present time and certainly other things such as diazinon etc. should be considered.

Mr. J. Miles: Yes. We have new detectors on our gas chromatographs now and are examining all of these for the organo-phosphorus compounds. Unfortunately when you get to the carbamates, the sensitivity drops down so far that you need horribly large samples to get the sensitivity that we're getting with the other chemicals. With reasonably sized samples there are lots of cases right now where the routine lab would miss detection, we're missing them ourselves even when we're looking for them specifically. I should expand just a little bit, one of the things missing from this talk is, how much of the insecticides are in the sediment, and how much are dissolved in water? We have done some work along that line and when you use glass filters to filter some of our water and then compare the sediment with the water in total we're finding 30% to 50% of the total insecticide that we report is in the sediment. Now, we're doing further work on that in finding larger proportions in the Holland Marsh Area where we've got the organic muck. Also, this year up in the marsh area we have a number of farms which are tile drained at which we have access to the delivery of the tile into the sump, and we've taken samples of them this spring that haven't been analyzed yet, but I look forward to seeing the results of those very eagerly. We've got the analysis of the soils from these farms. Because you can't really get on them in the spring we analyzed the soils in the early winter, and now we want to see how much of the insecticide that went in during the winter comes out in that spring runoff through the tile drains.

Dr. R. Frank: I'd like to comment on that. We did pick up waters this year from the marsh in connection with the University. These were waters collected from the sump and the canal. We have analyzed them and did find diazinon at rather high levels within a matter of a short period after it was applied to the soil and we traced it at weekly intervals. It tailed off very quickly.

Mr. J. Miles: You found diazinon, well I'd go along with this as I said before, it's about 40,000 times as soluble as DDT. I should also mention that I did not cover herbicides or fungicides. Fungicides are so difficult to analyze, even the ordinary residues on plants, that to tackle them in water is a pretty tough job. I imagine the plant pathologists will demand that soon. Herbicides; more people are getting into this area, there's some tile work being done now down at our Harrow station and I think they're finding some atrazine from the corn fields where they're collecting the tile drain and analyzing the water. But
there's much more data on insecticides as such, than there are on herbicides and fungicides.

Mr. R. Carter: The former speaker was talking about the proper application rate of fertilizers and I'm sure that as we get more into the regulation of pesticides there could hopefully be established application rates for the various types of pesticides. I have a great deal of difficulty with my own lawn spreader and my own nozzle sprayer for pesticides in determining just what application rate I'm really using. I either use it up too fast and I run out or whatever. When it gets to the people who are actually applying these large amounts, whether it's a farmer trying to apply his fertilizer or a helicopter applying pesticides in a spray or dry form, is the technology for knowing just how much you are applying in these areas really that good with the people who are actually applying it?

Mr. J. Miles: I think in agricultural work, on the farms you're okay, I mean you calibrate your sprayer and you change your nozzles when they get worn too much, and you calibrate your granular applicators. But I think that the big point is when you apply for your own small use. This has been a bad scene in the whole field for years. The home grower probably puts too much on in these instances compared to what a farmer would put on for the same insect pest; it's generally well calibrated on the farms. You have pesticide applicators there that are on the ball and they're not going to put any more on than is needed. We also this year have included orchards and vineyard areas in our work, but we haven't done any analyses on that yet. That has yet to come from our winter analysis. In our survey of the soil when we did the orchard work we found up to a couple of hundred parts per million DDT in the top two inches. It really stays in the top couple of inches of the soil in orchards; it doesn't penetrate down, contrary to others—say arsenic, which is more soluble, and which we found more evenly distributed down to around six inches.

Mr. M. Tellekson: You mentioned a certain amount of these pesticides in the bottom sediments. It's not quite clear to me how it is possible for these pesticides to get from the sediment into the water column and into the fish.

Mr. J. Miles: Well, it's a very interesting point that you have raised and I hope that part of that will be answered by some of our program data we're doing this year. Does the insecticide get into the water first or does it come through the mud? A lot of people speak of the larger concentration of insecticide in the bottom mud as being a reservoir that will go back into the water. From our data it doesn't appear this way because, as I have mentioned, the ratio of DDD to DDT is much higher on the bottom but the levels that we find in fish don't reflect this. We also analyze for the degradation products of DDD and we don't find them in large amounts in fish. The levels in fish being very high in DDE would indicate that they're getting DDT from the water. They
can absorb it from water through their gills besides getting it in their food supply.

Mr. M. Tellekson: One of the reasons I raised that issue is that you mentioned that they have high concentrations of these pesticides in fields, but it doesn’t appear in the crops that are grown except for carrots. That’s why I raised the question how would they get from the bottom sediments into some usable form.

Mr. J. Miles: Oh! You’ve got all the invertebrates that are living there and they become the food for the fish. But this bottom sediment is a very difficult portion to sample. It’s easy to get a water sample, but difficult to get a truly representative bottom sediment sample. Somebody was asking about measuring sediment. We were using this rather crude small cup on the end of a pole to get the top two inches but if you’re doing this close into shore where you can see what’s happening, as you lift, you see that the very fine sediment washes off as you lift it out of the water, and I feel we’ve lost the environment of the bottom feeding fish and the vertebrates. We recently got from the Water Survey of Canada in Guelph a diagram for what is called a Bogardi Bed Load Sampler and we used that. It is constructed in a box that slows down the water. It just sits down on the bottom, you don’t dig it in or anything, it slows down the bottom flowing water and sediments, and the sediment deposits in a chamber in the bottom. We’ve been taking that off, filtering and analyzing it separately, but the results are not available yet. But we were looking at that part also. And I feel when we get all these analyses done of the bed material, the bedload, the water and the sediment, the fish and the soil in the surrounding area, we’ll have a better picture of just where the residues come from because you put your finger on a part that really hasn’t been determined yet.

Mr. C. Schenk: Another important consideration in the transport process is that DDT is a fat seeker and there are small quantities in the water that are picked up to a great extent by your aquatic organisms of all types. It builds up, up through the food chain and is terminal in the fish.

Mr. J. Miles: Yes, some work done at Cornell, in Ithaca, and also Dick Frank’s work at Guelph shows that the parts per million of saturated DDT, in some fish corresponds linearly with the percent of fat of fish.

Mr. K. Shikaze: Recognizing that the use of hard chemicals was essentially terminated around 1970, do you have any information on the use patterns with respect to the insecticides in the various areas that you’ve studied? The amounts over previous, say five, ten, twenty years? And what impact has this had on the concentrations that you have found?

Mr. J. Miles: No we don’t have use data. We have sales data for Canada; we have some for Ontario. Unfortunately, you have the picture that a certain number
of insecticides are recommended by joint discussion of the Ontario Department of Agriculture and the Federal Department of Agriculture, but that doesn't mean that these materials are going to be used by the grower because he also has the specific chemical salesman coming out and giving him a push in the right direction or the wrong direction depending on your point of view.

Mr. K. Shikaze: In other words, all you have is the concentrations of the various insecticides as opposed to what's been used.

Mr. J. Miles: We feel that going into the fields and getting the actual levels in the soil gives us a starting point. We know then what's been used by the growers. We've got up in the Holland Marsh, DDT which is comprised of para-para DDT, para-para DDE, para-para DDD, ortho-para DDT, ortho-para DDE and ortho-para DDD up to 40 parts per million; aldrin up to .2ppm; dieldrin up to 1.4ppm; endrin up to .4ppm. We also have traces of diazinon, dyfonate, VC13, dursban, parathion, birlane and ethion on the farms that we worked on.

Dr. R. Frank: I might add that a survey is going on right now, like the one carried on in Wisconsin, to determine the quantities of pesticides used, possibly by watersheds.

Mr. J. Miles: Was this a questionnaire for growers?

Dr. R. Frank: Yes. It's a questionnaire concerning the amount used in different areas, different crops and different watersheds.

Mr. J. Neil: As a pesticide man and an environmentalist what advice might you give to the Land Drainage Reference Group with respect to the problems that you see in the future or continued problems that you see? For example, there are some classes of chemicals — carbamates for instance — which seem to me to carry with them a strong environmental hazard. Maybe there are others. Do you have any thoughts on this?

Mr. J. Miles: Analytical techniques. Sometimes materials get registered without there being an analytical technique that's suitable for a residue lab. Analytical techniques is one problem, and the other, as I pointed out, I would say would be the biological significance; the work by biologists to see what these low levels are going to do to the ecology. There is some interesting work being done by Metcalf with aquaria where he applies chemicals on the plants and they're taken up by the crustaceans, and by the fish. This sort of experiment with brand new chemicals I could see as being a real valuable guideline.

Mr. J. Neil: One other comment. In the province, for most chemicals classified or considered as hazardous, individual permits are required, so that there is documentation of the quantity used and where.

Mr. J. Miles: Yes, that would be from now on. When was that issued? It was this year, wasn't it?
Mr. J. Neil: Well, actually for some of them it's back to 1969.

Mr. J. Miles: In regard to your question, there will be more data available as we go on, as to what is actually being used.

Dr. V. Morley: Getting back to application route, I think the question was regarding how much loss we've had. Now you can consider the loss by erosion getting into the waterways. But the fact remains that when you're going to the aerial route to spray, there's a fantastic loss to the environment because the process of spraying is very inefficient. You may get as little as 10% hitting the target, the rest is being lost. Therefore, you'll get quite a lot travelling by the aerial route and I think perhaps getting into waterways and the bottom by sedimentation. One of the programs we have underway is to try to improve the efficiency of hitting the target.

Mr. J. Miles: Oh, yes there's an awful lot of work to be done there, and this will depend an awful lot on analytical technology too.

Mr. J. Neil: What about wind erosion?

Mr. J. Miles: Yes, wind erosion you should get with the air samples.

Dr. G. Chesters: Have you tried to look for degradation products of the phosphate insecticides in the waterways, particularly hydrolysis products such as the dialkoxy thiophosphoric acids?

Mr. J. Miles: If it was dihydroxy it is doubtful that our extraction would pick it up, but we do look for the oxygen analogs first which is the first ones you would expect. But once the organo-phosphorus compound oxidizes then it becomes more easily hydrolyzable to fairly non-toxic products, but unfortunately the analytical clean-up procedure is not good for a lot of insecticides. You have to examine each individual metabolite to make sure you're not throwing it away with the waste.

Dr. G. Chesters: Do you know anything about the toxicology of the thiophosphoric acid?

Mr. H. Miles: For the toxicology, yes extreme like phorate and DiSyston.

Dr. G. Chesters: I meant the thiophosphoric acid itself.

Mr. J. Miles: Oh, the thiophosphoric, I think I'd be getting out of my field, — Vic?

Dr. V. Morley: I would say there is very little information around. Toxicology is one of the areas in which we have the least information. The manufacturers are now required to give a methodology route, but as you say, this doesn't cover all aspects of the environment. They are supposed to give an environmental impact statement which could cover most of the points you're worried about —
the immediate points such as the immediate impact on the environment – but it wouldn’t go as far as in the case of dihydroxyacids unless you can show that these are actually persistent and most data show they are not.

**Dr. G. Chesters:** I’m talking about the dialkoxy ones and they are more persistent than most of the parent compounds.

**Dr. V. Morley:** Dialkoxy, these arrive by what route?

**Dr. G. Chesters:** By hydrolysis.

**Dr. V. Morley:** I don’t know anybody that’s working on them; I think the methodology is probably lacking. We’re getting into a different sort of ball park, a different game now, where all our old expertise in the persistent fat soluble ones is just going out of the window and we’re going to have to develop new techniques for the water soluble ones.

**Dr. G. Chesters:** At this time, if no more DDT or like compounds get into the Great Lakes, can you predict how long it will take before we’re back to acceptable levels?

**Mr. J. Miles:** Several papers in *Science*, this summer, have tried to answer that question; I’d have to look in my card file for them.

**Dr. R. Frank:** It appears in “Limits to Growth.”

**Dr. R. Parizek:** Isn’t part of the problem that these are stored in the soil? The measurements you showed us, show that in the upper several inches there is a considerable concentration of the material such as DDT. With erosion there seems to be a mechanism to get it off the landscape where it’s now stored and it means it can be released to the lakes for some prolonged period. Is that correct? And it’s a pretty stable compound you’re talking about.

**Mr. J. Miles:** It certainly is.

**Dr. R. Parizek:** So I think we’re talking about a prolonged release and I guess what concerns me is, at what rate are we finally going to erode the landscape down and get rid of it in order to feed into the lake, where the problem is compounded by the more soluble forms mentioned. Are they going to be absorbed in the soil or are they biodegradable in the soil, or are they just going to flush into the water tables like nitrate and eventually get into the watershed?

**Mr. J. Miles:** You’ve pinpointed some lines of research approaches, but when you multiply that by the number of materials and the number of metabolites for even say carbofuran (which I believe has 9 metabolites so far), then when you start looking for nine from one you really multiply your work. A lot of work has to be done.
Dr. R. Frank: I want to mention that book by Dennis Meadows; he projects that we won’t reach a peak in fish in the Great Lakes for another 25 years after we stop the use of DDT.

Dr. G. Chesters: Do you mean that maximum levels will be 25 years from now?

Dr. R. Frank: 25 years from the time we stopped.

Dr. J. Konrad: I’d just like to reiterate what Gordon said. To make the statement that the hard organophosphate compounds are believed to degrade to non-toxic or non-environmentally damaging material, is a very dangerous statement to make. Because I don’t think we know this. Take a look at the organophosphate chemicals. Just by hypothesizing degradation pathways, all of these degrade to biologically active materials, and I don’t think we know anything about them.

Mr. J. Miles: I hope I didn’t say they were more acceptable, did I?

Dr. J. Konrad: No. But we see it very often in the popular press. You get the idea that by switching from DDT to something like malathion or parathion that this is a panacea, and it really isn’t.

Mr. J. Miles: We’re looking at them very heavily for this reason. We are spending quite a bit of money right this summer in getting new GLC’s with detectors, so that we can work on these. Unfortunately some of the detectors are unstable and the flame photometric detector is not sensitive enough to get down to the levels I’ve been pointing out in water. We have to use the alkali flame and they are notoriously hard to operate, but that is our main tool for the O-P’s right now. Yet, some of these, especially carbofuran, are very toxic in themselves; it’s LD50 (acute oral) is down around 4 or 5mg/kg.

Dr. R. Parizek: Is it true that from the research time involved in this sort of work and the time frame that we’re operating under in our own Reference Group, that chances are we’re not going to make much of a dent in defining this problem, say in the next two years? I mean if you were to set up new instrumentation and really get under way?

Mr. J. Miles: I would say that the only thing that’s bright in that picture is the fact that it’s getting so darn expensive to produce an insecticide and get it on the market now, that the number that we’ve had to work with in the last few years has dropped way down and so I think this is what will level it off in the future. There will be less of the newer ones coming on the market, so you’ll have less materials to work with.

Dr. R. Parizek: At the same time if you try to make an assessment of the long list you showed us, over two years it would be pretty hard to gain much data on that too.
Mr. J. Miles: Oh, there are a lot of labs working on that right now; besides, as you know, when you see a paper in print the data is probably two years old.

Dr. G. Chesters: Is it also true of herbicides that the number of new compounds is decreasing?

Dr. V. Morley: No. The number of new herbicides is increasing and the number of fungicides. Fungicide use is going up dramatically and so is herbicide use. Manufacturers realize now, I think, the horrible recovery of funds expended. You’re talking now of about 10 million dollars and five years for production of one insecticide. So new insecticides on the market are virtually nil. No new ones are coming out; manufacturers are not willing to take the chance on something that may be on the market for a year or two and then disappear; data on fungicides is lacking; things are being produced now that we haven’t got a handle on. I think this is certainly why we’re getting lots of these being produced, this is where the research money is going.

Dr. G. Chesters: So we’re replacing one problem with another.

Dr. R. Holt: Isn’t there some evidence that the herbicides are increasing the effectiveness of the pesticides?

Mr. J. Miles: I just saw a paper the other day on something to this effect – yes. I also ran across an interesting paper on trout showing that they avoided some herbicides in tests but they didn’t avoid the insecticides and so, since they didn’t have an avoidance system for insecticides, they were succumbing to the effect of the insecticide.
SESSION 2

PILOT WATERSHED STUDIES AND RIVER AND GROUNDWATER TRANSPORT PHENOMENA

Chairman: J.G. Konrad,
Wisconsin Department of Natural Resources,
Special Studies Section
Dr. C. Maybe yes, there are a lot of the men working on that right now, because, as you know, what you see a power in using the site is probably two years old.

Dr. O. Certainly it is also true of herbicides that the number of new compounds is increasing.

Dr. V. Mention the number of new herbicides is increasing and the number of weeds. Particularly in cotton, there is going up dramatically and with herbicide use, manufacturers balance close. In Europe, the use of herbicides is generally accepted. You're talking now of about $5 million dollars a year for production of herbicides. So we're not saying we're in a crisis, but we are certainly faced with crises. The use of herbicides is increasing, but we're not being produced now that we haven't got a handle on. I think that inevitably, why we're getting lots of these being produced, that there are effects of the environmental impact of the herbicide.
ABSTRACT

The methodology and findings of nutrient budget studies done by Water Quality Branch — Ontario Ministry of the Environment, are discussed and the possible sources of errors in estimating relative contributions from various land uses are noted. The experience gained in these past studies is applied to the design of studies of various types of surveys for determining loadings and material balances which could be applied in the pilot basin studies.
INTRODUCTION

Significant changes in the aquatic environment can be attributed mainly to man's activities through increased population, industrial growth, intensification of agricultural production, recreational use of waters and improper management of land uses – to name a few.

In order to define the existing water quality and to determine proper implications for future water management of water uses, the former Ontario Water Resources Commission (OWRC) and now the Ministry of the Environment initiated numerous programs to evaluate the water quality of the river basins in the province and to assess their potential to support various water uses.

A major program in which the OWRC played a significant role was the investigation of the status of water quality of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River. This program, which was carried out at the request of the governments of Canada and the United States through the International Joint Commission in 1964, was initiated because of the increasing concern over the deterioration of water quality of the Lower Great Lakes and the increasing waste inputs. The resulting report of the International Joint Commission, published in 1970, quite clearly identified the major pollution problems. For example, the municipal and industrial waste inputs represented about 70% for Lake Erie, and 57% for Lake Ontario of the total phosphorus supply (IJC, 1970). It was also concluded in this report that the inputs to the waters of the basin of phosphorus, nitrogen and other nutrients from agricultural operations are difficult to control, but methods must be found to diminish them.

The report clearly established that land drainage is a significant source of many pollutants and that its contribution is difficult to measure. The relative significance of the problem is becoming magnified as the provision of tertiary treatment at the municipal point sources proceeds and nonpoint source pollution becomes more obvious. As a result, the International Land Use Activities Reference Group was formed to assess with an accuracy never done before, the various sources of pollution in land drainage and the impact of land use activities on the water quality of the Great Lakes.

The following summarizes the studies and experience of the Ministry of the Environment in measuring pollutants contained in land drainage and developing nutrient budgets using a mass balance equation. The experience gained is used in the design of the pilot watershed studies planned by the Land Use Activities Reference Group to be carried out in 1974.
THE MASS BALANCE EQUATION

In order to properly manage the water quality of a river basin, it is necessary to evaluate the sources and sinks of pollutants at various points within the basin and evaluate their relative significance. A mass balance for a given stream reach can be determined by the hydraulic, hydrological and geomorphological characteristics of the drainage basin and the river channel on the one hand, and the various physical, chemical and biological characteristics on the other hand. Such a mass balance equation should contain some or all of the following terms:

\[ Q_1 C_1 - Q_2 C_2 + \Sigma D + \Sigma P + \Delta S + K_D + L = 0 \]

where

- \( Q_1 C_1 \) is the total loading at the inlet of the river reach
- \( Q_2 C_2 \) is the total loading at the outlet of the river reach
- \( D \) is the total input from land drainage
- \( \Sigma P \) is the total input from point sources such as municipalities, industries and tributaries
- \( \Delta S \) is the change in storage of pollutants in the form of (i) sedimentation or scour and (ii) adsorption by attached algae or bacteria, etc.
- \( K_D \) is the decay of non-conservative substances
- \( L \) is the losses from the system through volatilization, emerging insects denitrification, fish taking etc.

The Material Transport, \( Q_1 C_1 \) and \( Q_2 C_2 \)

The first two terms represent the change in mass which is the net result of the inflow at the head of the reach and the outlet at the end of the reach over some time period. The accuracy of yield or mass rate (lb per day or lb per year) depends to a large extent on the frequency of sampling.

The Water Quality Monitoring Program carried out by the Ministry has been very useful in the calculation of material transport. This program includes collection of water quality samples from some 850 monitoring stations in the province at a frequency ranging between 12 and 18 samples per year. At each sampling approximately 18 parameters are measured, including nutrients.

In a review of the Water Quality Monitoring Program, Rizvi (1969) determined that at least 30 samples are required to obtain reasonable correlation between streamflow and concentrations of pollutants and thus allow a fairly good accuracy in the calculation of yields. (To facilitate yield calculations,
the Ministry has developed a computer program which allows integration of flow data from a continuous hydrograph and intermittently collected water quality data. The same review also indicated that it may be possible to reduce the number of readings required for a particular station. Several statistical analyses including one-way and two-way analyses of variance (parametric) and the Mann-Whitney U-test and the Kruskal-Wallis Analyses of Variance (non-parametric) were applied to the following parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved Oxygen</td>
<td>Suspended Solids</td>
</tr>
<tr>
<td>Coliforms</td>
<td>Nitrates + Nitrites</td>
</tr>
<tr>
<td>Total Solids</td>
<td>Total Kjeldahl nitrogen</td>
</tr>
<tr>
<td>5-day Biochemical Oxygen Demand (BOD)</td>
<td>Total Phosphorus</td>
</tr>
</tbody>
</table>

Because of the long term record of data, the Duffin Creek was chosen for this analysis. The data were grouped by trial and error by months, and the months within these groups were compared with one another to determine if the data for each month differed significantly. Though the grouping of months varied from one parameter to another, definite patterns were discernible and it was possible to establish groupings of months which applied in general to all eight parameters.

February March April
May June
July August
September October
November December January

While this study showed that it appears to be possible to reduce the number of monthly readings required for a particular station and still arrive at a reasonable estimate of mass transport, thereby achieving some financial gain, it was concluded that these results are not conclusive enough as they were based on a relatively short term set of data. A similar analysis is planned in the near future on a number of streams which represent varying degrees of agricultural and urban development in order to test the validity of the above groupings.

Using the Water Quality Monitoring data of the Moira, Salmon and Napanee rivers and Wilton Creek in the Eastern Lake Ontario Region, analyses of the phosphorus and nitrogen yields were made (Rizvi & Salbach, 1968). The streams drain primarily forest and pasture land and have essentially similar socio-economic, physical and climatological features. The analyses showed no cyclic trends of the nutrient concentration and the rise and fall of concentrations did not associate with the change in flow. The seasonal yield of both nutrients showed similar trends. During February, March and April the
total amount of nitrogen discharged from the streams ranged between 45-57 percent while the range for phosphorus was 40-50 percent. The mean yields of nitrogen and phosphorus for these streams were:

<table>
<thead>
<tr>
<th>Stream</th>
<th>Nitrogen (lbs N/sq mi yr)</th>
<th>Phosphorus (lbs PO_4/sq mi yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moira River</td>
<td>1580</td>
<td>332</td>
</tr>
<tr>
<td>Salmon River</td>
<td>1315</td>
<td>237</td>
</tr>
<tr>
<td>Napanee River</td>
<td>2028</td>
<td>810</td>
</tr>
<tr>
<td>Wilton Creek</td>
<td>2010</td>
<td>375</td>
</tr>
</tbody>
</table>

Land drainage contributions have been well documented in literature. Just to name a few, Sawyer (1947) reported a mean yield of phosphorus from agricultural drainage in the Madison Lakes area of Wisconsin of approximately 700 lbs PO_4 and 4500 lbs N per square mile per year. Sylvester (1961) determined yields up to 17,090 lbs. of PO_4 and 1360 lbs N per square miles year. Owen and Johnson (1966) and Neil, Johnson and Owen (1967) estimated the yields of total phosphorus (PO_4) and total nitrogen for sub-watersheds in the Metropolitan Toronto Region as follows:

<table>
<thead>
<tr>
<th>Basin</th>
<th>Total Nitrogen</th>
<th>Total Phosphorus (PO_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Humber River</td>
<td>1800</td>
<td>350</td>
</tr>
<tr>
<td>Little Rouge River</td>
<td>4800</td>
<td>600</td>
</tr>
<tr>
<td>Altona Creek</td>
<td>2300</td>
<td>290</td>
</tr>
</tbody>
</table>

The America Water Works Association Task Group (1967) reported contributions of 0.4 to 4 lbs of phosphorus per acre per year. Webber and Elrich (1967) reviewed the losses of phosphorus from agricultural land and reported these to range from .003 to 1.0 lbs per acre per year.

The above illustrates wide ranges of losses attributable to land drainage and makes it difficult to draw conclusions or make general rules to estimate the amount of nutrients in land drainage. Results of some of the studies conducted by the Ministry in several basins in the province show the percentage of nutrients attributable to land drainage as follows:

<table>
<thead>
<tr>
<th>Basin</th>
<th>Total Nitrogen</th>
<th>Total Phosphorus</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catfish Creek</td>
<td>95</td>
<td>75</td>
<td>Terry &amp; Salbach, 1968</td>
</tr>
<tr>
<td>Duffin Creek</td>
<td>89</td>
<td>50</td>
<td>Terry &amp; Salbach, 1968</td>
</tr>
<tr>
<td>Bay of Quinte</td>
<td>89</td>
<td>60</td>
<td>Owen &amp; Johnson, 1970</td>
</tr>
<tr>
<td>Metropolitan Toronto</td>
<td>19</td>
<td>42</td>
<td>IJC 1969</td>
</tr>
<tr>
<td>Region</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northwestern Lake</td>
<td>10</td>
<td>69</td>
<td>IJC 1969</td>
</tr>
</tbody>
</table>
The comparison of nutrient yield of Duffin and Catfish creeks in Southern Ontario indicated twice as high a rate for Catfish Creek. More intensive fertilizer application rates appeared to be the major reason for the higher levels. On the basis of this finding, it appeared that regression equations derived for estimating land drainage contributions should not be used for areas and ranges of data other than those from which they are derived. It is interesting to note that with few exceptions, land drainage represents a large proportion of the total yield of nitrogen and phosphorus. The generally lower phosphorus contribution when compared to nitrogen may be attributable to the fact that nitrogen compounds are more soluble and thus more readily carried away with land drainage. Phosphorus, on the other hand, adheres to fine soil particles and may gain access less readily through erosion. The relatively low yields for the Northwestern and Central Lake Ontario regions are attributable to the overriding influence of municipal waste inputs from Toronto and Hamilton.

It is noteworthy to mention the methodology followed to estimate land drainage contribution in the Thames River Basin. Twenty-eight sub-basins in the Thames River watershed were selected. None contain reservoirs and hence, changes in storage of pollutants and other losses were assumed to be zero on an annual basis. Fifteen to eighteen samples were collected at 31 sampling points and sampling frequency was increased during high flow periods. In addition to these 31 stations, there are 27 stations for point sources such as industries and municipalities. The selection of the river stations was based on the following considerations:

1. Wherever possible sub-basins were created where long term records for stream flow were available.

2. Sub-basins were selected on the basis of different land uses, such as urban, rural and a combination of both. Such a variety of land uses within the different sub-basins were considered necessary to evaluate land use-water quality relationships.

All stations were sampled for a variety of parameters including the nutrients.
The loading which is attributed to land drainage was obtained from a mass balance:

\[ \Sigma D = Q_2 C_2 - Q_1 C_1 - \Sigma P \]

This procedure produced reasonable results in every sub-basin with the exception of one, where a “negative” value for land drainage contribution was calculated. This may be attributed either to sampling error or to the fact that the term “AS” had significant influence in this particular case.

A regression analysis was made for all 28 sub-basins correlating loading against land use. A reasonable fit was obtained and the resulting equations were then used to estimate land contributions for the entire Thames River Basin. The Thames River Report, including the results of the analyses just mentioned, is expected to be published early next year.

Mathematical models are used in many cases and the types of mathematical models are well documented describing the decay of substances such as BOD\textsubscript{5}, radioactivity, and bacterial die-off in flowing streams. BOD\textsubscript{5} decay and its effect on the dissolved oxygen regime have been studied in many rivers in the province. Decay rates vary considerably according to the physical characteristics of rivers. The shallower fast flowing streams have higher decay rates. In addition, the decay rate depends on the type of material oxidized and the proximity to waste discharge, with higher rates generally occurring near the discharge point. Nutrient balance can be simplified if conservative forms of nutrients are considered. The organic form of nitrogen is non-conservative; however, total nitrogen may be considered a conservative substance if taken over a long time period such as a year.

Sedimentation can be a very significant factor in cases where river basins include reservoirs or lakes. Johnson & Owen (1970) estimated the amounts of nitrogen and phosphorus retained in impoundments indirectly by using the mass balance equation and directly using sediment traps. In the nutrient budget study for the Bay of Quinte, the authors followed both techniques and obtained the following estimates of retention for total phosphorus and total nitrogen.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Total Nitrogen retained %</th>
<th>Total Phosphorus retained %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment Traps</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>Nutrient Budget</td>
<td>33</td>
<td>44</td>
</tr>
</tbody>
</table>

The retention of constituents in the Kawartha Lakes watershed which have been calculated in that Budget Study, are as follows:
<table>
<thead>
<tr>
<th>Basin</th>
<th>Total Iron</th>
<th>Total Nitrogen</th>
<th>Total Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice Lake</td>
<td>36%</td>
<td>23%</td>
<td>45%</td>
</tr>
<tr>
<td>Scugog Lake</td>
<td>80%</td>
<td>17%</td>
<td>52%</td>
</tr>
<tr>
<td>Balsam Lake</td>
<td>—</td>
<td>28%</td>
<td>35%</td>
</tr>
<tr>
<td>Cameron Lake</td>
<td>24%</td>
<td>15%</td>
<td>38%</td>
</tr>
<tr>
<td>Stony-Clear Lake</td>
<td>37%</td>
<td>6%</td>
<td>19%</td>
</tr>
<tr>
<td>Sturgeon Lake</td>
<td>36%</td>
<td>7%</td>
<td>17%</td>
</tr>
</tbody>
</table>

It is evident that substantial amounts of pollutants can settle in large reservoirs or lakes. However, in order to simplify the mass balance equation, it is general practice to neglect the change of storage of pollutants $\Delta S$ in river reaches or basins which do not contain reservoirs or lakes.

The complex interaction of nutrients at the sediment-water interface and the technical difficulties of measuring the generation of nutrients from sediments as inputs, make the term $\Delta S$ difficult to evaluate directly.

Experience gained in the IJC Lower Lakes investigations where a considerable amount of estimating municipal and industrial waste inputs had to be made as part of the material balance, emphasized the importance to ensure measurement of all point waste sources, including storm water runoff, particularly in combined sewer systems. Bacteriological studies were made in the City of Kingston by the OWRC in 1970-1972 to represent the natural contamination of storm water as it drains across urban streets and private property. It was found that the counts of coliforms ranged from 20 to 45 million per 100 ml and from 10 to 330,000 per 100 ml for fecal coliforms.

McLaren Associates (1960) and Dunbar and Henry (1966) conducted studies about pollution due to storm water and overflows from combined sewers for the City of Toronto. It was revealed that $\text{BOD}_5$ ranged up to 260 mg/l from combined sewers. Also, in storm waters $\text{BOD}_5$ ranged 12 to 19 mg/l. The latter figures appear to be low. Suspended solids ranged from 17 to 930 mg/l for combined sewer outflows and from 43 to 150 mg/l for storm water runoff.

If chlorides are used for preparing a material balance, it is essential to take into account the contributions through the use of de-icing salt. Nutrient balance studies will also have to account for contributions through rainfall.
APPLICATION OF LOADING AND MASS BALANCE CALCULATIONS TO THE PILOT BASIN STUDIES

IJC STUDY PLAN DEFINITION OF TASK C

"Intensive studies of a small number of representative watersheds selected and conducted to permit some extrapolation of data to the entire Great Lakes Basin and to relate contamination of water quality, which may be found at river mouths on the Great Lakes, to specific land uses and practices."

Detailed intensive investigation will include:

1. On site investigations of various agricultural activities in different geological and climatic areas of the basin to measure the qualitative and quantitative significance of agricultural activities on surface and groundwater.

2. Field investigations to measure the significance and magnitude of urban and industrial runoff, and construction and maintenance of transportation and utility corridors.

3. Studies to measure material inputs from forest land, unused and unallocated land and recreational areas.

4. Field studies to measure the effects of disposal, sewage sludge disposal and liquid waste disposal practices on surface and groundwater quality.

5. Investigations to determine the significance of bank erosion and landfill operations on water quality.

6. Extensive and intensive water quality monitoring networks to determine transportation mechanisms of materials from land drainage in surface and groundwater systems.

It is to this last aspect of Task C activities and particular surface water monitoring that this portion of the paper is presented. Although there was some discussion of a surface water quality monitoring program at a recent meeting of the Task C Technical Committee, the following presentation is a conceptual plan currently being developed and discussed by staff of the Ontario Ministry of the Environment based on our past experiences in this type of study.

We recognize that a unified approach will have to be developed for all such studies in the Great Lakes Basin. We, therefore, offer these ideas as one way of tackling the problem and would welcome comments or suggestions that anyone might have.

Pilot basin studies are to be conducted in three Ontario basins: Grand River Basin, covering an area of 2600 square miles of the southern
and eastern portions of eastern Ontario and draining to Lake Erie; the Saugeen River, draining 1600 square miles of the central section of western Ontario and draining to Lake Huron; and the Wilton Creek Basin, draining 57 square miles in eastern Ontario and draining to Lake Ontario.

As many land uses as possible will be investigated within these basins, but to adequately evaluate all land uses, some sub-basins in other parts of Ontario will be studied.

Water quality surveys in the river basins will employ loading calculation and materials balancing techniques for a number of purposes. Figures 1 through 4 illustrate some of these uses.

Figure 1 represents, probably, the most common use of loading calculations — tributary loading to the Great Lakes. This calculation was used extensively in the preparation of the 1969 IJC Lower Lakes Report and will be employed in the IJC Upper Lakes Study. Confidence in the results of these calculations is dependent upon the adequate definition of C and Q. Measured tributary loading figures will be valuable in verifying extrapolated land use loadings outside the pilot basins.

Figure 2 represents a mass balance study that could be carried out in a sub-basin that supports one predominant land use. Material inputs from this land-use could be traced without interference from other land uses and transportation mechanisms for particular parameters could be defined. The results of this type of study could also be employed in the determination of the relationship between yield and distance from the watercourse using drainage patterns within the sub-basin.

Figure 3 represents a survey technique where the total loading from a particular land use could be calculated indirectly by subtracting upstream from downstream loading values. This method could be used where direct measurement of the source could not be made or it could be employed in any of the individual land use studies to measure seasonal loading fluctuations (when the more intensive studies as outlined in Figure 2 could not be undertaken).

Figure 4 presents the complete extensive basin water quality monitoring program. Sampling stations are located above and below all land use pilot study areas and at other key locations in the basin (in headwaters, at point sources, at reservoirs, lakes and other areas with unique physical features, etc.). Sampling frequencies would be determined for each individual station taking into account such features as the flow hydrograph, physiography, seasonal changes in nearby land uses, etc. A sufficient number of streamflow gauging stations would be established to adequately describe streamflow at each sampling station. Concentrations of suspended and dissolved material would be
PURPOSE:

1. To measure instantaneous, daily, seasonal or annual tributary loadings to Lake.

Total loading calculations include quantitative measurement of suspended and dissolved material, floating material and bedload material.

Figure 1
DEFINITION of TRANSPORT PHENOMENA for INDIVIDUAL
LAND USES

PURPOSES:

1. Calculation of materials input from individual land uses.
2. Definition of transport mechanisms for individual parameters.
3. Relating yield to distance from stream.
   (sub-section 3 v.s. sub-section 4)

Figure 2
Indirect Calculation of Land Use Inputs

INPUT FROM LAND USE "A" = $C_2 Q_2 - C_1 Q_1$

PURPOSE:

To measure indirectly, by materials balance loadings from land uses—

a) Where direct measurement of inputs is not possible.

b) To confirm input loadings measured directly.

Figure 3
LONG TERM EXTENSIVE BASIN SURVEILLANCE

PURPOSES:

1. To determine general transportation phenomena.
2. To confirm mathematical modelling techniques for extrapolation.
3. To determine seasonal changes in loadings from individual land uses.

Figure 4
measured at each station and bedload transportation and floating material would be measured wherever possible.

Data from this program would be employed, in part, to satisfy the requirements outlined in the study described in Figure 3. However, the more important use of data from this type of study would be the formulation and verification of modelling techniques for extrapolation of land use inputs to other rivers in the Great Lakes Basin.

Figures 5 and 6 present ideas on transport mechanism and material losses within the river system which should be taken into account when designing any of the aforementioned survey techniques.

In the past, the significance of bedload material, floating material and groundwater losses and gains has not, in general, been adequately studied in conjunction with material loadings or mass balances. Existing techniques must be employed or new methods developed to measure these portions of the total loadings.

In regard to the temporary and permanent losses shown in Figure 6, it is apparent that extensive studies of the physical characteristics (flow velocities, cross-sectional and longitudinal streambed profiles, biomass, etc.) of each river basin are required.

In summary, the information on the preceding few pages is by no means meant to be a complete basin survey plan. It is the authors' intention to present some ideas to stimulate discussion which will ultimately result in a comprehensive "Pilot Basin Study" employing the best technology available.

DISCUSSION

There are many possible sources of errors which could lead to unreliable estimates of yields of nutrients in general, and land drainage yields in particular. Some of the most important ones relate to reliable streamflow data (i.e. measured where chemical sampling is carried out) and an adequate number of measurements. Planning a material balance measurement of land drainage yields will have to take into account the seasonal variation of material transport. More intensive sampling appears to be generally required during the spring run-off, when about 50% of the nutrients escape. This procedure was followed in the IFYGL work on Lake Ontario with weekly sampling carried out during the spring run-off (mid-March to mid-May). Similar procedures are used in the water quality monitoring program of lakes Huron and Superior for the IJC Upper Lakes investigation and the Thames River and Kawartha Lakes Water Quality Management Studies, to name just a few.
Transport Mechanisms

-Floating Material (LF)
- Dissolved (CDQ = L_D)
- Suspended (CSQ = L_S)
- Bedload (LB)

Loss to groundwater

Input from groundwater

\( Q_{C1} + Q_{C2} \)

\( Q_{G1} - Q_{G2} \)

Figure 5
Temporary and Permanent Losses

GASES TO THE ATMOSPHERE

EMERGENT INVERTEBRATES & FISH TAKEN

SEASONAL LOSSES TO ROOTED AND ATTACHED AQUATICS

TEMPORARY LOSS OF PARTICULATE MATERIAL TO BOTTOM DEPOSITS
  (SETTLING DURING LOW FLOW -SCOUR DURING HIGH FLOW)

PERENNIAL LOSS OF PARTICULATE MATERIAL TO SEDIMENT

Figure 6
Other possible sources of errors may include the following, (not necessarily in order of importance):

1. Existence of a point source (municipal or industrial) near the outlet of the basin under consideration may result in incomplete mixing of the effluent causing interference with measurement of the yield at the outlet and hence, negative values for land contribution may result. Therefore, the assumption that one sample is representative for the water quality for an entire cross-section of a stream, may be erroneous; it requires careful field checks.

2. Insufficient information about stream flows due to lack of flow gauging stations: in many cases the flows are pro-rated from long term flow records for streams in the vicinity.

3. The influence of upstream inputs of pollutants may be affected by some or all of the following processes, which have to be carefully measured and taken into account in a mass balance: (a) removal of constituents by sedimentation or adsorption, (b) addition of BOD and nutrients by scour of bottom deposits or by diffusion of partly decomposed organic products from the benthic layers to the overlying water.

4. The lack of good municipal and industrial input data sometimes requires making estimates of contributions of point sources.

5. The extent of the reliability of laboratory analyses of parameters.

The decay of non-conservative substances becomes important in the event that the decay rate is high relative to the lengths of time travel from the source of pollutant to the point where measurements are made.

**CONCLUSIONS**

Although with the provision of tertiary treatment pollution abatement programs for point sources (industrial and municipal) are effective in limiting the material inputs to the Great Lakes, land drainage remains a largely unchecked source of a variety of pollutants, including nutrients. Previous studies conducted by the Ministry of the Environment indicated that land drainage contributions amounted to a large portion of the total loadings entering the waterways. As a result, the IJC formed the Land Use Activities Reference Group to assess the various sources of pollution in land drainage and their impact on the water quality of the Great Lakes. Well-planned sampling and measurement programs should be undertaken to collect data useful to determine magnitude and significance of materials contributed by land drainage to surface and
groundwaters. Such data would include flow velocities, cross-sectional and longitudinal streambed profiles, chemical (e.g. nutrients, metals, pesticides), physical and biological parameters for each basin.

Mathematical models derived for estimating land drainage contribution should not be used for areas other than those from which they are derived unless verification of modelling techniques for extrapolation of land use inputs is made. To assess the various sources of pollution in land drainage and the impact of land use activities on water quality of the Great Lakes, a number of mathematical modelling and mass balance techniques are available and all should be assessed to determine their worth in this project. While this paper includes a methodology for the proposed pilot studies, research should be continued to achieve comprehensive “Pilot Basin Studies Procedure” using the best technology available. A unified approach should be undertaken by Canada and United States in such studies in the Great Lakes Basin to assess with a high degree of accuracy the various sources of land drainage.

REFERENCES


International Joint Commission, 1969. Reports on the Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence Rivers, Vols. 1, 2 and 3.


**DISCUSSION**

*Mr. R. Carter:* If you are trying to determine the effect of land drainage on the boundary waters, you sample the input at the mouth of the streams and of course you sample the boundary waters and you find that there is a certain input, but it may or may not show up in measurements on the boundary waters. I thought perhaps that the pilot watershed studies were to determine where the inputs were coming from and what could be done about them. So I wonder if it's really important to be able to come up with a mass balance in the watersheds. In other words, are we really concerned with how much may be lost from the system that we can't equate if it has no real relationship to the effect on the water quality of boundary waters or at the mouth of a river? And if it is a nontreatable kind of thing—such as loss to
groundwater or input to groundwater — is this an academic type of exercise in order to come up with a true mass balance, or do you think all of these features relate to the pilot watershed study for this particular purpose?

Mr. J. Ralston: I think they can all relate to the task at hand if only for the purpose of helping with extrapolations. It appears that extrapolation from pilot basins to the remaining watersheds is going to be one of the most difficult tasks in this study. The more information available on the physical characteristics of any water quality parameter once it is in the river system, how it reacts within the watercourse, whether it will ever arrive at the lake, etc., the better the extrapolations we can make and the more confidence we’ll have in our final data. I agree that each of these pilot studies is going to give us good data for basin management purposes, but I think the important thing is that all aspects should be considered in this initial planning stage, to determine whether they are or are not in fact needed for the final stages of the program. Now in regard to the significance of various parameters at the mouth, I agree that some of the parameters may not be important. It’s unfortunate that this Reference Study is built in the time frame it is. I think if the Task B Group could answer some of the questions before the Task C Group were to go into the field, then a lot of work might be eliminated.

Mr. S. Salbach: For enforcement purposes I think one would have to know the relative significance of each source, because you know that agriculturists will tell you point blank that they’re not to blame, that they’re not contributing to pollution. If one can demonstrate through a mass balance that agriculture in fact does contribute then you’ll have the required ammunition for control. If you think that it’s an academic exercise, I would think that you would be in a very weak position to go that one step beyond just determining what the yield is, namely to enforce control. We have to get into practices that we can control.

Mr. W. Richardson: I was wondering if you had run across the same problem that I have when measuring the concentration and flow at the mouth of rivers that reach the Great Lakes, and that is the influence of the lake water itself on the concentration measured?

Mr. J. Ralston: Yes we have. One way we solve this problem is to move upstream away from the influence of the lake. There aren’t too many streams in Ontario that are influenced a great distance upstream. If you have to go five or six miles upstream I really think you would have a problem there and you would have to look at different techniques.

Mr. S. Salbach: The Essex-Kent County area is a problem in that the terrain is so flat you would have to go a long way upstream.

Mr. Ralston: Of course, in that area we’re talking about streams which have no significant streamflow for most of the year.
Mr. M. Tellekson: I was going to tell Steve that I wouldn’t worry about the negative loading on the stream there because it reminds me of a story several years ago when the EPA hired a professor from Harvard to develop a grandiose mathematical model for calculating stream flow and reservoir storage. You were supposed to be able to throw parameters in it and come out with loadings and that sort of thing. He spent six months developing it and the first problem that we gave him concerned that Big Muddy River in southern Illinois. The maximum flow that he gave us had already been exceeded a number of times down there and the minimum flow was a negative flow so that I think in any statistical analysis that you get into, you’re going to run into hang-ups like this.

Mr. S. Salbach: Of course, it all relates again to the data, to the availability of adequate information. It’s usually the case that one just doesn’t have all the information and therefore makes errors.

Mr. M. Tellekson: Sometimes in your statistical work, you have to make certain assumptions; whenever you get to the extremes of your curve, then the thing starts to fall apart. So you’re likely to end up with negative numbers.

Dr. G.J. Stopps: I was wondering, as a complete layman in this area, that you’re obviously attempting some very great mathematical modelling and extrapolations. To what extent can you make use of tracer materials to test your models?

Mr. J. Ralston: Well, we’re thinking of this. Both tracers which could be introduced and natural isotopes that may be found in only one particular land use and which we could follow a lot further than we could trace general water quality parameters. That would be fine if we had the tools and laboratory capabilities to handle sufficient quantities of these materials. However, the introduction of a tracer would only give us a handle on one particular type of material; characteristics of other materials might differ significantly when they entered the stream. One particular material might be coming in, in the dissolved form, whereas some of the other parameters are entirely attached to particulate matter. Again, here it depends on what type of particulate matter it may be attached to as to how far it’s going to move downstream. Another question is how readily it’s taken up, if the material enters the watercourse in soluble form. If we use tracers to determine the characteristics of transportation of materials, they may give us a totally wrong impression.

Dr. G.J. Stopps: I was thinking that you might need a battery of tracers and I recognize that there are severe limitations on what you could use as tracers.

Mr. K. Shikaze: John, I’m glad to see that the state of the art of carrying out stream surveys is improving. As a general comment, however, one of the reasons
that the Land Use Activities Reference Group was formed was because the Lower Lakes Report, which as the result of a study over a number of years, indicated that we couldn’t attribute or assess what the various diffuse sources contributing to the pollution of the Great Lakes were. In other words, there is an unaccountable thirty or forty percent input as far as pollution of the Great Lakes is concerned. You’ve carried out a number of water quality surveys recently. Have you interpreted your latest data to find out what the relative contributions are of diffuse sources to point sources now? In other words, have you updated the Lower Lakes Study information? Are we now talking thirty or forty percent or forty or fifty percent as coming from diffuse sources?

Mr. J. Ralston: We have updated our figures and to the best of my knowledge, I don’t think there is a significant change. The figures we came up with at that time are not significantly different from the data collected in 1971 or 1972. A lot of things have changed, however, since that material went into that earlier report. The information on point source discharges has improved significantly. But I think as far as tributary stream loadings are concerned, we’re still talking about somewhere between 50 to 90% of most pollutants coming from land drainage. When you compare land drainage to total lake loadings it is a somewhat lower percentage because of all the point sources that are on the lakes, particularly Lake Erie and the Detroit River system. But I still think the percentages mentioned hold fairly true for the rivers.

Mr. S. Salbach: With the implementation of phosphorus restrictions on the Canadian side, the relative significance of the land contribution would change and it would become more significant. I don’t think the U.S. has done this, but I stand to be corrected. Nevertheless, this would be one factor that would change the relative significance.

Mr. K. Shikaze: The question I asked was, is it measurable to date?

Mr. J. Ralston: Yes. There have been measured reductions in the phosphorus loading due to the change in the formulation of detergents.

Mr. S. Salbach: I do recall that we went through an exercise looking at data from sewage treatment plants and it showed a reduction in phosphorus because of the reformulation of detergents.

Mr. J. Ketchison: I’d just like to ask Steve Salbach if he could rationalize that statement that farmers are complaining that they’re at a loss, for answers and figures that 60 to 90% of inputs are coming from land drainage. If that were true, is there an explanation for it? Could it happen that way? In other words, could there be that much contribution from agriculture? Could stream bank erosion account for that much?
Mr. S. Salbach: Well, I think from what we heard this morning it becomes quite obvious that agricultural practices are a contributing factor and probably a very significant contributing factor. But our figures have been arrived at by using a black box approach, meaning we measure what goes in and what goes out, but we haven’t looked at the processes in between, so we are really in no position to say that this in fact, comes from agriculture and this comes from whatever else is there – septic tanks, urban populations etc., etc. But we have, as I pointed out in the talk, related the water quality variations and the poundages that are carried in a stream with various land uses. In Catfish Creek, which had two to three times as much fertilization as Duffin’s Creek, the yields are twice as large. This circumstantial evidence certainly leads one to conclude that agriculture plays a very significant factor in the so-called land drainage figure. This is my professional opinion.

Mr. M. Tellekson: I might say that a year and a half ago Illinois conducted a series of 10 public hearings on some proposed regulations for regulating the amount of fertilizer applied to the land. The one theme that ran throughout all 10 hearings as far as the farmers were concerned was that “no farmer would be stupid enough to spend money applying more fertilizer than was necessary”, therefore there couldn’t be any contribution from agricultural land, and yet I think this morning the figures demonstrated that at least 25% of the farmers are applying more fertilizer than is necessary. I think that while they’re a minority their contribution may be substantial as far as the amount that’s put into the stream is concerned.

Dr. M. Johnson: I’d like to recount one experience when we first started monitoring nutrients in rivers (inflows) in 1964 in the Toronto region. We looked at the data we had showing outputs from agricultural watersheds. It so happened this study coincided with a river bank erosion inventory around reservoir sites. The thought occurred to me that conceivably the phosphorus loadings we were finding might be accounted for by the erosion from the river banks alone. We had figures on the surface area or exposed area and evaluated that there was enough phosphorus in a one inch layer to account for all the phosphorus loading at the bottom of the watershed. I hope that we can discriminate some of these practical matters and that a distinction can be made between river bank erosion and surface erosion of soil, because the implication of responsibilities and the amount of subsidization required would be entirely different for these different sources.

Dr. K. Patalas: I would like to ask both authors about what I consider to be a methodological difficulty in the assessment of the contribution of agricultural land uses versus nonagricultural land uses. The difficulty is connected with the problem of how to find a proper control. You are comparing, for example, a part of the drainage basin which is used for agriculture, with another which is not used for this purpose. The reason for these different uses may be that one part
of the drainage basin is more fertile and therefore the geology of this drainage basin is also different. Therefore, just by a comparison of the land drainage from land used for agriculture and that which is not used for agriculture does not lead to valid conclusions about agriculture itself. The ideal would be to find a situation where you have identical geological drainage basins and for certain reasons one or part of these drainage basins is used for agriculture, and the other is not used.

Mr. S. Salbach: Does this relate to the question of background? In other words, if the yield is about 300 pounds per square mile per year, would you say 150 of those pounds may have come down that river whether anybody had been up there or not?

Dr. K. Patalas: I say that this difference may simply be the function of the differences in geology of these two land use drainage areas and not necessarily due to the fact that one was used for agriculture and the other was not.

Mr. S. Salbach: I talked about the experiences we had in Eastern Ontario with streams draining to Lake Ontario, and these are streams side by side that are quite similar in their physiographic nature and yet the yields out of them are completely different. So how do you account for this difference of yield or identify things that could affect this yield?

Mr. C. Schenk: Lloyd Eckel in Task B has expounded a number of times on the need for detailing the physiographic, geologic and physical characteristics of the representative basins, so I think that we will probably assess and determine these factors.

Mr. A.K. Watt: Question to Dr. Johnson. This analysis that you made of the soil in which you said one inch of erosion over the area would have accounted for the difference in the phosphorus loading. Was this what you meant to indicate?

Dr. M.G. Johnson: There was as much phosphorus in one inch of that exposed river bank as what we had measured in the year, at a point at the bottom of the watershed.

Mr. A.K. Watt: The soil sample that you took — do you remember what it was? Was it mineral deposits?

Dr. M.G. Johnson: It was field plain; we had been sampling from topsoil, subsoil and field plain.

Mr. A.K. Watt: So that topsoil might not have had in input of any kind, i.e. had no agricultural input.

Dr. M.G. Johnson: No, this was a sampling generally of the parent material. These were banks varying from several feet to a great height.
Mr. D. Jeffs: May I ask when the big loss in agriculture land occurs?

Dr. M. Johnson: It occurs in the period of heavy thunder showers, usually late June to July.

Dr. J. Konard: Dr. Patalas raised a very good question and a valid concern to the entire Reference Group and I was wondering if he might possibly have such a watershed in mind.

Dr. K. Patalas: Well, I think it needs a very exact study of a particular situation. I am doing a similar thing on the lakes. I’m trying to find out the direct influence of man’s activity on a particular lake. I’m trying to select a particular polluted lake and then I’m trying to find, in the same geological region, lakes which are the same from a geological point of view, that have the same hydrology; the only difference is the pollution in the lakes. I find that this is a most difficult problem because our conclusion about the influence or contribution of man’s activities, or in this case of a specific land use, is based on comparison. Therefore, we have to compare this land use and its contributions with something else; but what something else? Something which is identical, the only difference being that there are no agricultural activities on it.

Dr. D. Dodge: I think that you’ll find that in Ontario, if there’s a piece of land that looks fairly suitable for agricultural practices it’s already under cultivation, so it’s most enviable that you are in the position of having a control lake, but I don’t think you’re going to find that, at least not in the Ontario portion of the Great Lakes Basin.

Dr. K. Patalas: I know, but this is exactly the difficulty. Because when you do an experiment you have to have a control or reference point; if you don’t have this reference point, you simply cannot draw a valid conclusion. For example, you can’t conclude that a certain loading is related to agricultural practices; it may simply be related to the type of drainage patterns of the land, which means we can reverse the conclusion and state that this is the kind of high contribution seen not because of the agricultural practices, but because it’s a very rich drainage basin and that this is the reason why agriculture is located in this area.

Dr. M.G. Johnson: I think people are cutting this thing too coarse. We’re not interested here in agriculture as a whole but of practices within agriculture. We want to look at river banks, protected and unprotected; we want to look at Class 3 land which is tilled against Class 3 land which is covered permanently. I think we can get to a degree of resolution that tends to make this argument redundant.

Mr. S. Salbach: But are we suggesting in this discussion here that the whole contribution is natural that the source you’re concerned with does not contribute a significant quantity of nutrients and has nothing to do with
agricultural practices? Are you suggesting or implying then that we don’t have to do anything about it?

*Dr. K. Patalas:* No, I’m not suggesting that. I’m just indicating some methodological difficulties in this type of approach.

*Mr. S. Salbach:* Yes, but why are you worrying about trying to establish this precisely?

*Dr. K. Patalas:* Because you are asking a question. What is the contribution of agricultural land or agricultural land use? If you ask such a question, it means you have to find out how much agricultural land is contributing and then you have to find out the reference point. How much this land would contribute if there would be no agriculture?

*Mr. S. Salbach:* In either case nutrients are contributed, so I am only really interested in how much each land use contributes and then in controlling it as well as I can.

*Dr. K. Patalas:* Okay, but this is a different question; you have just presented a photograph of the situation. You are just describing the drainage basin as you see it. In other words, you’re saying this kind of drainage basin gives me so much contribution in nutrients. But I understood that you were asking the first basic question and that is what is the contribution of a particular type of land use.

*Mr. A.K. Watt:* Yes, because loadings may not be due to the land use at all but to natural conditions, without this comparison. You certainly can’t say that a certain percentage is from agricultural use.

*Mr. S. Salbach:* Possibly the term agricultural is misused here. I think one of the basic things that we want to zero in on is the relative significance of various land uses on water quality, sediments, etc. Once we find these, the obvious significance of each source compared to the municipal, industrial, and other point sources that we know of will be determined. Then I think we will want to design the control measures that we feel are feasible and necessary to protect against these loadings. And as to whether it’s natural or man made, that’s something else again.
ABSTRACT

This paper is a transcript of an oral report on the development and objectives of the Black Creek project. This is a cooperative project funded in part by the U.S. Environmental Agency with land treatment practices being planned and applied by the Soil Conservation Service and the local Soil and Water Conservation District. Purdue University will monitor and analyze the runoff. Biological and sociological studies are also included. The 12,000 acre watershed is primarily in agricultural use and is privately owned and operated. It is believed to be typical of most of the sub-basins in the Maumee River watershed. The project will attempt to evaluate and demonstrate the effect of land treatment practices on the reduction of sediment and related pollutants in runoff water.
This morning's program has been very enjoyable. Each presentation has been informative and specific. What I am going to talk to you about is not what we have done, but what we hope to do. It is reported in this plan of work published by the U.S. Environmental Protection Agency. I cannot report results to you today because we are only starting. It will be sometime yet before there are results: for example, we have made only a very few water sample analyses as most of our samples are still frozen waiting for the arrival of the necessary analytical equipment.

In the introduction this study was referred to as an Allen County project; it has also been referred to as the "Black Creek Study". The original name included "Reduction of Sediment and Related Pollutants in the Maumee River and Lake Erie". I do not have extra copies of this work plan for the committee; however, it is going to be reprinted, and I believe you will be able to obtain copies from the U.S. Environmental Protection Agency, Chicago office. The title of the publication is "Environmental Impact of Land Use on Water Quality".

Let me give you a little background on the project. Not quite two years ago, there was a conference held in the Fort Wayne area about the condition of the Maumee River. As you know, the Maumee River is formed at Fort Wayne, Indiana where the St. Marys and the St. Joseph rivers join to form the Maumee and from there it flows on out to Lake Erie at Toledo, Ohio. This conference on the Maumee raised a number of questions.

Some of the local people decided they would get a group together to see what could be done about the unknown factors. They invited representatives from 13 different agencies and organizations to a two-day workshop. The meeting was held in April, 1972 and the group took a look at the overall problems of the Maumee River. We went out in the field and looked at specific problems; then we came back and discussed possible solutions or studies that could be made. From this group came the recommendation that a demonstration type project be put together to evaluate and demonstrate the effect of land treatment on the quality of the runoff water.

It was suggested that the local Soil and Water Conservation District be the agency assuming leadership for the project. Now, for the benefit of some who are not from Indiana, the Soil and Water Conservation Districts in Indiana are state entities set up under state statute on a county basis. They have no powers, not even taxing powers. This gives them a very unique position. As the project developed, two other major agencies were involved: the U.S. Soil Conservation Service, and Purdue University, the land grant institution of the state. There are several other county offices, local environmental groups, and coordinating councils that are assisting with the project.
The three agencies, plus local officials and the Environmental Protection Agency investigated the situation to see what could be done. As a result, a six month study was initiated to examine in detail the problems of the entire Maumee Basin and then propose solutions or recommendations. For the benefit of those not familiar with the Maumee Basin, I would like to point out that it is primarily in the State of Ohio, not Indiana or Michigan. We looked at the overall problems and characteristics of the Maumee Basin and determined the land types, land uses, population and other basic data. From this we set criteria for selection of a target area on which we might work to demonstrate and evaluate various land treatment practices. Using these criteria, we examined potential target areas in the Allen County, Indiana, and selected the Black Creek watershed.

To show you how well the Black Creek watershed compares to the Maumee Basin, let us look at some figures of land classification. First I will read the Maumee Basin percentages followed by the Black Creek figures. Class I land, 0.9% and 2.4%. That may appear to be a pretty big difference, but when you start talking about a few percentage points it is not very much. Class II E, land with some erosion, 7.44% and 12.6%. Class III E, 3.5% and 3.0%. Class IV E, 1.4% and 1.3%. These last two sets of figures are almost too close to believe. Classes II W and III W, lands where excess water is a problem, 82.6% and 79.6%. For land use the figures are as follows: crop land, 73.0% and 80.7%; pasture, 4.0% and 4.3%; wood land, 8.1% and 7.1%; urban buildup, 9.0% and 3.6%. You may note that there appears to be a considerable difference in urban buildup, but I think we must recognize that much of this urban buildup involves two major cities, Fort Wayne and Toledo. I believe if you take these cities out of the area you will find that the Black Creek area and the Maumee Basin are very similar in terms of urban development.

Soils in the basins are also very similar except that there is one major soil group in the Maumee Basin that is not present in the Black Creek Basin. This particular soil is somewhat higher in clay. However, soil specialists believe the absence of this higher clay content soil will not produce any problems in analysis of the Black Creek Basin in comparing it to the Maumee Basin. If we do find the need for data from the high clay soil, we will work with the people in Ohio to obtain it. One of the criteria in selecting a target area was that it be a representative of the Maumee Basin. We believe we have accomplished this. We believe that the Black Creek Basin is representative of the Maumee Basin and also that the results can reasonably be extrapolated to the total Maumee Basin.

As I have said, we had a six month planning phase and from this we selected a target area and developed a work plan. This plan describes the land treatment and monitoring which should be done to demonstrate and evaluate the effect of land treatment on the runoff water quality. When I refer to land
treatment, I am talking about conventional practices. This morning we heard reference made to terraces; this is one of the many practices. Fortunately, in this area we have a very excellent and recent soil survey map. From this and from a knowledge of land classifications, we were able to estimate the types of land treatment practices that should be recommended. In other words, if we take a parcel of land and say that it is going to be used for certain purposes we are able to say these are the types of land treatment practices that would be in use. To repeat then, the land treatment practices that will be recommended in most cases are those that are well established and have demonstrated their value at least in research experiments.

We have mentioned the need for public relations work. On this project we are talking about a 12,000 acre watershed that is privately owned. Thus, any work that is to be done on the watershed must be done in cooperation with the landowner. So it is obvious, I think, that the landowners must be informed of what is involved and be encouraged by all techniques possible to support and cooperate, because if the landowner(s) says no, we can do nothing on the watershed. At the present time, we are waiting to build a sediment basin simply because the man figures his soybeans are worth quite a bit of money and he said, “yes, you may put the basin in but wait until I harvest”. So we are waiting to construct it and hope that we will be able to get it seeded and mulched this fall.

We have a very interesting social situation in the area that I find challenging. In the upper regions of the watershed live a considerable number of Amish farmers. As you know, we have not worked much with the Amish. However, to date we have found they are most cooperative; in fact, our first two construction contracts have been on Amish farms.

The project will be conducted as follows. The Allen County Soil and Water Conservation District is the local entity which works with the local people and therefore will be the contractors. The Soil Conservation Service and Purdue University are sub-contractors to them. The county extension service will assist the Soil and Water District in the promotion of the project and encourage people to cooperate. The Soil Conservation Service is responsible for the planning and the land treatment design. The prime responsibility of the university is in monitoring and analysis of the data. For example, we will do the stream gauging, sample collection, sample analysis. As a part of the model study we will attempt to predict what should happen with increased land treatment.

About 1/2 to 2/3 of the 12,000 acre target watershed is an old glacial lake bed with the remainder of the area rolling upland. This combination of glacial lake bed with some upland area is typical of the Maumee Basin. The lake bed is generally heavy soil and intensively cropped. This morning
someone mentioned fall plowing for the lake bed area because it is too wet to get on in the spring. In the past, the number one problem of this soil was considered to be excess water. It is heavy, wet and slow to drain. I do not think there has been a great deal of concern about erosion on this type of soil or at least we do not find too much research reported.

As I mentioned, the purpose of the study is the reduction of sediment and related pollutants. The Soil and Water District and the Soil Conservation Service will be asking landowners to cooperate with us. The Soil Conservation Service will design long term conservation practices for the land and the stream channels where needed and will attempt to get them installed. There are funds in the project to cost share these practices. The rates of cost share will be established by the local Soil and Water District Board. For example, a contract that is underway involves an upper reach of a stream channel. It has been terribly overgrazed in the past and the banks are eroded; in fact, there is just about everything wrong with that channel. A farm plan has been prepared and we are presently reshaping the stream banks to stabilize them. Livestock will be fenced out of the channel. We will also be using this area to conduct a mulch study to determine the success of different mulch materials on various slopes in controlling erosion and promoting the establishment of grass cover. The mulches that we will be using in this study are straw, stone, woodchips, sawdust, and commercial soil stabilizing products. We will repeat this type of study in one or two other locations. Thus, you will see we are combining known practices to control erosion and sedimentation along with special studies.

University personnel will be monitoring the stream flow and collecting samples for analysis. We have decided that it was best to get started collecting samples rather than wait until we could get everything installed just the way we wanted it. So we are sampling, in fact, we have something like 600 or 700 samples stored in the freezer at the present time waiting for the laboratory equipment to arrive so they can be analyzed. I believe there is a total of ten analyses to be made on these samples. We anticipate that on a yearly basis something in the order of 2,000 or 3,000 samples will be collected, so you can see why we are worrying about getting the lab properly equipped. There is no doubt that we will want to do some modification of sampling and analytical procedure as we gain experience and learn what the ranges of the various materials are in the runoff water. One fish survey has been completed. We were quite surprised to find a large number of species of fish in these channels, including several game varieties.

Another problem which appears to be typical of the Maumee Basin is the small rural towns that generally do not have sewage treatment plants. The watershed that we have selected includes such a small town. The residents tell us that in the summer the stream is in pretty bed shape, but surprisingly enough we found this year, even in August, it improved enough so there were
two or three species of fish in it. In addition to the staff members from Fishery we have two entomologists involved. One will be assisting with the biological analysis and the other will be doing some analysis for pesticides. So far, they have made one analysis and found that most material was in the order that they expected.

In addition to the conventional and treatment practices which will be planned and designed by the Soil Conservation Service, we will be doing some plot demonstration work of reduced tillage practices. They will start this fall (1973). Everything from fall plowing to spring plowing to diskimg and zero type tillage operations will be used. We will be relying on past research and what we know about the soils in attempting to develop a program of demonstration tillage operations that we have reason to believe will be beneficial. We are working on some minimum tillage equipment which will go on a horse drawn corn planter. This just represents one of the types of problems that is encountered when you are dealing with people.

Rainulator studies have been completed for 1973 on four specific soil types which were selected as representative of the soils in the area. As you know, the rainulator applies intense rainfall to a small area. With it we can collect samples and make very detailed analysis of the runoff from the single treatment. The studies this year were on bare soil. You can imagine the difficulty we had in convincing farmers to pull out 200 square feet of soybeans so that we could conduct a test. We have agreements with individuals to continue on the same representative soils, not necessarily the same site, with different tillage and culture practices for the next four years. These rainulator plots and studies are in addition to the demonstration plots which were mentioned earlier.

As all the data is collected it will be stored so that it may be easily retrieved. The modeling study will be using this data to see how well each model fits the conditions and adequately predicts the changes that have taken place as a result of the land treatment. Most of our data will be coming off this 12,000 acre area but there is limited sediment information and some other data available on the Maumee. We may also make a few measurements above and below the outlet of our watershed into the Maumee.

In addition to what might be considered the more basic or more traditional areas, we will also be conducting a sociological study. A sociologist will be doing a fairly detailed study of the social background of the people and of their attitude toward sediment control before and after the project. We hope that from this we'll come up with common answers to questions such as: 1) How do people respond to a project to reduce sedimentation? 2) Do they feel there is a need for sediment control? 3) How should sediment control be promoted? 4) What sort of incentives may be necessary to encourage
necessary land treatment practices? We would like to learn the answers of the people to these questions before the project, during the project, and after it has been completed. When the 13 agencies representatives got together to discuss the needs of this project, a general feeling of the group was that it would be extremely difficult to legislate control of sediment and other pollutants from nonpoint sources. There was a general consensus that there is a need for knowledge on the type of incentive that would assist in promoting the necessary pollution control practices. These incentives could be in the form of education, cost sharing, tax relief or some other method. This is one of the reasons the sociological study was included as a part of the project.

Are there any questions?

DISCUSSION

Mr. W. Mildner: Are any of the ten precisional analyses going to be invalidated by your freezing of the samples for a prolonged period of time?

Dr. R.Z. Wheaton: We know that there is going to be some loss. I am depending upon people who have experience in these specific areas. Darrell Nelson and Lee Sommers have studied this problem and know what the losses are going to be. We recognized this in the beginning, but we also knew that there is no way in which we could get samples into a lab any faster, and so we said well it is better to have some loss as long as we recognize it. Thus, we elected to go with freezing.

Dr. D. Dodge: What, if anything, is the study group trying to do to look over development in the area during the study period?

Dr. R.Z. Wheaton: As I mentioned, the Maumee Basin is basically an agricultural basin. One of our criteria was to stay with an agricultural basin, one which we had reason to believe was not going to develop during the study period. We used the knowledge of local officials who work with the planning agencies. They know where the development is going. This county probably is one of the better ones in our state in terms of overall planning. These officials all felt that this particular basin would not develop. It is farther out of Fort Wayne than where development is expected to take place in the next five years. Also, much of the lake bed area is land that is very questionable for development. Although there are a few houses being built, the county is clamping down more and more on development of these lands. So we have pretty good reason to believe this particular target area will not develop, throughout the life of the project.
Mr. R.L. Carter: Is it true that the Amish do not use artificial fertilizers, nor do they use pesticides and if so do you consider this an important aspect of the study?

Dr. R.Z. Wheaton: I think this particular group does use a limited amount of pesticides and a small amount of fertilizer. But, in general, they have not used the amount that other agriculturists have used. We hope this might even be part of a benchmark, in time, an area that has not had large chemical applications. We hope this turns out to be true. It will be very interesting to see whether or not as we leave the area controlled by the Amish, if there are major changes in runoff water quality. There are major soil type changes as you leave the Amish area that will give us a problem in this comparison.

Dr. J.G. Konrad: Could you discuss a little bit your criteria for sample site selection?

Dr. R.Z. Wheaton: Well, certainly one of the things that has to be considered in the sample site selection is accessibility of the site. This is really critical. I was interested when Boyd Ellis spoke about the Deer Creek Basin, because I worked on that basin back in the early 60's and a very major problem was getting to those sites. You are talking about getting to them at 2 o'clock in the morning, not going out between eight and five. In this latitude the intense runoffs tend to occur from summer time thunderstorms from 2-8 PM. A few occur at night, but most in the afternoon, so runoff took place in the evening hours up through the night hours. Thus, accessibility is a major factor. In most cases, the sites have been selected along roads or fairly close to roads where we can get to them. We have also tried to select sites which would allow us to separate major soil types, for example, the upland area versus the lowland area. We also looked for sites where we could install weirs or some type of channel stabilizing device to improve the quality of our stream flow records. We'll have continuous stream flow measurements on the majority of these sites and so we are hoping to install stabilizing structures of some type which will give us better measurements. I didn't mention the fact that we are also measuring rainfall. We will have 10 recording gages; we are also putting two rainfall quality samplers in the watershed. We want to know what is coming in in the rainfall. Does anybody know how to collect snow, so that we can analyze it for quality?

Mr. S. Salbach: The title of your program is “Effects on Water Quality” and the Maumee has a very significant maintenance dredging program every year. Is a large portion of this project of yours directed towards developing land use techniques that will minimize erosion?

Dr. R.Z. Wheaton: I think we would say yes to your question. At the same I think we have to ask ourselves: Can we do things on the land that will reduce the amount of sediment transported? As one geologist said to me, you know
the Maumee is a young stream and I am not sure if you stop all the material coming in that you are going to change the quality; it will probably just erode out of its bed. I do not know the answer to that statement. I have been surprised at its velocity. It has been thought of as a slow sluggish stream, but it does not appear that way to me.

Dr. G. Chester: What do you estimate is the cost of the total program?

Dr. R.Z. Wheaton: The total five year project, counting both the cost share and the federal input or EPA input, is in the order of two million dollars. That is, totalling all the land treatments, all the agency personnel and including all the hired technical staff.

Dr. T. Bahr: You mentioned mulching studies. This falls into the category of watershed manipulation. What percentage of this 12,000 acre watershed are you going to actually manipulate?

Dr. R.Z. Wheaton: We would hope that by the end of the study that we manage to treat the majority of the watershed. We decided to set this up in planning stages, in other words to start planning on the west side of the watershed and work east. We are fortunate in that we have a situation where we have five streams that are more or less parallel and each drains into the Black Creek. So, we are going to start on the west side of this watershed and work toward the east on sub-watershed basis. Of course, we cannot stop a landowner from doing something on his own. But, by moving across we hope to be able to determine any changes that may take place. We are also monitoring a very similar stream immediately to the east which is not in the treatment area.

Mr. K. Shikaze: I believe you mentioned that as far as the study program is concerned there is only going to be a limited amount of development, but surely there is going to be some urban development, some urban sprawl, some highway construction or bridge construction. Are you going to be taking a look at the impact of these things on water quality?

Dr. R.Z. Wheaton: From what we know of the area, the development will be almost at the level of the individual home — maybe a new farm home, that sort of thing; maybe a new feeding operation; this is possible.

Mr. K. Shikaze: What about road construction, highway construction?

Dr. R.Z. Wheaton: No, there is nothing in the area. There is state highway 37 that crosses it, that rides the old lakeshore line, but there is probably nothing taking place on that. We will be watching if it does. These are possibilities. But in working with the county highway people, and they have been involved in this, we do not see any major developments of this sort taking place. Major highways and major county roads already have good bridges, so development
will be about as slow as any watershed we could have picked in the State of Indiana.

Mr. K. Shikaze: But is that good from the standpoint of relating it to the total Maumee?

Dr. R.Z. Wheaton: In looking at the Maumee and talking to the people in Ohio we think it is relatively representative. Now admittedly, when you get around Fort Wayne and Toledo, there is a lot of development, but this is a pretty small part of the total basin. You are certainly right; there probably needs to be a similar type of study on land development. There is a possibility we may make a few measurements, if I can find a developer who will let me use his area for the study.

Dr. Bouldin: How do you get your baseline?

Dr. R.Z. Wheaton: It has to depend on events. That is why we insisted on five years for the whole thing; we really think this is too short. We could have five more years. I suppose we will have to go more to the double mass type plotting, and compare the sub-basins that were last treated to see how they changed with the climatic activities versus the ones that we have treated this year. For example, one of my measuring points will have had all of the stream channel about it improved by the end of the year. This involves a 6,000 foot waterway, where we replaced an old, badly maintained drainage channel with an intercept tile line on either side and a grass waterway to carry the highflows. This is in a fairly high livestock area. On the stretch below it, of about that same length we are now improving the banks, seeding, sloping and fencing to keep livestock out. Next month all of the channel about that particular measuring point will have had improvement work on it. Also, there will be considerable improvement work going on, on the farmed land, retention basins, total reorganization of the fields on one farm, pasture improvement and so forth. So we will have to watch the changes that take place in the areas that have been treated versus the comparable changes in those areas that haven’t been treated and see how they change in respect to each other. This is not the “control plot” we like in research. But in hydrologic studies a control is very difficult to obtain. In this type of study I think it is impossible.

Mr. E. Jarecki: Do you have any existing facts or historical data on the Black Creek watershed for sediment production?

Dr. R.Z. Wheaton: Not on Black Creek itself. There are some measurements in the Maumee, as you are aware, but these are not as complete as we would like.

Dr. J.F. Frank: You have been talking about the grade stabilization structures and this type of thing. What about this lack of municipal treatment plants and feed lot runoff? Are you going in and pouring some concrete and putting in settling basins or holding ponds and spray irrigation systems?
Dr. R.Z. Wheaton: The one feeding operation on the watershed is a very recent operation, a totally confined operation, and it uses land application from the pits to the land.

Dr. J.F. Frank: On 12,000 acres you only have one?

Dr. R.Z. Wheaton: We only have one confined operation.

Dr. J.F. Frank: Well, I am talking about let’s say open concrete or earthen feed lots of a couple hundred steers. You do not have any of these?

Dr. R.Z. Wheaton: The lake bed area is a crop area; those farmers just don’t have livestock. The livestock will generally be in the rolling lands, much of which is the Amish farms and consists of horses and cattle. I think one of the big things we need there is pasture improvement. You see this especially in the winter.

Dr. J.F. Frank: What is your attitude, what is Federal EPA’s on extrapolation of this data, if another state should want to apply it? Do you or do they see it as being extrapolated to other soil types with any validity?

Dr. R.Z. Wheaton: We would hope that our rainulator studies would give us benchmarks. These are research type studies. In terms of extrapolating say, sediment yield, from this watershed or from segments of this watershed you are going to have to extend them to other similar soils, land uses and so forth. Now it may be that through erosion equations that we can stretch this to certain limits. We have to be careful in extrapolation as I think you are implying in your question. As I said earlier, we selected this target area on the basis that it was as representative of the total Maumee Basin as we felt we could come up with. We believe the data can be extended to the Maumee Basin.

Mr. C. Schenk: Are you looking at the impact on ground water?

Dr. R.Z. Wheaton: No, we are not looking at ground water. We will be real happy if the Geological Survey or someone wants to get involved and do that.

Dr. S. Walesh: You mentioned that one of your criteria for selecting samples was accessibility. Do you mean that you have all of your sample stations on let’s say small tributary areas of homogeneous soil, and homogeneous land use?

Dr. R.Z. Wheaton: I mentioned one sediment basin that we had hoped to have under construction. This is one of our techniques of measuring sediment. I am going back to the question raised this morning about bed load and so forth. Typically, many sediment measurements have been suspended loads. We had hoped to put in a number of sediment basins in the area. Unfortunately this is one of the adjustments that you make when you start selecting areas that are suitable for the study, the area did not lend itself to as many sediment basins as we had hoped. But, we do have this one to construct this fall. It is
pretty much all the same soil type, approximately a square mile in size. It is flat glacial lake bed soil, with a corn, soybean type of operation and one very small livestock operation of about 30 head. That is the only livestock I have seen on that particular sub-watershed. We have some other sediment basin sites we are looking at, but we have not got to the design point on those yet.

**Dr. S. Walesh:** Are the bulk of the sampling stations in the stream?

**Dr. R.Z. Wheaton:** The bulk of our stations are in the steams. We will do some tile flow sampling. Right now we are looking for tile systems, sub-surface systems, which we can relate to soil type and land use. This is an old area and turns out to be very difficult to find the right system. We have only found two or three that look like good prospects. We want to measure flow from tile systems as opposed to individual lines as has generally been done in research.

**Dr. S. Walesh:** Also you mentioned that a model is being used, I assume this is some kind of water quality model?

**Dr. R.Z. Wheaton:** Yes. A mathematical model which will include water quality parameters.

**Dr. S. Walesh:** What is the basic objective of the model, what will it be doing?

**Dr. R.Z. Wheaton:** The basic objective of the model will be to take the data that we obtain, the data that is available or becomes available in the Maumee River, and extend it to larger areas, hopefully the whole Maumee Basin. But certainly to extend the little pilot studies to larger areas.

**Dr. S. Walesh:** What water quality indicators or parameters will be included in the model. For example, is it primarily a dissolved oxygen model?

**Dr. R.Z. Wheaton:** The model has not been selected. They are looking at a number of models. We have a full time research assistant who has an excellent computer background, working with one of our staff members in this area. Sediment will be a main part of it, along with other water quality measurements. In other words, this will be kept fairly flexible until we get enough of our data back. Our intention is to keep flexible enough so that we can make use of what we learn and progress in the study.

**Dr. S. Walesh:** I am interested in manpower. Is most of this work going to be done by staff and graduate students at Purdue and SCS people? Are there substantial numbers of additional people being brought in by SCS to handle some aspects of this work?

**Dr. R.Z. Wheaton:** Yes, SCS is bringing in some additional people. To date they have a new planner and they have shifted some local, state, and area staff time into this project. There will be a technician or engineering assistant added
to pick up some of the extra work. Actually, Allen County is pretty well supplied with staff. It is the only county in the State of Indiana where the district has a full-time soil conservationist, in addition to the SCS staff. For Purdue the project shows twelve academic staff members involved now. There will be something on the order of half a dozen graduate and research assistants; graduate assistant being a halftime, and research assistant being a halftime, and research assistant being full-time positions. We will also be hiring several technicians. For example, there are two technicians in the Water Quality Lab in addition to the academic staff involved. Also, we have one full-time man located in the county who coordinates all the field work for Purdue.
Our experience during the 1972-73 winter has clearly demonstrated that most of the phosphorus moves during periods of high flow; frequent samples (every 2 to 6 hours) must be taken during high flow episodes in order to calculate reasonable estimates of loading. The soluble phosphorus content of samples changes rapidly during storage and hence samples cannot be stored over 6 to 8 hours before analysis. In order to differentiate among point and diffuse sources, watersheds no more than a few km$^2$ in size must be studied.
Basically, this is a progress report on an ongoing project. The objective is to measure phosphorus transport in the stream and relate the phosphorus content of the stream to the several potential sources of phosphorus in the watershed. In other experiments phosphorus in runoff from individual plots is being measured. However, there are no estimates of how much of this phosphorus ever reaches a stream and if it reaches the stream how much will be transported to a lake. We hope to derive an estimate of this so-called delivery ratio.

We started in a small way with limited manpower and money. The experimental plan was evolved as we have proceeded. I would like to point out that a slow beginning has its advantages because the initial mistakes which are probably inevitable are not so costly.

The watershed we chose to work with is adjacent to the campus. The area is 126 square miles. It is a typical southern New York watershed with glacial-till derived soils in the uplands and soils derived from glacial outwash in the valleys. There is a USGS gaging station on the creek which has been in existence for 45 years. There are 5 good weather stations in or close to the watershed. There are about 8000 cows in the watershed with the majority of the agricultural operations aimed at feed production for these cows. There are about 10,000 people in the watershed, with the majority using private sewage disposal systems, although there is one sewage treatment plant for a village of about 2000 people.

We have put major emphasis on soluble inorganic phosphate since most of our lakes seem to be deficient in phosphorus. We are also measuring a number of other parameters, but so far we have not done much analyses of these data.

We have found that the samples must be processed within a few hours after sampling or else the soluble phosphate content changes markedly, particularly during periods of high flow.

Illustrated in Figure 1 is a portion of our data taken last winter (1972-1973). Illustrated in part A is the flow in cubic feet per second (cfs). A flow of 100 cfs will be exceeded about 50% of the time while a flow of 1000 cfs will be exceeded only about 2% of the time. Very early we recognized that the more interesting phenomena occurred during storms, so we have tried to take samples for chemical analysis at fairly short intervals of time during storms. Illustrated in part B of Figure 1 is the concentration of soluble inorganic phosphate. The concentration increases quite rapidly as flow increases and then falls off more rapidly than flow.

Illustrated in part C of Figure 1 is the total amount of soluble phosphate delivered per day during this period. This illustrates that most of the phosphate is being delivered during the very few days of peak runoff periods.
Figure 1. Flow, concentration of soluble inorganic phosphorus in water, and soluble phosphorus in total flow for November and December, 1972.
In further analysis of these data we have broken up the hydrograph somewhat empirically into surface flow and subsurface flow components. This is an arbitrary procedure, but it yields crude estimates of surface flow. Illustrated in Figure 2 is phosphorus concentration plotted against the fraction of the total flow which is estimated to be surface runoff. This illustrates about what would be expected—high concentrations of phosphorus are associated with large amounts of surface flow. The phosphorus in surface flow is derived from a variety of sources—for example, decaying leaves in wooded areas, cultivated fields treated with manure, decaying vegetation on hay fields, barnlots, and sediment in the stream bed.

The analysis did not help us to sort out the relative importance of the various sources, so we proceeded to take samples from subwatersheds. We found that there were differences among subwatersheds. In one small watershed, the water almost always had soluble phosphorus concentrations in the range of 80 or more parts per billion. Examination revealed that the two dairies in the watershed were not disposing of their milkhouse wastes or manure properly. In other watersheds, the phosphorus concentrations were quite low in spite of large amounts of manure spread on cultivated fields. However, the soil where the manure was spread was very permeable to water so that no surface runoff occurred. This latter observation is an important point often missed. That is, manure spread on a field is not a source of phosphorus unless surface runoff occurs.

In the future we hope to expand our analysis of the composition of the flow to such constituents as Ca, Mg, K, Na, Cl, etc. We will also investigate smaller watersheds and try to assess the significance of decaying tree leaves, vegetation, etc. We are now speculating that decaying "natural vegetation" (that not associated with agriculture) is an important source of phosphorus, particularly in the late fall and early winter.

There are no subwatersheds in the area which can serve as "control watersheds" or indicators of what phosphorus levels are typical of "unpolluted" watersheds. Except for isolated small areas which are atypical geologically of the area, all subwatersheds are influenced to some extent by housing and farming. Thus we cannot estimate what the output of phosphorus might have been from the watershed prior to its current state of development.

Our experiences with one watershed over a period of about a year lead us to the following procedural recommendations:

1. The soluble phosphorus content of water samples changes rapidly during storage over 4 or 5 days for a variety of reasons. In any case, analysis soon after sampling seems essential, particularly during periods of high flow.
FIGURE 2.
Concentration of soluble inorganic phosphorus in solution plotted against the overland (surface) flow expressed as fraction of the total flow.
2. Samples should be taken at frequent intervals (2 or 4 hours) during storms (periods of high flow) because the composition changes rapidly. Furthermore, most of the phosphorus moves out of the watershed during these periods and loading based on random samples taken bi-weekly or monthly will likely miss entirely the most important periods of phosphorus movement.

3. Any assessment of the contribution of point sources (such as milkhouse wastes, sewage outflows, etc.) and surface sources (such as decaying vegetation, manure, etc.) to total phosphorus loading must rest on measurements of watersheds, perhaps on the order of one or at most a few square miles. With watersheds over this size such a variety of sources are involved that analysis of the contributions of the individual sources is impractical.

4. Continuous records of flow are essential since the hydrograph yields information about the fraction of the total flow which likely moved to the stream over the surface of the land. The subsurface flow is likely to contain less than 10 ppb phosphorus and hence the higher concentrations of phosphorus found must be derived from point sources or surface flow.

5. Phosphorus from “point sources” (such as sewage and milkhouse wastes) reacts with sediments in the creek bed. During periods of high flow, these sediments are swept up in the flow and probably contribute appreciable amounts of soluble phosphorus to the water. This phenomenon greatly complicates analysis of the sources of soluble phosphorus.

**DISCUSSION**

*Mr. R. Carter:* Do you get less soluble phosphorus in the sediment form?

*Dr. D. Bouldin:* Yes. I don’t know what the problem is with this exactly; it’s kind of a complex microbiological thing. We were separating the solids out and then putting them in a refrigerator. We tried freezing and that didn’t work—that was kind of disastrous. Then we just decided to store it at about 4 degrees, thinking that after we got the solids out everything would be all right. Well, now everything isn’t all right, when you’re dealing with high flow samples. Over a period of about three or four days you’ll lose anywhere from 30–60% of the soluble inorganic phosphorus. And it won’t be converted to soluble organic phosphorus; it’s stuck on the walls of the container apparently, in biological cells. That’s my interpretation of it; although I can’t prove it.

*Dr. T. Bahr:* You touched on a point that’s very interesting to me, and that had to do with the loss of phosphorus through a stream bed by percolation.
Have you followed this through and tried to quantify this in terms of what percent of that which comes in is lost in this manner?

Dr. D. Bouldin: Yes, we've been trying all summer to get that experiment run. A sewage treatment plant comes in at a point in the stream where there's relatively little input from feeder streams for quite a long distance, and we thought this to be a beautiful situation in which to study the transport of phosphorus and what happens to it. Well, you start thinking about that and it becomes more difficult than what you first think. First of all you have to have flow measurements. Then I've been trying to get some samplers put together, so I don't have to go out there every fifteen minutes, and do it myself. And that turned out to be a little more of a problem than I thought. I bought some and they don't work very well.

Dr. T. Bahr: Could it be that some of the phosphorus that is introduced may be temporarily stored in biological material? For example, river macrophytes or periphyte organisms in the stream. Some of the work that we've done in Michigan indicates that there's a tremendous storage throughout the growing season and during the fall, during the period from late September into November when macrophytes die out and the periphyton organisms slip off, that as much as 80% of the total phosphorus flux through the stream, may occur during this period. Have you looked at this?

Dr. D. Bouldin: Well, we're thinking about that; we've thought about a lot of hypotheses, but I'm afraid we haven't gotten very far in measuring them. But I think you're right, because this six or seven parts per billion we've measured all through the summer, I can't think that it's entirely due to loss through the stream bottom. I think it's exactly as you say. There's a lot of stuff on the rocks. If you notice, last fall the base flow contained something on the order of 20 parts per billion. We sort of have the idea that that's what is going on, but I think that it's kind of hard to document.

Dr. R. Parizek: We just completed a study on a stream that was losing P from below a sewage treatment plant and in fact that's what we observed. You could not find the phosphorus in the water or going through the stream bed sediments a few inches below, but it was nevertheless disappearing from the stream, or absorbed. But this is a long process of having a sewage plant there and with six inch samplings depths you'd have thought that you'd have some in the sediment with the volumes of loss you had; so it's even more complicated than just straight absorption. Again in the valley bottom, settlings such as you talk about in these outwashed sands and gravels, you may be gaining water in the reaches of the main trunk of the stream although you do observe losses from tributaries coming across the gravels. Is not the main stream actually gaining water?
Dr. D. Bouldin: Well, you can find anything you want to during low flow, but I think during high flow it's not too bad. We've carried out, on two separate occasions, a water balance from November 15 to April. Let's say in one year we had roughly 15 inches of precipitation and let's say we had about 14.7 inches of outflow and you can calculate on the basis of the hydrograph that you'd have about two-tenths to three-tenths of an inch of storage; that is if you looked at the slope of the thing and so on and so forth. I've done that for two winters and I've come within two or three tenths of a water balance, so you know there's no permanent storage down here. You know it's a matter of running it up and down. But, you know, I'm really afraid to look at a third year because, that third year, you know that something is going to go wrong with it coming out that well.

Dr. R. Parizek: You're basically convinced then, that in order to make an extrapolation of what sort of phosphate production you have, you almost have to have a rating curve for the groundwater total flow relationship in that stream in order to really know day by day exactly what the pollution load might be. For the long term problem with the whole Great Lakes you say we would need a rating curve basis of judgment of how much is coming out of every watershed. Is that true for things other than phosphates?

Dr. D. Bouldin: Well, again you know I've only touched on one little piece of the elephant and this may be a very strange watershed, although I think it's typical of the southern tier of New York. The nitrate thing kind of surprised me. There is so very little variability of nitrate concentration in flows that this tricked me until I thought: well, okay, historically we loaded up the groundwater with about 1-1¼ parts per million nitrate. We are running off stuff up here that contains on the average a half part per million nitrate, so that's kind of telling me that things aren't changing that much in that valley and I think that's probably right, because basically it's a dairy farming region. The farmers aren't using a lot of nitrogen fertilizer; they're recycling their manure and they've been recycling their manure for a long time. The total number of cows hasn't changed very much and the number of people hasn't changed very much. One of the interesting things is we find relatively little ammonia, and this has bothered me because I thought I might use that as a tracer for manure. I think that it's being volatized out of the steam, because the pH is pretty high and there are places in the stream where there are a lot of rocks and so you get a lot of aeration. So I have a feeling that it may be it's volatized, but I'm not sure.

Dr. L. Heiling: I'm interested in the fact that what you measure coming out of the basin is only one or two percent of what's stored somewhere in the basin. If that's true, you know you're in a tough situation.
Dr. D. Bouldin: Yes, well basically we looked at the cows, and we know how many cows there are, and we know roughly how much phosphorus is contained in the manure. We are making rough estimates on how much phosphorus is contained in the vegetation that's decaying every year. And we know roughly the amount of phosphorus in the sewage from the human population.

Dr. L. Hetling: This doesn't include the soil?

Dr. D. Bouldin: No, we're just talking about things that are going through a biological cycle every year. Things we feel are going through some sort of decomposition, deposition, or something of that sort basically.

Dr. T. Bahr: Of the phosphorus that reaches a stream, that gets into the stream either in solution or on particulates, what percentage of that will ultimately be transferred or transported downstream?

Dr. D. Bouldin: That was one of my objectives and I haven't gotten there yet. I'm convinced that during periods of high flow—a hundred percent. During the low flow period, well you know I thought we'd make a lot of progress on that this summer, and we haven't made any. The problem is getting everything lined up. I have now got a graduate student and a research associate, and I'm beginning to gear up to do things on a much grander scale.

Mr. S. Salbach: Have you looked at the seasonal yields? I'm not sure whether I understood you correctly, when you said that the maximum amounts were drained off during November and December. This is sort of contradictory to the data that we've got.

Dr. D. Bouldin: Yes. This depends on the year you're talking about, and again I've got the spring data and this year in Ithaca we didn't really have all that much snow. We didn't have the large volumes of spring runoff that you usually have. The concentrations in the runoff in the spring were much lower than they were in fall. We didn't get any really very high concentrations in the spring runoff, and maybe that was because we didn't have a lot of snow, and so didn't have a lot of surface runoff. The other problem with that data is that we did store some samples, so there are missing pieces because we don't want to really use the data from samples that were stored for two years. We can ressurect something out of it, but I just didn't bring it here. So I think in a normal year, we would not have quite as much runoff as we had last fall. We had some beautiful storms last fall, and its not very many times that you get such nice, textbook examples of hydrographs which you can break down. In spring we got these things that kind of go up and down and flop around and we haven't figured out how to analyze these yet. Ordinarily we'll have much more phosphorus coming off, I think, in the spring than in the fall. We just had a funny fall, so to speak.
Dr. R. Frank: One thing that bothers me about watershed studies — and I'm thinking now of pesticides — is that we've gone to a lot of work in monitoring different types of things, but then you get one accident on the watershed, and you have a spillage and the quantity going down in the watershed sometimes amounts to more than the amount that you have in a year. This happens more frequently than we think. And we haven't dealt with these. I think these could be point sources in agriculture that we may be overlooking, and maybe point sources in agriculture we should be talking about, but we generalize in agriculture.

Dr. D. Bouldin: I think that's certainly true of our situation in this particular watershed. This bothers me. Both farmers are not very progressive, and you sort of have a feeling that before we get through, these fellows will not be in business any longer. Those two fellows, are putting an awful lot of phosphorus on just from the outhouse operation and things of this sort. And here is this poultry farm down here with manure plastered on well drained soil, very, very heavily but that's not the kind of soil you get much runoff from.

Dr. R. Parizek: But is it in the groundwater?

Dr. D. Bouldin: Well, again I think this is something I need to do. We need to go around and sample wells or sink wells, but I would guess that even though it's gravel and sand compared to outwash, I think it still has the ability to react with a lot of phosphorus. Whether it will end up in the groundwater, I don't know. But it may, and this is something that I really want to look at, in other words I want to go around and look at wells, look at shallow wells, and what would really be nice is if we could find some of these wells that are in the midst of a barn lot that have two or three hundred parts per million of nitrate, so that you're sure that you're getting a lot of contamination from nitrate and see what the phosphorus levels are. Have you, has anybody ever done any of that?

Mr. W. Marks: We've done some in Michigan, but not with that high of a concentration; very little phosphorus has showed up.

Dr. D. Bouldin: You mean ten, twenty parts per billion.

Mr. W. Marks: Well, maybe up to eight as far as nitrogen, but very little phosphorus.

Dr. M. Johnson: What is the rationale for measuring soluble reactive phosphorus?

Dr. D. Bouldin: Well, I've talked quite a lot with Ray Ogilvie and it's his opinion and I think he feels that this is the important thing in the lake. This stream empties into the southern end of the lake, there are already a lot of sediments there, and lots of plants there, so there's lots of high phosphorus sediments there, what difference does it make if you put another two inches of high
phosphorus soils on top of high phosphorus sediments? It doesn't really make any difference because it all falls out in the southern end of the lake. There's plenty of high phosphorus sediment already there; that isn't the limiting fact. So you put another two inches on top of it, so what?

**Dr. L. Hetling:** You might say that this probably represents the view of most limnologists in New York State, that the critical thing is the soluble phosphorus that enters the lake during the growing season, and as far as the total amount of phosphorus, a good share of this is part of the reactive sediments.

**Dr. M. Johnson:** But when you look at the way the soluble reactive phosphorus test is done, where you glass fibre filter first, do we have assurance that what is absorbed is filtered out and doesn't reach, stays unreactive in the lake?

**Dr. D. Bouldin:** Well, I was afraid you'd bring that up. Everybody has pointed out, what do you call solution? We've chosen settling jars. I don't think it's very different from a .45 micron glass fibre filter; we've also used filters of various sizes. Something that I think would be very worthwhile is to devise some sort of a sedimentation procedure so that you can look at the particle size distribution of the suspended solids you find in your sample. And then you can say something about whether, if we know something about the turbulence and so on and so forth in a body of water, much of this will stay the same. But really a bioassay of sorts is required. And incidentally, I might add, somebody over there I think was asking about how do you measure sediment; it turns out that I was very lucky in this particular case. The water comes over a ten or fifteen foot dam and it falls directly onto a solid rock base contained in a gorge, so I can grab a sample right below that dam and there's no such thing as bed load or anything else. When you've got a lot of water coming over it, it's all pretty well mixed, and we've taken samples, just taken sequential samples and we can do most anything we want to in the way of sampling, and we can grab one sample out, or you take a grab sample out and you really don't worry about going across the stream or waiting five minutes or something like this. It's well mixed, now that's an unusual circumstance and I think it's something that you really have to be careful about. In some of these other locations, where you go out and you have kind of a muddy stream, with a muddy bottom, funny things happen with a real elegant piece of equipment, such as a fruit juice can on a piece of rope. You don't know what you are sampling when you look at that thing in a very turbulent situation where you got this stuff kind of oozing downstream.

**Dr. M. Johnson:** I'm not really convinced. You are removing anything attached to particles bigger than a half a micron, and you're reacting with molybdate what passes through. It's a very artificial sort of separation and the soluble reactive phosphorus test is not just for orthophosphates; it's orthophosphate plus some of the organic phosphorus compounds that happen to react to the
molybdate. And these may not be in the nutrient form. Of course they're fair
game, but you've removed in the test, particles that may settle in the lake at
rates of one meter or less per day and they are fair game with the microbes
as mediators.

Dr. D. Bouldin: Yes, I agree completely; if you've got a better definition of
what's important to the lake. I think you know what you finally do is say
this is what I measured and by definition this is what I'm calling it, and I don't
know, I think that there's a whole grey area in here. How do we assess this
mess that we get out of the stream? We happen to choose and put a lot of
emphasis on soluble and inorganic P, but you know, we've got the sediment and
I just haven't bothered to talk about it, but I don't really know what to do
with it. I'd like to do a lot of chemistry with it. I have a feeling that isn't
going to work very well in this particular case because we've got relatively
low suspended solid loads and I also feel that soluble inorganic P kind of domi-
nates things. I must say though that I'm kind of talking off the top of my head
here, because I haven't really studied it that much, and I just haven't done the
chemistry on the sediments that I should have done. I sort of have a feeling
in this particular case that the absorbed P and so on and so forth is relatively
small in relation to the soluble inorganic P. We've done different things in
terms of separation and if you get the blasted color out—there's a little color
that stays in if you don't do any centrifuging at very high speed—and if you
aren't careful with your analytical procedure that will look like phosphorus.
But I think if you get that color out I don't think there's much difference
between centrifuging to get everything out at two tenths of a micron versus
something that will take solids out at about one tenth or so.

Dr. M. Johnson: I can truly agree that we don't know enough about the behav-
ior of these forms in the receiving lake. But we can't go so far as to do
anything in terms of a mass balance or say that there's one or two percent
of the usage output appearing in the output because you've got a loaded deck,
when likely as not the tendency in a stream is for the stream biota to increase
your soluble reactive phosphorus, in that enough of it is orthophosphate, and
built up your combined and particulate form. So there's a bias.

Dr. D. Bouldin: Well, on low flow, you don't have to filter, you don't have to
centrifuge, you don't have to do any of that, and you don't really make any
difference. In high flow, the flow rate is fast enough that the biological trans-
formations are relatively slow. In other words you increase the time of flow
between the upper end of the water and the lake by a factor. So, in the high
flow it's going so fast that I'm not quite sure biological reaction is all that is
important; there's so much phosphorus there anyway. At low flow there's no
suspended solids anyway so you're dealing strictly with soluble inorganic which
is 75 to 80% of the total soluble.
Dr. J. Konrad: But to really understand the impact the stream is going to have on the lake, the immediate concern is the soluble P that enters the lake at the time that the utilization is greatest; but, some of these other forms of P that get into the lake may not be immediately available. That doesn’t necessarily mean that they’re not going to be important — they’re coming off the watershed, and they’re coming through the tributary, and they may drop into the sediment this spring; but next spring it might come back up again.

Dr. D. Bouldin: Well, I’m not a limnologist, and I guess I’ll duck out and say well why don’t limnologists hassle over that one, and tell us which one. We’ve measured both of them; in fact, you know I think is true enough; I wish that we did have a little more time and money to do some bioassays. For example, we put these things in a cylinder, let it settle for 24 hours, or maybe twelve hours, 24 hours, 48 hours and then run a bioassay on what’s left and do a very complete analysis. I think that would be a fascinating sort of thing to do and I don’t know, is there much of that going on? I sort of get the impression there isn’t.
SESSION 3

WASTE DISPOSAL ON RURAL LAND

Chairman: M. G. Wood,
Ontario Ministry of the Environment, Supervisor Planning Section,
Waste Management Branch
Session 3

Waste Disposal on Rural Land
LAND APPLICATION OF WASTEWATER

Belford L. Seabrook

ABSTRACT

The American Public Works Association in 1972 made a field survey of 100 facilities where land application of domestic or industrial wastewater effluents were applied to the land. In addition an extensive bibliography was compiled; data were gathered from many other existing land application systems; determinations were made as to state regulations governing the use of land application facilities; and a survey was made of experience gained in many foreign countries.

The facilities surveyed were relatively large, with long-established operations. Among others, the major conclusion was that land application of sewage effluents is practiced extensively and successfully in the U.S. and in many foreign countries.

SUMMARY

The American Public Works Association Research Foundation, in 1972, conducted an on-site field survey of approximately 100 facilities in all climatic zones where community or industrial wastewaters are being applied to the land, as contrasted to the conventional method of treating such wastes and discharging them into receiving waters.

Additional data were gathered from many existing land application facilities across the country by means of a mail survey addressed to responsible officials. Another survey was carried out to ascertain the nature and extent of state health and water pollution control regulations governing the use and control of land application systems. To augment information on U.S. practices, a survey was made of experiences gained in certain foreign countries. In addition, an extensive bibliography was compiled of literature on all pertinent phases of land application practices.

The facilities surveyed were relatively large, long-established operations. These were selected to obtain as much information as possible on the operating experience of those using this technique. The surveyed facilities whose municipal wastes were applied on land were predominately located in western and southwestern portions of the U.S., while industrial facilities were generally sited in the northeastern section, because this is where the majority of such installations are in service. This method of handling waste water has been used to meet definable needs and is technically feasible in most areas.

Land application of effluent has been employed for a variety of reasons. Those most frequently mentioned were:

1. to provide supplemental irrigation water;
2. to give economical alternative solutions for treating wastes and discharging them into receiving waters, without causing degradation of rivers, lakes and coastal waters;
3. to overcome the lack of suitable receiving waters and eliminate excessive costs of long outfall lines to reach suitable points of disposal into large surface bodies of water.

Among the major means of accomplishing land application of wastewaters are:

1. irrigation of land areas by spraying with high-pressure or low-pressure devices, using either stationary or moveable types of distribution systems;
2. ridge and furrow irrigation systems;
CLIMATIC ZONES

A—MEDITERRANEAN CLIMATE—DRY SUMMER—MILD, WET WINTER
B—ARID CLIMATE—HOT, DRY WINTER, HOT, WET SUMMER
C—HUMID SUBTROPICAL—MILD WINTER, HOT, WET SUMMER
D—HUMID CONTINENTAL—SHORT WINTER, HOT SUMMER
E—HUMID CONTINENTAL—LONG WINTER, WARM SUMMER
3. use of overland flow or flooding methods; and
4. use of infiltration lagoon or evaporation ponds.

Although facilities of all types were surveyed, this report is primarily concerned with irrigation-type facilities for supplying supplemental water to crop areas, forest areas and unharvested soil cover acreages. The other types are not widely used because the climate or soil conditions in some locations have an adverse impact on these alternative methods of applying wastewater to land.

Irrigation-type facilities were found to be used in many instances under a wide variety of climate and soil conditions, with various degrees of prior treatment of the applied wastewater and various types of ground cover utilized.

Each method of application has inherent advantages and disadvantages which must be evaluated for their feasibility and efficacy.

Land application of wastewaters has been practiced extensively in various parts of the world for many years, long before the turn of the century. The majority of earlier facilities applied untreated domestic wastewaters with varying degrees of control and success.

As knowledge of wastewater treatment processes improved and techniques were developed which confined the entire process needed to produce a “treated” effluent for disposal into receiving waters into a relatively small area, land application was relegated, in most states, to being an undesirable and unacceptable process.

New concerns about preserving the quality and re-use of the nation’s water resources have resulted in a reawakening of interest in land application as a viable alternative to conventional wastewater treatment and disposal into receiving waters. Increasing volumes of sewage and industrial wastes, growing complexity of such raw wastes, and mounting needs for water to serve growing urban and industrial processing needs, have created doubts about the ability of receiving waters to assimilate effluents which do not meet high-quality standards. In addition, increasing evidence of eutrophication of non-flowing receiving waters has focused attention on the need to eliminate the presence of nutrients in wastewater effluents. Further, the presence of toxic trace elements in effluents is sometimes considered a threat to the safety of receiving waters. Thus, advanced treatment methods have been developed and utilized to avoid discharge of such objectionable components. Inasmuch as land application appears to offer comparable or superior degrees of treatment by augmenting waste treatment with the “natural” purification offered by soil contact, land application is again being considered as one of the acceptable means of achieving full treatment of wastewaters.
However, a most important factor of the current land application concept is that it be limited to the use of treated wastes. Generally, effluents are being conventionally treated to meet secondary treatment quality criteria. In at least three observed facilities, applied effluents have received tertiary treatment, to the point where the effluent would fully meet the generally prescribed, as well as proposed, criteria for discharge to receiving waters. Thus, land application is being used to give a degree of advanced waste treatment, including high degrees of nutrient and bacterial removal. In this context, land application can be viewed as an alternative to physical-chemical processes and other methods of ultra-treatment which are designed to achieve a high quality effluent.

Economics of construction cost, operating costs, energy requirements, and efficiencies of performance of land application systems must be balanced with the ability to acquire the right to apply wastewater upon the required land areas. The cost of advanced waste treatment by conventional means must be weighed in the light of the cost and complexities of land application systems.

Two informative reports were published on the subject of land application in 1972. Green Lands — Clean Streams, a report by Temple University Center for the Study of Federalism, is a frankly written advocacy of the land application of wastewaters and sludges. Wastewater Management by Disposal on the Land by the U.S. Army Corps of Engineers is a thorough review of the physical, chemical, and biological interactions involved in the technique of land application. The Consulting Engineering firm of Metcalf and Eddy has also prepared a companion report for the U.S. Environmental Protection Agency, concerned with engineering considerations of land application systems, entitled Wastewater Treatment and Reuse by Land Application. The M&E report will be printed by the U.S. Government Printing Office in 1973. These three reports, together with this report on the study conducted by the AWPA Research Foundation, should be considered in evaluating land application systems because they deal with somewhat different aspects of the common problem.

The report on the AWPA studies has made no special effort to examine the specific aspects covered in detail in the other reports. Rather, it is concerned with reporting upon the policies, practices and performances of a representative group of the relatively larger land application systems within the U.S.; policies, or lack of policies, of state regulatory agencies; and the experience with land application in certain foreign installations.

Systems which were under construction, such as Muskegon County, Michigan, and several major domestic and industrial systems which were intimately known to Metcalf and Eddy project personnel were not investigated for this report. However, the firm of Metcalf and Eddy has supplied copies of its field interviews at such sites to APWA evaluators and data on many of these
installations have been incorporated in this report. Conversely, all field information obtained during the APWA investigations was supplied directly to the firm of Metcalf and Eddy for its use in analyzing its own study results.

HIGHLIGHTS

The following highlights from the field survey are presented to give a composite picture of the observations made during the land application site visits:

1. Communities generally use their land application system on a continuous basis. Food processing plants, the predominant industrial users of the system, generally use discharge-to-land systems for three to eight months per year.

2. Ground cover utilized for municipal systems is divided between grass and crops. Industries generally use grass cover.

3. Land application systems are generally used on a daily basis, seven days per week.

4. Application rates for crop irrigation are very low in terms of inches of water per week. Two inches or less was commonly used. (Two inches per week equals 48,000 gallons per acre per week.)

5. Many types of soils are used, although sand, loam and silt were the most common classification given. Two systems using applications over many feet of sand were applying up to 8 inches per day once a week, and one system on clay was applying a daily rate of 0.1 inch.

6. Most operating agencies, municipal and industrial, are planning to either expand or continue their land application installations. The few examples of systems which had been abandoned were due to either the desire to make a higher use of the land, or because of reported overloading and incompetent operation of the land application facilities.

7. Industries surveyed generally treat their total waste flow by land application. Practices of municipalities varied from less than 25 percent, to all the wastewaters discharged.

8. Secondary treatment is generally, but not always, provided by municipalities prior to land application, often times accompanied by lagooning. Industries using this technique frequently treated their process wastes by screening only.

9. Spray irrigation is the most frequently used (57 facilities) method of application, although most municipalities use more than one method.
Ridge-and-furrow irrigation is used at 23 facilities and flooding irrigation by 34 systems. Industry generally used spray irrigation.

10. Land use zoning for land application sites is predominantly classified as farming, with some residential zoning in contiguous areas.

11. Wastewater generally is transported to the application site by pressure lines, although a number of municipalities are able to utilize ditches or gravity flow pipelines.

12. Many municipal land application facilities have been in use for several years – more than half for over 15 years. Industrial systems generally have been in use for a lesser period of time.

13. Renovated wastewater is seldom collected by under-drains; rather, evaporation, plant transpiration, and groundwater recharge take up the flow.

14. Land application facilities generally do not make appreciable efforts to preclude public access. Residences are frequently located adjacent to land application sites. No special effort is made to seclude land application areas for recreational facilities and from those who use these leisure sites.

15. Monitoring of groundwater quality, soil uptake of contaminants, crop uptake of wastewater components, and surface water impacts is not carried out with any consistency.

OVERVIEW

In order to present all of the details and data relating to the conduct of the studies, and to explore the influence of possible factors influencing the handling of sewage from many sources, at many sites, and with many and diverse methods of application, the APWA report has resulted in a rather large document.

Among other things, the report has been compiled to answer the inquiries of the U.S. Environmental Protection Agency from other U.S. Government agencies, municipalities, industries and engineering consultants. The total report is valuable, not because of its size, but due to its contents. This is the first time some of this data has ever been assembled, evaluated and reported. It will become available from the U.S. Government Printing Office in the autumn of 1973 and from the National Technical Information Service (NTIS) of the U.S. Department of Commerce.

This overview is for those who require a brief summary of the contents of the American Public Works Association report, entitled, Survey...
of Facilities Using Land Application of Wastewaters, and an equally concise evaluation of the principles, practices and performances of the land application systems now in service in the United States and in certain foreign countries. Summaries of the basic intent and information contained in each section of the report are presented as well as a demographic evaluation and a discussion of the fate of materials applied to the land.

The conclusions drawn from the study serve to verify the relative success of present land application systems for supplementing ground-water sources; providing economical means of effluent utilization where discharge to surface waters would be excessively difficult and costly; affording augmented effluent quality improvement by soil uptake of constituents which would adversely affect receiving water quality, offering opportunities to enhance crop growths and silviculture; and augmenting indigenous water supplies for recreational and aesthetic purposes.

Successful application of effluent wastewaters to land areas is not without its problems. This management technique is not a universal panacea.

The need for public acceptance of land application methods is strongly advocated, particularly for proposed installations covering large volumes of flow to extensive acreage in relatively densely populated regions. Over and above the problem of neutralizing the aesthetic and psychological objections to any direct or indirect contacts with wastewaters or waste residues, unfounded fears of virological or pathological infections must be overcome by carefully planned and effectively executed public education programs.

This public relations problem emphasizes the recommendation that irrefutable findings on the presence or absence of health hazards in land application practices must be defined and reported before guidelines for this method of wastewater effluent management are promulgated. Guidelines are soon interpreted as “the law” rather than suggested criteria. This gives credence to the sound suggestion that formalization of “guidelines” be deferred until “interim evaluation procedures” are published and given the opportunity to bridge the gap between today’s rather limited use of land application systems and any greatly expanded utilization of this treatment-disposal procedure in the future.

THE STUDY — SECTION II

The studies conducted by the American Public Works Research Foundation on behalf of the U.S. Environmental Protection Agency were planned and consummated to produce the fundamental information needed to
give validity to the intent of Section 201 of the 1972 Amendments to the Water Pollution Control Act such as:

- Affirmation of design and operational data for a large number of U.S. installations in various climatic regions, handling wastewaters of various types and volumes; by various methods of application; for different purposes; on various types of soil, ground cover and cropping; and demonstrating different local environmental conditions and monitoring practices.

- Collection and interpretation of similar data on foreign installations where land application has been in effect for longer periods and under varying conditions.

- Collation of bibliographic records and reference on every conceivable facet of land application, including design, operation, physical, chemical, pathological, virological, parasitic, aesthetic, hydrologic, agricultural, herbicultural, silvicultural benefits and detriments, and other related matters.

- Evaluation of all data in terms of practical interpretation of their meaningful answers and guidelines to land application practices.

The studies, in great measure, achieved these goals.

SURVEY INVESTIGATIONS — SECTION III

On-site, in-depth investigations of more than 67 community and 20 industrial land application systems were carried out by trained engineering specialists. The 87 installations designated provided data of significance. These sites were chosen to be representative of national experience with varying types of wastewaters, applied to varying types of soils, ground cover and other indigenous conditions under diverse climatic conditions.

To augment the findings of the on-site surveys, a mail investigation of similar land application sites was carried out, covering the same study subjects explored by the field study team. Significant data were obtained for approximately the same number of municipal and industrial installations covered by the field studies. Five climatic zones, each with its own temperature, precipitation, humidity and seasonal characteristics, were designated. Evaluation of survey findings was interpreted on the basis of the impact of climatic conditions on wastewater application to land areas and other factors influenced by meteorological phenomena.

The demographic, geographic, geologic, hydrologic and other factors and impacts of land application practices, procedures and performance are discussed in this section.

The findings of the survey offer evidence of acceptable operating experiences, which should be useful in guiding future land application decisions.
An important finding, among all of the diverse conclusions that can be drawn from field and mail survey data, is the fact that 90 percent of communities and 95 percent of industries making use of land application methods plan to continue their use; nearly 50 percent of communities and one-fifth of the industries contemplate increasing or expanding their systems. If the "proof of the pudding" is in the performance, the approval of users is the final appraisal of the land application technique.

The study indicated that existing land application systems are serving, predominantly, in relatively small communities and industrial sites, in terms of population and flow loadings. Future applications may involve larger loadings, greater irrigation areas and greater land values, but the expansion of facilities may represent an orderly enlargement of scope and a manageable increase in costs. It is significant that the costs involved in existing land application systems apparently lie within the capabilities of small communities and industry installations. Choice of this means of wastewater disposal has been based on various factors: need for supplemental irrigation water; augmentation of ground water resources; simplicity and economy of providing required degrees of treatment; problems of excessive cost of providing treatment and outfall lines to distant points of effluent discharge into suitable receiving waters; and merely "to get rid of the sewage" in a convenient, trouble-free manner that is acceptable to the community.

The findings of the survey are so manifold and technological that any attempt to capsulate them would hinder value and endanger their interpretation. The following points are borne out by the report: Existing practice stresses land application of treated effluents, not raw wastewaters; the percentage of land application acreage frequently represents only a portion of the land reserved by the owners for their systems; application periods may vary from one month to twelve months a year, and from one to seven days a week, depending on climatic conditions, need for land application for surplus flows, seasonal industrial processing, such as in the food industry, and other local factors; land values are relatively low, zoned for either agriculture or residential uses, often in undeveloped areas, and subject to minimal degradation of value due to use for irrigation purposes; all types of soil are utilized, with sand, clay and silt most favored; groundwater interference problems influence choice of sites and, after choice of unaffected sites, cause minimal difficulties with land application methods; predominant wastewater distribution methods are spray irrigation, overland flooding irrigation and ridge-and-furrow irrigation.

Use of the irrigated land varies with the owner's needs and dictates, from no ground cover to grass cover, cultivated crops and forested areas. Grass is the most common ground cover in community systems. It is evident that the cropping value of supplemental irrigation with wastewaters and their nutrient components is not universally utilized.
Rates of application of sewage effluents to the land, and duration of uninterrupted application vary from 0.1 inch per day to over 1 inch per day, with varying periods of irrigation and resting. The most commonly used application rate is two inches per week. Few systems are over-stressed by such loadings; it is apparent that increased rates of application could be practiced without jeopardy to the system or the environment, and with more effective and economical utilization of assigned acreages. The follow-the-leader trend in application rates is apparent; proposed guidelines — either tentative or final — would do much to establish more rational application rates, based on facts rather than blind adherence to the accidental or arbitrary rates used by other researchers.

Little concern and protective measures have been shown for the deterioration of the environment in application areas, or to the impact on contiguous lands and their occupants. Security provisions are not universally used to protect against intrusion of trespassers or against the dispersal of on-site conditions to surrounding land areas. Fencing and patrolling is not universally practiced; buffer zones to isolate land application areas and impede dispersal of aerosol sprays are used but no common practice is in effect; monitoring of groundwater, surface water sources, soils, crops, animals and insects is practiced in some locations and minimally used in others, often dependent solely on the requirements of public health authorities.

It is hazardous to characterize the above thumbnail findings as truly representative of the practices and experiences disclosed by the survey. Similarly, these factors do not represent all of the disclosures of the study. They do, however, give indication for those who will not study the full text and details of the comprehensive investigations explored in the full report that land application methods have been found to be workable and relatively amenable to the local environment, even under control and regulatory procedures which must be improved in all future land application practices. The future will require more complete supervision of land application sites, supported by definitive proof of the capabilities of such systems to serve as wastes handling facilities worthy of the term “alternative” techniques.

OPINIONS AND REGULATIONS OF STATE HEALTH AND WATER POLLUTION CONTROL AGENCIES – SECTION IV

The survey conducted by APWA with state health and water pollution control agencies indicated that most state agencies have no set policies on this
phase of wastewater handling or attendant environmental impacts, do not impose specific conditions on installations, seldom inspect existing systems, and seldom require monitoring procedures and the filing of official reports on operation.

Only four states reported rules governing the types of crops that can be grown on sewage-irrigated lands. The few agencies which invoke restrictions of this nature specify the quality of effluents applied to land areas. Of 27 state control agencies which participated in the data-gathering program, a maximum of 25 percent involved themselves with any single item of the 11 guideline criteria covered by the opinion survey.

In defense of this record of irrelevance with the land application practice, it must be said that some states have few such installations and even fewer have installations of any major significance. In addition, states contend that they have been deeply involved with the control and regulation of conventional sewage treatment facilities and stream quality protection. Shortage of qualified personnel has been offered as the reason for absence of attention to the installation, operation and monitoring of land application installations.

In the absence of formal state regulations, some agencies have used unofficial staff opinions as the basis for land application decisions. Similarly, each-case-for-itself decisions on health hazards have been invoked or expressed by state health agencies but a minimum of translation of such policies into specific regulatory actions was disclosed by the survey.

SUMMARY OF FOREIGN EXPERIENCE — SECTION V

Data from such widely located countries as Argentina, Australia, Belgium, India, Israel, Hungary, and Mexico confirm the use and value of the land application technique for various purposes, for a variety of growing crops, under diversified conditions, and with different results. Enhancement of soil productivity, through the mechanics of supplemental irrigation with waste water and the enrichment of soil with the organic constituents of sewage and industrial processing waters are widely acknowledged.

Health hazards have been studied in various countries and protective measures have been invoked. Some countries, such as water-short Israel, utilize wastewaters for irrigation purposes — where over 100 systems are in service, but they tend to avoid the use of raw, untreated sewage and contact with crops that are eaten raw by humans or domesticated animals.

On the North American continent, the most dramatic land application system on record is in Tula Hidalgo, Mexico, where lands operated by the Mexican Federal Department of Agriculture are assigned to ejidos, heads of families, in units of limited hectares. On 47,000 hectares, equivalent to 115,000
acres, some 1,476,000 metric tons of food products were grown in 1971. Approximately the same tonnage was produced in 1972. Additional arid land is available for cultivation when additional wastewater from Mexico City becomes available. Currently some 570 million gallons per day of raw untreated sewage flows by canal to this area, 95 percent of which reaches the cropland. During the rainy season there is an additional storm water flow through the same canal, most of which is impounded in a series of dams for use during the dry season for cropland irrigation.

In England the Hertfordshire facility has had over 20 years experience irrigating liquid digested sludge containing about 3 per cent solids. Technically this land application system is more related to sludge than to sewage effluents, but its long and successful experience confirms the feasibility of that method of land application of wastewaters. There is a non-technical 16 mm color film, entitled, Wealth from Waste, which shows the Herfordshire operations.

GUIDELINES FOR IMPLEMENTATION OF LAND APPLICATION SYSTEMS – SECTION VI

The survey provided many guidelines that could be translated into “do’s” and “don’ts” in land application procedures. In addition, the literature searches brought added criteria to light, confirming the basic facts evolved from the survey. From these information sources and others, the report suggests guidelines for the implementation of land application systems.

For the guidance of the regulatory administrator staffs, decision-makers, designers and owners of future land application installations, some tentative procedures have been presented as they may be affected by climatic conditions and applicability of the process to specific meteorological phenomenon; availability and location of land areas suitable for wastewater application; rates of application; types of soils, crops and ground cover; methods of application and their relationship with geological, topographical and hydrological conditions; types of wastewater pretreatment to assure proper and safe land application; capital and operating costs; monitoring and health protective measures; and other related aspects of system planning and execution.

References have been drawn from all possible sources to support the tentative parametric procedures outlined in the guidelines. The listed criteria are not presented as “standards”; this would be improperly anticipatory of the next official step which must be taken to distill from this study and the other parallel investigations sponsored by the U.S. Environmental Protection Agency on land application techniques. Rather the guidelines are offered as suggested criteria, a necessary input into the overall fund of information upon which eventual official guidelines must be based. As mentioned in the Overview, this
gives credence to the suggestion that formalization of guidelines be deferred until "interim evaluation procedures" are published.

PLACING LAND APPLICATION OF EFFLUENTS IN PERSPECTIVE: AN INTERPRETATION – SECTION VII

This section stresses the importance of placing land application techniques in their proper perspective, and interpreting the alternative "pluses" and "minuses" on the basis of local factors and local needs.

It is evident that an "alternative" must be compared with something for which it is an alternative. Thus, the determination of the choice of wastewater utilization process must be based on a full-dimensional decision; and that decision must stem from placing the land application process into the proper perspective with itself and with other means of managing wastewaters.

When viewed in this light, land application technology is not a panacea for all wastes, in all areas, under all circumstances. It is not a "quick and easy" means of getting rid of unwanted wastewaters. It involves adequate pretreatment, effective operational procedures, rigid monitoring controls and rational cost evaluations. As a substitute for the return of waters into the drainage basins from whence it originally came, it can effect the "cycle of water" and create an imbalance in the water resources of a region. Land application can no longer be compared with disposal of wastes by dilution; just as conventional wastewater treatment now involves high degrees of treatment, so land application must assure that the soil will receive highly treated influent water or that the soil will provide the equivalent of tertiary treatment and removal of deleterious components by biological-chemical-physical phenomena. The effectiveness of land application must be judged by what it accomplishes — not merely as a means of eliminating the direct discharge of comparably well treated effluents into receiving waters.

To fulfill its full possibilities and benefits, land application must be examined from the standpoint of what has become known as the "4-R cycle" — return of waste water to the local land rather than being lost by stream flowage to downstream areas; renovation of the wastewater by soil and vegetative actions; recharge of the groundwater resources which then become the reservoir aquifer which feeds surface water sources; and the reuse of wastewater either directly off the land or via the tapping of the groundwater reservoir. Practical examples of these land application benefits are available; they must be placed in proper perspective with the needs and potentialities of the area in which a proposed land application project will be constructed as an alternative to conventional wastewater treatment works.
DEMOGRAPHIC EVALUATION OF LAND APPLICATION TECHNIQUES

Demography is the science of social statistics. Wastewaters are the product of people and of industrial production in an urban industrial society. The nature of wastes produced by community life and industrial processing and the amounts of such wastewaters are affected by regional conditions and their impact on life and living processes. Automatically then, the manner in which wastewaters are handled and disposed of is influenced by demography, or regional environmental needs. For example, the degree of sewage and industrial treatment in the past was influenced by the water resources needs of regional areas and how regulatory bodies interpreted these needs to protect the natural environment and preserve public health and safety. Over and above the natural setting for any region, policies were and will continue to be affected by population densities, water needs, public desires and antipathies, and other factors. This represents demography in action.

If it were possible to relate the applicability of wastewater management on land areas to such factors as climatic conditions, population and population densities, economic-social patterns, and similar demographic parameters, these would serve as important guides for the choice of this alternative method of wastewater treatment and utilization vis-a-vis today's conventional treatment standards and the advanced degrees of effluent quality that will be required in the future. If such relationships could be established, based on the findings of the APWA Report, or by parallel investigations now sponsored by EPA, the viability of the land application technique could be verified or clinically questioned.

The factors involved in a full demographic evaluation of land application practices appear to be too numerous, too complex and too interwoven to be capable of clarification by the current APWA study. Many of the factors are too intangible to be explained by basic survey data; the type of study parameters used in the current study could not include such incomprehensible implications. But the study did involve the relationships between land application and climatic conditions, and concurrent relationships involving urban populations and densities, industrial operations, local ecological conditions and other indigenous factors.

Climate is a major factor in the applicability of land application procedures, on the purpose and continuity of operation, and on the performance of this alternative technique. In recognition of the importance of climatic conditions, the study was based on the choice of site investigations in five climatic regions of the United States and evaluations were aimed at determining the impact of the specific zonal meteorological characteristics on every phase of the study.
Broadly characterized, Zone A (mid and south Pacific coast) is an area of dry summers and mild wet winters; Zone B (the southwest) is an arid region, with hot, dry climate; Zone C (southeast-Gulf coast-Atlantic coast and Pacific northwest) experiences hot wet summers and mild winters; Zone D (east-continent and northeast Atlantic coast) is subject to humid weather, with short winters and hot summers; Zone E (mid-continent and far northeast) is a humid area, with long winters and warm summers.

While climatic conditions have the most significant impact on the land application principle, other factors have potential bearing: size of the community and the industry; the volume of wastes flow; the population contributing sanitary wastes plus the population equivalent of the industrial wastes contributed to the municipal sewer system; the availability of open land for irrigation use; the land-use zoning of the region; the cost of land; the type of crops to be grown with supplemental irrigation and the market needs and demands for such crops; the groundwater depth and quantities, and their use for water supply purposes, protection against salt water intrusion into aquifers and other functions; the nature of the soil; the proximity of surface waters which can become recipients of conventionally treated effluents; and correlated circumstances of local or indigenous nature.

It is not difficult to rationalize the effects of these climatic-demographic conditions on land application practices, and conversely, the impacts of land application on these environmental conditions. It is difficult, however, to translate the findings of the subject into these relationships. Efforts have been made to draw every possible relationship between these various factors but the findings are often too indeterminate to warrant such translations.

The following highlights can provide valuable guidance for decision-makers and designers of land application systems, even though they are not always affirmed and confirmed by study findings.

CLIMATIC CONDITIONS: The 67 community systems and 20 industrial land application sites covered by the on-site visits, and the comparable numbers of such installations covered by the mail inquiry, were representative of the actual total projects in each of the five climatic zones. The major number of community systems surveyed was located in Zones A and B, with California sites predominating. These two zones represent dry and arid conditions which make supplemental water resources — reused water in the form of effluents — a precious commodity. No industrial sites in these zones were surveyed by on-site investigators because minimal use of land application techniques is made by local industrial installations. In lieu of such industrial irrigation projects, communities in Zones A and B accept industrial wastes into public sewers andonto publicly owned application sites in the form of population equivalent loadings.
In Zones C, D, and E, industrial sites were surveyed because the use of land application is practiced more generally in these parts of the nation. The industries involved are primarily food canning-processing factories, dairy processing plants, pulp and paper mills, and organic chemical manufacturing firms.

The differentiation between the zonal incidences of community systems and industry sites is explained, at least in part, by the needs for supplemental water and the uses for such water. Thus, climatic water-short and water-rich areas dictate decisions either to retain sanitary wastewaters in the areas which produce them, or to permit them to flow away downstream into other receiving watersheds and water basins.

In regions A and B, water is in relatively short supply, due to dry summers and year-round aridity, and wastewaters are often times considered by communities as a valuable commodity for land irrigation, for groundwater augmentation, and for use for such ancillary purposes as golf course and highway median watering and the creation of recreational water facilities. Industries in these areas however, as in other areas, are less concerned with such beneficial uses of wastewater and may not practice land application; they may use this management procedure primarily for the purpose of "getting rid" of such effluents in the cheapest and simplest manner without adversely affecting the environment.

This brings the matter of wastewater, or used water, economic and ecologic value and utilization into focus as the determining factors in the practice of land application. In arid regions, land application offers strong incentives. In wet, humid regions water-husbanding is not a vital motivating reason for land application installations; but such motivation can be found in the economies of producing high-quality effluent by means of the "free" purification capabilities of soil. Whether planned as a water resource conservation procedure or not, the ultimate fate of wastewaters applied to land areas by spray irrigation and surface application, such as ridge-and-furrow methods, is a means of enhancement of the local groundwater reservoir. The fact that 85 percent of the water stored in the United States is contained in subsurface aquifers adds significance to this wastewater fate.

Climatic, geographic and geologic conditions have other influences on the choice of wastewater disposal systems. Inland areas that have no convenient receiving waters may find it cheaper to apply wastewaters to the land rather than to construct long, expensive outfall lines from their treatment plants to suitable discharge points. On the other hand, the water-cycle imbalance which may occur in local waters by taking water supplies from them and not returning wastewater back to the same rivers and lakes may place a negative
aspect on land application procedures. This type of water resource imbalance does not apply to coastal waters.

The relationship between hard winters and land application systems is obvious. In areas where full-year irrigation can be practiced, land application would have greater applicability than where adverse winter conditions would make irrigation inappropriate or inefficient. While land application is practiced in some ice, snow and sub-freezing conditions, optimum conditions are represented by year-round mild weather such as is experienced in Zones A, parts of B, and in C.

Similarly, the relationship between climatic conditions and holding pond capacities is equally understandable. Where seasonal cessation of land applications is necessary, the principle of "not one drop of wastes into water resources" impels the construction and use of adequate holding facilities. "Adequacy" is a relative term; 31 percent of community and industrial systems use ponds with capacities of five days or less. In Zones, A, B and C, 75 percent of the sites have holding capacities of less than 30 days, or less than needed for a full winter season. One installation in a cold zone provides a 50 million gallon pond for a daily flow loading of 0.5 mgd.

Of some significance, if not as pertinent as other seasonal conditions, is the amount of rainfall in humid areas which may impede soil absorption of applied wastewaters and require the use of flow-equalization or flow-holding of excess waters until required rates of application can be reinstated. As stated, where rainfall is generally adequate, if not always predictable, land application for enhancement of crop growths, forest growths and groundwater augmentation is not the dominant reason for the choice of this wastewater management technique.

While the survey studies brought these climatic relationships into focus, they did not always provide positive proof of these effects and impacts. This does not detract from the validity of the above observations. No attempt has been made to draw all possible climatic-environmental relationships with land application principles and practices; however, the rationale is adequate to demonstrate that there is a direct correlation which must be considered before choice of wastewater management is made for each individual project. No set standards can be established; each case will require its own relationship evaluation.

**SIZE OF WASTEWATER FACILITY:** In the case of publicly owned systems, the population served is translatable into volumetric and qualitative loadings. For industries, the flow loading is a factor of volume and population equivalency of the organic constituents, as measured by BOD, COD, suspended solids and other significant parameters.
The survey indicated that some outstanding large community land application installations have been in service in the United States and foreign countries. However, the major percentage of current operating installations are in the smaller-size range.

The on-site survey disclosed that 73 percent of communities studied have land application capacities of under 5 mgd; the mail survey covered no community systems with over 10-mgd capacity. Industry installations covered by the on-site survey were all under 5-mgd capacities; the mail-surveyed installations were all under 10-mgd size. It is conjectured that the small cities and industries have found land application within their economic range and that adequate conventional treatment would have been more costly.

Size factors are numerous but few showed definitive relationships with other land application site acreage parameters. The area used for irrigation application varied without basic reason from the total acreage owned by the community or industry. In some cases the major extent of the area is used for distribution; in other instances only a portion is so used, the rest of the acreage being devoted to holding ponds, buffer zone and general isolation of sites.

The size of the area varies, with the volume of flow applied, the nature of the soil and its absorptive character. The effect of climatic conditions, such as rainfall, humidity and temperature, on irrigation area acquired by communities and industries is minimal, despite any impression that such a direct relationship should exist. No specific trend was found in buffer zone regulations and usage. The open land available for such buffering or isolation facilities is undoubtedly influenced by state regulatory agency requirements and the type of distribution systems used (Spray irrigation tends to be associated with buffering acres and plantings to impede the off-site dissemination of aerosol mists and particulates.)

CONTINUITY OF OPERATION: The relationship between continuity of wastewater application, on a days-per-week or a months-per-year basis, and land acreages used for land application was found to be indeterminate. Continuity of operation appeared to be dictated by other factors than availability of site acreage. It is obvious that rates of application should have a bearing on the land areas required, particularly on sites that are limited in size and not over-generous in dimensions. While the analysis of study data does not disclose this relationship, it is undeniable since the failure of irrigated land to handle distributed wastewaters for planned periods will necessitate the resting of such areas and the immediate utilization of other equivalent acreages to replace the overloaded or ponded soil plots.

If wastewater production is in effect for longer weekly or monthly periods and pond storage capacity is not available to retain excess flows,
irrigation areas may be affected by the requirement that direct application of produced flows must be provided. Similarly, the land-need requirements for any site will be influenced by whether the system will function on a twelve-month basis or shorter yearly periods.

Communities tend to maintain yearly continuity of land application more completely than industries; broadly interpreted, communities operate full-year at 60 percent of installations, and industries at 40 percent of sites. The relationship between climate and continuity of irrigation was partially clarified by the study, despite the fact that positive patterns were not confirmed. The on-site survey-interview procedures used in the study disclosed that twelve-month continuity of community operation for Zones A, B, C, D and E was practiced in 76, 63, 56, 71 and 67 percent of sites, respectively, while industrial systems showed similar year-round irrigation service in Zones C, D and E of 50, 56 and 30 percent of sites, respectively.

The mail survey showed the industries in Zones A and B (not surveyed in the on-site program) operated on a 12-month basis at 100 percent of the sites involved, with 100 percent of the Zone C community installations functioning on a full-year basis. Thus, the zonal factors showed little effect of widely divergent climatic conditions on whether systems functioned without cessation.

Full-week service seemed to be dictated more by the actual purpose of land application than by other factors. Full-week irrigation was found to be more common when crop irrigation was practiced than when wastewater disposal onto grass-cover lands was utilized for groundwater augmentation or for the simple purpose of effluent disposal. Application rates and continuity of irrigation were, surprisingly, unaffected by soil types.

METHODS OF DISTRIBUTION: The relationship between the method of application and climatic conditions was brought into focus by the study. In general, spray irrigation is more commonly used in humid areas than in arid sectors; and surface application techniques, such as ridge-and-furrow irrigation and overland irrigation, are more frequently utilized in arid regions. Zones A and B were characterized by surface application sites.

The relationship between size of site and type of distribution used showed a trend of more or less specificity. Smaller sites were served by twice as many spray systems as surface application facilities. Larger sites, over 1,000 acres in size, were usually equipped with surface application systems; intermediate-sized sites, from about 100 acres to 1,000 acres, utilized spray and surface application systems about equally. In surface application installations, so-called overland flooding which depends on sheet-flow action has been used more frequently than ridge-and-furrow distribution.
No specific correlation was found between distribution methods and soil types, but some generalized patterns were evaluated: spray irrigation is more commonly used on loam, silt and clay lands; spray and surface application methods are generally used equally on more granular soils. Surface application methods were found more frequently on crop lands or on unplanted, non-cover areas. Spray irrigation was found more frequently on crop lands and forested acreages. Community sites handling under 1-mgd flows were most commonly grass-covered, while larger areas of over 1-mgd capacity generally stressed crop growth. Forest irrigation was practiced more frequently in humid areas than arid regions, probably because tree growth is more common in the humid climatic regions. Cropping on arid region lands is relatively common, indicating the value of wastewater for supplemental irrigation.

Groundwater depths are a dominant factor in choice of sites, but, once acquired, these application lands experience minimal impacts on choice of application methods and on operation performance. Obviously, groundwater depths are greater in arid regions and are less of a factor in choice of land application sites. Application rates, while not consistently influenced by climatic conditions or soil character, and while varying minimally from the almost traditional level of one-half inch per day and two inches per week, are influenced by aridity and high humidity-precipitation conditions.

LAND AVAILABILITY, LAND USE AND LAND VALUE: A direct relationship between demographic criteria and land availability, zoning use and acreage price is unavoidable. The first requirement of a land application system is land. It must be available in reasonably close proximity to the source of community or industrial wastes; the land must be useable for wastewater application by zoning and other use regulations; the price must not be prohibitive.

These conditions are most commonly met in areas of low population density where open lands are available, and where undeveloped and properly zoned properties can be acquired at relatively low cost. This is why the survey showed the predominance of land systems in use by small communities and relatively small industries, and land prices ranging basically in the under-$500 per acre price level. Areas of the nation will become progressively more densely populated because over a million acres of rural lands are absorbed annually in urbanization and related facets of community growth. The availability of nearby lands, zoned for agriculture or residential purposes, and priced at low enough levels, will become a greater problem for users of land application systems. The cost of long-distance wastewater transmission will become an important factor in determining the economic feasibility of land application for wastewaters.

The impact of land application installations on neighboring areas and their residents can be in direct ratio to population density. While existing systems have demonstrated their ability to be “good neighbors” to residents living as
close as 500 feet to the application site, this close proximity may not be good practice in all cases. Reported complaints have been minimal against present installations despite the fact that, for example, 20 percent of community systems in Zone A are located less than 500 feet from the nearest neighbors and 22 percent are similarly located in Zone B. Industrial sites are located in Zones C, D and E within 500 feet of residences in 10, 10 and 21 percent of the cases investigated, respectively.

The relationship between local demographic conditions and land application system monitoring is obvious. The degree of monitoring was found to be less related to zone climatological conditions than to state health and water pollution control regulations in the limited cases where such governmental stipulations are imposed. It is understandable that increasing population intrusions in an area and the density of the residential population will dictate that closer attention should be given to the impacts of land application on land and water resources and on persons exposed to actual wastewater, sludge residues, spray mists and animals and insects which come in contact with irrigation liquids and vegetative growths. The frequency and location of monitoring points, such as test wells and other sampling facilities, and the extent of monitoring parameters will be intensified in the future to satisfy actual hazards or the psychological impressions of local residents.

Site security measures, such as fencing may be required and buffer zones may be specified. Operation and maintenance costs will react to all such monitoring and security requirements but the reasonable cost levels for present systems could be increased without seriously affecting the feasibility and economy of land application techniques. Future wastewater treatment works, particularly those requiring full secondary treatment and processing to remove such components as phosphorous, nitrogen, trace metals and organic pesticides, will require similar augmentation of present specific laboratory control and site safety and security measures.

FATE OF MATERIALS APPLIED TO THE LAND

To complete this extended summary of the land application of wastewaters, a review of the fate of applied materials is presented to round out the information which has been presented. Reference is made to two papers entitled, Experiences with Land Spreading of Municipal Effluents, and Fate of Materials Applied, prepared by Richard E. Thomas, Soil Scientists, Robert S. Kerr Water Research Center, Environmental Protection Agency, Ada, Oklahoma. For the future applicability of land utilization of wastewaters, it is important to know with some measure of certainty what the fate of wastewater components will be.
The materials contained in wastewaters are reminiscent of the origin of these flows — either sanitary, sanitary and combined storm water, industrial process water, or combinations of sanitary and industrial wastes. Since the application of raw wastewaters onto land areas is not contemplated under the definition of this alternative waste management technique, all such wastes have been subject to some degree of pretreatment before they are applied to land. The purpose of monitoring of influent flows onto land areas is to ascertain the composition of the wastewater after the stages of pretreatment provided.

A classification of wastewater materials could be: suspended materials; major plant nutrients; and other constituents. Another delineation of the wastewater components, based on the actual physical nature of the substances is: suspended solids; colloidal solids; dissolved organic materials; and dissolved inorganic substances.

The fate of these substances during the process of land application will vary with the type of distribution system, the nature of the soil, the rate of application, the climate, the resting periods, and the location and proximity of the groundwater aquifer and the surface water source which receives runoff from the site. The phenomena involved include: the physical condition of entrapment or mechanical filtration; the biological, biochemical, electrochemical and other manifestations in and in contact with the soil; evaporative factors; atmospheric oxidation; bacteriological, germicidal, and bacteriophage or anti-contamination reactions, and others which are not totally understood even by highly trained and experienced scientists.

Suspended solids entrapped in the interstices of the soil or adhering to soil particles by electrochemical entrainment can experience biological oxidation and decomposition into stabilized substances. The fate of this suspended material can vary; it can remain in the soil to form humus soil conditioning or nutritive material or, in coarse media, it may be sloughed off and percolated into lower soil depths or into the groundwater.

Colloidal materials — solids of minute size which may be able to filter through soil media — can be coalesced or coagulated by electro-chemical agglomeration and then adsorbed onto soil particles. The fate of this material, normally considered to possess electrical charge, may parallel that of true suspended solids, by oxidation-digestion phenomena. Accumulations in the soil may affect the rate of application of subsequent wastewater loadings.

Organic dissolved solids may be utilized by plant crops, retained in the body of the soil by chemical fixation or other bonding phenomena, or may be oxidized by atmospheric reactions in the course of air contact with sprays or sheets of wastewater flowing over the land.
A major concern is centered on the nitrogen and phosphorus in wastewaters. The presence of these dissolved constituents can influence the use of land application systems in lieu of advanced treatment and discharge into surface receiving water, primarily because they can act as “triggers” in the eutrophication of surface waters. Similarly, if these materials can adversely “fertilize” lakes, why cannot they be used to fertilize land?

The fate of nitrogen and phosphorus will be influenced by many factors, including the type of wastewater distribution system utilized, and the type of ground cover and crops grown. The factors involved in the different land application methods are covered in excellent details in the above-referenced papers, and it is not the intent here to explore these manifestations beyond brief reference to the fact that the fate of these two basic elements can be regulated by proper practices to avoid serious effects on groundwater or surface water sources. The ability of soil to retain and fix phosphorus is more important than its capacity to handle nitrogen because phosphorus delivery to the soil may be greater than the crop uptake ability to utilize it. Fortunately, soil retention is able to prevent phosphorus intrusion into groundwaters that are adequately deep for any effective land application site.

Nitrogen could enter the groundwater in concentrations that might exceed the safe levels of this material in water for human consumption. However, the ability of land application techniques to complete a nitrification-denitrification cycle can be utilized to prevent this fate, as in the spray-runoff technique. A substantial proportion of the phosphorus contained in applied wastewaters in the same spray runoff process could reach surface water sources unless steps are taken to improve phosphorus removal by land contact.

Other constituents of land-applied wastewaters have fates that may influence the use of land methods, either in favor of this alternative process or opposed to its utilization. These include heavy metals, even in trace amounts, pesticides and other organo-compounds, and various salts. Evaporation and evapotranspiration of liquids from soil, vegetative surfaces or water surfaces will not change the fate of these dissolved materials; the evaporative process parallels the distillation phenomenon, in that the water is converted to vapor or gaseous form and the solids are thus concentrated in the soil or vegetation. Salts may thus reach the groundwater by percolation and leaching action. Heavy metals and pesticides can undergo physical, chemical and biochemical interactions with the soil, making land application an auxiliary means of providing so-called “tertiary” treatment for wastewaters, in lieu of more complex and more costly artificial wastes treatment processes.

To repeat the statement made above, the intent of this dissertation on the fate of materials applied to land areas is to point out that the soil and
vegetative forms to offer a "bonus" factor that must be given consideration in determining the future of the land application process. Current concern about the impacts of nitrates, phosphorus, trace metals, pesticides and other organic compounds on receiving waters is sufficient reason for knowing more about the fate of these objectionable materials in the land application process. More remains to be known about them, and about the way various methods of wastewater distribution, various types of soil and topographic and climatic conditions, and other factors and combinations of factors, influence their fate.

The fate of wastewater contaminants during the land application process, in short, offers opportunities for beneficial use for soil and crop enhancement which must be considered as a "plus" for this alternative technique. In addition, the capability of the land application system to remove, modify and stabilize pollutants which would require augmented processing in conventional sewage treatment systems offers another advantage for this alternative management procedure. But, these benefits must be evaluated in the light of whether the applied materials will in any way adversely affect the water and soil environment of the region where land application systems will be utilized. Only through a weighing of the benefits and hazards can the feasibility and applicability of land application processes be properly judged for each specific wastes problem.

CONCLUSIONS

1. Land application of wastewaters from community and industrial processing sources is practiced successfully and extensively in the United States and in many countries throughout the world. Facilities investigated handled from less than 0.5 mgd, providing service for sixty days per year, to over 570 mgd applied on a year-round basis.

2. Land application of wastewaters is practiced for several specific reasons. Among the major reasons were: to provide for supplemental irrigation water; the desirability of augmenting groundwater sources; excessive distances to suitable bodies of receiving waters or extraordinary cost to construct facilities to reach suitable disposal sites; economic feasibility, as contrasted with the cost of construction and operation of advanced or tertiary treatment facilities; and inability of conventional treatment facilities to handle difficult-to-treat wastes.

3. Present land application facilities generally are not "stressing" the system. Many facilities were found to be using effluent on a crop-need basis. Even where efforts were being made to use land as the only point of disposal,
application rates were generally conservative and the soil-plant components of the system were not stressed to limits of assimilation or used to their optimum capacities, thus providing a large factor of safety.

4. **A variety of beneficial uses are being made of wastewater effluents.** Uses include irrigation of parks, golf courses, cemeteries, college grounds, street trees, highway median strips, sports grounds, ornamental fountains and artificial lakes. Wastewater effluents are also used to irrigate many types of crops, including grasses, alfalfa, corn, sorghum, citrus trees, grapes, and cotton. Forest lands are also being irrigated in many areas. Groundwater augmentation to prevent salt water intrusion is being practiced. In Mexico, a wide variety of truck garden crops has long been irrigated with effluent. Crops appeared to benefit from both the nutrients and the increased amount of water which is applied.

5. **A large variety of potential opportunities for land application of wastewater exist in many communities.** Wastewaters that are given a high degree of treatment could well be considered for irrigating large public and private facilities to relieve the demand for irrigation with potable water supplies. Golf courses, cemeteries, parkways, school grounds, parks, airports, planned unit developments, green belts, forest preserves, and marginal land all offer the useful application of effluents to the land.

6. **Sale of effluent for beneficial use has been generally unsuccessful.** Few examples were found where a public agency had been able to obtain more than a token payment for supplying treated effluent. In several cases it was reported that land for the treatment plant had been given in consideration of a right to all or a portion of the effluent. Where an agency received a tangible dollar return, it was generally based upon use of both land and the effluent.

7. **Successful operation of a land application system requires the inputs from a variety of disciplines.** For many systems, the services of a geologist and environmental engineer are required. For systems designed to augment the indigenous crop water requirements by supplemental irrigation, the advice and guidance of soils specialists will be needed. For larger systems, social and behavioral scientists, as well as medical-health personnel may be required to assist in evaluating and securing acceptance of this alternative means of disposal.

8. **Operation of land application facilities can be accomplished without creating a nuisance or downgrading the adjacent environment.** The survey indicated that a majority of the facilities were conducted by well-trained personnel, aware of the need for careful operation of the systems. Training, supervision, and adequate monitoring of pertinent factors are necessary to ensure that systems will not be over-stressed. If ponding on the land is not allowed, odors will not be a problem. The hazard of creating other adverse effects on the environment by discharging treated effluent on land is minimal.
9. Monitoring of land application facilities and effects has been minimal and mostly inadequate. Few states appear to have taken an active role in requiring use of monitoring facilities, apparently because there was no direct discharge of effluents to receiving waters. Many of the municipal systems surveyed had little or no monitoring, inasmuch as the effluent was being used only for supplemental irrigation. Industrial systems were generally better monitored, but control in most cases cannot be characterized as being adequate.

10. Environmental analysis of the effects of land application facilities reflects a general improvement of the environment rather than impairment of the indigenous ecology. Many facilities were observed where the effluent provided the only irrigation water available. Land values for sites with a right to such wastewaters were greater than that of adjacent land because crop and forest growth was enhanced, and use of potable water supplies reduced. No instances of health hazards were reported from any existing facilities, although the State of Delaware indicated concern over potential virus transmission. Farming and recreation potentials exist, as well as improved habitat for wildlife.

Treatment of wastewater prior to land application has generally been dictated by the desire to use the best practical means consistent with available technology and to minimize any adverse effects upon the environment. Land application of wastewater, by eliminating direct discharges of effluent into receiving waters, could be regarded as satisfying the ultimate national policy goal of “zero discharge” of pollutants.

11. Energy requirements for land application systems may be an important consideration. Reported energy requirements for most advanced tertiary treatment proposals are very high, as compared to conventional treatment. Depending upon the location and availability of land, energy requirements associated with land application techniques may be substantially less than other means of treatment and effluent management. This factor deserves further evaluation.

12. The nature and quantity of receiving waters must be carefully evaluated prior to diverting effluent to land application. Few existing systems were found that used underdrains to collect the renovated effluent. Rather, the groundwater aquifers received the flow. If a land application area is adjacent to the receiving water, much of the groundwater may serve to augment the flow into the receiving waters by a gradual seepage into the drainage basin. Elimination of direct wastewater discharges to a stream could unbalance the flow regimen associated with downstream beneficial uses, inhibit desirable dilution of waste discharge, and interfere with the tempering of thermal water discharges. Land application can prevent the intrusion of saline waters into normally fresh water zones. The impact of effluent diversion onto land areas with respect to the basic principle of riparian water rights must be considered where irrigation is planned as an alternate to discharge into surface waters.
13. When wastewater is discharged to land and this method is used as a means of advanced treatment by natural means, the land must receive priority for this use over other optional land uses. The needs of crop production, recreation and other benefits can be in conflict with the utilization of a land application system for the treatment of wastewater. For instance, the planting, cultivation and harvesting of crops and the use of recreation facilities may interfere with continuous application of wastewater onto land areas. The need for the system to either utilize all of the flow or provide sufficient retention storage for needed periods of non-operation must be recognized. The objective of providing adequate treatment of the effluent cannot be sacrificed for other needs and uses of the land; proper handling of the wastewater must be the first priority.

14. Choice of ground cover can play an important role in the success of a land application system. On other than sandy soil, it appears that forested or minimally wooded or cultivated areas will accept greater rates of application of effluent without ponding than will cultivated agricultural areas. Many existing facilities utilize forest areas and grassed areas for application. Forested areas appear particularly useful for winter applications when fixed spray systems are used. Reed Canary grass appears to be particularly well suited for producing mulched ground cover which can enhance soil assimilation and adsorption characteristics.

15. Land application facilities that have been used for many years are available for the study of long-term effects of such use. They offer the opportunity to study effects on soils and groundwaters. Thus, it appears unnecessary to support separate demonstration facilities in each of several states and regions. During the course of the study project, several small-scale research and demonstration projects involving land application were disclosed. Some of these projects appeared to have been instituted simply for the purpose of convincing local and state officials of the safety of this alternative method of treatment and disposal. Specific evaluation at established systems in the various climatic zones would appear to be more fruitful than new research installations for determining long-term effects upon soil, vegetation, groundwater, and the indigenous ecology, or on the health of site workers and adjacent residents.

16. Observations in the field and the survey of land application systems which handle municipal wastewater flows and industry-owned systems which handle process waters did not reveal the existence of specific health hazards and disclosed very little concern over threats to the health of on-site workers, residents of neighboring areas, domestic animals or wildlife, or of those who consume or come in contact with land-applied wastewaters. The mail survey of other representative municipal and industrial land application systems similarly provided no evidence of any health problems associated with this method of utilization.
Some concern over potential health hazards was, however, expressed or inferred by officials of some state agencies, who supplied information about their policies on land application of effluents as an alternative means of wastewater management. Whether this concern was based on specific information or mere suspicions, founded or unfounded, could not be determined from their responses.

Inquiries have been made with inconclusive results about the health implications of land application systems by several Federal, state and local agencies, and by other quasi-governmental and public service organizations. Concern over "the unknown" was expressed for such factors as potential viral and pathogenic hazards resulting from dissemination of aerosol sprays or mists and contacts with sanitary and industrial sludge residues.

While the study did not disclose the cause for such concerns, the bibliographic abstracts*** prepared as an integral part of this investigative project to include references describing possible health hazards which warrant further study and these potential problem areas should certainly not be ignored. A balanced consideration of the concerns, and of the absence of any study evidence to support these questions, would be of great value at this time.

The APWA report and the foregoing conclusions lead to additional conclusions:

17. Emphasis in the future should be on wastewater utilization, reuse, and renovation, the 4-R cycle, and not on disposal.

18. Public acceptability is the primary factor limiting land treatment of effluents and land utilization of sludges.

19. Land application of wastewater is not an alternative to secondary treatment if secondary treatment is required as a pretreatment.

20. Land application of sewage effluents is an alternative to tertiary treatment for the removal of nutrients, suspended solids and certain pollutants. It is not effective for the removal of soluble salts.

21. In water-short areas land treatment of effluents may be considered as part of the reuse cycle.

22. Small communities will probably continue to be the principal users of land treatment of effluents for the near future, but stringent discharge restrictions will make land treatment more attractive to large communities.

***The bibliography for the APWA report is being published separately, entitled, Land Application of Sewage Effluents and Sludges: Selected Abstracts.)
23. Admirable as it may be to obtain drinking water quality from the land treatment of sewage effluents, since the goal of Public Health Service Drinking Water Standards is not required for secondary treatment, and it does not appear to be practical at present for land treatment either, it therefore should not be used to unduly limit the benefits to be derived from the land application technique.

RECOMMENDATIONS

1. **Guidelines for land application of wastewaters should be prepared by the U.S. Environmental Protection Agency to provide full consideration of the wide choices of available methods and procedures.** Guidelines should be prepared in a manner which will not restrict unduly the ability of local officials to make full use of this alternative method of treating and managing wastewater.

2. **Land application must not be considered as a panacea or universal method of treatment.** Suitability of each land application system can only be determined as a result of an interdisciplinary study for the particular site. Soils, climate, degree of pretreatment, ground water conditions and availability of suitable land acreages are important considerations.

3. **Preparation of a suitable publication to inform the public about the practice of disposal of sewage effluent on land should be sponsored by the U.S. Environmental Protection Agency.** Public relations problems are usually encountered by agencies attempting to implement any large public wastewater project. Recent efforts to consider land application as an alternative in planning for regional approaches to wastewater management have highlighted the need for such publication.

4. **Training opportunities should be provided to bring to the attention of all disciplines involved in the consideration and evaluation of a land application facility the technical information which is available.** Widespread consideration and utilization of land application can not be made until such time as adequate information concerning the technique involved is made available. The experience gained by those who have successfully utilized this wastewater management method should be publicized.

5. **Guidelines for the increased use of land application methods, which could result from the implementation of Section 201 of the 1972 Amendments to the Federal Water Pollution Control Law and its emphasis on alternate wastes management techniques and systems, should clarify the question of whether health hazards are a factor in the use of this system of treatment and disposal.** Definitive findings are essential to the acceptance of land application
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systems, or to their adoption for municipal or industrial effluent management. Such findings should be provided with promptness and clarity, either through evaluation of existing data or any additional necessary research. Without such positive information, published guidelines might either be inadequate or tend to be too restrictive. If they are too stringent, this could endanger the proper utilization of land application systems as effective and economical solutions to water pollution control problems and the rational use of wastewater for crop and groundwater enhancement and other environmental-ecological benefits.

DISCUSSION

Mr. R. Carter: I was kind of looking down the road, and I know that various methods of treatment have got to be considered under the new act. And of course this is one of them. We may have EPA telling us, or we may ourselves say, that we know we'll have to evaluate land application. But are the details going to be known for the consulting engineer to adequately look at the information and for the state regulatory agencies and the EPA to evaluate his recommendations? And will there be adequate information for the operators, if it is installed, to operate these systems?

Mr. B. Seabrook: Well, one of the things that we did at the University of Illinois, July 9th to 13th, where we had a workshop entitled "Recycling Municipal Effluents and Sludges on the Land" was to try to identify these needs. At that workshop there were around 110 people present by invitation. I would say that 75% of the real expertise in the United States was at that meeting. That report ought to be available some time within the next 6 to 8 weeks. We identified, or tried to identify, the research needs that would be required for land application of sludges and effluents. We took into consideration the information we had; that is, the information that came from the American Public Works Survey, the information that came from the other two reports—the Metcalf and Eddy Reports and the Battelle one on sludges—and other piece-meal information that we had. And then we went on from there and said, well now, this is the information that we've got, what is the information that we don't have that we ought to have. Perhaps this would be the appropriate place to also mention Muskegon. This is the first meeting on land application of waste water that I've ever attended, where somebody who was a commissioner of public health or commissioner of environmental protection has not got up and described the land application system at Muskegon, Michigan as the best example of the land treatment technique in the U.S. Of thousands of systems in use around the world, the only one that is ever mentioned, at any of these meetings I've ever been at is Muskegon. Muskegon hasn't even been completed yet; it's not in operation yet; there isn't any information on it yet, but that's the only one they
talk about. I don’t know why, when we’ve got so many thousands of them that have been in use for 50, 70 and 100 years, it would be more meaningful to talk about successful systems of long experience.

*Mr. W. Marks:* Muskegon is partially in operation and there are some problems associated with it. But I don’t want to discuss it.

*Mr. B. Seabrook:* Well, they say it’s partially in operation because they are now running water into the 800 acre lagoon, but it hasn’t started to function yet. It’s not irrigating yet; they don’t have their crops planted yet.

*Mr. W. Marks:* It’s not irrigating, but all the wastes from several communities are going out to the site, and the lagoon system itself is not at this point in time functioning as it properly should. But the question I want to ask is, in the evaluation of these 100 sites, were any of the municipalities combining industrial wastes with municipal wastes? Were there complicated industrial wastes?

*Mr. B. Seabrook:* Yes. In all of the cases of municipal waste land application systems, they all included industrial waste.

*Mr. W. Marks:* And were there any problems associated with ground water contamination associated with the use of these sites?

*Mr. B. Seabrook:* Yes. Some of them might have had such problems.

*Mr. W. Marks:* Is this brought out in the survey, and does it describe the possible ground water contamination and/or problems such as nutrient buildup?

*Mr. B. Seabrook:* Well, it tries to identify where the information is available. In most instances the information is very sparse. The operators of these systems have been primarily responsible for getting rid of the waste, doing something about it. They aren’t research people, and they don’t have budgets to do this sort of thing. Most of them are blue collar workers, so there’s a lot of raw data. They have made pencil notes on forms and some of the forms have been accumulating for decades, stacked up in boxes and cases full of all kinds of reports that have never been evaluated. This is one of the things that I think we ought to do something about. Instead of starting a brand new research project, we ought to evaluate the data that we’ve already got for a lot of systems that are already in operation.

*Mr. W. Marks:* One of the problems I think we have here in the Great Lakes Region is that this is a relatively water rich area and irrigation is supplemental at best. For many years you probably wouldn’t use a great deal of it, so that the amount of water presently in ground water can be significant. I think this could be a most disconcerting factor, that we don’t end up creating problems through another avenue. While you don’t have the surface discharge, you do have ground water movement. It is something that we need to look at?
Dr. R. Frank: Is there any data on the elevation of heavy metals in the soil or uptake in the plants?

Mr. B. Seabrook: The survey did indicate where the information was known. There were heavy metal problems, but, the questionnaire that was submitted was prescribed by the U.S. Office of Management and Budget and they were very insistent that we had to eliminate a lot of questions. We had questions in there which OMB felt we shouldn’t bother people by asking. However, there is a great deal known on heavy metals. The West Hertfordshire Main Drainage Authority in England has a lot of information on heavy metals. The British Ministry of Industry or of Agriculture has made a ten year study on heavy metals, at the Hertfordshire Authority. Here, in this country there is some effort being made. The U.S. Department of Agriculture, the Agriculture Research Service at Beltsville, Maryland, about a year ago started research work on heavy metals. And Dr. Rufus Chainy has been specializing in that.

Dr. R. Frank: Is there a report available from the Hertfordshire study; you said they did a ten-year study?

Mr. B. Seabrook: You could probably get that from the Hertfordshire Main Drainage Authority, in Richmansworth, Herts, England.

Dr. J.F. Frank: Have many of these projects that were reviewed been sludge, such as the Metropolitan Sanitary District, or have they mostly been secondary effluent?

Mr. B. Seabrook: The American Public Works study was all on effluent, not only secondary effluent, but all effluent including primary effluent and raw effluent. The Battelle-Columbus study was the study on land spreading of liquid digested sludge, and that was primarily a literature review. However, there’s a great deal known about the sludge operation by the Chicago Metropolitan Sanitary District. That operation is primarily on 10,000 acres of reclaimed or mined land and they’re applying the sludge by two methods; one is by irrigation, and for the other by ploughing it in. They are making soil and they do have some crops that are growing there. The land they started with looked like an abandoned airforce base. It’s land that won’t even grow grass, so the fact that they’ve got anything growing there is a somewhat of a miracle. They’re also using ploughing in of the sludge at Williamsburg, Virginia, where they’re taking a plough with a manifold, applying sludge that has from 1% to 4% solids content, and ploughing it in and making soil. I believe there are other places around the country where they are also injecting liquid sludge.

Dr. J.F. Frank: I think the problem that MSD is having in Fulton County gives emphasis to your point of public acceptance and the stigma that must be overcome in selling a program before you start bringing the stuff in, and fill 180
acres of lagoon. They've had some real problems getting acceptance and it comes from a small nucleus of people.

**Mr. B. Seabrook:** Well, the problem that the Metropolitan Sanitary District has had, is that they have a lot of lagoons in and around the Chicago area. Of course, the Metropolitan Sanitary District takes in some 200 communities in addition to Chicago; many people don’t seem to realize that. Some of these lagoons have been in use, running sludge in them, for many years. Some of them have as much as ten years accumulation of sludge, and some of that sludge has not been properly digested. They have now let contracts to empty those lagoons. One of the problems they ran into when they were emptying one of these lagoons was that there were a lot of odours involved from undigested sludge. Now if the sludge had been properly digested and pasturized, you could apply it on the land without any serious odour problems, and this is one of the things that the Hertfordshire Authority in England has very meticulously done. They have applied the sludge in a rural community with people living around it and the public has accepted it. I think that one of the major mistakes that the Chicago Metropolitan Sanitary District made was putting in improperly digested sludge. It stunk; it was just a real bad case of poor judgement.

**Mr. N. Berg:** We’ve been involved in this activity in rural America for many years, and the reasons that farmers and ranchers haven’t been taking their livestock wastes out on the land in some cases — especially the concentrated feed lots — is that first of all they may not have the land area, and second, you can buy the nutrients needed for land cheaper in a bag. What with labour problems and one thing and another, you can put it out there a lot cheaper than you can put the manure out there and so forth. Now I think if we have that problem in rural America with agricultural wastes, what we’re talking about here with urban wastes is really a problem of disposal. With land values being what they are close to these big Metropolitan areas, and transportation cost becoming almost prohibitive the further out you go . . . We’re finding that when we are asked about the kinds of soils that will receive this material that the problem that we’re facing in one area, say the Northeast, is considerably different from what we face in another, like Florida, California, Arizona, etc. I think that between the soils people and the geologists they’re telling us that there’s a whole lot in this area that we have never really seriously examined, in terms of some of the characteristics that we need to recognize, so as not to create some additional problems. I don’t know what your literature shows on that, but we’re finding that there’s a great deal of research here that hasn’t even been structured yet, but needs to be thought about seriously.

**Mr. B. Seabrook:** Well, the land irrigation system, as I said, is not a panacea; it doesn’t apply in every case, but it does need to be very closely designed and very carefully operated and I think that it can be used almost any place if you
pay sufficient attention to the people. Just like the illustration I use for the airplane; there have been lots of airplanes that people have built, that crashed. I think Howard Hughes built a big airplane that wouldn't fly; the SST has never been taken off the ground, but an awful lot of airplanes do fly, and there are a lot of land application systems that do work, if managed properly. But there are a lot of them that don't and there's been a lot of adverse publicity because of improper design and incompetent operators, so I think that it's very true you certainly can't say it applies in every instance.

Mr. M. Tellekson: Did any of these systems apply their irrigation by injection, or was it strictly spray? I know they tried out a method northwest of Chicago, where a fellow was combining swine feedlot manure and liquid sludge from the sanitary district and injecting it into his oats and corn fields. There wasn't any odour apparent from that type of application while some of it that was just spread out on the land would cause everybody to just climb the walls.

Mr. B. Seabrook: I mentioned Williamsburg and also that the Bauer Engineering Company is applying the Metropolitan Sanitary District sludge by injection: that's in Arcola, Illinois. They're the two instances I have seen, but in the case of effluents, I don't know of any injection operation.

Mr. K. Shikaze: Recognizing that on your map of climatic zones the majority of the Great Lakes is in the E zone, where there is a short summer, long winter situation, what are the limitations with regard to land application of waste on the land during the winter? One other question: what is EPA doing with regard to possibly developing some guidelines in this area? Is there anything, any rules they can put on this?

Mr. B. Seabrook: Well, the winter-time operation does present some problems. You certainly can't grow crops in winter and if the land is going to be used for growing crops, then you've got to store the effluent. This is the Muskegon concept, to store it during the non-growing season. However, if you have an infiltration area or forested area, you can apply it during the winter-time. Penn State University has some ten years or more of experience in applying effluent during the winter-time, during the freezing weather in the winter-time. As far as guidelines are concerned, the EPA is currently in the process of developing some evaluation procedures for evaluating applications for construction grants for land application systems. We are calling them land application construction grant procedures rather than guidelines because at the present time what we're trying to do is to give assistance to the regional offices of EPA that handle these Federal construction grants. We're trying to give them sufficient information to evaluate an application. These evaluation procedures probably eventually, when we get sufficient information on them, will become guidelines, but, I wouldn't want to dignify them at the present time by saying they're guidelines.
Mr. K. Shikaze: Are you familiar with any studies that may have been carried out with regard to the health hazards associated with spray irrigating primary sewage; aerial transport and such?

Mr. B. Seabrook: No. At the present time there is a lot of fragmentary information available, but there isn’t any comprehensive study on it.

Mr. K. Shikaze: Would you consider there to be a need for research in this area?

Mr. B. Seabrook: I consider this a very important need. If you look back at the history of Berlin, Melbourne, Mexico City, and the western part of the United States, we’ve got 50 or 75 or 80 years of experience, and so far as we’ve been able to discover there are not any adverse health affects. But there’s an awful lot of public speculation about it: a lot of state public health officials have expressed all kinds of concern. The Virginia state public health officials will say they aren’t going to permit it until they have proof that there are no adverse health effects coming from it. When I ask how they’ll get that proof, if they don’t permit some demonstration projects, they say let somebody else do it in another state. Well, this is the attitude of a lot of people. Let somebody else do it first. Personally, I don’t think that the health effects are anywhere near as bad as people imagine them. I can’t see that when you take effluent from a secondary treatment plant and dump it in a river, and a 100 yards down the river a farmer puts a suction pump in and takes it out and puts it on the land, I can’t see that that’s any worse than putting it on the land in the first place under properly prescribed operating procedures. In fact, I’d say that you’d be better off putting it on the land under the proper procedures than you would to do what is already being done in so many parts of the country and that is dumping it into the river. By continuing to dump secondary effluent from conventional treatment plants into the most convenient surface water instead of using land treatment where feasible, is sort of putting your head in the sand, I think, and that’s part of our problem.
AGRICULTURAL USE OF SEWAGE SLUDGE

S.A. Black

ABSTRACT

The benefits and disadvantages associated with the application of sewage sludge on agricultural land are discussed. The value of sewage sludge as a fertilizer and soil conditioner and the possible hazards to soil and crops associated with the heavy metal content of sludges, are described. Research underway to determine desirable sludge application rates to maximize benefits to soil and crops and minimize crop damage and environmental problems is discussed. Ontario Ministry of the Environment interim guidelines of the disposal of sludge on agricultural land are described.

I'm going to spend a little time discussing sewage sludge and its application onto agricultural land in relation to its agricultural value, the possible harmful effects of its usage and the various research projects that are being carried out on the application of sewage sludge onto farm lands. Then I will touch lightly upon some of our provincial regulations concerning its application. These regulations are being handled by the Ministry's Solid Waste Management Branch, and if there are any questions on these I think I'll refer them to Martin Wood.

The application of sewage sludge onto agricultural land in the vicinity of sewage treatment plants is a well established practice in Ontario, as elsewhere. In 1969 there were 59 sewage treatment plants operated by the Province of Ontario and 37 of these disposed of most or all of their sludge onto agricultural land. Some 18,000 tons of sludge were applied onto agricultural land in 1969 from these 59 plants. Although sludge is applied at rates of up to 100 tons of dry matter per acre per year, normal application rates are generally in the order of 5 to 10 tons per acre.

The conventional activated sludge process is outlined in Figure 1. The raw sewage comes in, gets coarse screening and grit removal, goes through the primary clarifier where the solid material settles out, and passes on into the aeration section, a biological process for the removal of organic material. The mixed liquor passes on to the secondary clarifier where the sludge settles out and the clear supernatant goes out in the effluent. I should say that in Ontario, our objectives for secondary treatment are 15 parts per million BOD and suspended solids, rather than the 30 parts per million in the EPA standards. The return activated sludge which comes off the secondary clarifier is returned to the aeration section to provide seed for the biological growth within the aeration process. The waste activated sludge is generally returned to the head end of the plant and goes back into the primary clarifier, so the raw sludge is a combination of the primary sludge (the heavier grit material and heavier organic material) and the waste activated sludge. As such it is a very putrid material and it will undergo decomposition fairly readily with resultant odors. It is an ideal medium for flies and vermin to accumulate in, so generally we pass it into a digestor which has a retention time of anywhere up to 30 or 40 days. Here the sludge undergoes anaerobic decomposition with the supernatant being returned to the head end of the plant and the digested sludge drawn off the bottom for disposal.

Land disposal of sewage sludge has the advantage of being less expensive than sludge incineration or drying, and it may be considered as an ultimate disposal method; whereas with sludge drying and incineration there are end products that again have to be disposed of. It is also in line with our overall concept of reuse, recycling and reclamation.
The value of sewage sludge as a fertilizer and soil conditioner is well known. As a soil conditioner it can increase the field moisture capacity of the soil from 3 to 23%, can increase the soil organic matter by up to or over 40% and increase the soil aggregation by 25 to 600% because of the organic material it contains. This last property is of considerable significance in that on a heavy soil it will improve the soil-moisture relationship of the soil, improve the soil structure for root penetration and increase the rate of water infiltration. The greatest benefit, physically, from organic matter application usually occurs within 15 to 18 months of the application. After that period the favourable effects of the sludge gradually diminish and, therefore, it is recommended that, if sludge is going to be used as a soil conditioner, it be applied at least every three to five years. Because of its soil building properties, sewage sludge is ideal for making top soil on natural sub-soil where top soil has been taken away or eroded. And, as we also heard this morning, it is being used for reclaiming stripmining areas.

As a fertilizer, sewage sludge contains on the average about 4% by weight of nitrogen and 2.5% by weight of phosphorus, so there's a considerable amount of nutrient benefit in the sludge. As well as containing the macro nutrients nitrogen, phosphorus and some potassium, sludges contain pretty well all the micro nutrients that are required for plant growth. So of this 18,000 tons of sludge spread on agricultural land from 37 of our 59 sewage treatment plants in 1969, we put on about one and a half million pounds of nitrogen and half a million pounds of phosphorus. The Advisory Fertilizer Board for Ontario recommends as an average figure the application of about 100 pounds of nitrogen per acre for corn. If we take this 1.5 million pounds of nitrogen figure, we have adequate nitrogen for about 10,500 acres, assuming 70% of the nitrogen applied becomes available to the crop. In actuality, this 18,000 tons of sludge was applied on 4,000 acres of land. So really we’re not making good use of the nitrogen fertilizing ability of this sludge and perhaps in some of our applications we are contributing to ground water pollution, at least in the form of nitrogen.

Although sewage sludge has definite value as a soil additive, there are also possible hazards associated with the heavy metal content of these sludges. Sewage sludge contains metals such as Cu and Zn, which are essential micro-nutrients for plants and animals. As with major nutrients, however, their availability in large amounts is harmful and may damage crops.

The heavy metal composition of three municipal sewage sludges in Ontario is indicated in the table below. The wide variability in heavy metal content between different sludges of different municipalities becomes immediately apparent. For example, we have copper at 1100 parts per million in one sludge and 142 parts per million in another. There is a wide range from
one sludge to another as well as from one month to another in the same sludge. This is a real problem when we try to set limits on sludge application in relation to heavy metal content. The nutrient content also varies considerably from one period to another and from one municipality to the other.

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The availability of heavy metals to the crop is by no means constant. It varies from species to species, as well as with the conditions of the soil. In any one species there may be variations in concentrations between the various parts of the plant, and these concentrations may change with stage of growth. They may be high initially, and low at the time the plant is harvested or it may be the other way around, depending on the species. Soil pH, soil organic matter and soil drainage are factors which have a marked effect on the availability of heavy metals to the crop. These are factors which generally can be controlled somewhat through crop and soil management. The hydroxides and carbonates of heavy metals are fairly insoluble and generally, the higher the pH of the soil, the greater the probability of insoluble hydroxide and carbonate formation. For a metal to be absorbed by the plant, it has to be in a soluble form; thus it is generally agreed that to minimize the availability of heavy metals to the plant, the soil should be limed to maintain a pH of about 6.5.

Heavy metals are capable of forming complex compounds with soil organic matter. Therefore, the more organic matter in the soil, the less probability of problems associated with heavy metal toxicity to plants. Since sewage sludge is relatively high in organic matter, it tends to tie up not only the heavy metals applied in the sludge, but also any heavy metals which may be in the soil initially. Our studies have shown that where we added sewage sludge to land which had a relatively high heavy metal concentration initially, that although considerable amounts of heavy metals were added, the crop in the first year had a lower heavy metal content than the crop grown as a control.
A water-logged soil will favor the existence of metals in the more soluble, lower valence form. Therefore, it is better to apply the sludge only on land which has fairly good drainage.

Based on many years data from pot and field experiments, the National Agricultural Advisory Service in England has set limits on the application rate of nickel, copper and zinc which they consider to be the heavy metals of most concern in the application of sewage sludges to land. A "zinc equivalent" has been established which takes into account the fact that nickel is 8 times as toxic as zinc and copper twice as toxic as zinc. On the basis of several assumptions, a maximum safe level in the soil of 500 lbs./acre of zinc equivalent has been suggested. On a 30-year addition period this would amount to a maximum yearly application of 17 pounds per acre. I think one thing they didn't do when they set these limits, is that they did not take into account any removal of the metal by the crop or any movement out of the root zone area.

Referring back to the Table which shows the heavy metal content of the 3 sludges in Ontario and based on this zinc equivalent, we could apply the North Toronto sludge at a rate of two tons per acre per year, the Pt. Edward sludge at a rate of 4 tons per acre per year, and the Newmarket sludge at a rate of 8 tons per acre per year. So the land required for the Newmarket municipality is going to be considerably less than that required for North Toronto.

During recent years increasing emphasis has been placed on removing phosphorus from wastewater treatment plant effluent. Experimental work performed both in laboratory and full scale plant studies has shown that the most practical method of phosphorus removal from municipal wastewaters is by chemical precipitation. Experience has shown that good phosphorus reductions can be obtained by using lime, ferric chloride or aluminum sulphate. As a result of the addition of these chemicals, a considerable portion of the heavy metals is precipitated. Thus, as well as removing more phosphorus, we are concentrating the heavy metals in the sludge; therefore, it is most important that we get rid of this sludge in a reliable manner.

Lately there has been a great deal of concern over the application of these sewage sludge onto land, generally because of a lack of understanding and knowledge of the effects of the various constituents in the sludges on crops, soils and ground and surface waters. Because of this concern, considerable research in this regard is being carried out under the Canada – Ontario Agreement. A total of 8 projects totalling some $250,000 have been funded in 1973/74 under the Canada – Ontario Agreement to investigate various aspects of sludge application to agricultural lands relating to crop, soil, surface and subsurface water pollution.
The University of Guelph is looking at the application of sludge onto farmland and studying field conditions to determine the effect of the sludge on the crops, the soils, surface water and to a certain extent the ground water. The University of Toronto has a contract to characterize different sludges for heavy metal content and to look at some sludge disposal sites to determine the movement of heavy metals from these disposal sites. The Ministry of Health has a contract to look at the microbiological aspects of sludge disposal including viruses. The Canada Centre of Inland Waters is looking at the effect of sludge application on crops, soils and its movement through soil to ground water, by the use of lysimeters located at the Centre. The Region of Niagara has a contract to compare the effects of different types of equipment on the compaction of the soil, rather than on the effect of the sludge application on plant growth.

Out of these studies we hope to be able to determine the maximum sludge application rate to be applied to agricultural soils without polluting the ground water or surface water with elements or organisms toxic or pathogenic to humans and animals, and without reducing the quantity and quality of crops produced.

In the meantime the Waste Management Branch of the Ministry of the Environment has established interim guidelines for the utilization of sludge by land application. In determining the allowable rates of sludge application under these guidelines, the objective is to match as closely as possible the quantity of nutrients applied with the amount removed by the crop. The allowable rates will, therefore, be determined by the crop concerned, the soil conditions, and the nutrient requirements of that crop. At present this rate is being determined on the basis of nitrogen, but in so doing it is felt that only in isolated instances will there be any likelihood of problems arising due to the heavy metal content of the sludge. These guidelines will be continually updated as more information is collected and evaluated.

In conclusion, I think we can safely say that because of the economic advantage and the present emphasis on reuse, the application of sewage sludge to agricultural land will continue to be practiced within the Province of Ontario. The current research being carried out on the land application of sewage sludge should provide us with adequate information to ensure that no environmental damage occurs as a result. In the meantime, I think that if we keep our application rates down to reasonable levels no interim problems will be encountered.
DISCUSSION

Dr. D. Dodge: Steve, what kind of levels of zinc equivalents has the University of Guelph found in the runoff water that's coming off some of these experimental plots?

Mr. S. Black: I'm sorry I can't tell you.

Dr. D. Dodge: You can't!

Mr. S. Black: I don't know. As far as I know they can't tell you just yet; they just started. Their first sludge application was the fall of 1972 and I don't think they have the runoff of that fully analyzed yet.

Dr. L. Webber: Mr. Chairman, if I might add to that, there have been relatively few analyses. I think it's something like half a dozen, and this was during winter runoff at which time it is primarily so-called clean water from snow melt with insignificant amounts of heavy metals. They were looking at nickel, lead and mercury, I believe - something like that - so to back up what you say Steve, as a preliminary survey, levels are rather minor.

Dr. R. Frank: We are working with Natural Resources on checking Hamlin Creek. We are picking up some levels that are unusual and we don't know where they are coming from. I think we've got to look to find out where these are coming from, but that's not what I wanted to talk to you about. I'm bothered about your complacency in putting this stuff out on agricultural land. I'm bothered by your policy because I think it's grossly unfair to agriculture to be dumping some of this sludge out there. Some of this sludge has got such high levels that we should probably be storing it and reclaiming the metals from it at a later date, not dumping it on agricultural land where it's going to be a real problem to reclaim it. I am also bothered that we aren't going back and checking industries and making sure that they can't recover some of these heavy metals. We did a lot when mercury hit the lakes, now why can't we do it for copper, and why can't we do it for some of these other compounds?

Mr. S. Black: Well, we are. As I said, the University of Toronto is carrying out a sludge characterization study in which they are looking at the new sludges from chemical precipitation processes for phosphorus removal. Levels of the heavy metals in the various sludges are being obtained. Where it is high, we are definitely going to go back to the industry to see if it can be removed there, or if it can be removed somewhere along the line prior to the time it gets into the sludge. As far as policy goes, I'm not going to speak on the policy of the Ministry because I'm not in a position to. Personally, I feel that in most cases the heavy metal content of the sludge, at the application rates at which it is
going on now, is not going to cause any problems. Although we’re not sure of this, we are investigating it in various studies. But if we keep our application rates down in the interim, even if we are increasing the heavy metal content of these soils, we are going to know when it will be a problem in the future and we can cut out the application on those lands early enough.

Dr. M. Johnson: I suppose everyone would agree that the concept of recycling is fundamentally sound, but I think you hit the nail on the head when you said that the sludges weren’t going on efficiently enough. When you synthesize a lot of the information some of which we’ve heard here, you take your five or ten tons per year application rates. At 4% phosphorus, this is 400 – 800 pounds of phosphorus per year. Yesterday we were told that the absorptive capacity of soils, and these are presumably medium to heavy textured good producing soils, was 200 pounds of phosphorus. I suppose that a lot of the weight would go to lighter textured soils where the absorption capacity is likely down below a hundred pounds. Boyd Ellis told us yesterday that in terms of utilization of nutrients in agriculture we had to get accustomed to two things, the management of excesses of phosphorus and the management of the timing of nitrogen application. My question is, has anyone ever used as a design criteria the absorptive capacity of the soil for phosphorus? I have visions of removing the phosphorus at the plant under the terms of the Agreement, taking it up on the land and then having the stuff go back down to the river again.

Mr. S. Black: Well, the figure I gave you of 4,000 acres for the sludge was in 1969. Our guidelines on the application of sewage sludge on land are just coming into effect now. Previously we really had no control over where the sludge was hauled. We had very little control over where it was applied and how it was applied. The local officer of public health was involved in some cases, but in most cases nobody really knew where the sludge was going or how much or how great the application was. Now with our new interim guidelines we are looking at the soil conditions, the type of soil, the slope of the land, and the use of the land and using these in the guidelines. We are licensing the sludge haulers through a fairly comprehensive system, and we’re keeping closer track on where this sludge goes and how much is applied. We are going to be monitoring the fields to a certain extent to determine any increases in nitrogen, phosphorus, or heavy metal content, and I think in the future we are going to keep a fairly close tab on where problems might develop or where they are developing. But I don’t think we can really look at the past and say we did a good job.

Dr. M. Johnson: Would they have put much of this on under-drained lands?

Mr. S. Black: I don’t think so.
Dr. R. Parizek: Sludge in the States can often go into landfills, whether sanitary or otherwise; sludges may have gone into abandoned mines, abandoned quarries and in other places that are really far more objectionable in terms of the adverse effect they may have by perhaps being in an anaerobic state, or being close to the water table, or even below the water table in some cases, compared to the possibility of spreading on land where we have a better chance of doing something with it. Do you have any studies planned around past practices such as burial in landfills, to see if in fact this is a worse way to handle the problem?

Mr. S. Black: The University of Toronto is looking at a sanitary landfill, a dumping site, a lagoon and fields where sludge has been applied on the surface. They are measuring the transport and the accumulation of the heavy metals in these sites. I know there is a problem at the North Toronto Sewage Treatment Plant where sludge is stored. There is no soil left on the bank of the Don River; it's all sludge as far as we can see. We are checking river water, groundwater and plant material for heavy metal accumulation.

Mr. M. Wood: A partial answer to your question, the University of Waterloo is presently carrying out a research program concerned with the migration of leachates from a landfill site. The way it is presently set up, we will not be able to definitely identify the leachate as coming from the sewage sludge that is dumped there, but there is a relatively sophisticated monitoring program to give us the overall picture. Also, from the provincial point of view, we've stopped using the word sludge and use processed organic waste, as part of the image in trying to sell it. Certainly some of the applications where we're certifying and licensing both the hauler and the site will lend themselves very well to a relatively sophisticated monitoring program, and we suggest as time goes by that we'll be able to learn a lot more. Also, if you don't mind, I'll throw in a couple of comments on behalf of the Ministry. The guidelines that were sought for this processed organic waste application on land basically arose from the inter-departmental committee dealing with agricultural waste. Professor Robinson was involved as well as Ed Brubaker and we used some of their background and experience in terms of the aesthetics and public health aspects of spreading this sludge. I think with the various technical disciplines and input that went into the inter-departmental committee on sludge disposal, the heavy metal problem certainly was recognized. Dr. Frank made a philosophical point about this application on agricultural land, and in so many cases we are getting flack from people by saying you're forcing these farmers to take this. Well, we're not. What the regulations and guidelines say is that if you are going to put this sludge on agricultural land, then you should limit it to these guidelines. We are certainly trying to promote the use, reclamation or recycling of this sludge, and we do believe that it has some value. I hope we are fully aware of the ramifications of the potential build up of heavy metal in these soils,
and I think Steve has given a fairly good overview of this. We do intend to monitor these sites and I'm certain heavy metals will be one of our major concerns in this.

Dr. J.F. Frank: Your comment about keeping the pH high enough so the metals will be retained. In Illinois we've taken a little different concept on this. We recognize that if you go out there and for several years apply ammonia in high quantities without liming you get the pH down to about 5, and you would get a tremendous release. In many of the projects that we've permitted, we suggest that the crop grown be corn silage so that you get a high uptake in the kernels of the 19 macro and micro nutrients found; you have copper, zinc, boron, manganese and magnesium, that are required for plant growth. The kernel or the pericarp will hold a lot of these and then if you take off your silage, your vegetated matter, you get a lot of N and P off. So we use not only the amount taken off in the heavy metals as criteria, but N and P also, whichever of those is limiting. That is, when you get a mass balance, this amount going in in heavy metals, this amount of N and P coming off with a recognized reserve store of heavy metals in the soil. That is what we use as the limiting factor for how much can be applied when we look at heavy metals. Then, when the farmer harvests the silage and feeds it to cattle, he uses the FDA standards along with consultation with veterinarians on what can be ingested safely by the livestock. So we have a constant removal of heavy metals which are going to be beneficially used. To do this we try to keep the pH at a moderate level, about 6 to 6.5, so that the metals are not tied up tight, but yet are not released completely.

Dr. R. Frank: I think why I expressed such concern is because in agriculture we've made a few mistakes in using heavy metal or arsenical pesticides. Quite recently a number of apple orchards were removed; we actually paid money to people to pull out these orchards, and we went in and recommended they plant various crops. Of course, where we have a high arsenic content, we've run into problems with toxicity to certain crops; but, we've also run into a problem where grapes and cherries have gone into old apple soils and the juices made into wine and now we have the Liquor Control Board after us because the arsenic levels in the grape wine and in the cherry wine are close to the tolerances that we are going to permit. This is something that we've done inadvertently and we're just scared that this same thing could happen. Another thing that has happened and which we've had to go into considerable review on is in the case of mushrooms. People have picked up soils, taken them into the house and grown mushrooms in them, now we find elevated mercury levels in these mushrooms. We are now having to point out that they better be careful what components they use for their composting and their production of mushrooms, otherwise they can violate Food and Drug regulations. So you can see why we're sensitive in this area.
Dr. R. Parizek: We have examples in Pennsylvania where the sludge is going into strip mines in the fractured bedrock. The mine operator doesn’t care and it’s a solution for the moment for the operator of the sewage plant. This stuff goes down into the fractured rock, and no one can tell me that that’s a good practice, because you might as well dump it into the creek directly; you at least protect the groundwater in the interim. So your idea of recycling it as a reclaimed metal is great, but who can afford it? Maybe some day we will, but the point is you’re faced with a problem that if you don’t put it on the farmland and maybe risk ruining a certain crop, you have the other choice of dumping it in a hole somewhere and that can’t be any better.

Mr. B. Seabrook: Commenting on Mr. Wood’s statement that we should change the name of sludge. The Hertfordshire Main Drainage Authority in England called their sludge hydig, for highly digested sludge, which proves that a rose by some other name may smell sweeter.

Dr. R. Parizek: Commenting on your use of changing terminology to make it acceptable. That’s fine if in fact the practice you’re going to enter into will do the job, but I’ve dealt with examples where the terminology has been used to hide a very bad act, and not being involved in regulatory work, I would want to make sure that the people aren’t fooled by the systems you may design just because you change the word. I know you’re familiar with what I have in mind. There’s a lot of good examples where terminology is hiding a very bad practice and people think it’s okay, but let’s hope we are smart enough not to sell that.

Dr. J. Robinson: I’d just like to comment on some statements that were made earlier and make a plea for some consideration of phosphorus, in this. The fact is that in southern Ontario many of our soils are highly enriched with phosphorus already. Phosphorus is one of the major elements that appears to be on the very long term in rather limited supply. And phosphorus can move with soil movement from the surface. If we get all of our surface soils in the Great Lakes Basin very highly enriched with phosphorus, then for every pound of sediment that does move into the streams and to the lakes we’re just sinking that much more phosphorus. One problem is that as we tend to decrease the nitrogen in the wastes that we’re disposing of, using biological methods – and I’m thinking now of oxidation methods by which we’re applying for application rates for those wastes on the soils, then the application rates are going to increase, and we’re not doing anything about phosphorus. And our enrichment is going to get much more critical. So it seems to me that at some point in this thing we should be able to at least keep in mind the fact that phosphorus is there, that our application rates in the terms that you were expressing, Steve, are probably about 20 times what the crop demands would be, and this is very, very much in excess of what we would be recommending as a cropping practice.
Dr. V. Morley: I was very interested in the point you made regarding the uptake by plants being less in soil treated with sludge having heavy metals than in the control. But I was very pleased to learn that you use more of these biological indicators, rather than just using soil analyses. Going back to Dr. Frank’s point, you do have selective uptake by various plants; in lettuce you have cadmium taken up preferentially; it’s accumulative, but we don’t know much in the way of toxicology. It’s the same story when you get into pesticides. Has thought been given to using this monitoring as a continuous process? It’s a little late to wait until the build up of the metals in the soil is toxic to say, well don’t apply any more; it is now getting into the food chain.

Mr. S. Black: In greenhouse studies, we started out with tomatoes; then we switched to barley, alfalfa and corn, and actually we’re finding little heavy metal uptake in the first year’s application. If we put a heavy application on the first year and don’t put any on the next year, we find out that in the first year we get very little uptake of heavy metals in the plant. As far as tomatoes are concerned, we took the entire plant, the tomato itself, and we took just the stock itself, and we analyzed these, and compared them, but, it wasn’t until the second year that we started getting heavy metal uptake. The availability of the heavy metal does become apparent the second year, whereas it doesn’t the first year.

Mr. N. Berg: What’s the magnitude of the need in terms of the tonnage produced either within the drainage basin or introduced into the basin and the land area required, say in the year 1980 or the year 2000.

Mr. S. Black: Well, this is something that we’re trying to get right now under the Canada-Ontario Agreement. We have a subcommittee set up to look at the sludge disposal problem and we’re in the middle of an inventory. We have contacted every sewage treatment plant in Ontario trying to find out how much sludge they are producing, whether it’s digested and whether it goes onto the land, sanitary landfill or agricultural land. I don’t have any figures yet.

Dr. M. Johnson: Is there any rule of thumb to equate effluent gallons per day in the plant to the chemical sludge produced?

Mr. S. Black: Well, sludge production amounts to about 0.5% of the sewage treated.

Mr. N. Berg: I want to raise a question in terms of the Illinois experience and perhaps this will help us throughout the whole basin on our side. Are you not leasing the land in effect from the farmers in that area?

Dr. J.F. Frank: Which project, MSD? No, the Metropolitan Sanitary District has purchased ten thousand acres and is using its own land, purchased from local farmers. The arrangement with the farmers is to contract with them for the planting and harvesting of corn, and contracts are let for buying of that corn.
Mr. N. Berg: What we're concerned about on our side is that we recognize the need to crank in the need for this kind of land use someplace in the process of the planning activity that's going to have to occur, primarily the local planning and decision making process. Aside from public land acquisition, this is the ultimate in land decision. We need to couple the knowledge of the identification of the types of the areas that are going to have to be available for waste disposal with all of the other types of areas that are going to be required for urbanization, agricultural, and forestry production and wildlife uses and so forth. So perhaps in this process we can get some recognition of the need to relate the magnitude of the problem with the area needed.

Mr. S. Black: Well, our biggest sludge producing area is around Toronto, Oakville and Hamilton. We do have an incinerator in Toronto and an incinerator in Hamilton. This probably handles a third of the sludge produced in Ontario. Generally, the smaller municipalities will have adequate land available for sludge disposal.

Mr. N. Berg: What about the tillage practices that are required to handle this sort of an application?

Mr. M. Wood: In terms of the guidelines, the only requirement for the application of sludge on land is that, if there is an odour problem associated with it, then there is a requirement to till it in within 24 hours. Normally, using the guidelines, for an appropriately selected land there would be, we feel, little, or very little need to do it. But, as Steve pointed out, these are interim guidelines and we're prepared to change them as soon as we find out that they are either inadequate or something else is required.

Mr. B. Seabrook: Speaking to Mr. Berg's question on leasing land on the Metropolitan Sanitary District, the ARCOLA application of sludge is on leased land. They have leased the land and are ploughing it in so that although the Fulton Country operation is on land that is owned by the Metropolitan Sanitary District, there is also leased land in that sludge application operation.

Mr. S. Black: As far as I know in Ontario there is only one case where land is being leased for the application of sludge. Generally, farmers volunteer to take it. I know when we started up our lime treatment process at Newmarket, the sludge hauler there had people coming and asking him for the sludge, mainly because it had been applied to an area of land that had been fallow for four or five years and the results were very noticeable. It was right at a main intersection where many people saw how green the grass was where the sludge had been applied.
WASTE DISPOSAL ON RURAL LAND

L.R. Webber

ABSTRACT

The primary function of land is the production of food and feed for people and livestock. The proposal to use land as the ultimate sink for society's wastes involves many considerations. Land disposal of wastes exploits natural soil reactions, but, despite a long history of using land for waste disposal, research has not fully defined the limitations and potential hazards associated with the practice.

Land disposal of urban wastes must be done in such a fashion as to assure society that no segment of the environment is placed in jeopardy. To achieve this all-encompassing objective, further research is required to characterize the adsorptive, oxidative and biochemical activities when wastes are incorporated with soil.

1 Professor, Land Resource Science, University of Guelph.
Man has always had a problem with the disposal of his wastes and when he couldn’t burn them or give them away, he naturally turned to land spreading or burial. Waste disposal on or in soil is as old as the waste disposal problem itself.

THEN AND NOW

The first irrigation system designed primarily for sewage disposal began in 1559 in Prussia and operated for more than 300 years (1). Modern disposal systems are large impressive installations such as the 26,000 acres used by Melbourne, Australia to handle the waste from 2.5 million people. This land carries around 20,000 beef cattle and 30,000 sheep. Chicago has purchased 7100 acres, primarily strip-mined land, that is to be restored by sewage sludge from a population of 10 million. A proposal in Muskegon County, Michigan, includes waste disposal on 10,000 acres in lieu of building a conventional treatment system. Opponents of the Muskegon project maintain that the scheme is extremely costly, will cause irreparable ecological damage, and will never create an agricultural economy but “the colorless facts, statistics and cost estimates were no match for flamboyant academic theories, claims and predictions” (2). In southern Ontario there are approximately 60 operations involving canneries, tanneries, milk and cheese plants and municipalities using land for wastewater disposal (3).

THE SOIL RESOURCE

As the human population continues to increase there is a concomitant increase in volume of wastes produced – a measure of our affluence. For a variety of reasons, the urban centres seek waste disposal sites in the rural and often agricultural areas. This approach leads to a confrontation between the urban and rural society as evidenced by the number of Environmental Board hearings in Ontario. As of this time (Sept. 1973), Ontario does not have a recognized land use plan that defines the use of land for waste disposal and the use of land for agricultural purposes.

The primary function of land is the production of food, feed and fibre. If we accept the premise that the expansion of world agriculture into new lands has just about ended, then man’s management of the land already developed is crucial (4,5). If we propose to use land as the ultimate sink for society’s waste as well as food production, what considerations are involved? Despite the long history of waste disposal on land, research has not fully defined the limitations and potential hazards associated with the practice. The practice exploits natural soil reactions, but the limit of use has not been
determined. Dubos (4) maintained that the primary cause of the collapse of ancient civilizations was probably the damage caused to the quality of soil and to water supplies by poor ecological practices.

**SOIL PROPERTIES AND WASTE DEGRADATION**

The rationale underlying the many proposals to use soil as a waste utilization and disposal medium appears to be related to the adsorptive, oxidative and biodegradation properties of most soils. A soil contains liquid, solid and gaseous phases consisting of various organic and inorganic compounds. The structure and arrangement of the solid phase determine to a large extent the capacity of a soil to degrade added wastes. A soil has a complex of microflora and microfauna, each with preferences for foodstuffs and environmental conditions. End products of degradation are mineralized, escape the system with percolating waters, are taken up by plant roots or evolved as gases.

Let us look at a few soil properties that are fundamental considerations in using rural lands for waste disposal. Throughout this discussion we are concerned only with well-drained soils which implies an aerobic environment. The complexity of waste disposal on soils with restricted drainage and the potential for anaerobic conditions has not been adequately investigated.

**SOIL TEXTURE**

The mechanical composition of a soil in terms of sand, silt and clay determines the adsorptive surface area, water retention, release and movement and the aeration status. Data (6) are available which indicate that:

1. inert sand (Ottawa sand) had a very low phosphate adsorption.

2. coarse sand (0.25 to 0.5 mm) was not a satisfactory renovation medium in terms of BOD removal, oxidation of organics or phosphate removal.

Heywood (7) demonstrated that during a test period of 13 days and under field conditions, it was possible to remove up to 87 percent of the COD in cannery wastes. The soil was a silt loam with a daily loading rate of 320 pounds of COD per acre in 0.8 inches of liquid waste.

The subsurface disposal of septic tank effluents has been investigated in Ontario (8) and in Wisconsin (9). The Ontario study indicated adequate purification of the effluents (BOD reduction, oxidation, phosphate removal and suspected virus removal) was achieved when coarse sand was mixed with "red mud" containing oxides of calcium, aluminum and iron. Mounds of sandy material containing about 2.5 percent clay accepted almost 2 gallons of waste
per square foot per day and in terms of bacteriological and chemical tests the effluent from the mound was satisfactory (9).

In a three-year lysimeter study at Guelph (10,11) liquid poultry manure containing 900 pounds of nitrogen and 600 pounds of phosphorus per acre were added to a Guelph sandy loam soil. During this period, 60 to 84 percent of the nitrate-nitrogen that occurred in the percolates was emitted after corn harvest. The concentration of nitrate-nitrogen in the percolates exceeded 10 mg/l each year for all treatments including non-manured lysimeters. The total amount of phosphorus in the percolate was generally less than 0.5 pounds for all years combined. These data confirm many other observations that applied phosphorus tends to remain immobile in a soil.

Soil texture and packing significantly influence the moisture-aeration status of a soil. For the aerobic degradation of organic wastes, a relatively high percentage of air-filled pores is required, approximately 20 to 40 percent. This porosity relationship can be attained in coarse textured soils at relatively low tensions, but such is not the case in clays of similarly textured soils. This relationship has been well documented in the previously mentioned Wisconsin publication (9).

SOIL PERMEABILITY

A knowledge of and an appreciation for soil permeability under natural or field conditions are indispensable in planning the land disposal of liquid wastes. The entire soil profile, usually to a depth of five feet or more, must be considered in evaluating soil permeability. Some surface soils exhibit a greater capacity to transmit water than subsoil layers or strata.

As summarized by Presant et al (12) various authors have related permeability to soil structure. Details on soil structure are normally recorded in soil survey publications and reports. These data along with texture, the presence or absence of large pores, natural channels and hardpans provide a body of characteristics that, in general, permit a survey crew to evaluate soil permeability in the field.

Sites that are not in contact with groundwater and that comprise soils of low to very low permeability (less than 0.2 inches per hour) should be considered for sanitary landfills. Soils with a low permeability should not be considered as sites for the land disposal of liquid wastes by overhead irrigation. If the water fails to enter the immediate soil, surface runoff and erosion with the attendant problems of nutrient losses and sediment accumulation are assured. Industries and municipalities are generally not interested in irrigating wastes on land if the recommended total application should not exceed 1.0 inch per week and a rate of application less than 0.15 inches per hour.
While water renovation and waste degradation occur primarily in the surface cultivated layer, the soil permeability must be such that the clean water moves through the profile and eventually augments the groundwater supply. A flooded or saturated surface layer of soil restricts aerobic decomposition and enhances the potential for runoff, erosion and sediment accumulation. Furthermore, prolonged or continual use of a soil as a disposal medium, especially with wastewaters, induces a reduced infiltration capacity caused by a disintegration of soil structure, the growth of biological slimes in an organic mat, and the deposition of ferrous sulphide. Remedial measures include the application of wastewaters followed by a drying cycle. Presumably, an aerobic environment discourages the development of organic slimes and other materials that effectively restrict the admission of wastewater at the surface (13).

OTHER SOIL PROPERTIES

Other soil properties not included in this review that must be considered in waste disposal on rural land are only mentioned at this time. A soil exhibits a physical-chemical property of adsorbing positively charged ions to the negatively charged clay micelles and the soil organic matter. The magnitude of this adsorption for cations is generally known and can be demonstrated. The relationship of this soil phenomena to virus inactivation has not been adequately developed (14).

Soil pH is a property of soil that may very well become the determining factor in the use of land for waste disposal. Concern has been expressed about the build-up of heavy metals in soils from additions of sewage sludge, fertilizers and pesticides. The pH of a soil influences the solubility and availability to plants of many heavy metals. For example, zinc deficiency is most likely to occur in Ontario soils where the pH is greater than 7.2. Presumably, the soil zinc occurs as precipitates of phosphates, carbonates, or hydroxides. Chelation of zinc with organic matter renders the zinc less available to plants. The zinc chelates may breakdown and release toxic amounts of zinc if the soil pH is decreased (15). Research data from England (16) indicate that zinc, copper and nickel affect different functions in a plant and that their toxic effects may be additive. Pot experiments were interpreted to mean that copper was twice as toxic as zinc and nickel was 8 times as toxic as zinc. The recommendation was that over a long period of time, e.g., 30 years, the maximum zinc equivalent (zinc, copper and nickel) that should be added was 500 pounds per acre and soil pH would be maintained at values above 6.5.

URBAN WASTE DISPOSAL RESEARCH

Research concerned with the land disposal of urban wastes represents a significant effort at the University of Guelph. Projects underway include
field trials with the direct incorporation with soil of shredded garbage alone and in combination with sewage sludge and poultry manure and the application of lime, alum and iron precipitated sludges.

Table 1 records the quantities of various elements added to a soil from shredded waste, anaerobically digested sludge and liquid poultry manure.

One of the most important properties of organic soil amendments such as solid waste, sludge or livestock manures is the carbon to nitrogen ratio (C:N). When materials with C:N ratios greater than 30 are incorporated with soil, the microorganisms involved in decomposing the material cannot obtain sufficient nitrogen from the material itself to sustain their growth. Under these conditions, the organisms utilize existing soil nitrogen with the result that plants are nitrogen deficient. Incorporation of materials with C:N ratios less than 20 results in net release of nitrogen to the soil.

It is recognized that the range of C:N ratios listed above may vary for materials such as solid waste due to the differing levels of availability of the carbon and nitrogen. However, the principle of nitrogen immobilization at high C:N ratios and nitrogen release at low C:N ratios is valid for a wide range of soil amendments. It naturally follows that a high rate of solid waste with high C:N ratio plus sludge or manures with low C:N ratio could be applied to agricultural land if the C:N ratio were adjusted to the level normally occurring in a soil, approximately 15 to 20.

<table>
<thead>
<tr>
<th>Element</th>
<th>Shredded Waste</th>
<th>Sludge</th>
<th>Poultry Manure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sh125 tons/ac.</td>
<td>0.5 in/ac.</td>
<td>0.5 in/ac.</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>960</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>130</td>
<td>160</td>
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</tr>
<tr>
<td>Potassium</td>
<td>520</td>
<td>19</td>
<td>180</td>
</tr>
<tr>
<td>Zinc</td>
<td>67</td>
<td>36</td>
<td>3</td>
</tr>
<tr>
<td>Copper</td>
<td>5</td>
<td>24</td>
<td>1</td>
</tr>
<tr>
<td>Lead</td>
<td>34</td>
<td>5</td>
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<tr>
<td>Cadmium</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Chromium</td>
<td>5</td>
<td>12</td>
<td>*</td>
</tr>
<tr>
<td>Nickel</td>
<td>N.A.</td>
<td>0.9</td>
<td>N.A.</td>
</tr>
<tr>
<td>C:N ratio</td>
<td>65</td>
<td>4.0</td>
<td>2.3</td>
</tr>
</tbody>
</table>

* less than 0.5 pounds
N.A. data not available.
The results in terms of corn yields and soil nitrate-nitrogen distribution following the land incorporation of solid waste, sludge and poultry manure have been presented elsewhere (17,18). A general summary of the data would be:

1. a sludge application of 0.5 acre-inches was sufficient to produce an acceptable yield of corn 112 bu./acre and the yield increments from additions of 1.0 and 2.0 acre-inches of sludge were not statistically greater (17);

2. after corn harvest 42 pounds of nitrogen remained in the 0 to 36-inch depth of soil (17);

3. up to 30 percent of the total nitrogen applied as sewage sludge remained in the cultivated soil layer as residual solids and was not expected to yield significant amounts of nitrogen by subsequent decomposition (17);

4. the direct incorporation of solid waste alone and in combination with sludge or manure was entirely feasible in terms of yield of corn 96 to 116 bushels per acre, and the mechanics of incorporation (18);

5. regarding heavy metal concentration in corn, four observations were made; (a) zinc concentrations were highest in treatments involving solid waste or poultry manure, (b) the greatest concentration of cadmium was found in the corn stover from the highest application of milled refuse and sludge (250 tons/acre plus 1.8 ac.-in. of sludge), (c) maximum lead concentration in corn grain was related to the treatment of milled refuse plus poultry manure and (d) the concentration of metals in the crops of corn and rye after one application of waste did not appear to reach toxic levels (18).

SUMMARY

For some time sewage treatment plant wastes and domestic garbage have been disposed of in such a manner that the assimilative capacity of surface and ground waters has been exceeded. The resulting deterioration of the quality of the receiving waters has been and in some cases continues to be of public concern. The concern has led to a search for alternative disposal methods.

Land disposal of urban wastes must be done in such a fashion as to assure society that no segment of the environment is placed in jeopardy. To achieve this all-encompassing objective the areas of further research include:

1. assess the plant nutrient content over a period of years with the land incorporation of urban wastes;
2. determine the feasibility of incorporating urban wastes singly or in combination and at various seasons of the year to immobilize the nitrogen not used by a crop and reduce the additions to the groundwater;

3. evaluate a practice of inter-seeding the corn with a crop that will utilize the nitrogen released after corn harvest; and

4. explore the potential for the release and uptake by plants of heavy metals as a function of sources and kinds of waste and relevant soil conditions.

REFERENCES


DISCUSSION

Mr. R. Carter: What was the final packed height of your 15" garbage level? You did it a year ago, and then you did it again this time, in the same format?

Dr. L. Webber: We did it first in 1971. We piled the garbage on in August, planted the rye in September and used the rye as an index of uptake of metals. The next year, 1972, we ploughed down the rye and sowed a crop of corn. In this country we can't get the corn off soon enough to get another application on, so there's one year (1972) when no application was made. Now, to answer your question, if you look at the plots up there now after two applications of 500 tons of shredded garbage per acre, my opinion would be that they are setting up about 6 inches above the rest of the plots. It's a noticeable bulk increase.

Mr. R. Carter: Are you saying then that land is the most sacred of the three elements in which we dispose our wastes; water, land and air? I think your
last remark was that land disposal or land utilization should be practiced only when it can be shown that there are no detrimental environmental aspects; is this what you're implying?

Dr. L. Webber: You're getting into a bit of what should I say, is argumentive. There are generally three aspects to the environment, soil, air and water; lose any one, and we do not exist. We in the Province of Ontario have a lot of pressure on us for sludge disposal, and in fact in this very room, about October 9, Dick Frank over here has called a session. We're going to get, I suspect, some criticism for recommending that we put any waste on land, whatsoever, without knowing the answer. Dr. Frank knows we haven't got all the answers, but I do think we must proceed with caution, to ensure complete safety for all of us. Whether you subscribe to the Dubos Theory that our development and expansion of agriculture on unknown, uncharted, undeveloped lands is close to the limit, then maybe it's something to be serious about.

Mr. R. Carter: I've only raised this point since we seem to have made the commitment already in the U.S., that land disposal is where it's at, by having a no discharge limitation in our national goals and guidelines.

Dr. L. Webber: I'm not about to comment on that.

Dr. R. Parizek: One of your conclusions or research needs you spoke of was the need for a combination of corn and some other cover crop when the corn was no longer active in the fall. We are in effect doing that now in Pennsylvania, for the very purpose of minimizing erosion runoff, favoring infiltration during the corn harvest period, and into the fall and winter season. It seems to be working very well.

Dr. L. Webber: It was one of the older practices that the SCS recommended. To interseed the corn with rye or something else to control erosion, but again, while in the textbook it may be fine, you've got the problem of convincing the farmer that he should do it. There's a mechanical or tillage problem.

Dr. R. Parizek: It looks like a very weedy corn crop when you see it.

Dr. L. Webber: We believe there are benefits to be gained; the amount of nitrogen that's taken up by that rye. In fact, in our rye crop I think the highest percentage was 0.9 percent dry weight of nitrate nitrogen. It was material that you would hesitate to feed unrestricted to livestock, because of the high nitrate content.

Dr. G. Stopps: This might be a little bit outside the terms of reference of the Reference Group, but there seems to be an awful lot of complacency about the product that we're being asked to spread on the land and it seems to me that there hasn't, from what I understand, been the proper sort of effort put into improving the quality of the sewage treatment plants or the record of most
municipalities, which is less than creditable, in the allowing of materials to get into the sewage treatment plants. I think that we should be far more restrictive about what we are being asked to place on the land. This is where a lot of the emphasis should be, and not on what we do as passive recipients of somebody else's garbage. A great deal could be done about improving the quality of the material that we're receiving in the first place. It seems to me that sewage treatment plants, from what I understand, are pretty primitive pieces of apparatus that haven't improved greatly since the 19th century.

Dr. L. Webber: No comment.

Dr. D. Dodge: Professor Webber, to the best of your information, what investigations, if any, are being made on the relative effects of drainage from manure piles and liquid wastes on farm lands that are never really handled appropriately or put back on the land, but that eventually could end up in ground water? It seems to me these could be as significant in total effect as some of the bad effects of dumping sludge and composted material on land as a planned operation.

Dr. L. Webber: Well, Dr. Dodge, I think you're quite aware of the fact that the nutrient content of animal waste in terms of COD, BOD or some other nutrients is quite comparable, probably slightly richer, than well-digested anaerobic sludge. Percolates from some sanitary landfills also come in that category. We cannot deny that if these wastes get into streams or bodies of water they will contribute to deterioration of water quality; there's no doubt about it. I don't know if that answers your question or not, but I think the relative differences among those three liquid wastes, anaerobic digested sludge, or animal manures in liquid form, or even the percolate from sanitary landfills are all about the same calibre.

Mr. M. Wood: In reply to Dr. Stoppo's comment. I don't believe any one can say sewage treatment plants haven't changed much, although I don't accept the statement that in general sewage treatment is far better today than it used to be. But there's another aspect to the policing or the regulation of producers of wastes that are the prime sources. We do have an Industrial Waste Branch, which I think is relatively effective in trying to regulate this source of pollution with regard to the effluent that is allowed to go into an open water course or is allowed to be put into a municipal sewer. The other point to this is that if you take several thousands of point sources of pollution, e.g. industries, agriculture, etc. . . and make them each treat their waste on site prior to putting it into the municipal system, then from the point of view of policing that disposal system you have a tough job on your hands. If it gets to a municipal treatment plant, it gives you a better form of control and at least a centralized point where you can work with this material. In terms of the solid wastes approach in Ontario, the Ministry is doing all it can to promote
what we call area planning studies, in which we’re trying to get away from small individual communities each operating their own collection systems and disposal sites. Because of the problems involved in the size and the cost of small operations, they just can’t do it properly. We are promoting the use of larger systems with one or two centralized sites. This is a parallel to the sewage treatment plant and also brings out the point that Dr. Frank has mentioned about the sludge, dealing with the economies of volume. It is just a non-viable operation to try and recover metals from sludge in small plants. But if you get these put together in enormous quantities, whether it is the sewage sludge, municipal refuse or industrial waste, at least it does give you the opportunity to work with them in those volumes and perhaps set up an economic and viable operation to promote reuse and recovery.

Dr. R. Parizek: I’d like to address a point, a point of size. We have in Pennsylvania a problem with the city of Philadelphia which has been dumping garbage in the sea. This seems to be a bit of a bad practice and therefore the need to go inland is quite apparent. The problem is that when you get a city that size we’re talking about a large volume of waste and already about 7 counties have rejected the possibility of receiving Philadelphia garbage. No one wants to be the garbage capital of the East, as they all say. At the last hearing that was held, the local citizens voted to close the meeting before the proposal was ever presented. So we really have a major problem when you go large, in finding a home for this material, even using private land and all the institutional arrangements we have to work with. We have a question here of the public good, condemn land that’s best suited for, as an example, solid waste. Normally we don’t think of doing it that way in the states, or at least I don’t have any experience with this; we normally go to somebody who is willing to use his land for that purpose and try to get the regulatory agency to agree to using this land for that purpose. We now find the regulatory people desperately trying to find a place to bury the stuff, often times having to promote something which they shouldn’t be promoting. They should just be looking at the suitability of the design, but they’re now trying to find the best site. We really haven’t faced that problem in the states.

Mr. M. Wood: Under the new or relatively new Environmental Protection Act for the Province of Ontario, the establishment of waste disposal sites is now regulated fairly closely. Basically what the Act says is that any site that is to accept waste from a population equivalent of 1500 or more must go before an environmental hearing board. The environmental hearing board is made up of people who are not necessarily technically capable in the field. Their main job is to assess the socio-economic aspects of the establishment of that site at that particular location, assuming that technically the site will meet all the requirements in terms of ground water, land permeability, etc. This still does not preclude the local township from passing a bylaw prohibiting that
land use activity. Now this is causing us great concern in southern Ontario. There’s a parallel situation with the Metropolitan Toronto area where there’s just no land whatsoever within the municipal confines, and they are very shortly going to have to rail haul it or truck it out of the municipal confines. Fortunately they do have some lands that they expropriated some years ago for this purpose. But really it’s an extremely serious situation; they have tried a number of areas and each time they have been thwarted by this public opposition. I suspect that our Ministry is probably as remiss as anybody in not having an adequate public education program in effect over these past years. I agree with Mr. Seabrook that this is an absolutely vital part of our approach to the whole waste problem; that is public education and acceptance of certain land use applications for the various wastes that we have to deal with.

Dr. R. Parizek: If you look at our charge in terms of the watersheds of the Great Lakes, certain lands may be better suited for certain of these wastes and/or handling practices, and yet there may be no basis by which you can let that land ever be used for that purpose. Taking our own experience, it can be voted down by the local citizens committee sitting in that immediate area so we really have a problem. It’s one thing to say what’s technically a sound place, and another thing to win acceptance for it.

Mr. M. Wood: Well, in some of our area studies we have come across the situation where in some of the rural counties the centroid for waste disposal happens to be located on excellent agricultural land, and for that particular reason has not been used. So where the situation arises we will advise the consultant that is doing the study that the centroid then should not receive that much weight and he should look elsewhere for land that is presently not used or unavailable for other types of use.

Mr. B. Seabrook: Mr. Chairman, could I comment on the public acceptibility again? We’ve been looking at this problem at EPA in Washington. We have come up with the idea that if we can stabilize the sludge, reduce the odours or eliminate the objectionable odours, and come up with a product that will not be objectionable in a community, then we will have gone a long way toward reaching public acceptability. To that end we have a joint project with the U.S. Department of Agriculture at Beltsville (research station) for developing the procedures for composting. This has been running about 6 months now. We’ve taken sludge from the Washington D.C. Blueplains Plant with about a 20% solids content and we’ve eliminated the objectionable odours. We think we have a product that we can then apply on to the land in a lot of places, and it would not be objectionable, if we can eliminate the odours and eliminate the flies, the two problems that people usually raise objection about. Therefore composting is not an end in itself, but merely a manufacturing process to render the sludge stable and eliminate the objectionable qualities.
Mr. M. Wood: Could you comment, Mr. Seabrook, on the economic aspects of this? Is it still a matter where you have to produce the compost and haul it away yourself for spreading on land?

Mr. B. Seabrook: Yes, I think the municipality has got to share the cost of hauling it away. There are some people who take the position that you ought to sell this. As I mentioned earlier, the economic value of it is not the total cost; it's the legal costs and the social costs. There are some land developers who build buildings and houses who would be willing to take sludge and use it to build up soil, but just as soon as they do, the bleeding heart environmentalists come along and start a law suit. So, in addition to the cost or the economic value of the compost, you also have the cost of defending this. Therefore, we have been recommending that no attempt be made to recover any of the costs by trying to sell it, in other words give it away, even to the point of hauling it to the site. This is what the Hertfordshire Main Drainage Authority is doing. The Authority is hauling the sludge to the farmer, and applying it on the land, and it's free; it's given to the farmers. This is part of their solution, putting it on the land so that it is an advantage. Now the person who accepts it under those conditions still has come costs involved, he has got to defend it, and it seems to me we've got to get over that phase. How long that's going to take, maybe a decade, maybe 15 years, but somewhere down the road possibly we'll be able to sell it, and receive something from it.

Mr. M. Wood: Yes, I think that situation is paralleled up here. Another point dealing with sewage sludge — I know it's been done elsewhere but I can't pick the location off right now. We have a somewhat pet project in mind with regard to sod farms, that is hauling sludge out to sod farms and using the sludge to condition poor soil that's hauled in. Then planting your sod, skinning it off and selling it, bringing in more soil, and mixing the sludge with that, which just at a quick overview would certainly help curtail the continual buildup of these heavy metals which is certainly a concern.

Mr. J. Bruce: In connection with the question of public acceptibility, I think in many cases the public is a lot smarter than we usually give them credit for and it just seems to me in listening to the discussion here today and from other things that I've heard, that the public is reacting largely to our lack of definitive knowledge of what's going to happen when you put all these sludges and garbage on the land. I think until we can really definitively answer the questions about heavy metals, and viruses, nitrates, and ground water and so on, we're going to continue to have public opposition and likely quite rightly so.

Mr. M. Wood: I would welcome that type of public opposition based on valid reasons. Most opposition I have run into has been strictly the emotional kind and I have difficulty operating at that level.
Dr. R. Parizek: The disposal site that I spoke of for Philadelphia had a complete containment of liners, and although you don’t know enough about how long they’ll last, it had interception devices, intercepting wells, gas collection devices. It had everything you want and a procedure to fill in great big abandoned mines, at a great profit to the community. The community didn’t want to hear any of that and many of the people didn’t even know what they voted down. They were highly emotional in a little town. Really, they had nothing there in this town and it was going to give them something. They didn’t really realize that they could have doubled the ante to not $200,000 a year but maybe a $1,000,000. They could dictate the terms, but those people just didn’t want any part of it; they didn’t know what they had rejected. It’s a highly emotional thing and that group of people will never have the solid wastes venture in their yards as long as they have that kind of an attitude.

Mr. N. Berg: I know your program is limited in time, but you have an excellent discussion of this activity primarily connected with agriculture; what is the effect of disposal on forest lands?

Mr. B. Seabrook: The U.S. Forest Service has been looking into it. They say when they have fast growing species such as pulp species that there is substantial uptake of nitrogen and phosphorus but in regular forest the uptake is rather minimal.

Dr. D. Dodge: I don’t know what advantage you’d gain in some of our boreal forests of Ontario because the growing season is so short that the limiting factor in most cases is not the nutrient level of the soil as much as the amount of sunshine it’s getting.

Dr. R. Frank: I’m not going to defend myself at all. You don’t have any data on arsenic, and arsenic, in my mind, is probably one of the more toxic of the non-metals to crop production. I didn’t see anyone present anything on arsenic levels in sludges. Do you have that data?

Mr. M. Wood: We really have no data at all to date. It’s a relatively new program. So we have just now in the last week actually started getting some results in, and really these are base tests of areas that we have planned to use. So we really have no information on any sort of build up at all. But certainly arsenic would be one of the things that we would be looking at in terms of this program.

Dr. R. Frank: My other comment in talking to Dr. Corke at the University of Guelph, he’s beginning to point out to us that the presence or the application of heavy metals will often block enzyme systems that are breaking down other components in the soil. One of the things that he’s pointed out to us was
that putting a herbicide on a soil with a heavy metal may considerably prolong the persistence of the chemical. He also pointed out to me the conversion from nitrate to nitrate can be very readily blocked by heavy metal applications in a soil. These are things that are coming out which are causing concern.
Mr. Hume: I know you're engaged in farming, but you have an excellent example of the economy primarily associated with agriculture, what is the effect of stock on farm land?

Dr. A. Seabrook: The U.S. Bureau of Reclamation has been working on it. They say when they have this growing species such as jute species like there is substantial uptake of nutrients and nitrogen and salt in regular forest the opposite is opposite atmosphere.

Dr. R. Dugger: I don't know what information you're going to come up with some of the federal policies of Georgia because the growing season is so short that the nutrient levels are not at their highest level of the soil as much as the maximum of making a profit.

Dr. R. Black: I am not going to defend myself at all. You don't have any idea what we are doing, and we're not doing, is probably one of the many books of the nonmarket to crop production. I didn't see any other present anything as genetic breed in cotton. Do you have this data?

Mr. M. Boone: We really have no data at all to date. It's a relatively new concept, so we have just now in the last week actually started genetic plant breeding, and we know that we have plenty of data that we have planted to date. We really haven't any information on any sort of built up at all. But certainly specific would be one of the things that we would be looking at in terms of this program.

Dr. R. Furse: My other comment in talking to Dr. Dugger at the University of Georgia, he's beginning to point out to us that the growing on the application of heavy mirror will often make anything we want to extract the morning dew to be the sort of the things that he's pointed out in his renaissance...
SESSION 4

LIMNOLOGICAL PROCESSES IN THE GREAT LAKES

Chairman: C. Schenk,
Ontario Ministry of the Environment, Supervisor, Biological Section,
Water Quality Branch
Session A

LIMNOCICAL PROCESSES IN THE GREAT LAKES
EUTROPHICATION PROCESSES

A.M. Beeton

ABSTRACT

Lakes in their natural state are in some kind of equilibrium with their watersheds. In order for a lake to become more eutrophic, an increase in the nutrient supply from the watershed would have to occur. Events such as forest fires or landslides may alter the input, but then a new equilibrium is established. Man-induced eutrophication is the result of continually increasing nutrient loading. In large lakes the inshore environments are affected first and gradually the offshore waters. All the evidence to date show that the inshore waters of the Great Lakes have greater concentrations of nutrients than the offshore. Algae are also more abundant inshore and eutrophic species are important. Data on nutrients, plankton, benthos, and fish in Lake Erie show progressive changes from shore lakeward and from west to east.

1Associate: Director, Centre for Great Lakes Studies, University of Wisconsin, Milwaukee.
Those of you who know me won’t be surprised if I talk about eutrophication this afternoon. I don’t intend to bore you with all the documentation of eutrophication because this is readily available literature. What I hope to do is point out some aspects of the eutrophication problem in the Great Lakes that will be of direct interest to your deliberations. Figure 1 gives one of the ideas about eutrophication. Actually this is more or less the classical idea, and has been developed from studies of small lakes. The classical idea maintains that you have oligotrophic lakes; that is lakes that have a low supply of nutrients, and that through their normal aging process they might become nutrient rich or what we call eutrophic. The process of increased nutrient supply is what is commonly called eutrophication. This process can be accelerated at any point in the history of the lake, as indicated in Figure 1. Most limnologists no longer accept this explanation for eutrophication and we realize that lakes, whether small or large, come into some types of balance with the inputs to the lake and if there are constant inputs, then some kind of an equilibrium is established and conditions will remain relatively the same for a very long period of time. Of course, there are various natural catastrophes that happen in the history of a lake, such as a forest fire, a landslide, or an earthquake that disrupt things and, therefore, change the sediment loadings and the nutrient supply to a receiving body, but these are relatively temporary things. With the advent of the industrial revolution and development of our technological society, environments have been subjected to major and continuing changes. Drainage patterns have been changed through the cutting of forests, agricultural practices, highway construction, and development of large urban areas. Entire drainage basins have been disturbed by changing the soils, by altering the vegetation and increasing the nutrient supply by using fertilizers. Certainly the development of very large metropolitan areas and all the sewage inputs from these areas have changed the nutrient supply to lakes so that over the fairly recent history there has been a continuing increase in supply of nutrients to lakes. Consequently, some type of equilibrium cannot be established, since each year there has been an ever increasing nutrient supply. This is actually what were witnessing in many of the lakes that have undergone what we call accelerated eutrophication or, as some people like to call it, artificial eutrophication or cultural eutrophication. In a small body of water you could see changes occurring within a relatively short time and the entire lake undergoing these changes. So, you could detect an increased nutrient supply to the lake and then increased growth of the plants, whether they be macrophytes or phytoplankton. This increased plant production very likely would alter the chemical situation by increasing the dissolved oxygen at times or greatly decreasing it, primarily through death and decay of accumulated biomass. Benthic organisms and fish normally found in the bottom waters would be adversely affected. The St. Lawrence-Great Lakes and other great lakes of the world are just too large to respond in this simplistic way.
EUTROPHICATION

TIME

FIGURE 1.

Diagram of nutrient enrichment of a lake. Solid line shows the naturally occurring changes, broken lines indicate that accelerated eutrophication could occur at any time.
Because you have too many diverse habitats you just cannot get this overall response.

Let's look at what the situation is in the Great Lakes. Over a period of time, as Figure 2 shows, we have seen some long term increases in chemical content involving the entire water mass of the lake. For example, in Lake Michigan there has been this long upward trend in total dissolved solids, and this involves the entire water mass. The same thing for lakes Erie and Ontario, and to a lesser degree for Lake Huron, but no detectable change in Lake Superior. Also plotted on Figure 2 is the increase in human population going back to the very earliest census for both the U.S. and Canada. For example, in the Lake Erie drainage basin you had less than 100,000 people about 1810, and now in 1970 you have about 12 million. The lakes that we have seen the greatest changes in, for example Lake Erie, are those subjected to the greatest population pressure. This also affects Lake Ontario, where the increase in total dissolved solids closely parallels that for Lake Erie. This is not surprising since the major source of water supply to Lake Ontario is from Lake Erie.

Table 1 shows the chemical characteristics of the Great Lakes and some of the other waters of the world, for example Lake Baikal, which is quite similar to Lake Superior in water quality. Those of you familiar with water quality data will see that although there have been increases in various ions in the Great Lakes the concentrations we have in the Great Lakes waters are actually not any higher than the average waters of North America. For example, calcium concentrations average about 21 ppm, and these values, even in Erie and Ontario, are not particularly high. So, while there have been increases in calcium, sulphate, chloride, sodium and potassium, it is not the fact that the actual concentrations are greater that is of any consequence, because biologically speaking, concentrations of around 30 or 40 parts per million of calcium is not of that great a consequence to the biota. However, the fact that there has been an increase in these things suggests that there very well might be increases in nutrients and maybe heavy metals and so on; things for which we do not have good historical data. For a few situations we do have information about nutrients; i.e., for southern Lake Michigan, western Lake Erie and a few other places. Figure 3 shows a decrease in nitrate over the years at the Milwaukee water intake and an increase in albuminoid nitrogen. This is what you would expect. As the lake has become more productive in the Milwaukee area, more of the inorganic nitrogen has been incorporated in the albuminoid fraction. So, more of the nitrogen is showing up in the organic form, presumably in the plankton or materials produced by the plankton and less in the inorganic.

In the Great Lakes it appears that what has actually taken place is that changes have not been overall changes, as far as the biota have been
FIGURE 2.

Changes in total dissolved solids (solid line, mg/l) and population, since earliest census, for each of the Great Lakes. Broken bar for Lake Michigan indicates the period prior to completion of the Chicago Sanitary and Barge Canal, which diverted sewage away from the lake.
Table 1

Average chemical characteristics of the Great Lakes, Lake Baikal, Mississippi River, and Northern American waters.
(from Beeton, 1971.)

<table>
<thead>
<tr>
<th>Lake</th>
<th>Calcium (ppm)</th>
<th>Magnesium (ppm)</th>
<th>Potassium (ppm)</th>
<th>Sodium (ppm)</th>
<th>Total Alkalinity (ppm CaCO)</th>
<th>Chloride (ppm)</th>
<th>Sulfate (ppm)</th>
<th>Silica (ppm)</th>
<th>Phosphorus (ppb)</th>
<th>Nitrate (ppm)</th>
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<tbody>
<tr>
<td>Superior</td>
<td>12.4</td>
<td>2.8</td>
<td>0.6</td>
<td>1.1</td>
<td>46</td>
<td>1.9</td>
<td>3.2</td>
<td>2.1</td>
<td>5</td>
<td>0.52</td>
</tr>
<tr>
<td>Michigan</td>
<td>33</td>
<td>11</td>
<td>1.1</td>
<td>3.9</td>
<td>110</td>
<td>6.5</td>
<td>20</td>
<td>2.5</td>
<td>13</td>
<td>0.13</td>
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<tr>
<td>Huron</td>
<td>26.7</td>
<td>6.3</td>
<td>0.9</td>
<td>2.5</td>
<td>82</td>
<td>5.9</td>
<td>13</td>
<td>1.9</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Erie</td>
<td>37.9</td>
<td>9.6</td>
<td>1.4</td>
<td>10.6</td>
<td>95</td>
<td>23.4</td>
<td>21.1</td>
<td>0.8</td>
<td>61</td>
<td>0.10</td>
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<td>Ontario</td>
<td>38.2</td>
<td>8.2</td>
<td>1.3</td>
<td>12.0</td>
<td>10.2</td>
<td>26.7</td>
<td>27.1</td>
<td>0.3</td>
<td>9.6-28</td>
<td></td>
</tr>
<tr>
<td>Baikal</td>
<td>15.2</td>
<td>4.1</td>
<td>2.3</td>
<td>3.9</td>
<td>63.5</td>
<td>0.7</td>
<td>4.8</td>
<td>1.5-5.5</td>
<td>3-20</td>
<td></td>
</tr>
<tr>
<td>Mississippi R.</td>
<td>34</td>
<td>7.6</td>
<td>3.1</td>
<td>11</td>
<td>101</td>
<td>15</td>
<td>41</td>
<td>5.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N. America (average)</td>
<td>21</td>
<td>5</td>
<td>1.4</td>
<td>9</td>
<td>68</td>
<td>8</td>
<td>20</td>
<td>9</td>
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FIGURE 3.
Decrease in nitrate-N (broken line) and increase in albuminoid-N (solid line) at Milwaukee, Wisconsin (from Beeton, 1969).
concerned, but they have been changes that have progressed from the shore out into the open lake. This can be demonstrated with various data. For example, Figure 4 presents information from a report prepared back in 1929-1930 by Stillman Wright (1955). This shows that there were much higher nutrient levels in the inshore areas and in the inshore areas blue-green algae were dominant. There were lower concentrations of various things in the open lake. So, even in the very early days, we did have much higher concentrations of nutrients in the inshore areas and we did see a response of the algae, with blue-green algae being abundant. But the importance of this was not realized at that time, so the conclusions of those studies were that pollution was not of any consequence and probably that it was good for the lake because it would promote more fish production. Over the years, concentrations of these things that were high inshore, back in the twenties, are now out in the open lake, and concentrations inshore are much higher. We can see similar changes in the benthos; for example, back in the 1930’s oligochaetes had large populations near shore, in the mouth of the Detroit River or off the Raisin River and in Maumee Bay, but over the years there was a progressive spread of the benthic forms such as oligochaetes further out into the lake, replacing some other forms that had lived there in the past (Beeton 1969). This also can be documented for other areas such as Saginaw Bay and Green Bay. Some zooplankters that lived only in the inshore areas or in the harbours back in the twenties and early thirties have become the dominant forms in the lakes. For example, *Diaptomus siciloides* found only in a few places along the shore back in the twenties, is now the second most abundant copepod in Lake Erie (Beeton 1969) and it has long been considered a eutrophic form primarily found in small eutrophic lakes. Changes progressing from west to east in Lake Erie are indicated by changes in the catch of the whitefish (Figure 5). Between 1870 and 1880 fishermen were catching almost a million pounds of whitefish in the Detroit River, but by very early around the turn of the century the fish population in the Detroit River had almost dropped right out of the picture. They were still catching whitefish in the far west end of Lake Erie, in the Michigan waters, but then the catch declined there also. Production remained high in Ohio waters, then declined and the major fishing shifted further east. This same kind of thing can be documented for the cisco or lake herring in Lake Erie.

Figure 6 presents data for Lake Michigan collected by the Federal Water Pollution Control Administration (1968). It shows that if you’re going to have high nutrient levels they will be found in inshore waters (inshore waters as defined here would be waters less than 10 miles out into the lake). Along with the higher phosphorus and ammonia concentrations, you find the lowest silica values; i.e., low silica values near the shore and higher silica values out in the open lake. Now this is a pattern that has been documented many times, and you’ll note that in Lake Michigan the areas of highest phosphate are near
FIGURE 4.

Changes in the concentrations of nitrogen compounds and algae from the mouth of the Maumee River into Lake Erie, 1930. (from Beeton and Edmondson 1972).
FIGURE 5.
Changes in the commercial catch of whitefish from the Detroit River eastward in Lake Erie (from Beeton and Edmondson, 1972).
<table>
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</tr>
</thead>
<tbody>
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<td>1.7</td>
</tr>
<tr>
<td>0.36</td>
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</tr>
</tbody>
</table>

Milwaukee, in the southern part of the lake, and especially in Green Bay. The areas where you have high phosphate concentrations are usually those in which we have lower silica concentrations. Figure 7 shows the situation for the algae for spring, summer and fall 1963 during the same sampling period as the chemical data. In the inshore areas, where the nutrient discharges are, there is a greater abundance of plankton.

During the past three years we have been sampling on a transect between Milwaukee and Ludington across Lake Michigan, using one of the railroad ferries as a sampling platform. We can sample about once a week throughout the entire year. Figure 8 shows the results of just one of the sampling dates, but it was quite typical. This shows that inshore on both sides of the lake the total phosphorus was quite a bit higher than out in the open lake and this was true to a lesser degree for the soluble reactive phosphorus. Silica was lower in the inshore areas on both sides of the lake. The bar graph represents the abundance of diatoms and so you can see that with nutrient input into the inshore areas the growth of diatoms is stimulated and that the diatoms are using the silica. This low silica persists despite the fact that most of the rivers that empty into Lake Michigan have relatively high silica content as compared to the Lake. Silica in the Lake is around one to two mg/l; silica in the rivers is around five, six or seven mg/l. So there is a substantial input of silica to these inshore areas. Not only do we have a greater abundance of algae in inshore areas in response to the nutrient loading, but we have different species associations (Holland and Beeton 1972). Some species, for example, *Stephanodiscus hantzchii*, have been found predominantly in the inshore areas. *Stephanodiscus hantzchii* is a species that has been recognized as being a eutrophic species and it is one of the species that has been important in Lake Erie, so, here we find that it is becoming important in the inshore areas of Lake Michigan. This is also true for some other species like *Tabellaria flocculosa* and *Fragilaria crotonensis*. *Fragilaria crotonensis* is also a species that is favoured more by nutrient rich conditions. On the other hand, looking at some other species, we find that those species that are usually associated with nutrient poor conditions are more abundant in the open lake; for example, the *Cyclotellus*. *Cyclotella stelligera* is one of the diatoms that is dominant in Lake Superior and it is very important in the open waters of Lake Michigan, but not that important in the inshore waters. Not only do we have these inshore-offshore differences of various species for different genera, but within one genus we can see some differences. For example, in the eutrophic waters of Green Bay several species of *Melosira* were abundant; *M. granulata*, *M. ambiguca*, and *M. binderena*, but you do not have *M. islandica* which is considered to be an oligotrophic species (Holland 1968). Out in open Lake Michigan this oligotrophic species was dominant while in the inshore area, near Ludington, *M. ambiguca* was present. So, at this time, which was 1965, we concluded that the inshore waters, instead of being oligotrophic would be more mesotrophic. Now not only do we find a
FIGURE 7.
Distribution of algae in Lake Michigan in 1963 (from FWPCA 1968b).
FIGURE 8.
Abundance of diatoms (frustules/ml, bar graph) and concentrations of total phosphorus, soluble reactive phosphate, and silica 3 miles off of Milwaukee, Wis. and Ludington, Mich., mid-lake and half-way between mid-lake and near shore stations in Lake Michigan.
greater abundance of algae in the inshore areas and different species, but we find that their doubling rate, that is the length of time it takes for the population to double, is much more rapid in the inshore areas than out in the open Lake (Figure 9). In the inshore Wisconsin waters of Lake Michigan it was taking somewhere around ten to fifteen days for populations of *Fragilaria crotonensis* to double, while out in the open lake it would take over twenty-five days for the population to double. So you have the algae showing three types of response to the nutrient loading: different species associations, greater abundance, and a much faster doubling time in the inshore waters.

We have been measuring some other things on this car ferry transect across the lake (Holland and Beetion 1972). Regardless of the fluctuations, phosphorus was always much higher (.014 mg/l) inshore, at a station near Milwaukee where there are constant inputs from an urban area. Out in the open lake the phosphorus did not vary greatly (.008 mg/l). We have been measuring reactive chlorophyll and the highest concentrations (.004 mg/l) were at the station off Milwaukee. The uptake of radioactive carbon 14, the amount of carbon fixed per cubic meter per hour, was much greater in the inshore waters off Milwaukee and off Ludington, although to a lesser degree, but out in the open lake uptake was low and varied slightly seasonally.

When thinking about eutrophication in the Great Lakes, you have to relate it to nutrient loading, and the changes that have occurred in the Great Lakes appear to be confined primarily to certain areas. The real problem areas are southern Green Bay, the southern part of Lake Michigan, Saginaw Bay, western Lake Erie (especially along the southern shore of Lake Erie), and the western part of Lake Ontario. All of these are areas where you have constantly increasing nutrient inputs as well as various industrial inputs year after year. Because of the ever increasing discharges, conditions required for the establishment of an equilibrium are not present.

One other point I want to bring up here is that there have been various attempts to look at nutrient budgets for the Great Lakes. I am sorry I did not have this on a diagram, but here is one that was developed for Lake Michigan; this would be phosphorus inputs: direct wastewater sources 3.9 million pounds per year, indirect wastewater sources 9.3 million pounds per year, erosion and other diffuse sources 1.7 million pounds per year. So you can see, as indicated by the range in values, that we know little about nutrient inputs. The generalized total phosphorus load was 14-20 million pounds per year. Right away you can see something wrong with this, and that is that the contribution from precipitation and dustfall was not included. Recent information indicates that this is very likely an important aspect of any nutrient budget or nutrient loading to a lake. Thomas Murphy has been working on phosphorus in rainfall around Chicago, and he found average total phosphorus concentrations of .048 mg/l and average orthophosphate of .033 mg/l. Based on these data,
FIGURE 9.

Population doubling times for 3 species of diatoms at 4 locations in Lake Michigan. Inshore stations were within 2 miles of shore; offshore stations were about 10 miles from shore (from Holland & Beeton, 1972).
he calculated an annual input of 4.8 million pounds of total phosphorus to Lake Michigan rainfall per year. Now that is greater than the input from direct wastewater sources. We felt that these results may not apply to the entire lake because this had been in the rainfall collected in the Chicago area, so we have been looking at the situation around Milwaukee. We have had several sampling places, and though we have not been carrying on our study very long, and here is what we found. Our total phosphorus values ranged from .036 to .090 mg/l and our soluble phosphorus ranged from .014 to .055 mg/l. The average rainfall in the area is 30 inches, then the total phosphorus input to the lake would be a little over 5 million pounds per year. So this is a little bit higher than what Murphy calculated, but it is in the same ballpark, probably somewhere around 5 million pounds. Here again, this is another metropolitan area and we do not know if this applies to all of Lake Michigan. We hope to expand our program and have a sampling station on Beaver Island, use the same railroad ferry that we used for this other study, see if we can do some routine sampling of rainfall, and maybe get some stations established on the other side of Lake Michigan. We also propose to relate phosphorus in rainfall to direction of storm movement and some other factors. But we are just getting started. At this point I want to call on Keith Rodgers because I understand that he is involved with a network that is collecting rainwater to determine phosphorus and also heavy metal concentrations.

LITERATURE CITED


Mr. J.P. Bruce: I might add briefly to your last point A1, that Mike Shiomi's paper at the last Great Lakes Conference gave data of this kind related for Lake Ontario, and as I recall the phosphorus loading from main Duck Island in Lake Ontario is substantially less than the phosphorus loading from stations at Toronto and Hamilton, so that I agree with you entirely that while it's a very significant loading, it's likely a little less significant than the amount you're collecting at the industrialized locations.

Dr. A. Beeton: Your point is well taken in terms of the total nutrient budget and also in relating this back to the idea of differences between inshore and offshore and nutrient loading in the inshore areas. This is just another factor to consider in determining the impact of urban areas on the lake, and the idea that eutrophication must spread from these areas lakeward. That would be another aspect I should think would be especially pertinent for this group to consider. We have been trying to get a handle on why we have these pronounced inshore differences. If you look at the distribution of conservative things like sodium, calcium, chloride, and sulfate, even though some of those come in at high concentrations, they are soon diluted. You see a relatively uniform concentration for these things from point to point in the lake, but this is not true for some nutrients, so there must be some kind of mechanism that keeps higher concentrations of nutrients near shore besides the fact that there is high loading in these areas. So we've looked at various mechanisms and we know it can't be explained just on the basis of physical mechanisms like circulation, because this would apply to both the conservative ions as well as the nutrients. We've also looked at shoreline erosion. A lot of clay is moved out into the lake and knowing the adsorptive capacity of clay for phosphorus we thought that this might be a mechanism; maybe the clay was picking up a lot of phosphorus, keeping it inshore, and gradually recycling to the water. However, in some preliminary studies we found that open-lake waters took up phosphorus just as fast and in as large amounts as the inshore waters containing clay. Now maybe there's something faulty about our experiment or perhaps all the sites for phosphorus were already taken up on these clay particles. Nevertheless, our results haven't been conclusive. The explanation might be in biological uptake. For example, the Milwaukee sewage outfall dumps a lot of phosphorus and yet at times, when there's a lot of phytoplankton in the harbour, you can't measure any dissolved phosphorus unless you're near the discharge pipe. Evidently the algae have taken up the phosphorus so rapidly that it all ends up in the particulate fraction.

Dr. R. Frank: Have you identified any of these ingredients in the total phosphorus? We picked up air samples in which we were mostly looking for
organo-phosphorus insecticides and we picked up considerable numbers of organo-phosphorus compounds, but they were not insecticidal, and we've not been able to identify these, at this time, I just wondered whether they may be included in what you're picking up and whether you've identified anything?

Dr. A. Beeton: We haven't tried to break the total phosphorus down into anything other than soluble reactive phosphorus and total phosphorus. We're concerned from the standpoint of these things as nutrients in the production of algae and so on, and not so much from the standpoint as to what they might actually be, although many limnologists have been concerned for a long time as to what forms of phosphorus occur in natural waters and whether the various forms of phosphorus are available to the organisms, but we really don't have any definitive answers on that point.

Mr. W. Marks: Is there any work being done on the effect of excess water, with the extreme high lake levels where they are, on pollution and nutrients?

Dr. A. Beeton: Not to my knowledge.

Mr. W. Marks: Particularly on Lake Erie where you have a great influx of water, the water should be somewhat diluted, at least the water coming from the upper lakes.

Dr. A. Beeton: It would be difficult to really pinpoint this, because you do not have adequate nutrient budgets for the Great Lakes. Our knowledge about these things is not good enough to enable us to measure the impact of the difference caused by water supply.

Dr. T. Bahr: My question concerns the balance between the diatom population versus green algae in Lake Michigan and the role of silica in controlling one or the other. Do you see an immediate danger resulting from a reduction in silica levels in Lake Michigan due to biological incorporation of silica and subsequent precipitation? Will we find more green algae may take over?

Dr. A. Beeton: Well, what you're referring to, of course, is the contention of Eugene Stoermer and Claire Schelske that over the years silica levels would drop down to a point in Lake Michigan that it might be critical. In other words, there may not be enough silica left to support the diatom population and therefore, if their populations were to decline, then the greens, and especially blue greens might take over. And while this has some merit, I tend to disagree with it, for the following reasons. One, is that we're not certain as to the level of the decrease in silica over the years. Some of this concern is related to methodology. For example, some of the earlier water samples sat around in polyethylene bottles for as much as two years before any analyses were made. So that some of the silica that was tied up in the diatom frustules probably went back into solution. Some of the earlier samples were frozen and we know that you get different values for silica if you freeze a water sample and then thaw it out and
do your analysis. Also some of the earlier samples were stored in soft glass bottles which would give you a much higher silica value, because silica leaches from soft glass. Silica levels do seem to be stratified. You’re getting down to 0.2 milligrams per litre in the surface waters, during the summer. But on the other hand, the lake is not stratified that long a time. The period of stratification is a little over two months, and the lake is essentially monomictic; i.e., it starts mixing in late summer and continues to mix until stratification is reestablished late the following June. There’s a lot of silica, relative to surface waters, in the depths of the lake. By a lot, I’m talking about one and a half to two parts per million, which is certainly more than adequate to support the diatoms. And the main period of diatom production is in the spring and early summer before stratification develops.

**Dr. T. Bahr:** Is there an adequate tributary input of silica to sustain the diatom biomass you see out there right now?

**Dr. A. Beeton:** Well, we don’t know that much about the silica budget. Where silica has been measured there’s well over five milligrams per litre of silica in the river waters. We don’t know that much about silica from what’s been measured.

**Mr. C. Schenk:** In the previous sessions we’ve had a good bit of discussion about the potential transport of various nutrients, particularly nitrates and phosphates associated with various land use activities. I wonder for the benefit of those perhaps from an agricultural background or less familiar with lake processes, what you as a limnologist regard as important in terms of the relative significance of nutrients entering the lake system?

**Dr. A. Beeton:** You mean which ones are important? Well, it would appear from studies that have been done in Lake Michigan and Lake Superior that phosphorus is a key element to the growth of algae. This information is based on studies conducted in various kinds of nutrient enrichment studies using water enclosed in bottles or water enclosed in large plastic bags. We can demonstrate that if you introduce almost any kind of nutrient combination, you’ll get some stimulation of growth. But to get a really significant stimulation of growth it’s primarily related to phosphorus and then if you add some nitrogen along with a higher phosphorus level you’ll get more growth. If you add some silica, manganese, and so on you’d get another spurt of growth, but the major increase can be related to phosphorus. There’s been a lot of controversy that was stimulated by the soap and detergent association, I believe, about things other than phosphorus being important. There are some soft water lakes where even carbon could be a limiting nutrient, but those kinds of waters are unusual and they are not the type of waters that we’re considering here. This argument could get one off on a tangent. The Great Lakes waters are not especially soft waters, they are bicarbonate waters.
Mr. N. Berg: Dr. Beeton, the work that you did for the National Water Commission Study, and I don’t know how much of that survived in terms of the report, I saw some reference to your studies there.

Dr. A. Beeton: I don’t know how much survived either.

Mr. N. Berg: But I gathered from that brief summary that you felt that there was considerable need for additional study areas, research evaluation, etc. Now in guiding this group that has this assignment with the limited time to make a report back, what are the high priority areas that you see?

Dr. A. Beeton: Well, in terms of your interest, I think it’s really getting at this nutrient budget problem. Also, the idea that while we are not concerned with the entire mass of water responding to nutrient inputs, the critical areas are those inshore areas used for our water supply, waste disposal, fish reproduction, recreation, and so on. It is the inshore areas that receive the large nutrient input. Some people say, well we don’t have to worry about relatively low levels of nutrient loading because we have this 1,300 cubic miles of water to dilute it, but that’s just not so.

Dr. S. Walesh: Is there enough known about these near shore practices in terms of direction of movement, width and depth to utilize the information to predict future levels of eutrophication in a lake?

Dr. A. Beeton: Well, I think we’re moving in that direction, certainly with the results of the Lake Ontario studies we should be at least one step closer to understanding the type of mechanism that is involved. What I think we really need at this point is to understand the mechanisms of exchange between the inshore areas and the open lake. In considering inputs to the lake, there’s a certain amount of inshore-offshore exchange in these inshore areas, so that up to a certain level of loading there would be enough movement and exchange through an area that you wouldn’t see that much effect. But there must be a level of pollution loading beyond which you would go, that the exchange rate would be exceeded, and from that point on you might see a very rapid degradation of water quality. Here again, Keith Rodgers could speak better to any physical processes than I, because he’s a physical limnologist and has worked with hydrodynamics of the Great Lakes so he might answer a question along that line, far better than I.

Dr. L. Hetling: Would you care to speculate on the importance of the phosphorus that comes in attached to solids or as particulate phosphorus? Is that as significant as the soluble phosphorus?

Dr. A. Beeton: Well, I’m tempted to say yes, but that’s only based on ignorance. I really don’t know how much of this is lost to the sediments, or may be buried in the deep sediments, or the rate at which it may be recycled. There have been relatively few studies along this line.
SEDIMENTATION IN THE LOWER GREAT LAKES

A.L.W. Kemp

ABSTRACT

Sedimentation rates and changes in organic carbon, nitrogen, phosphorus and mercury concentrations have been determined at 14 core locations, representing basins of fine-grained sediment in lakes Ontario, Erie and Huron. Sedimentation rates are estimated by averaging the weight of sediment deposited above the Castanea (chestnut) pollen decline dated at 1930 for Lake Erie, and above the Ambrosia (ragweed) pollen rise, dated at 1850. There is a three-fold increase in sedimentation rate in Lake Erie and the Kingston basin of Lake Ontario since European settlement of the lake drainage basins.

The nutrient and Hg concentration are enriched at the sediment surface in all the cores from lakes Ontario and Erie, while the Huron cores show little change at the surface from their background concentrations. The enrichments are attributed to increased nutrient and Hg loading to the Ontario and Erie sediments, with the major increases after about 1950. The present-day loading of nutrients and Hg to the sediments parallels the rates of sedimentation at each location, being greatest in Lake Erie. Early-colonial loading of nutrients and Hg to lakes Ontario and Erie are generally similar to the modern loading of Lake Huron.

1Lakes Research Division, Canada Centre for Inland Waters, Burlington, Ontario
Ladies and Gentlemen, the sediments of a lake reflect the environmental conditions of the land and land-use practices in the drainage basin at their time of deposition. Careful examination of sediment cores can reveal the recent history of a lake and therefore fill in gaps in our knowledge regarding changing input to a lake system. Al Beeton, the previous speaker, has looked at past records of water intakes and so on and has given a very clear picture of the changing and accelerating inputs to the Great Lakes. We have the ability to measure certain parameters in the sediments of the Great Lakes, where there are no past records. Now, I would like to describe the results of a study on 14 cores taken from lakes Ontario, Erie and Huron. I would particularly like to acknowledge the help of Thane Anderson, Rich Thomas and Alena Mudrochova in this study. In fact, we have drawn on all of the staff of the geochemistry and sedimentology sections at CCIW for this work.

This diagram shows lakes Huron, Erie and Ontario, the stippled part representing the zone of fine grained sediments within each lake (Figure 1). These sediments consist of clays and silty clay muds. You will notice that the fine grained materials are confined to the offshore regions. The white background within each lake represents the coarser materials (sand, gravels, bedrock and tills). We took our samples from what we considered to be representative points within each basin of sedimentation in the three lakes. Our sampling pattern is shown in Figure 1 and goes from station 1 in South Bay, Lake Huron to station 14 at the entrance to the St. Lawrence River.

Now, I'd just like to say something before going on. We regard the nearshore zone as the high energy region within the lakes. Although fine grained materials may settle in this region for a period of time, they are eventually transferred out into the offshore regions of the lake. Therefore fine grained materials, which are rich in nutrients or toxic materials, only have a limited lifetime in the nearshore zone. You will also notice that there are areas within the middle of the lakes, where we also have high energy regimes (Figure 1). These areas divide the lakes up into individual basins. For example we call this the eastern basin of Lake Erie, the central basin of Lake Erie and the western basin of Lake Erie and so on (Figure 1).

As a geologist, when one is looking at a core, one would like to have an idea of a time scale. We use pollen frequencies as the most convenient indicator in the Great Lakes. In fact we are very lucky in the Great Lakes, to have such an indicator. The open circles represent ambrosia pollen counts and the closed circles represent castanea counts (Figure 2). Ambrosia is the ragweed pollen and castanea is the chestnut pollen. Ambrosia pollen is related to the clearance of the forest land by the early settlers and we term this period as the time of early-colonial agriculture. This has been dated from varved lake sediments from Crawford Lake, near Lake Ontario, by Jack McAndrews, as
around 1850. Therefore where the *ambrosia* frequencies start to increase we have the time horizon of 1850 (Figure 2). In the case of the chestnut pollen, the trees were killed off by a fungus disease, which spread from New York slowly eastwards. This has dated by Thane Anderson at CCIW as being around 1930 for Lake Ontario and 1935 for Lake Erie. In the case of the chestnut counts we have a situation with a fairly steady background level of *castanea* pollen with a sudden cutoff (Figure 2). We take the cutoff point as 1935 or 1930, depending on the lake (Figure 2). Therefore in each one of these 14 cores we have established time horizons. As there were no chestnut trees around...
Changes in Ambrosia and Castanea pollen concentrations in the surficial sediments at stations 3, 8, 9 and 13.

**FIGURE 2.**

- **STN. 13**
- **STN. 9**
- **STN. 3**
- **STN. 8**

**APPROXIMATE DATE OF DEPOSITION**

**THOUSANDS OF GRAINS PER GRAM DRY WT. OF SEDIMENT**

**DEPTH IN CENTIMETRES**

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Lake Huron, we are not able to utilize the *castanea* horizon for stations 1, 2 and 3. Knowing the water content of the sediment and the bulk density of the sediment, we can assume an average sedimentation rate from the surface down to the time horizon and calculate how many grams per square metre a year are accumulated at that point. The *castanea* horizon, of course, is very useful in giving modern sedimentation rates. These cores (Figure 2) are typical of all the 14 cores. For example at station 3 in Lake Huron, there is an 1850 horizon at 17 centimetres. A core from the central basin of Lake Erie has a 1935 horizon at 18 centimetres and an 1850 horizon at 28 centimetres (station 8). The first thing that you will notice in this core is that there is a great deal of difference between the two time horizons and I will be talking about this later on.

This diagram summarizes our estimates of present day sedimentation rates starting at stations 1 and going through to station 14 (Table 1). Rather than talk in terms of grams per square metre per year which may be hard for you to understand, we have calculated the mean annual thicknesses of sediment accumulating per year in millimetres. You can see that in Lake Huron we have 0.7, 0.9 and 1.4 millimetres of fine grain sediment accumulating per year. When we go to western Lake Erie we have 7.6 and 6.7 millimetres; central Lake Erie 5.1 millimetres and in the eastern basin of Lake Erie 13.4 millimetres per year (Table 1). This latter value is one of the highest sedimentation rates I have seen in a large body of water, other than in a few reservoirs. The rate is much higher than in any large lake or ocean. In Lake Ontario, we have 1.2 millimetres, 2.2 millimetres and then at the eastern end of Lake Ontario in what we call the Kingston basin we have 5.4 millimetres per year. Therefore the picture we get from these results in terms of present day sedimentation rates, is that we have very low sedimentation rates in Lake Huron, extremely high but variable sedimentation rates in Lake Erie, and intermediate and constant sedimentation rates through the main basin of Lake Ontario with very high sedimentation rates at the eastern end of Lake Ontario.

Now, utilizing our horizon for 1930 or 1935 and our horizon for 1850, we have calculated the sedimentation rate for the time period between 1850 and 1935. We call this the *early-colonial sedimentation* rate. This gives us an average for sedimentation rates between 1850 and 1930 or 1935. This diagram shows the present day sedimentation rates in grams per square metre per year, compared with the early-colonial sedimentation rates (Figure 3). You can see, we have a situation here of accelerating sedimentation rates in the Great Lakes since in 1935. There is generally a three fold increase in Lake Erie. We do not have much change in the main basin of Lake Ontario and have a three fold increase in the core at the eastern end of Lake Ontario. We have some confirmation of our sedimentation rates. Durham and Williams at CCIW have been measuring cesium 137 at one centimetre intervals in a number of
TABLE 1.

Present-day sedimentation rate and annual thickness of sediment accumulation at the 14 sample locations.

<table>
<thead>
<tr>
<th>Station Location</th>
<th>Level of Castanea horizon</th>
<th>Level of Ambrosia horizon</th>
<th>Estimated Present-Day Sedimentation Rate $\operatorname{cm} \times \operatorname{cm}$</th>
<th>Mean Annual Thickness of Sediment Accumulating mm</th>
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<td>1156</td>
<td>5.4</td>
<td>9.6</td>
</tr>
</tbody>
</table>

*not detectable
present time, we are also in the process of measuring minor and major elements in our cores. This diagram shows a core (station 4) from the western basin of Lake Erie, this is our 1850 time horizon, this is our 1935 horizon (Figure 4). You can see that we have a nice low steady background of organic carbon up to about 1935; then we have an increase near the surface at about 15 centimetres. The same increase occurs with nitrogen and phosphorus. In the case of mercury we have about a twenty fold increase from the background level up to the surface. The core from the central basin of Lake Erie is shown in (Figure 5). We have the same thing again except that there is a finer grained sediment at this location and you can see that the increases in organic carbon,

FIGURE 3.
A comparison of present-day and early-colonial sedimentation rates in lakes Ontario, Erie and Huron.
FIGURE 4.
Changes in the concentration of organic carbon, nitrogen, phosphorus and mercury in the surficial sediments at station 4.
Changes in the concentration of organic carbon, nitrogen, phosphorus and mercury in the surficial sediments at station 8.
nitrogen, phosphorus and mercury are much greater than in the western basin of Lake Erie. In a Lake Ontario core we have the same large increases and in the case of mercury, where we have a very low background level, we have about a 200 fold increase in the input of mercury to the sediments (Figure 6). Each of these cores is typical of lakes Erie and Ontario. Now we go to Lake Huron. This is a core from South Bay and is typical of the Huron cores (Figure 7). The parameters are linear in Lake Huron, except for phosphorus which increases near the surface. We explain the phosphorus curve in terms of diagenetic processes. One has to be very careful in interpreting increases in nutrients or metals in sediment cores. It is possible that increases can be due to mixing of the sediments, diagenesis and/or upward migration of elements within the pore waters of the sediment. And of course the increases can also be due to increases in loading. We consider that in the case of carbon, nitrogen, phosphorus and mercury that loading increases are the most important factor and that diagenetic processes or mixing are not as important in the Great Lakes.

It is more useful to try and get some absolute loading measurement so that we can start to estimate a nutrient or toxic substances budget for the Great Lakes. As we know the sedimentation rates and we also know the concentration of parameters in the top centimetre of sediment, we can calculate the absolute loading at each core location. i.e. how many grams of the parameter that one is interested in are sedimenting per square metre per year? I summarize this diagramatically here in terms of phosphorus, mercury, nitrogen, organic carbon and the total sediment at each one of our sample locations (Figure 8). Let us look at sediment loading first of all. We see that it is very low in Lake Huron, extremely high in Lake Erie and rather intermediate in Lake Ontario, except at the location down at the eastern end. All of the other parameters tend to follow this trend. Although the sedimentation rates in Lake Ontario were only about twice that of Lake Huron, you can see that we have much greater quantities of mercury, organic carbon, nitrogen and phosphorus in Ontario because of the higher input of nutrients and toxic materials to the lake. We have also calculated the present-day and early-colonial inputs of carbon, nitrogen, phosphorus and mercury to the lakes (Figure 9). I won’t bore you with the numbers. You can see that the early-colonial inputs of carbon, nitrogen, phosphorus, and mercury to lakes Ontario and Erie are very similar to the present-day inputs to Lake Huron. We have up to a tenfold increase in present-day inputs to the two lower lakes.

Now the final objective of our study is to try and calculate an overall budget for the lakes, based on these 14 cores, realizing that there is some variability from station to station. We have tried to estimate how many metric tons of material are being deposited in each lake. In order to make this calculation we have taken our surface concentration of each parameter, the
FIGURE 6.
Changes in the concentration of organic carbon, nitrogen, phosphorus and mercury in the surficial sediments at station 12.
FIGURE 7.

Changes in the concentration of organic carbon, nitrogen, phosphorus, and mercury in the surficial sediments at station 1.
Present-day annual inputs of total sediment, organic carbon, nitrogen, mercury and phosphorus to the 14 core locations in lakes Ontario, Erie and Huron.
Figure 9.
A comparison of present-day and early colonial inputs of organic carbon, nitrogen, phosphorus and mercury to lakes Ontario, Erie and Huron.
TABLE 2.

Total annual loadings of sediment, organic carbon, total nitrogen, total phosphorus and mercury to the basin of fine-grained sediment in lakes Ontario, Erie and Huron.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Sediment</th>
<th>OC</th>
<th>N</th>
<th>P</th>
<th>Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontario</td>
<td>4,600,000</td>
<td>230,000</td>
<td>28,900</td>
<td>7,000</td>
<td>12.7</td>
</tr>
<tr>
<td>Erie</td>
<td>23,400,000</td>
<td>753,000</td>
<td>102,000</td>
<td>27,700</td>
<td>17.4</td>
</tr>
<tr>
<td>Huron</td>
<td>3,900,000</td>
<td>161,000</td>
<td>21,400</td>
<td>4,600</td>
<td>1.4</td>
</tr>
</tbody>
</table>

sedimentation rate at the location, and the area of the sub-basin within which the sample was collected. In the case of the western basin of Lake Erie we have three cores and we were able to average three cores for our estimates. I had to give Jim Bruce an estimate about five years ago, and the numbers here are a little different to the original ones. These numbers seem to be more reasonable than our earlier calculations. If we look at total sediment loading we have 4.5 million tons per year for Lake Ontario, 23.5 million tons per year for Lake Erie and just under 4 million tons for Lake Huron (Table 2.). I would like to emphasize that this is the input of fine-grained sediment to each lake. I won’t go through the carbon results. If we look at phosphorus, we’ve calculated 7,000 tons per year for Lake Ontario and 27,700 tons for Lake Erie. Now if you go back to the IJC report for lakes Erie and Ontario you will find that 27,000 tons of phosphorus are retained in Lake Erie making us feel that our estimates for Lake Erie are quite reasonable. For Lake Ontario, the IJC report estimated a retention of 10,000 tons. However we have to take into consideration the larger volume of Lake Ontario. Therefore we would expect to have a lower quantity retained in the Ontario sediments than reported as retained in the lake. This is what we have here, 7,000 tons as opposed to 10,000 tons, presumably the remaining 3,000 tons is in the water column. In the case of nitrogen, the IJC report estimated 110,000 tons we got 102,000 for Lake Erie. The IJC report estimated 60,000 tons for Lake Ontario and we estimated 28,900 tons (Table 2.).

Now, I’d just like to summarize the preliminary conclusions from these studies. First of all, we have accelerating inputs of sediment to the Lower Lakes and it would appear that we have had a threefold increase, since the 1930’s. I suspect that the increase has been mainly since the 1940’s. I have
a feeling that this increase is somehow related to the numbers of bulldozers in the drainage basin. This is something that we'll discuss later or perhaps. We can demonstrate from these sediment studies that we have an increase in nutrient loading of up to ten times the natural loading to the lakes, and an increase of mercury inputs of up to a hundred times the natural loading.

Now remembering the numbers that I gave you before, 4 million tons for Lake Ontario, 23.5 for Lake Erie and just under 4 for Lake Huron: where is all this fine grained sediment coming from? We have as potential sediment sources: (1) Erosion of the shoreline around each lake. (2) We can have inputs from the land drainage basin either via the rivers from ground water or from sheet erosion from the tops of the bluffs. (3) We can have industrial or urban inputs of fine grained materials. (4) Sediment from the draining of marshes. (5) There is also dredging and dumping of dredgings in the lake. (6) There are also eolian sources. The sediments are generally the final sink for the fine grained materials. Most of the material will stay on the bottom and get buried once it is deposited. Only in the shallower locations such as western Lake Erie or Lake St. Clair are the fine grained sediment liable to be transitory and be passed along the system. What has caused this three fold increase? I don't really know. I think it must be mainly due to urbanization and the increases in population around the lakes, such as shown by A1 Beeton in his previous work. We've got very little information as to river or lake inputs. There have only been a few studies carried out on the inputs and I've tried to drag up some numbers. Professor Ongley at Queen's University has looked at the input of suspended sediment from all the small rivers into Lake Ontario from the Ontario shore. He comes up with a number of close to 200,000 tons per year. So if you assume another 200,000 tons from the New York State rivers, that gives us a total of 400,000 tons. Then one assumes that the Niagara River supplies about 4 times that total amount. One can arrive at about 2 million tons supplied via the river systems to Lake Ontario. These are just estimates by the way. You could say then that the river inputs are an important source of sediment to Lake Ontario. Bluff erosion would seem to be the other large source. In the case of Lake Erie, there have been some American studies on the south shore. We come up with an estimate of around 7 or 8 million tons of river inputs for the whole lake, the remaining sediment coming mainly from shoreline erosion. The lesser sedimentation in Lake Huron is presumably due to the bedrock shoreline around the northern rim and the lesser urbanization around the lake. It is hard to explain the three fold increase in sedimentation to the lower Great Lakes when shoreline erosion is such a large factor in the two lakes. It is obvious that studies should be initiated immediately to determine the sources of the accelerating input of sediment to the lakes and to determine the effect of these inputs on the lake system. As a final remark, I'd like to say that if the Canada-U.S. agreement is going to be honoured, I would like
someone to go out, in about fifteen years time, to see if these core profiles have changed, such as has been reported for Lake Washington.

DISCUSSION

Dr. Parizek: The calculations you gave from the IJC report include all losses. Is it true the phosphorus has been precipitated out of the lake water?

Dr. Kemp: The IJC calculations show the amount of phosphorus retained in the lakes, the difference between the inputs and the outputs. It was stated in the report that the material would eventually get down to the sediments. The reason there is a difference between our results and those of the IJC is due to the different approach to the calculation. I do not know if the phosphorus is a chemical precipitate; for example, calcium phosphate. It is likely that much of the phosphorus comes down in an organic form with the detritus and is then converted to an inorganic insoluble form, such as apatite.

Dr. A. Beeton: You showed some increases in organic carbon. To what extent do you think that precipitation of organic materials generated within the lake contribute to the total sedimentation?

Dr. Kemp: I thought somebody would ask that question. One of the things that we're trying to calculate is the mean integral primary productivity in the lakes. Using the productivity data and our sedimentation rate data together with upcoming data on shoreline erosion from CCIW, we are trying to estimate the autochthonous input to the lakes. As a guess, I would say that in Lake Ontario about 90% of the organic matter that is in the sediments is derived via the food chains from CO₂ in the atmosphere. We have done some C¹²/C¹³ isotope work in Lake Erie which suggests that something queer is going on there. I would think much less, maybe only 50% of the organic carbon, actually comes from the CO₂ in the air to the Lake Erie sediments.

Dr. R. Parizek: How much of the material might be harvested out through fish; take mercury for example? I guess you can’t harvest away mercury that way.

Dr. Kemp: Not only fish, but bottom fauna and zooplankton can be in the mixed zone of the sediment. This is the top three centimetres in the Great Lakes. You can have amphipods, small organisms which continually go in and out of the sediment; oligochaetes, which are inesting the sediment material and then there are numerous types of fish such as sculpins and trout and perch that live on the bottom. These species of fish and fauna that live at the bottom
of a lake keep the surface sediment mixed. I presume that this mixing provides the oxidized zone, where the positive redox potential allows a build-up of phosphorus at the surface sediment. The microbiological cycle also is most active in this surface sediment zone, where I would think that most of the mercury that is going to get back into the lake system will be transformed. We are not sure as to the forms of mercury in the Great Lakes sediments, but I would think some of it may get back into the food chains via the bottom fauna, fish and the microbiological cycle. From our results I would tend to think that most of the mercury stays in the sediment and gets buried. This is why we have got such large mercury concentrations at the surface sediments. We would like to collect some more cores to try and come up with the most accurate loading figures so that we can see if the mercury loadings to the lake agree with the calculated inputs. At the moment we’re not far out for Lake Ontario, suggesting that most of the nutrients and mercury are retained eventually in the sediments and not cycled by the organisms.

Dr. A. Beeton: I have two questions: one would be, just where would dustfall fit into your calculations? The second one would be about Lake Erie. I’ve seen published figures of about 1,000 tons a day of material going in from Detroit, industrial and municipal wastes. Where would that figure enter your calculations?

Dr. Kemp: All that we have calculated is the input to the sediments where the lake acts as a sink. As far as the sources of the sediment, we have no idea of source and I think this is what the Land Use Activities Reference Group should be thinking about. Where does this material come from? Which rivers? And is the airborne load very significant? We can observe microscopically fly ash in the sediment, for example. It contains about 1% phosphorus, according to Julian Williams at CCIW. We don’t know what form of phosphorus is in the fly ash. In terms of the total weight of sediment, the fly ash represents probably only a very small part. Other dustfall would not be so easily recognizable, so I have no idea how much that would represent of the total sediment loading. I feel this source should be urgently studied.

Mr. Schenk: In the figures that you provided for the annual loading of sediments and associated nutrients to the lake, have you considered the variability of climatic conditions and associated zone types?

Dr. Kemp: No, we have no means of working out a true annual sediment input. Our results are based on averages from 1935 or 1930 to 1971. In addition, the top three centimetres are well mixed up anyway, so that it is only possible to calculate an averaged annual input over a time period. I think as a geologist one prefers to look at this steady-state type of situation. It is much easier for us to say that in the last twenty years these results are the average for all the sedimentation events, and our close corroboration with the cesium 137 work that I previously mentioned indicates that our results are close to present day
sedimentation rates. I think that use of sediment traps would be the only way to estimate a true annual sedimentation rate and then to correlate this with climatic conditions. Without knowing the source of sediment, it is hard to relate our results to local climatic conditions.

Dr. Parízek: Is it possible that the accelerated rate of fine-grained sedimentation that you observed might be related to movement of sediment that, for instance, is now accumulating with high lake levels closer to the shore? That is, it will only be re-eroded again and all of sudden there would be a big bulge of fine grain sediments hitting your deeper basins?

Dr. Kemp: Our sedimentation rates are based on long term averages and I believe that settling of fine-grained materials in the nearshore zone is a short-term event, of only a few months at the most. The lake levels fluctuate over 10-15 year cycles and would not affect our calculated averages. However, recycling of the sediments within the lake itself, and then further redeposition is a very definite source of sediment that I did not mention. It is difficult to determine if sediment is redeposited. We would have to look for damaged minerals and pollen grains out of character with the normal sediment. This we have not had time to look for at our core locations. But I'd like to clarify something Al Beeton said earlier on, and your question. We look on the nearshore zone as only being very short-term as far as deposition of fine-grained materials. We have carried out transects of lines from the north shore of Lake Ontario out to a depth of about three hundred feet of water. In this whole north shore region you do not find any fine-grained materials until a depth of 300-400 feet is reached. You may have observed that when you're bathing on the beach on a very calm day, you are able to see a very fine layer of detritus settling out over the sand. As soon as there are waves, the detritus is removed. Thus, I think the currents over the course of a year are strong enough to carry the detritus right out into the middle of the lake. It's only in the situation of a shallow lake such as Lake St. Clair or the western basin of Lake Erie that you could expect to find redeposited sediment. The mercury that was first deposited in the St. Clair River has now moved down into the western and central basins of Lake Erie as has been demonstrated by Rich Thomas very nicely in his mercury studies. This movement of mercury through the lake systems, however, may also be due to biological mechanisms as well as sediment transport.

Mr. Norm Berg: Could you estimate about what it has taken in terms of time and dollars to get to where you are now, and also state what you think still needs to be done?

Dr. Kemp: This particular study has taken about five years to date and has utilized about three full time employees, ignoring the ship's costs. Therefore
to carry out such a study let us assume that we are paying salaries of $10,000 each so that is $30,000 per year. We are probably talking about $200,000 for the project. You do not need the fanciest of equipment to do this work. My own feelings are similar to Dr. Beeton's from the previous talk. One of our major objectives should be to look at a nutrient or toxic material budget for the Great Lakes System. We should also look at the potential sources of these materials and try and pinpoint them. I look on our own study as achieving the goal of determining the final resting place of the materials in the lake. We are only able to measure certain parameters this way. For example, we should be measuring how much nitrogen goes into the lake system, how much is present within the lake waters, how much is drained from the lake outlet and how much nitrogen is sedimented and buried. If we can determine these factors, we will have a complete limnological budget. Mr. Hugh Dobson and several of us at CCIW are working on this at the moment and I'm sure there are a lot of other researchers thinking these lines.

Dr. A. Beeton: You mentioned when you first started, I suppose facetiously, about bulldozers and sedimentation rates and so on.

Dr. Kemp: Well, I was hoping that some of the people here who are interested in land drainage could tell me something about it. I don't know if it is facetious or not.

Dr. A. Beeton: Well, another thing that happened in the Great Lakes drainage basin was the period of extensive lumbering. Does this show up anywhere in the older sediments?

Dr. Kemp: No, and this really bugs us. We would have thought that the deforestation of the Great Lakes Basin area should have shown an impact of some kind in the sediment distribution. We have looked for silt lenses, layers of bark, or any evidence of deforestation and can see no changes. I think you have to remember that I'm talking usually about offshore locations and locations where the sediment material is very fine-grained because of an almost zero energy environment. It is possible there may be evidence in the nearshore zones; we have not looked at this zone.

Dr. Parizek: Did you find things like cinders or other things that may have been cast out of ships in that area?

Dr. Kemp: Yes, we have seen cinder horizons and fly ash horizons. Our real problem is that we do not have the staff at the present time to study these horizons.

Mr. Bill Marks: You haven't seen an ash layer, say from forest fires?

Dr. Kemp: No, we haven't seen anything like that in the Great Lakes cores, as yet.
Mr. R. Carter: I take it that the materials deposited at the mouths of the streams or in harbour areas are not in the same classification as the fine-grained sediments that you're talking about?

Dr. Kemp: There could be fine-grained sediments in those areas. I think the current regime would be usually such that they would be eroded away.

Mr. Carter: Why do they have to dredge the harbours then?

Dr. Kemp: The harbours themselves are an enclosed body of water which is still, except for ships' movement or streams. In these situations, the fine-grained sediments can often settle rather nicely. Much of the harbour dredging is at harbour mouths where longshore currents have moved coarse sediment in to block the mouths. The next speakers, Drs. Rukavina and Boyce, will be talking about energetics of the nearshore zone. They can probably answer these questions better than I can.

Mr. Jeffs: Have you done anything on the settling rates of pollen grains?

Dr. Kemp: No. We have done nothing at all. Thane Anderson, of the GSC, is at the moment doing some calculations on absolute pollen sedimentation rates, which of course give a different set of numbers to our own. I think Margaret Davis has done some work along those lines, at the University of Michigan. I believe that the pollen grains sink at roughly the same rate as the fine-grained organic detritus. Noel Burns has some studies underway at CCIW. He has estimated a rate of about a metre per day. I would presume that the pollen is settling at a similar rate.

Mr. S. Salbach: I wonder if you can give us your views on the variability of settling rates within a lake? I notice you have five cores per lake and based on that an estimate on sedimentation rates. Do you have some feeling for how many cores you might need, to really come up with something you have confidence in?

Dr. Kemp: Yes, I do, we're trying to study Lake Ontario in detail at the moment. Originally, I thought that 20 cores would be enough and we're just analyzing our 40th core at the moment. That will be sufficient for Lake Ontario. For Lake Erie, we think we have to examine about 60 cores, which, with the staff I have will take about five years to finish, which is a horrible thought.

Mr. S. Salbach: It's surprising the correlation you have between your work and the IJC report.

Dr. Kemp: I would say it is a little fortuitous, based on five cores. However, in our Lake Ontario work, we have found terrific uniformity within each basin on all 40 cores. For example, we based our Kingston basin average on that one high sedimentation rate. We have examined four more cores in the
same basin, now. These are all highly sedimenting with roughly the same rates. At the eastern edge of the eastern basin of Lake Ontario, we have found similar high rates. Remembering that Lake Ontario is the last of the Great Lakes and that with shallowing water the detritus has to go somewhere, it is not surprising we have also found high rates in this zone. Glooschenko and Vollenweider demonstrated that there's a definite movement down the whole lake system towards the St. Lawrence River. They looked at chlorophyll and degradation of chlorophyll in the lake system and found degradation of detritus towards Kingston. Thus as the lake shallows up toward the Kingston basin and the St. Lawrence River, this end of Lake Ontario becomes a sort of dumping ground for the whole lake.
PROCESSES AFFECTING THE DISTRIBUTION
OF SOLUBLE MATERIALS INTRODUCED
FROM A GREAT LAKES SHORELINE*

F.M. Boyce

ABSTRACT

Following a brief discussion of a large lake’s responses to
meteorological forcing, the Coastal Boundary Layer is described.
The process of turbulent diffusion is outlined from both theoretical
and experimental points of view and is described in terms of lake
dynamics from local to basin wide scales.

*A fuller discussion of these topics is to be found in the review prepared
by Boyce, 1974. The present note contained a resumé of the more complete
treatment.

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for Inland Waters, Burlington, Ontario.
The basic characteristics of water motions in the Great Lakes are dominated by the closed nature of the basins, the predominance of wind as the major source of mechanical energy, and the seasonal thermal structure of the lakes which alternates between periods of vertical homogeneity and periods of stable stratification in temperature and density.

The site of the lake basins is large enough so that lakewide circulation patterns are strongly influenced by the coriolis force (earth's rotation) and the configuration of the boundaries. The net result is that the rotational currents associated with largescale circulations are longest next to the shoreline (Bennett 1973) and the streamlines of these flows tend to follow the bottom contours. Meteorological disturbances pass over the lakes every few days (Oort and Taylor 1969), and since the estimates of the time taken for the lakes to achieve a steady circulation in response to a constant wind field tend to be longer than this period, the state of motion of the lakes is one of continual readjustment to changing forces. At any given moment the circulation pattern represents the overlapping of earlier responses with those generated by the immediate forcing. Only when a severe storm occurs after a long period of calm is it possible to catch a glimpse of cause and effect relations.

When the lakes are stratified, an additional complication is introduced into the circulation patterns. The stable stratification in the thermocline tends to attenuate vertical turbulence and thereby reduce vertical turbulent transport of energy and materials from the surface to the lower layers. The wind acts directly on the upper layer epilimnion only and the lower layer is set in motion via the pressure gradients resulting from the tilting of the free surface and the internal isothermal surfaces. The thermocline behaves both as a barrier to vertical exchanges and as free surface upon when internal gravity waves form and propagate. In large areas, the internal waves analogous to free surface seiches are strongly modified by the earth's rotation (Mortimer 1971), and tend to be organized into complex standing wave patterns which produce rotating currents and vertical oscillations of the thermocline at periods close to the local inertial period (about 17 hours).

From the point of view of dispersal of soluble and suspended materials, the lakes divide into two main regions: a coastal zone extending from the beach to about 10 km. offshore, and a mid-lake region.

In the mid-lake region the lake's wide circulations are weakest and the effects of standing internal waves are most marked. With the exception of standing internal waves which are to a first approximatic a purely oscillatory phenomenon, the structure of the water column is influenced primarily by local vertical fluxes of heat and mechanical energy. At seasonal time scales, the large scale water motions can be viewed as a basin wide turbulence and the horizontal transport of materials treated as a simple turbulent diffusion.
phenomenon characterized by an eddy diffusion coefficient appropriate to an eddy scale commensurate with the basin width. The persistent pattern of chloride ion distribution in Lake Erie's central basin can be approximately accounted for by such a mechanism (Boyce & Hamblin 1973). This analysis suggests that a time scale for significant horizontal mixing in the offshore regions of the Great Lakes is of the order of one month.

In the coastal zone, the direct effects of basin wide circulations on dispersal of materials is very marked. In these regions, most of the kinetic energy of horizontal motion is to be found at time scales of several days; the effects of standing internal waves are small (Blanton 1973a, 1973b). Two main regimes occur: in the first a quasi-steady current flows along the shore, with the velocity being largest a few kilometers offshore and decreasing both inshore and offshore from that point. The second is characterized by a reversal of the coastal currents as the lake adjusts to a changing wind field. The time of reversal of the current varies with distance offshore and the changeover periods is marked by large horizontal current shears and vertical motions (upwelling and downwelling).

In the first regime (steady alongshore current) the diffusion of material from a shoreline source seems to be reasonably well predicted by theoretical models (mean concentration field). There is a tendency for plumes to hug the shoreline, a phenomenon often termed “Coastal Entrapment” (Csanady 1971). This is thought to be a result of “roughness” of the shoreline which generates horizontal turbulence. In fact it appears that the coastal zone comprises two boundary layers, an external one as a result of the large scale dynamics of enclosed basins (Walin 1972), and an inner one similar to the turbulent boundary layer adjacent to the wall of a rough pipe or flume.

In the second regime, one of rapidly changing shore currents, the effective dispersal process can be much more rapid, particularly on a shoreline where upwelling of deeper water forces the nearshore water offshore. The horizontal current shears associated with the reversal of coastal currents are known to accelerate the dispersal if dissolved and suspended materials (Murthy 1972).

In periods of calm or feeble coastal currents, the dispersal processes can be quite inefficient and pools of high concentration can form next to a shoreline source.

Measurements of the temporal behaviour effluent concentration at points on the shore near an outfall can then be expected to reveal periods of high concentration alternated with periods of low or zero concentration depending on the vagaries of the coastal flow regime, itself dominated by the major wind events. It is doubtful if deterministic predictions of concentration can be made, particularly since the applicable theories deal only with the mean
concentration field and not with the small scale fluctuations. From an environmental point of view, one needs information on the mean field and on the magnitude of the fluctuations in order to evaluate the probable peak concentrations.

A basic prerequisite to the management of the coastal environment is a statistical climatology of the coastal currents. Knowledge of the frequency of current reversals, upwelling and downwelling episodes and periods of stratification will be essential to estimates of the percentage of time a particular stretch of coastline is likely to be "fumigated" by an effluent source.

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DISPERSION OF SHORE- AND STREAM-DERIVED SEDIMENTS BY NEARSHORE PROCESSES IN THE GREAT LAKES

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ABSTRACT

The Lake Ontario nearshore zone is used as an example of how mapping of nearshore bottom sediments combined with shore erosion and stream discharge data can provide a generalized model of nearshore dispersion of sediment.

In the Lake Ontario case, net littoral drift is eastward in the eastern four-fifths of the basin and westward in the western one-fifth. This is in response to prevailing westerly winds and intermittent easterly storms respectively. The result is a concentration of sediment at the two ends of the lake with smaller mid-coast deposits where littoral drift is interrupted by changes in shoreline configuration or bathymetry. Sediment supply is mainly the result of shore and offshore erosion of glacial drift exposed along the south shore and central north shore.

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My experience in lakes research is as a geologist involved in the mapping of nearshore sediments. Our surveys cover the zone extending from the shore-line to a water depth of 20 metres. Although they are principally inventory studies of bottom materials, they do provide information on the source of lake sediments and the dispersion of sediment in shallow water. I will be speaking about how it is possible to assemble a preliminary model of nearshore sedimentation from rather basic data on the location of modern sediments, the distribution of potential source materials, and the evidence in the geometry and grain size of modern sediments of their net transport direction. I will use Lake Ontario as an example because we have most experience there, but my comments will have general application to the other Great Lakes as well.

Figure 1 is a summary of the distribution of bottom types in the Lake Ontario nearshore zone based on surveys during the period 1968-71. Modern sediment forms only a minor portion of the zone, about ten percent by area, and tends to be concentrated in six major sediment bodies. These occur at the ends of the basin at Hamilton and Mexico Bay, and at Toronto and Brighton on the north shore and Niagara and Rochester on the south shore. Most of the sediment is in the sand and gravel size range; fine silt-clay sediment, the inshore edge of the basin sediment, occurs at the offshore boundary of the zone.

The major part of the zone, about 60 percent by area, is floored by semi-consolidated glacial sediments deposited directly by glaciers or by lakes associated with de-glaciation. This portion of the zone is currently being eroded and as a result, most of the parent glacial material is covered by a thin veneer of lag deposits, a residue of coarse sand, pebbles and boulders remaining after the finer sediment has been removed.

The remaining 10 percent of the zone is exposed bedrock. In Canadian waters, this is shale and siltstone at the western end of the lake and limestone in the northeastern exposures. Bedrock areas are sites of erosion or non-deposition, but erosion and the resultant production of sediment is limited in comparison to the glacial sediments because the bedrock is consolidated and more mechanically stable.

In general the shoreline materials are of the same type as the adjacent material offshore. Most of the south shore and the central portion of the north shore consist of shore bluffs of glacial sediment averaging 5-10 metres in height. Bedrock is exposed onshore between Burlington and Port Credit and east of Cobourg. Depositional shorelines of beaches or beaches and dunes are associated with the major sediment deposits with the exception of the Niagara deposit which is detached from the shoreline and fronted by bluffs.

Figure 2 summarizes the distribution of onshore and offshore glacial sediments. These are potential sediment-producing areas. Measured rates
sand and gravel
silt - clay
glacial sediment and lag deposits
bedrock
glacial/bedrock undifferentiated

FIGURE 1
of bluff erosion which indicate the actual contribution of sediment from the bluffs are available at selected sites from historical survey records and recent measurements by DOE. At present we are using the survey information as a control for a lakewide assessment of erosion based on aerial photographs. We are comparing the position of the shorebluff in 1973 with that of the previous high-water period (1952-54) in order to get a meaningful long-term average rate of erosion. Results should be available by late 1974. As an estimate of the amount of sediment contributed by offshore erosion we are monitoring changes in selected offshore profiles annually in areas of exposed glacial sediment. Meaningful results here will require several years of data.

We have no equivalent program to monitor the sediment input by streams. Ongley’s recent paper on stream discharge to Lake Ontario suggests that bedload discharge of coarser sediment is negligible. Since most of the modern sediment in the nearshore zone is in the bedload size range it is unlikely that stream supply is an important factor. I should emphasize that stream sediment in suspension does represent an important source of lake basin sediments and deserves study from that point of view.

Once the sediment enters the nearshore zone, it is moved laterally by longshore currents, or offshore by wave action or transverse rip currents. The extent and mechanism of transport in the onshore-offshore direction is poorly known. Large scale adjustments of the offshore profile to changing water levels have been observed in a year-long program of monthly surveys offshore from Burlington. Smaller changes in response to individual storms have also been surveyed at Burlington, and CCIW is currently developing a program for monitoring short-term bottom changes by underwater time-lapse cinematography.

The direction of movement in an alongshore direction is determined by the angle of wave approach to the shoreline. Figure 3 indicates that the wave rose for Lake Ontario has maxima along the east-west axis of the basin. This is in response to prevailing westerly winds and periodic easterly storms. This situation should lead to a predominance of westward-moving longshore currents in the western end of the basin and eastward-moving longshore currents in the eastern end of the basin with a reversal at a position in mid-basin determined by the relative frequency of waves from both directions. Evidence of the direction of net sediment movement is available in the sediment itself. Natural or artificial barriers to alongshore movement (promontories, groynes, jetties, etc.) show a pattern of accumulation of sediment on the up-drift side and erosion on the down-drift side. Within the sediment bodies, the direction of transport is indicated by the gradients in sediment grain size; grain size tends to decrease in the direction of transport. Figure 3 summarizes the net drift directions inferred in this manner. The pattern is one of net eastward drift of sediment in the eastern four-fifths of the basin and westward drift in the
nearshore current directions

Storr (1964)

NWPQA (1986)

Scott & Lansing

Net littoral drift direction inferred from accretion patterns

Toronto

Cobourg

Hamilton

Rochester

Stony point

Sources of wave rose data

Toronto

Cobourg

Hamilton

Rochester

Stony point

U.S. Corps of Engineers

Figure 3
westernmost part of the basin. The reversal occurs mid-way between Toronto and Cobourg on the north shore, and Hamilton and the Niagara River mouth on south shore.

Rates of longshore sediment movement are more difficult to establish than directions. Studies of the dispersion of natural or artificial tracers which move with the sediment provide one means of estimating transport rate, but collection and analysis of sufficient data to be meaningful is arduous and extended studies are required to document the influence of various wave properties. Both the American Coastal Engineering Research Centre and the French Atomic Energy Commission have developed automated equipment for collection and analysis of tracer data, but this is extremely costly and the reliability of the interpretations is still in question. CCIW has conducted tracer studies in Lakes Erie and Ontario, and is currently evaluating automated tracer equipment as the next step in a developing program for measurement of sediment transport rates.

An independent measure of transport rates can be obtained by measuring accumulation rates in nearshore sediments. Short cores of sediment from Burlington and Niagara sediments are currently being analyzed for fossil pollen with the hope that recovery will be sufficient to permit the pollen dating that has been so successful in basin sediments.

If the data we have been discussing on bottom sediment types, potential source materials, and nearshore circulations is assembled as in Figure 4, the result is a preliminary qualitative model of Lake Ontario nearshore sedimentation. It tells us where modern sediment is accumulating, the areas of sediment supply, and the net transport directions alongshore. What we need to know now is rates of onshore and offshore erosion and sediment transport, the nature of sediment movement transverse to shore, short-term response in erosion and deposition to individual storms, accumulation rates in the areas of modern sediment, and long-term trends in shore and nearshore evolution as revealed by studies of sediment stratigraphy. Studies now in progress should permit us to attach some numbers to the model and give it some predictive power.
net drift direction: offshore accumulation
sediment input: bluff erosion bottom fluvial
as dunes

FIGURE 4
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