THE USE OF A COMPUTER MODEL TO PREDICT WATER QUALITY TRANSFORMATIONS DURING SUBSURFACE MOVEMENT OF OXIDATION POND EFFLUENT

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Oxidation lagoons are increasing in popularity in the southwestern United States for the economical treatment of small quantities of domestic sewage. However, seepage may occur from the bottom of these lagoons, possibly endangering the quality of the groundwater.

This study was devised to 1) estimate seepage losses during the inception of a new oxidation lagoon; 2) monitor the subsurface movement of seepage water; 3) study the transformations in nitrogen and certain other quality characteristics during movement of effluent through the sediments above the water table and during mixing with the native groundwater; and 4) compare the field data on nitrogen transformations during vertical flow from the lagoon with parallel data from a predictive computer model.

The lagoon study site was located northwest of Tucson on Interstate 10 and Ina Road. The lagoon was constructed in 1970-1971 for an additional treatment area for the increasing amount of raw sewage from northwest Tucson. The lagoon, managed by the Pima County Sanitation Department, has a surface area of 10 acres (Fig. 1).

Three existing wells were encompassed by the lagoon after final construction of the dikes. These wells include 2 PVC sampling wells terminating within the zone of aeration at depths of 40 and 60 ft and a 100 ft steel access well designed to be used in conjunction with a neutron probe for obtaining moisture profiles.

A nearby irrigation well provided samples of the native groundwater before and during the operation of the lagoon. A critical depth flume located in the inlet line of the lagoon coupled with an automatic water stage recorder was used to meter the daily sewage flow into the lagoon (Fig. 2).

Raw sewage inflow averaged 0.80 mgd over the approximate 3 months of monitoring. Seepage rates were calculated from data on inflow, evaporation, and change in storage of the lagoon. The seepage rates ranged from 0.40 ft/d to 0.03 ft/d. Although the seepage rates were low, the total infiltration of the lagoon was high. Approximately 76 percent of all sewage entering the lagoon was lost as seepage.

Water samples were obtained from 40, 60, and 100 ft below the lagoon. These water samples together with samples of the lagoon water, were examined for coliform organisms, plus various physical and chemical constituents. After several days of lagoon operation, samples from the PVC wells illustrated a reduction in COD and coliforms due to the percolation of the effluent through the zone of aeration as compared to the COD and coliform values for the raw sewage. High nitrate levels, composed of indigenous nitrate and nitrate introduced into the soil from the effluent, appeared in the PVC wells.

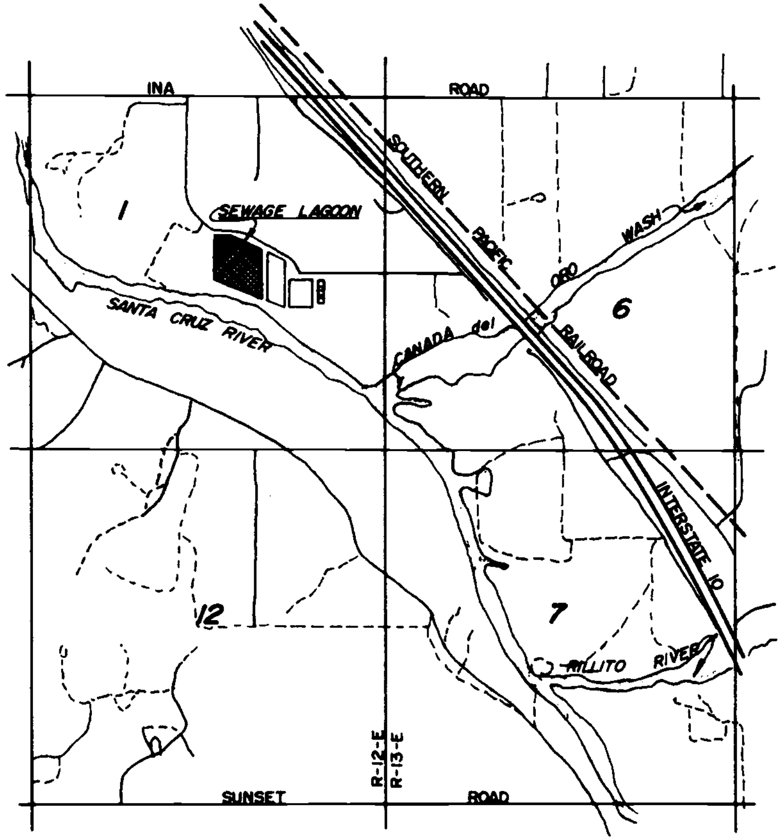

Figure 1. Location of Sewage Lagoon

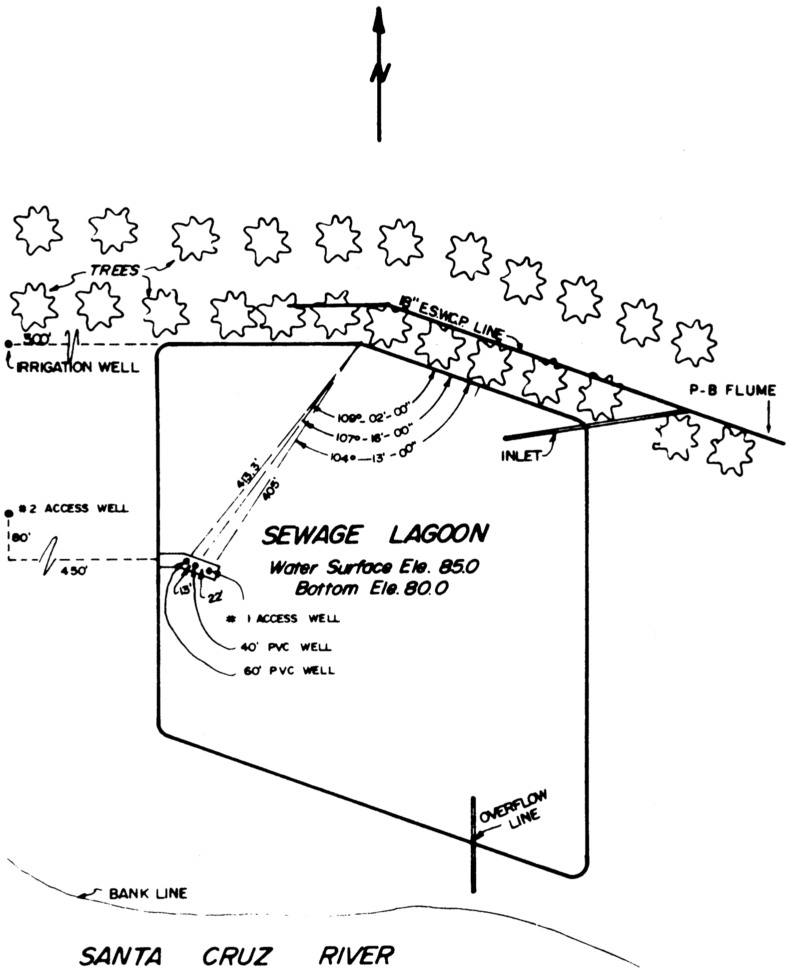

Figure 2. Location of Existing Wells in the Lagoon Vicinity

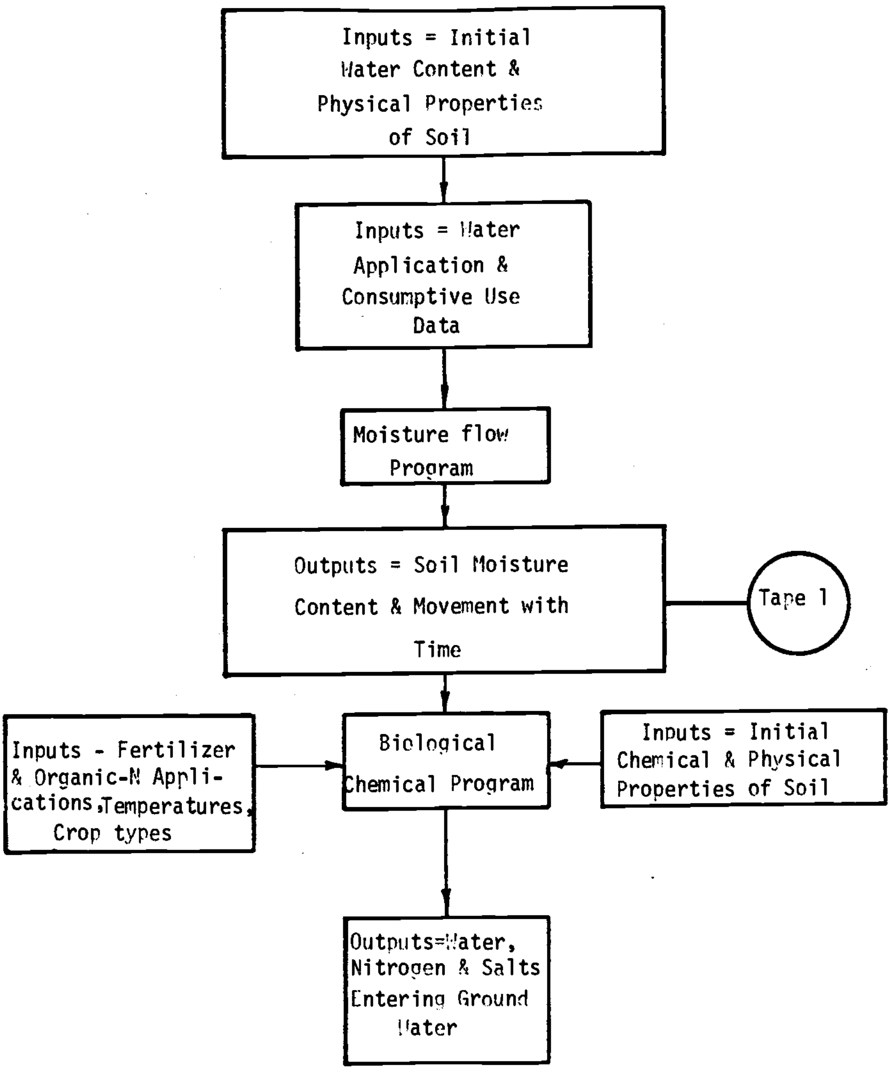

Figure 3. Generalized Block Diagram of the Computer Model (after Dutt et al., 1970)

Dissolved oxygen concentrations of the lagoon surface water reached supersaturation levels during the daylight hours although the benthic deposits on the bottom of the lagoon were approaching anaerobic conditions. This resulted in nitrification taking place in the upper lagoon waters and denitrification occurring in the benthic deposits.

Moisture logs showed substantial water content changes in the first 10 ft of sediment with only a slight water content change occurring at 40 and 60 ft. Even though the moisture logs indicate saturation in the first 10 ft of sediments enough air apparently remained trapped within the soil pores to permit nitrification of the infiltrated effluent and the indigenous nitrogen. Additional results were presented by Small (1973).

A computer model developed by Dutt, et al (1970) was used to approximate the change in nitrogen concentrations of the groundwater, employing the soil segment concept. This concept was adopted to approximate field variations, using mathematical relationships developed for homogeneous soil systems. The basis of the soil segment concept is the use of a finite number of equal length units of soil along the flow lines. Each soil segment is considered to be homogeneous and the same segment may or may not be considered to be homogeneous with its connecting segments.

The model assumes that the effects of solute-soil interaction on soil moisture flux are negligible in comparison with physical and biological properties effecting water movement, independent of chemical changes in the soil solution. Therefore the model is divided into two independent parts; the first deals with moisture movement, Moisture Flow Program, and the second deals with changes in chemical composition and distribution, Biological-Chemical Program.

In the execution of the model, the initial moisture contents and physical properties of the soil are inputs to the Moisture Flow Program as well as the amount and time of water applications and consumptive use data (Fig. 3). Using these inputs the Moisture Flow Program calculates the moisture content and movement at stipulated time intervals for each soil segment.

The output from the Moisture Flow Program is then used as input for the Biological-Chemical Program, along with temperature at various stipulated times and depths plus initial chemical parameters for the solutes being considered in each soil segment. Also serving as inputs are the amount and time of fertilizer applications plus the organic matter residues and the concentrations of solutes in the applied water. The Biological-Chemical Program calculates the chemical composition of the soil segments and the chemical composition of the water entering the water table.

The following list of assumptions was devised to simplify the modeling of the soil-water system [Dutt, et al (1970)].

1. No gaseous losses of nitrogen occurs. This assumption is valid when aerobic conditions exist in the soil, and urea and ammonia fertilizers are not applied on or near the land surface. The assumption would not hold in cases such as bog soils where restricted aeration exists, nor in cases where ammonia is easily lost as a gas.

2. The soil pH remains in the range 7.0 to 8.5. The effect of hydrogen ion activity on soil nitrogen transformations is approximately constant in this interval.

3. Symbiotic and non-symbiotic nitrogen fixation and fixation of ammonia in clay crystal lattices are small in magnitude by comparison with other nitrogen transformations considered in this research.

4. The ammonia-N mentioned in this study is total soil ammonia-N less that fixed in clay lattices and any ammonia gas.

5. Nitrites do not accumulate in the soil beyond trace amounts.

6. Fertilizers and other nitrogen additions are applied uniformly and thoroughly mixed with the soil.

7. The microbial populations of different soils are approximately equivalent in their responses to pertinent parameters associated with nitrogen transformations.

8. The upward movement of nitrogen species in the soil during evaporation of moisture is not significant.

9. The chemical composition of the soil (other than nitrogen species) has little effect on nitrogen transformations.

The following assumptions were necessary in order to model the nitrogen transformation and movement beneath an oxidation lagoon.

1. Initial-nitrogen concentrations in the first 10 ft of soil may be approximated by an average of the first 5 ft (NH_4-N, NO_3-N, and organic-N).

2. Initial-nitrogen from 10-60 ft may be approximated by well analysis at 60 ft (organic-nitrogen taken from soil analysis at the lower part of the first 5 ft).

3. The lateral and upward movement of water is negligible.

4. The temperature profile is independent of time.

5. The system remains aerobic at all times.

6. The infiltration rate of water is constant with respect to any one day.

7. Complete mixing occurs in each soil segment with respect to time and space.

8. Soil organic-nitrogen does not move.

9. Exchangeable NH_4-N does not move.

10. Soluble NH_4-N and NO_3-N moves with the water (no hold back volumes).

11. Local infiltration (seepage) rates can be approximated by average rates for the entire lagoon.

12. The NH_4-N and the NO_3-N concentrations of the input (lagoon) water remains constant. (Numbers are an average of several values).

13. The organic-nitrogen entering the soil with the lagoon water is insignificant.

14. (NO_2-N + NO_3-N) $\cong$ NO_3-N at all times.

15. No losses as NH_3 gas.

16. The carbon: nitrogen ratio of the soil's organic matter equals 10.0.

17. No water flow occurred on day one.

Water analyses from the 60 ft PVC well were compared with the results of the computer model (Table 1). A similar comparison of computer values with field values taken from a depth of 5 ft was not possible because of insufficient field data. The computer model predicted values for the complete nitrogen series: however, only the NO_3-N values could be compared. Deviation in the results were apparently due to river seepage which moved through a nearby sanitary landfill and into the 60 ft zone. The model assumed strictly vertical flow and did not account for horizontal flow of water through the soil profile. Furthermore, the model assumes aerobic conditions throughout the soil profile. The lagoon during filling was observed to shift from aerobic to the anaerobic state.

Table 1. Computer Model Prediction of NO_3-N Concentrations at the Water Table

Date	NO_3-N (mg/l) MEASURED	NO_3-N (mg/l) PREDICTED
8-12-71	39.0	40.9
8-19-71	55.0	41.0
8-26-71	55.0	44.4
9-2-71	57.5	45.3
9-15-71	18.5	45.3
9-22-71	32.0	41.4
9-29-71	21.0	35.6
10-13-71	26.0	22.9

Sealing of the lagoon did not occur in the first few months of operation. The combined effect of compaction by heavy equipment moving across the base of the lagoon during construction and the accumulation of sludge during filling did not promote sealing. The total volume of sewage infiltrated during the approximate 3 months of operation was 152 ac-ft. However, to date, no known contamination has occurred in the native groundwater from lagoon seepage in this area (Small, 1973).