



MISCELLANEOUS PAPER Y-74-3

# OVERLAND FLOW TREATMENT OF WASTEWATER

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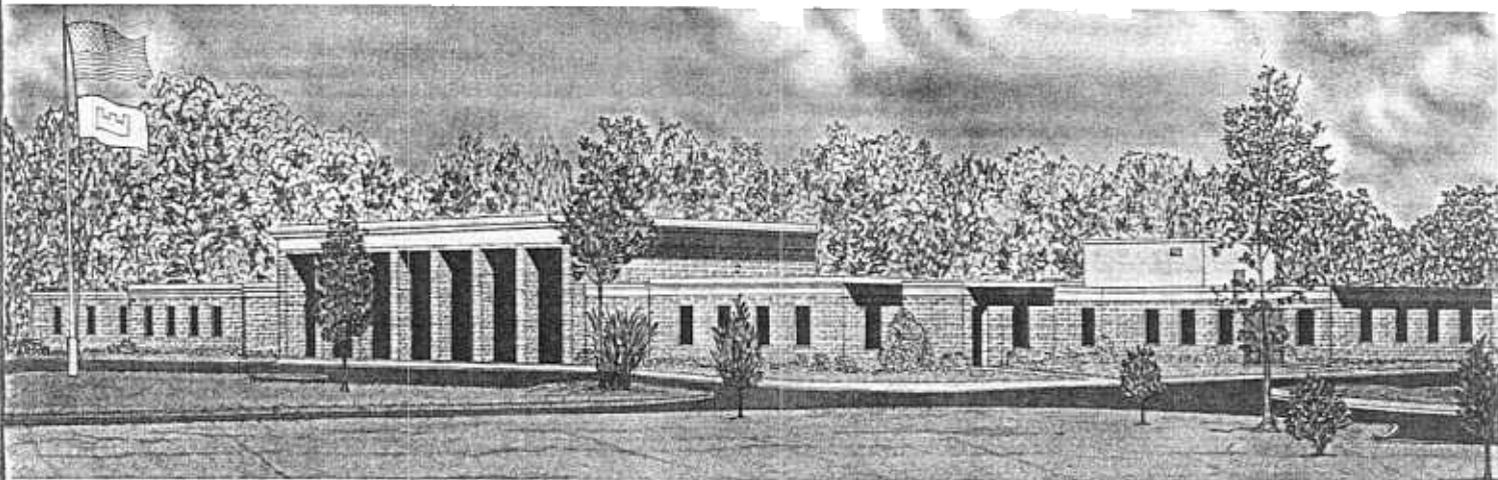
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## 20. ABSTRACT (Continued)

0.2 mg/l each of cadmium, copper, lead, manganese, nickel, and zinc to simulate average wastewater. The study was conducted for 12 weeks with effluent applied by flooding from the upper end of the slope at 0.5 in./day (6-hr periods) for 4 days per week. The wastewater was generally distributed into 20, 30, and 50 percent for subflow, evapotranspiration, and runoff, respectively. Analyses showed that 100, 95, 91, and 75 percent of the ammonium, nitrate, and organic nitrogen and phosphorus, respectively, were retained in the model. The balance of the nitrogen and phosphorus remained in the runoff, with essentially none in the subflow. The grass harvest removed 31 percent of the nitrogen and 6 percent of the phosphorus. The model retained from 98 to 100 percent of the cadmium, copper, manganese, and nickel; 91 percent of the lead; and 72 percent of the zinc. The balance was lost in runoff, except for 2 percent manganese and 6 percent zinc that were lost in the subflow. The grass removed 4 percent of the applied copper, lead, and nickel; 9 percent of the zinc; 13 percent of the manganese; and none of the cadmium. The elements retained in the model were strongly fixed or volatilized since they were not readily extracted or exchanged. Conditions for gaseous loss of nitrogen through nitrification-denitrification existed at the surface of the model as evidenced by low oxidation-reduction potentials during periods of saturation and higher potentials after drainage. Nitrogen and potassium were removed from surface water before traveling half the model length. Hence, nitrogen loading could be increased, and the resulting increased grass growth would probably improve treatment effectiveness for other elements. The loss of 25 percent of the applied phosphorus in runoff indicated a need for more surface contact, probably obtainable by increasing the model length. The subflow analyses showed excellent removal of nitrogen, phosphorus, and most heavy metals indicating effective removal mechanisms by the soil during the study period.

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## FOREWORD

This work was funded by the Department of the Army under Project No. 4AO61101A91D, Task 02, "In-House Laboratory Independent Research Program," sponsored by the Assistant Secretary of the Army (R&D).

The work was conducted during the period July 1972-June 1973 at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., by Mr. C. A. Carlson, Dr. P. G. Hunt, and SP4 T. B. Delaney, of the Environmental Effects Laboratory. The study was under the general supervision of Dr. John Harrison, Chief, Environmental Effects Laboratory.

Mr. Ronald DeLaune of Louisiana State University assisted in the preparation of the literature review and constructed the redox electrodes.

Directors of WES during the conduct of this study and preparation of the report were BG E. D. Peixotto, CE, and COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

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## CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
square feet	0.092903	square meters
pounds	0.45359237	kilograms
inches per hour	2.54	centimeters per hour
inches per day	2.54	centimeters per day
pounds per square inch	0.070307	kilograms per square centimeter
pounds per acre	1.1208	kilograms per hectare
tons (2000 lb) per hectare	0.90718474	metric tons per hectare
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

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\* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula:  $C = (5/9)(F - 32)$ . To obtain Kelvin (K) readings, use:  $K = (5/9)(F - 32) + 273.15$ .

## SUMMARY

Land application has been suggested as an effective, low-cost method for advanced treatment of wastewater from military reservation treatment plants. This study is being conducted to determine the mechanisms involved in wastewater treatment by overland flow so that operational feasibility, design, and performance criteria can be more accurately evaluated.

A model 5 ft wide and 20 ft long was prepared with grass sod and a low-permeable Susquehanna clay to a 6-in. depth at a 2 percent slope. Secondary effluent from a motel treatment plant was supplemented with 13.4 mg/l of nitrogen as ammonium nitrate and 0.2 mg/l each of cadmium, copper, lead, manganese, nickel, and zinc to simulate average wastewater. The study was conducted for 12 weeks with effluent applied by flooding from the upper end of the slope at 0.5 in./day (6-hr periods) for 4 days per week.

The wastewater was generally distributed into 20, 30, and 50 percent for subflow, evapotranspiration, and runoff, respectively. Analyses showed that 100, 95, 91, and 75 percent of the ammonium, nitrate, and organic nitrogen and phosphorus, respectively, were retained in the model. The balance of the nitrogen and phosphorus remained in the runoff, with essentially none in the subflow. The grass harvest removed 31 percent of the nitrogen and 6 percent of the phosphorus. The model retained from 98 to 100 percent of the cadmium, copper, manganese, and nickel; 91 percent of the lead; and 72 percent of the zinc. The balance was lost in runoff, except for 2 percent manganese and 6 percent zinc that were lost in the subflow. The grass removed 4 percent of the applied copper, lead, and nickel; 9 percent of the zinc; 13 percent of the manganese; and none of the cadmium.

The elements retained in the model were strongly fixed or volatilized since they were not readily extracted or exchanged. Conditions for gaseous loss of nitrogen through nitrification-denitrification existed at the surface of the model as evidenced by low oxidation-reduction potentials during periods of saturation and higher potentials after drainage. Nitrogen and potassium were removed from surface water before traveling half the model length. Hence, nitrogen loading could be increased, and the resulting increased grass growth would probably improve treatment effectiveness for other elements. The loss of 25 percent of the applied phosphorus in runoff indicated a need for more surface contact, probably obtainable by increasing the model length. The subflow analyses showed excellent removal of nitrogen, phosphorus, and most heavy metals indicating effective removal mechanisms by the soil during the study period.

## OVERLAND FLOW TREATMENT OF WASTEWATER

### PART I: BACKGROUND AND PURPOSE

1. Although many municipalities and Government installations such as military reservations are now treating their wastewater to secondary quality, pollution problems from wastewater still exist. While these problems are not as acute as those caused by the discharge of raw wastewater, secondarily treated wastewater contains nutrients and heavy metals that can cause accelerated eutrophication in receiving waters or toxic accumulations in the food chain.

2. Phosphorus is probably the nutrient most commonly associated with eutrophication since it is quite often the limiting factor in the growth and bloom of algae. However, algae blooms are stimulated by numerous factors, including micronutrient concentrations and pH. One common misconception is that nitrogen is not an important factor in accelerated eutrophication because nitrogen-fixing algae provide sufficient nitrogen to support an immense growth of algae. This, however, is normally not the case since only a few algae, primarily the blue-green class, fix nitrogen. Consequently, the concentration of nitrogen in wastewater is also quite important.

3. To minimize adverse effects of wastewater upon the environment, the Department of the Army intends to comply with the spirit as well as the letter of clean water legislation in the most economical manner. Thus, some form of advanced treatment of wastewater from its military reservations is desirable. Unfortunately, advanced biological or chemical-physical treatment facilities are complex and their cost is high. However, land treatment of wastewater can accomplish significant advanced treatment of wastewater. Most military reservations have considerable acreage available. In order to pursue the possibility of land treatment of wastewater, the Office of the Adjutant General, Department of the Army, requested in December 1972 that the major commands consider this alternative in their wastewater treatment plans because of its effectiveness and low cost.

4. Several studies on the use of highly porous soils for wastewater treatment have been conducted, with the most notable one being the Flushing Meadows study in Phoenix, Ariz. In addition, deep sand filter systems at Fort Devens, Mass., and Otis Air Force Base, Mass., are presently being investigated. Treatment of wastewater on soils of low permeability has received little attention. One of the few examples of wastewater treatment on soils of low permeability is the Campbell Soup Company's overland flow system in Paris, Texas. This system has been shown to function quite well in the removal of nitrogen and biological oxygen demand (BOD) materials from cannery wastewater. Unfortunately, the exact mode of treatment has not been established, and similar systems that use secondarily treated municipal-industrial wastewater have not been studied.

5. Thus, the design of overland flow treatment facilities for military reservations on which low-permeability soils predominate until now has been based on "best guess information." The study reported herein was conducted to elucidate the principles involved in overland flow treatment and to determine the operational feasibility of using this mode of advanced treatment for wastewaters from military reservation treatment plants and municipal-industrial treatment plants. The results of this study should help to evaluate practical design and performance criteria for overland flow treatment of wastewater. The basic data are listed in Appendix A; and model characteristics are discussed in Appendix B.

## PART II: LITERATURE REVIEW

### Composition of Secondarily Treated Wastewater

6. The composition of secondary effluent can be quite variable depending on the characteristics of the primary waste materials and the modes of primary and secondary treatment. However, a typical secondary effluent (table 1) has recently been presented by Reed.<sup>1</sup>

### Nitrogen Removal in Land Treatment of Secondarily Treated Wastewaters

7. In an evaluation of overland flow or any other type of land treatment, a division can be made between treatment processes that are primarily biological and those that are primarily chemical by distinguishing nitrogen treatment from the other elements of concern. This is not to imply that biological processes are not important in the treatment of components other than nitrogen, but to point out the significant role that microorganisms and plants play in the removal of nitrogen during land treatment of wastewater.

8. The major factor in nitrogen removal in most properly functioning land treatment systems is plant uptake.<sup>2,3</sup> The conversion of nitrogen into plant protein is quite desirable since it is not only removed from wastewater, but is also made available directly or indirectly as a source of protein for animals and humans. Removal of 100 to 200 lb/acre\* of nitrogen by agronomic crops is quite common. Fried and Broeshart<sup>4</sup> report total removal of nitrogen of 155 and 133 lb/acre for corn and soybeans, respectively. Removal of 42 percent of the nitrogen applied in cannery wastewater by reed canary grass has been estimated for the Campbell Soup Company, Paris, Texas, overland flow treatment system.<sup>5</sup> This removal of nitrogen in the form of plant protein is one of the inherent advantages of wastewater treatment on agricultural as opposed to forested lands.

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\* A table of factors for converting British units of measurement to metric units is presented on page ix.

9. Forested sites on low-permeability soils also seem to have a distinct disadvantage for overland flow systems in that a reasonably smooth soil surface is required to minimize channeling. Overland flow in forested areas also has the disadvantage of possible tree destruction from water-saturated soil profiles.

10. However, for plant uptake of nitrogen to occur on either wooded or agricultural land, the nitrogen must be available to the plant root. Two of the obvious ways nitrogen becomes unavailable to the plant are by water rapidly flowing off a slope or leaching through the soil profile. Such losses of nitrogen are undesirable because they normally result in pollution of streams and lakes or groundwater. A more acceptable means of nitrogen unavailability occurs when nitrogen is immobilized in microbial cells and their by-products. Alexander<sup>6</sup> describes immobilization as the conversion of an inorganic chemical into an organic compound. The reverse of this process can be described as mineralization. The extent of immobilization or mineralization is dependent upon the environmental parameters and energy supply in the soil system. Microorganisms are good competitors for nitrogen, and under aerobic conditions, with a good source of organic compounds, nitrogen is normally immobilized. The energy source can be inorganic, but immobilization under these conditions is normally not extensive. Nitrogen immobilization in the root zone is not an objectionable phenomenon since the nitrogen will be available for plant uptake upon release. It should be noted that a 0.01 percent increase in immobilized nitrogen in the upper 6 in. of soils with a dry unit weight of  $1.35 \text{ g/cm}^3$  amounts to 180 lb/acre of nitrogen, a rather substantial amount.

11. However, when the energy source is depleted or the soil profile turns anaerobic, mineralization of nitrogen is likely to occur. In the case of a depleted energy source, mineralization results from the breakdown of microbial protein as the population becomes smaller.<sup>6,7</sup> In the case of anaerobic conditions, less nitrogen is required per unit energy source consumed, because anaerobes are not nearly as efficient in converting organic materials to cellular materials.<sup>8</sup>

12. If mineralization takes place under aerobic conditions,

ammonium is likely to be converted to nitrate quite rapidly. This conversion is referred to as nitrification, and it normally is performed in the sequence of ammonium to nitrite to nitrate by Nitrosomonas and Nitrobacter, respectively. Both of these genera are autotrophic. They synthesize organic matter from inorganic carbon. Acknowledging the fact that nitrification can be performed by heterotrophic microorganisms, those that feed on organic matter, it is probably acceptable to think of and plan for the nitrification aspects of a land treatment system in terms of autotrophic nitrification.

13. Thus, to have extensive nitrification, aerobic conditions must be present, and pH values must be above 5.5.<sup>6</sup> In irrigated, arable soil systems, the aerobic requirement can be satisfied by microaerobic sites that may be within a few millimeters of anaerobic sites.<sup>9</sup> In flooded soils, nitrification normally occurs in the upper few millimeters of soil in the aerobic zone of the "aerobic-anaerobic" double layer. The thickness of the aerobic layer and, concomitantly, the area of nitrification are dependent upon such factors as the depth of flooded water, organic content of the flooded water and underlying soil, texture and structure of the underlying soil, and duration and frequency of flooding.<sup>10</sup> The depth of floodwater is quite important since the diffusion constant of oxygen is approximately  $10^4$  times less in water than in air, and any increase in diffusion distance significantly affects the concentration of oxygen reaching the soil surface per unit time.<sup>9</sup> It logically follows that long flooding and short drying periods will tend to keep the soil pores filled with water and thus promote smaller aerobic zones. In addition, soils of heavy texture and poor structure will tend to retain water in the soil pores longer and present more tortuous diffusion paths. The oxidized layer can even be eliminated if the organic content and microbial activity of the overlying water are high enough to consume oxygen more rapidly than it can diffuse to the soil surface.

14. It is generally accepted that the soil pH must be kept above 5.5 for nitrification to occur. Flooded soils tend to approach a neutral pH, so nitrification is normally enhanced by the soil reaction although it is slowed by limited oxygen under flooded conditions.<sup>11</sup>

Nitrite may accumulate at pH values greater than 7.2 because of the differential sensitivity of Nitrobacter and Nitrosomonas. It is possible, but not common, for nitrite to accumulate to toxic levels under these conditions.<sup>7</sup>

15. Nitrification is important in the treatment of wastewater because denitrification, the gaseous loss of nitrogen, cannot occur unless nitrogen is in the nitrate form. Nor can denitrification occur unless the particular site of reaction is anaerobic. Thus, the reason for hypothesizing the importance of an aerobic-anaerobic double layer in an overland flow treatment system is apparent. The aerobic zone is necessary for nitrate formation from either ammonium or organic nitrogen, and the anaerobic layer is necessary for denitrification.

16. However, anaerobic conditions alone are not sufficient for denitrification. An energy, i.e., a food, source must also be available. Organic compounds normally serve this function, but in the case of Thiobacillus denitrificans, the energy source is reduced sulfur compounds. Since the ratio of carbon consumed to  $N_2$  evolved is about 1.5:1 and the amount of nitrate available for denitrification is seldom over 100 ppm, the organic energy source for denitrification normally is not limiting in the upper foot of most soil profiles.<sup>12</sup> At greater depths (3 to 5 ft) in the soil profile, organic energy sources may become limiting. However, in the upper inch of soils in an overland flow system, the combination of organic material in the wastewater and that excreted and secreted from plants and microbes will normally be more than sufficient to reduce the 10 to 25 ppm of nitrate in secondarily treated wastewater.

17. The oxidation-reduction or redox potential (Eh) is probably a better measure of conditions in the soil for denitrification than the actual oxygen concentration, because the redox potential can be measured over a much larger range. However, redox potential is not a reliable measure of determining to what extent a soil is aerated.<sup>13</sup> It should be borne in mind when discussing oxygen status and redox potential that the two are so interrelated that the separation for discussion or measurement is somewhat an academic exercise.<sup>14</sup> The exact redox potential at which

denitrification begins or nitrate becomes unstable is not agreed upon.<sup>14</sup> However, at an Eh of +320 mv, in reference to the hydrogen electrode, and adjusted to a pH of 5.0, nitrate can be considered unstable. The reduction of manganese, iron, and sulfate follows as the soil redox potential decreases. Redox potentials of +320 mv and denitrification occur within a few hours after flooding of a soil.<sup>15</sup> However, the exact rates of redox decline and denitrification are dependent on the factors previously mentioned in the controlling of the thickness of the aerobic-anaerobic double layer.

18. It should be mentioned, however, that significant denitrification in land treatment of wastewater has not been proven, although it has been hypothesized to occur in overland flow systems and it is known to be significant in rice paddies and marsh areas.<sup>8</sup> The major reasons for lack of conclusive proof of significant denitrification in land treatment systems are probably the relatively short time that it has been viewed as a potential source of significant nitrogen loss and the difficulty of measuring soil nitrogen accurately enough to determine the amount of nitrogen actually retained by the soil. In addition, the gaseous collection and accurate measurement of <sup>15</sup>N-labeled nitrogen are extremely difficult.<sup>16</sup> However, nitrogen removal from wastewater in overland flow treatment by a number of mechanisms including denitrification appears to be both significant and long term.

#### Conditions Resulting from Overland Flow Treatment of Wastewater

19. The process of overland flow treatment of wastewater should have a profound effect on normal aerobic soil processes. This effect may be similar to that found under flooded conditions occurring in rice fields. The restricted entry of oxygen into the soil after flooding a soil has been shown to result in the formation of oxidized and reduced zones,<sup>17-20</sup> an increase in pH and specific conductance,<sup>11,20</sup> a decrease in redox potential,<sup>21</sup> and changes in the solubility and availability of various elements.<sup>11,20,22-25</sup>

20. When a soil is flooded, especially when it is supplied with

organic matter, biological and chemical reduction occur. The exchange of gases between the soil and the atmosphere has been shown to be confined to the top few millimeters of the soil-water interface.<sup>17-20</sup> This thin oxidized layer at the soil surface is characterized by a reddish to yellowish-brown color, a high redox potential and oxygen content, and a high content of the oxidized forms of certain elements such as nitrate, sulfate, and ferric iron.<sup>19</sup> The chemical and biological characteristics of this oxidized layer are apparently little different from those of a well-drained, well-aerated soil.<sup>19</sup> Below this oxidized layer, oxygen is almost nonexistent.<sup>17-20</sup>

21. The reduced layer underlying the oxidized zone, whose thickness in many flooded soils varies from 15 to 20 cm, is characterized according to Mitsui<sup>26</sup> by a bluish-gray color, low values of redox potential and oxygen content, and the presence of reduced products such as nitrite, ammonium, nitric oxide, ferrous ions, manganous ions, and sulfide ions, and the products of anaerobic decomposition of organic matter.

22. It is apparent from the foregoing discussion that both oxidation and reduction processes will be occurring in overland flow treatment of wastewater.

23. A characteristic feature of waterlogged soils is that even though they may be deficient in bases they are usually not very acidic or basic. Generally, acid soils increase in pH and alkaline soils decrease in pH after submergence, with the pH values tending to stabilize around the neutral point.<sup>11,20</sup> According to Ponnampuruma,<sup>20</sup> flooding causes an initial decrease in soil pH during the first day or two, followed by an increase to a maximum value near the neutral point after reducing conditions predominate. He associates this increase in pH with the reduction of the soil, since it has been shown that retardation of reduction slows the pH rise. This increase in pH is important in the solubility of various elements.

24. Ponnampuruma<sup>20</sup> also suggests that the pH of slightly acid or neutral soils is regulated by the  $\text{CaCO}_3\text{-CO}_2\text{-HOH}$  equilibrium, and the pH of acid soils rich in iron is regulated by the  $\text{Fe(OH)}_2\text{-CO}_2\text{-HOH}$  equilibrium.  $\text{Mn(OH)}_2$  may be the dominant compound in soils low in active iron

but high in manganese, while CO<sub>2</sub> tension may be the regulating factor in soils low in both active iron and manganese.

25. The redox characteristics of a waterlogged soil are considered to be similar to a ferric-ferrous system.<sup>19</sup> Under anaerobic conditions, the ferric ion undergoes reduction to the ferrous form, and the relative concentrations of both ions vary with the degree of reduction of the system. As the redox potential decreases, the amount of iron in solution increases because of the reduction of the ferric to ferrous form, the latter being more soluble in the soil solution. As a result of this process a corresponding increase in pH occurs. Patrick<sup>27</sup> explains that the simultaneous increase in pH and decrease in redox potential are due to the reduction of ferric hydroxide to ferrous hydroxide under reducing conditions; i.e.,



He states that a rapid decline in redox potential is characteristic of soils having a low content of reducible iron and manganese and a high organic matter content. Manganese and iron systems tend to buffer the soil at an intermediate redox potential of about +100 to +300 mv.

#### Availability of Various Elements Under Overland Flow Treatment Conditions

##### Nitrogen

26. The availability of nitrogen under overland flow treatment conditions was discussed in paragraphs 7-18.

##### Phosphorus

27. Well-drained soils have been shown to differ in their capacity to fix phosphorus depending on the quantities of iron and aluminum oxides present,<sup>28-30</sup> the kinds and amounts of clay minerals,<sup>31-33</sup> and the soil pH.<sup>28</sup>

28. Iron and aluminum compounds are largely responsible for the fixation of phosphorus, especially under acid well-drained soil conditions.<sup>28</sup> Wild<sup>29</sup> found that: (a) a positive correlation exists between

phosphate fixation and the amounts of iron and aluminum in soils; (b) the removal of iron and aluminum oxides from soil colloids reduces phosphate fixation; and (c) the addition of iron and aluminum compounds to soils and clays increases their capacities to fix phosphate.

29. Bear and Toth<sup>30</sup> note that the amounts of soluble iron and aluminum are very low when compared with the amount of phosphorus a soil is capable of fixing. Coleman<sup>28</sup> concludes that iron and aluminum do not have to be in solution in order to fix phosphates. It is assumed that iron and aluminum are present in soils as film coatings of oxides and hydroxides. While much controversy has developed regarding the mechanisms and reactions of phosphorus fixation with iron and aluminum oxides, certain aluminum and iron phosphate compounds have been identified in well-drained soils.<sup>34,35</sup> Among the aluminum compounds identified are variscite ( $\text{AlPO}_4 \cdot 2\text{HOH}$ ) and wavellite. The iron compounds found are strengite ( $\text{FePO}_4 \cdot 2\text{HOH}$ ), vivianite [ $\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{HOH}$ ], and dufrenite.

30. Phosphorus has been shown to be fixed by kaolinite clay through phosphate ions replacing hydroxyl groups exposed on the kaolinite lattice.<sup>31</sup> Black<sup>32</sup> suggests that the phosphate ions might even penetrate into the clay crystal lattice and replace a hydroxyl group within. Low and Black<sup>33</sup> report that phosphate can also be fixed through replacement of silicate ions in the clay lattice with phosphate ions. In highly acid soil solutions, phosphate is present primarily in the  $\text{H}_2\text{PO}_4^-$  form.<sup>36</sup> In general, well-drained soils with pH values below 5.5 tend to fix large amounts of phosphorus, mainly due to the formation of aluminum and iron compounds. Phosphorus becomes most soluble in well-drained soils with pH values between 6.0 and 7.0. The predominant form of phosphate in this pH range is  $\text{HPO}_4^{2-}$ . Above a pH of 9.0, the predominant form of phosphorus is  $\text{PO}_4^{3-}$ , which becomes fixed and less soluble in calcium compounds.

31. The behavior of phosphorus in flooded soils is remarkably different from phosphate behavior in well-drained aerated soils.<sup>13</sup> Reasons for the wide differences in phosphate response observed under aerobic and anaerobic conditions have not been clearly defined, but it is generally believed that the chemical nature of phosphate compounds

and their reduction, hydrolysis, fixation, and re-fixation in the soil are responsible for these differences. These differences in behavior are of the greatest practical significance in the phosphorus nutrition of rice.<sup>13</sup>

32. In general, the phosphorus in flooded soils can be divided into two main groups: inorganic and organic. The inorganic forms of phosphorus have been classified by Chang and Jackson<sup>22</sup> into four sub-groups: calcium phosphate, aluminum phosphate, iron phosphate, and reductant-soluble iron phosphate. Both types of iron phosphates are of special importance in flooded soils used for rice cultivation.

33. According to Chang and Jackson,<sup>37</sup> calcium and aluminum phosphates are more likely to be formed than iron phosphate immediately after phosphate fertilization of rice fields, with movement into the iron phosphate fraction taking place as time passes. This is to be expected in view of the lower solubility product of iron phosphate.<sup>22</sup> Movement into the reductant-soluble iron phosphate fixation is believed to be a slow process related to soil maturity.<sup>37</sup> The formation of reductant-soluble iron phosphate is apparently unhampered by soil management practices.<sup>37</sup> This soil phosphate fraction may be of significant importance as a phosphorus source for plants grown on waterlogged soils even though it is not considered so for upland crops.

34. Considerable research has been conducted with flooded soils to evaluate the crop response to the different inorganic phosphate compounds mentioned above.<sup>24,26,27,38-41</sup> It is fairly well established that flooding a soil results in an increased solubility of phosphorus.<sup>24</sup> Iron phosphates are generally found to be more soluble than aluminum phosphate or calcium phosphate under flooded conditions.

35. Fujiwara<sup>38</sup> explains that the better response of rice to ferric phosphate is due to the occurrence of hydrolysis under flooded conditions and the resultant increase in available phosphorus. Shapiro<sup>24</sup> suggests that, since both aluminum and iron undergo hydrolysis, the superiority of the iron phosphate must be attributed to reduction as well as hydrolysis. Patrick<sup>27</sup> reports a marked increase in the extractable phosphorus with a lowering of the redox potential below +200 mv at

a pH of 5.7. The fact that at +200-mv ferric ion also begins to reduce to the ferrous form tends to confirm the belief that this increase in phosphate comes from the conversion of ferric phosphate to the more soluble ferrous phosphate.

36. Valencia<sup>23</sup> found that immediately after flooding there is an increase in phosphorus availability, apparently due to hydrolysis of  $AlPO_4$  and reduction of  $FePO_4$ , but after a long incubation period less phosphorus is available. This is explained as re-fixation of the available phosphorus.

37. Significant changes in the solubility patterns of soil phosphorus occur when a soil is flooded, especially in the presence of a good supply of easily decomposable organic matter. The effects of organic matter on phosphate availability have been investigated by Bass and Sieling.<sup>42</sup> Generally, organic matter increases both the solubility and the availability to plants of soil phosphorus. A number of mechanisms have been postulated to explain the increased availability of soil phosphorus by organic matter. Under flooded conditions, it has been suggested that organic matter affects available phosphorus through reduction and chelation phenomena.<sup>24</sup> It should be noted, however, that a reduction in the amount of available phosphorus can occur through the process of assimilation that accompanies bacterial decomposition of organic matter.

38. As pointed out earlier, soil pH can have a remarkable effect on the availability of phosphorus. However, under flooded conditions, reduction of phosphate compounds overcomes the pH factor in determining the solubility of soil phosphorus. Even so, Aoki<sup>40</sup> found that the solubility of phosphorus is minimal at pH values between 5 and 7. At pH values below 5 and above 7, the quantities of soluble phosphorus are much larger under flooded soil conditions.

39. The solubility-pH curves for flooded and nonflooded soils resemble those of precipitated ferrous and ferric phosphates, respectively.<sup>26</sup> This led Mitsui<sup>26</sup> to postulate that phosphate availability under flooded conditions is governed mainly by the solubility of iron phosphate. The high solubility of phosphate in the alkaline pH range

is presumed to be due to the hydrolysis of this compound. It is generally concluded that the pH of a soil plays a lesser role in determining the availability and solubility of phosphorus in a waterlogged soil than it does in a well-drained soil.

40. As previously mentioned, when a soil is flooded, several oxidized compounds are replaced by their reduced counterparts. However, the possible reduction of phosphate to phosphine should not be excluded. Tsubota<sup>43</sup> found that traces of phosphine are produced when working with extremely reduced soil samples. He also determined that the higher the incubation temperature and the higher the organic matter content of the soil, the greater the degree of dephosphorification. In a separate experiment, Tsubota<sup>43</sup> shows that phosphate when reduced first goes to phosphite and then to hypophosphite before reaching the phosphine form.

41. It was concluded that the phenomenon of reduction of phosphate to phosphite, hypophosphite, and possibly to phosphine can occur in reduced soil and that this reduction is due to microbial action.<sup>43</sup>

#### Heavy metals

42. Manganese and iron. Under well-drained soil conditions, both manganese and iron availability are determined to a great extent by the soil pH and the readily decomposable soil organic matter. Both manganese and iron are generally more soluble at pH values of 5.0 and below, and less soluble at pH values of 6.0 or above. Soil pH values below 5.0 have been reported to increase the solubility of manganese to such an extent that many agronomic crops produce very low yields due to manganese toxicity.<sup>36</sup> However, the application of lime to raise the soil pH above 5.0 eliminates toxic concentrations of manganese and returns crop yields to normal levels.<sup>44</sup> Decomposing soil organic matter generally tends to increase the availability of manganese and iron through the creation of reducing conditions.<sup>45,46</sup>

43. Both manganese oxides and ferric iron compounds, which predominate in well-drained soils, are reduced to the more soluble manganous and ferrous forms when a soil is flooded.<sup>20</sup> The kinetics of the reduction of manganese and iron are similar in nature, the only difference being one of degree, manganese being more easily reduced than iron.<sup>20</sup>

Turner and Patrick<sup>15</sup> report that manganese becomes reduced at a redox potential of +400 mv and is essentially completely reduced at a redox potential of +200 mv. Iron, on the other hand, becomes reduced when the redox potential falls below +200 mv.<sup>27</sup> Patrick<sup>27</sup> attributes this increase in reduced iron (ferrous iron) to the reduction of insoluble ferric compounds, which are unstable at this reducing potential.

44. The conditions that favor the reduction of manganese and iron in flooded soils have received much study.<sup>6,20,45,47-50</sup> These studies show that the reduction of manganese and iron is favored by: (a) the absence of substances at a higher level of oxidation, such as nitrate;<sup>20</sup> (b) the presence of readily decomposable organic matter;<sup>20,45,47,49,50</sup> and (c) a good supply of active iron.<sup>20</sup> There have been numerous mechanisms hypothesized that might govern the reduction of manganese and iron in flooded soils. The general consensus of the numerous reports indicates that manganic and ferric compounds are reduced to the more soluble manganous and ferrous forms either by serving as biological electron acceptors<sup>6,50,51</sup> or by being reduced chemically by organic compounds during the anaerobic decomposition of organic matter.<sup>6,20,45,47,51</sup>

45. According to Mann and Quastel<sup>45</sup> and Alexander,<sup>6</sup> several factors may be involved in these mechanisms: (a) The solubilization of unavailable manganese and iron oxides can be accomplished by an increase in acidity accompanying fermentation that favors the mobilization of manganese and iron; (b) The depletion of oxygen as a consequence of microbial metabolism tends to lower the redox potential and lead to the reduction of manganic and ferric compounds; (c) Fermentation products (reducing organic substances) react directly with the oxidized forms of manganese and iron and shift the equilibrium from oxidized forms to the reduced manganous and ferrous forms; and finally, (d) Electron transport results, with the iron and manganese functioning as electron acceptors in cell respiration in a manner analogous to the reduction of nitrate by denitrifying bacteria.

46. According to Leeper,<sup>49</sup> microbial reduction of manganese can take place at any pH value, if the oxygen tension is low, when the anaerobic bacteria use the higher oxides as a source of oxygen. Reduction

of the higher oxides in flooded soils takes place when the biological oxidation of organic matter proceeds so rapidly that air cannot supply oxygen in adequate amounts. When this occurs, reduction of the higher oxides of manganese takes place to supply the needed oxygen, with a subsequent increase in the available manganese. Redman and Patrick<sup>11</sup> report a sixfold average increase in extractable manganese after 30 days of submergence.

47. Manganese and iron reactions in reduced environments are very closely related.<sup>52,53</sup> In solutions with low redox potentials, manganese and iron form carbonates, sulfides, and silicates that are fairly insoluble in neutral or basic solutions. Berner<sup>53</sup> states that once  $H_2S$  is formed in flooded sediments, it reacts with various iron-containing minerals to form insoluble iron sulfide. Kraushopf<sup>52</sup> found that manganese sulfide is readily oxidized under aerated conditions to give insoluble oxides of higher valence. Oxidation of manganous compounds requires higher potentials than does oxidation of ferrous compounds, and hence manganese sulfide is more soluble than iron sulfide. Connell and Patrick<sup>54</sup> report that reduced manganese is less efficient than reduced iron in precipitating  $H_2S$ . The fact that  $FeS$  is more insoluble than  $MnS$  indicates that iron is a more effective sulfide precipitating agent than manganese.

48. Aluminum. As was discussed in paragraphs 28 and 29, aluminum plays a dominant role in the fixation of phosphorus in well-drained soils. The form in which aluminum exists in aerated soils depends to a large extent on the soil pH. At low soil pH values (4.0 and below), aluminum exists as the  $Al^{+3}$  ion. As the soil pH increases to 4.9 and above, aluminum quickly converts to  $Al(OH)^{+2}$ , to  $Al(OH)_2^+$ , and finally to  $Al(OH)_3$  above a pH of 5.0. The first three forms of aluminum actively are capable of fixing phosphorus.<sup>55</sup>

49. Many crops grow poorly when soil pH values fall below 5.0. This poor growth has been attributed to toxic concentrations of soluble aluminum in soils.<sup>56</sup> This condition can be remedied by applying lime and raising the soil pH to above 5.0.<sup>56</sup>

50. There has been little research into the behavior of aluminum

under flooded soil conditions. However, it is apparent that aluminum is not sensitive to or involved in redox phenomena. As long as the pH values of flooded soils remain above 5.0, aluminum should not become soluble enough to be toxic to vegetation.

51. Zinc, copper, cadmium, nickel, and lead. While there has been considerable research on the availability of zinc and copper in well-drained soils, there has been very little research conducted on that of cadmium, nickel, or lead. Zinc and copper are considered minor elements and thus have been studied in relation to the requirements of many agronomic crops. Since there have been no reports of plants requiring either cadmium, nickel, or lead, these elements have not been considered important in agriculture.

52. The availability of zinc and copper in well-drained soils is related in a large extent to the soil pH and the soil organic matter. Generally, as soil pH values decrease below 6.0, zinc and copper become more soluble.<sup>48,57</sup> The availability of zinc and copper decreases when soil pH values increase above 6.0.

53. Soil organic matter has been shown to complex or chelate zinc and copper very effectively.<sup>58</sup> DeMumbrum and Jackson<sup>58</sup> report a positive correlation between zinc and copper sorption and organic matter content of soils. Depending on the complex, the availability of either may increase or decrease. It is well established that copper deficiencies are very prevalent in organic peat soils due to the copper being complexed in a form that is unavailable to plants.<sup>56</sup> Zinc also undergoes similar reactions although to a lesser degree than copper.

54. While agriculturalists are concerned about having sufficient amounts of zinc and copper present in soils to meet the needs of crops, there have appeared in recent years problems relating to excess amounts of heavy metals, particularly zinc.<sup>59</sup> Excess zinc in soils appears to induce an iron deficiency in plants.<sup>59,60</sup> Liming a soil to a pH of 6.0 or above eliminates the toxic effects of zinc by precipitating the zinc and rendering it less available to plants.<sup>61</sup>

55. Only in recent years with more emphasis on cleaning up the environment have studies been established to investigate the absorption

and availability of cadmium, nickel, and lead in soils. Sufficient information is lacking at the present time.

56. Very little research has been done on the availability and solubility of zinc, copper, cadmium, nickel, and lead under anaerobic conditions. Jenne<sup>25</sup> suggests that the role of hydrous oxides of manganese and iron is important as a control on heavy-metal solubility through sorption and desorption reactions with the heavy metals. Jenne<sup>25</sup> indicates that the principal factors affecting the availability of hydrous-oxide-occluded heavy metals are the redox potential, pH, concentration of the metal of interest, concentration of competing metals, and concentration of other ions capable of forming inorganic complexes and organic chelates. Jenne<sup>25</sup> states that the most significant factors probably are the redox potential and pH. Geologists have demonstrated that heavy metals readily form very insoluble sulfide salts when exposed to anaerobic conditions where  $H_2S$  is present.<sup>52</sup>

### PART III: TEST MATERIALS AND PROCEDURES

#### Soil

57. To provide conditions for overland flow and surface treatment effects, a low-permeable clay soil of the Susquehanna series was selected for study. Susquehanna soils occur in scattered areas at higher elevations of the Atlantic and Gulf Coastal Plains from Virginia to Texas, extending into western Tennessee, Arkansas, and Oklahoma. The soil for this study was obtained in the De Soto National Forest, 4 miles south of Camp Shelby in Forest County, Miss.\* The site was an abandoned eroded field supporting a sparse growth of grass and scattered pine trees and with clay subsoil exposed. The soil was a red or yellowish clay passing to a mottled red and yellow clay and into a mottled red, yellow, and gray or bluish-gray plastic clay at depths of 3 to 4 ft. This clay is hard and stiff when dry and highly plastic and sticky when wet, but shows granular structure on partial drying. Permeability to water in the field is estimated at less than 0.06 in./hr.

58. The soil was dug in a moist condition (28 percent water content) following initial autumn rains and stored in covered containers to prevent drying. The material was taken from the surface to 6-in. depth at one location approximately 40 ft across. Surface litter and grass tufts were scraped away, but roots remained in the soil. Lenses and pockets of a gray silty material were excluded as far as practicable. Gray silt coatings on the reddish clay occurred to some extent, and these were allowed in the sample.

59. The soil was a clay loam according to U. S. Department of Agriculture textural classes; according to the Unified Soil Classification System, it was a clay (CH) with 90 percent fines, a liquid limit of 65, and a plasticity index of 37. The soil was acid with a pH of 5.0 for a 1:1 soil-water suspension. The cation exchange capacity

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\* The soil was located and identified in the field by Mr. Rex Davis, Soil Scientist, Soil Survey and Mapping Unit, U. S. Soil Conservation Service, Hattiesburg, Miss. 39401.

was 25 milliequivalents per 100 g of soil and was 35 percent saturated with bases.

### Vegetation

60. Grass was selected as the vegetative cover because it establishes rapidly, forms a complete ground cover, and responds well to treatment. The grass was started in trays 3 in. deep containing the test soil to make a sod for transplanting for immediate treatment application following preparation of the model. The soil was screened through 1/2-in. hardware cloth to remove large roots and was placed in trays to a compacted depth of about 2 in. A grass seed mixture at portions of 5:2:2:1, by weight, of reed canary grass (Phalaris arundinacea L.), Kentucky 31 variety of tall fescue (Festuca arundinacea), perennial ryegrass (Lolium perenne L.), and Bermuda grass (Cynodon dactylon L.) was seeded at the rate of 1 lb per 100 sq ft, covered with a sprinkling of soil, and watered occasionally using tap water. The grass germinated and grew slowly, so it was fertilized after 2, 5, and 9 weeks. A liquid starting solution of 20:20:20 (nitrogen:phosphorus:potassium) was used at a rate of 1/2 lb per 100 sq ft. The Bermuda grass failed to grow. After 6 weeks, local spots of dying and rotting grass developed, so all trays were sprayed with an organic fungicide (Ortho-Captan). After 11 weeks, a dense short sod was established.

### Overland Flow Test Model

61. The test model simulated a prepared field with a soil layer of conventional plow depth overlying an impervious layer which in nature could be a sublayer of higher clay content, hardpan, or bedrock.

#### Construction

62. The container for the model was constructed of 3/4-in. plywood with inside dimensions of 5 by 20 ft by 7+1/2 in. deep. The box was supported by transverse 2- by 6-in. joists on 24-in. centers and double 2- by 12-in. sills along each side. Side support was provided by

a double 2- by 6-in. collar abutting a 2- by 8-in. board backing the plywood sides. The box was maintained at a 2 percent slope for this study but was equipped with pivots at one end and screw jacks at the other so that the slope could be adjusted between 0 and 10 percent. The interior and edges were painted with an inert epoxy\* to prevent water seepage or chemical contamination. Ports were installed in the bottom of the box for sampling subflow. The ports consisted of a Plexiglas nipple embedded in epoxy and stoppered with a rubber septum from a medical vial to allow insertion of a hypodermic needle for sampling. Four ports were spaced across the bottom at selected distances from the upslope end, namely, at 2, 3, 5, 7.5, 10, and 15 ft. Additional nipples were installed at the downslope end to conduct subflow and surface runoff from the box to containers for volume measurement and sampling. Eight nipples were spaced along the junction of the end and bottom, and four were equally spaced across the end at 2-1/2 in. above the bottom for subflow. A Plexiglas shelf, 1 by 15 by 1/8 in., was installed to direct water to each of the upper subflow nipples. Spacings for all subflow nipples were separated by 1- by 1-1/2- by 1/8-in. Plexiglas dividers. For runoff, four nipples were equally spaced along the end, 5 in. above the bottom. These connected to 1/8-in. Plexiglas trays that were 3/4 in. wide, 1/2 in. deep, and 15 in. long with a lip extending out 3/4 in. Plexiglas trays with 15-in.-long compartments were also made for application of water at the upslope end. The water was distributed through a paper towel wick across the lip of the tray so as to drip, spread, and flow evenly downslope over the soil surface. A longitudinal section of the model is shown in fig. 1.

#### Model preparation

63. The soil was added by layers to obtain uniform density with depth. Approximately 400 lb of soil was passed through a 1/2-in. mesh screen into the box, mixed by hand, and spread into a layer approximately 1 in. thick. The layer was then compressed to half its thickness

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\* CONO-GLAZE made by Con/Chem, Inc., 15524 South Broadway, Gardena, Calif. 90247.

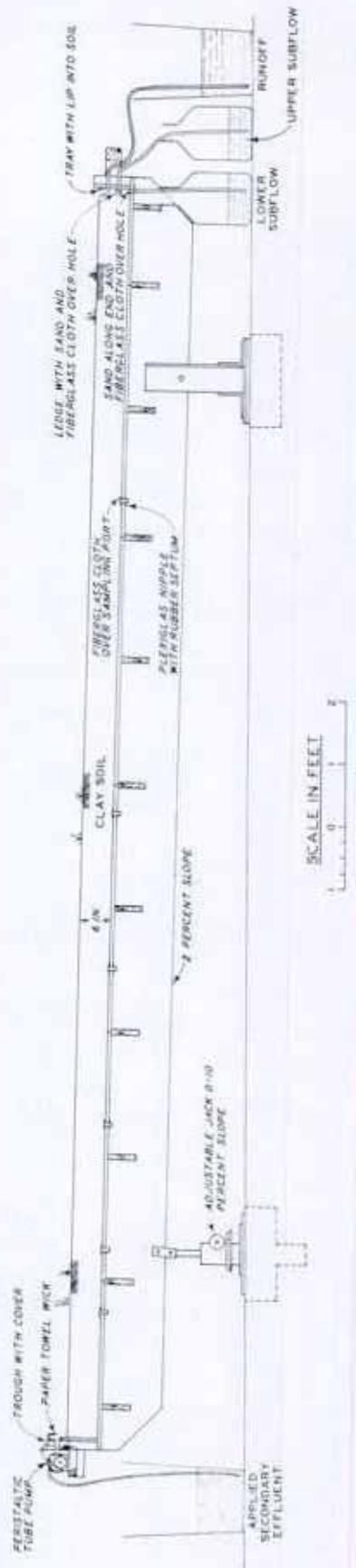


Fig. 1. Longitudinal section of the overland flow wastewater treatment model

using hardwood blocks weighted to 5 psi. The blocks were placed without dropping them for impact. The surface was scarified to promote bonding and continuity with the next layer, and to eliminate any skin or surface between layers that could alter the path of water flowing through the soil mass. Layers were then added to a depth of 5 in.

64. The sod from the trays was trimmed of the root mat on the sides and bottom, and placed in strips 1 in. apart across the width of the box. The 1-in. spaces between the 1-ft-wide sod strips were packed with screened soil. Sod and soil were compressed under the 5-psi blocks to a final total depth of 6 in. Total wet weight of the soil in the box was approximately 6000 lb at a bulk density (dry unit weight) of 1.25 g/cm<sup>3</sup>.

65. All sampling and drainage nipples were covered with three layers of a fine woven fiberglass cloth to pass solutions while retaining the soil. At the ports along the bottom of the box, the cloth was covered directly with soil. At the lower corner, 1 in. of poorly graded sand was placed across the width to provide drainage to the sub-flow outlets. As the box was filled, the sand was covered with soil and packed by hand.

66. A slit was cut along the lower end of the sod so that the lips of the runoff trays extended 1/2 in. into the sod at 1/2 in. below the surface. At the upslope end,

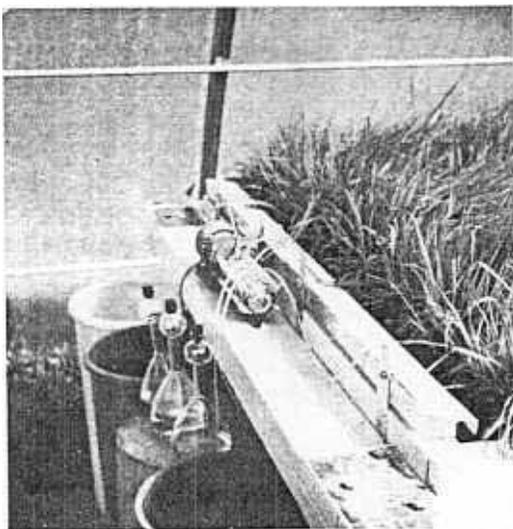


Fig. 2. Peristaltic tube pump

the 3-in. strip that received drip water was left unsodded. The applicator trays were mounted on supports to extend over the bare strip. One peristaltic pump head supplied each applicator tray compartment. Fig. 2 shows the pump setup at the upslope end of the model.

67. The model was maintained for 2 weeks by sprinkling daily with tap water to establish the sod.

Epoxy-coated dividers were installed

down the length of the box to form four 15-in.-wide strips, each serviced by an applicator and runoff tray.

### Treatments

68. The wastewater volume applied in a day was equal to a layer 1/2 in. deep covering the model. This volume was applied over a 6-hr period. Applications were made on 5 consecutive days per week for the first month and on 4 consecutive days a week thereafter.

69. On the first day of sampling, deionized water was applied to check the initial outflow quality. Thereafter, secondarily treated effluent from the treatment plant of a local motel was used. The effluent was picked up on the afternoon previous to or on the morning of application, transported to the model location, and stored in epoxy-coated drums. The effluent was found to be low in nitrogen and heavy metals relative to typical municipal effluent. Nitrogen was added to the effluent at a rate of 13.4 mg/l using reagent-grade ammonium nitrate to give a total nitrogen content of approximately 20 mg/l. The nitrogen addition was increased to 30 mg/l beginning with the twelfth week of application. The heavy metals, cadmium, lead, manganese, and zinc, were added to the effluent at a rate of 0.2 mg/l starting in the fourth week. Copper and nickel were also added at a rate of 0.2 mg/l starting at the end of the sixth week. The heavy metals were added as chlorides with the exception of lead, which was added as an acetate. The motel effluent was high in elements associated with cleaning agents, sodium and phosphorus. Routine analyses of the motel effluent indicated that the composition of the effluent varied considerably during the study period. The motel effluent was disinfected with chlorine at a rate of 4 ppm of chlorine added as calcium hypochlorite.

70. Deionized water was sprinkled over the grass to simulate rainfall between the eight and ninth weeks to prevent excessive drying.

## Sampling and Analysis

71. Samples were taken on each application day from the effluent, runoff, and subflow to analyze for nitrate and ammonia using specific ion (ORION) electrodes. Periodically, other samples were taken for nitrogen analysis by macrochemical methods, including nitrate,<sup>62</sup> ammonia,<sup>63</sup> and total Kjeldahl nitrogen (TKN), i.e., for ammonium plus organic nitrogen.<sup>64</sup> Occasionally, samples were also taken of these waters to analyze for total phosphorus,<sup>65</sup> chemical oxygen demand (COD),<sup>66</sup> and heavy metals and bases, including cadmium, copper, lead, manganese, nickel, zinc, calcium, magnesium, sodium, and potassium by atomic absorption methods.<sup>67</sup> Other characteristics and constituents analyzed in the waters included pH using the glass electrode, electrolytes in solution by electrical conductivity measurements,<sup>68</sup> sulfate,<sup>69</sup> bicarbonate,<sup>70</sup> and chloride using the specific ion (ORION) electrode.

72. Additional samplings of surface water were made down the length of the box, generally at distances of 2.5, 5, 10, and 15 ft, to determine the effects of treatment with increases in distance down the model. Samples were taken for analysis of one or more constituents at 15, 30, 36, 50, 71, and 78 days after the start of the study. One sampling was made of subflow through the ports under the length of the box. Samplings were also made during application on two separate days to determine runoff changes with time.

73. The first grass harvest was 10 days after sod placement and consisted of cutting to a height of 1 in. Second and third harvests were made 48 and 71 days after the start of effluent treatments and consisted of cutting to a height of 4 in. The second and third harvests were made in duplicate, labeled east and west, at distances of 0 to 2.5, 2.5 to 5, 5 to 10, and 10 to 20 ft from the upper end. The cut grass was oven-dried at 60 C and chopped up. A 2-g sample was digested by heating with nitric acid to near dryness, redigested with nitric and perchloric acids, and filtered.<sup>71</sup> Another sample of grass was used for TKN determination. After the wet digestions, the procedures for analyses followed those previously described for water and effluent.

74. Soil samples were taken three times. Separate composite samples were taken from the grass sod and the bulk soil at the time the box was loaded. Next, composite samples were taken the day before effluent treatment was started from the surface to 2-, 2- to 4-, and 4- to 6-in. layers. The third set of soil samples, from the 0- to 1.5-in. depth, were taken 68 days after the start of treatment in duplicate, labeled east and west, at distances from the upper end of 0.5, 2.5, 4.8, 10, 15, and 19.5 ft. Samples from the 1.5- to 3-in. depth were taken at the 0.5-, 2.5-, and 10-ft distances only. The first two samplings were air-dried and pulverized to pass a 10-mesh sieve. The third set was analyzed in the moist condition. All samples were corrected to oven-dry weight. Cation exchange capacity was determined by ammonium saturation, sodium exchange, and distillation.<sup>72</sup> The ammonium acetate extract was used to determine heavy metals and exchangeable bases using the atomic absorption methods.<sup>67</sup> Exchangeable ammonium by distillation and TKN were determined on separate samples. Additional subsamples were digested using a nitric-sulfuric acid mixture in an autoclave at 240 F for 1 hr and filtered, and the filtrates were neutralized. Color was then developed by the stannous chloride method for phosphorus analysis.<sup>65</sup>

75. The runoff and subflow waters were collected and measured for each day of effluent application. The amount of subflow collected over the weekend was added to that for the last previous application day. During the first 4 weeks, runoff and upper subflow were collected individually from the 15-in.-wide strips. For the remainder of the study, waters leaving the box were collected according to the outlet location, east or west of the center line of the box, giving two values each for runoff and subflow. These values and the concentrations were used to calculate quantities of constituents removed in waters from the box.

76. Oxidation-reduction potentials were monitored in the soil system of the model using platinum electrodes and a calomel reference electrode. The 2-mm-long platinum electrodes were precalibrated in a saturated aqueous quinhydrone solution at a pH of 7.0 (25 C) before use, then inserted into the soil along with small wooden supports the

ay before monitoring. Electrode readings were measured on a portable RION Model 407 millivoltmeter by moving the reference electrode to each site and attaching the second lead successively to each platinum electrode. Random locations were sampled in the model at downslope distances of 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 17.5, and 20.0 ft. Two electrodes were placed less than 2 in. apart at each location, one 0.2 in. into the soil surface just under the surface organic layer and the other at a depth of 0.5 in. within the soil. The 16 electrodes were monitored from Thursday through Monday of the twelfth week. The purpose of the measurements was to show the discrete fluctuations that occur during alternating periods of surface saturation and drainage on the model.

## PART IV: RESULTS AND DISCUSSION

### Analyses of Waters

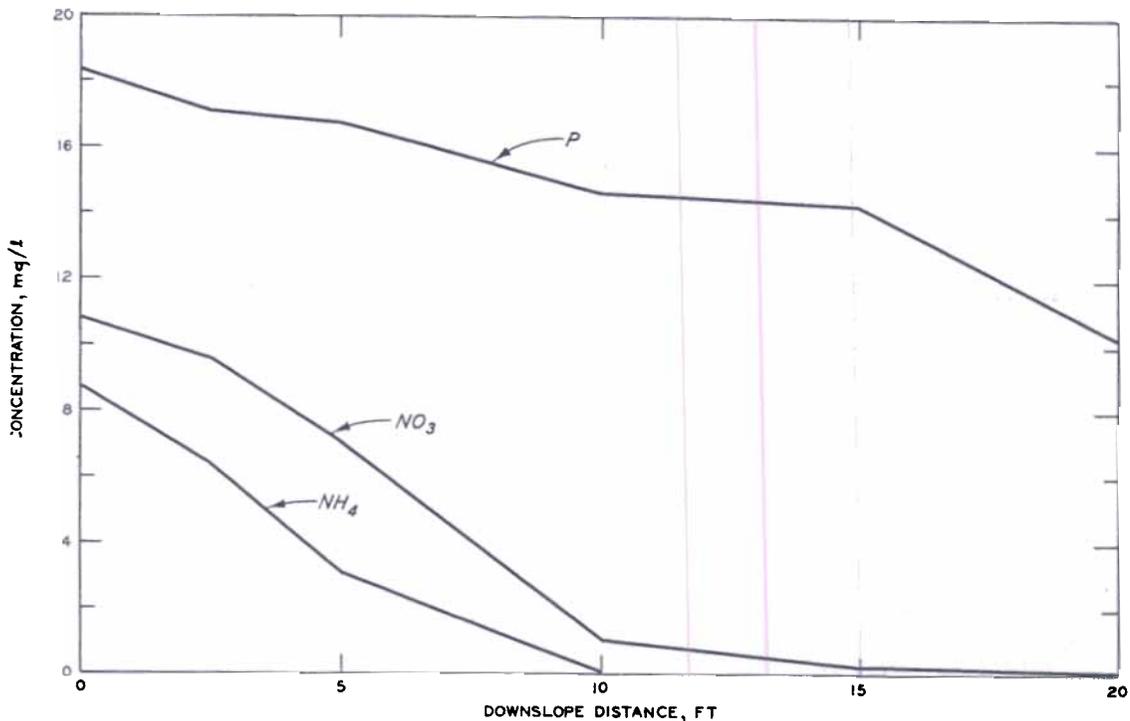
#### Nitrogen compounds and phosphorus

77. Nitrate nitrogen. Since the secondary effluent only contained low concentrations of nitrate nitrogen, it was fortified with 6.7 mg/l of nitrate nitrogen from ammonium nitrate in order to obtain concentrations more commonly found in municipal wastewater. The fortified secondary effluent ranged from 6 to 20 mg/l in nitrate nitrogen concentrations. At the start of the experiment, nitrate concentration in the runoff was 6 mg/l, but it decreased in subsequent weeks to trace levels. Nitrate was detected in the subflow initially but was not found thereafter. Average weekly concentrations of nitrate nitrogen and other elements, etc. are given in table 2. (Average weekly pH values are given in table 3. Daily values of concentrations in applied effluent, runoff, and subflow, representing averages from two samples, are presented in tables A1-A16. Similar values for pH are given in table A17.)

78. The decrease in wastewater nitrate occurred primarily within the upper 10 ft of the model (fig. 3, table A18). The average concentration decreased from 11 mg/l at the upper end of the model, to 1 mg/l at 10 ft, to 0.1 mg/l at 20 ft. For half of the samplings, no nitrate was detected from the lower 10 ft of the model.

79. Percentage mass removal values of various elements in the applied wastewater accounted for volume differences as well as concentration differences. Daily means of the effluent, runoff, and subflow volumes are presented in table A19. The percentage of mass removal of nitrate nitrogen on a weekly basis showed 69, 97, and 100 percent removed from the applied effluent in the first, third, and sixth weeks, respectively (table 4). Runoff essentially accounted for the balance of the nitrate. The subflow had a trace of nitrate for the first 2 weeks, and none thereafter.

80. Ammonium nitrogen. The secondary effluent also contained low



3. Average nitrogen and phosphorus concentrations in surface water flowing over Susquehanna clay

concentrations of ammonium, so it was fortified with 6.7 mg/l of ammonium nitrogen in the form of ammonium nitrate. The applied effluent on a weekly basis ranged from 5 to 14 mg/l in ammonium nitrogen concentration, a value somewhat lower than that for nitrate. Some ammonium was detected in the runoff during the first 2 weeks, but only occasional traces were found thereafter. The subflow had traces of ammonium the first 2 weeks and essentially none thereafter.

81. Ammonium was removed from the solution at a faster rate and over a shorter distance than nitrate. The ammonium nitrogen concentration at 5 ft was 3 mg/l as compared with 7 mg/l for nitrate nitrogen (fig. 3). All ammonium was removed from the wastewater within the first 10 ft of the model surface. Results for the five sampling days were quite consistent, more so than those for nitrate (table A18). After the first week, essentially all of the ammonium was retained in the model (table 4). A fraction of 1 percent was found in the runoff during the first half of the study, but none was found thereafter. After the second week, no ammonium was found in the subflow.

82. TKN. Upon application of the deionized water (week 0),

TKN concentration was measured in the runoff at 0.6 mg/l as compared with a trace or none for nitrate and ammonium nitrogen (table 2). TKN in the runoff reached the same concentration as potassium and was two to three times that of phosphorus, calcium, and magnesium. These proportions suggest that bits of plant tissue or decomposition products therefrom were the primary sources of the constituents in the runoff following application of the deionized water. The subflow had a trace of organic nitrogen following the water treatment.

83. The applied effluent measured about 9 to 16 mg/l in TKN concentration, averaging 3 mg/l greater than that for ammonium nitrogen alone. This difference of 3 mg/l represented the organic nitrogen component, and it varied  $\pm 2$  mg/l from week to week. TKN was reduced to 1.5 to 3.2 mg/l in the runoff, and this concentration was nearly all organic nitrogen since the runoff had practically no ammonium. The subflow had 0.1 to 0.3 mg/l of TKN, which again was mainly in the organic form.

84. The mass distribution of TKN was  $90 \pm 5$  percent retained in the model, 4 to 16 percent carried in the runoff, and less than 1 percent in the subflow (table 4). However, this accounting is considerably changed if the quantity of ammonium is deducted. Then, the retention of organic nitrogen becomes 40 to 80 percent in the model, 20 to 60 percent in the runoff, and 1 to 2 percent of the applied amount of organic nitrogen in the subflow.

85. Phosphorus. The applied effluent contained about 13 mg/l of phosphorus during most of the experiment, but increased to 29 mg/l for the last 2 weeks (table 2). The phosphorus concentration in the runoff was 40 to 60 percent of that of the applied effluent, whereas the subflow generally contained only a trace.

86. Phosphorus concentration in the surface water showed a decrease with distance that was consistent for the sampling days (table A18). The concentration decreased at a fairly uniform and substantial rate amounting to 8 mg/l over 20 ft (fig. 3). However, the average concentration leaving the model at 20 ft was still 10 mg/l.

87. The percentage mass distribution of phosphorus showed that

amounts retained in the model ranged from 62 to 80 percent of that applied (table 4). The balance was lost primarily in runoff. After week 4, essentially no phosphorus was lost in subflow.

88. The model did not remove phosphorus as efficiently as nitrogen from secondary effluent. Apparently, the supply of phosphorus exceeded the demand. The absence of phosphorus in the subflow shows that removal was complete once the effluent entered the soil mass. These results indicate that to improve effluent treatment, a longer model, lush growth throughout, and opportunity for more soil contact may be required.

#### Heavy metals

89. Cadmium, copper, and nickel. The results with cadmium, copper, and nickel added to the wastewater were similar. Prior to the additions, no measurable amounts were found in the applied effluent, runoff, or subflow (table 2). After the fortification began, the metals were present in the applied water but generally were retained in the model.

90. The concentration of cadmium reduced to a trace at 10 ft and generally to zero at 15 and 20 ft (fig. 4). Copper and nickel were

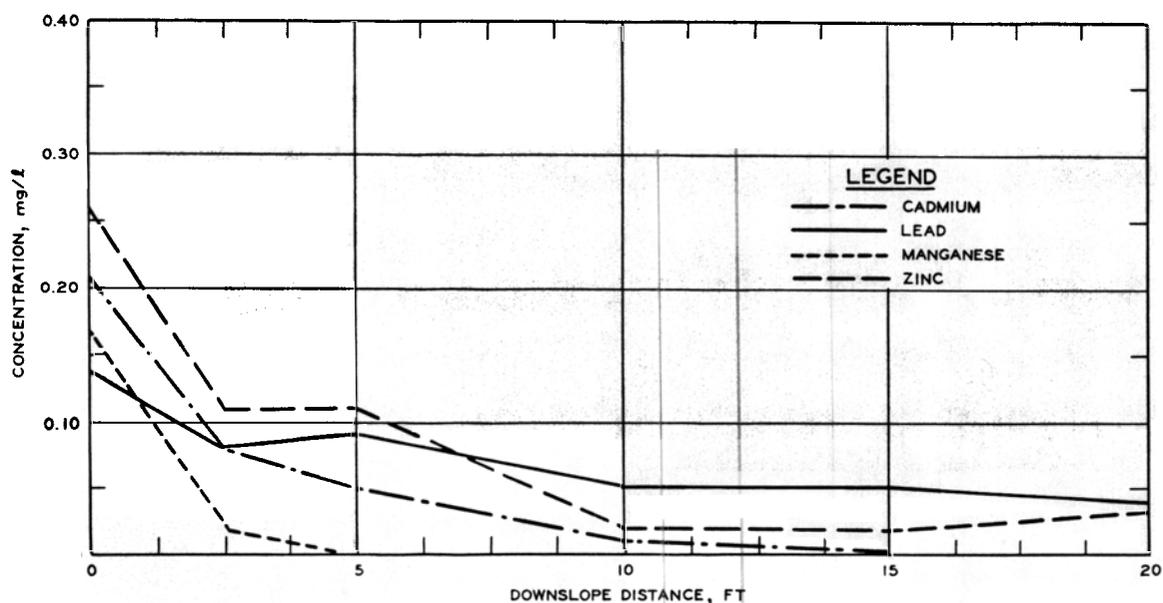


Fig. 4. Heavy-metal concentrations in surface water flowing over Susquehanna clay

removed from the surface water within shorter distances (table A18).

91. The wastewater treatment efficiency of the model for these metals was excellent. The mass removal was essentially complete within 10 ft.

92. Lead. Analyses showed no lead in the applied effluent, runoff, or subflow before lead was added to the wastewater (table 2). After fortification began, lead was generally found in the runoff. It was also detected in the subflow in half the samples at concentrations about half of that in the runoff.

93. The samplings of surface water averaged for four separate days showed removal in the first 10 ft (fig. 4). On 2 days, the concentration of lead at all locations down the model was from half to equal that of the concentration applied (table A18). On the other 2 days, the concentration decreased to zero at 5 ft.

94. The percentage mass distribution of lead showed a variable amount left in the runoff, from 0 to 28 percent, averaging approximately 6 percent (table 5). The quantity in the subflow was considerably less, often zero. These results reflect the analytical difficulty of lead measurements. However, treatment efficiency was good since more than 90 percent of the lead was removed.

95. Manganese. The analysis for manganese showed none present in the runoff or subflow following application of deionized water during week 0 and during subsequent weeks when nonfortified secondary effluent was applied (table 2). Apparently for the first 3 weeks of overland flow treatment, any manganese in the soil remained stable and did not enter into solution. After fortification of the wastewater, manganese was generally zero in the runoff, but was fairly consistent in occurrence in the subflow, from 0.02 to 0.06 mg/l.

96. Manganese left the solution within a shorter distance than other heavy metals (fig. 4). The average concentration of manganese was reduced by 90 percent to 0.02 mg/l at 2.5 ft, and by 100 percent at 5 ft for three of the four samplings (table A18). The amount of manganese leaving the model by subflow was 1 to 3 percent of that applied (table 5). Essentially no manganese was in the runoff (table A8).

97. The distribution of manganese (some in the subflow but none in the runoff) was different from that of the other elements. The oxidized form was removed from the surface water, and possibly the reduced form was carried in the subflow. The appearance of manganese in the subflow coincided with the additions to the effluent. Apparently, the added manganese was more reactive and mobile than the residual soil manganese.

98. Zinc. The pretreatment with deionized water during week 0 evidenced a trace of zinc in the applied deionized water, runoff, and subflow (table 2). In contrast to the other heavy metals, considerable zinc occurred in the nonfortified effluent. Runoff and subflow always contained zinc. Following addition of zinc to the secondary effluent, the concentration of zinc in the runoff did not change, whereas concentration in the subflow increased with passage of time (table 2).

99. Zinc was present in the surface water at all locations in the model (fig. 4, table A18). The concentration was reduced to 40 percent of the initial value at 5 ft down the model and to 10 percent at 10 ft, and remained at this level to 20 ft. The mass percentage of zinc retained in the model was generally near 85 percent (table 5). After the third week, the runoff and subflow values ranged from 0 to 10 percent and 3 to 12 percent, respectively (table 5).

#### Major cations

100. Calcium. Some calcium was found in the applied deionized water and runoff at week 0, but a higher concentration was in the subflow, nearly 31 mg/l (table 2). The calcium concentrations in runoff and subflow followed the change in concentration of applied effluent from week to week indicating little buffer effect for calcium. The calcium concentration in the surface water decreased down the length of the model (fig. 5). More calcium left the model than was added during the first week (table 6). For subsequent weeks, a higher and consistent amount of calcium, ranging from 83 to 94 percent of the amount applied, was retained in the model. The percentage of calcium found in the runoff and subflow varied from 2 to 9 percent and 4 to 12 percent, respectively.

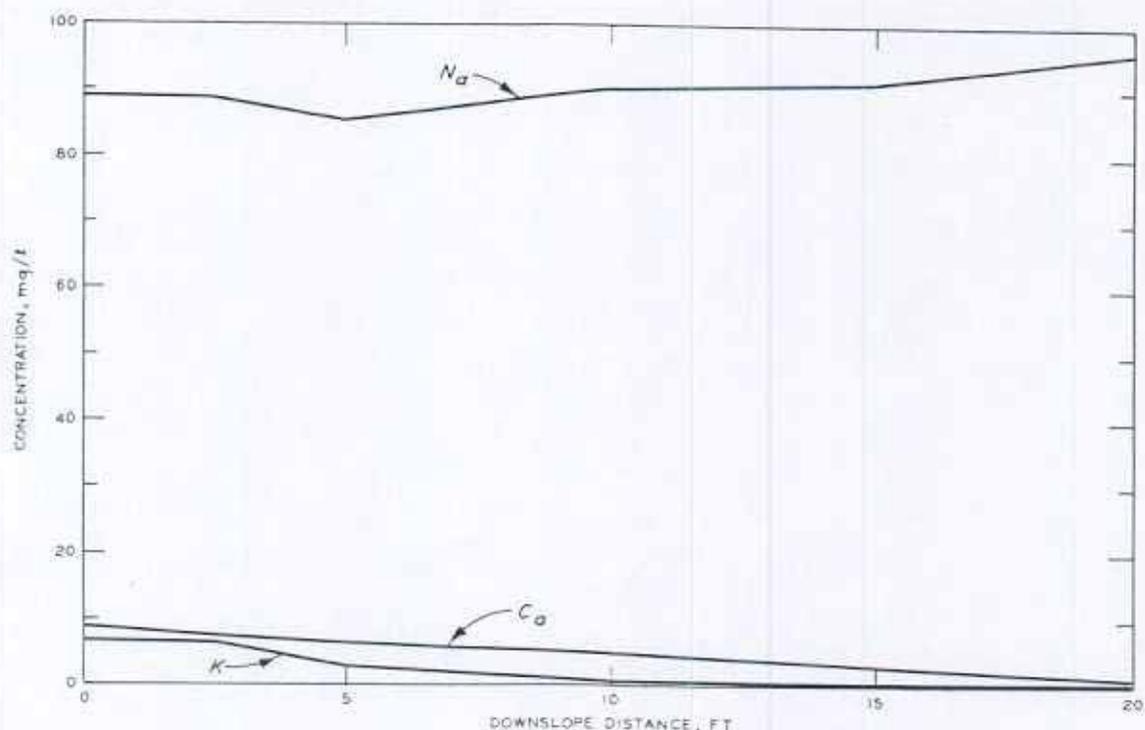


Fig. 5. Average sodium, calcium, and potassium concentrations in surface water flowing over Susquehanna clay

101. Magnesium. The deionized water contained no magnesium, but with application during week 0, the runoff concentration reached 0.4 mg/l. The subflow contained considerably more, 2 mg/l (table 2). This magnesium may have resulted from previous wetting by tap water or from magnesium leaching from the soil. Magnesium concentration was lower in the runoff than in the subflow. The magnesium concentration in surface water decreased down the length of the model, similar to that for calcium but with lower values (table A18). Over the test period, a smaller proportion of applied magnesium was retained by the model than calcium (table 6).

102. Sodium. The sodium concentration in the applied effluent ranged from 70 to 100 mg/l, roughly three times the total concentration of all other cations (table 2). The concentration of sodium in the runoff during week 3 was 15 percent less than that in the applied effluent. As the test progressed, the concentration increased in the runoff until it equaled and exceeded the applied sodium. Apparently, the

evapotranspiration loss of water resulted in a concentration that more than offset any usage of sodium. Although half the sodium entered the soil, the subflow concentration was only a tenth of that applied. Sodium exchanged with hydrogen on the clay, as evidenced by the low pH of the subflow. The subflow showed a regular increase in sodium concentration during the course of the study.

103. The average concentrations of sodium in surface water exhibited some increase with distance down the model, perhaps the progressive influence of evapotranspiration (fig. 5). The percentage mass distribution of applied sodium was 50 percent retained in the model and 50 percent lost in runoff (table 6). This distribution persisted throughout the study. Only 1 to 2 percent of the sodium was lost in the subflow.

104. Potassium. Some potassium was found in the applied deionized water at week 0, and even more was found in the runoff and subflow (table 2). The applied secondary effluent contained concentrations of potassium approaching those of calcium but higher than those of magnesium. Concentrations in the runoff were reduced to about 0.1 mg/l, a value much lower than that of other major cations and approaching the concentration of zinc in the runoff. The subflow potassium concentration was about 0.3 mg/l, three times higher than that in the runoff after week 4.

105. The potassium concentration in surface water collected down the model decreased with distance (fig. 5). There was a marked decrease at 5 ft, and the concentration remained low from 10 to 20 ft.

106. The percentage mass distribution showed that 95 to 99 percent of the applied potassium remained in the model (table 6). From 0.2 to 4 percent of the applied potassium was contained in the runoff, and generally less than 1 percent was contained in the subflow.

#### Other constituents

107. COD. The COD of the applied effluent ranged from 20 to 45 mg/l (table 2). The COD concentration was 20 to 50 percent greater in the runoff than in the applied effluent, ranging from 23 to 62 mg/l. As with sodium, water was apparently lost from the model by

evapotranspiration at a greater rate than the COD was lowered, resulting in a concentration increase as the water moved down the model. The concentration in the subflow was about  $3 \pm 2$  mg/l. This was much greater than the concentrations for phosphorus and nitrogen compounds, and approached those for calcium and magnesium. Reduced inorganic elements may have accounted for some of the subflow COD.

108. The percentage mass distribution of COD material showed that from 33 to 50 percent was generally retained in the model (table 7). The runoff contained the major portion of the applied COD material. The subflow contained 0 to 3 percent.

109. Electrolyte. The electrolyte concentration was 2 mg/l in the deionized water applied at week 0 (table 2). With application of deionized water, the runoff contained 14 mg/l of electrolyte while the subflow contained 38 mg/l. These values follow the determinations for individual elements and reflect the high concentration of calcium in the subflow. The effluent contained 300 to 450 mg/l. The runoff showed an increase of electrolyte concentration with time, from 113 to 363 mg/l, for which sodium would be the major source. The subflow likewise showed an increase with time, from 38 to 132 mg/l, with sodium, calcium, and magnesium as the principal sources.

110. The concentration of electrolyte in the surface water decreased with distance down the model (table A18). The overall reduction from 0 to 20 ft was about 100 mg/l for each trial, indicating a consistent reduction in surface water concentration.

111. The amount of applied electrolyte retained in the model was generally near 65 percent (table 7). The runoff carried about 32 percent, and the subflow carried nearly 3 percent throughout the test.

112. pH. The pH of the deionized water was 5.8 (table 3). The runoff from the deionized water application had a pH of 5.1, and the subflow had a pH of 6.0. The effluent was neutral with a pH near 7.0. Following initial treatment, the pH of the runoff was slightly acid, near 6.0, but rose to 7.0 in 5 weeks to match the applied effluent. The pH of the subflow started near 6.0 and decreased to 5.4 during the course of the test. The pH in the surface water collected down the

model varied randomly by distance and among samplings, but stayed near 7.0, the value for the applied effluent (table A20).

### Analyses of Grass

113. In the water analyses, the percentage mass distribution of elements that had been applied to the model accounted for the percentage removed in runoff and in subflow and that retained in the model. One important redistribution of elements in the model was the absorption and uptake by vegetation and the subsequent removal by harvesting the grass. Analyses for elements removed in grass harvested from the model are considered in this section.

#### Yield of dry grass and nitrogen and phosphorus analyses

114. The yield data represent sums for the two parcels across the 5-ft width of the model. The lower half of the model grew less grass than the upper half considering combined harvests (table 8). The yield of grass was reduced at the day 72 harvest for the 0- to 2.5-ft parcel mainly because of bare spots resulting from death of the grass caused by a fungus.

115. The TKN concentration for the pretest harvest was 23 mg/g (table 8), an expected value for grass.<sup>73</sup> Averages of 2 samples are listed in table 8. The harvest at day 49 after 31 applications of effluent fortified with nitrogen showed a slight increase of TKN concentration in the grass from the upper 10 ft of the model and a decrease in the lower half. With the harvest at day 72, the TKN concentration in the grass increased even more in the upper 10 ft and decreased more in the lower 10 ft (table 8). The continued nitrogen reduction and lower yield of grass in the lower 10 ft of the model indicate a nitrogen deficiency in the grass. The progress of grass growth is shown in figs 6-11.

116. Phosphorus concentration in the pretest harvest was 6 mg/g (table 8). The level tended to be slightly less for the balance of the study showing no difference by location on the model or by harvest. The

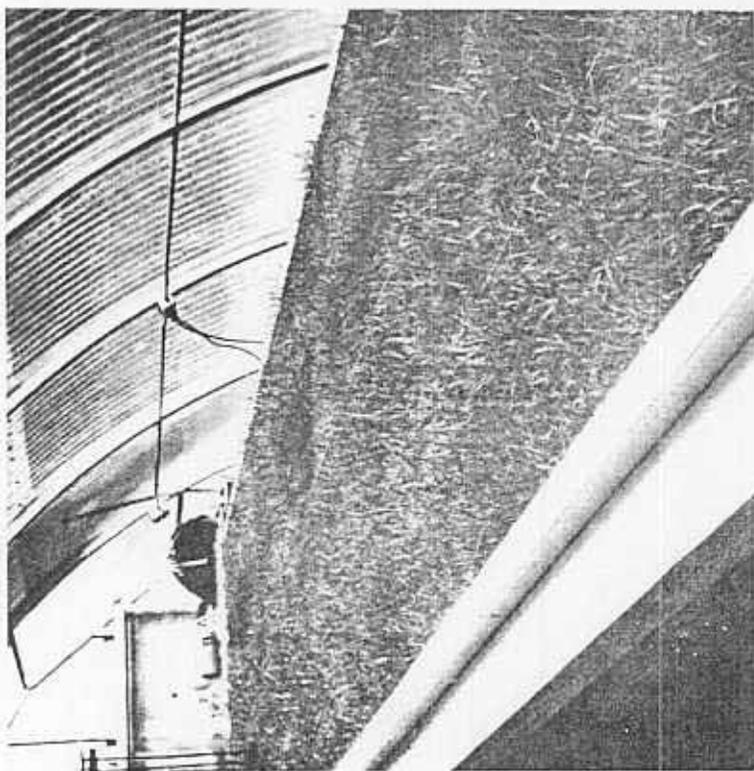


Fig. 6. 23 Feb 73: Wastewater model 1 day after first application of secondary effluent. Grass height remained uniform throughout model for 12 days after pretest harvest

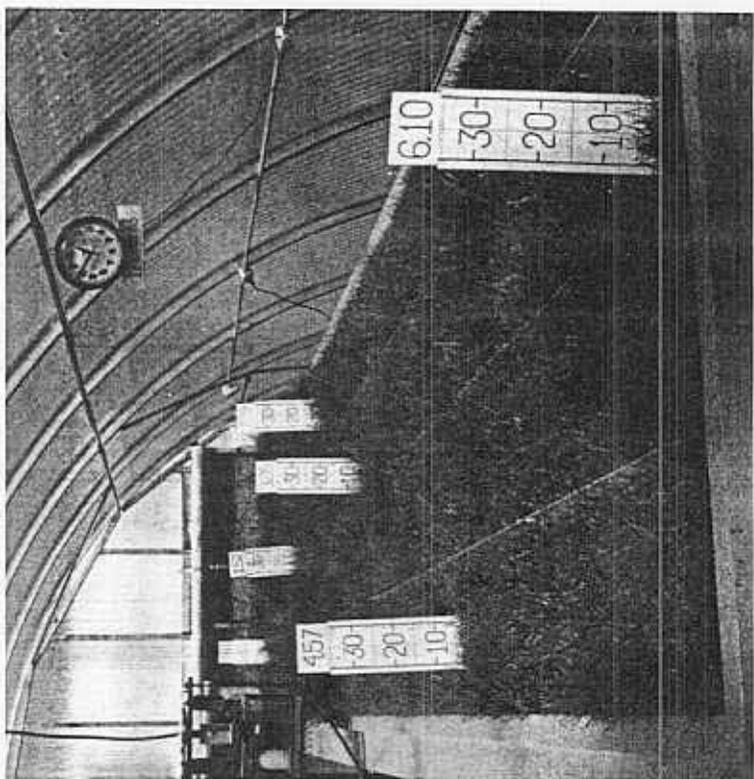


Fig. 7. 12 Mar 73: Wastewater model 19 days after start of treatment. Grass height reached 10 to 20 cm in upper 5 ft (1.52 m)

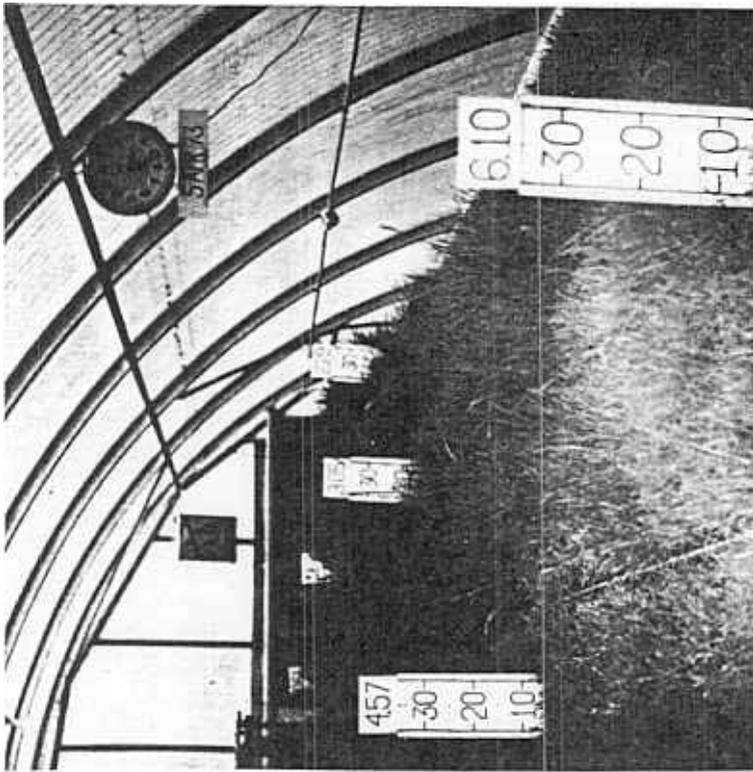


Fig. 8. 5 Apr 73: Wastewater model 43 days after start of treatment. Grass height reached no increase in height and zero nitrogen content in surface water beyond 15 ft (4.57 m)

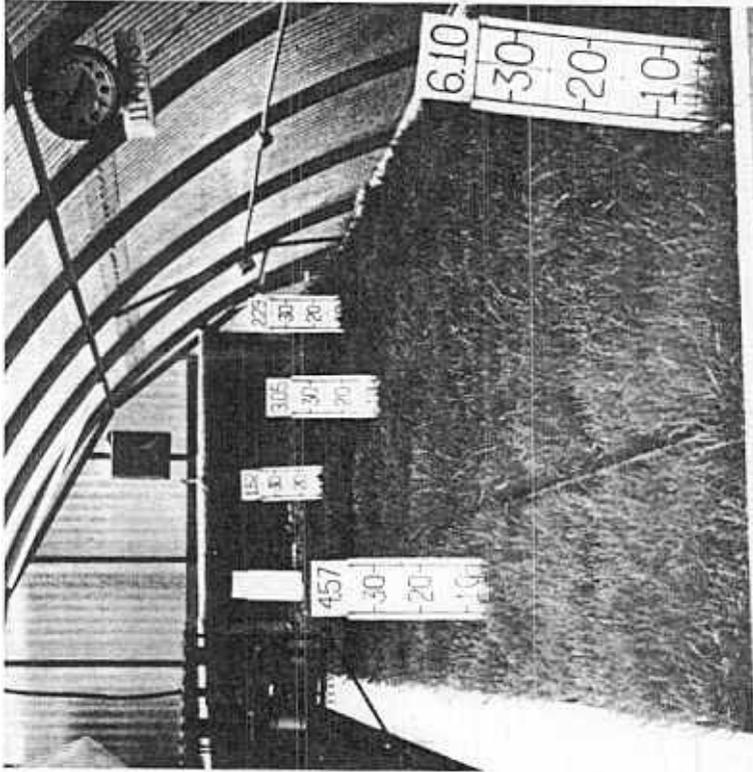


Fig. 9. 11 Apr 73: Wastewater model 49 days after start of treatment. Grass was cut to 10 cm for first treatment harvest on previous day

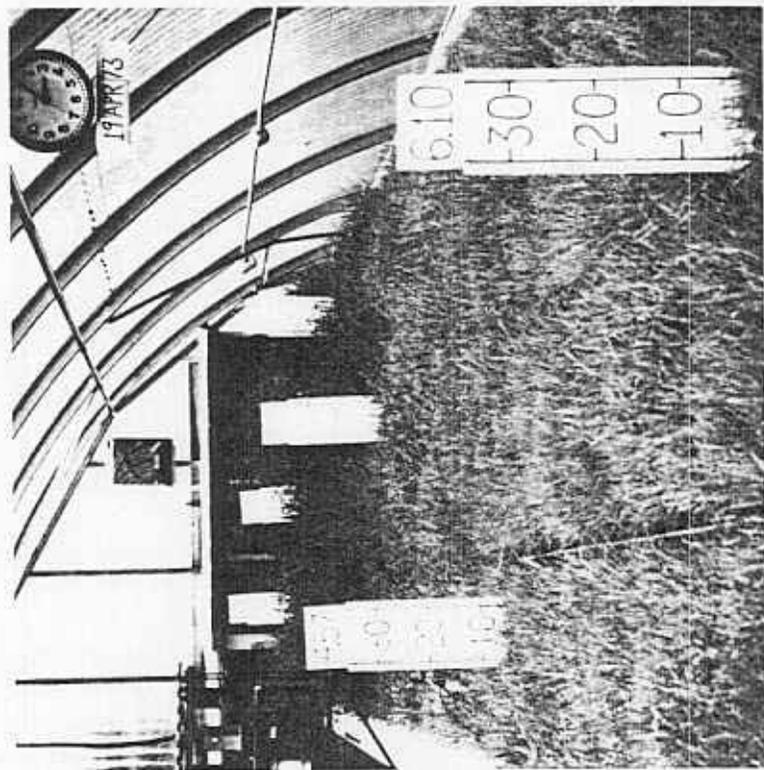


Fig. 10. 19 Apr 73: Wastewater model 9 days after first treatment harvest. Grass height reached 20 cm in upper 7.5 ft (2.29 m); practically no increase in height and zero nitrogen content in surface water beyond 10 ft (3.05 m)

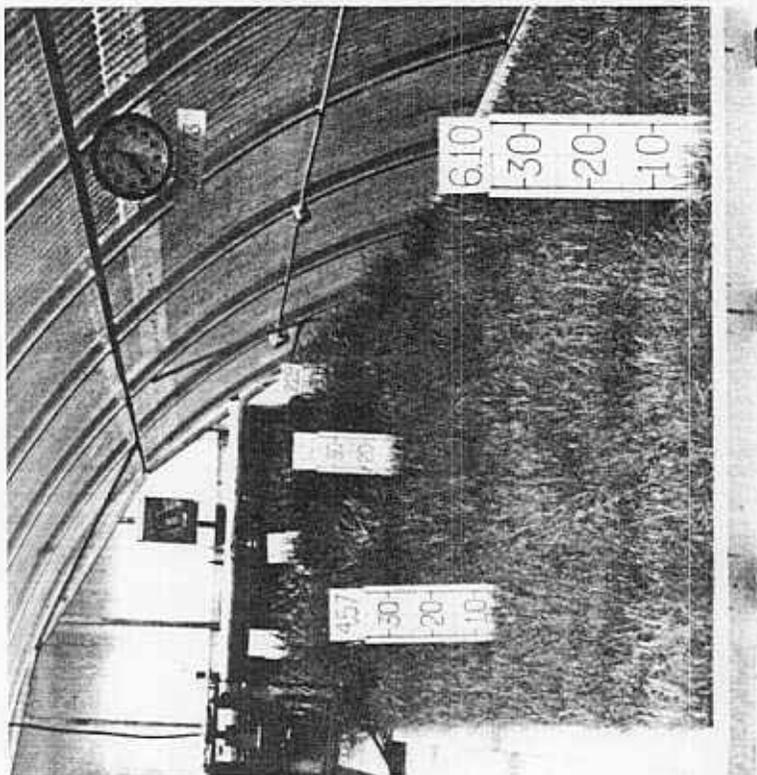


Fig. 11. 3 May 73: Wastewater model 23 days after first treatment harvest. Grass height reached 30 cm in upper 7.5 ft (2.29 m); practically no increase in height and zero nitrogen content in surface water beyond 10 ft (3.05 m)

phosphorus content of the grass was at an adequate level throughout the study.<sup>73</sup>

#### Heavy metals

117. The analysis of grass harvested before treatment started showed (according to Chapman)<sup>73</sup> no cadmium or nickel, normal concentrations for copper and lead, and high but nontoxic concentrations for manganese and zinc (table 8).

118. Applications of effluent fortified only with nitrogen were made for 21 days. Then, the effluent was fortified additionally with cadmium, lead, manganese, and zinc. Addition of copper and nickel was begun 18 days later. The first four heavy metals were applied 18 times, and the last two metals were applied 7 times before the harvest at day 49. Very little nickel was absorbed by the grass, but considerable copper was absorbed throughout the length of the model (table 8). Cadmium was absorbed by the grass in the upper few feet, and little was absorbed farther down the model. Lead and manganese concentrations in the grass tended to be lower during this growth period compared with that before the start of effluent treatment. The zinc concentration in the grass increased 50 to 100 percent.

119. The grass was harvested again at day 72 after 13 more applications of the fully fortified effluent. By this time, the cadmium concentration had increased from 3 to 10 times in the midpart of the model (table 8). Copper increased 50 to 100 percent. Lead concentration increased from 2 to 4 times in the upper half. The manganese concentration showed little change. The nickel concentration increased drastically from a trace to 20 mg/kg and more in the grass grown in the upper half of the model. Zinc concentration also increased moderately in the grass grown on each parcel down the length of the model. A large and consistent drop in concentration was noted for all heavy metals in the grass from the lower half of the model. There was more copper and nickel taken up in the grass at the day 72 than at the day 49 harvest. The heavy-metal content of the grass at the day 72 harvest indicated a buildup of cadmium, lead, nickel, and zinc in the first 10 ft of the model.

### Major cations

120. The concentrations of major cations in the pretest harvest had expected levels for grass with 1-, 2-, and 24-mg/g concentrations for calcium, magnesium, and potassium, respectively (table 8).<sup>73</sup> There was a higher calcium concentration in the grass at the lower half of the model at the day 49 and day 72 harvests. There were also higher concentrations of magnesium and sodium in the grass harvested at day 72 as compared with that harvested at day 49. Potassium content of the grass decreased at day 49 and further decreased at day 72. The grass in the lower 10 ft of the model had a 8.85-mg/g concentration of potassium, which is approaching a deficiency level for grass.<sup>73</sup>

### Quantities of elements removed in grass

121. The quantities of elements removed in grass reflect the amount of grass harvested as well as the concentration of elements in the grass previously presented. At day 49, nearly half of all elements removed in the grass were taken in the first 2.5 ft, and about one-fourth were found in the next 2.5 ft (table 9). Less than 5 percent of the harvested elements were removed from the lower half of the model.

122. At day 72, less than 1 percent of the removal of major elements and heavy metals occurred beyond the first 10 ft of the model. The lower 10 ft of the model was not utilized for element removal by vegetation. The growth of grass in this part of the model appeared to be suffering from nitrogen and potassium deficiencies, and without growth, the grass was ineffective in removing large amounts of elements.

### Analyses of Soils

#### Nitrogen, phosphorus, and cation exchange capacity

123. Nitrogen in the soil was determined as organic-ammonium nitrogen by a Kjeldahl digestion (TKN) and as exchangeable ammonium. The day 0 TKN values ranged from 2.5 to 3.9 meq/100 g of soil (table 10). At day 69, the TKN values ranged from 3.0 to 4.3 meq/100 g, with a

value of 5.6 at the area of application. The variable data indicate an increase in the top layer of the upper end of the model that was balanced by decreases at the lower end and in the second layer. The exchangeable ammonium initially tested at 0.2 to 0.3 meq/100 g in the surface layer and decreased some by the end of the test period. The second layer also indicated a decrease following the treatment period. The overall results indicate no net change of soil nitrogen in the model.

124. Initial phosphorus values were 0.1 to 0.2 meq/100 g of soil, whereas after treatment the values were generally greater than 0.5 meq/100 g, particularly at the upper end of the model (table 10). There were no significant differences among locations at day 69 for phosphorus or nitrogen values.

125. Cation exchange capacity apparently did not change before or after effluent treatment (table 10). The average was 25 meq/100 g of soil.

#### Heavy metals

126. Analyses of soil collected in bulk during preparation of the model showed some zinc but no trace of other heavy metals including cadmium, copper, lead, manganese, and nickel (table 10). The next samples, taken after three applications of tap water by overland flow but preceding the first application of effluent, showed manganese as well as zinc in all layers (table 10). No traces of the other four heavy metals were detected.

127. At day 69 of treatments, manganese was found at all locations at the same concentration as that before effluent application. Zinc was found at most locations and showed a significant increase in the lower layer near the application end of the model (table 10). A trace of cadmium was found at this location in the top layer. No traces of other heavy metals were found in the extracts.

#### Major cations

128. Calcium was determined to be 3 to 4 meq/100 g of soil before treatment with effluent, and the analyses after treatment showed generally higher than 4 meq/100 g (table 10). The area of application

reached 7 meq/100 g of soil. Magnesium tested higher than calcium initially, at 4.5 meq/100 g. Extracted magnesium tended to increase slightly in the area of application at day 69. Potassium initially tested at 0.38 meq/100 g, and at day 69 values tended to be lower in both layers. However, means of the duplicates collected at day 69 showed no probable difference by location within either layer for extractable calcium, magnesium, or potassium.

Oxidation-reduction potential at soil surface

129. The oxidation-reduction measurements made over a 5-day period that encompassed a wetting-drying cycle showed that conditions favoring denitrification occurred (fig. 12, tables A21 and A22). The horizontal line at +320 mv in fig. 12 represents the potential at which nitrate instability occurs and denitrification can begin with soil at a pH of 5 and a temperature of 25 C.<sup>13,15</sup> The redox potential of the soil at a depth of 5 mm was in the denitrifying range during the

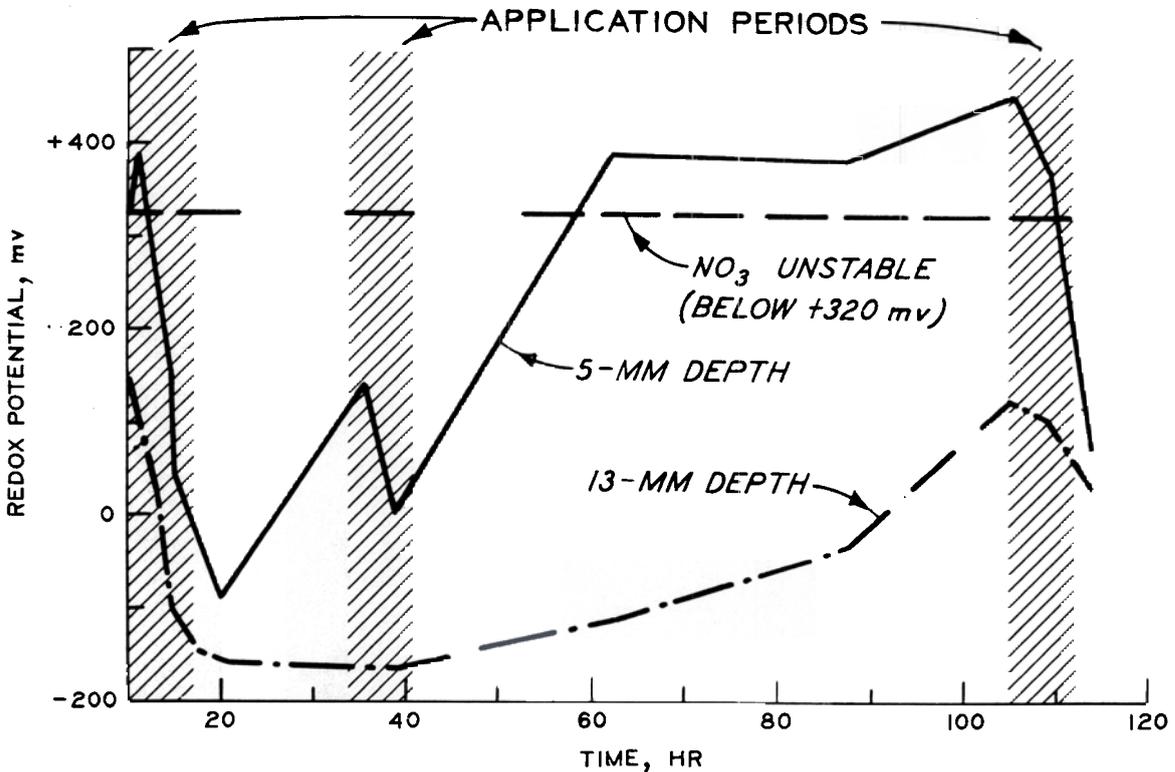


Fig. 12. Redox potential of the Susquehanna clay during a wastewater application-drying cycle

wetting period but in the nitrifying range during the weekend drying period. The redox potential at the 5-mm depth declined into the denitrifying range in only a few hours after wastewater application was initiated following the 2-day drying period. The redox potential at the 13-mm depth did not increase to +320 mv after the 2-day drying period. The accuracy of these redox curves is supported by similar results in two other experiments, one with soil from a cannery overland flow treatment site and the other with clay soil as used in this study but mixed with sewage sludge.<sup>74</sup>

### Discussion

130. An account of the wastewater constituents applied and removed during the study period measures the effectiveness of the overland flow method of disposal. This account was derived from results presented in the previous sections and is presented here in order to give an overall summary of the study period.

#### Nitrogen

131. Nitrogen from all sources was applied at the rate of 113 kg/ha of which 92 percent was retained in the model (tables 11 and A23). Losses were only 9 percent organic nitrogen and 5 percent nitrate nitrogen in the runoff and essentially none in the subflow (table 11). Ammonium nitrogen retention in the model was nearly 100 percent (table 11). The grass harvests contained 35 kg/ha, 56.5 percent of the TKN. The unaccounted TKN and nitrate nitrogen, 69 kg/ha, may have been bound in the grass roots and stubble, located in the increased biological population of the soil, or lost as gaseous nitrogen following denitrification. The redox potential measurements indicate that denitrification could have been occurring continuously during the study period.

#### Hypothesis of nitrogen loss by denitrification

132. The model was operated for 4 days and allowed to dry for 3 days during most of the experiment, thus providing an additional

drying day compared with the period for the redox test. Hence, a layer deeper than 5 mm may have passed into the aerobic state during the usual weekend drying period. Conditions for nitrification could have developed. Any nitrate formed during this period would have been subjected to denitrification when it diffused downward to the anaerobic zone during the drying period or when wastewater was reapplied. Denitrification was suggested as a major mechanism in the loss of nitrogen from cannery wastewaters at the Campbell Soup Company's Paris, Texas, plant.<sup>75</sup>

133. The hypothesis for gaseous loss of nitrogen with overland flow treatment has similarity to the hypothesized system in flooded rice fields. As shown in figs. 13 and 14, a rice field normally has an aerobic-anaerobic double layer that functions to the detriment of the farmer by converting ammonium to nitrate in the aerobic layer and denitrifying it in the anaerobic layer, thus causing a loss of nitrogen fertilizer into the atmosphere as nitrogen gas.<sup>10</sup> It is believed that the overland flow system would be even more effective in eliciting the gaseous loss of nitrogen, because most rice fields are kept flooded rather than cycled with flooding and drying periods. As a result, nitrate is only formed in the aerobic portion of the double layer in rice fields and must diffuse into the denitrifying zone. In the cycled overland flow system, the surface aerobic layer increases in depth during the dry periods, and the nitrate formed during this time is subject to denitrification upon wastewater application. It should be recognized, however, that the results of this study only show that, for a relatively short period, a very high degree of nitrogen treatment was achieved by overland flow on a clay soil. The proof of mechanisms and establishment of criteria for design and operation of such systems must await further study.

#### Phosphorus

134. Less phosphorus than nitrogen was added in the effluent, but three times more phosphorus was lost in the runoff. The subflow contained little phosphorus. The model retained 75 percent of the 86 kg/ha of applied phosphorus (table 11), and the grass removed 5.5 kg/ha of

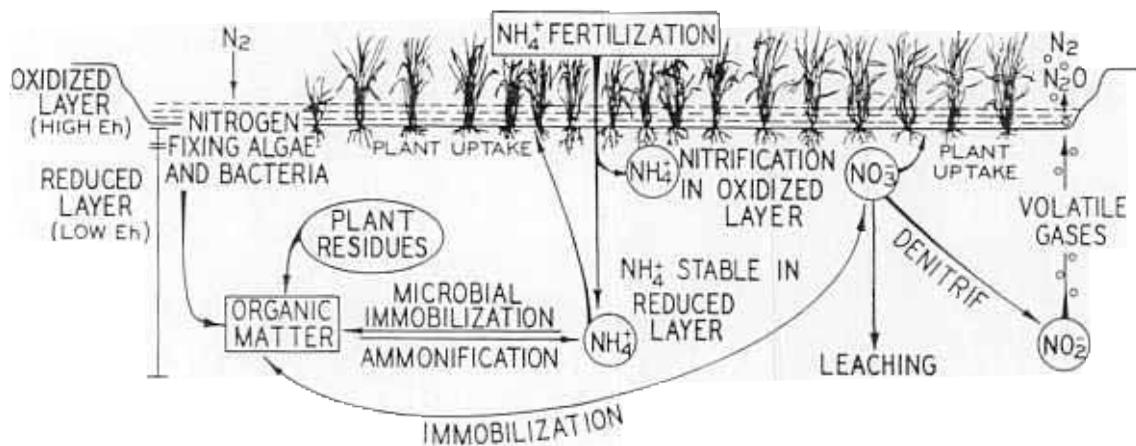


Fig. 13. Nitrogen transformations in flooded soils (after Patrick and Mikkelsen<sup>10</sup>)

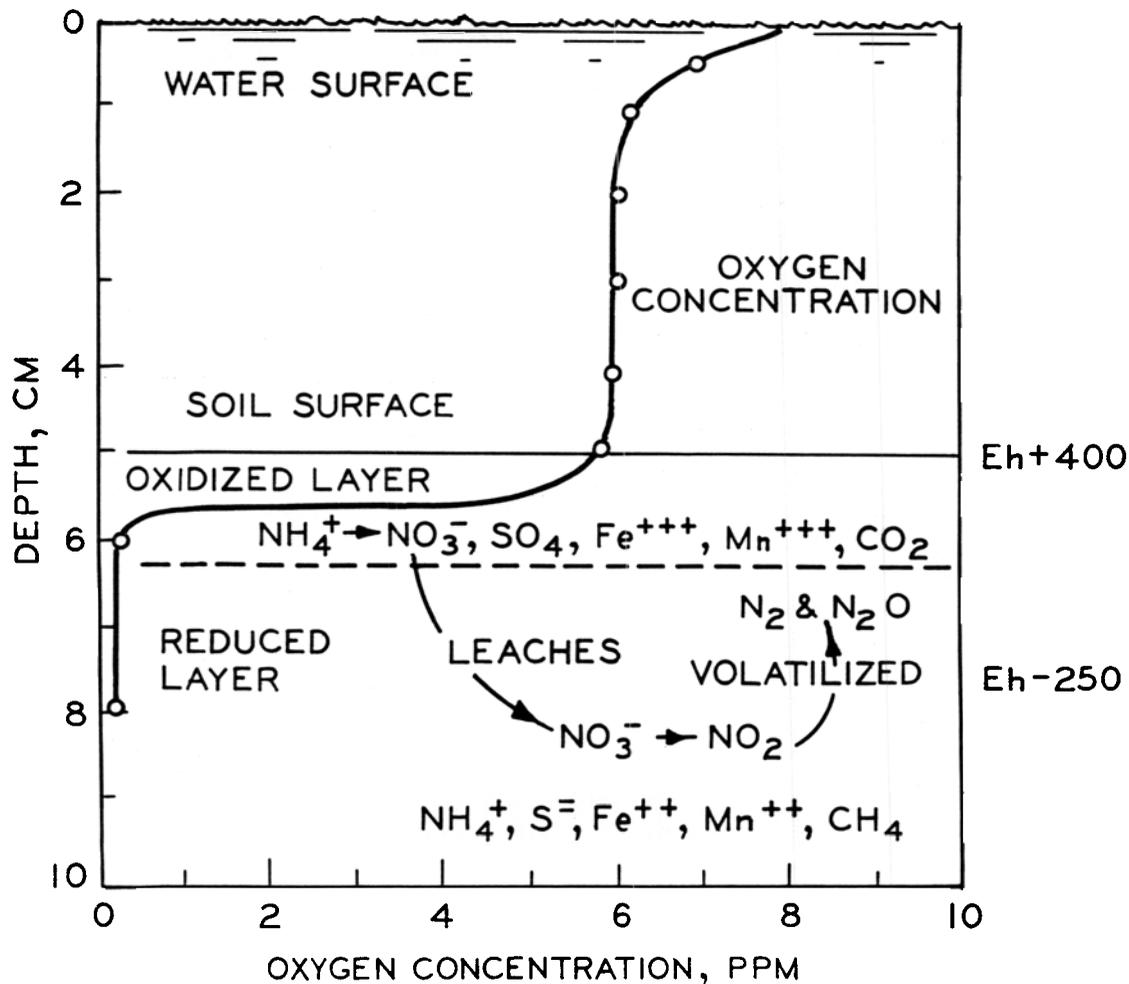


Fig. 14. Oxygen profile in flooded soil (after Patrick and Mikkelsen<sup>10</sup>)

the applied phosphorus (table A23). Phosphorus was used by the grass, but the supply apparently was more than the grass could take up. Based on results of other studies,<sup>13,24,26,38</sup> phosphorus found in the runoff water could be attributed to the hydrolysis and reduction of aluminum and iron phosphates at the soil surface. However, the clay soil used in the model contained sufficient aluminum and iron for fixation of considerably more than the applied phosphorus, indicating that the limiting factor was lack of soil contact. The extractable soil phosphorus increased, accounting for 10 percent of that applied. The strongly fixed or unaccounted phosphorus was 58 percent of that applied.

#### Heavy metals

135. Overland flow treatment of wastewater was very effective in removing heavy-metal constituents. The percentages of copper, nickel, cadmium, manganese, lead, and zinc removed from wastewater by flowing the wastewater over a grass-covered soil system were 100.0, 98.3, 98.1, 98.0, 91.4, and 71.8 percent, respectively (table 11). The most mobile heavy metal in the wastewater was zinc. As much as 22.3 and 5.9 percent of the applied zinc were found in the runoff and subflow water, respectively (table 11). Lead was also more mobile than the other heavy metals, with 8 and 0.6 percent of the applied lead appearing in the runoff and subflow waters, respectively.

136. The largest proportions of the heavy metals applied in wastewater were fixed in the soil within 10 ft from the point of effluent application. The use of grass on the soil was effective in removing small proportions of the cadmium, copper, lead, manganese, nickel, and zinc applied in the effluent. While the applied manganese appeared to be removed from the wastewater within 5 ft of the point of application, the grass took up small amounts along the entire length of the model, indicating uptake from the soil. These results indicate a great potential in the use of overland flow treatment of wastewater.

#### Major cations and other constituents

137. While overland flow treatment of wastewater was very effective in removing potassium applied in the wastewater, removal of

effluent sodium was less effective. The grass-covered soil model retained 96 percent of the applied potassium but only 50 percent of the applied sodium (table 11).

138. The percentage distribution of electrolytes follows trends observed for the combined major cations, with 67 percent of the applied electrolytes retained in the model.

139. The concentration of COD materials was unexpectedly high in the runoff at 91 kg/ha, 57 percent of that applied (tables 11 and A23). Small amounts also appeared in the subflow. Decomposition products from the grass and microorganisms could contribute to the high loss from the model. Reduced inorganic elements may have been the COD material measured in the subflow.

#### Retention of elements in the model

140. Following overland flow application of wastewater, most elements were retained in the model. Part of the elements absorbed by the vegetation was removed in the harvest. The balance was held by the soil. The reference to soil here includes the biological population and the root system and stubble of the vegetation as well as the mineral particles and humus. The retention may be transitory and represents the difference between removals from solution by exchange reactions, adsorptions, flocculations, etc., and the continuous dissolution and exchange in the mineral and humus fractions. Transitions also occur between the absorption by roots and organisms and the excretion or decomposition of products of these life forms. More permanent retentions may occur by precipitations of insoluble forms, coatings, occlusions, interlattice substitution, or other immobile forms. However, the capacity for retention may be limited.

141. The mechanisms and permanence of the soil fixation and retention of elements have not been determined as of this interim report. Yet, this knowledge must be gained so that long-term operational feasibility and performance criteria can be evaluated. Leeper<sup>76</sup> and Murrmann and Koutz<sup>77</sup> reviewed the reactions and chemical processes in diverse soils and indicated that there was insufficient knowledge of reversion from adsorbed or exchangeable forms to the less soluble precipitates.

The results herein show almost complete removal of elements after waters pass through short distances of the soil mass into subflow. However, it is not known to what extent the elements are retained in organic forms in the surface layer, which increased significantly in amounts of microorganisms, roots, and stubble during the study period. The organic forms would not be immobilized for as long a time as that in the soil. Studies are required with detailed sampling and analyses of the surface organic and mineral layers in order to locate and define fixations and to determine duration and quantity of removals before saturation occurs.

#### Removal by grass

142. The vegetation is a major mechanism for treatment of effluent in the overland flow system. The treatment is selective: some elements are absorbed more than others, and the selectivity can differ by plant species. At the same time, a balance of essential elements is required for growth. If one required element is deficient, growth will diminish, and treatment efficiency for other elements will decrease. On the other hand, if an element is excessive and toxic to plants, reduction in growth and in treatment efficiency for other elements can occur. Even the essential elements can be toxic at high concentrations. A balance in essential element supply from soil and from applied effluent must be provided to obtain maximum treatment of wastewater by vegetation. Since the model was not utilized fully in the growth of grass (the upper half accounted for 97 percent of the grass harvest), the element composition was studied for model efficiency improvement.

143. The luxuriant growth in the upper half of the model evidenced no deficiencies and no toxicities. The sparse yellow-green growth in the lower half of the model indicated a deficiency. The analyses of surface waters at the 10-ft sampling location showed that 95 percent of both nitrogen and potassium were removed, whereas more than half the content of the other major elements (phosphorus, calcium, and magnesium) remained in solution halfway down the model. Analyses of grass revealed a sharp drop in nitrogen and potassium concentrations in the lower half of the model, amounting to 50 percent in the last harvest. These

reduced levels in the lower half of the model, 1.5 percent nitrogen and 0.9 percent potassium, were at reported deficiency levels for many grasses and cereals.<sup>73</sup> Since 60 percent of the applied potassium was absorbed by the grass in the upper half of the model, obviously additional potassium is required to provide growth in the lower half of the model equal to that in the upper half. Soil analyses showed that the exchangeable potassium was already being depleted; hence, the soil cannot supply the deficit. The required potassium must be added to enable the grass to improve treatment efficiency for phosphorus and heavy metals in the lower half of the model.

144. Since only 30 percent of the applied nitrogen was absorbed by the grass, a sufficiency for the entire model may be surmised. Yet the analyses of surface water and grass in the lower half showed removal to a deficiency level. The greater immobilization of nitrogen, compared with potassium in the upper half of the model, indicates that a specific process for nitrogen such as denitrification may be operating at a high rate. The results show that the model was half utilized for nitrogen treatment and also that the nitrogen and potassium loads must be increased in order to increase removal of phosphorus and other elements from surface water in the lower half of the model.

145. Analyses indicated no heavy metal at toxic levels in the grass, although most of those applied were retained in the model. The sodium concentration in grass significantly increased with successive harvests to 0.8 percent, which approaches a toxic level as reported for many grasses and cereals.<sup>73</sup> The applied effluent had a sodium-adsorption ratio of 4.8 and a conductivity of 550  $\mu\text{mhos/cm}$ , which is a water with a low sodium hazard-medium salinity hazard according to the U. S. Salinity Laboratory.<sup>68</sup> Such water can be used on all soils without deleterious sodium effects on soil structure but would require moderate leaching to remove accumulating salts. Sensitive plants may suffer sodium injury. No injury of grasses was observed, but the model accumulated salts during the 81-day test period amounting to 34, 14, and 246 kg/ha for calcium, magnesium, and sodium, respectively. Periodic applications of deionized water are advised to flush sodium and other

salts from the model. The water would simulate rainfall under field conditions.

#### Comparison with sludge-treated soil

146. A second experiment was conducted concurrently with the one reported herein to test the use of sludge from primary treatment in addition to secondary effluent.<sup>74</sup> Primary sewage sludge from a municipal trickling filter plant was mixed in the top inch of soil at the rate of 24 metric tons/ha on a dry weight basis. A grass mixture was seeded to the sludge-treated soil of the 5- by 10-ft, 2 percent sloped model. Model preparation, soil, grass seed, and secondary effluent composition and application were identical with those of the 20-ft model described in this report.

147. The two models performed similarly for the treatment of applied effluent. Both models exhibited a lag in treatment efficiency during the first weeks.

148. After the fourth week, 95 percent of the nitrate and 100 percent of the ammonium were removed from surface water at 10 ft down the slope for both models. The grass from the 10-ft model with sludge had 1.8 percent nitrogen compared with 2.9 percent in the upper 10 ft of the 20-ft model. This lower nitrogen content may evidence competition for nitrogen between grass and sludge decomposition, or it may reflect a later growth stage at harvest. Although a composition difference existed, both models removed 30 percent of the applied nitrogen in the grass. Further indication of equal performance was shown by both models having nearly 60 percent of the nitrogen remaining fixed, immobilized in organisms, or denitrified. Additionally, 60 and 67 percent removals of phosphorus from surface water after flowing 10 ft were found in the 20-ft model and in the sludge-treated model, respectively. Both models removed from 90 to 100 percent of the applied cadmium, copper, lead, manganese, and nickel from surface waters by 10 ft. Removal of zinc in the runoff was only 75 percent for the sludge-treated model compared with 92 percent for the 20-ft model. The sludge contained nearly 2 percent zinc; consequently, the zinc content of the grass grown on the

sludge-treated model was 200 mg/kg, whereas the grass from the 20-ft model contained approximately 100 mg/kg.

149. Equal performance was also shown for major cations. For example, potassium was 96 percent or more removed from surface water at 10 ft for both models. Sodium was 50 percent removed for both models. Also, in grass composition, potassium was 1 to 2 percent in both models, whereas sodium was 0.8 percent in both.

#### Comparison with field disposal of cannery wastewater

150. Results and recommendations from work on cannery wastewater treatment at the Campbell Soup Company, Paris, Texas, plant guided the 20-ft model design.<sup>75,78</sup> Two of the test watersheds at Paris, Y-1 and B-11, were grass-covered clay soil with a 2 percent slope, similar to that of the model with the exception that the slope lengths were 280 and 220 ft. The effluent was applied at 0.5 in./day for 5 days per week at Paris and for 4 days per week on the 20-ft model. The water distributions during March, April, and May for evaporation, runoff, and subflow were very similar (table 12). The lower evaporation during March from the field watersheds as compared with that of the model in the heated greenhouse was expected. Flooding the model an additional day each week would increase runoff and subflow and reduce evaporation, which would bring the distributions into closer agreement with those for the watersheds.

151. The nitrogen contents of the applied wastewater were similar (table 12). The effluent applied to the model had twice the phosphorus content of the cannery water, but the cannery water had 25 times the amount of COD material.

152. The treatment efficiencies for mass removals of nitrogen were quite similar for the watersheds and the greenhouse model during the spring season (table 12). These results indicate that the down-slope distance apparently is not a factor for nitrogen removal under the test conditions. Only half the 20-ft model length was used for nitrogen removal. Removal efficiencies may differ by slope length under longer treatment periods. More phosphorus was retained by the model

than by the watersheds. Age of system and type of phosphorus compound may be contributing factors. The mass removal percentages for COD material indicate a good removal for cannery waste by the watershed. However, the runoff water from the Paris watershed contained twice the concentration of COD compared with that of the effluent applied to the model. Considering water distribution and mass removals of nitrogen and phosphorus, the greenhouse system appears to have functioned well as a model of a watershed slope.

## PART V: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

153. The conclusions drawn from the analysis of data in this report are as follows:

- a. The model of a new overland flow system was effective for advanced treatment of secondary effluent with mass removal of 92 percent for nitrogen; 75 percent for phosphorus; 100 percent for cadmium, copper, manganese, and nickel; 91 percent for lead; and 72 percent for zinc.
- b. The grass harvest was effective for removal of 31 percent of the applied nitrogen, but smaller amounts of phosphorus and heavy metals, generally less than 10 percent of that applied, were removed in the grass.
- c. The elements retained in the model were fixed or volatilized since they were not readily extracted or exchanged with neutral ammonium acetate solution.
- d. Conditions for gaseous loss of nitrogen through denitrification existed at the surface of the model as evidenced by oxidation-reduction potential measurements.
- e. The nitrogen load of the model can be increased since only half of the length was used for nitrogen removal, provided that the minimum fertilization requirements of the grass are satisfied.
- f. Increased nitrogen supply and grass growth would probably improve treatment effectiveness for other elements.
- g. The removal of only 75 percent of the applied phosphorus indicates a need for more surface contact, either by surface roughness of soil or by increased model length.
- h. The subflow showed excellent removal of nitrogen, phosphorus, and heavy metals indicating effective removal mechanisms by the soil during the study period.

### Recommendations

154. Based on the literature and results of this study, interim recommendations for guidance in the design and operation of overland flow treatment systems for wastewater from military reservation treatment plants are given as follows:

- a. Slopes of an overland flow system should be graded and smoothed to eliminate rills and gullies to a practical degree to promote uniform sheet flow of water.
- b. Slopes should be up to 300 ft in length and 2 to 8 percent in slope.
- c. The length should increase with slope and rate of application to allow sufficient residence time on the soil for treatment.
- d. Vegetation that can tolerate semiflooded surface conditions and nearly continual reduced conditions below 6 in. of depth should be used. Reed canary grass, rice, and freshwater sedges are examples of such.
- e. At this time, overland flow is not recommended for forested areas.
- f. Water quality monitoring stations should be built and monitored where treated water from several slopes enters a natural stream or lake.
- g. Phosphorus treatment efficiency should be checked carefully, and the application rates should be adjusted to maintain the desired efficiency.
- h. Application rates of 1/3 to 3/4 in./day for 4 or 5 days a week should be used depending upon the quality of the wastewater, weather, and condition of treatment slopes.
- i. Application periods of 6 to 16 hr on 4 or 5 days a week should be used.
- j. Spray application should be used to promote uniform application.
- k. Slopes should be sprayed at night as well as during the day to minimize peak pumping.
- l. Slopes should be cycled so that wastewater quality and treatment condition average out over the treatment area.
- m. Operation and treatment information should be logged so that system design can be refined.

155. Based on the initial results of this study, it is further recommended that:

- a. The study of the model should be continued with increased applications of nitrogen and potassium to determine improved uses and treatment efficiency of the model, particularly for phosphorus, lead, and zinc.
- b. Oxidation-reduction potential measurements should be continued in order to delineate layers of occurrence and

define changes subject to scheduling of overland flow application. Tests should be initiated to verify and quantify nitrification-denitrification as a mechanism for nitrogen removal from the system.

- c. Studies should be made in the model for elucidation of mechanisms for fixation of phosphorus and heavy metals. These studies will require detailed sampling and analyses of the surface organic and mineral layers in order to locate and define fixations and to determine the duration and quantity of removals before saturation occurs.
- d. Studies should be initiated with new models to determine surface and soil factors that influence phosphorus removal, with variables including model length, surface configuration (roughness), and slope and rate, duration, and periodicity of overland flow application.
- e. Small-scale studies should be made with particular metals at increasing rates that exceed normal effluent composition in order to accelerate fixations leading to soil saturation or toxic conditions for vegetation. Results can be useful for time projections at normal rates, for defining critical conditions, and for determining mechanisms that may be diluted beyond analysis at normal rates.

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Table 1  
Concentrations, mg/l, and Other Characteristics of a  
Typical Secondary Effluent<sup>1</sup>

1. <u>BIOSTIMULANTS</u>		4. <u>METALS AND NONMETALS</u>	
a. <u>Nitrogen</u>		a. <u>Metals</u>	
Total N	20.0	Cadmium	0.1
Organic (as N)	2.0	Chromium	0.2
+NH <sub>4</sub> (as N)	9.8	Copper	0.1
-NO <sub>3</sub> (as N)	8.2	Iron	0.1
b. <u>Total Phosphorus</u>	10.0	Lead	0.1
		Manganese	0.2
2. <u>OXYGEN-DEMANDING COMPOUNDS</u>		Mercury	5.0 mg/ml
a. <u>BOD</u>	25	Nickel	0.2
b. <u>COD</u>	70	Zinc	0.2
		Sodium	S.A.R. = 4.6 Units
3. <u>OTHER ORGANIC COMPOUNDS</u>		b. <u>Nonmetals</u>	
a. <u>Phenols</u>	0.3	Boron	0.7
b. <u>Chlorinated and other complex organics</u> (Concentrations vary. Total concentration of these refractory organics approaches 45 mg/l as indicated by the difference between COD and BOD concentrations above.)		Chlorides	100.0
		Sulfate	125.0
		5. <u>OTHER CHARACTERISTICS</u>	
		a. <u>Suspended solids</u>	25.0
		b. <u>pH</u>	7.0 Units

Table 2

## Element Concentrations in Applied Secondary Effluent, Runoff, and Subflow

Constituent	Type of Water	Average Concentration, mg/l, for Cited Week												
		0	1	2	3	4	5	6	7	8	9	10	11	12
Nitrate Nitrogen	Effluent	0.0	12.40	10.15	7.63	6.30	7.56	8.11	8.77	8.36	9.60	9.29	10.21	20.05
	Runoff	0.0	6.60	3.00	0.48	0.30	0.50	0.16	0.0	0.17	0.12	0.04	0.05	0.09
	Subflow	0.0	0.05	0.22	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Nitrogen	Effluent	0.0	6.62	7.55	7.85		5.02	8.36	7.42	7.37	5.87	7.99	14.35	13.06
	Runoff	0.05	0.23	0.05	0.01		0.02	0.0	0.07	0.01	0.0	0.0	0.0	0.0
	Subflow	0.05	0.06	0.03	0.0		0.0	0.0	0.02	0.0	0.0	0.01	0.0	0.0
TKN	Effluent	0.0	9.10	9.02	11.34	7.90					8.70	12.87	14.70	16.80
	Runoff	0.60	1.57	1.47	1.44	1.47					2.20	3.25	1.82	1.65
	Subflow	0.05	0.31	0.24	0.08	0.24								
Phosphorus	Effluent	0.0				12.90	12.50	14.95		14.00	12.80	10.62	29.87	28.54
	Runoff	0.30				4.90	5.95	6.60		6.80	8.00	7.50	8.45	16.75
	Subflow	0.30				1.95	0.03	0.10		0.10	0.0	0.0	0.12	0.0
Cadmium	Effluent	0.0	0.0		0.0	0.21	0.24			0.21	0.23	0.17	0.22	0.21
	Runoff	0.0	0.0		0.0	0.02	0.0			0.0	0.02	0.0	0.0	0.0
	Subflow	0.0	0.0		0.0	0.01	0.0			0.0	0.0	0.0	0.0	0.0
Copper	Effluent				0.0	0.0	0.0			0.10	0.09	0.10	0.13	0.18
	Runoff				0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0
	Subflow				0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0
Lead	Effluent				0.0	0.20	0.17			0.22	0.10	0.11	0.06	0.16
	Runoff				0.0	0.01	0.09			0.02	0.02	0.02	0.01	0.0
	Subflow				0.0	0.02	0.04			0.01	0.0	0.0	0.01	0.0
Manganese	Effluent	0.0	0.0		0.0	0.22	0.15			0.19	0.22	0.21	0.19	0.18
	Runoff	0.0	0.0		0.0	0.0	0.0			0.01	0.0	0.0	0.0	0.0
	Subflow	0.0	0.0		0.0	0.02	0.02			0.0	0.04	0.05	0.03	0.06
Nickel	Effluent									0.03	0.09	0.06	0.11	0.16
	Runoff									0.01	0.0	0.01	0.0	0.0
	Subflow									0.01	0.0	0.0	0.01	0.01
Zinc	Effluent	0.01	0.17		0.04	0.32	0.27			0.35	0.57	0.44	0.25	0.19
	Runoff	0.03	0.09		0.04	0.07	0.02			0.05	0.09	0.07	0.02	0.0
	Subflow	0.07	0.08		0.02	0.08	0.09			0.12	0.22	0.34	0.19	0.21
Calcium	Effluent	0.10	15.35		15.50	8.05	7.65			11.75	1.50	1.35	6.18	5.85
	Runoff	0.20	17.70		0.65	1.20	1.25			1.80	0.05	0.04	1.07	0.74
	Subflow	30.75	44.10		3.40	2.65	3.50			6.45	0.76	0.74	4.73	6.21
Magnesium	Effluent	0.0	5.00		4.90	5.60	8.85			6.50	6.05	1.90	0.79	2.29
	Runoff	0.40	1.90		3.35	1.65	1.90			1.75	1.80	2.05	1.39	1.31
	Subflow	2.05	2.25		0.95	2.55	4.55			5.75	6.30	7.35	6.45	6.02
Sodium	Effluent				84.5	69.7	84.5			82.1	89.8	99.9	91.0	98.2
	Runoff				72.2	64.0	82.0			94.1	81.2	107.4	91.0	111.0
	Subflow				3.8	7.5				8.4	9.0	11.9	13.7	17.7
Potassium	Effluent	0.10	6.00		10.45	6.85	11.20			7.90	6.55	3.05	1.20	5.64
	Runoff	0.60	2.20		0.70	0.35	0.05			0.10	0.06	0.11	0.08	0.20
	Subflow	0.25	0.25		0.35	0.15	0.20			0.30	0.33	0.26	0.22	0.52
COD	Effluent		31.5	31.6	36.6	21.5		26.0		19.5	23.0	29.5	44.9	33.4
	Runoff					28.0		33.0		23.0	35.0	29.5	61.6	40.4
	Subflow					5.5		0.0		1.5	3.5	4.0	3.2	4.6
Electro-lyte	Effluent	2.0	297.0	348.0	350.4		329.5			372.0			327.5	455.7
	Runoff	13.5	113.5	159.3	178.3		195.7			278.0			242.0	363.5
	Subflow	37.5	38.2	41.5	46.8		59.5			74.5			101.0	132.7

pH Values in Applied Secondary Effluent, Runoff, and Subflow

Type of Water	Average pH for Cited Week												
	0	1	2	3	4	5	6	7	8	9	10	11	12
Effluent	5.8	7.0	7.0	7.0	7.0	7.0	6.6					6.8	6.8
Runoff	5.1	5.8	6.6	6.7	7.0	7.0	6.9					6.8	7.7
Subflow	6.0	6.1	5.9	6.0	5.6	5.6	5.5					4.9	5.4

Table 4

## Distribution of Nitrogen and Phosphorus in the Model, Runoff, and Subflow

Element	Location	Percent Mass Removal for Cited Week											
		1	2	3	4	5	6	7	8	9	10	11	12
Nitrate nitrogen	Model	68.7	82.5	96.5	97.7	96.4	99.0	100.0	99.1	99.3	99.8	99.8	99.8
	Runoff	31.2	17.1	3.5	2.3	3.6	1.0	0.0	0.9	0.7	0.2	0.2	0.2
	Subflow	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium nitrogen	Model	96.0	99.5	99.9	99.8	100.0	99.6	100.0	100.0	100.0	100.0	100.0	100.0
	Runoff	2.0	0.4	0.1	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
	Subflow	2.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TKN	Model	83.4	90.3	92.8	95.7								
	Runoff	15.9	9.2	7.1	3.9					15.3	12.3	5.3	4.1
	Subflow	0.7	0.5	0.1	0.4								
Phosphorus	Model				79.9	74.2	76.6		78.7	62.3	65.6	80.7	75.2
	Runoff				18.3	25.8	23.3		21.2	37.7	34.4	19.3	24.8
	Subflow				1.8	0.0	0.1		0.1	0.0	0.0	0.0	0.0

Table 5

Distribution of Selected Heavy Metals in the Model, Runoff, and Subflow

Element	Location	Percent Mass Removal for Cited Week											
		1	2	3	4	5	6	7	8	9	10	11	12
Lead	Model		96.7	67.6	96.1	87.2	92.3	97.9	100.0				
	Runoff		2.5	28.7	3.9	12.8	7.7	2.1	0.0				
	Subflow		0.8	3.7	0.0	0.0	0.0	0.0	0.0	0.0			
Manganese	Model		99.2	98.6	97.8	97.1	98.0	98.1	96.5				
	Runoff		0.0	0.0	2.2	0.0	0.0	0.0	0.0				
	Subflow		0.8	1.4	0.0	2.9	2.0	1.9	3.5				
Zinc	Model	60.0	34.8	86.2	91.4	88.5	84.4	86.5	85.7	87.7			
	Runoff	30.0	56.5	10.6	3.9	6.1	9.3	7.7	4.5	0.0			
	Subflow	10.0	8.7	3.2	4.7	5.4	6.3	5.8	9.8	12.3			

Table 6

Distribution of Major Cations in the Model, Runoff, and Subflow

Element	Location	Percent Mass Removal for Cited Week											
		1	2	3	4	5	6	7	8	9	10	11	12
Calcium	Model	-29.7		93.6	88.8	84.3			84.9	89.7	94.5	85.4	83.0
	Runoff	67.6		2.3	7.2	8.8			6.7	2.0	1.4	7.4	5.3
	Subflow	62.1		4.1	4.0	6.9			8.4	8.3	4.1	7.2	11.7
Magnesium	Model	68.0		58.2	80.2	80.6			74.7	64.9	17.9	-52.7	47.0
	Runoff	22.3		38.2	14.2	11.6			11.8	18.0	52.6	75.3	24.1
	Subflow	9.7		3.6	5.6	7.8			13.5	17.1	29.5	77.4	28.9
Sodium	Model			51.5	53.9	46.4			48.2	43.8	46.8	55.8	50.3
	Runoff			47.7	44.3	52.3			50.2	54.6	52.3	42.8	47.7
	Subflow			0.8	1.8	1.3			1.6	1.6	0.9	1.4	2.0
Potassium	Model	77.6		95.7	97.3	99.5			98.9	98.7	97.7	95.5	97.5
	Runoff	21.5		3.7	2.4	0.2			0.5	0.5	1.7	2.8	1.5
	Subflow	0.9		0.6	0.3	0.3			0.6	0.8	0.6	1.7	1.0

Table 7

Distribution of COD Material and Electrolyte in the Model, Runoff, and Subflow

Constituent	Location	Percent Mass Removal for Cited Week											
		1	2	3	4	5	6	7	8	9	10	11	12
COD	Model				34.1		33.1		47.2	5.6	50.3	40.5	47.4
	Runoff				62.8		66.9		51.6	91.9	48.7	58.8	51.1
	Subflow				3.1		0.0		1.2	2.5	1.0	0.7	1.5
Electrolyte	Model	74.8	71.4	69.1		65.3		64.2				65.5	63.1
	Runoff	22.4	26.5	28.4		32.0		32.7				31.6	33.7
	Subflow	2.8	2.1	2.5		2.7		3.1				2.9	3.2

Table 8

## Yield and Element Concentration of Grass

Results of Pretest Harvest	Results of Day 49 Harvest for Cited Downslope Parcels, ft				Results of Day 72 Harvest for Cited Downslope Parcels, ft											
	0 to 2.5		2.5 to 5		5 to 10		10 to 20		0 to 2.5		2.5 to 5		5 to 10		10 to 20	
Dry weight yield, % (average values of both sides of model)	416.8	305.5	176.4	188.4	32.2	116.8	133.3	190.7	4.7	A, B						
Element concentration, mg/g																
TKN	22.85	27.20	27.20	25.50	19.20	35.50	29.50	30.50	15.05	A, B						
Phosphorus	6.25	4.60	2.75	5.10	3.95	4.70	5.05	4.65	4.50							
Calcium	1.25	1.31	1.38	1.50	1.94	1.40	1.54	1.58	2.44	A						
Magnesium	2.10	3.32	2.50	2.88	2.67	3.34	3.81	3.76	3.56	B						
Sodium	1.39	2.99	2.92	4.37	3.92	6.25	8.60	8.85	5.45	B						
Potassium	24.35	20.90	16.15	21.25	15.80	19.20	18.50	18.50	8.85							
Element concentration, mg/kg																
Cadmium	0.00	5.10	1.75	0.45	0.65	4.95	5.65	4.45	0.0							
Copper	2.90	9.70	8.65	7.30	6.10	13.35	12.30	15.50	10.25	B						
Lead	14.50	11.00	8.50	13.50	12.00	38.00	32.00	23.00	12.50							
Manganese	107.45	84.30	89.25	80.80	64.30	69.70	86.40	96.15	53.85							
Nickel	0.00	0.05	0.15	0.15	0.00	20.50	22.00	27.00	12.00	B						
Zinc	56.00	107.50	93.50	84.00	77.00	123.00	136.50	147.50	86.50							

A denotes significant difference using the F test (0.05 probability level) among locations comparing means of harvest at 49 and 72 days.

B denotes significant difference using the F test (0.05 probability level) between harvests combining all locations within each harvest.

Table 9

Quantities of Nitrogen, Phosphorus, Major Cations,  
and Heavy Metals Removed in Grass

Element	Quantity Removed, g, at Day 49 for Cited				Quantity Removed, g, at Day 72 for Cited					
	Downslope Parcels, ft				Downslope Parcels, ft					
	0 to 2.5	2.5 to 5	5 to 10	10 to 20	0 to 2.5	2.5 to 5	5 to 10	10 to 20		
Nitrogen (TKN)	8.287	4.796	4.804	0.605	18.492	4.150	3.938	5.837	0.075	14.000
Phosphorus	1.409	0.507	0.960	0.127	3.003	0.549	0.673	0.892	0.021	2.135
Calcium	0.405	0.242	0.282	0.063	0.992	0.163	0.205	0.298	0.011	0.677
Magnesium	1.014	0.442	0.543	0.086	2.085	0.390	0.509	0.714	0.017	1.630
Potassium	6.412	2.856	4.004	0.512	13.784	2.247	2.467	3.522	0.054	8.290
Sodium	0.905	0.526	0.823	0.131	2.385	0.726	1.141	1.701	0.027	3.594

Element	Quantity Removed, mg, at Day 49 for Cited				Quantity Removed, mg, at Day 72 for Cited					
	Downslope Parcels, ft				Downslope Parcels, ft					
	0 to 2.5	2.5 to 5	5 to 10	10 to 20	0 to 2.5	2.5 to 5	5 to 10	10 to 20		
Cadmium	1.55	0.32	0.08	0.02	1.97	0.58	0.75	0.89	0.0	2.22
Copper	3.09	1.53	1.37	0.19	6.18	1.57	1.64	2.96	0.06	6.23
Lead	3.40	1.48	2.54	0.38	7.80	4.65	4.34	4.60	0.06	13.65
Manganese	26.22	15.66	15.23	2.07	59.14	8.20	11.52	17.99	0.33	38.04
Nickel	0.02	0.02	0.03	0.0	0.07	2.36	2.93	5.25	0.06	10.60
Zinc	33.23	6.26	15.82	2.53	67.84	14.31	18.20	28.30	0.42	61.23

Table 10

Nitrogen, Phosphorus, Cation Exchange Capacity, Heavy Metal, and Major Cation Analyses of Soils

Element	Pretest Element Extract meq/100g Bulk Soil		Element Extract, meq/100g, in Day 0 Sample for Cited Layers, cm				Element Extract, meq/100g, in Day 69 Sample of 0- to 3.8-cm Layer at Cited Downslope Distances, ft				Element Extract, meq/100g, in Day 69 Sample of 3.8- to 7.6-cm layer at Cited Downslope Distances, ft			
	Sod	Soil	0 to 5	5 to 10	10 to 15	0.5	2.5	5	10	15	20	0.5	2.5	10
TKN	3.22	2.50	3.89	3.93	2.54	5.63	4.30	4.31	3.74	3.54	3.71	3.14	3.27	3.00
Ammonium nitrogen	0.34	0.06	0.18	0.09	0.06	0.08	0.15	0.20	0.15	0.10	0.07	0.07	0.07	0.03
Phosphorus <sup>-1</sup>	0.50	0.04	0.08	0.04	0.17	2.85	0.84	0.56	0.77	0.57	0.03	0.77	0.20	0.18
Cation exchange capacity	28.21	25.86	22.71	22.87	23.84	29.97	26.31	23.95	22.44	21.95	24.37	31.68	19.64	23.68
Calcium	3.94	3.74	3.14	3.24	3.24	7.06	3.96	4.46	4.51	5.14	4.19	4.11	3.41	3.79
Magnesium	4.41	4.93	4.33	4.67	4.52	5.56	3.63	3.97	4.61	4.45	4.23	4.00	3.30	4.43
Potassium	0.38	0.29	0.32	0.40	0.29	0.18	0.05	0.14	0.20	0.15	0.18	0.10	0.04	0.09
Cadmium	0.0	0.0	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lead	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Manganese	0.0	0.0	0.03	0.02	0.01	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.01	0.02
Nickel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zinc	(25.75 ppm)	0.02	0.04	0.06	0.04	0.08	0.06	0.0	0.01	0.01	0.01	0.18	0.06	0.01 A

A denotes significant difference using the F test (0.05 probability level) among locations for the 3.8- to 7.6-cm layer.

Table 11

Percent Distribution of Elements, Electrolyte, and COD\*

<u>Constituents</u>	<u>Percent Removed in Runoff</u>	<u>Percent Removed in Subflow</u>	<u>Percent Retained in Model</u>	<u>Percent Removed in Grass Harvest</u>	<u>Change in Percent Soil Extract- able</u>	<u>Percent Fixed in Soil or Volatilized</u>
Ammonium nitrogen	0.2	0.1	99.7		-2.1	
TKN	9.2	0.3	90.5	56.5	0.0	34.0
Nitrate nitrogen	5.1	0.1	94.8			
TKN plus nitrate**	7.4	0.2	92.4	31.0	0.0	61.4
Phosphorus	25.1	0.3	74.6	6.4	10.3	57.9
Calcium	10.9	11.2	77.9	3.9	31.8	42.2
Magnesium	21.4	13.3	65.3	14.3	-12.1	63.1
Sodium	48.2	1.6	50.2	1.3		
Potassium	2.9	0.6	96.5	60.6	-14.9	50.8
Copper	0.0	0.0	100.0	4.0	0.0	96.0
Nickel	1.7	0.0	98.3	4.7	0.0	93.6
Cadmium	1.9	0.0	98.1	0.5	0.0	97.6
Manganese	0.3	1.7	98.0	12.6	0.0	85.4
Lead	8.0	0.6	91.4	3.4	0.0	88.0
Zinc	22.3	5.9	71.8	8.9	-35.5	62.9
Electrolyte	30.3	2.7	67.0			
COD	57.4	1.4	41.2			

\* Amounts are given in table A23.

\*\* It is assumed that there is no nitrate present in harvested grass.

Table 12

Comparison of Water Distribution and Amounts of Nutrients Applied and Removed  
From Field Disposal of Cannery Wastewater and the Greenhouse Sod Model

System	Component	Water Distribution, Percent for Cited Month			Wastewater Composition					
		March	April	May	Concentration Applied, mg/l			Portion Removed, Percent		
		Material	N	P	Material	N	P	Material	N	P
Paris watershed Y-1	Evaporation	5	24	22	17.1	8.4	697	86.2*	74.6*	93.3*
	Runoff	81	55	64						
	Subflow	14	21	14						
Paris watershed B-11	Evaporation	12	28	26	21.2	9.0	759	86.6*	50.4*	91.3*
	Runoff	64	48	52						
	Subflow	24	24	21						
Greenhouse sod model	Evaporation	27	36	47	20.9	17.0	30	92.0	74.6	41.2
	Runoff	56	49	43						
	Subflow	17	15	10						

\* April to October average.

APPENDIX A: BASIC DATA

Table A1

## Nitrate Nitrogen Concentration in Applied Secondary

## Effluent, Runoff, and Subflow

Type of Water	Average Concentration, mg/l, for Cited Week														
	0*	1	2	3	4	5	6	7	8	9	10	11	12	Mean	
Effluent															
Mon			9.55	8.40		7.25	5.85	6.80	7.90	8.20	8.45	9.10	18.35	8.98	
Tue			11.75	8.85		5.80	9.20	8.25	7.95	10.60	9.00	9.15	22.50	10.30	
Wed	0.0		10.20	7.00		8.50	8.60	10.00	9.20	9.10	8.65	11.50	16.60	9.93	
Thu		12.30	8.80	6.40	6.30	8.70	8.80	10.05	8.40	10.50	11.05	11.95	22.75	10.50	
Fri		12.50	10.45	7.50								9.35		9.95	
Mean	0.0	12.40	10.15	7.63	6.30	7.56	8.11	8.77	8.36	9.60	9.29	10.21	20.05		
Runoff															
Mon			3.60	1.60		2.00	0.65	0.0	0.0	0.10	0.0		0.20	0.91	
Tue			4.85	0.05		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	
Wed	0.0		3.50	0.35		0.0	0.0	0.0	0.60	0.20	0.15	0.0	0.05	0.48	
Thu		7.40	1.90	0.40	0.30	0.0	0.0	0.0	0.10	0.20	0.0	0.0	0.0	0.86	
Fri		5.80	1.17	0.02								0.20		1.80	
Mean	0.0	6.60	3.00	0.48	0.30	0.50	0.16	0.0	0.17	0.12	0.04	0.05	0.09		
Subflow															
Mon			1.10	0.0		0.05	0.0	0.0	0.0	0.0	0.0		0.0	0.13	
Tue			0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Wed	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Thu		0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Fri			0.0	0.0								0.0		0.0	
Mean	0.0	0.05	0.22	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

\* Deionized water applied on week 0. Values not included in 12-week means.

Table A2

## Ammonium Nitrogen Concentration in Applied Secondary

## Effluent, Runoff, and Subflow

Type of Water	Average Concentration, mg/l, for Cited Week												Mean	
	Day	0	1	2	3	4	5	6	7	8	9	10		11
Effluent	Mon		7.00	11.25	6.90	8.15	7.40	6.55	6.00	9.50	21.65	12.75	9.71	
	Tue		7.50	5.50	5.10	9.70	7.20	8.90	5.30	7.95	22.40	13.05	9.26	
	Wed	0.0		8.00	6.80	5.10	6.90	8.90	6.25	5.70	7.50	13.75	14.25	8.32
	Thu		6.50	6.00	3.00	8.70	6.20	7.80	6.50	7.00	6.95	12.20	7.08	
	Fri		6.75	9.25							7.00		7.67	
Mean	0.0	6.62	7.55	7.85	5.02	8.36	7.42	7.37	5.87	7.99	14.35	13.06		
Runoff	Mon		0.25	0.02	0.10	0.0	0.30	0.0	0.0	0.0	0.0	0.0	0.07	
	Tue		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Wed	0.05		0.02	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.02	0.0	0.01
	Thu		0.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03
	Fri		0.12	0.0							0.0		0.04	
Mean	0.05	0.23	0.05	0.01	0.02	0.0	0.07	0.01	0.0	0.0	0.01	0.0		
Subflow	Mon		0.15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	
	Tue		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Wed	0.05		0.0	0.0	0.0	0.10	0.0	0.0	0.0	0.02	0.0	0.02	
	Thu		0.07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01	
	Fri		0.05	0.0							0.0		0.02	
Mean	0.05	0.06	0.03	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0		





Table A5

Cadmium Concentration in Applied Secondary  
Effluent, Runoff, and Subflow

Type of Water	Day	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean
		Average Concentration, mg/l, for Cited Week													
Effluent	Mon												0.24	0.27	0.25
	Tue												0.26	0.22	0.24
	Wed	0.0								0.21	0.23	0.21	0.23	0.16	0.21
	Thu		0.0		0.0	0.21	0.24					0.13	0.19	0.19	0.14
	Fri												0.19		0.19
	Mean	0.0	0.0	0.0	0.0	0.21	0.24			0.21	0.23	0.17	0.22	0.21	
Runoff	Mon													0.0	0.0
	Tue													0.0	0.0
	Wed	0.0								0.0	0.02	0.0	0.0	0.0	0.0
	Thu		0.0		0.0	0.02	0.0					0.0	0.0	0.0	0.0
	Fri												0.0		0.0
	Mean	0.0	0.0	0.0	0.0	0.02	0.0			0.0	0.02	0.0	0.0	0.0	
Subflow	Mon													0.0	0.0
	Tue												0.0	0.0	0.0
	Wed	0.0								0.0	0.0	0.0	0.0	0.0	0.0
	Thu		0.0		0.0	0.01	0.0					0.0	0.0	0.0	0.0
	Fri												0.0		0.0
	Mean	0.0	0.0	0.0	0.0	0.01	0.0			0.0	0.0	0.0	0.0	0.0	





Table A5

## Manganese Concentration in Applied Secondary

## Effluent, Runoff, and Subflow

Type of Water	Day	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean
		Average Concentration, mg/l, for Cited Week													
Effluent	Mon												0.20	0.20	0.20
	Tue												0.20	0.20	0.20
	Wed	0.0							0.19	0.22	0.22	0.22	0.20	0.15	0.20
	Thu		0.0		0.0	0.22	0.15					0.20	0.17	0.18	0.13
	Fri												0.18		0.18
	Mean	0.0	0.0	0.0	0.0	0.22	0.15		0.19	0.22	0.22	0.21	0.19	0.18	
Runoff	Mon													0.0	0.0
	Tue												0.0	0.0	0.0
	Wed	0.0						0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Thu		0.0		0.0	0.0	0.0				0.0	0.0	0.0	0.0	0.0
	Fri												0.0		0.0
	Mean	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subflow	Mon													0.05	0.05
	Tue												0.03	0.05	0.04
	Wed	0.0						0.0	0.04	0.04	0.04	0.04	0.01	0.06	0.03
	Thu		0.0		0.0	0.02	0.02				0.05	0.05	0.05	0.07	0.03
	Fri												0.04		0.04
	Mean	0.0	0.0	0.0	0.0	0.02	0.02	0.0	0.04	0.04	0.05	0.05	0.03	0.06	0.06

Table A9

## Nickel Concentration in Applied Secondary

## Effluent, Runoff, and Subflow

Type of Water	Day	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean
		Average Concentration, mg/l, for Cited Week													
Effluent	Mon:												0.10	0.21	0.15
	Tue												0.10	0.13	0.11
	Wed							0.03	0.09		0.04		0.11	0.13	0.08
	Thu										0.07		0.07	0.17	0.10
	Fri												0.17		0.17
	Mean							0.03	0.09	0.06			0.11	0.16	
Runoff	Mon													0.0	0.0
	Tue												0.0	0.0	0.0
	Wed							0.01	0.0		0.0		0.0	0.0	0.0
	Thu										0.01		0.0	0.0	0.0
	Fri												0.0		0.0
	Mean							0.01	0.0	0.01			0.0	0.0	0.0
Subflow	Mon													0.0	0.0
	Tue												0.0	0.0	0.0
	Wed							0.01	0.0		0.0		0.0	0.02	0.01
	Thu										0.0		0.0	0.0	0.0
	Fri												0.02		0.02
	Mean							0.01	0.0	0.0			0.01	0.01	0.01

Table A10

Zinc Concentration in Applied Secondary  
Effluent, Runoff, and Subflow

Type of Water	Day	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean
		Average Concentration, mg/l, for Cited Week													
Effluent	Mon												0.33	0.23	0.28
	Tue												0.30	0.20	0.25
	Wed	0.01							0.35	0.57	0.24		0.27	0.14	0.31
	Thu		0.17		0.04	0.32	0.27				0.64		0.20	0.16	0.26
	Fri												0.17		0.17
	Mean	0.01	0.17	0.04	0.32	0.27	0.35	0.57	0.44	0.25	0.19				
Runoff	Mon													0.01	0.01
	Tue												0.04	0.0	0.02
	Wed	0.03							0.05	0.09	0.03		0.01	0.0	0.04
	Thu		0.09		0.04	0.07	0.02			0.10			0.01	0.0	0.05
	Fri												0.02		0.02
	Mean	0.03	0.09	0.04	0.07	0.02	0.05	0.09	0.07	0.02	0.0				
Subflow	Mon													0.20	0.20
	Tue												0.21	0.21	0.21
	Wed	0.07							0.12	0.22	0.18		0.18	0.23	0.19
	Thu		0.08		0.02	0.08	0.09			0.49			0.17	0.21	0.16
	Fri												0.20		0.20
	Mean	0.07	0.08	0.02	0.08	0.09	0.12	0.22	0.34	0.19	0.21				

Table All

## Calcium Concentration in Applied Secondary

## Effluent, Runoff, and Subflow

Type of Water	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Effluent														
Mon												4.40	5.00	4.70
Tue												4.55	5.00	4.77
Wed	0.10								11.75	1.50	1.50	8.60	6.85	6.04
Thu		15.35		15.50	8.05	7.65				1.20		5.30	6.55	8.51
Fri												8.05		8.05
Mean	0.10	15.35		15.50	8.05	7.65			11.75	1.50	1.35	6.18	5.85	
Runoff														
Mon													0.86	0.86
Tue												0.56	0.65	0.61
Wed	0.20								1.80	0.05	0.04	0.60	0.55	0.61
Thu		17.70		0.65	1.20	1.25				0.04		0.56	0.90	3.19
Fri												2.55		2.55
Mean	0.20	17.70		0.65	1.20	1.25			1.80	0.05	0.04	1.07	0.74	
Subflow														
Mon													4.85	4.85
Tue												6.70	4.75	5.72
Wed	30.75								6.45	0.76	0.65	2.26	8.00	4.38
Thu		44.10		3.40	2.65	3.50				0.83		5.25	7.25	9.57
Fri												4.70		4.70
Mean	30.75	44.10		3.40	2.65	3.50			6.45	0.76	0.74	4.73	6.21	

Table A12

## Magnesium Concentration in Applied Secondary

## Effluent, Runoff, and Subflow

Type of Water	Average Concentration, mg/l, for Cited Week													
	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Effluent														
Mon												1.10	1.35	1.23
Tue												1.20	1.00	1.10
Wed	0.0							6.50	6.05	2.30		0.26	2.65	3.55
Thu		5.00		4.90	5.60	8.85				1.50		0.55	4.15	4.36
Fri												0.83		0.83
Mean	0.0	5.00		4.90	5.60	8.85			6.50	6.05	1.90	0.79	2.29	
Runoff														
Mon													1.25	1.25
Tue												1.65	0.18	0.92
Wed	0.40							1.75	1.80	2.10		1.35	1.40	1.68
Thu		1.90		3.35	1.65	1.90				2.00		1.70	2.40	2.13
Fri												0.87		0.87
Mean	0.40	1.90		3.35	1.65	1.90		1.75	1.80	2.05		1.39	1.31	
Subflow														
Mon													4.75	4.75
Tue												6.75	4.69	5.72
Wed	2.05							5.75	6.30	7.10		6.65	7.15	6.59
Thu		2.25		0.95	2.55	4.55				7.60		7.80	7.50	4.74
Fri												4.61		4.61
Mean	2.05	2.25		0.95	2.55	4.55		5.75	6.30	7.35		6.45	6.02	

Table A13

Sodium Concentration in Applied Secondary  
Effluent, Runoff, and Subflow

Type of Water	Day	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean	
Effluent	Mon									82.10	89.80	93.35	70.85	98.25	84.55	
	Tue												84.35	95.00	89.67	
	Wed														90.94	
	Thu				84.50	69.75	84.50						106.55	108.70	100.90	92.48
	Fri													100.60	100.60	
	Mean				84.50	69.75	84.50			82.10	89.90	99.95	91.05	91.05	98.21	
Runoff	Mon														108.90	108.90
	Tue												81.85	100.25	91.05	
	Wed								94.10	81.25	106.35		78.65	108.75	93.82	
	Thu				72.25	64.00	82.00					108.50	107.10	125.95	93.30	
	Fri												96.55		96.55	
	Mean				72.25	64.00	82.00		94.10	81.25	107.42	91.04	110.96			
Subflow	Mon													14.90	14.90	
	Tue												12.65	15.90	14.27	
	Wed								8.45	9.00	10.75		14.30	15.85	11.67	
	Thu				3.85		7.50					13.05	13.55	24.20	12.43	
	Fri															
	Mean				3.85		7.50		8.45	9.00	11.90	13.72	13.72	17.71		

Table A14

## Potassium Concentration in Applied Secondary

## Effluent, Runoff, and Subflow

Type of Water	Average Concentration, mg/l, for Cited Week													
	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Effluent														
Mon												1.10	1.31	1.21
Tue												1.25	5.20	3.23
Wed	0.10							7.90	6.55	3.85		0.57	7.45	5.26
Thu		6.00		10.45	6.85	11.20				2.25		2.10	8.59	6.78
Fri												0.98		0.98
Mean	0.10	6.00		10.45	6.85	11.20		7.90	6.55	3.05		1.20	5.64	
Runoff														
Mon													0.07	0.07
Tue												0.06	0.15	0.11
Wed	0.60							0.10	0.06	0.10		0.10	0.15	0.14
Thu		2.20		0.70	0.35	0.05				0.12		0.06	0.45	0.56
Fri												0.11		0.11
Mean	0.60	2.20		0.70	0.35	0.05		0.10	0.06	0.11		0.08	0.20	
Subflow														
Mon													0.73	0.73
Tue												0.28	0.45	0.37
Wed	0.25							0.30	0.33	0.34		0.36	0.42	0.35
Thu		0.25		0.35	0.15	0.20				0.18		0.14	0.49	0.25
Fri												0.11		0.11
Mean	0.25	0.25		0.35	0.15	0.20		0.30	0.33	0.26		0.22	0.52	

Table A15

## COD Concentration in Applied Secondary

## Effluent, Runoff, and Subflow

Type of Meter	Average Concentration, mg/l, for Cited Week											Mean		
	0	1	2	3	4	5	6	7	8	9	10		11	12
Effluent														
Mon			35.50	29.00									38.00	34.17
Tue			20.50	29.00								46.50	36.00	33.00
Wed			54.00	37.50		26.00		19.50	23.00	26.00		44.00	29.50	32.44
Thu		35.00	20.00	51.00	2.150					33.00		57.00	30.00	35.36
Fri		28.00	28.00									32.00		29.33
Mean		31.50	31.60	36.63	21.50	26.00		19.50	23.00	29.50		44.88	33.38	
Runoff														
Mon													41.50	41.50
Tue												74.50	47.00	60.75
Wed						33.00		23.00	35.00	30.50		84.00	40.50	41.00
Thu					28.00					28.50		48.50	32.50	34.38
Fri												39.50		
Mean					28.00	33.00		23.00	35.00	29.50		61.63	40.38	
Subflow														
Mon													3.50	3.50
Tue													12.00	12.00
Wed						0.0		1.50	3.50	4.00		0.0	3.00	2.00
Thu					5.50					4.00		4.50	0.0	3.50
Fri												5.00		5.00
Mean					5.50	0.0		1.50	3.50	4.00		3.17	4.63	

Table A16

## Electrolyte Concentration in Applied Secondary

## Effluent, Runoff, and Subflow

Type of Water	Day	0	1	2	3	4	5	6	7	8	9	10	11	12	Mean
		Average Concentration, mg/l, for Cited Week													
Effluent	Mon			333.5	372.5										353.0
	Tue			340.5	375.0										357.7
	Wed	2.0		353.0	343.5		344.0		372.0				327.5	439.0	363.2
	Thu		300.0	351.0	326.0		315.0							472.5	352.9
	Fri		294.0	362.0	335.0										330.3
	Mean	2.0	297.0	348.0	350.4		329.5		372.0				327.5	455.7	
Runoff	Mon			136.0	172.5										154.2
	Tue			156.5	175.0										165.7
	Wed	13.5		167.5	176.0		190.5		278.0				242.0	330.5	230.8
	Thu		117.0	165.5	179.0		201.0							396.5	211.8
	Fri		110.0	171.0	189.0										156.7
	Mean	13.5	113.5	159.3	178.3		195.7		278.0				242.0	363.5	
Subflow	Mon			41.5	48.0										44.7
	Tue			37.5	42.5										40.0
	Wed	37.5		42.0	44.0		60.5		74.5				101.0	130.5	75.4
	Thu		40.0	44.0	48.5		58.5							135.0	65.2
	Fri		36.5	42.5	51.0										43.3
	Mean	37.5	38.2	41.5	46.8		59.5		74.5				101.0	132.7	

Table A17

pH Values in Applied Secondary Effluent,  
Runoff, and Subflow

Type of Water	Average pH's for Cited Week												Mean				
	0*	1	2	3	4	5	6	7	8	9	10	11		12			
Effluent																	
Mon			6.95	6.95													6.95
Tue			6.85	6.90													6.87
Wed	5.80		7.00	7.10		6.90		6.60				6.80	7.00				6.90
Thu		7.10	7.00	6.90		7.10							6.50				6.92
Fri		6.85	7.10	7.00													6.98
Mean	5.80	6.97	6.98	6.97		7.00		6.60				6.80	6.75				
Runoff																	
Mon			6.10	6.30													6.20
Tue			6.60	6.60													6.60
Wed	5.10		6.55	6.80		6.90		6.90				6.75	8.05				6.99
Thu		5.75	6.75	6.85		7.20							7.30				6.77
Fri		5.75	6.85	6.85													6.48
Mean	5.10	5.75	6.57	6.68		7.05		6.90				6.75	7.67				
Subflow																	
Mon			6.05	5.90													5.97
Tue			5.95	5.70													5.82
Wed	6.00		5.90	6.25		5.55		5.50				4.90	5.45				5.59
Thu		5.95	5.90	5.75		5.55							5.35				5.70
Fri		6.30	5.85	6.60													6.25
Mean	6.00	6.12	5.93	6.04		5.55		5.50				4.90	5.40				

\* Deionized water applied on week 0. Values not included in 12-week means.

Table A18

Element Concentrations in Surface Water Collected Down the Model

Element	Sampling Time		Concentration, mg/l, for Cited Distances, ft. from the Upper End of the Model					
	Week	Day	0	2.5	5	10	15	20
Nitrate nitrogen	3	3	8.05	6.62	4.55	0.85	0.50	0.30
	5	4	8.70	7.70	5.20	1.10	0.05	0.0
	8	3	9.20	8.55	6.20	0.45	0.55	0.10
	11	3	11.50	10.75	7.50	1.00	0.0	0.0
	12	3	16.60	14.30	11.65	1.60	0.0	0.0
	Mean		10.81	9.58	7.02	1.00	0.22	0.08
			* LSD(.05) = 0.797					
Ammonium nitrogen	3	3	6.50	3.22	2.15	0.0	0.0	0.0
	5	4	3.00	2.20	0.55	0.0	0.0	0.0
	8	3	6.25	5.40	2.30	0.0	0.0	0.0
	11	3	13.75	10.75	4.75	0.0	0.0	0.0
	12	3	14.25	10.30	5.50	0.0	0.0	0.0
	Mean		8.75	6.37	3.05	0.0	0.0	0.0
			* LSD(.05) = 0.985					
Phosphorus	5	4	12.50	12.30	11.35	7.95	7.35	5.95
	6	3	14.95	13.05	12.75	10.20	8.45	6.50
	8	3	14.00	13.55	13.80	11.15	9.30	8.05
	12	3	32.02	29.41	29.22	29.25	32.33	20.70
		Mean		18.37	17.08	16.78	14.64	14.36
	NS							
Cadmium	5	4	0.24	0.05	0.05	0.02	0.01	0.0
	8	3	0.21	0.16	0.10	0.03	0.0	0.0
	11	3	0.23	0.07	0.02	0.0	0.0	0.0
	12	3	0.16	0.04	0.05	0.0	0.0	0.0
		Mean		0.21	0.08	0.05	0.01	0.0
			* LSD(.05) = 0.023					

(Continued)

\* denotes significant difference using the F test at the 0.05 probability level, with the least significant difference (LSD) for the means given.

NS denotes nonsignificant difference using the F test at the 0.05 probability level.

(1 of 4 sheets)

Table A18 (Continued)

Element	Sampling Time		Concentration, mg/l, for Cited Distances, ft, from the Upper End of the Model					
	Week	Day	0	2.5	5	10	15	20
Copper	5	4	0.0	0.0	0.0	0.0	0.0	0.0
	8	3	0.10	0.13	0.05	0.01	0.03	0.0
	11	3	0.13	0.0	0.0	0.0	0.0	0.0
	12	3	0.14	0.04	0.02	0.0	0.0	0.0
	Mean		0.12	0.06	0.02	0.0	0.01	0.0
		* LSD(.05) = 0.031						
Lead	5	4	0.17	0.10	0.15	0.09	0.08	0.09
	8	3	0.22	0.19	0.22	0.11	0.11	0.07
	11	3	0.04	0.02	0.0	0.0	0.01	0.0
	12	3	0.15	0.01	0.0	0.0	0.0	0.0
	Mean		0.14	0.08	0.09	0.05	0.05	0.04
		* LSD(.05) = 0.060						
Manganese	5	4	0.15	0.04	0.02	0.0	0.0	0.0
	8	3	0.19	0.03	0.0	0.0	0.0	0.0
	11	3	0.20	0.01	0.0	0.0	0.0	0.0
	12	3	0.15	0.0	0.0	0.0	0.0	0.0
	Mean		0.17	0.02	0.0	0.0	0.0	0.0
		* LSD(.05) = 0.024						
Nickel	8	3	0.03	0.01	0.01	0.01	0.01	0.01
	11	3	0.11	0.02	0.0	0.0	0.0	0.0
	12	3	0.13	0.04	0.03	0.01	0.0	0.0
	Mean		0.09	0.02	0.01	0.01	0.0	0.0
		* LSD(.05) = 0.023						
Zinc	5	4	0.27	0.10	0.06	0.03	0.03	0.02
	8	3	0.35	0.24	0.31	0.05	0.03	0.06
	11	3	0.27	0.08	0.07	0.02	0.0	0.02
	12	3	0.14	0.01	0.01	0.0	0.02	0.01
	Mean		0.26	0.11	0.11	0.02	0.02	0.03
		* LSD(.05) = 0.051						

(Continued)

\* denotes significant difference using the F test at the 0.05 probability level, with the least significant difference (LSD) for the means given.

Table A18 (Continued)

Element	Sampling Time		Concentration, mg/l, for Cited Distances, ft. from the Upper End of the Model					
	Week	Day	0	2.5	5	10	15	20
Calcium	5	4	7.65	6.40	5.90	4.75	2.95	1.25
	8	3	11.75	10.85	9.25	6.90	4.55	2.05
	11	3	8.60	6.25	5.40	3.25	1.75	0.60
	12	3	6.85	5.15	4.80	3.50	1.70	0.55
	Mean		8.71	7.16	6.34	4.60	2.74	1.11
		* LSD(.05) = 0.422						
Magnesium	5	4	8.85	8.15	6.60	4.10	3.35	1.90
	8	3	6.50	6.45	6.40	4.90	3.75	1.95
	11	3	0.26	1.35	1.80	1.70	1.70	1.25
	12	3	2.65	2.60	2.60	2.65	1.90	2.05
	Mean		4.56	4.64	4.35	3.34	2.67	1.79
		* LSD(.05) = 0.45						
Sodium	5	4	84.5	87.0	87.0	86.5	87.0	82.0
	8	3	82.1	82.3	71.1	94.4	95.7	97.6
	11	3	90.7	88.0	87.3	83.8	82.2	98.5
	12	3	98.7	98.3	97.6	98.0	102.3	107.9
	Mean		89.0	88.9	85.7	90.7	91.8	96.5
		NS						
Potassium	5	4	11.20	11.40	3.25	0.70	0.20	0.05
	8	3	7.90	6.95	3.95	0.0	0.0	0.0
	11	3	0.57	2.25	1.04	0.30	0.35	0.29
	12	3	7.45	5.55	2.79	0.20	0.16	0.14
	Mean		6.78	6.54	2.76	0.30	0.18	0.12
		* LSD(.05) = 3.63						
COD	6	3	26.0	20.0	28.5	26.5	28.0	33.5
	8	3	19.5	30.5	24.5	23.0	25.5	25.0
	11	3	44.0	71.5	70.0	80.0	75.5	90.5
	12	3	29.5	40.5	39.0	29.0	41.5	34.0
	Mean		29.7	40.6	40.5	39.6	42.6	45.7
		NS						

(Continued)

\* denotes significant difference using the F test at the 0.05 probability level, with the least significant difference (LSD) for the means given.

NS denotes nonsignificant difference using the F test at the 0.05 probability level.

(3 of 4 sheets)

Table A18 (Concluded)

Element	Sampling Time		Concentration, mg/l, for Cited Distances, ft, from the Upper End of the Model					
	Week	Day	0	2.5	5	10	15	20
Electrolyte	5	4	315.0	266.0	269.0	235.0	217.5	201.0
	8	3	372.0	367.5	348.5	314.0	303.0	284.5
	11	3	327.5	262.5	246.5	201.5	215.5	228.5
	12	3	439.0	418.0	376.5	330.5	306.0	327.5
	Mean		363.4	328.5	310.1	270.2	260.5	260.4
			* LSD(.05) = 11.76					

\* denotes significant difference using the F test at the 0.05 probability level, with the least significant difference (LSD) for the means given.

Table A19

Volumes of Applied Secondary Effluent,  
Runoff, and Subflow

Type of Water	Day	Volume, $\ell$ , for Cited Week												Mean								
		0*	1	2	3	4	5	6	7	8	9	10	11		12							
Effluent	Mon			58.90	58.90	58.90	58.90	58.90	58.80	58.80	58.90	58.90	58.90	58.90	58.90	58.90	58.90	58.90	58.90	58.80	58.90	
	Tue			58.90	58.90	58.90	58.90	58.90	57.90	58.80	58.90	58.90	58.90	58.80	58.90	58.90	58.90	58.90	58.80	58.80	58.80	
	Wed	58.90		58.90	58.90	58.90	58.90	58.90	58.80	58.80	58.90	58.90	58.80	58.80	58.70	58.80	58.80	58.80	58.80	58.80	58.80	
	Thu		58.90	58.90	58.90	58.00	58.90	58.90	58.80	58.80	58.90	58.90	58.80	58.80	58.90	58.80	58.80	58.80	58.80	58.80	59.00	58.84
	Fri		58.90	58.90	58.90	58.90	58.90														58.80	58.88
	Mean	58.90	58.90	58.90	58.90	58.90	58.90	58.90	58.57	58.80	58.90	58.85	58.80	58.85	58.85	58.85	58.85	58.85	58.88	58.88	58.85	
Runoff	Mon			26.58	14.50	19.30	17.40	10.65	0.90	6.80	25.15	7.10	0.0	15.95	13.15							
	Tue			35.15	38.80	38.40	39.90	39.45	37.60	31.35	44.75	38.10	31.25	30.05	36.80							
	Wed	24.75		36.35	32.30	41.60	35.85	32.90	38.90	31.30	36.35	34.35	38.55	26.50	35.00							
	Thu		34.75	34.85	39.90	42.80	33.70	41.15	28.45	33.50	35.95	35.00	28.45	26.95	34.62							
	Fri		34.45	37.10	38.95																	27.85
	Mean	24.75	34.60	34.06	32.89	35.52	31.71	31.04	26.46	25.74	35.55	28.64	25.22	24.86								
Subflow	Mon			8.95	7.25	3.45	6.75	8.40	4.55	5.64	8.40	6.40	0.0	5.90	5.97							
	Tue			10.00	11.30	10.75	8.65	9.10	8.70	8.90	11.20	9.85	5.20	6.65	9.12							
	Wed	10.35		10.15	10.60	11.10	9.70	10.80	9.30	10.55	9.30	9.60	7.10	6.55	9.52							
	Thu		11.40	11.30	11.15	10.75	10.55	13.85	11.95	10.90	9.80	10.05	7.00	6.85	10.46							
	Fri		14.10	11.35	14.25																	8.65
	Mean	10.35	12.75	10.35	10.91	9.01	8.91	10.54	8.62	9.00	9.67	8.97	5.59	6.49								

\* Deionized water applied on week 0. Values not included in 12-week means.

Table A20

pH Values in Surface Water Collected Down the Model

<u>Sampling Time</u>		<u>pH for Cited Distances, ft, from the Upper End of the Model</u>					
<u>Week</u>	<u>Day</u>	<u>0</u>	<u>2.5</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>
5	4	7.1	7.1	7.1	7.2	7.1	7.2
8	3	6.6	6.8	6.7	6.9	6.7	6.9
11	3	6.8	6.7	6.4	6.4	6.8	6.7
12	3	7.0	7.0	6.9	7.1	7.5	8.2
Mean		6.9	6.9	6.8	6.9	7.0	7.2

Table A21

Oxidation-Reduction Potential at 5-mm Depth

		<u>Oxidation-Reduction Potential, mv, for Cited Downslope Distances, ft</u>								
<u>Date</u>	<u>Hours</u>	<u>2.5</u>	<u>5.0</u>	<u>7.5</u>	<u>10.0</u>	<u>12.5</u>	<u>15.0</u>	<u>17.5</u>	<u>20.0</u>	<u>Mean</u>
10 May	10:50	+179	+304	+494	+484	+394	+549	-296	+454	+320
	11:00	+309	+249	+469	+494	+454	+494	+204	+444	+390
	13:00	+009	-086	+434	+549	+414	+434	-296	+499	+245
	14:50	+004	+029	+199	+229	+194	+304	-246	+444	+145
	15:00	-021	-011	-149	+079	-066	+239	-296	+524	+037
	17:50	-041	-026	-006	-036	-251	+009	-296	+479	-021
	20:00	-071	-056	-201	-071	-196	-131	-286	+324	-086
11 May	11:00	-016	+164	-156	+094	+334	+484	-236	+454	+140
	14:50	-036	-056	-211	-056	-101	+134	-166	+514	+003
12 May	13:50	+124	+484	+084	+544	+384	+904	+044	+544	+389
13 May	15:00	+184	+484	+494	+474	+404	+624	-106	+534	+386
14 May	9:00	+284	+549	+549	+689	+464	+654	-106	+549	+454
	13:00	-001	+354	+449	+554	+464	+364	+224	+549	+370
	17:50	-041	+234	-136	+124	-241	+404	-221	+494	+077

Table A22

Oxidation-Reduction Potential at 13-mm Depth

<u>Date</u>	<u>Hours</u>	Oxidation-Reduction Potential, mv, for Cited Downslope Distances, ft								
		<u>2.5</u>	<u>5.0</u>	<u>7.5</u>	<u>10.0</u>	<u>12.5</u>	<u>15.0</u>	<u>17.5</u>	<u>20.0</u>	<u>Mean</u>
10 May	10:50	+424	-006	+144	+344	+129	+104	+024	+064	+153
	11:00	+424	-061	+234	+314	+054	+084	-106	-011	+116
	13:00	+164	-206	+114	+294	-046	+084	-196	-046	+020
	14:50	-171	-226	-016	+014	-161	+094	-216	-121	-100
	15:00	-201	-231	-146	+164	-171	+104	-231	-141	-107
	17:50	-241	-241	-211	+044	-221	+119	-246	-166	-145
	20:00	-241	-226	-121	-161	-226	+124	-236	-176	-158
11 May	11:00	-176	-176	-186	-276	-196	+144	-246	-196	-163
	14:50	-196	-166	-186	-246	-206	+144	-256	-201	-164
12 May	13:50	+129	-056	+069	-176	-131	+364	-261	-051	-014
13 May	15:00	-206	+334	+044	-266	-096	+174	-276	-016	-038
14 May	9:00	+574	+469	+064	-141	+004	+194	-261	+074	+122
	13:00	+504	+354	+094	-066	-006	+179	-261	+044	+105
	17:50	+059	+279	+099	-201	+014	+154	-236	+069	+030

Table A23

Account of Elements for Study Period, kg/ha

Element	Applied in <u>Effluent</u>	Removed in <u>Runoff</u>	Removed in <u>Subflow</u>	Retained in <u>Model</u>	Removed in <u>Grass Harvest</u>	Change in Soil <u>Extractable</u>	Fixed in Soil or <u>Volatilized</u>
Ammonium nitrogen	46.32	0.09	0.04	46.19	34.96	-0.97	20.99
TKN	61.86	5.70	0.21	55.95		0.0	
Nitrate nitrogen	51.04	2.62	0.03	48.39			
Phosphorus	86.24	21.62	0.28	64.34	5.53	8.87	49.94
Cadmium	0.909	0.017	0.0	0.892	0.005	0.0	0.888
Copper	0.330	0.0	0.0	0.330	0.013	0.0	0.317
Lead	0.683	0.055	0.004	0.624	0.023	0.0	0.601
Manganese	0.833	0.002	0.014	0.817	0.105	0.0	0.712
Nickel	0.246	0.004	0.0	0.242	0.012	0.0	0.230
Zinc	1.559	0.347	0.092	1.119	0.139	-0.553	1.533
Calcium	45.89	5.02	5.15	35.72	1.80	14.59	19.33
Magnesium	27.87	5.96	3.72	18.20	4.00	-3.38	17.58
Sodium	502.00	224.77	7.92	252.22	6.43		
Potassium	39.22	1.15	0.25	37.82	23.75	-5.85	19.92
Electrolyte	2031.27	614.90	54.34	1362.02			
COD	170.62	90.95	2.44	70.32			

## APPENDIX B: MODEL CHARACTERISTICS

### Variation of Constituents in Runoff and Subflow

1. Concentration measurements associated with particular model sections or water outlets provide a check on uniformity of performance of the model. Uniformity in concentrations after different times of runoff or subflow also indicates performance of the model.

2. Determinations of variations in concentration of runoff and subflow constituents were made during one application. Separate samples were taken from the four runoff outlets, each collecting water from a quarter section of the model. Samples were collected in the minimum time required to obtain sufficient volume for analyses, usually several minutes. Runoff samples were collected four times, three at hourly intervals and the last after 5 hr.

3. Separate samples were taken from the upper east, upper mideast, and upper midwest subflow outlets, and from the lower west outlet. Water volume from the upper west outlet was too small for analysis. Subflow started later and proceeded at a slower rate than runoff. Subflow was collected three times, initially at 6-hr intervals, but the last after 10 hr. Individual samples were also collected twice from the four containers of secondary effluent: first, near the start of application and again 4 hr later near the end of application.

4. Chemical analyses were confined to those elements normally found in runoff and subflow in this study, so nitrogen compounds and most heavy metals were not tested. Data are listed in tables B1 and B2. Statistical analyses were made on each element to determine differences among sample means for outlet locations and sampling times. Significant differences among location means for an element are indicated in table B3 by an asterisk, followed by a value for least significant difference at the 0.05 probability level.

5. Sodium and phosphorus were uniformly treated across the model as shown by the similarity of concentrations in runoff waters (indicated by the NS designation in table B3). Calcium and magnesium were higher in

the mideast runoff. Potassium, electrolyte, and COD material were higher along the edges, east and west. A definite border treatment effect was not shown. The midwest section was consistently low in all constituents compared with other sections, yet this section had the largest bare area from dead grass. The electrolyte concentration appears high, but it properly reflects the anion content, which was twice the weight of the cations. Considerable variation occurred between individual values, particularly for the elements lowest in concentration. The analysis at different sampling times showed that potassium and COD concentrations significantly decreased in the runoff during the test period. All other elements had only random variation in concentration among sampling times. Obviously, a proper appraisal of runoff constituents requires a representative sample from the entire model over the entire runoff period.

6. Phosphorus was not detected in the subflow. Only potassium had uniform concentration from all subflow outlets (table B4). No outlet was consistently low in all elements. Calcium and magnesium were higher in concentration in the subflow than in the runoff, whereas other constituents were lower in the subflow. Potassium and COD concentrations again significantly decreased at the later sampling times. The variability of subflow data indicates the need for representative sampling.

7. The secondary effluent only showed random differences in element composition for the four containers at two sampling times.

#### Distribution of Water from the Model

8. Another check of uniformity of operation of the model was a comparison of water volumes collected daily from the runoff and subflow outlets. The same volume of secondary effluent, usually 29.5 l, was pumped from four separate containers into each quarter section of the model. The volume decreased by an amount infiltrated into the soil and by that lost by evapotranspiration. The remainder as runoff collected in separate containers should have had about the same volume from each

section. The runoff volumes during the initial weeks differed by a factor of three from the east and west container lows (table B5). On 2 days of the second week, runoff from the mideast section exceeded the applied volume. Obviously, this section received water from adjacent sections. The strips separating the sections were packed with additional soil along their length where they cut into the sod to stop any crossover of the overland flow water. The runoff from the mideast section thereafter had the lowest volume, while the east section had the highest, demonstrating that surface water had crossed over between sections. By the fourth and fifth weeks differences among strips had narrowed from a range of 18 l down to 5 l. The random differences that persisted do not indicate any plot border effect at this stage of grass growth. Some water crossover between strips may still occur as well as differences in infiltration and evaporation between strips to explain the differences in volume collected.

9. The distribution of upper subflow was independent of the runoff. More water was collected from the mideast outlet than from the three other upper subflow outlets combined (table B6). The differences among outlets were the same before and after the packing along the strips to eliminate water crossover. Water movement from the upper subflow outlets was not affected by the redistribution of the surface water. Apparently the pore distribution from which the water drained to the upper subflow outlets and, possibly, the volume of soil drained were not the same among strips even though care was taken to pack the soil uniformly when the model was prepared.

10. The lower subflow volumes were compared by west and east sides only (table B7). The volumes from the lower outlets differed so greatly and many volumes were so small that separate collections and analyses were not possible. The combined collection from four lower east side outlets amounted to 100 ml in each of the fourth and fifth weeks. At the same time, more than 10 l was collected from the lower west side. As with the upper subflow, the change in surface water distribution did not influence the lower subflow volume distribution. Again, the pore size distribution must be different for the soil draining to the lower

subflow outlets. The gradual decrease in water volume over the first 4 weeks may indicate a settling, more probably a swelling of, the clay.

11. The upper and lower subflow volumes were not consistent by location. The largest volumes were collected on the lower west side and upper east side. The subflow movement was obscure, not uniform by depth or sides. Obviously, the surface water movements are not related to the subflow movements in this clay soil model.

12. Analyses were made for electrolytes comparing upper with lower subflow concentration during this period (table B8). The collections of the largest volumes, upper east side and lower west side, had similar concentrations of electrolyte. The smaller volumes of the upper west side had increased electrolyte. The least volumes of the lower east side had an electrolyte concentration three times greater than that of the lower west side. Analyses for elements were not made on these solutions, so the cause of the electrolyte difference cannot be ascertained. The results show that the solution concentrations as well as volumes differ from the different subflow outlets, emphasizing again the need for representative sampling from the various outlets.

Table B1

Concentration, mg/l, of Constituents in Runoff  
by Time and Model Section  
 Sample Week 12, Day 4

Constituents	Hours	Model Section			
		West	Midwest	Mideast	East
Calcium	3:10	0.4	0.6	0.9	0.8
	4:10	0.6	0.9	1.2	0.5
	5:06	0.7	0.9	1.4	0.8
	10:10	0.8	0.9	1.6	0.7
Magnesium	3:10	1.9	1.8	3.4	2.2
	4:10	1.9	2.1	2.7	1.9
	5:06	2.5	2.5	3.0	2.2
	10:10	3.0	2.5	3.2	2.4
Sodium	3:10	128.1	123.2	121.0	123.6
	4:10	110.3	120.0	123.3	125.5
	5:06	127.4	121.0	120.7	130.0
	10:10	128.8	125.8	116.9	132.3
Potassium	3:10	0.59	0.27	0.80	0.88
	4:10	0.38	0.34	0.57	0.83
	5:06	0.31	0.17	0.26	0.61
	10:10	0.25	0.18	0.16	0.38
Electrolyte	3:10	400.0	376.0	393.0	400.0
	4:10	393.0	385.0	393.0	400.0
	5:06	393.0	385.0	393.0	408.0
	10:10	408.0	385.0	393.0	408.0
Phosphorus	3:10	18.14	25.71	20.20	20.20
	4:10	20.43	30.67	22.48	18.44
	5:06	20.26	20.13	22.68	20.36
	10:10	20.13	20.04	21.63	17.62
Zinc	3:10	0.0	0.0	0.01	0.0
	4:10	0.0	0.0	0.0	0.0
	5:06	0.0	0.0	0.0	0.01
	10:10	0.0	0.0	0.0	0.0
Manganese	3:10	0.01	0.0	0.0	0.01
	4:10	0.01	0.0	0.0	0.0
	5:06	0.0	0.0	0.0	0.0
	10:10	0.0	0.0	0.0	0.0
COD	3:10	56.7	44.5	42.9	48.6
	4:10	40.5	34.0	33.2	43.7
	5:06	37.2	24.1	22.6	25.7
	10:10	25.7	26.5	25.7	25.7
pH	3:10	7.3	7.3	7.3	7.3
	4:10	7.5	7.4	7.4	7.6
	5:06	7.4	7.2	7.2	7.2
	10:10	7.4	7.1	7.3	7.2

Table B2

Concentration, mg/l, of Constituents in Subflow  
by Time and Outlet Location  
 Sample Week 12, Day 4

<u>Constituents</u>	<u>Time</u>	<u>Outlet Location</u>			
		<u>Lower West</u>	<u>Upper Midwest</u>	<u>Upper Mideast</u>	<u>Upper East</u>
Calcium	4:27 p.m.	3.4	5.2	8.7	9.2
	10:47 p.m.	5.6	4.4	6.8	8.4
	8:40 a.m.	6.0	7.4	7.6	8.6
Magnesium	4:27 p.m.	6.5	6.7	7.9	8.5
	10:47 p.m.	6.3	6.4	7.5	8.6
	8:40 a.m.	9.0	6.5	7.9	8.6
Sodium	4:27 p.m.	17.0	24.4	17.2	17.2
	10:47 p.m.	17.6	32.0	15.3	19.3
	8:40 a.m.	17.6	20.8	15.1	18.3
Potassium	4:27 p.m.	0.47	0.52	0.55	0.56
	10:47 p.m.	0.48	0.48	0.47	0.48
	8:40 a.m.	0.41	0.45	0.42	0.52
Electrolyte	4:27 p.m.	133.0	130.0	134.0	142.0
	10:47 p.m.	130.0	139.0	130.0	142.0
	8:40 a.m.	134.0	136.0	130.0	146.0
Phosphorus	4:27 p.m.	0.0	0.0	0.0	0.0
	10:47 p.m.	0.0	0.0	0.0	0.0
	8:40 a.m.	0.0	0.0	0.0	0.0
Zinc	4:27 p.m.	0.18	0.32	0.20	0.29
	10:47 p.m.	0.18	0.26	0.19	0.28
	8:40 a.m.	0.18	0.31	0.21	0.43
Manganese	4:27 p.m.	0.05	0.05	0.04	0.08
	10:47 p.m.	0.04	0.03	0.03	0.09
	8:40 a.m.	0.04	0.07	0.05	0.08
COD	4:27 p.m.	2.3	4.7	0.8	1.6
	10:47 p.m.	1.6	3.9	0.0	0.0
	8:40 a.m.	0.0	0.0	0.0	0.0
pH	4:27 p.m.	4.7	5.5	5.5	5.4
	10:47 p.m.	4.7	5.5	4.9	5.0
	8:40 a.m.	4.9	5.9	5.2	5.6

Table B3

Runoff Sample Comparison, mg/l,  
Among Model Sections

Constituents	Concentration for Cited Model Section					Least Significant Difference
	West	Midwest	Mideast	East		
Calcium	0.62	0.82	1.27	0.70	*	0.25
Magnesium	2.32	2.22	3.07	2.17	*	0.45
Sodium	123.6	122.5	120.5	127.8	NS	
Potassium	0.38	0.24	0.45	0.67	*	0.18
Phosphorus	19.7	24.1	21.7	19.2	NS	
Electrolyte	398.0	383.0	393.0	404.0	*	7.0
COD	40.0	32.3	31.1	35.9	*	6.1

Note: Values are averages for four samples.

\* Indicates significant difference using the F test at the 0.05 probability level with the least significant difference for the means given.

NS indicates nonsignificant difference.

Table B4

Subflow Sample Differences, mg/l,  
Among Outlet Locations

Constituents	Concentration for Cited Model Section					Least Significant Difference
	West	Midwest	Mideast	East		
Manganese	0.04	0.05	0.04	0.08	*	0.02
Zinc	0.18	0.30	0.20	0.33	*	0.08
Calcium	5.0	5.7	7.7	8.7	*	2.4
Magnesium	7.3	6.5	7.8	8.6	*	1.5
Sodium	17.4	25.9	15.9	8.3	*	6.0
Potassium	0.45	0.48	0.48	0.52	NS	
Electrolyte	132.0	135.0	131.0	143.0	*	7.0
COD	1.3	2.9	0.3	0.5	*	2.1

Note: Values are averages for four samples.

\* Indicates significant difference using the F test at the 0.05 probability level with the least significant difference for the means given.

NS indicates nonsignificant difference.

Table B5  
Distribution of Runoff Volume, l

<u>Week</u>	<u>Volume for Cited Model Section</u>			
	<u>West</u>	<u>Midwest</u>	<u>Mideast</u>	<u>East</u>
21-23 Feb	7.23	19.72	25.85	9.84
26 Feb-2 Mar	10.32	18.66	28.67	10.46
5-9 Mar	13.37	19.58	11.73	21.12
12-15 Mar	16.66	19.50	14.41	20.50
19-22 Mar	14.62	17.06	13.00	17.86

Note: These are daily values averaged by week.

Table B6  
Distribution of Upper Subflow Volume, l

<u>Week</u>	<u>Volume for Cited Model Section</u>			
	<u>West</u>	<u>Midwest</u>	<u>Mideast</u>	<u>East</u>
21-23 Feb	0.19	1.00	4.37	2.06
26 Feb-2 Mar	0.12	1.15	4.06	1.68
5-9 Mar	0.08	1.63	4.97	1.50
12-15 Mar	0.04	1.57	4.62	1.61
19-22 Mar	0.0	0.93	3.74	1.67

Note: These are daily values averaged by week.

Table B7

Comparison of Upper with Lower Subflow Volume,  $\lambda$ 

<u>Week</u>	<u>Upper Subflow Side</u>			<u>Lower Subflow Side</u>		
	<u>West</u>	<u>East</u>	<u>Total</u>	<u>West</u>	<u>East</u>	<u>Total</u>
21-23 Feb	1.19	6.43	7.62	15.95	0.36	16.31
26 Feb-2 Mar	1.27	5.74	7.01	13.41	0.26	13.67
5-9 Mar	1.71	6.47	8.18	13.46	0.18	13.64
12-15 Mar	1.61	6.23	7.84	10.08	0.11	10.13
19-22 Mar	0.93	5.41	6.34	11.03	0.10	11.13

Note: These are daily values averaged by week.

Table B8

Distribution of Electrolyte in Subflow, mg/ $\lambda$ 

<u>Application Date</u>	<u>Upper Subflow Side</u>		<u>Lower Subflow Side</u>	
	<u>West</u>	<u>East</u>	<u>West</u>	<u>East</u>
23 Feb	58	62	28	
26 Feb	67	47	35	132
1 Mar	70	50	38	111
2 Mar	73	45	40	116
5 Mar	92	50	46	144
6 Mar	66	45	40	134
7 Mar	75	41	47	146
9 Mar	66	46	51	149
13 Mar	67	47	55	153
22 Mar	68	53	64	

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

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