STATE OF CALIFORNIA
EARL WARREN
Governor

FIELD INVESTIGATION
OF
WASTE WATER RECLAMATION IN RELATION TO GROUND WATER POLLUTION

1953

STATE WATER POLLUTION CONTROL BOARD
SACRAMENTO, CALIFORNIA

(1)

SWPCB Publication No. 6

Exhibit
1012
State of Minnesota v. 3M Co.,
Court File No. 27-CV-10-28862

FOREWORD

In an area such as California, where water becomes a limiting factor in growth and development, the possibilities of waste water reclamation take on special significance. Although sanitary engineers have acquired a knowledge of the kind of effluent that can be produced by waste treatment, much information is still needed on the use of treatment plant effluent for irrigation and for recharging underground water basins by means of spreading ponds or injection wells. The report contained in the following pages is the result of a field investigation on one phase of the problem of waste water reclamation—that of underground recharge by spreading.

This investigation was commenced in February, 1950, when the State Department of Public Health was designated by the Surgeon General of the U. S. Public Health Service as the California "state water pollution agency" for the purposes of the Federal Water Pollution Control Act (Public Law 845, 80th Congress) and, as such, became the recipient of a federal grant for research in the field of water pollution. Using funds from this grant, the department contracted with the University of California for a field investigation and research on waste water reclamation and utilization in relation to underground water pollution.

In March, 1951, the State Water Pollution Control Board was designated as the "state water pollution agency" for the purposes of Public Law 845, and the waste water reclamation study was continued under the sponsorship of the state board until its completion on June 30, 1952. Following submission of the final report by the university, the board authorized its publication and distribution.

The investigation was conducted by the university's Sanitary Engineering Research Project under the direction of Professor Harold B. Gotaas, and the investigative work was done principally by Mr. Arnold E. Greenberg of the project staff. The site chosen for the study was adjacent to the City of Lodi's sewage treatment plant. Through the cooperation of the Lodi City Council and with the assistance of Mr. H. D. Weller, City Manager, and Mr. Arthur Heckenlaible, City Engineer, facilities of the city's treatment plant were made available to the university.

As outlined in more detail in the preface to the report, this investigation was made (on specially prepared test plots) primarily for the purpose of determining rates of percolation through different soils, optimum spreading periods, extent of penetration of mineral and organic matter in the waste water, changes in mineral and organic characteristics of both soil and waste water, degree of treatment necessary, and costs of spreading operations.

Although the investigation reported herein was conducted under the sponsorship and direction of the State Department of Public Health and the State Water Pollution Control Board, the conclusions and recommendations given in the report are those of the research contractor and do not reflect opinions or policies of the contracting agencies.

[redacted]

FINAL REPORT

ON

FIELD INVESTIGATION AND RESEARCH ON WASTE WATER RECLAMATION AND UTILIZATION IN RELATION TO UNDERGROUND WATER POLLUTION

Conducted at Lodi, California
and prepared for

STATE OF CALIFORNIA
STATE WATER POLLUTION CONTROL BOARD
STANDARD SERVICE AGREEMENT No. 14 A-1

By

UNIVERSITY OF CALIFORNIA
SANITARY ENGINEERING RESEARCH PROJECT
BERKELEY, CALIFORNIA

June, 1952

LETTER OF TRANSMITTAL

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1301 SOUTH 46TH STREET, RIC

State Water Pollution Control Board
305 Financial Building
927 Tenth Street
Sacramento, California

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PREFACE

Organization of Study

The investigation of waste water reclamation in relation to ground water pollution herein reported was conducted by the Sanitary Engineering Research Project of the University of California. During the Fiscal Year 1949-50 and the first nine months of the Fiscal Year 1950-51 the State Department of Public Health was designated "state water pollution agency" of California for the purposes of the Federal Water Pollution Control Act (Public Law 845). In accordance with Section 8(a) of the act, the department entered into contracts with the Regents of the University of California under which funds were provided to support waste water reclamation studies by the University.

On March 30, 1951, the State Water Pollution Control Board was designated as the "state water pollution agency." This board continued the policy of supporting research on waste water reclamation and provided an additional grant of Public Law 845 funds to support the Project until its termination on June 30, 1952.

The study was made under the general direction of Professor Harold B. Gotaas, Chairman, Division of Civil Engineering and Irrigation of the University. Vinton W. Bacon, as Assistant Director of the Sanitary Engineering Research Project, developed and guided the study at its inception, with the assistance of Dr. Jerome F. Thomas, and Raymond V. Stone, who later succeeded Mr. Bacon as assistant director. Professor Harvey F. Ludwig directed a considerable portion of the work before joining the staff of the U. S. Public Health Service. Throughout the final eighteen months of the study Arnold E. Greenberg was responsible for the conduct of the field work. The final report was prepared for publication by Mr. Greenberg with the editorial assistance of P. H. McGauhey, Assistant Director.

Purpose of Study

The purpose of the project as set forth in the Standard Service Agreement (No. 1472) between the State Department of Public Health and the Regents of the University of California under date of February 14, 1950, and as continued in Standard Service Agreement No. 14 A-1 with the State Water Pollution Control Board, was as follows:

> "For the performance of laboratory and field investigations on specially prepared small test plots in order to determine the following:
>
> (1) Rate of percolation of industrial waste and sewage effluents on different soil types during spreading operations;
>
> (2) Optimum spreading and resting periods to obtain maximum rates of percolation;
>
> (3) Extent and degree to which mineral and organic matter (including bacteria) in the water will penetrate different soils;
>
> (4) Changes in mineral and organic characteristics of both soil and water at different depths during percolation;

(5) Degree of treatment necessary for industrial waste and sewage to obtain satisfactory percolation rates, protection against contamination and nuisances (odors, etc.) and protection of underground water supply;

(6) Cost of spreading, as far as this is incidental to research."

Acknowledgments

The Project is indebted to numerous individuals whose labor, advice, and counsel helped make the study possible. Grateful acknowledgment is made to Professors Wilfred F. Langelier, Erman A. Pearson, and Bernard A. Tebbens for their ideas and advice throughout the duration of the study; to Frank M. Stead and Edward A. Reinke and others of the State Health Department, and to T. R. Simpson and others of the Division of Water Resources for assistance in planning the study; to Arthur Heckenlaible, City Engineer of the City of Lodi, for his cooperation; and to Dr. Paul R. Day, Professor of Soil Physics, for his valuable advice.

Acknowledgment is also made to members of the Project staff who worked on the investigation and the report; especially, George E. Bell, John M. Stewart, William D. Ward, Arnold J. Hoffman, Ray B. Krone, Frank O. Doughty, Constance Krehoff, and Margaret Cathcart; and to Lodi Sewage Plant operators, Waldon L. Klaffke and Alvin C. Inman.

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Summary

For a period of 28 months the Sanitary Engineering Research Project of the University of California investigated the reclamation of water from sewage by spreading. This work was supported by federal funds granted under Public Law 845 and administered at first by the State Department of Public Health and later by the State Water Pollution Control Board, and by funds contributed by the University of California.

The principal objectives of the investigation included a study of spreading on field plots to determine the following:

1. Rate of percolation of industrial waste and sewage effluents on different soil types during spreading operations.
2. Optimum spreading and resting periods to obtain maximum rates of percolation.
3. Extent and degree to which mineral and organic matter (including bacteria) in the water will penetrate different soils.
4. Changes in mineral and organic characteristics of both soil and water at different depths during percolation.
5. Degree of treatment necessary for industrial waste and sewage to obtain satisfactory percolation rates, protection against contamination and nuisance (odors, etc.) and protection of underground water supply.
6. Cost of spreading, as far as this is incidental to research.

A site suitable for such a study was selected adjacent to the sewage treatment plant in the City of Lodi, California. Eight circular spreading basins, 19 feet in diameter, were constructed with sheet metal dikes. Four of the basins were equipped with sampling facilities so that samples of the percolating liquid could be collected for bacteriological and chemical analyses at 1, 2, 4, 7, 10 and 13 feet below the ground surface. Spreading was studied with three liquids: fresh water, sewage treatment plant final effluent having a BOD of about 10 ppm, and settled sewage with a BOD of about 100 ppm.

A number of operating variables were studied in order to determine the conditions leading to maximum percolation rates and minimum contamination or pollution of the ground water. These variables included:

1. The nature of the liquid being spread.
2. The length of the spreading period.
3. The length of the resting period.
4. The effect of surface treatment such as spading, the use of a sand cover, and the application of a soil stabilizer.

After the termination of the field study the installations were dismantled and a careful study made of soil conditions and sampling devices.*

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* See Addendum, page 77 et seq.

Conclusions

1. A bacteriologically safe water can be produced from settled sewage or from final effluent if the liquid passes through at least four feet of soil.

2. A water of satisfactory chemical quality can be produced from settled sewage or from final effluent, providing high concentrations of undesirable industrial wastes are not included in the raw sewage.

3. A highly treated sewage plant effluent must be used for spreading in order to obtain high rates of percolation.

4. A percolation rate of at least 0.5 acre-feet per acre per day can be expected when spreading a final effluent on a Hanford fine sandy loam.

5. The optimum method of spreading basin operation is to spread continuously for about a month, preferably with a liquid containing large amounts of organic matter, then to allow the basin to rest until the moisture content is reduced to about the permanent wilting point. Thereafter, cultivation of the dry soil seems desirable. Following this preliminary treatment, continuous application of a final effluent may be carried on for as long as six months. Resting and cultivation may then be repeated.

6. Mosquitoes in spreading basins will create a nuisance and health hazard unless control measures are adopted. If algal odors are pronounced, the control of algae may also be necessary.

7. Further investigations of percolation of sewage in different soils, and of phenomena associated with the movement of water into such soils, are needed in order to generalize the foregoing conclusions reached as a result of this study with Hanford fine sandy loam.

INTRODUCTION

The reclamation of sewage has been practiced for many years. Cesspools and septic tanks have returned sewage effluents to the soil for centuries. Sewage farms and farms utilizing sewage effluents have done likewise. Reclamation of this type has been termed incidental (1-3) since the reclamation of water is incidental to the disposal of sewage. Planned reclamation, as distinct from incidental reclamation, is a more recent development. It is designed specifically to produce a usable water from sewage. Not only may water be produced for use in industry (4) and agriculture (5) but it may also be returned to the ground water by means of surface spreading or injection wells. In water shortage areas such as parts of California where large quantities of sewage are now being discharged to the ocean, planned reclamation is receiving serious consideration, since it may relieve the overdraft on local water resources more economically than by the importing of water from distant places or by the distilling of sea water (6, 7).

One of the first planned operations for the reclamation of sewage water by spreading was begun in Los Angeles, California, in the early 1930's. It was demonstrated (8) that a highly polished sewage treatment plant effluent could be spread on soil, thereby contributing significantly to the ground water without impairing its quality. A percolation rate of 3 acre-feet per acre per day was considered feasible. A later review of sewage salvage (9) presented a viewpoint not now generally accepted in California: namely, that planned reclamation programs for ground water replenishment were rare and usually unsound economic ventures. A survey conducted by a Board of Engineers of Los Angeles County (1) concluded that safe additions may be made to the ground water and, further, that the cost of water reclaimed from sewage is competitive with that of water obtained from other sources. Included in their report was a description of an experimental spreading basin at the Whittier sewage treatment plant. The same agency made a subsequent study at the treatment plant in Azusa. The results of both operations were described by Stone and Garber (10). These authors concluded that percolation rates of about 2 feet per day could be expected in spreading a final sewage treatment plant effluent on a relatively coarse soil. Freeman (6) in a report to the Santa Clara Water Conservation District recommended that a well polished effluent could be spread at a safe rate of 0.5 acre-feet per acre per day and that no significant changes in the ground water quality would result. Still another review (3) stated that planned reclamation works, in water shortage areas, were definitely competitive in cost with other methods of obtaining additional water.

Although investigations made during the past 20 years presented some conflicting data, they supported the general view that reclamation of sewage by spreading is both safe and practical. It was therefore deemed worthwhile to continue such investigations, placing special emphasis on the fundamental problems involved. Accordingly, such a project was undertaken by the University of California at Berkeley.

SITE FOR THE FIELD SPREADING STUDY

In March of 1950, after consulting with a number of agencies in the State which had done test work on spreading and percolation of fresh and reclaimed waters, preparations were made for the selection of a site and the construction of spreading basins.

To obtain conditions approximating those which might be encountered in an actual spreading operation, it was decided to conduct the investigation at a sewage treatment plant which received both industrial and domestic wastes. For ideal conditions such a plant and spreading site should provide:

1. A sewage treatment plant employing both primary and secondary treatment.
2. An area adjacent to the plant suitable for spreading operations.
3. A soil which is not too impervious.
4. An underground water table 20 or more feet below ground surface.
5. A location not too distant from the university laboratories.

With these criteria in mind, members of the Sanitary Engineering Research Project staff and representatives of the Bureau of Sanitary Engineering of the State Department of Public Health studied eleven sewage treatment plants within a radius of 200 miles of Berkeley. These plants were located at Alisal, Chowchilla, Fresno, Gilroy, Lodi, Madera, Manteca, Morgan Hill, Salinas, Tracy, and Turlock (Table 1). Although each of these plants provided sewage treatment facilities, unsuitable soil conditions or high water tables immediately eliminated all but two plants from further consideration. These plants were located at Lodi and Turlock, and they were investigated thoroughly before making the final choice of site.

Test borings made at Turlock showed the presence of an impervious hardpan at depths between 2 and 4½ feet, which made this site unsatisfactory. At Lodi, occasional lenses of impervious clay were found at depths varying from 8 to 20 feet below the surface. It appeared possible, however, to select an area of sufficient size for the needs of this study in which the clay stratum was 13 or more feet from the surface.

The site at Lodi, as measured against the five criteria for an ideal site, showed it to be generally satisfactory.

1. Provision of Primary and Secondary Sewage Treatment

The sewage treatment plant is an activated sludge plant about 30 years old (Figs. 1 and 2) treating an average of 2.0 million gallons per day. The raw sewage passes through a coarse bar screen, a revolving mechanically cleaned fine screen, and then directly into the aeration tank. The mixed aeration tank liquor passes to a sedimentation tank where separation of the solids from the liquid is affected. Both the liquid and solid phases of the treated sewage are discharged through separate closed channels to a stream five miles distant from the plant.

The biochemical oxygen demand (BOD) of the effluent ranges from 10 to 15 parts per million (ppm). The turbidity is of the same order of magnitude.

TABLE 1

SITES INVESTIGATED FOR FIELD SPREADING STUDY

Location	Sewage treatment provided	Spreading area available Acres	Soil	Water table Feet	Distance from Berkeley Miles	Remarks
Alisal	Bio-filter	<1	Hard pan-adobe		100	Impervious soil
Chowchilla	Bio-filter				140	Plant completed May 1950
Fresno	Primary	1,300	Sandy loam	15	200	Distant from Berkeley
Gilroy	Primary with land disposal	10	Heavy loam		80	Impervious soil
Lodi	Activated sludge	15	Sandy loam	25	80	Satisfactory
Madera	Bio-filter				150	Plant completed May 1950
Manteca	Primary bio-filter with land disposal	>10	Sandy with shallow hard pan	4-5	70	Impervious soil and high water table
Morgan Hill	Imhoff tank, trickling filter with land disposal	10	Very tight		70	Impervious soil
Salinas	Roughing filter and two stage bio-filter	4	Adobe	<8	100	Impervious soil and high water table

It will be noted that the plant produces a good final effluent although a primary effluent (settled sewage) is unobtainable. The absence of conventional primary treatment was not of major importance since settled sewage could be provided at little additional cost.

2. *Area Suitable for Spreading*

The sewage treatment plant is located outside the city limits and with the exception of the operator's residence there are no dwellings within a radius of 200 yards. Immediately adjacent to the plant is a 15-acre field owned by the city. A portion of this field was available for the spreading study.

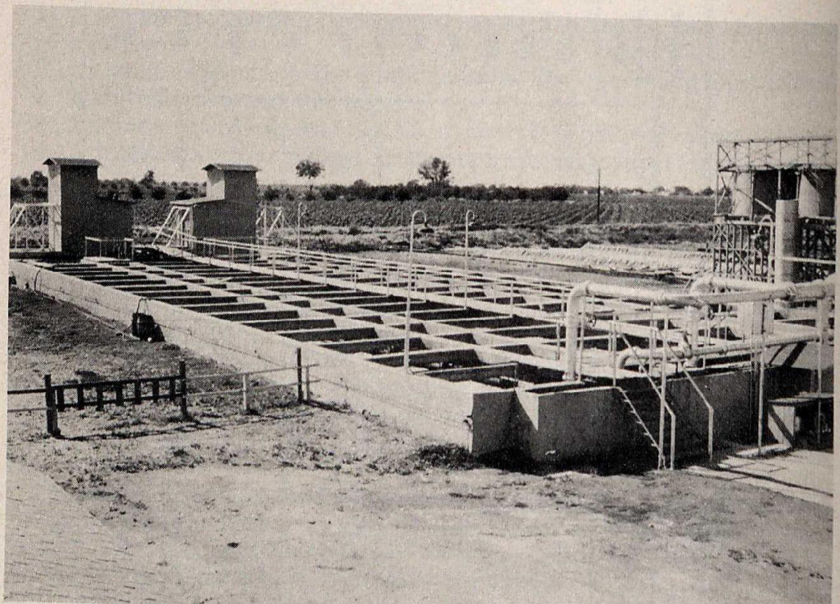


FIGURE 1. Aeration and sedimentation basins, Lodi sewage treatment plant

3. *A Soil Which Is Not Impervious*

Prior to and during the construction of the spreading basins, samples of the soil taken from the basin area were collected and analyzed in the project laboratories.

The soil profile is illustrated in Figure 3. The soil is classified as a Hanford fine sandy loam. This soil type is a recent alluvial soil which overlays uncompacted alluvium. It is neutral in reaction in both the surface and subsoil. Figure 3 shows that although there are occasional clay lenses, permeable conditions generally exist to a depth of about 13 feet. On the basis of texture and structure, conditions limiting the infiltration rate exist on the surface rather than immediately below it. (See Appendix A for detailed soil profiles.)

Particle size distribution was determined on samples collected during the construction of the basins. Sand sizes were measured by sieving and soil particles having a diameter less than 0.05 mm were determined

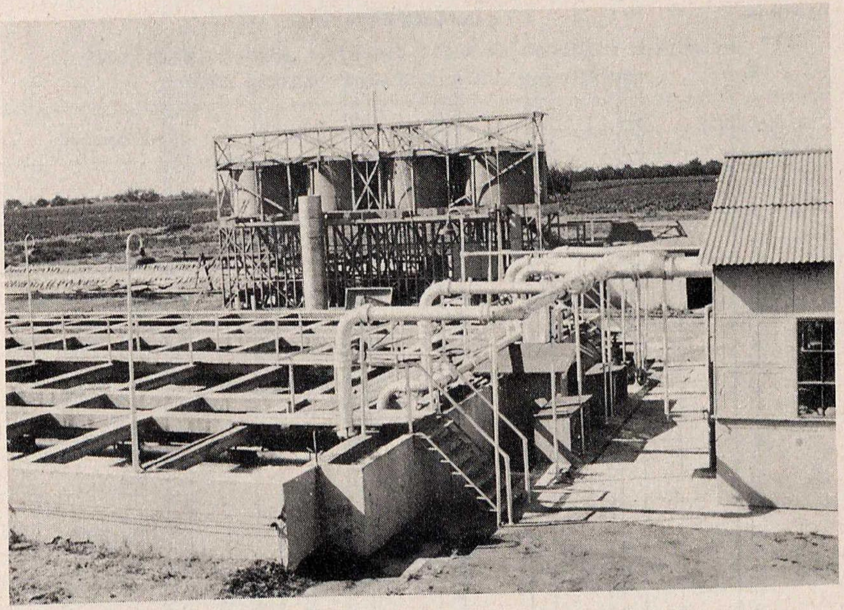


FIGURE 2. Elevated storage tanks, Lodi sewage treatment plant

by use of a soil hydrometer (11). The particle size distribution in four basins is shown graphically in Appendix A. The effective size and uniformity coefficients (Hazen) are tabulated in Table 2. The fractions of clay, silt and sand are presented in Table 3.

Permeability of undisturbed soil cores was determined on surface samples in the conventional manner. (See Appendix B.) The values obtained are given in Table 4. These permeabilities must be considered as maximum possible rates rather than as average expected rates, since the tests were not conducted over a suitably long period of time to give

TABLE 2

VARIATIONS OF EFFECTIVE SIZE AND UNIFORMITY COEFFICIENT WITH DEPTH IN FOUR SPREADING BASINS, LODI, CALIFORNIA

Depth in feet	A		B		C		D	
	E. S.*	U. C.†	E. S.	U. C.	E. S.	U. C.	E. S.	U. C.
1	0.0056	45.5	0.0035	85.7	0.0032	67.3	0.0018	77.9
2	0.0019	116.0	0.0027	92.6	0.0025	96.0	0.0018	50.0
4	0.0036	66.7	0.0038	52.6	0.0014	111.0	0.0053	45.3
7	0.0420	11.9	0.0024	175.0	0.1550	3.2	0.0074	32.5
10	0.1200	4.3	0.1700	3.6	0.1600	3.1	0.0150	16.0
13	0.0800	7.9	0.0012	241.0	0.0026	25.4	0.0019	105.0
Average	0.0422	42.1	0.0306	108.0	0.0541	51.0	0.0055	54.5

* Effective size of Hazen in mm.

† Uniformity coefficient of Hazen.

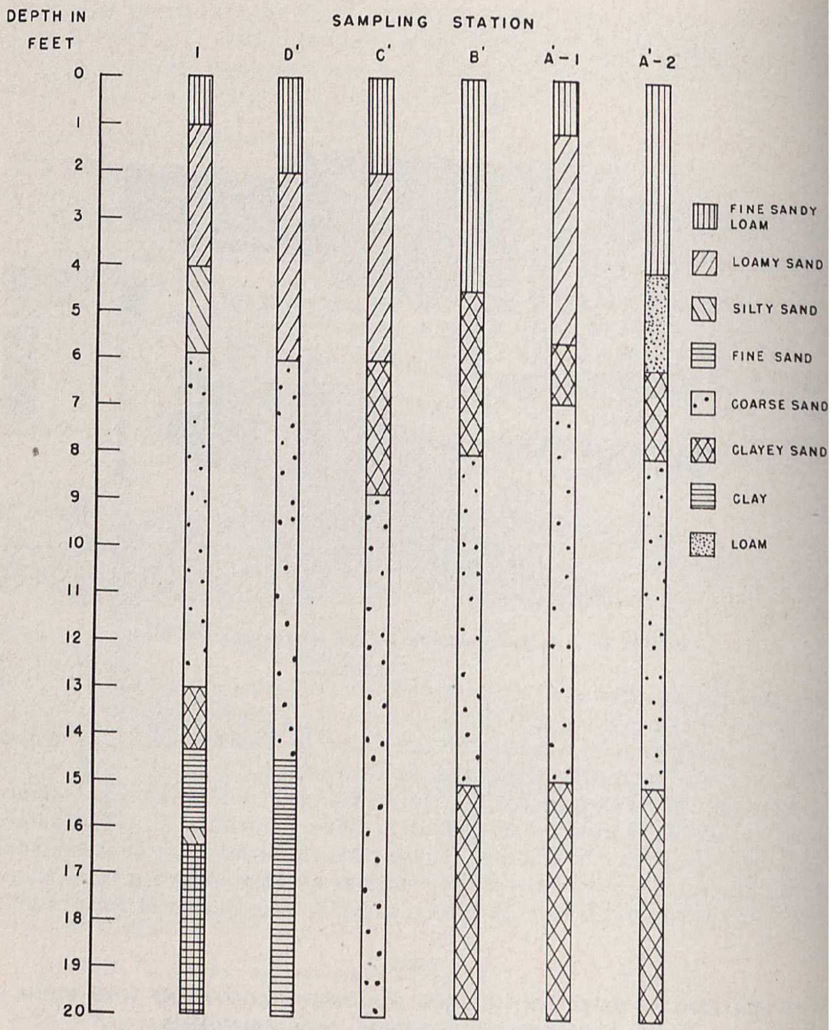


FIGURE 3. Profile sketch of spreading basin area, Lodi, California

average rates. Permeabilities of disturbed soil samples are shown in Appendix A. These values are of relative rather than absolute significance. A close correlation exists between the relative permeabilities of the different strata and their textures.

In addition to the above mentioned analyses soil samples were analyzed for the base exchange complex. The results are in Table 5.

The high proportion of divalent ions would be conducive to a high degree of aggregation of the clay fraction in the natural surface soil. Of particular interest is the large amount of magnesium relative to the calcium. The relationship appears typical of California soils.

TABLE 3

FRACTIONS OF CLAY, SILT, AND SAND AT DIFFERENT DEPTHS IN FOUR SPREADING BASINS, LODI, CALIFORNIA

Depth in feet	Basin	Percent clay[1]	Percent silt[2]	Percent sand[3]
1	A	8	16	76
	B	9	12	79
	C	8	28	64
	D	11	43	46
2	A	11	18	71
	B	10	13	77
	C	11	15	74
	D	15	33	52
4	A	9	18	73
	B	8	24	68
	C	15	22	63
	D	8	22	70
7	A	6	6	88
	B	8	12	80
	C	0	5	95
	D	8	16	76
10	A	3	2	95
	B	1	6	93
	C	2	1	97
	D	4	14	82
13	A	5	3	92
	B	11	17	72
	C	7	51	42
	D	11	28	61
Average	A	7.0	10.5	82.5
	B	7.8	14.0	78.2
	C	7.2	20.3	72.5
	D	9.5	26.0	64.5

[1] Clay: Defined as particles less than 0.002 mm.
[2] Silt: Defined as particles greater than 0.002 mm but less than 0.050 mm.
[3] Sand: Defined as particles greater than 0.050 mm but less than 2.0 mm.

Although variations existed among the basins and clay lenses were present, the soil was deemed satisfactory for use in a spreading study. Consideration of the variations among the basins and the effect of these variations on experimental results was given and are discussed elsewhere in this report.

4. Low Water Table

The ground water level is at least 22 feet below the ground surface.

5. Distance From Laboratories

Lodi is located approximately 80 miles from Berkeley. Public transportation facilities are available so that samples collected in the morning can be received in the laboratory early that same afternoon.

On the basis of the preceding analysis of the site available at the Lodi Sewage Treatment Plant it was selected as best suited to this study. Permission was granted to the University by the City Council of Lodi to use the facilities of its sewage treatment plant.

TABLE 4

PERMEABILITY OF SURFACE SOIL CORES IN FOUR SPREADING BASINS, LODI, CALIFORNIA*

Basin	Permeability (feet per day)
A	0.96
B (north)	0.89
B (south)	0.72
C	3.91
D (north)	2.73
D (south)	2.89

* Undisturbed soil cores.

TABLE 5

BASE EXCHANGE COMPLEX OF SURFACE SOILS IN SPREADING BASINS LODI, CALIFORNIA

Sampling station	Milli-equivalents per 100 grams of soil				
	Ca	Mg	Na	K	Total
1	2.8	1.5	Trace	0.28	4.6
1 (subsoil)*	3.1	1.7	Trace	0.37	5.2
A′	3.8	2.6	0.72	0.42	7.5
A′	4.2	3.2	0.73	0.56	8.7
A′	4.4	3.7	0.70	0.37	9.2
B′	3.9	1.8	0.77	0.51	7.0
B′	4.1	1.9	0.76	0.51	7.3
B′	3.8	2.9	0.58	0.69	8.0
C′	4.2	2.3	0.64	0.60	7.7
C′	3.3	2.5	0.76	0.60	7.2
C′	3.8	2.2	0.76	0.55	7.3
D′	3.3	3.4	0.67	0.64	8.0
D′	4.2	3.8	0.72	0.66	9.4
Average	3.8	2.7	0.65	0.53	7.7

* Not included in average.

CONSTRUCTION OF FIELD SPREADING BASINS

Initially, four test basins, each 19 feet in diameter, were constructed (Figs. 4-14). Prior to making the actual basins, sampling wells were installed. Holes, 38 inches in diameter and 15 feet deep, were dug by a cesspool drilling rig. A caisson of 36-inch diameter corrugated galvanized iron pipe 15 feet long, with access windows at the 1, 2, 4, 7, 10 and 13-foot levels, was dropped into each hole (Fig. 4). The one-inch annular clearance around the pipe was backfilled with soil which was tamped into place in order to prevent the free flow of water down the side of the caisson. Soil was mounted to a height of one foot around the caisson at the ground surface (Fig. 5). All joints in the uppermost five feet of the caisson were welded to prevent leakage.

Ladders and shelves were built into each well making it possible to reach the access windows readily (Fig. 6). Lateral tunnels only slightly larger than the sampling pans were dug out at each access window (Fig. 7). A minimum clearance of one foot between the caisson and the pan was allowed. The collecting pans (Fig. 8) are approximately 10 inches by 10 inches by 18 inches outside dimensions, constructed with false bottoms, and sloped to a ¼-inch section of tubing soldered at the discharge end. Rubber tubing was connected to the metal nipple, providing a lead into the sampling well. Each pan was filled with sand and gravel as follows: The bottom layer, comprising ¼ of the pan volume, was filled with ⅛-inch to ¼-inch gravel; the next layer, ⅜ of the pan volume, was filled with 1/16-inch to ⅛-inch gravel; the remainder of the pan was

FIGURE 4. Sampling wells in place

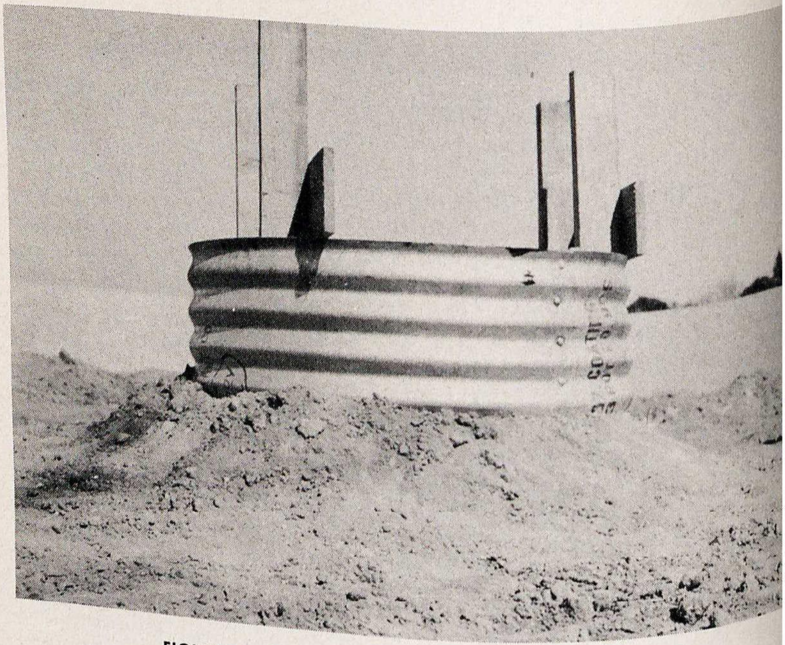


FIGURE 5. Sampling well, showing ladder and earth mound

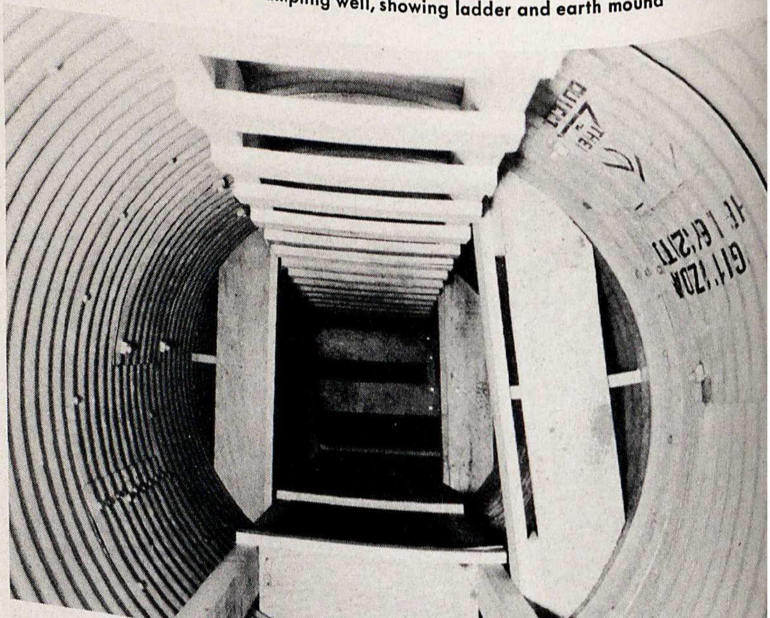


FIGURE 6. Sampling well, showing ladder, sample collecting trays, and sampling ports

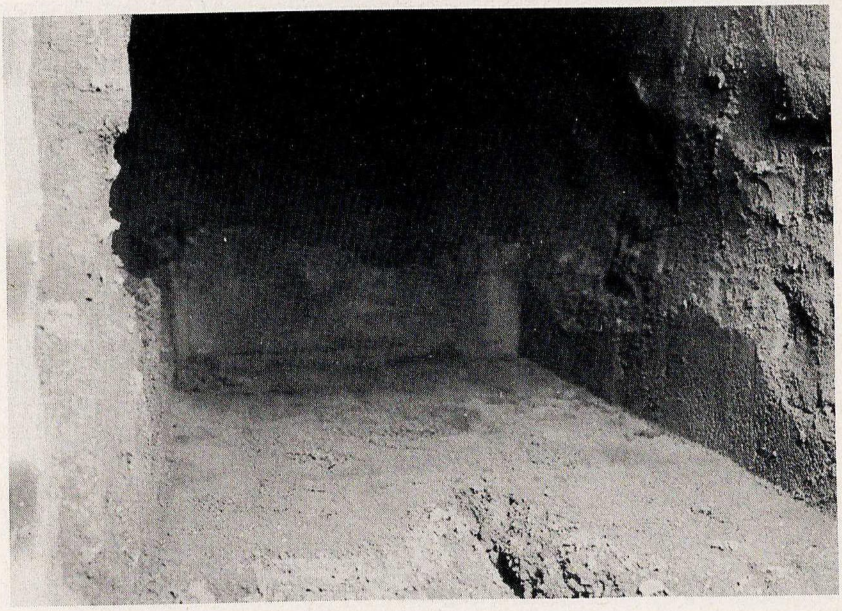


FIGURE 7. Lateral tunnel prior to insertion of collecting pan

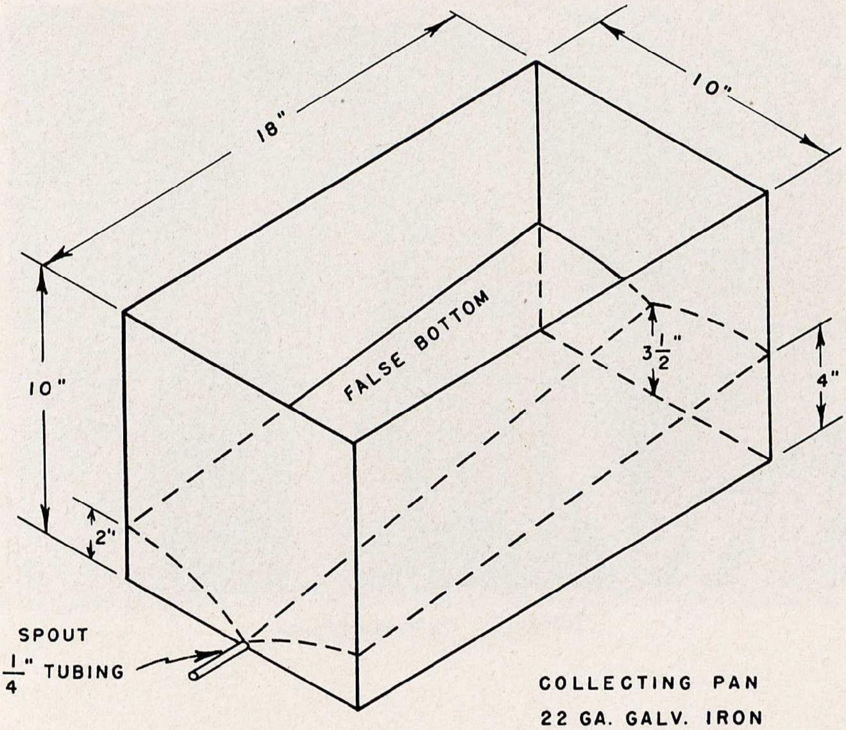


FIGURE 8. Isometric view of galvanized sheet metal sample collecting pan

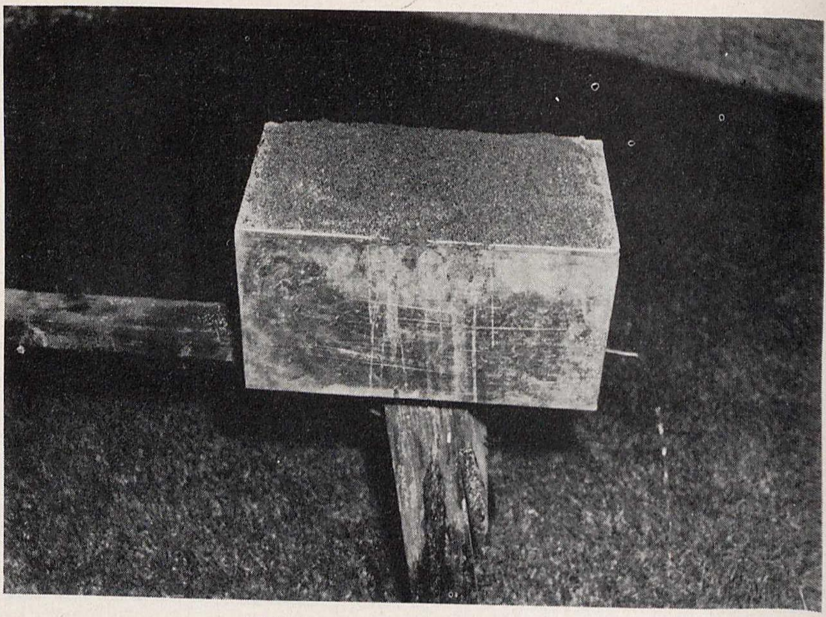


FIGURE 9. Testing filled sampling pan

FIGURE 10. Placing sampling pan

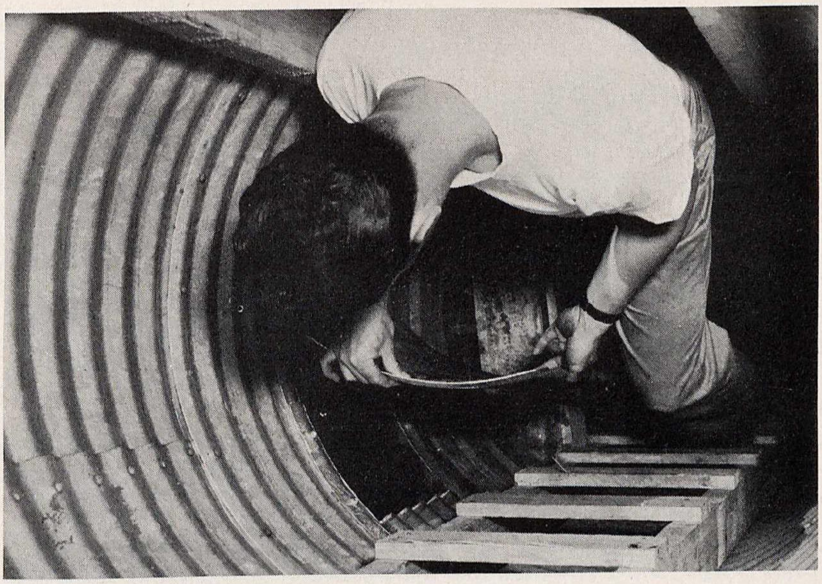


FIGURE 11. Replacing access window

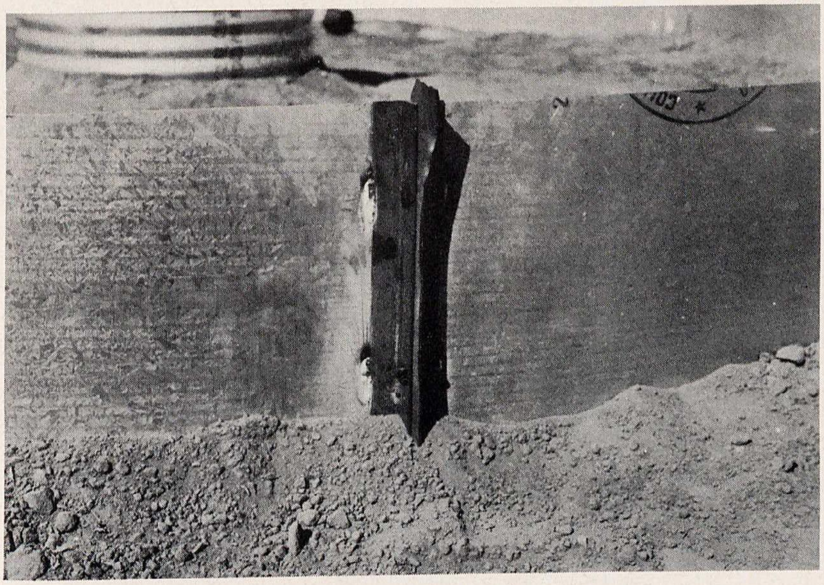


FIGURE 12. Dike joint detail

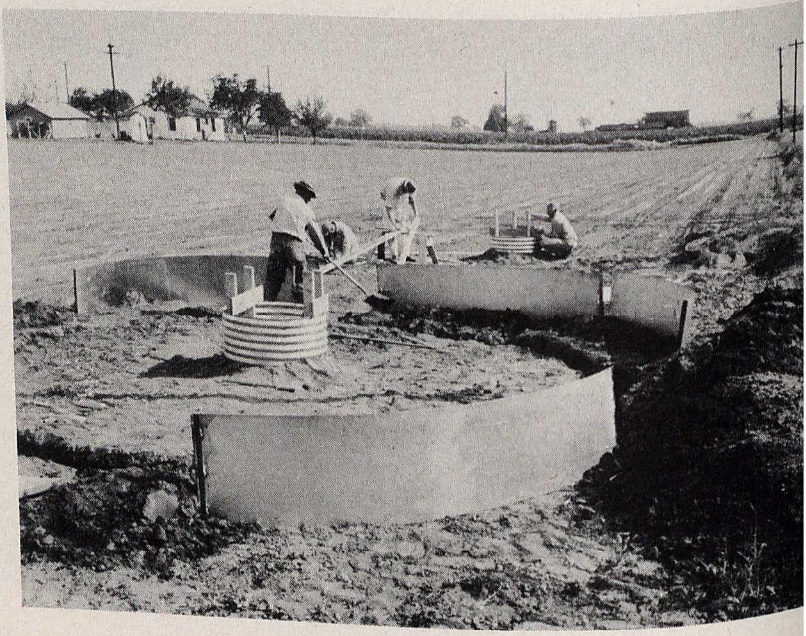


FIGURE 13. Digging trench for dike

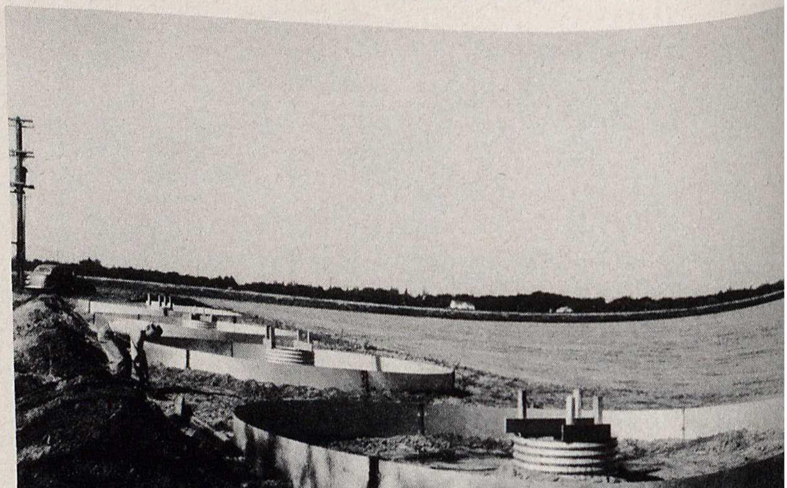


FIGURE 14. Completed spreading basins

filled with 1/30-inch to 1/20-inch sand (Fig. 9). The filled pans were slid into the tunnels and packed into place (Fig. 10). Field soil was used as packing to insure complete soil-sand contact. The clearance space between pan and caisson was backfilled and the access window bolted on after leading the sampling tube through it (Fig. 11).

The spreading basins were formed from 14-gauge metal sheets, 24-inch by 120-inch, bolted together to form a dike (Fig. 12). The dikes were set into circular trenches which were backfilled and mounted to prevent seepage under the dikes (Fig. 13). The dikes extend 14 inches above the ground surface (Fig. 14). To minimize lateral water flow, earth dikes, 25 feet square, were built around each test basin.

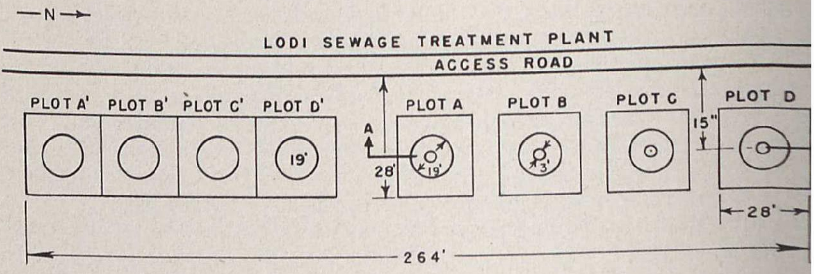
Figure 15 shows a plan of the test basins as well as the layout of the sampling points.

Modifications of the existing piping system at the Lodi Sewage Treatment Plant were necessary to convey the plant effluent to the elevated storage tanks (Fig. 2). These tanks are four in number, of 5,000 gallon capacity, and are 15 feet above ground. Enough head is available so that a gravity feed from the storage tanks to the spreading basins is possible. Each tank is connected through a 6-inch manifold to a 4-inch diameter house connection transite sewer pipe leading directly to the basins. Originally, two 1-inch by 5/8-inch water meters measured the amount of liquid spread on each basin and cattle feed float valves were used to maintain constant liquid depth. These devices for metering liquid flow and maintaining constant head soon proved unsatisfactory. They were removed and a manually operated intermittent liquid application system was used. A small stilling well was set into each basin so that measurements of the liquid depth could be made with a hook gage.

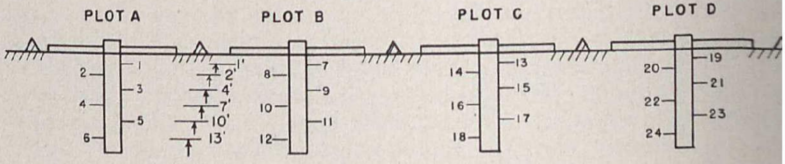
To provide primary effluent for spreading purposes an elevated 3,000-gallon sedimentation tank was built. This was operated on a fill and draw basis as needed.

During the summer of 1951 four additional spreading basins were constructed for studying percolation rates. These are identical to those already described except that no sampling facilities were provided.

A flow diagram of the sewage treatment plant and of the spreading basin facilities is shown in Figure 16.

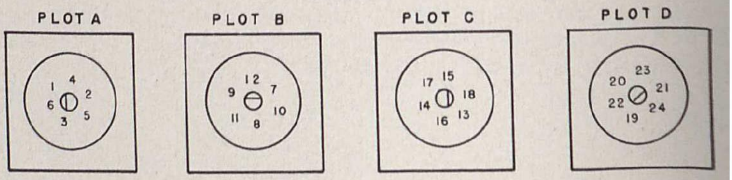


TEST BASIN PLAN



SECTION A-A, ELEVATION

(SHOWING ELEVATION OF SAMPLING PANS)



SECTION A-A, PLAN

(SHOWING LOCATION OF SAMPLE PANS AND LADDERS)

FIGURE 15. Spreading basin layout, Lodi, California

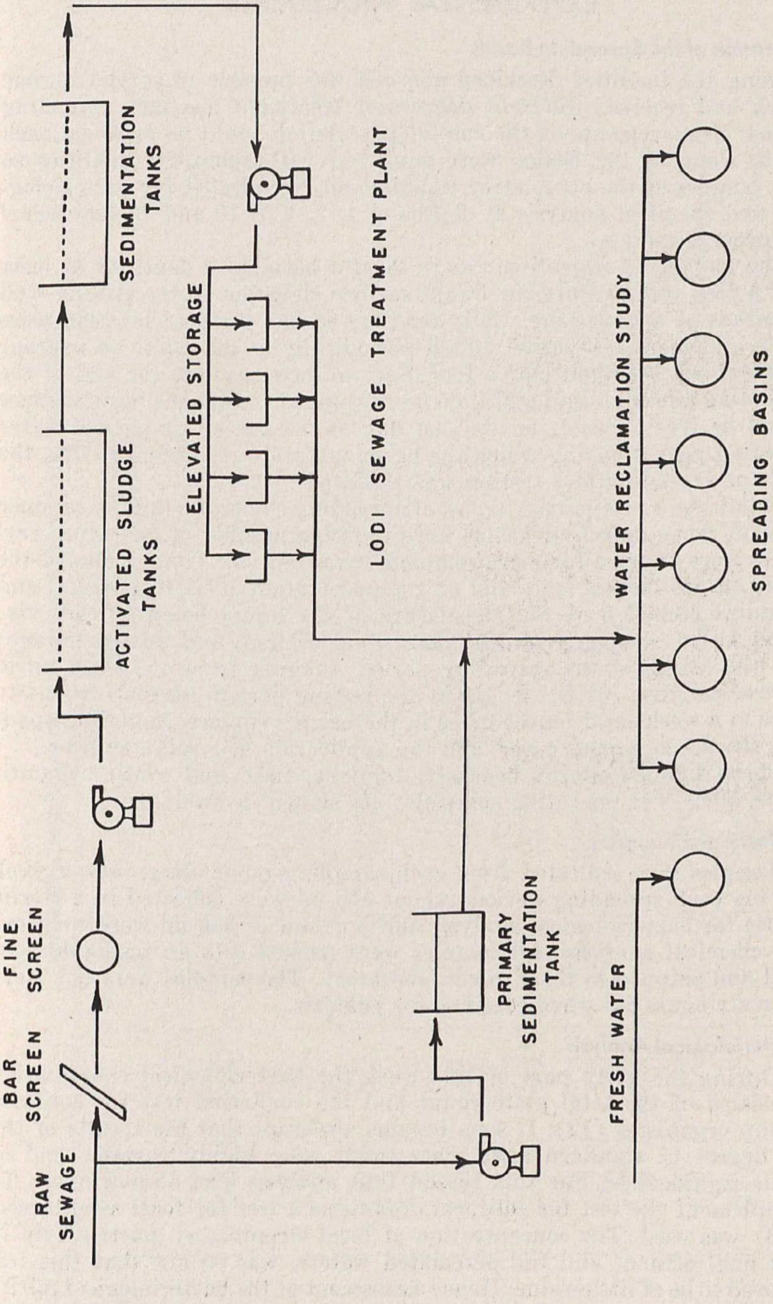


FIGURE 16. Flow diagram water reclamation study, Lodi, California

EXPERIMENTAL PROCEDURES

Operation of the Spreading Basins

Using the facilities described above it was possible to spread sewage which had received different degrees of treatment on eight spreading basins. Measurements of the rate of percolation could be made on each basin. Four of the basins were equipped with sampling facilities so that samples of the percolating liquid could be collected for bacteriological and chemical analysis at depths of 1, 2, 4, 7, 10 and 13 feet below the ground surface.

The method of operation was to flood a basin to a depth of at least half a foot and measure the liquid surface elevation in the stilling wel by means of a hook gage. Daily readings of the surface elevation wer made and more test liquid added periodically to maintain an averag depth of not less than half a foot. Several days prior to the end of th spreading period, liquid additions were stopped so that the basin surfac would be free of water on the last day of the spreading period. Afte a resting period during which the basin surface was allowed to dry, th cycle of spreading and resting was repeated.

Following a preliminary series of spreading cycles during the summe of 1950, when only four basins were in use, a number of operating var iables were selected for more complete investigation. These included th effect on percolation rates and on the penetration of bacteriological an chemical pollution of (1) the nature of the liquid being spread, viz fresh water, sewage treatment plant final effluent, and settled sewage (2) the length of the spreading period, ranging from one week up t several months; (3) the length of the resting period, ranging from tw days to a week; and (4) changes in the basin's surface, including spad ing, the use of a sand cover, and the application of a soil stabilizer.

These detailed studies began in January, 1951, and continued unti June, 1952. The operating schedules are shown in Table 6.

Collection of Samples

Samples were collected from each sampling point about once a wee during each spreading period. About 150 ml were collected in a steril bottle for bacteriological analysis and portions of 500 ml were collecte for chemical analysis. All samples were packed into an insulated bo iced and shipped to the Project laboratory. The samples were not mor than six hours old when received for analysis.

Bacteriological Analysis

During the early part of this work the bacteriological examinatio consisted of the total plate count and the confirmed test for colifor group organisms (12). It soon became apparent that the results of th 37 degree C. standard agar plate count were highly variable and o little significance. For this reason that analysis was discontinued. T supplement the test for coliform organisms a test for fecal streptococ (13) was used. The concentration of fecal streptococci, particularly i the final effluent and the percolated waters, was so low that this test proved to be of little value. Hence assessment of the bacteriological purity of the water relied on the most probable number of coliform group organisms.

TABLE 6

OPERATING SCHEDULE OF SPREADING BASINS, LODI, CALIFORNIA

Basin	Length of run		Number of cycles	Liquid spread	Spreading period—days	Resting period—days	Remarks
	Start	Finish					
A	3/51	11/51	16	final effluent	7	7	
	11/51	3/52	7	final effluent	14	7	
	3/52	6/52	4	settled sewage	14	7	
B	1/51	6/51	12	final effluent	7	7	Basin spaded at end of each cycle
	7/51	11/51	9	final effluent	7	7	
	11/51	3/52	7	final effluent	14	7	
	3/52	6/52	----------	settled sewage	continuous	0	
C	4/51	8/51	----------	final effluent	continuous	0	Basin spaded before spreading started
	8/51	6/52	----------	final effluent	continuous	0	
D	1/51	6/51	12	fresh water	7	7	Basin spaded at end of each cycle
	7/51	11/51	9	fresh water	7	7	
	11/51	2/52	3	fresh water	14	7	
	2/52	6/52	7	final effluent	14	7	
A′	8/51	11/51	7	settled sewage	7	3	
	11/51	1/52	4	settled sewage	14	7	
	2/52	6/52	5	settled sewage	14	7	Basin spaded before spreading started
B′	7/51	12/51	13	settled sewage	7	7	Surface covered with 3″ sand
	1/52	2/52	2	settled sewage	7	7	1″ sand replaced
	3/52	3/52	1	settled sewage	14	7	
	4/52	5/52	1	settled sewage	14	7	All sand removed
	5/52	6/52	1	settled sewage	14	7	Krilium applied 1#/100 sq. ft.
C′	6/51	2/52	19	settled sewage	7	7	Basin spaded before spreading started
	3/52	6/52	----------	final effluent	continuous	0	
D′	5/51	7/51	----------	settled sewage	continuous	0	Basin spaded before spreading started
	8/51	12/51	----------	settled sewage	continuous	0	
	2/52	6/52	----------	settled sewage	continuous	0	Basin spaded before spreading started

Chemical Analysis

Relatively complete chemical analyses were made on all samples. Th analyses included determinations of four forms of nitrogen—ammo nitrite, nitrate, and organic; the anions—boron, chloride, phospate, fate, and sulfide; and the cations—calcium, magnesium, potassium sodium. The alkalinity, conductivity, pH, BOD, and dissolved oxy were also determined. To check the accuracy of the separate determi tions on any one sample, a balance was made of the sums of the ani and the cations. From the difference between these sums a percent dif ence was calculated. A percent difference less than five was conside satisfactory.

Measurement of Percolation Rates

The differences between daily liquid level readings as measured b hook gage gave the gross percolation. These results were expressed acre-feet per acre per day, or more simply, as feet per day. A weat reporting station maintained at the Lodi Sewage Treatment Plant p vided data on evaporation and rainfall. Applying a correction fac for the daily net rainfall or evaporation to the daily gross percolat gave the daily net percolation.

RESULTS

1. Bacteriological Analyses

The average results of the determinations of the most probable num (MPN) of coliform group organisms are presented in Table 7. Th results are the average values obtained from 50 to 80 individual analy made between January, 1951, and June, 1952. In Table 8 is show further breakdown of the data obtained during the spreading of fi effluent on Basins A, B and C. The data in Table 8 indicate that until three to eight months after the beginning of spreading was th an appreciable penetration of coliform organisms to a depth of four fe With only two exceptions on Basin A (one-foot and four-foot dept did the average MPN for the first period fail to conform to the Uni States Public Health Service bacteriological standards for drinki water. During the second period, samples collected at depths up to fo feet had average coliform counts higher than those acceptable drinking water. The samples from greater depths remained satisfacto

From Table 7 it is clear that the change from final effluent to sett sewage or from fresh water to final effluent did not result in an increa penetration of coliform organisms. On Basins A and B the change tually resulted in a decreased penetration. This is probably associa with a decreased rate of percolation.

A definite inverse relationship between sample depth and colifo count is demonstrated in Figure 17. It will be noted the average M at a depth of two feet in Basins A and C were greater than the corr ponding values at one foot. This break in the inverse relationship tween coliform count and depth was due to the existence of chann which tended to lead the surface water directly to the pan, thus minim ing the filtration effects of the soil. Further corroborative exidence the existence of channels in these basins is offered in another section this report.

TABLE 7

MPN OF COLIFORM ORGANISMS AS A FUNCTION OF DEPTH IN FOUR SPREADING BASINS, LODI, CALIFORNIA

Depth in feet	Average MPN per 100 ml						
	Basin: A		B		C	D	
	Liquid applied						
	Final effluent	Settled sewage	Final effluent	Settled sewage	Final effluent	Fresh water	Final effluent
Surface	179×10^3	4140×10^3	188×10^3	5700×10^3	188×10^3	232.	164×10^3
1	1.2	1.6	482.	20.	148.	1.6	0.2
2	285.	32.	5.6	0	305.	------	------
4	2.1	0.6	0.5	0	2.0	------	------
7	0	0	0.2	0	0.2	0	0
10	0	0	0.1	0	0.1	------	------
13	------	------	0	0	0.3	0	0

TABLE 8

MPN OF COLIFORM ORGANISMS AT DIFFERENT PERIODS AS A FUNCTION OF DEPTH IN THREE SPREADING BASINS, LODI, CALIFORNIA

Depth in feet	Average MPN per 100 ml					
	Basin:* A		B		C	
	4/11/51-12/6/51	12/27/51-2/29/52	1/14/51-7/29/51	11/9/51-2/29/52	4/2/51-7/29/51	11/9/51-2/29/52
Surface	82×10^3	248×10^3	163×10^3	223×10^3	62×10^3	307×10^3
1	2.7	0	0	950.	0	235.
2	0.9	558.	0.2	10.3	0.1	573.
4	1.8	38.	0.1	0.9	0	3.2
7	0	0	0	0.4	0	0.3
10	0	0	0	0.2	0	0.1
13	------	------	0	0	0	0.6

* Final effluent applied throughout test period.

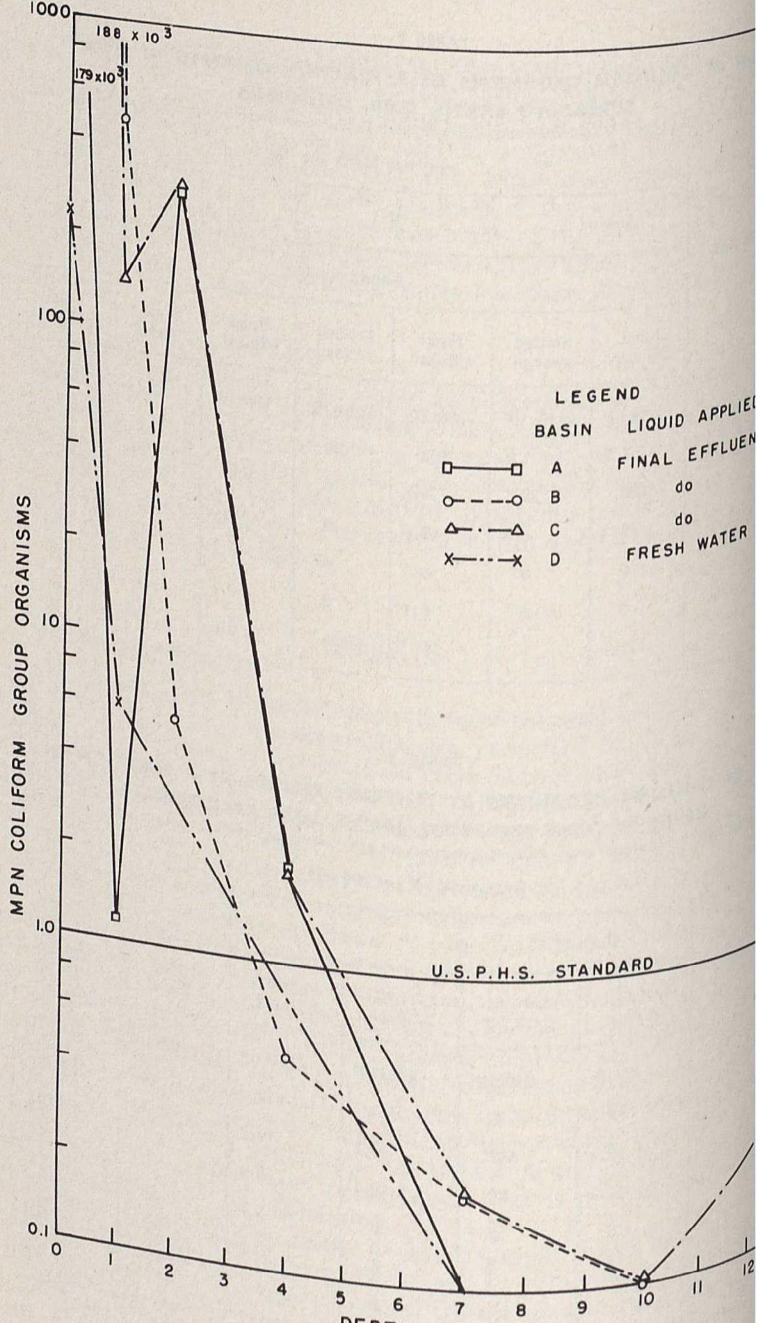


FIGURE 17. Most probable number of coliform group organisms as a function of depth in four spreading basins

2. *Chemical Analyses*

The chemical data were collected principally during four periods: The summer of 1950, the winter-spring seasons of 1951, the fall of 1951, and the spring of 1952. For purposes of convenience the results of the first three periods are presented in a summary table (Table 9) whereas those of the last are given separately (Table 10). The data in Table 9 are shown graphically in Figures 18 and 19.

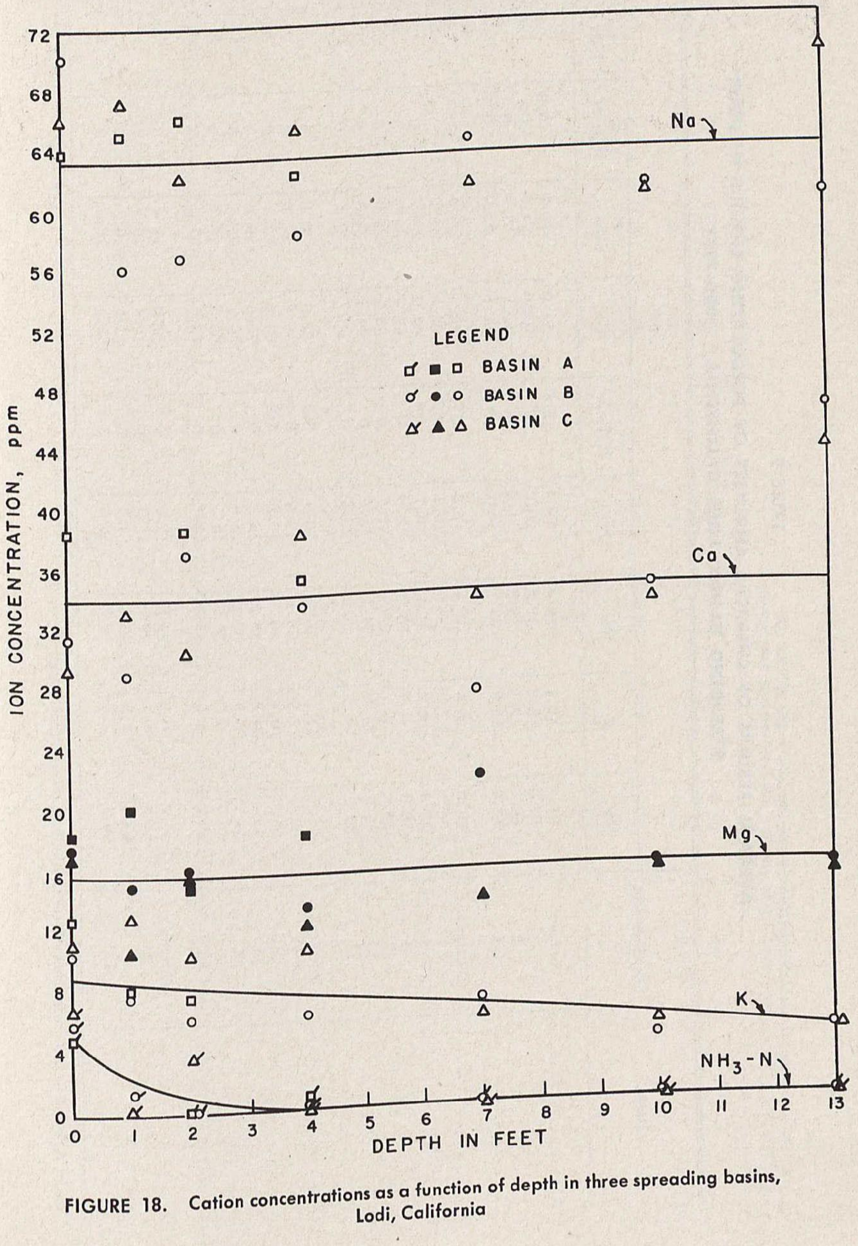


FIGURE 18. Cation concentrations as a function of depth in three spreading basins, Lodi, California

TABLE 9

AVERAGE RESULTS OF CHEMICAL ANALYSES OF PERCOLATING LIQUIDS IN FOUR SPREADING BASINS, LODI, CALIFORNIA,* 1950-1951

Basin	Depth in feet	ppm										
		Na	K	Ca	Mg	NH_3–N	Cl	SO_4	NO_2–N	NO_3–N	PO_4	HCO_3
A	Surface	63.7	12.7	38.4	18.4	5.1	71.0	26.9	0.9	2.5	12.5	216.
	1	65.0	8.2	31.5	20.2	0	58.9	24.5	0	5.8	0	223.
	2	66.1	7.8	38.8	14.8	0	65.6	31.9	0.1	4.3	1.0	210.
	4	62.2	10.2	35.1	18.1	0.8	66.9	28.0	0.1	4.0	0.8	214.
B	Surface	70.0	10.5	31.5	17.3	5.9	70.4	29.9	0.4	3.0	8.3	169.
	1	56.1	7.7	29.0	15.1	1.4	66.1	28.5	0.1	2.8	2.2	193.
	2	56.8	6.2	37.1	16.1	0	62.0	34.7	0	8.5	0	196.
	4	58.0	6.4	33.9	13.5	0	57.9	38.2	0	8.9	0	168.
	7	64.0	6.9	27.3	21.6	0	56.5	28.0	0	8.0	0	236.
	10	61.8	4.2	34.1	15.6	0	64.5	39.0	0	8.7	0	208.
	13	60.0	4.5	45.9	15.3	0	66.7	41.3	0	8.6	0	231.
C	Surface	66.2	11.2	29.6	16.9	6.9	65.9	33.4	0.4	1.8	9.1	214.
	1	67.2	12.9	33.1	10.8	0.4	73.6	31.4	0	2.1	0	248
	2	62.1	10.4	30.7	15.6	3.9	64.5	32.3	0	0.9	0	266.
	4	65.1	10.8	38.2	12.2	0	70.0	29.1	0	1.3	4.1	269.
	7	61.2	5.9	33.7	13.6	0	69.3	32.5	0	4.2	0.1	232.
	10	60.7	5.0	33.3	15.5	0	60.0	26.3	0	3.3	0	229.
	13	69.9	4.6	43.3	15.1	0	70.0	37.1	0	6.3	0	268
D	Surface	32.6	4.1	22.3	15.9	1.6	32.0	17.4	0.1	0.4	2.5	137.
	1	34.5	6.5	20.7	14.9	0	31.4	19.1	0	1.2	1.6	193.
	7	46.5	5.5	35.1	4.5	0	42.6	29.3	0	1.0	0	172.
	13	36.3	2.4	19.7	6.8	1.6	32.6	17.0	0	1.3	0	162.

TABLE 10

AVERAGE RESULTS OF CHEMICAL ANALYSES OF PERCOLATING LIQUIDS IN FOUR SPREADING BASINS, LODI, CALIFORNIA,* 1952

Basin	Depth in feet	ppm										
		Na	K	Ca	Mg	NH_4–N	Cl	SO_4	NO_2–N	NO_3–N	PO_4	HCO_3
A**	Surface	81.5	17.2	22.5	30.8	21.6	67.1	29.4	0	1.4	20.2	282.
	1	113.9	15.1	32.8	23.4	1.1	70.1	25.7	0	7.1	1.0	363.
	2	118.9	13.2	27.2	19.2	1.9	68.3	35.0	0	0.9	3.1	352
	4	116.0	18.8	63.1	42.2	0.5	219.6	26.1	0	4.8	1.4	331.
B	Surface	86.4	19.3	28.6	32.8	17.1	77.8	19.9	0	1.2	20.2	337.
	1	80.8	13.5	32.4	21.8	2.6	79.4	9.4	0	2.5	1.1	322.
	2	80.4	13.4	27.1	20.5	0.6	64.1	9.4	0	2.4	1.0	330.
	10	74.6	4.5	32.6	15.1	1.1	70.0	16.9	0	9.0	0	276.
	13	62.6	4.3	37.7	24.1	2.9	60.9	18.9	0	8.7	0	298.
C	Surface	80.0	13.1	18.3	25.4	15.7	68.6	28.0	0.1	1.3	11.6	265.
	1	72.8	14.9	17.4	22.0	10.3	70.2	15.5	0	0	10.8	276.
	2	70.5	14.3	20.9	27.3	16.4	65.7	6.1	0	0	13.6	323
	4	72.2	15.2	19.0	21.4	15.0	60.9	16.6	0	0	9.1	277.
	7	70.8	15.2	21.9	20.2	3.7	60.1	9.8	0	14.2	4.1	250.
	10	75.6	9.2	18.0	13.0	3.2	58.8	14.0	0	17.9	0.7	188.
	13	70.5	4.2	31.3	21.8	0.6	65.1	16.2	0	8.0	1.0	273
D	Surface	79.1	12.8	23.4	18.5	5.3	69.7	27.2	0.2	1.0	8.9	208.
	1	71.3	12.2	24.1	20.9	0.9	62.0	30.3	0	8.1	2.1	206.
	13	69.8	3.7	29.6	14.8	2.8	62.0	22.5	0	9.0	0.1	234.

* Basins A and B spread with settled sewage, Basins C and D spread with final effluent.

** High ion concentration due to application of mixed chlorides in flow through test.

From the data it is apparent that quantitative chemical changes in the liquid during percolation were few. Among the cations, calcium magnesium and sodium remained relatively constant down to a depth of thirteen feet. The lack of change in the concentrations of these ions may be explained by the setting up of equilibrium conditions between

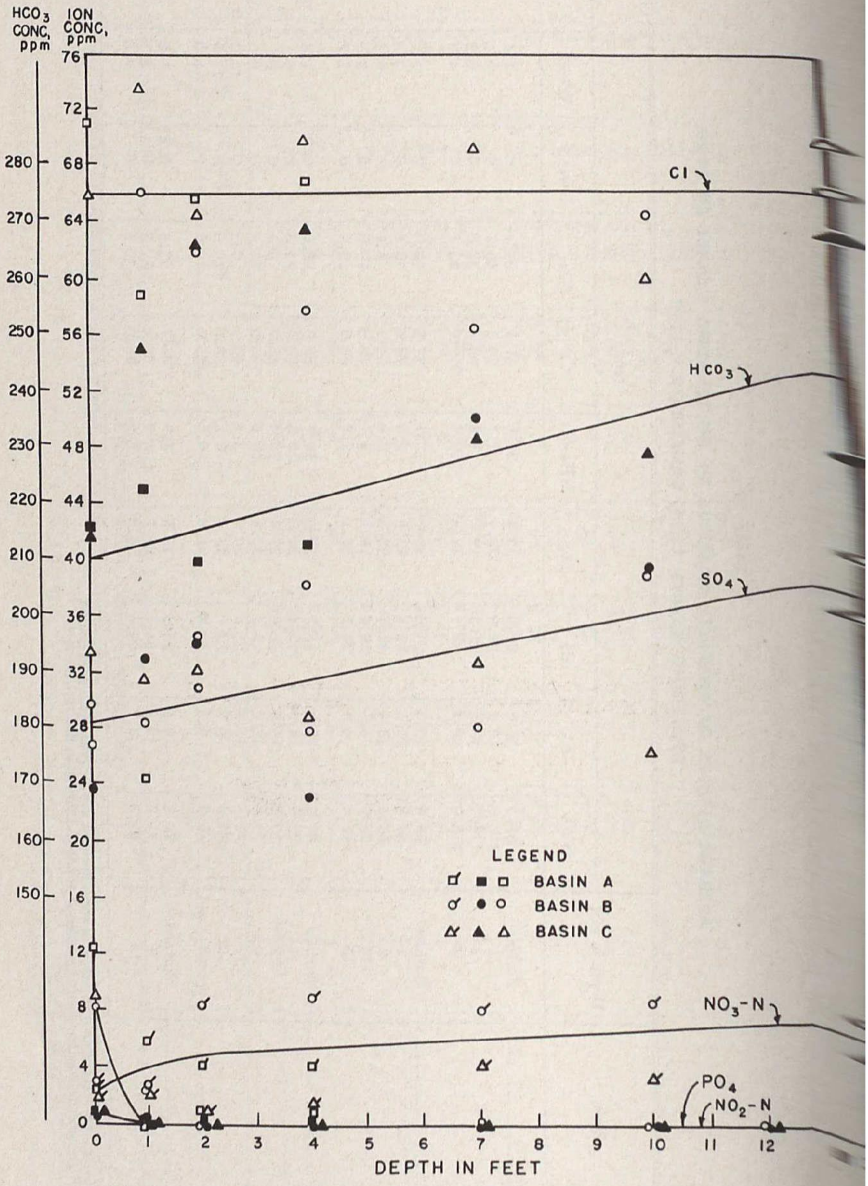


FIGURE 19. Anion concentrations as a function of depth in three spreading basins, Lodi, California

the percolating liquid and the clay minerals of the soil. Since the cation concentration in the liquid which was applied remained relatively constant, the establishment of a base exchange equilibrium among the exchangeable bases in the liquid and solid phases of the system resulted in the absence of change in ionic concentration.

The cation, potassium, however, decreased by about 50 percent during percolation of the liquid through thirteen feet of soil. The fixing of potassium in a nonexchangeable form on certain clay minerals would account for this.

Ammonia was completely removed within four feet. This was caused by both physical and biological factors. A base exchange of the ammonium ion for hydrogen ions, or other cations, adsorbed on the clay minerals would account for part of the ammonia loss. The remainder disappeared through the agency of the flora indigenous to the soil which either incorporated ammonia nitrogen in cell substance or oxidized it to nitrites and nitrates.

Among the anions, chlorides remained unchanged. Sulfates increased by about 40 percent, an increase which was probably due to the oxidation of sulfur from organic sources such as the amino acids, cystine, cysteine and methionine present in sewage protein. Inasmuch as aerobic conditions existed in the soil, a favorable environment for oxidative reactions was provided.

A comparable increase in the bicarbonate ion concentration was also noted. As with the sulfates the existence of aerobic conditions would be conducive to the breakdown of organic compounds to carbon dioxide and water. At the pH of the soil the greater portion of the carbon dioxide produced would be recovered as the bicarbonate ion.

As a result of nitrification, nitrate concentration increased by several hundred percent during the percolation process. The nitrogen available in the form of ammonia and nitrites plus the presence of oxygen would lead to conditions favorable to the biological oxidation of reduced forms of nitrogen. Surface nitrites rapidly disappeared. This is consistent with the appearance of nitrates. Since the equilibrium concentration of nitrite is much smaller than that of nitrate, it is expected that the reaction would proceed to the right and that nitrate rather than nitrite ions would accumulate.

Like the nitrites, phosphate ions disappeared during the first foot of vertical water travel. This may have been due to an isomorphous replacement of hydroxyl ions in the clay lattice (14), or to a biological removal of dissolved phosphates. Phosphate phosphorus is readily available to bacteria which require this element for both energy transformations and cell synthesis. Since available evidence indicates that the uppermost few feet of soil are the most active biologically, significant removals of soluble phosphate are to be expected.

The data in Table 10 show that the concentration of sodium, potassium, calcium, magnesium, chloride, sulfate, nitrite and bicarbonate ions varied very little from beginning to end of the time of the study. The ionic concentrations of ammonia, nitrate and phosphate were different. Since changes in the concentrations of these ions were associated with biological activity, this result was to be expected after long spreading. The differences were most marked in Basin C which was under continuous submergence. Ammonia and phosphate penetrated to greater depths while nitrate accumulation did not begin higher than four feet below surface. This may have been due to increased numbers of micro-org isms developing further from the surface as the organic material cumulated in the soil. As conditions grew favorable to heterotrop organisms at greater depths, the onset of nitrification, an autotrop process, was delayed. Stated differently, as the total amounts of nitro and phosphorus increased due to long spreading, the rate of concent tion change in terms of vertical distance traveled was slower.

The samples collected from the two foot depths in Basins A and had concentrations of ammonia and phosphate not consistent with explanations given above. Evidence presented later shows the prese of channels leading from the surface directly to the sampling pans. data on coliform concentration also indicated the presence of chann leading to the pans at the two-foot depth in Basins A and C.

The biochemical oxygen demand (BOD) of the percolating liqu were never greater than 5.0 ppm and the average BOD was considera lower. From Table 11, which shows the results of one series of analy on Basin C, it is clear that no significant variations in BOD occurred different depths. Data collected on the BOD of the liquid on the ba surface as a function of time of day were not conclusive and are presented here.

The dissolved oxygen (DO) varied with depth in an unexpected w Figure 20 shows the average of about 15 sets of results. After decreasi to a minimum at a depth of about two feet, that is, the zone which considered the most active biologically, the dissolved oxygen conc tration rose to a secondary peak and then fell off. The difference betw Basin D which was spread with fresh water and Basins A, B and which were spread with final effluent is significant. Biological activi which utilized oxygen and accounted for the decrease in dissolv oxygen, depended upon organic matter as a source of food and ener Where the organic loading was low, as in Basin D, the oxygen utili tion was low and the decrease in dissolved oxygen relatively sma where the organic loading was comparatively high, as in Basins A, and C, the decrease in dissolved oxygen was great.

TABLE 11
BOD AS A FUNCTION OF DEPTH IN BASIN C
LODI, CALIFORNIA

Depth in feet	ppm BOD							Aver
1	3.08	3.00	1.12	4.82	1.78	1.12	-------	2.
2	1.48	1.64	2.04	0.96	1.50	1.24	1.86	1.
4	1.00	1.24	0.60	0.88	2.50	0.66	-------	1.
7	1.64	2.56	1.36	0.60	3.58	<0.50	-------	1.
10	2.40	2.68	1.60	1.64	2.54	-------	-------	2.
13	2.68	2.36	0.96	1.04	1.66	1.66	1.24	1.

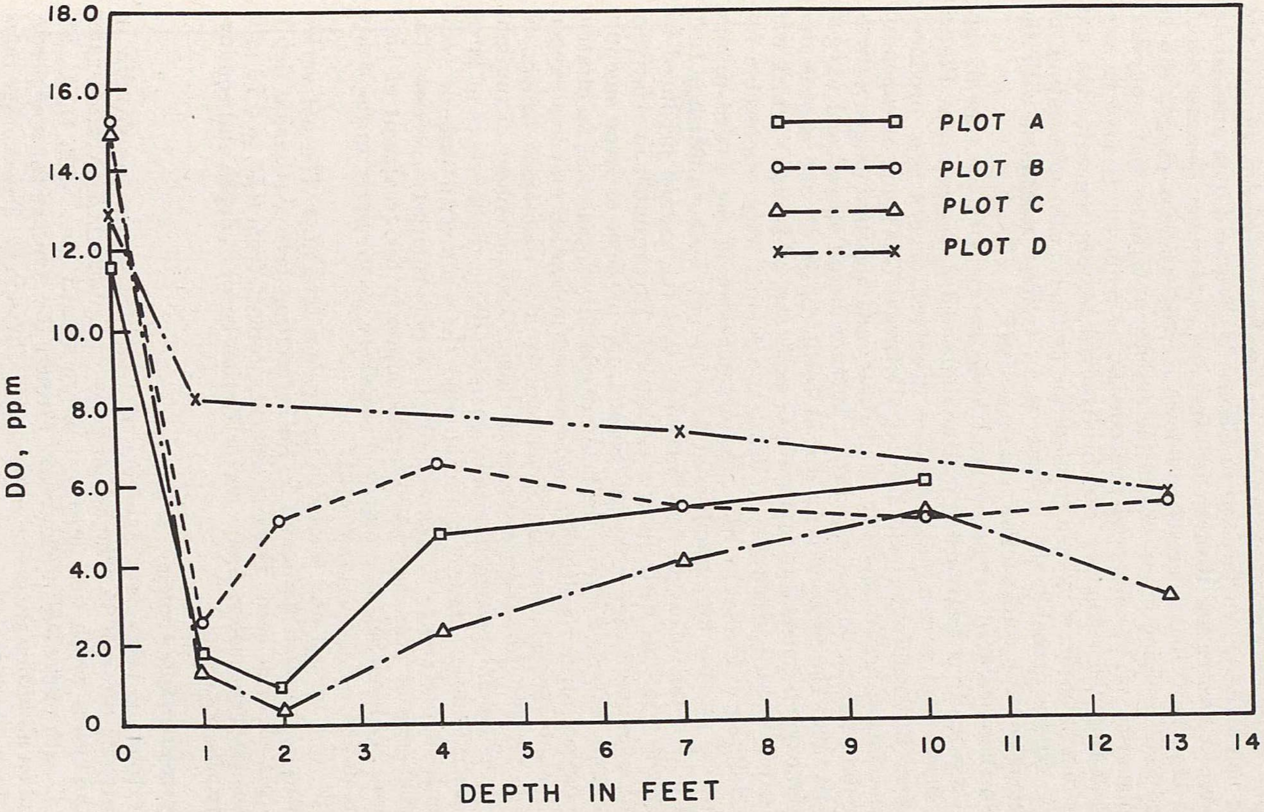


FIGURE 20. Dissolved oxygen concentration as a function of depth in four spreading basins, Lodi, California

The secondary increase in dissolved oxygen concentration is difficult to explain. The more typical curve of dissolved oxygen as a function of depth would show a rapid decrease in dissolved oxygen in the first few feet below the soil surface (as in Figure 20) followed by a gradual decrease to zero rather than an increase and subsequent decrease which was observed (15). There is no known method whereby oxygen can be produced by living organisms in the absence of light so that a physical explanation of the observed phenomenon is required. It may be suggested that the secondary rise in dissolved oxygen concentration was due to a diffusion of oxygen through the unflooded soil surrounding the basin. Quite probably the increase is an artifact associated with the method of basin construction and operation.

Surface dissolved oxygen concentration varied with the time of day and was in direct relationship with sunlight and/or temperature. Figure 21 shows that a maximum surface dissolved oxygen was produced between three and four o'clock in the afternoon. This hour corresponded to the time of maximum daily temperature and maximum algae growth The data indicate also a correlation between liquid spread and oxygen production. The final effluent spread basin, Basin C, had a peak dissolved oxygen concentration about five times that of Basin D′ which was spread with settled sewage. At least two factors were responsible for the difference. First, the increased organic load in the settled sewage tended to produce high numbers of heterotrophic bacteria which in turn had a high rate of oxygen utilization so that the oxygen produced by the algae would be used up at a rapid rate. This resulted in relatively small amounts of excess oxygen. Second, the presence of large amounts of organic material favored the heterotrophic development of facultative autotrophic algae resulting in more oxygen utilization and less oxygen production. Stated more simply, it can be said that algae which are able to live either by the use of carbon dioxide and the energy of sunlight or by the use of preformed organic compounds, in the presence of large concentrations of organic material used the preformed organic compounds in preference to going through a photosynthetic process. The phenomenon of decreased oxygen production in the treatment of high organic loadings has been observed elsewhere, particularly in the study of oxidation pond operation (16).

The data on pH and conductivity are not tabulated. The pH varied erratically between 6.5 and 7.5. No correlation between sample depth and pH could be seen. The conductivity ranged from 0.55 to 0.70 millimhos per centimeter. Again no correlation between depth and conductivity was observed.

3. *Percolation Rate Analyses*

Percolation rates as a function of time are shown graphically in Figures 22 through 35. The actual daily variations in percolation rates on the basins which were operated intermittently, i.e., A, B, D, A′, B′, and C′, are presented in Figures 22 through 27. Average rates of percolation on all basins are given in Figures 28 through 35. The average rates are those which include resting as well as spreading time in any given cycle. For example, the average rate of percolation for a two week cycle (one week spreading—one week resting) was calculated from the mean

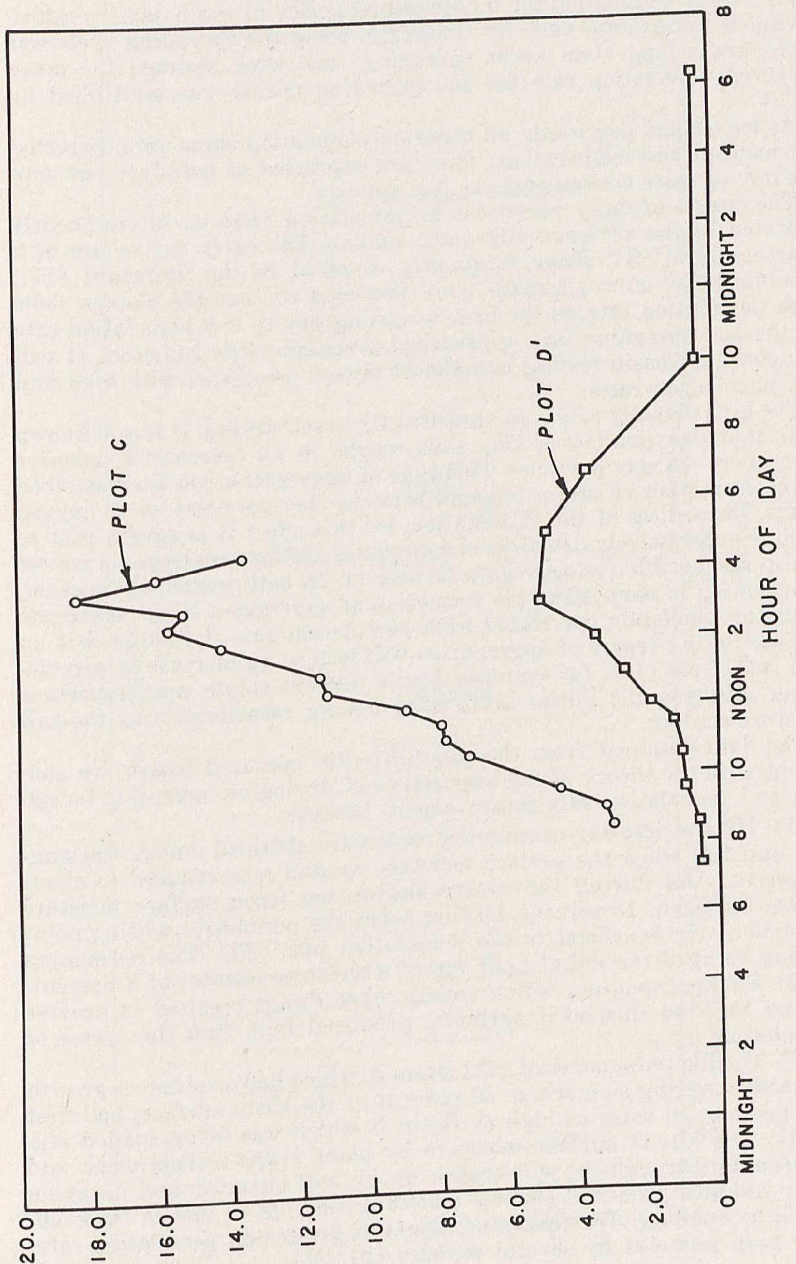


FIGURE 21. Surface dissolved oxygen concentration as a funcoin of time of day in two spreading basins, Lodi, California

daily rate of percolation for the spreading period of seven days by multiplying it by a factor of 7/14. Similarly, when the spreading cycle wa three weeks long (two weeks spreading—one week resting) the mea observed percolation rate for the spreading period was multiplied b 14/21.

As mentioned previously all reported percolation rates were correcte for rainfall and evaporation. They are expressed as acre-feet per acr per day or more conveniently as feet per day.

The curves of daily variations in percolation rates on intermittently operated basins are generally quite similar. The early curves are of a characteristic "S" shape frequently reported in the literature (17). Gradually the curves became more flattened so that the change from high percolation rate on the first spreading day to low percolation rate on the last spreading day approached a straight line function. It will be noted that basin resting was almost always associated with high first day percolation rates.

The high first day rate is related directly to soil drying. It is well known (18) that dehydration of clay soils results in an increase in cohesive forces between clay particles. This type of aggregation has been ascribed to the formation of cation linkages between clay particles, or to oxygen bonds. Regardless of the explanation for this effect it is agreed that as a soil is progressively dehydrated aggregates are formed. Organic matter is also responsible for aggregate formation. In both instances, however, dehydration is essential to the formation of aggregates. Since aggregate formation is closely correlated with percolation rate it follows that an increase in the degree of aggregation will lead to an increase in percolation rate. Neal (19), for example, found that the single most important factor affecting the initial infiltration during rainstorms was the soil moisture content.

The data obtained from the intermittently operated basins are consistent with the theory of the importance of drying on aggregate formation and percolation rate improvement, because:

(1) Higher first day percolation rates were obtained during the summer and fall when the surface moisture content was reduced to about 5 percent than during the winter and spring when surface moisture seldom fell below 18 percent. Drying below the permanent wilting point is particularly beneficial to the percolation rate (20). The permanent wilting point of the soil at Lodi was at a moisture content of 8 percent.

(2) Surface spading, which among other things resulted in greater drying than on unspaded surfaces, produced high first day rates of percolation.

(3) During the summer of 1951 Basin A, which had a volunteer growth of weeds covering as much as 80 percent of the basin surface, had first day percolation rates as high as Basin B which was being spaded regularly. The loss of surface moisture by plant evapo-transpiration and evaporation through the soil broken up by root channels and decaying plant residues produced surface moisture contents as low as those obtained by spading. The favorable effects of grasses on percolation rates have been reported by several authors (21, 22).

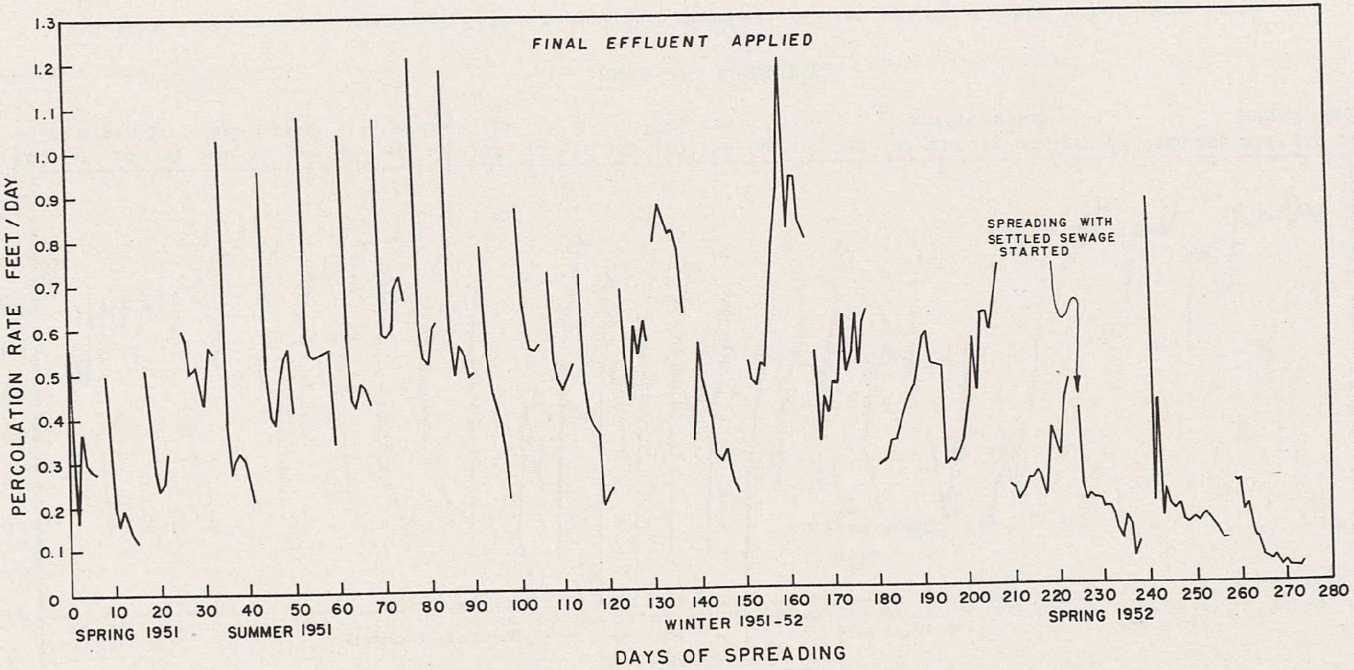


FIGURE 22. Daily percolation rate changes on Basin A. (Note: Each discontinuity in curve represents a resting period of seven days.)

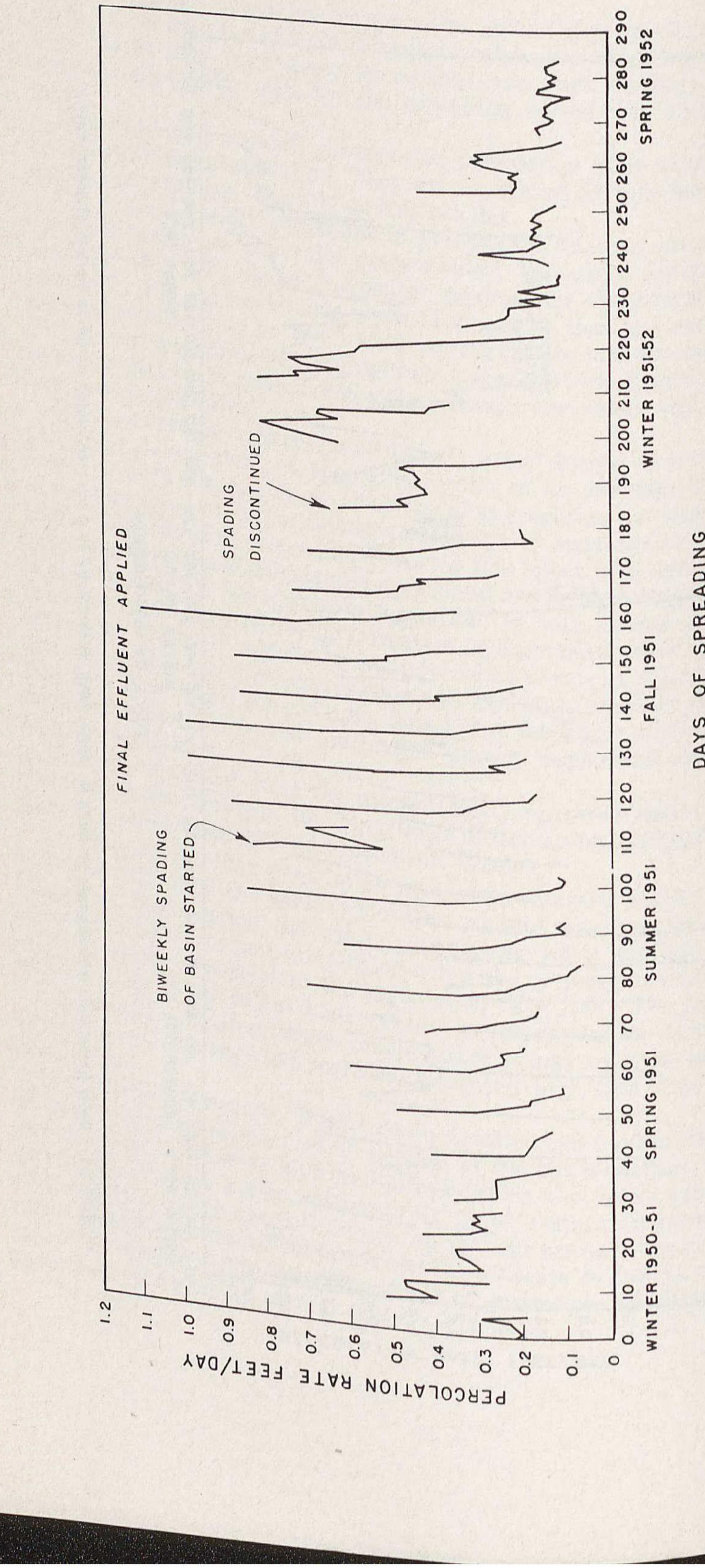


FIGURE 23. Daily percolation rate changes on Basin B. (Note: Each discontinuity in curve represents a resting period of seven days.)

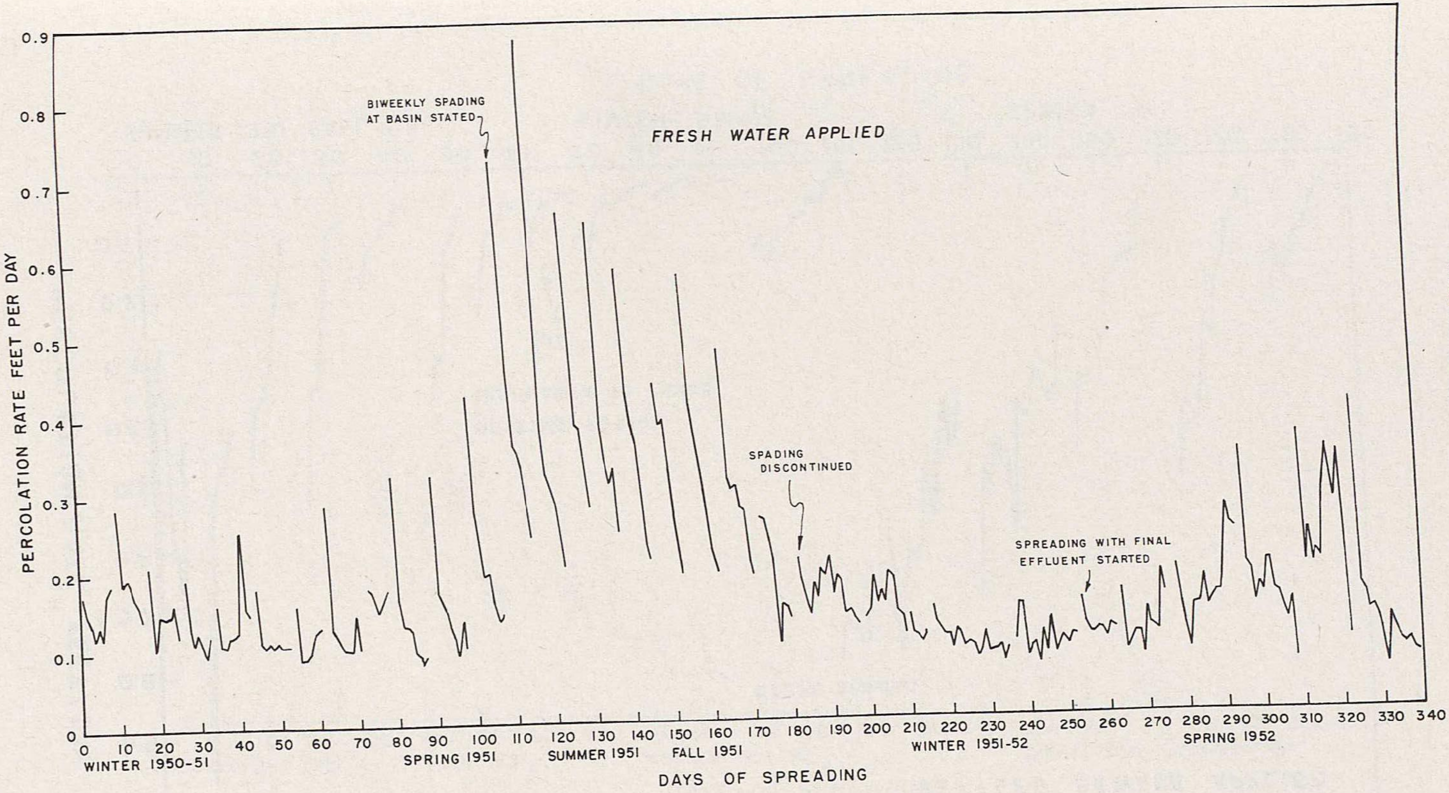


FIGURE 24. Daily percolation rate changes on Basin D. (Note: Each discontinuity in curve represents a resting period of seven days.)

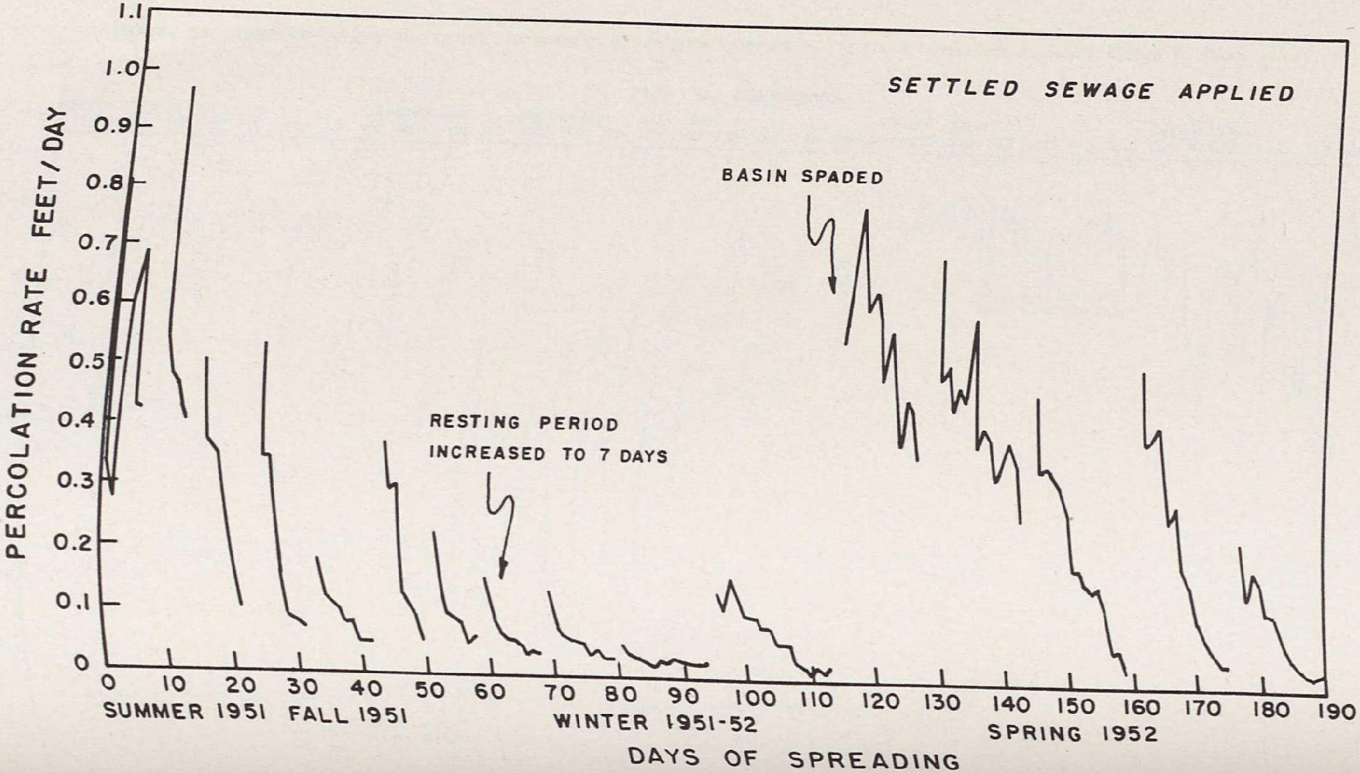


FIGURE 25. Daily percolation rate changes on Basin A′. (Note: First seven discontinuities in curve

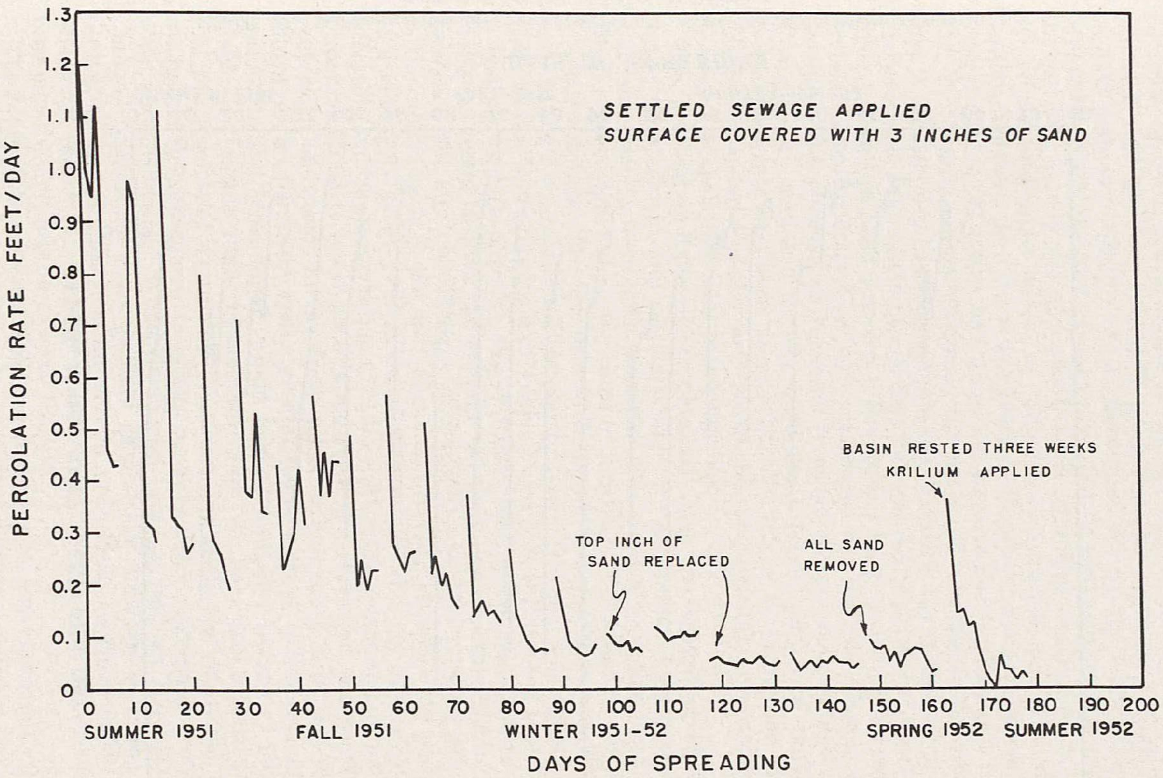


FIGURE 26. Daily percolation rate changes on Basin B′. (Note: Each discontinuity in curve represents a resting period of seven days.)

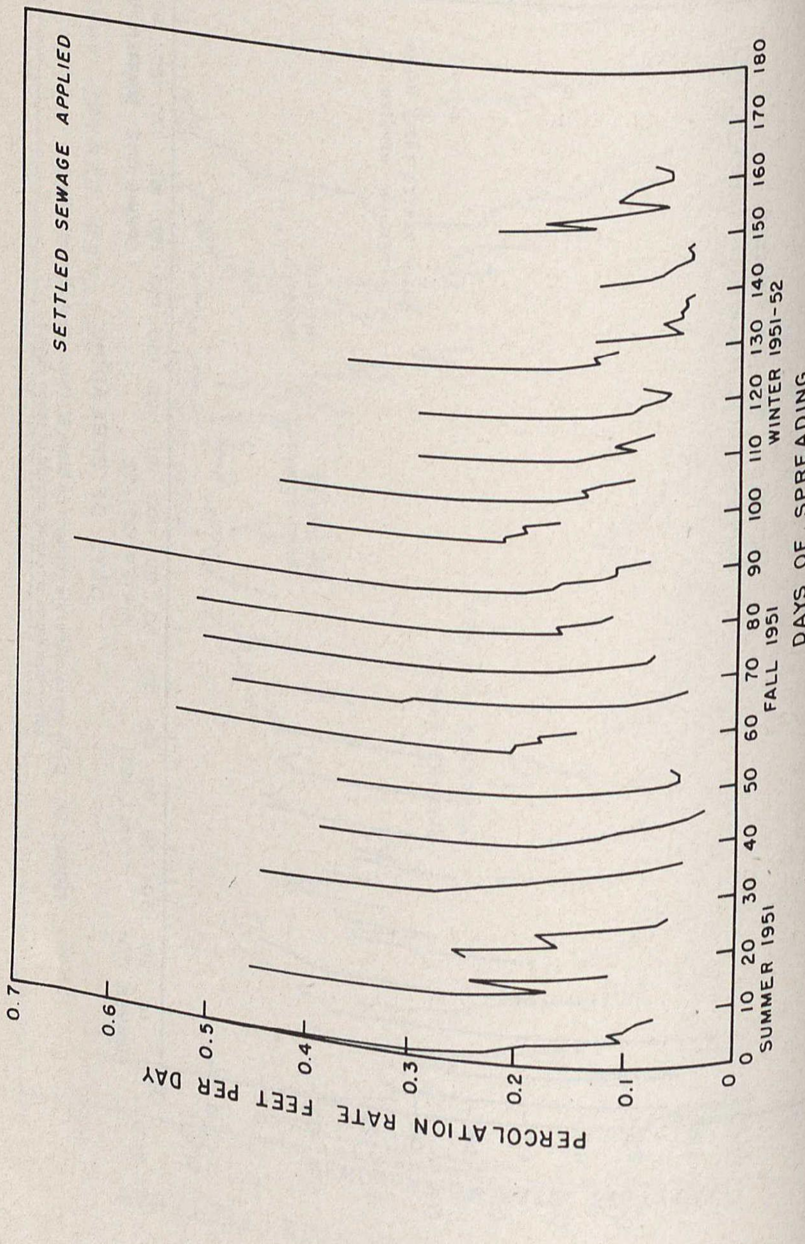


FIGURE 27. Daily percolation rate changes on Basin C'. (Note: Each discontinuity in curve represents a resting period of seven days.)

The rapid decrease in percolation rate after the first day was due to a combination of factors: the reversal of cementation and aggregate formation, soil pore clogging by microbial products, and possibly, the decrease in hydraulic gradient. Although the cohesive forces between oriented clay particles generally produce stable aggregates, high rates of aggregate reversibility can be accounted for by the temperature of dehydration and the continuous application of water during the spreading period. Among the end products of microbial metabolism in soils are slimes and gums which, in proper concentration and after dehydration, increase the rate of percolation. However, when excessive concentrations of the slimes and gums are present pore sealing can result (17, 23). Another possible reason for the rapid decrease in percolation rate is the decrease in surface liquid depth during the spreading period. The available evidence indicates that this was not of primary importance since changes in head between a few inches up to a foot could not be correlated with percolation rate variations. On the other hand, when the spreading period was increased from one to two weeks, which made it possible to maintain greater head for a longer period of time, the percolation rate decreased more gradually. Thus, an evaluation of the relative importance of the three above mentioned factors responsible for decreased percolation rates is not conclusive.

The percolation rate curves obtained from the spreading of fresh water, final effluent and settled sewage are all similar. One important difference among them must be noted: The rates of percolation of final effluent were higher than the rates of percolation of either fresh water or settled sewage. The low rate of fresh water percolation was due, in part, to the finer texture of the soil in Basin D which was spread with fresh water. Referring back to Tables 2 and 3, it will be seen that Basin D had an average effective size of 0.0055 mm, which was smaller by a factor of about 10 than the average effective sizes in other basins. The combined silt and clay content of Basin D was 35.5 percent, whereas in the other basins it was only about 20 percent. Although the presence of a relatively large proportion of fines could lead, on drying, to appreciable aggregate formation (18) it could, on rehydration and particle dispersion, lead to lower percolation rates. Furthermore, the lower concentration of cations in the fresh water as compared with the sewage effluents, and particularly the greater percentage of sodium among the cations in the fresh water, would lead to a greater degree of particle dispersion; hence, lower percolation rates (24, 25). Still a third factor was the absence of significant amounts of organic matter in the fresh water and the subsequent failure to produce stable aggregates cemented with organic matter. When the liquid being spread on Basin D was changed from fresh water to final effluent the increases in cation concentration and organic loading served to increase the percolation rate somewhat indicating more specifically that the low rates of percolation were not due entirely to the soil texture.

The rates of percolation of settled sewage were also consistently lower than the percolation rates of final effluent. This was not due to differences in inorganic composition between the liquids but rather to differences in organic and particulate composition. Since the BOD of the settled sewage was 10 times as high as the BOD of the final effluent it appears that conditions were more conducive to greater slime and gum production, hence, to greater pore sealing. McCalla (23) has also observed that large quantities of organic matter may clog the soil and decrease permeability. The effect of the suspended solids in the settled sewage, 100 ppm, may have been also to clog the soil, but in a more mechanical fashion.

A better picture of over-all percolation rate changes can be obtained from an examination of the average percolation rates. From Figures 28 through 35 it is possible to evaluate the effect of the operating variables investigated.

Among the intermittently operated basins the most striking effect apart from the increase in percolation rate following drying, was that due to regular basin spading. On Basins B and D the average rates of percolation over 12 two-week cycles were, respectively, 0.153 and 0.095 feet per day. For nine identical cycles during which these basins were spaded the average percolation rates increase roughly by 70 percent to 0.254 and 0.168 feet per day. Following the discontinuing of spading the percolation rate of Basin D fell off rapidly while that of Basin B fell more gradually. Pillsbury (26) has also noted the effect of hand cultivation and concluded that it results in only a temporary increase in the rate of water entry into a soil.

In order to be effective, spading or other soil cultivation must be repeated. Frequent cultivation, especially with the heavy equipment generally available, may do more harm than good since it may result in the formation of a plow pan or compact impervious stratum beneath the soil surface. Huberty (27, 28) has warned of this danger in irrigated fields, particularly if they are cultivated when the soil is not well dried.

An increase in the length of the spreading period on intermittently operated basins also served to increase the rate of percolation. Two opposing factors were acting simultaneously to produce this effect. First, the longer spreading period made it possible to have the basin under submergence for two-thirds instead of one-half of the total time in a single cycle. This tended to raise the average percolation rate. Second, the longer spreading period made conditions conducive to a greater degree of microbial soil clogging. This tended to lower the actual percolation rate during the spreading period. The two factors are closely balanced so that the net percolation rate increase was small.

The low average rate of percolation on Basin D has already been discussed. The relatively high percolation on Basin A, which unlike Basin B, a comparable basin, was not spaded, was related to the volunteer growth of weeds previously mentioned. During 1952 the weed growth was reduced considerably because of weed deaths during the winter and the unsuitability of settled sewage as a substrate for weed growth. The percolation rate then fell to a level comparable to that of other basins similarly treated.

Those basins to which settled sewage was applied generally had lower rates of percolation than basins on which final effluent was spread. The reasons have already been discussed. Basins C′ and B can be compared to show the effect of applied liquid on percolation rates. With a two week spreading cycle Basin C′ which received settled sewage had an average percolation rate of 0.093 feet per day while Basin B had a rate of 0.153 feet per day. When the liquid applied to Basin C′ was

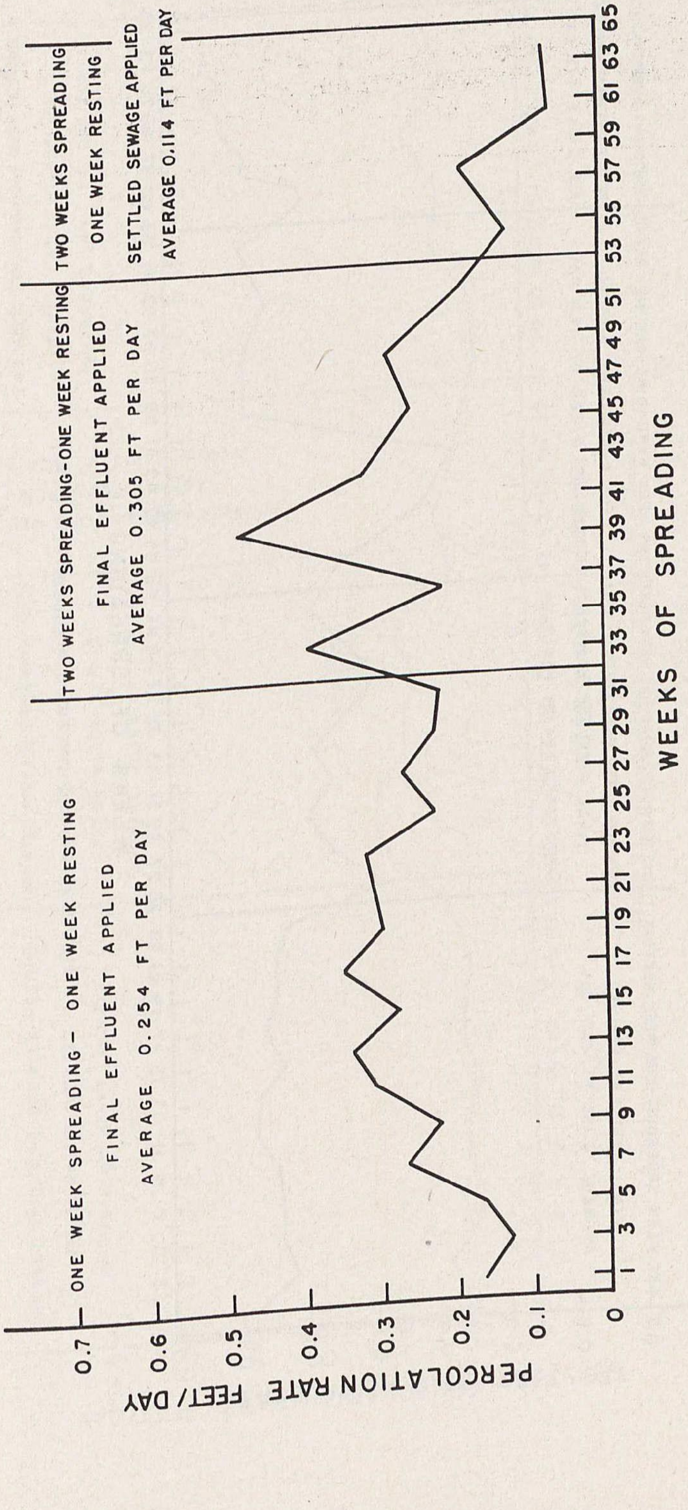


FIGURE 28. Average percolation rate changes on Basin A

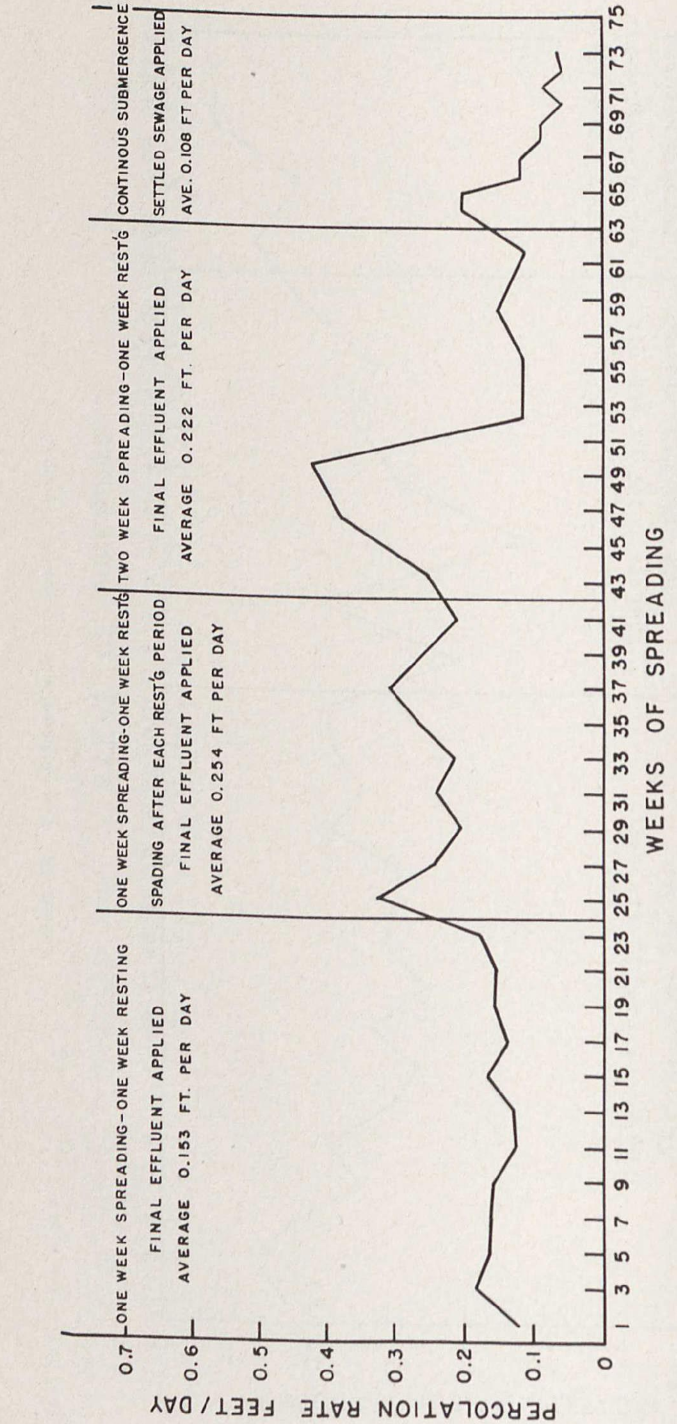


FIGURE 29. Average percolation rate changes on Basin B

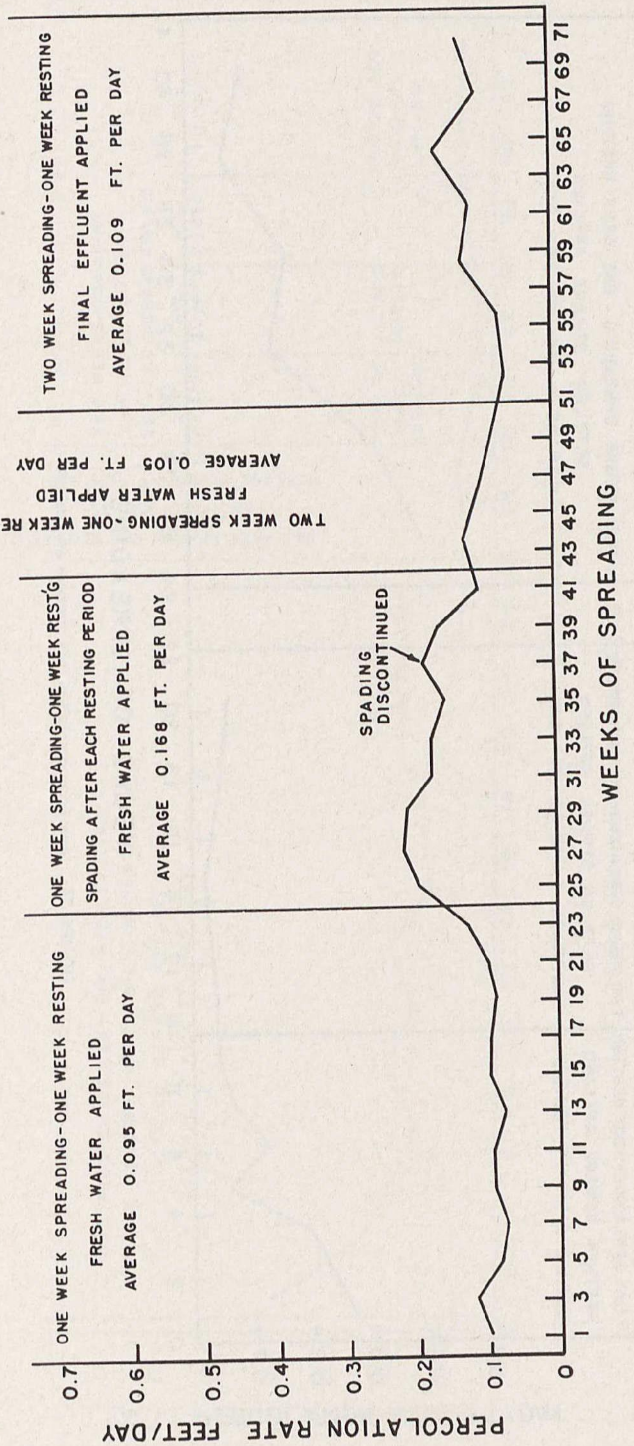


FIGURE 30. Average percolation rate changes on Basin D

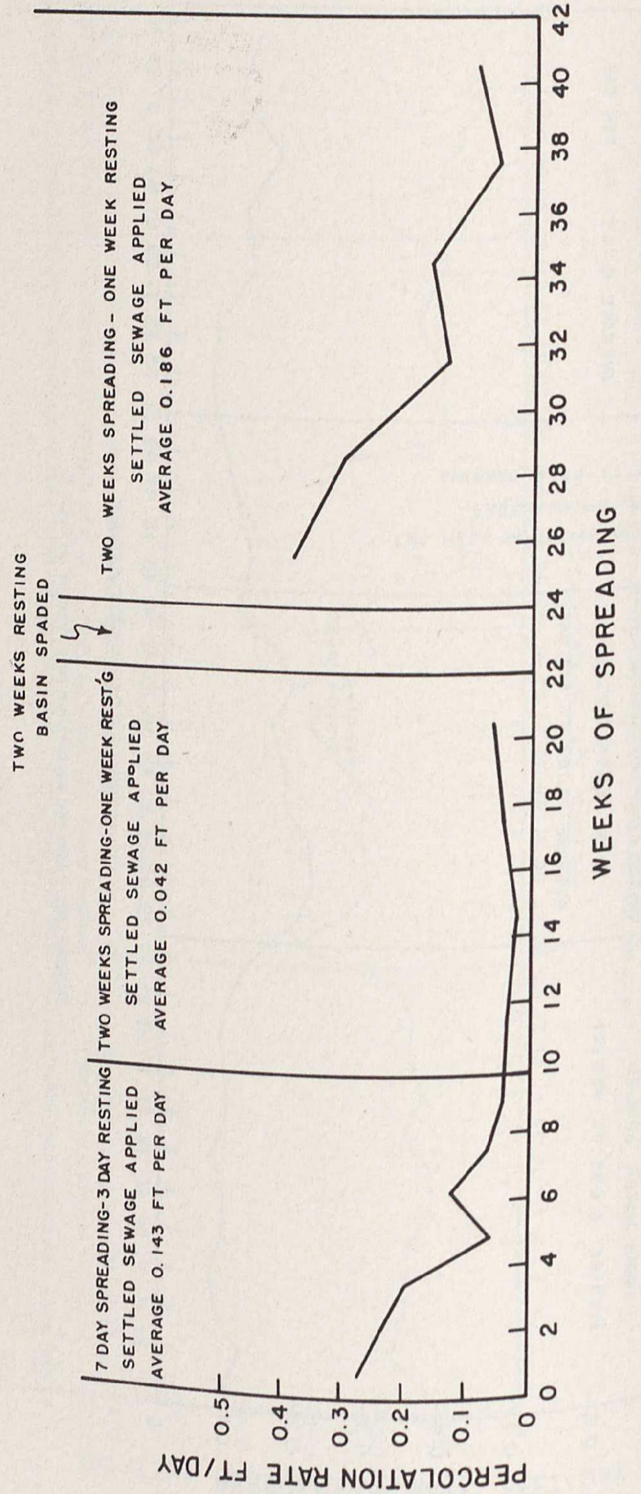


FIGURE 31. Average percolation rate changes on Basin A'

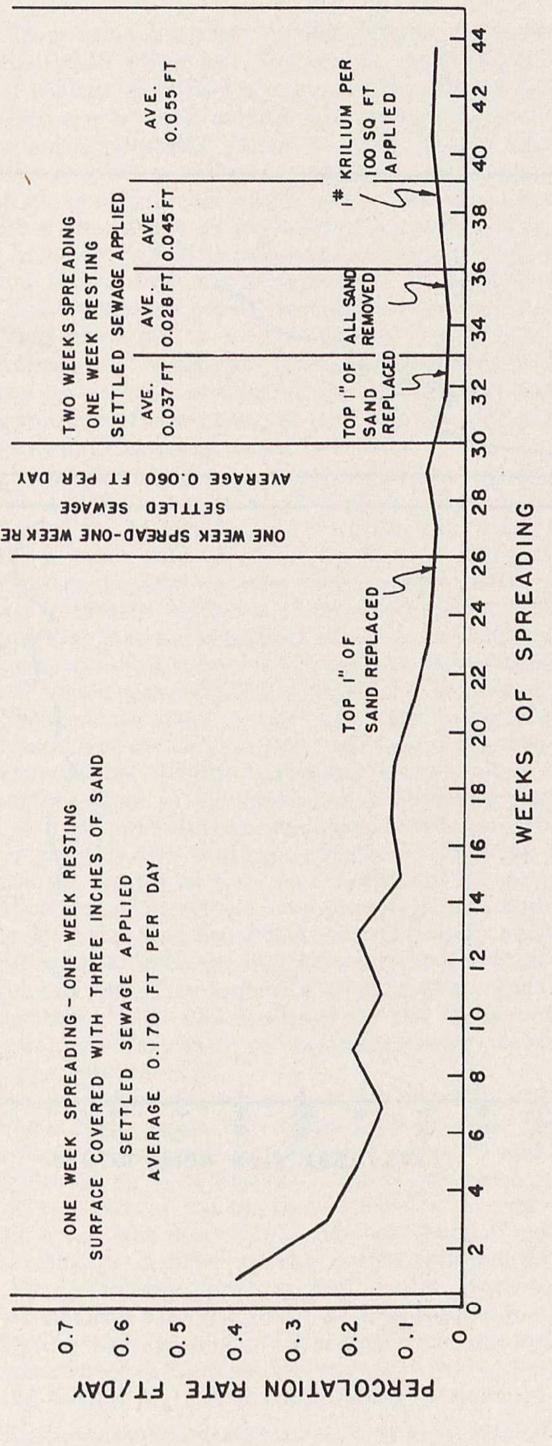


FIGURE 32. Average percolation rate changes on Basin B'

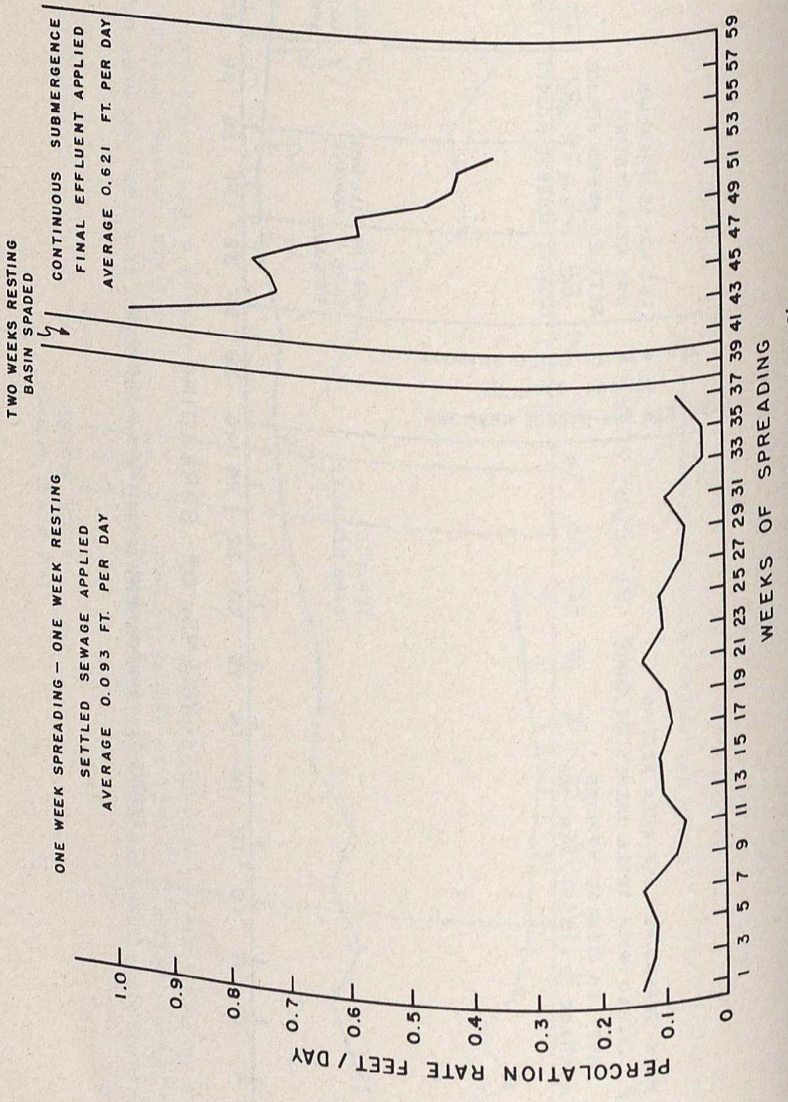


FIGURE 33. Average percolation rate changes on Basin C'

changed from settled sewage to final effluent the percolation rate increased manyfold (Fig. 33). Conversely, when Basin B was changed from final effluent to settled sewage the rate went down (Fig. 29).

The difference between a three day resting period and one lasting a week was not appreciable. Basin A′ (Fig. 31) on which this variable was studied presents a typical average percolation rate curve in which the effect of changing the length of the resting period cannot be detected. Since the extent of drying has been offered as an explanation for high initial percolation rates and subsequent high average rates of percolation, this finding may be considered inconsistent with theory. The effect of a short resting period was studied during the summer months when drying proceeded at a rapid rate so that even so short a resting period as three days could have produced beneficial results as marked as those given by a week's resting. If the variable had been studied under less favorable conditions during the wet season of the year, it is expected that a significant difference would be noted.

A single spading on Basin A′ increased the initial percolation rate from 0.060 to 0.385 feet per day. The effect was not permanent since the rate decreased to the original value during the course of five cycles.

Covering a basin with sand, as was done in Basin B′ (Fig. 32), resulted in higher percolation rates over a longer period of time than was possible on untreated surfaces. Unless the sand is replaced or cleaned often it appears that the beneficial effect is lost. Although Basin B′ had an average percolation rate of 0.170 feet per day as compared with 0.093 on Basin C′ which was treated identically but did not have a sand cover, the rates became the same by the end of the eleventh cycle. A replacement or removal of the sand at that time had no effect on the percolation rate. It appears that the filtering action of the sand no longer exerted a rate increasing effect as the applied organic matter penetrated through the sand and set up limiting conditions in the underlying soil.

Another variable was studied on Basin B′. This was the effect of the soil conditioner known as Krilium.* Following the manufacturer's recommendation, an application of one pound per hundred square feet was used. The material was broadcast over the basin surface and wetted down. Following a day's drying, spreading was resumed. The evidence of two cycles of spreading indicates no effect of the material. The lack of benefit may have been due to either the use of an unsuitable method of application or it may indicate the unsatisfactory nature of Krilium in improving percolation rates.

The final operating variable to be reported is that of continuous basin submergence. Here again the differences between final effluent and settled sewage were clearly demonstrated (Figs. 34 and 35). The initial spreading period on both Basins C and D′ produced typical die away percolation rate curves. On the basin spread with settled sewage, Basin D′, the die away was more rapid than on Basin C which was spread with final effluent. A brief resting period followed by basin spading restored the percolation rates to high levels. However, the curve of average percolation rate for Basin D′ was similar to the one first obtained. Resting and spading for a second time followed by continuous spreading produced a third similar curve. It will be noted from Figure 35 that the second and third submergence periods on Basin D′ were

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* Material supplied by the Monsanto Chemical Co., St. Louis, Missouri

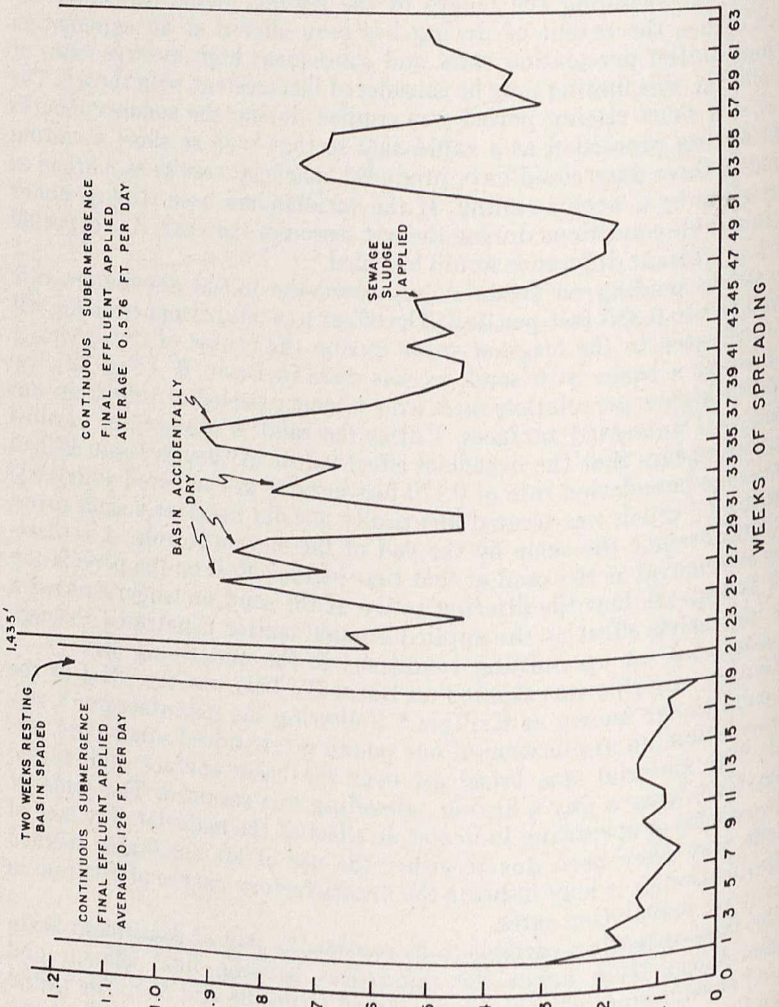

FIGURE 34. Average percolation rate changes on Basin C

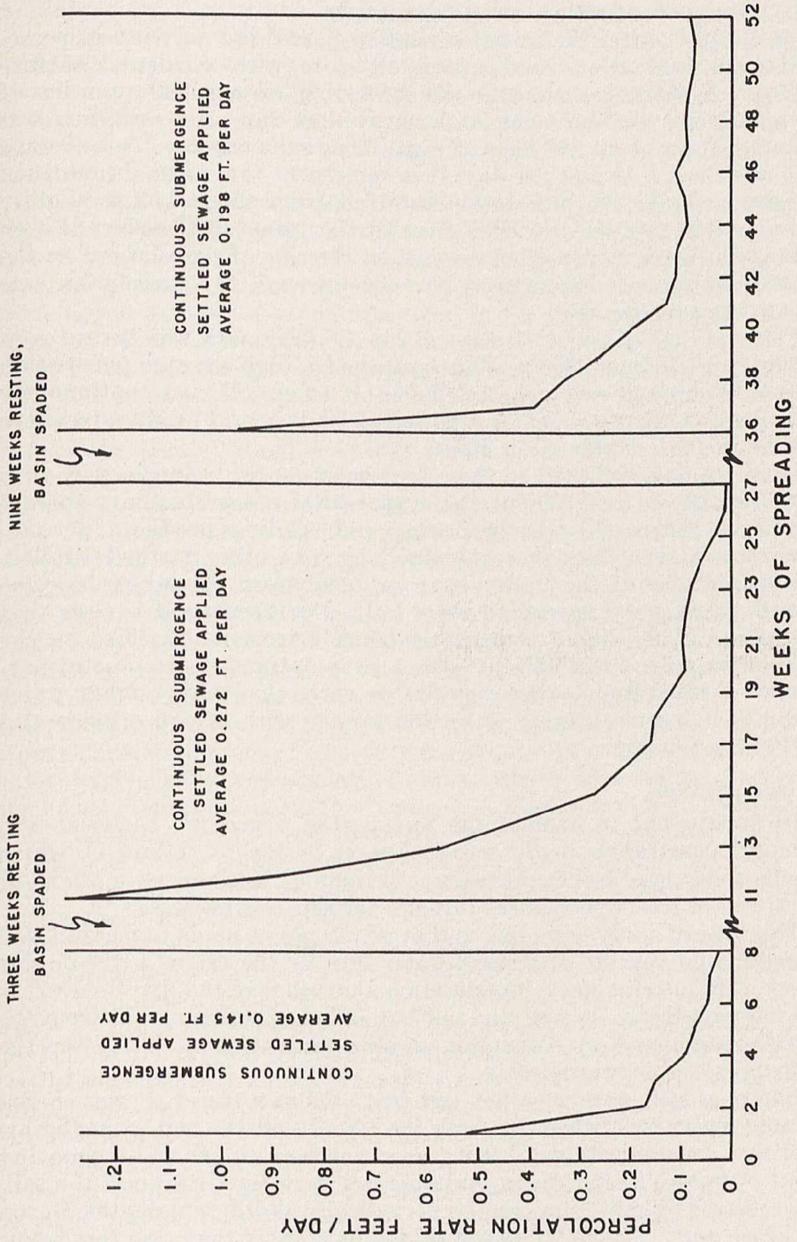

FIGURE 35. Average percolation rate changes on Basin D'

longer than the first, and also that the average percolation rates over the last two periods were higher than during the first. This indicates a beneficial result from a preliminary spreading, but that the effect is not long lasting when settled sewage is spread.

On Basin C, after the initial spreading period the decrease in percolation rate was erratic and associated more with accidental surface drying for short periods and the spreading of a small quantity of sewage sludge. On the whole, a high average rate of percolation was maintained for about 280 days of continuous submergence. This average rate was about 0.58 feet per day. It is significant that after the addition of sewage sludge the percolation rate fell from about 0.53 to slightly less than 0.20 feet per day. This gives further proof of the effect of high organic loadings, as in settled sewage, on the rate of percolation. As the organic matter was decomposed and disappeared, the percolation rate rose to the average value.

For a period of about 80 days Basin C′ (Fig. 33) was spread continuously with final effluent. This basin had a high average percolation rate of about 0.60 feet per day. Basin B (Fig. 29) was continuously spread with settled sewage for a period of 70 days and produced a curve similar to those obtained on Basin D′.

From the data collected on these four basins spread continuously with settled sewage or final effluent, it is apparent that a preliminary spreading period followed by basin resting and spading produced percolation rates higher than those obtained by any other method studied. The importance of the preliminary or incubatory spreading has also been noted in water spreading work (21). Furthermore it is clear that the nature of the liquid being spread had a tremendous effect on the percolation rate. Final effluent with a near optimum organic and particulate loading had higher percolation rates than either fresh water with a low organic loading or settled sewage with a high organic and particulate loading.

4. Tracer Studies

In an attempt to explain the unexpected degree of bacterial and chemical penetration to the two-foot level in Basins A and C, which results were described in preceding sections of this report, a study of the travel of tracer substances through the soil was made.

This type of study is similar to that which can be made to measure the direction and velocity of ground water flow by the use of a dye or salt tracer (29). Preliminary investigation showed that the dye fluorescein did not pass freely through the soil but rather it was removed from the liquid containing it by adsorption on clay minerals. For this reason the salt tracer method was selected.

Boron, as sodium tetraborate, was first used as a tracer. It was chosen because boron was present in both the liquid and the soil in negligible quantity. An application of 1,000 ppm of boron was made and the moving front of boron, as the water containing it percolated through the soil, was followed by collecting samples periodically at different depths. Boron enriched water was not observed at depths greater than two feet below the ground surface and the maximum concentrations of boron at the 2-foot level were much lower than those which might have been expected if the changes in concentration were due only to dilution. Subsequent laboratory work with Hanford fine sandy loam also demonstrated that soil can remove boron from high boron waters. It appears that the soil contains some constituent which is capable of fixing boron, thereby removing it from solution. The conclusion reached was that boron is unsatisfactory for use as a tracer in soils such as Hanford fine sandy loam containing appreciable quantities of clay. A possible application of this observation might be in the removal of boron from wastes such as wash water from the citrus industry by some as yet unidentified constituent of the soil.

As a result of the lack of success with fluorescein and boron as tracers, chlorides were finally tried. Sodium chloride, which is commonly used in tracer work, was considered unsatisfactory because of the high concentration of sodium ions which would be liberated in an aqueous solution. Large quantities of sodium ions in the presence of small quantities of other cations are known to result in a replacement of the divalent ions on the base exchange complex of the clay minerals of the soil, and to cause a subsequent particle dispersion and a decrease in percolation rate (25, 30). Since the Lodi soil contained a relatively high percentage of clay, roughly twenty percent, the effects of the addition of sodium chloride would be pronounced. If, instead of using sodium chloride as the sole source of the chloride ion, a mixture of chlorides were used this dispersion would be avoided. The chlorides which were used were sodium chloride, potassium chloride, calcium chloride, and magnesium chloride. The ratio of the cations in the applied chloride solution was the same as the ratio of cations in the liquid which was being spread. The average cation ratio of the final effluent, i.e., the ratio of milliequivalents per liter of sodium to potassium to calcium to magnesium, was 7 to 1 to 2 to 1.8. To maintain this ratio while providing 25 pounds of chloride ions required 22 pounds of sodium chloride, 3 pounds of potassium chloride, 9 pounds of calcium chloride, and 11 pounds of magnesium chloride. The salts were dissolved and mixed in final effluent in one of the elevated storage tanks, then spread on Basins A and C. Samples of the percolating liquid were regularly collected from the sampling pans at the one-, two-, and four-foot levels and analyzed for chlorides.

The runs on the two basins were made at different times with different quantities of applied chlorides.

Figures 36 and 37 present the data obtained. It is clear that the chloride enriched water reached the two-foot level in both basins sooner than the one-foot level. The presence of small channels such as those made by grass roots, or of a single large channel, possibly made by a gopher, would explain these results. Instead of percolating through two feet of soil the water passed from the surface almost directly to the sampling pan. That there was some filtering action is shown by the bacteriological data (Fig. 17). Although the coliform count at the two-foot level was high, it was very much less than in the surface liquid.

In any field spreading installation it appears that an allowance must be made for the possible presence of channels which might carry contamination or pollution to the ground water.

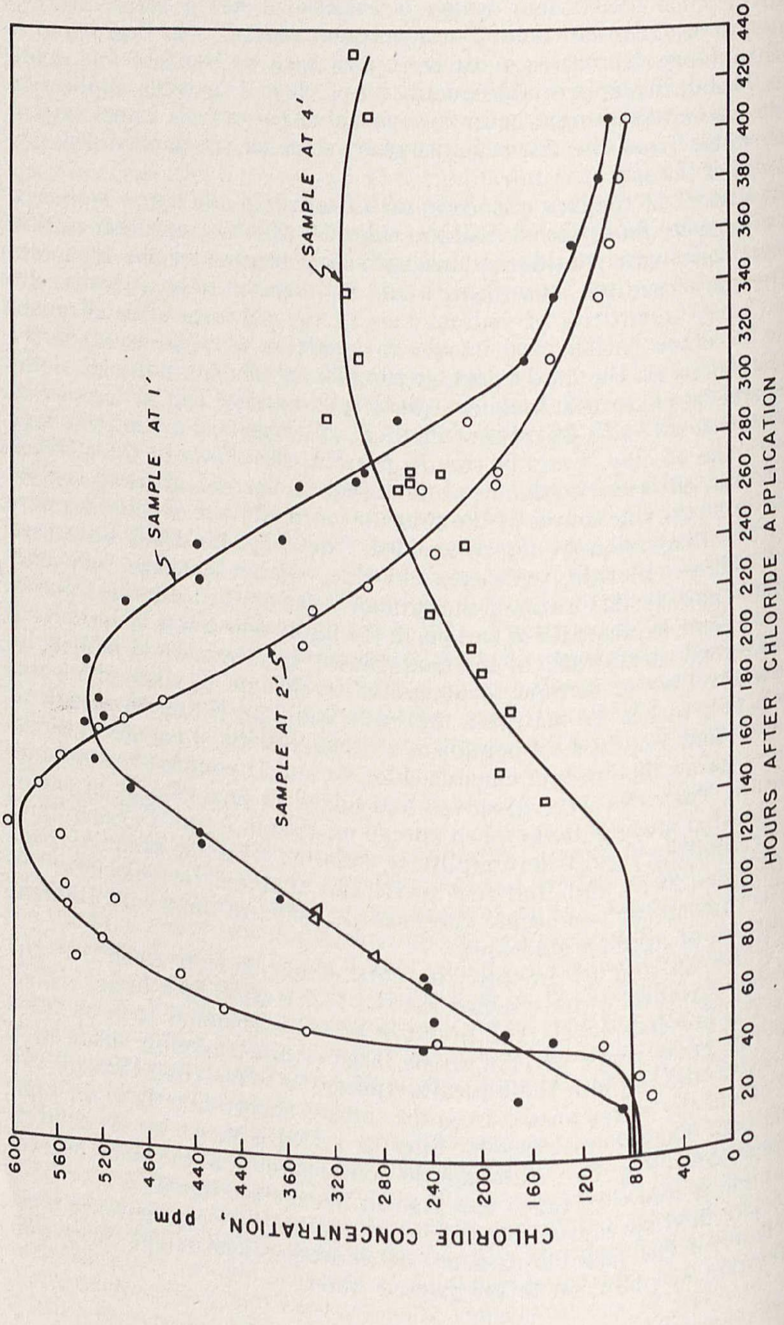

FIGURE 36. Chloride concentration as a function of hours after chloride application at 1, 2, and 4-foot levels in Basin A (707 ppm chlorides applied at O hour)

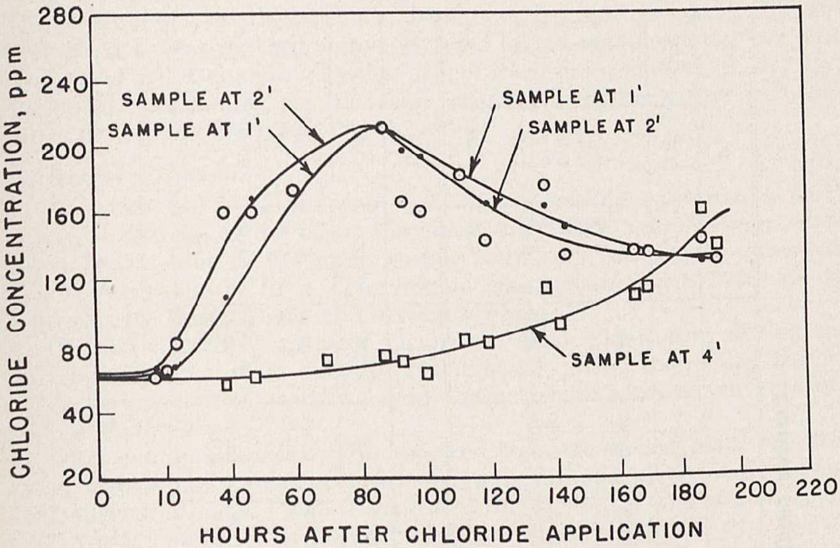

FIGURE 37. Chloride concentration as a function of hours after chloride application at 1, 2, and 4-foot levels in Basin C (455 ppm chlorides applied at O hour)

5. *Studies of Soil Organic Matter*

Samples of surface soil were collected periodically for analyses of organic carbon and nitrogen. The data are reported in Table 12. Before spreading, the untreated surface soil had an average of 1.05 percent of organic carbon and 0.0125 percent of organic nitrogen. The ratio of carbon to nitrogen was 84.

The data in Table 12 show that the carbon to nitrogen ratio decreased during the course of the spreading process to 10 or less. This ratio indicates a stable condition since it is approximately the ratio found in living organisms (15).

In previous sections of this report the importance of organic matter in soil clogging and aggregate formation were discussed. The data presented in Table 12 show that little difference in organic matter existed among the basins spread with fresh water, final effluent, or settled sewage. It should be noted, however, that most of the samples which were analyzed were collected during the resting period. If there were accumulations of organic matter during the spreading period, the material could have been oxidized while the basin was being rested. The data collected from Basin A during May, 1952, indicate increasing stability of organic matter as the resting period progressed.

Basin C which was under continuous submergence had relatively high concentrations of carbon and low concentrations of nitrogen. The carbon to nitrogen ratio was high so that the organic matter was not well stabilized. Nonetheless, the basin had high sustained percolation rates.

The data on soil organic carbon and nitrogen are inconclusive and generally not consistent with theoretical expectations. One important factor may account for this: Although the amounts of organic matter differ little with different applied liquids on a weight basis, they may be significantly different on a volume basis. The analyses made determined

TABLE 12

ORGANIC MATTER IN SURFACE SOIL OF SPREADING BASINS ‡

Date	A			B			C			D		
	%C††	%N	C/N	%C	%N	C/N	%C	%N	C/N	%C	%N	C/N
21 August 1951†							0.56	0.013	43.1			
24 September 1951†	1.02	0.032	31.9	0.76	0.022	34.5				0.68	0.021	32.4
8 February 1952	0.86	0.11	7.8	0.68	0.080	8.5				0.78	0.10	7.8
27 March 1952†	1.36	0.14	9.8	0.89	0.098	9.1				0.85	0.090	9.4
2 May 1952*	1.45	0.070	20.7				1.43	0.030	47.7	0.78	0.15	5.2
5 May 1952*	1.20	0.073	16.5				2.14	0.079	27.5	0.73	0.12	6.1
13 May 1952**	1.37	0.12	11.4									
14 May 1952**	2.08	0.26	8.0									
4 June 1952†	2.00	0.17	11.8							0.83	0.087	9.5

Date	A′			B′			C′			D′		
	%C	%N	C/N	%C	%N	C/N	%C	%N	C/N	%C	%N	C/N
May 1951‡‡	1.11	0.012	92.5	1.06	0.012	88.4	1.00	0.013	76.9	1.04	0.013	79.9
24 September 1951†	0.87	0.027	32.2				0.79	0.019	41.6	0.76	0.013	58.5
8 February 1952†	0.97	0.14	6.9									
14 February 1952†				0.68	0.088	7.7	0.74	0.11	6.7	1.05	0.16	6.6
27 March 1952†	0.95	0.11	8.6	0.90	0.081	11.1	1.06	0.13	8.1			
6 May 1952†							1.10	0.10	11.0			
14 May 1952**	1.80	0.13	13.8									
4 June 1952†	1.04	0.12	8.7	1.45	0.12	12.1						

* Samples taken while basin submerged.
** Samples taken at beginning of resting period.
† Samples taken at end of resting period.
†† Percent carbon and nitrogen on a dry weight basis.
‡ Average of triplicate samples.
‡‡ Samples of untreated soil before spreading started.

the weights of organic carbon and nitrogen per unit weight of dry soil but did not measure the volume occupied by the organic matter per unit volume of soil. Depending on the form of the organic matter, i.e., density, chemical composition, etc., the same weights of organic matter may produce greatly different effects.

6. Studies of Nuisances

A. Odors. During the course of the spreading operation a daily record was kept of the odors associated with each basin. Sewage odors such as the odor of hydrogen sulfide were only occasionally observed. There seemed to be little difference in odor production between basins spread with final effluent and settled sewage.

On intermittently operated basins the algae which grew during the spreading period were partially decomposed during the resting period. This decomposition produced mild characteristic odors which were not odors of sewage.

Odor complaints were never received from the sewage plant operator who maintained a residence directly opposite and about 50 feet from the spreading area. From a private residence which was located about 200 yards from the spreading basins but which was in the direction of the prevailing winds from the basins, no complaints were received.

It appears likely that a large scale spreading operation, intermittently operated, may produce sufficient odor problems to warrant control. Copper sulfate which is frequently used to control algae (31) may be used. Since this material is used to control algae in reservoirs, it may be used safely in a reclamation operation. Although copper is a toxic material, the concentrations used to control algae are not considered dangerous. For example, the standards for drinking water of the United States Public Health Service state that the concentration of copper shall not exceed 3 ppm. The concentrations used to control algae are seldom greater than 0.5 ppm.

Chlorine may also be used for algae control. This has the advantage over copper sulfate in not leaving a toxic residue. Furthermore, the chlorine will act as a disinfecting agent, thereby reducing still more the danger of ground water contamination.

It must be pointed out that the prevention of algae growth will result in lowered concentrations of surface dissolved oxygen. The benefit derived from the algae as an oxygen source is probably more important than the possible odor nuisance. For that reason, if local conditions are suitable, the algae should be permitted to develop freely.

B. Insects. The spreading basins acted as mosquito breeding grounds. Surveys made by the Northern San Joaquin County Mosquito Abatement District reported the presence of several mosquito species in appreciable number. The species were *Culex pipiens*, *Culex stigmatosoma* and *Culex tarsalis*.

During the summer of 1950 an attempt was made to control mosquito breeding by the use of mosquito fish, *Gambusia affinis*. Although the fish were able to reduce the number of mosquitoes the difficulty of handling the fish in intermittently operated basins and the unsuitability of highly polluted waters as an environment for them made this method of control unsatisfactory.

Spraying with DDT in various formulations was tried. The simplest method of mosquito control was by the use of "toss-its," small gelatin-like balls which contain DDT with a water emulsifying agent. The "toss-its" were thrown into the basins and as the covering material dissolved, the DDT was liberated.

All of the work on mosquito control was done by representatives of the Northern San Joaquin County Mosquito Abatement District.

A survey was made during May, 1952, by Mr. William R. Kellen, Research Entomologist at the University of California. The insects which were collected from the spreading basins were classified as follows:

Hemiptera	
Salidae:	*Saldula interstitialis*
Gerridae:	*Gerris incognitus*
Corixidae:	*Corisella decolor* *Corisella inscripta*
Odonata	
Coenagriidae:	*Enallagma sp.*
Libellulidae:	sp.
Coleoptera	
Dytiscidae:	*Thermonectes basillaris* *Agabus disentigratus* *Agabus lutosus* *Hydroporus subpubescens* *Laccophilus aristernalis* *Hygrotus lutescens* *Hygrotus collatus*
Hydrophilidae:	*Berosus miles* *Berosus striatus* *Tropisternus lateralis*
Diptera	
Psychodidae:	*Psychoda alternata*
Culicidae:	*Culex tarsalis*
Tendipedidae (= Chironomidae):	*Tendipes decorus* *Glyptotendipes barbipes*
Ephydridae:	*Scatella laxa* *Scatella stagnalis* *Scatella paludum* *Paracoenia bisetosa* *Ephydra riparia*
Borboridae:	*Leptocera fontinalis*
Dolicopodidae:	sp.

It is interesting to note that these insects, in general, are the same as those which have been collected from oxidation ponds (32).

Of the species collected, *Psychoda alternata* and the various chironomidae have been known to be nuisances. Psychoda flies are particularly associated with trickling filters. In the numbers found around the spreading basins no nuisances were created; however, the potentiality of the formation of nuisance conditions existed.

Mosquito breeding, unlike fly breeding, presents a real public health danger. The presence of conditions conducive to the development of mosquitoes may lead to the multiplication of malarial mosquitoes. Although no anopheline or malarial mosquitoes were collected, under other spreading conditions they may be found. Fortunately primary malaria is rarely found in California, and it may be suggested that spreading operations will lead to few new cases.

More important than the danger from malaria is that from encephalitis. A vector in the transmission of encephalitis is the mosquito, particularly *Culex tarsalis* (33). The presence of this species in and around the spreading basins indicates the existence of an unsafe situation. This is particularly true in California where mosquitoes have been implicated frequently in the transmission of both western equine and St. Louis encephalitis (34).

To summarize, insect nuisances are unlikely in spreading areas in spite of the presence of numerous insect species. Insect menaces to public health, i.e., mosquitoes, are to be expected unless adequate mosquito control operations are undertaken.

DISCUSSION

At the spreading site in Lodi it was possible to study a number of aspects of the reclamation of water from sewage. Essentially, this included the methods of operating a reclamation project and the results which might be expected from such a project in terms of water reclamation and public health.

In order to evaluate the dangers connected with the use of sewage effluents in agriculture and industry much recent work has been done on the occurrence and survival of enteric organisms in water and soil (35). After an exhaustive study on the contamination of vegetables grown in sewage polluted soil, Rudolfs, Falk, and Ragotzkie concluded that vegetables can be grown without health hazard in polluted soils if appropriate precautions are taken (36).

Studies on the survival of various enteric organisms in soil have demonstrated that coliform bacteria do not survive long periods (37) and that pathogenic organisms, such as the typhoid bacillus, died out in soil within as short a time as two weeks (38).

The available literature indicates the possibility of the spread of disease through the use of sewage effluents .although it has never been proven that disease was caused. The probability of the transmission of disease by means of sewage effluents used in agriculture appears small.

The present work has shown that a bacteriologically safe water, that is, a water which conforms to the United States Public Health Service bacteriological standards for drinking water can be produced by percolating settled sewage or final sewage treatment plant effluent through at least four feet of soil.

The reduction in coliform count is consistent with that reported in the literature. Calaway, Carrol, and Long (39) studied the removal of bacteria in an intermittent sand filter of which the effective sand size was 0.31 mm. They found greatly reduced coliform counts after passing settled sewage through 30 inches of sand. Similar results were obtained in England by Allen, Brooks, and Williams (40) who found coliform reductions as high as 98 percent. Extrapolating from these data to sand sizes as small as those at Lodi leads to the conclusion that the coliform removals obtained in this study are as might have been anticipated.

The removal of coliform organisms was affected by the filtering action of the soil. Once removed from the liquid these organisms rapidly died out as a result of the unfavorable conditions of the environment and also because of the production of antagonistic substances by the normal soil flora (37).

Chemically, the water produced by the spreading operation differed little from the sewage effluent from which it was reclaimed. Unless the sewage contains toxic materials or high concentrations of undesirable elements such as chlorides, sulfates, sodium, boron, etc., the water reclaimed from it will be satisfactory. Chlorides can be used as an indicator in measuring the suitability of sewage water for reuse. The data in Table 9 show that during the process of water utilization and sewage production the chloride ion concentration increased from 32 to roughly 70 ppm, an increase of 38 ppm. Employing this figure of chloride ion concentration increase per cycle of water use, at least five cycles would be possible before the concentration reached 250 ppm which is set as the upper limit for chlorides by the standards of the United States Public Health Service. This reuse would be possible even if no dilution were obtained in the ground water so that the figure of five cycles is a conservative one.

In the reclamation of domestic sewage it is possible that an unsatisfactory drinking water would be produced if there was no dilution by ground water. This would result from the high nitrate concentrations produced at the greater depths. Nitrate ion concentrations greater than 10 ppm are generally considered unsatisfactory since nitrates are held to be responsible for infant methemoglobinema (41, 42). The expected dilution factor, however, would reduce the concentration to a safe level.

The data on percolation are generally consistent with those reported in the literature (10, 21, 43). The spreading operation at Lodi produced results intermediate between those obtained in sewage farming and those obtained in reclamation programs under other soil conditions.

Continuous submergence with final effluent gave the highest percolation rates. The continuous application of settled sewage gave considerably lower rates which, nonetheless, were higher than the rates obtained from the intermittent spreading of settled sewage.

It appears that a preliminary spreading and resting period prior to the start of continuous spreading will produce best results. The preliminary spreading may be made with material such as settled sewage containing a high organic load. The large amount of organic matter may result in rapid clogging, however, when the basin is rested this organic matter will be broken down with the formation of aggregates of maximum stability. Following the resting period, which should be continued until the surface soil moisture content is reduced to the permanent wilting percentage, spading seems desirable. Continuous submergence may then begin.

A similar operating scheme has been suggested by Bliss, Johnson, and Schiff (21). They have used cotton gin trash to build up the soil organic matter and improve aggregate formation. The preliminary resting period was called the incubation period and was considered essential in order to obtain maximum percolation rates.

The data indicate the desirability of using a highly purified sewage effluent for reclamation purposes. If a percolation rate of 0.5 acre-feet per acre per day is taken as a design criterion for a reclamation plant, 6.14 acres would be required for a flow of 1,000,000 gallons per day. Providing for basin nonoperation during two months of the year the land requirement would be increased to 7.36 acres. Initial costs, in addition to that of the land, would include basin leveling, dike erection, piping and controls. Operating costs would include dike maintenance, pumping, mosquito control, etc.

It may be stressed here that the steady rate of 0.5 feet per day was that obtained at Lodi with a single soil. In other soils entirely different maintained rates may be found. For this reason it may be dangerous to extrapolate to other conditions which might be encountered in the field.

The prohibitive cost of making large-scale field studies for reclamation under different soil conditions led to the development and construction of small pilot-scale basins at the Richmond Field Station of the university. Preliminary work done since the inception of this project consisted of studying different small units and methods of packing soil into them. During the summer of 1951 it was demonstrated that reproducible conditions could be produced in small scale soil columns. By carefully packing air dried, homogenized and screened soil into corrugated metal tanks, 5 feet high and 3 feet in diameter, reproducible percolation rates were obtained.

In such an installation the pan method of collecting samples at intermediate depths would be completely unsatisfactory. To sample the percolating liquid at different depths filter sticks or "probes" which are porous ceramic cylinders, have been developed (44). It was found that the most important criterion in selecting a probe is its average porosity, and that the best porosity lies in the range between 1 and 10 microns. Permeability is another factor influencing probe behavior and can be adjusted or corrected for by applying a proper degree of tension to the probe. Still another factor is the structural strength of the probe itself. For example, carborundum tubes were found to be sufficiently strong and durable to withstand continued use. By burying the probe at any desired depth and connecting it to a hanging column of water it would be possible to collect samples for chemical analysis without affecting significantly the percolation of water through the soil.

Following the development of a method for making pilot-scale spreading basins, which are called lysimeters, twenty basins were constructed. They are corrugated metal tanks 5 feet high and 3 feet in diameter. Each tank is supplied with sewage effluent or water from a 2-inch header pipe. Lines draining each tank run into separate collecting tanks, 55 gallon steel drums, in which measurements of percolation rate will be made.

Five representative California soils have been selected for study in the lysimeters. These soils are Hanford fine sandy loam. Hesperia sandy loam, Columbia loam, Yolo loam, and Oakley sand. The Hanford fine sandy loam was taken from the spreading area in Lodi and will be used to give correlative factors between disturbed and undisturbed field soil.

The lysimeter study has not yet been completed. It is hoped that the information derived from the small scale study will make possible a generalizing of the Lodi experience so that percolation rates in different natural soils can be anticipated. If this is possible, design criteria for any reclamation plant can be established.

The studies made with chloride tracers indicate the dangers which can result from the presence of channels within the spreading basin. If the ground water table is close to the soil surface, contamination or pollution of the ground water can easily result where only a few channels are present. If the ground water table is lower it is unlikely that channels will connect it directly to the surface in the usual agricultural soils. Spreading operations over an aquifer which may be recharged directly without purification of the sewage by passage through an appropriate thickness of suitable soil is definitely dangerous. The proposed site for a reclamation plant should be carefully examined to insure the absence of such conditions. Limestone formations or recent alluvial fans which do not have a soil cover will, in most instances, be unsuitable.

The results of the study of soil organic matter were inconclusive. The literature of soil science abounds with references to the effect of organic matter on soil clogging and aggregate formation. No evidence for the accumulation of large amounts of organic matter in the surface soil after several years of spreading was found. Clogging may then have been due largely to the dispersion of the clay minerals. A factor in the dispersion may be the accumulation of ammonia in the soil. Ammonia may act like sodium in dispersing clay particles. During a spreading period, if the ammonia is supplied more rapidly than it can be utilized by microorganisms, it may be exchanged for divalent ions on the clay complex, thereby causing a dispersion. At the conclusion of the spreading period the adsorbed ammonia would be oxidized making for a greater aggregation on the resumption of spreading. This explanation may account, in part, for the differences between final effluent and settled sewage. The latter being higher in ammonia than the former would tend to have a greater dispersing action, hence a lower percolation rate.

Nuisances connected with a reclamation plant may be serious. This would happen particularly if mosquitoes were allowed to breed freely. The importance of mosquito control in the control of encephalitis makes consideration of the public health factor of reclamation vital.

Weed growths which may occur appears to be beneficial rather than otherwise. That is, improvements in rates of percolation have been associated with the growth of various grasses in spreading areas. On the other hand, the growth of weeds may increase the difficulty in controlling mosquitoes. However, if depths of three feet or more of sewage effluent are maintained on the spreading basin weeds can usually be controlled. This technique has been used successfully in controlling tules in oxidation ponds.

ADDENDUM

During the week of July 18, 1952, subsequent to the completion of the field study, the spreading basins were carefully examined. Surface and subsurface soils were collected and analyzed, and a number of sampling pans were removed in order to ascertain the reasons for their failure to function properly during the investigation.

1. *Spreading Basin Surfaces*

Figures a through h show the appearance of the surfaces of the dry basins after approximately two years of spreading. Generally, the basins had a dry cracked crust consisting largely of residues of algae which had developed on the basins during spreading. All basins, with the exception of D and C, were similar in appearance. Basin D had experienced little algal growth, due to the relatively short time of spreading with a sewage effluent; hence the crust was almost lacking. Basin C, which had been under continuous submergence for almost a year had deep cracks which extended as much as one to two inches below the surface of the soil, which was a typical clayey loam with a platy structure.

By spading the basins to a depth of several feet it was possible to observe changes which had taken place in the soil profile. The final soil profiles are shown in Figure i.

Particle size distribution in the surface soil were determined and the effective sizes and uniformity coefficients were calculated (Table 13).

The fractions of clay, silt and sand are presented in Table 14.

In Table 15 is shown the base exchange complex of the surface soils of the eight spreading basins. Table 16 gives the concentration of organic matter in the surface soils.

By comparing the data on particle size distribution presented in Table 3 with that given here it is apparent that, in general, there has been a migration of the finer particles from the surface to lower depths. This is most clearly shown in Basin C, which, as a result of the greater amounts of water applied, had the greatest decrease in fines in the surface. This migration may have a twofold effect: (1) by decreasing the absolute amount of clay in the surface soil the base exchange capacity of that surface would be decreased and (2) by decreasing the relative amount of clay in the surface the percolation rate through the surface should be correspondingly increased. Since, at Lodi, the subsurface soils are poorer in clay than the surface soils, the increase in the clay fraction of the subsurface would tend to decrease the percolation rate through the subsurface. The percolation rate through the subsurface was initially so much larger than the rate through the surface that the decrease in percolation through the subsurface would be negligible unless clay lenses or layers would be formed by the migrating fines. The net effect, if no clay lenses formed, would be an increase in the over-all rate of percolation.

The data on base exchange (Table 15) show that a decrease of about 50 percent in total exchangeable bases occurred during the spreading study. Part of this decrease is associated with the decrease in surface clay as mentioned above. The remaining fraction of the decrease was due to a cation displacement by hydrogen ions and a slow leaching

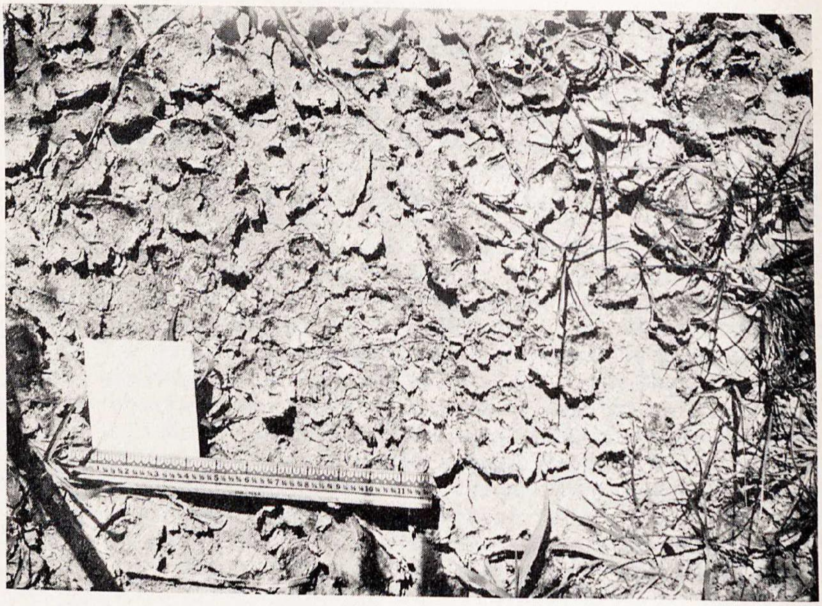

FIGURE a. Surface of Basin A

FIGURE b. Surface of Basin B

FIGURE c. Surface of Basin C

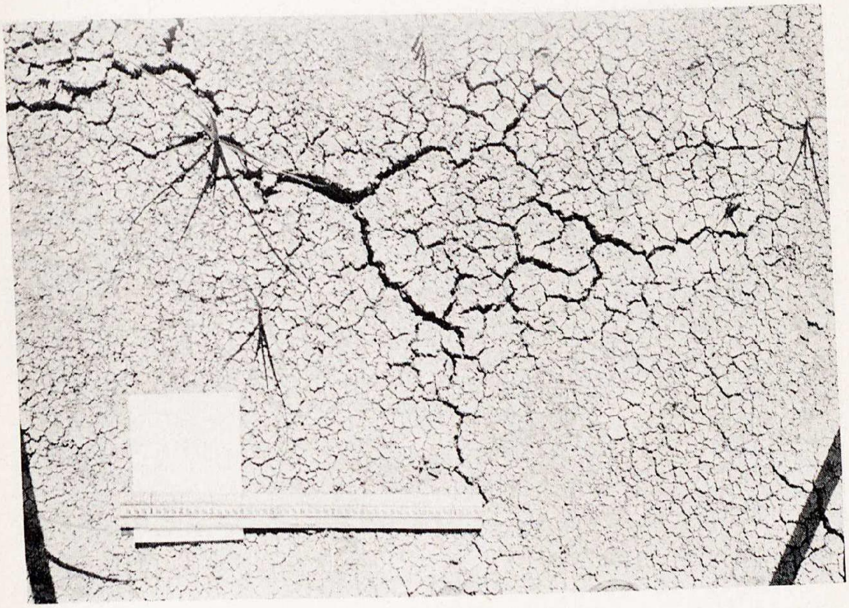

FIGURE d. Surface of Basin D

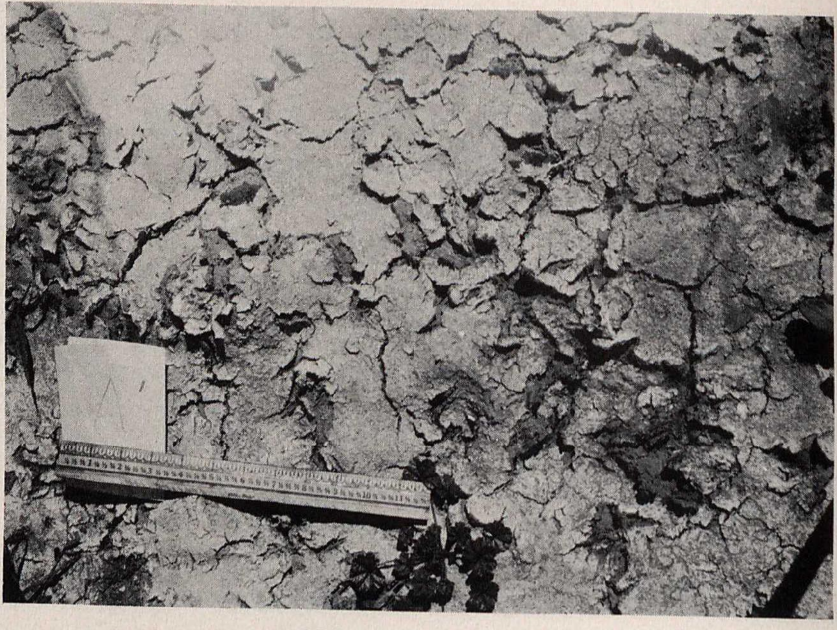

FIGURE e. Surface of Basin A′

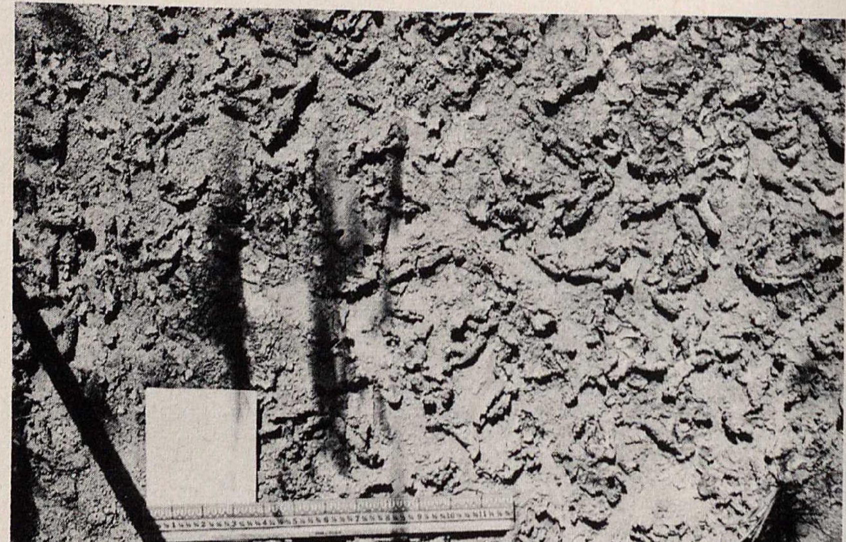

FIGURE f. Surface of Basin B′

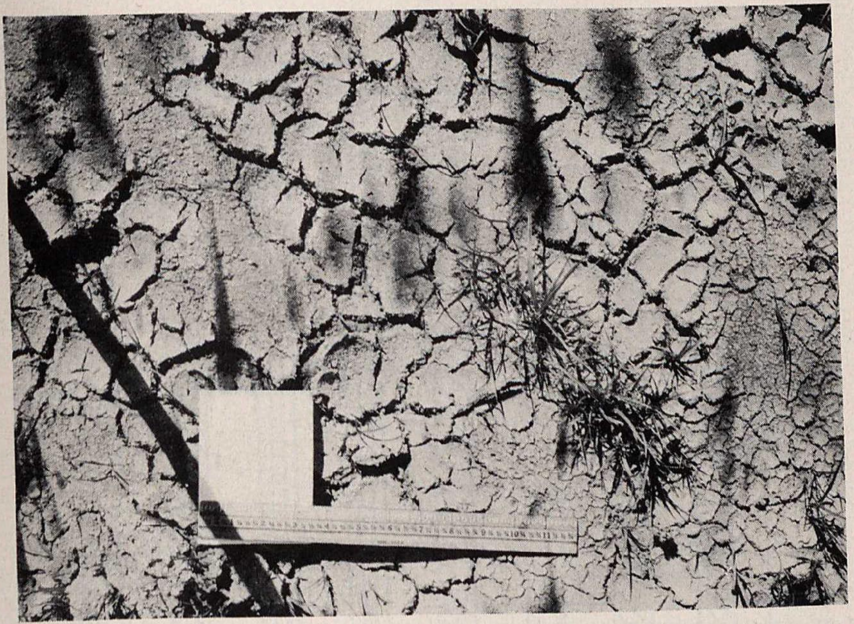

FIGURE g. Surface of Basin C′

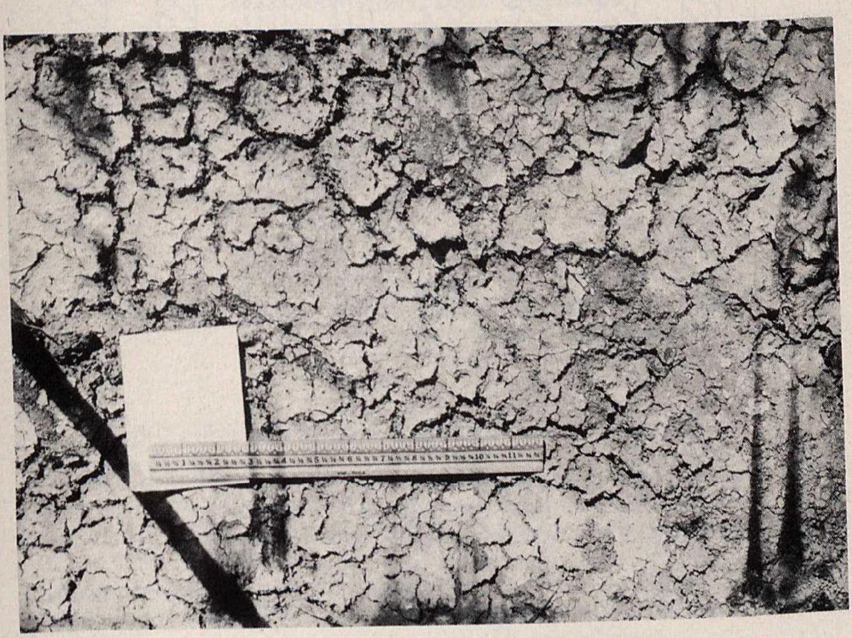

FIGURE h. Surface of Basin D′

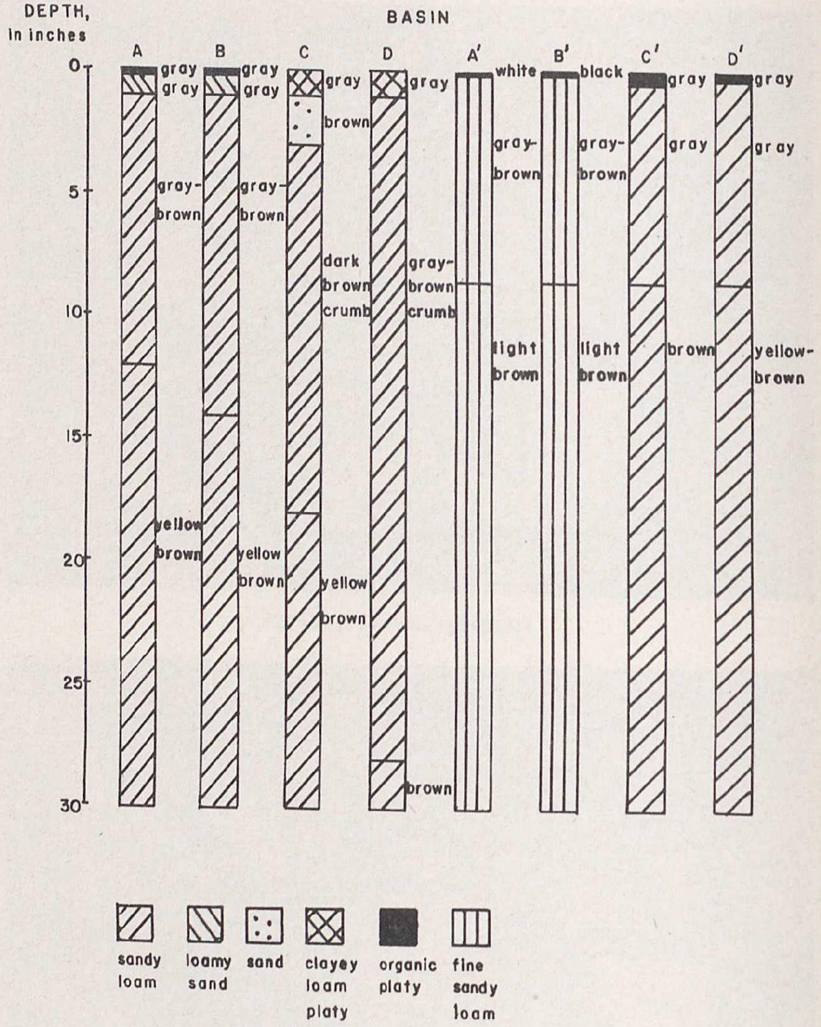

FIGURE i. Profile sketch of spreading basins at close of spreading study

away of the displaced ions. Measurement of the soil pH indicated that the pH decreased from neutrality to about 5.5, thereby lending support to the foregoing explanation. Such an increase in soil acidity is to be expected after prolonged leaching or percolation.

As in the main body of the final report the data on organic matter concentrations in the surface soil is inconclusive (Table 16).

2. *Sampling Pans*

Six sampling pans were removed from their positions in the soil. These were pans No. 20, 21, 22, 23, 14, and 2. The first four of this group had yielded intermittent or no samples during the entire study, while

TABLE 13

VARIATIONS OF EFFECTIVE SIZE AND UNIFORMITY COEFFICIENT OF FIRST FOOT OF SOIL AT CLOSE OF SPREADING STUDY, LODI, CALIFORNIA

Basin	Depth in inches	E. S.*	U. C.**
A	0- 6	0.0020	45.7
	7-12	0.0027	60.4
B	0- 6	0.0050	48.0
	7-12	0.0023	44.3
C	0- 6	0.0032	9.1
	7-12	0.0035	34.9
D	0- 6	0.0037	51.1
	7-12	0.0027	50.7
A^1	0- 6	0.0025	67.6
	7-12	0.0013	70.8
B^1	0- 6	0.0019	94.7
	7-12	0.0011	109.1
C^1	0- 6	0.0017	85.3
	7-12	0.0016	101.3
D^1	0- 6	0.0011	136.
	7-12	0.0022	77.3

* Effective size of Hazen.
** Uniformity coefficient of Hazen.

TABLE 14

FRACTIONS OF CLAY, SILT, AND SAND OF FIRST FOOT OF SOIL AT CLOSE OF SPREADING STUDY, LODI, CALIFORNIA

Basin	Depth in inches	Percent clay[1]	Percent silt[2]	Percent sand[3]
A	0- 6	10	29	61
	7-12	9	27	64
B	0- 6	7	21	72
	7-12	9	30	61
C	0- 6	4	12	84
	7-12	8	31	61
D	0- 6	8	22	70
	7-12	9	27	64
A^1	0- 6	9	28	63
	7-12	12	36	52
B^1	0- 6	10	29	61
	7-12	13	30	57
C^1	0- 6	10	28	62
	7-12	11	28	61
D^1	0- 6	11	27	62
	7-12	10	25	65

[1] Clay: Defined as particles less than 0.002 mm.
[2] Silt: Defined as particles greater than 0.002 mm but less than 0.050 mm.
[3] Sand: Defined as particles greater than 0.050 mm but less than 2.0 mm.

pans 14 and 2 showed evidence of channeling through the soil overlaying them.

It was found that Pan 20 had failed to yield liquid samples because of a tear in the rubber tubing connecting the pan to the sampling well. In addition, the copper nipple on the pan was clogged.

Pan 21 was separated from the soil overlaying it. A horizontal gap about one and one-half inches high between the pan and the soil above it had prevented the percolating liquid from entering the pan.

Pan 22 had a smaller horizontal gap similar to that found over Pan 21.

TABLE 15

BASE EXCHANGE COMPLEX OF SURFACE SOILS IN SPREADING BASINS AT CLOSE OF SPREADING STUDY, LODI, CALIFORNIA

Sampling station	Milli-equivalents per 100 grams of soil				
	Ca	Mg	Na	K	Total
A	2.07	0.78	0.26	0.44	3.55
B	1.39	0.42	0.10	0.37	2.28
C	1.12	0.92	0.12	0.15	2.31
D	2.61	0.66	0.69	0.54	4.50
A¹	1.83	0.57	0.36	0.36	3.11
B¹	2.15	0.84	0.62	0.51	4.12
C¹	2.27	0.53	0.32	0.42	3.53
D¹	1.78	0.39	0.44	0.44	3.05
Average	1.92	0.64	0.36	0.40	3.31
Average before spreading*	3.8	2.7	0.65	0.53	7.7

* See Table 5 in body of report.

TABLE 16

ORGANIC MATTER IN SURFACE SOILS OF SPREADING BASINS AT CLOSE OF SPREADING STUDY, LODI, CALIFORNIA*

Basin	Depth in inches	Percent C	Percent N	C/N
A	0- 6	1.29	0.11	11.7
	7-12	0.93	0.08	11.6
B	0- 6	0.44	0.08	5.5
	7-12	0.77	0.07	11.0
C	0- 6	1.07	0.05	21.4
	7-12	1.11	0.10	11.0
D	0- 6	0.82	0.08	10.3
	7-12	0.61	0.06	10.2
A¹	0- 6	0.82	0.08	10.3
	7-12	0.91	0.08	11.4
B¹	0- 6	0.92	0.08	11.5
	7-12	0.81	0.08	10.1
C¹	0- 6	1.02	0.09	11.3
	7-12	0.61	0.06	10.2
D¹	0- 6	1.06	0.11	9.6
	7-12	0.63	0.08	7.9

* All samples taken after a two-week drying period. Results are given on a dry weight basis.

Pan 23 had a one-half inch horizontal gap over it.

Pan 14 was solidly placed. The pan gravel, however, was continuous with a gravel vein, 3 inches in diameter, which extended from the pan to near the basin surface. This gravel vein was probably formed during the basin construction and accounts for the high coliform counts obtained from this pan and also for the rapid flow-through observed in the tracer studies. That is, the presence of a pervious channel led surface water to the pan with a minimum of filtering action.

The condition of Pan 2 was similar to that of Pan 14. Instead of a gravel channel, however, a coarse sand channel was observed.

In all instances the failure of a pan to operate properly was correlated with a mechanical difficulty associated with the placement of the pans or the construction of the basins. The observations of Pans 14 and 2 substantiate the theory of channeling offered on page 67.

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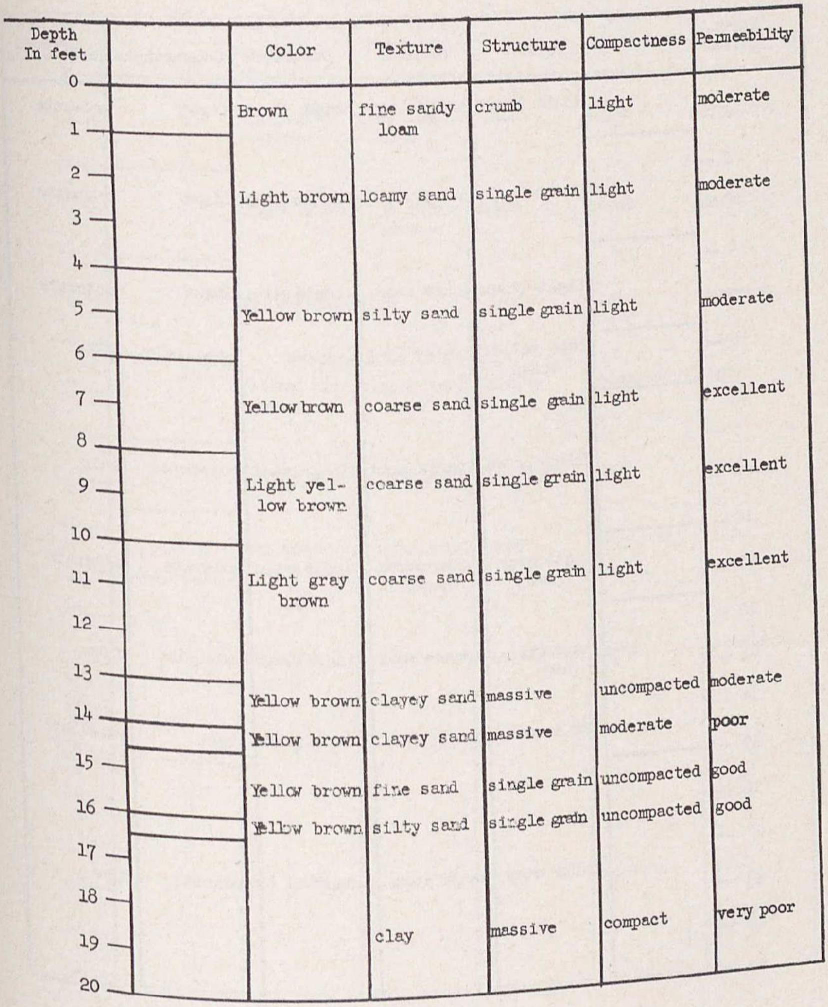
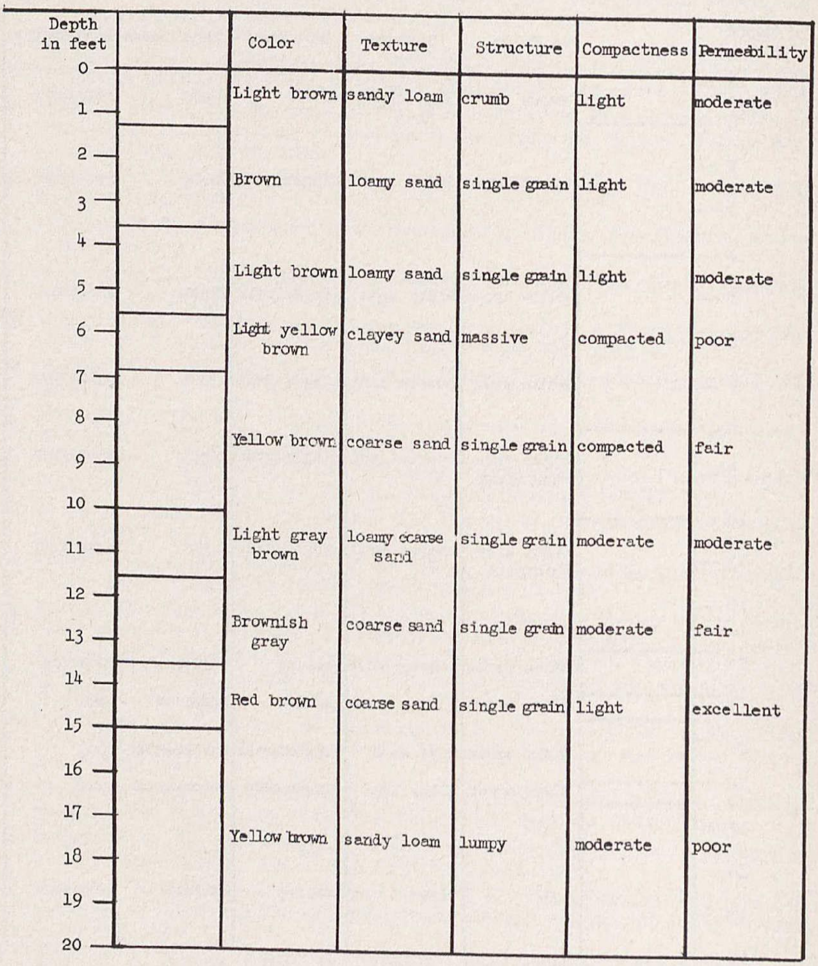
APPENDIX A



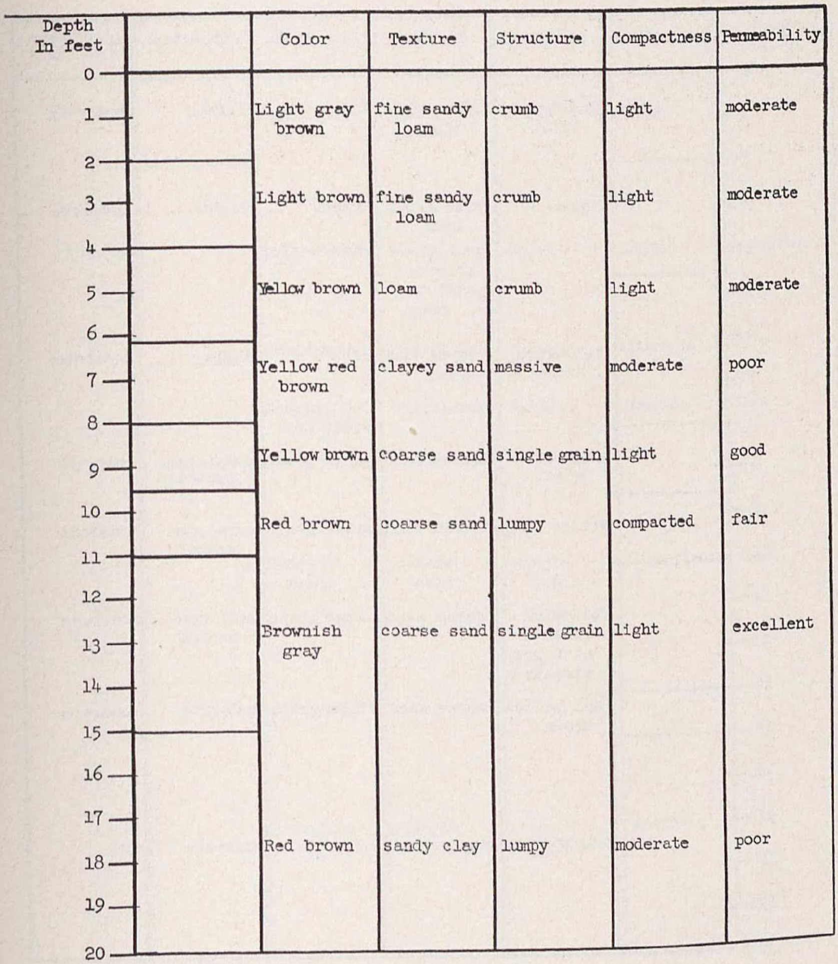
Color	Texture	Structure	Compactness	Permeability
Brown	fine sandy loam	crumb	light	moderate
Light brown	loamy sand	single grain	light	moderate
Yellow brown	silty sand	single grain	light	moderate
Yellow brown	coarse sand	single grain	light	excellent
Light yellow brown	coarse sand	single grain	light	excellent
Light gray brown	coarse sand	single grain	light	excellent
Yellow brown	clayey sand	massive	uncompacted	moderate
Yellow brown	clayey sand	massive	moderate	poor
Yellow brown	fine sand	single grain	uncompacted	good
Yellow brown	silty sand	single grain	uncompacted	good
	clay	massive	compact	very poor

FIGURE 38. Profile sketch, detail, Sampling Station 1



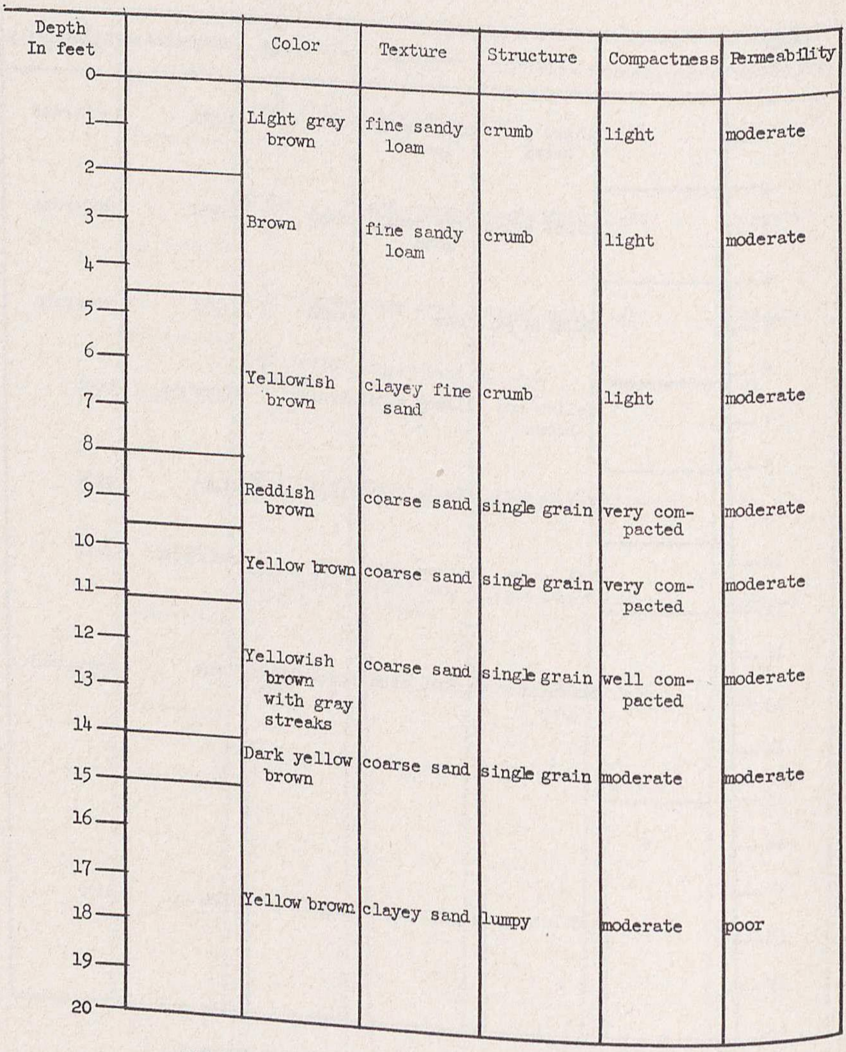
Color	Texture	Structure	Compactness	Permeability
Light brown	sandy loam	crumb	light	moderate
Brown	loamy sand	single grain	light	moderate
Light brown	loamy sand	single grain	light	moderate
Light yellow brown	clayey sand	massive	compacted	poor
Yellow brown	coarse sand	single grain	compacted	fair
Light gray brown	loamy coarse sand	single grain	moderate	moderate
Brownish gray	coarse sand	single grain	moderate	fair
Red brown	coarse sand	single grain	light	excellent
Yellow brown	sandy loam	lumpy	moderate	poor

FIGURE 39. Profile sketch, detail, Sampling Station A′-1



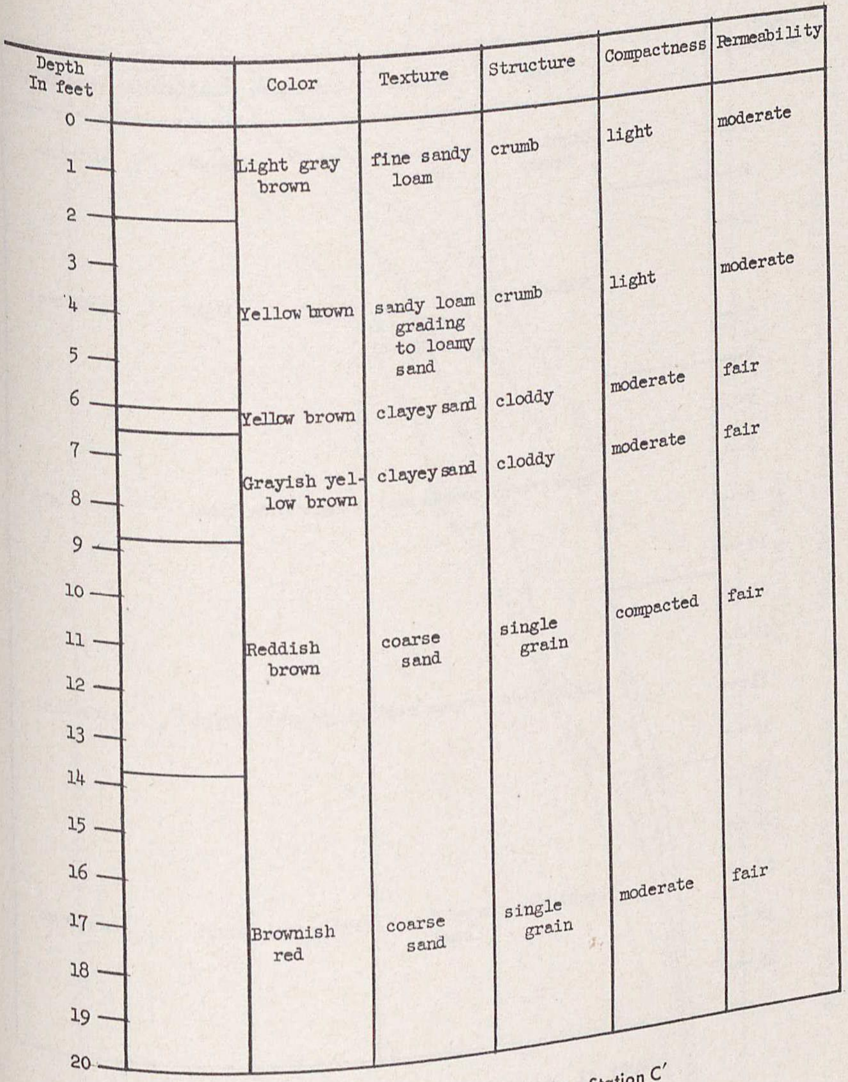
Color	Texture	Structure	Compactness	Permeability
Light gray brown	fine sandy loam	crumb	light	moderate
Light brown	fine sandy loam	crumb	light	moderate
Yellow brown	loam	crumb	light	moderate
Yellow red brown	clayey sand	massive	moderate	poor
Yellow brown	coarse sand	single grain	light	good
Red brown	coarse sand	lumpy	compacted	fair
Brownish gray	coarse sand	single grain	light	excellent
Red brown	sandy clay	lumpy	moderate	poor

FIGURE 40. Profile sketch, detail, Sampling Station A′-2



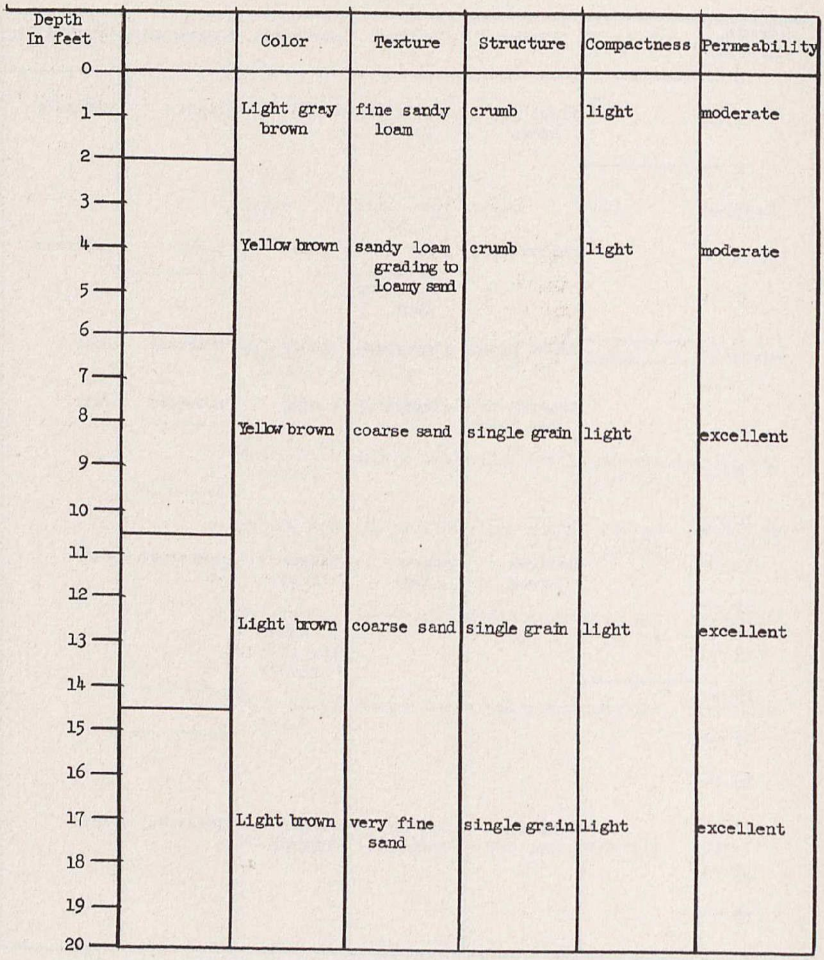
Color	Texture	Structure	Compactness	Permeability
Light gray brown	fine sandy loam	crumb	light	moderate
Brown	fine sandy loam	crumb	light	moderate
Yellowish brown	clayey fine sand	crumb	light	moderate
Reddish brown	coarse sand	single grain	very compacted	moderate
Yellow brown	coarse sand	single grain	very compacted	moderate
Yellowish brown with gray streaks	coarse sand	single grain	well compacted	moderate
Dark yellow brown	coarse sand	single grain	moderate	moderate
Yellow brown	clayey sand	lumpy	moderate	poor

FIGURE 41. Profile sketch, detail, Sampling Station B′



Depth In feet		Color	Texture	Structure	Compactness	Permeability
		Light gray brown	fine sandy loam	crumb	light	moderate
		Yellow brown	sandy loam grading to loamy sand	crumb	light	moderate
		Yellow brown	clayey sand	cloddy	moderate	fair
		Grayish yellow brown	clayey sand	cloddy	moderate	fair
		Reddish brown	coarse sand	single grain	compacted	fair
		Brownish red	coarse sand	single grain	moderate	fair

FIGURE 42. Profile sketch, detail, Sampling Station C′



Color	Texture	Structure	Compactness	Permeability
Light gray brown	fine sandy loam	crumb	light	moderate
Yellow brown	sandy loam grading to loamy sand	crumb	light	moderate
Yellow brown	coarse sand	single grain	light	excellent
Light brown	coarse sand	single grain	light	excellent
Light brown	very fine sand	single grain	light	excellent

FIGURE 43. Profile sketch, detail, Sampling Station D′

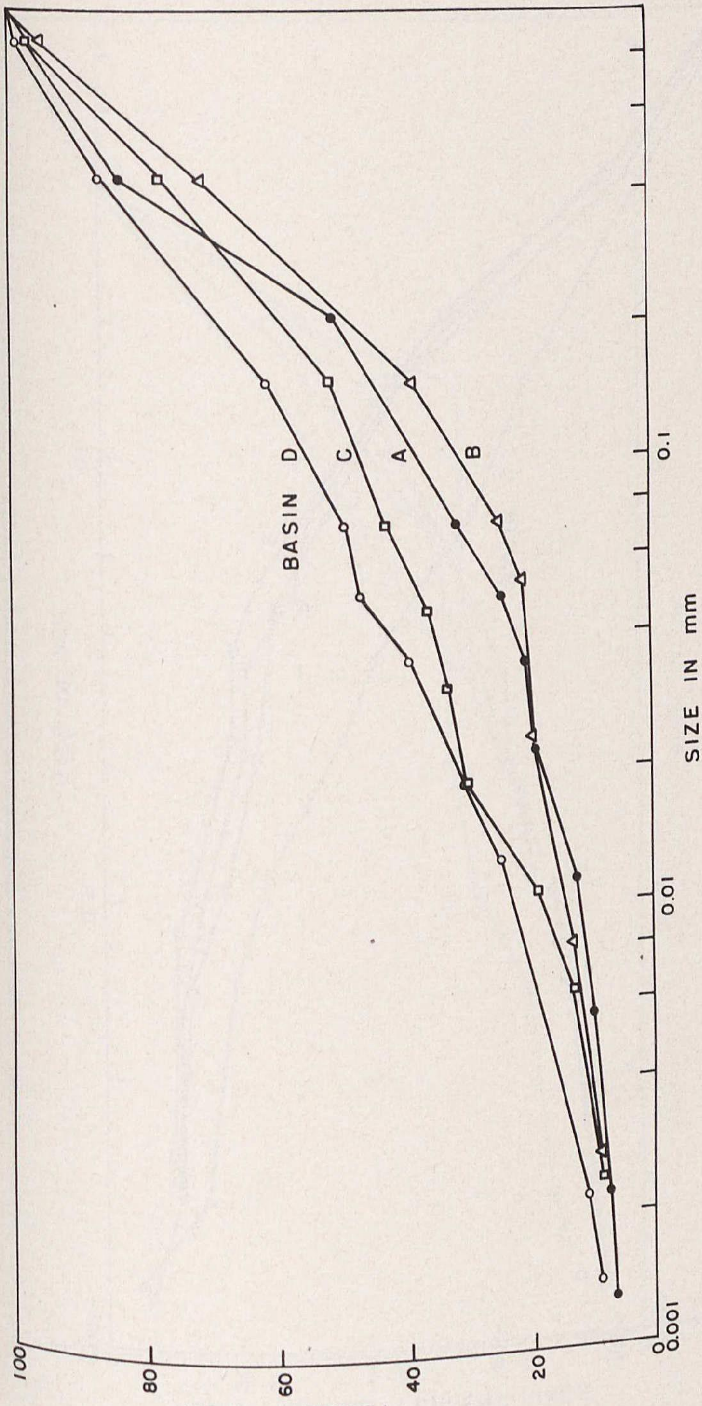


FIGURE 44. Particle size distribution at the 1-foot depth in four spreading basins, Lodi, California

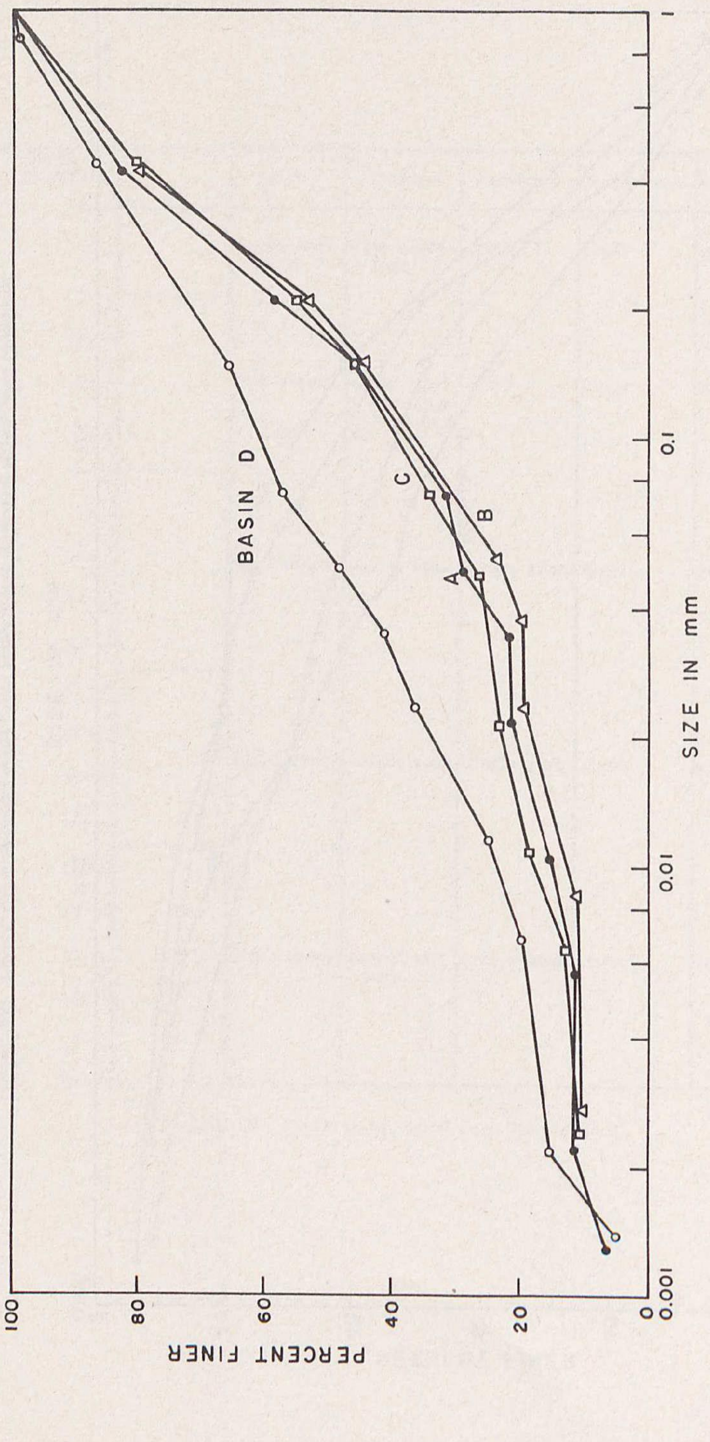


FIGURE 45. Particle size distribution at the 2-foot depth in four spreading basins, Lodi, California

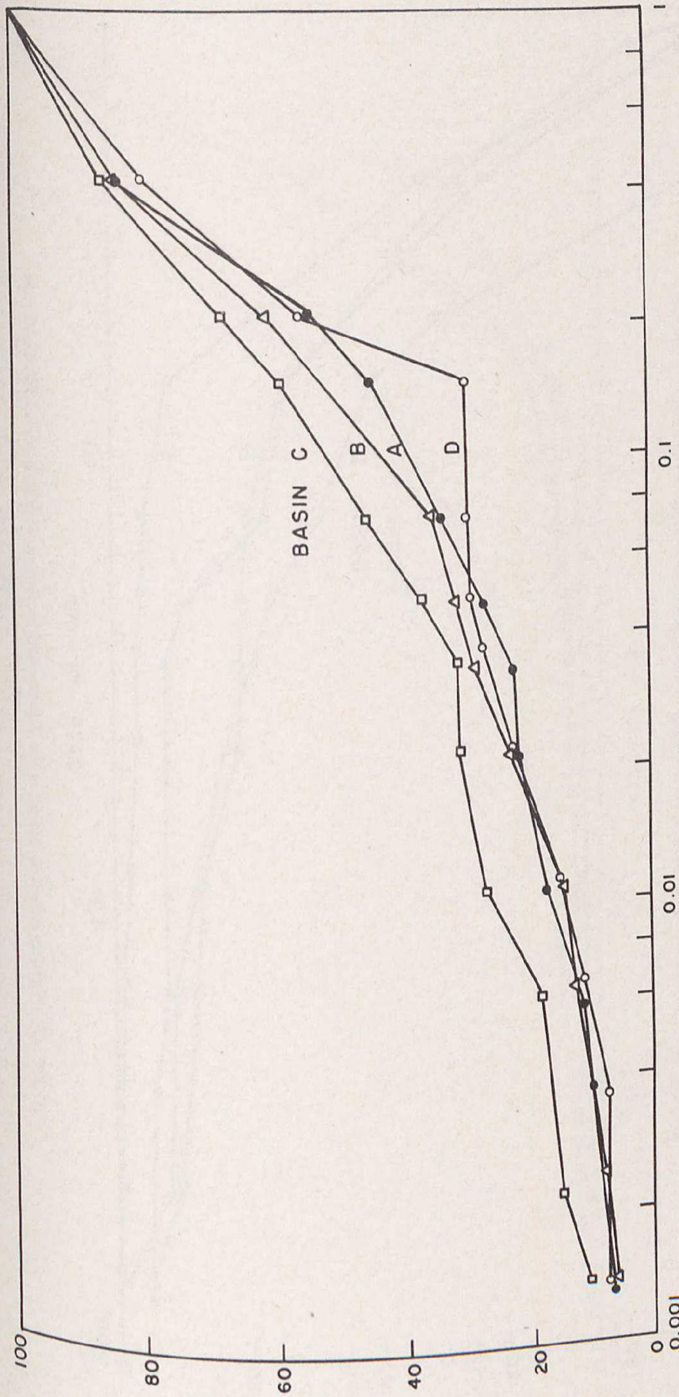


FIGURE 46. Particle size distribution at the 4-foot depth in four spreading basins, Lodi, California

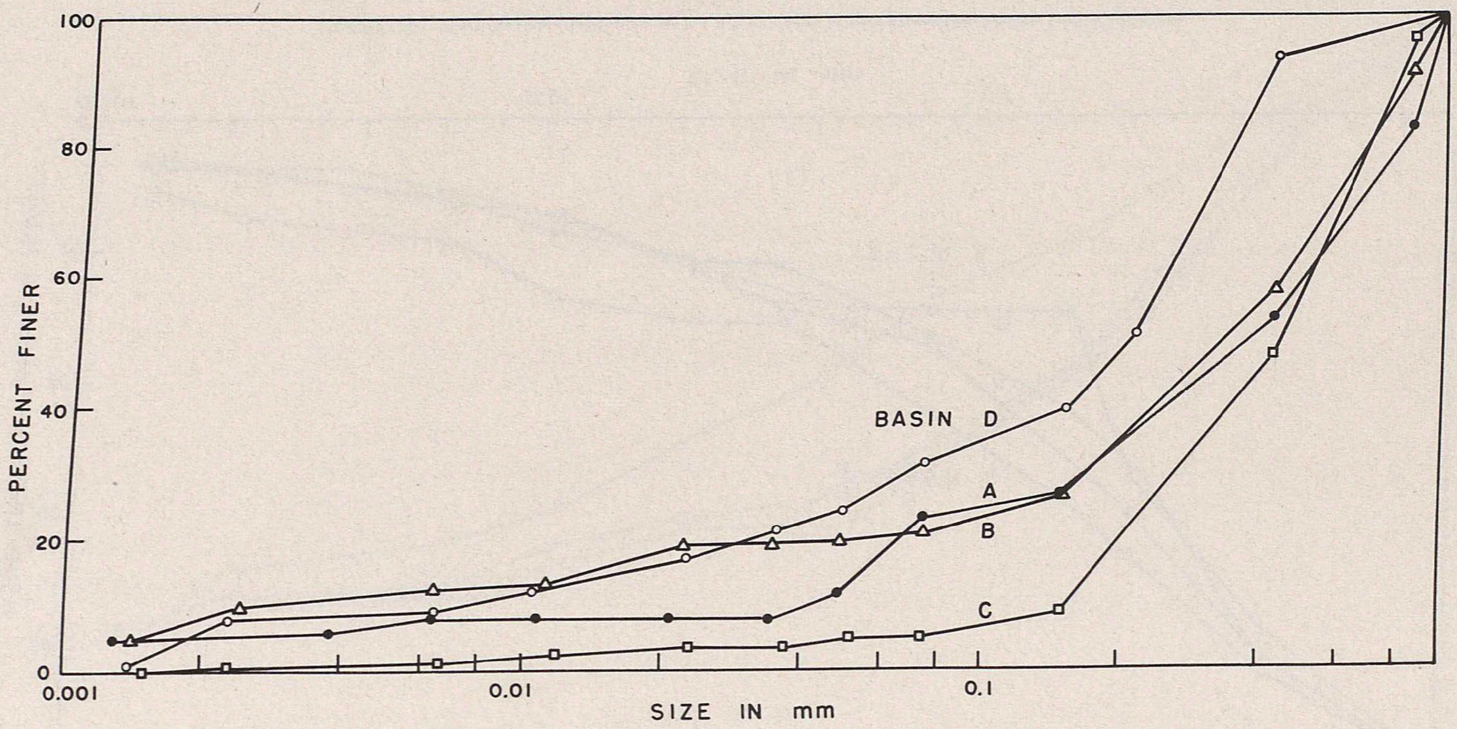


FIGURE 47. Particle size distribution at the 7-foot depth in four spreading basins, Lodi, California

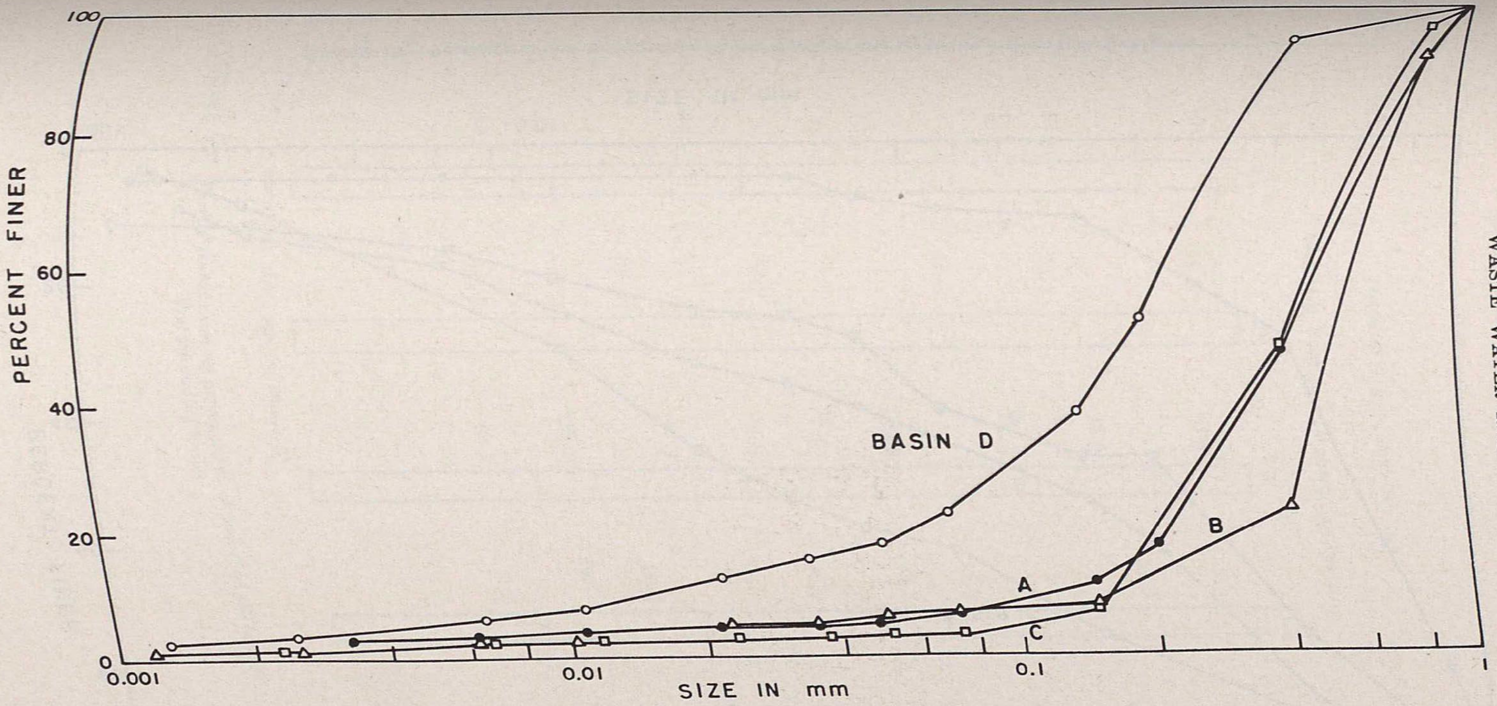


FIGURE 48. Particle size distribution at the 10-foot depth in four spreading basins, Lodi, California

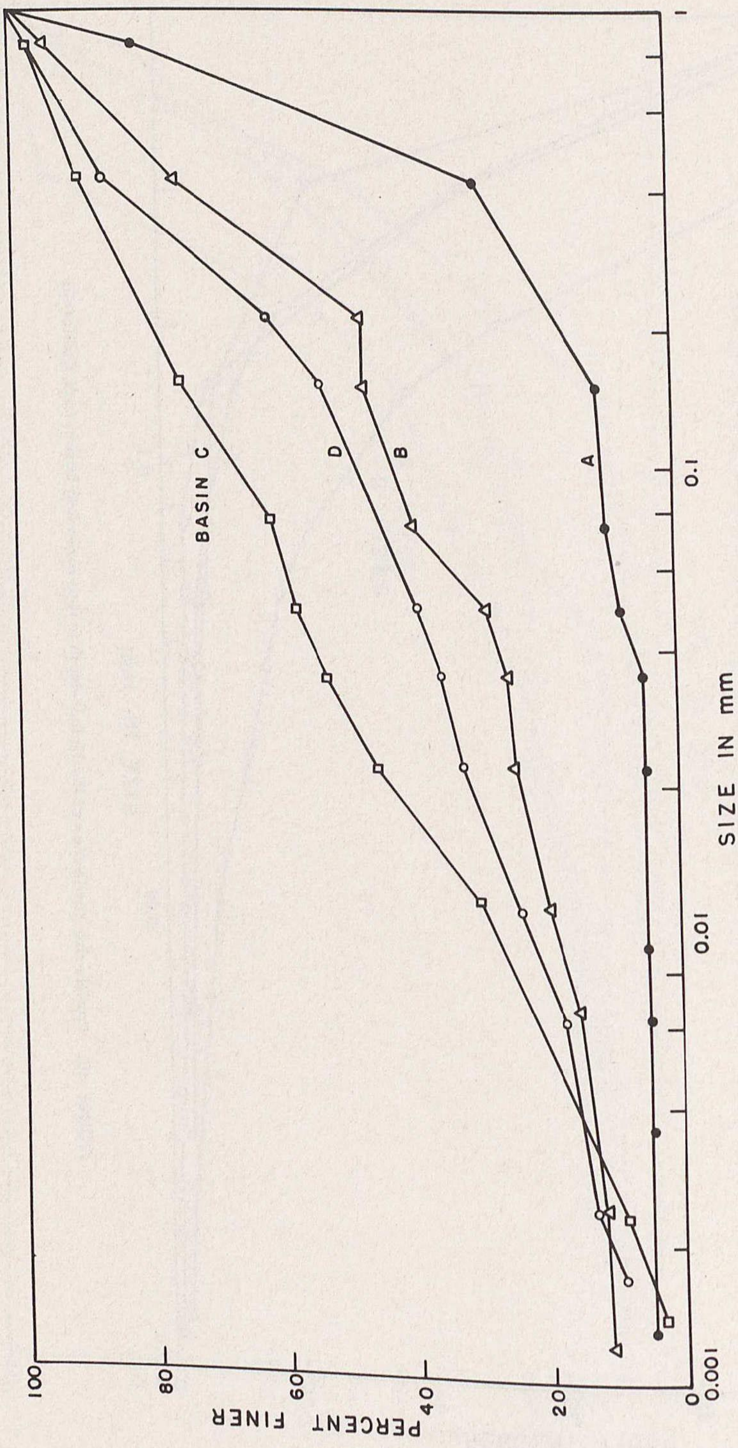
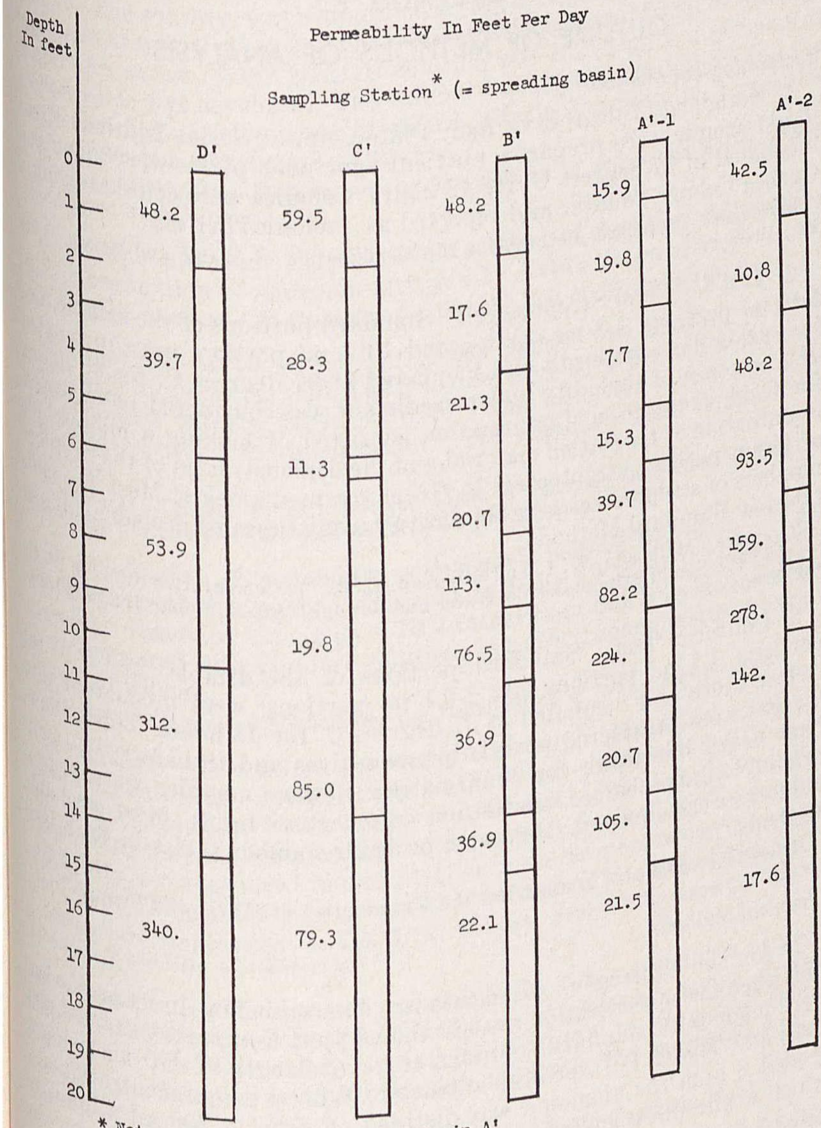


FIGURE 49. Particle size distribution at the 13-foot depth in four spreading basins, Lodi, California



* Note: 2 sampling stations in Basin A'

FIGURE 50. Profile sketch showing permeability of disturbed soil samples in four spreading basins

APPENDIX B

OUTLINE OF METHODS OF ANALYSIS

Bacteriological Methods

1. Standard 37 degrees C. Agar Plate Count. Serial dilutions of the liquid sample were prepared, nutrient agar pour plates were made and incubated at 37 degrees C. for 48 hours. Colonies were counted using a Quebec Colony Counter and reported as ''colonies per ml.''

Reference: "Standard Methods for the Examination of Water and Sewage," 9th Ed., 1946.

2. Test for Fecal Streptococci. Standard portions of the sample, i.e., 5-10 ml portions, 1-1 ml portion and 1-0.1 ml portion, were inoculated into azide dextrose broth and incubated at 37 degrees C. for 48 hours. The presence of turbidity and/or sediment was considered presumptive for fecal streptococci. Confirmation consisted of making a microscopic examination of the settled material and the demonstration of the presence of Gram positive streptococci in Gram strained smears. Most probable numbers of streptococci were obtained by using the most probable number tables in Standard Methods.

Reference: Mallmann, W. L. and Seligman, E. B., "A Comparative Study of Media for the Detection of Streptococci in Water and Sewage," Am. J. Public Health *40*:286-289, 1950.

3. Coliform Test. Standard portions of the sample, i.e., 5-10 ml portions, 1-1 ml portions and 1-0.1 ml portions, were inoculated into lactose broth and incubated at 37 degrees C. for 48 hours. Tubes showing gas were considered positive presumptives and transferred to brilliant green bile broth for confirmation. Sewage samples were appropriately diluted before inoculation into lactose broth. Most probable numbers were obtained from most probable number tables in Standard Methods.

Reference: "Standard Methods for the Examination of Water and Sewage."

Chemical Methods

1. Ammonia-nitrogen. Ammonia was determined by direct nesslerization when the concentration was less than 8 ppm. Comparisons of samples were made with standard solutions at a wavelength of 410 $m\mu$ using a Beckman Model DU spectrophotometer. Where the concentration exceeded 8 ppm the ammonia was distilled off from a 200 ml aliquot to which a phosphate buffer had been added. The distilled ammonia was caught in a saturated solution of boric acid and back titrated with a standard sulfuric acid solution. Methyl orange -xylene cyanole was used as the indicator.

Reference: "Standard Methods for the Examination of Water and Sewage."

2. Nitrite-nitrogen. The standard sulfanilic acid-α naphthalamine colorimetric procedure was used. Samples were compared with standard solutions in a spectrophotometer at a wavelength of 535 $m\mu$.

Reference: "Standard Methods for the Examination of Water and Sewage."

3. Nitrate-nitrogen. To a 10 ml portion of the sample were added silver sulfate, hydrogen peroxide and 1 ml of a 1 percent suspension of $CaCO_3$. The solution was evaporated to dryness and cooled. The residue was treated with 2 ml of 2, 4-phenoldisulfonic acid and 20 ml of distilled water. An excess of 1:2 NH_4OH solution was added until a permanent yellow color was developed. The volume was adjusted to 100 ml and the color was compared against standard nitrate solutions in a spectrophotometer at a wavelength of 420 mμ.

Reference: "Standard Methods for the Examination of Water and Sewage" with unpublished modifications.

4. Organic-nitrogen. The Kjeldahl method of digestion, followed by the determination of ammonia-nitrogen by distillation was used.

Reference: "Standard Methods for the Examination of Water and Sewage."

5. Chloride. A 10 ml portion of the sample was acidified to a pH of 4.2 with dilute nitric acid. The chlorides were then titrated with standard mercuric nitrate (about 0.015N) from colorless to purple using diphenylcarbazone as the indicator. The standard Mohr method was also used.

References: Clarke, F. E., "Determination of Chloride in Water," Analytical Chemistry 22:553-555, 1950 with unpublished modifications.

6. Phosphate. The standard colorimetric method was used. The sole modification of this method consisted in using a reducing reagent prepared by dissolving tin metal in HCl rather than $SnCl_2$ in HCl. Samples were compared with standard solutions in a spectrophotometer at a wavelength of 690 mμ.

Reference: "Standard Methods for the Examination of Water and Sewage."

7. Sulfate. To a 50 ml portion of the sample was added 10 ml of a standard salt-acid solution (240g NaCl, 20 ml concentrated HCl in 800 ml of distilled water). An excess of solid $BaCl_2$, 30 mesh (about 0.3g) was added and the solution stirred for exactly 5 minutes. The resulting turbidity was measured immediately in a spectrophotometer at a wavelength of 420 mμ and compared with standard sulfate turbidities.

Reference: Unpublished method, J. F. Thomas, Sanitary Engineering Research Project, University of California.

8. Calcium. Calcium was determined by a flame analysis using the flame attachment to a Beckman Model DU spectrophotometer. A standard curve was produced by setting limits from 0 to 50 ppm of calcium at 554 mμ. Samples were put through the flame and compared with the standard curve.

Reference: Bulletin 259, Beckman Instruments, South Pasadena, Calif.

9. Magnesium. Combined calcium and magnesium were determined by the versene method for hardness. A 50 ml portion of the sample was titrated with a standard versene solution using Univer as the indicator. Magnesium was determined by subtracting the concentration of calcium from the combined calcium-magnesium concentration.

Reference: Hach Ver Catalog, 1950, Hach Chemical Co., Ames, Iowa.

10. Potassium. Potassium was determined by means of a flame analysis. A standard curve was made by setting limits from 0 to 15 ppm of potassium at 770 mμ. Samples were compared with the standard curve.

Reference: Bulletin 259, Beckman Instruments, South Pasadena, Calif.

11. Sodium. Sodium was determind by flame analysis. A standard curve between the limits of 0 and 100 ppm of sodium was made at a wavelength of 588 mμ. Samples were compared with the standard curve.

Reference: Bulletin 259, Beckman Instruments, South Pasadena, Calif.

12. Alkalinity. The sample was titrated with a standard acid solution using a pH meter rather than indicator solutions. End points at pH 8.2 and 4.3 were used to calculate the bicarbonate and carbonate alkalinity.

Reference: "Standard Methods for the Examination of Water and Sewage."

13. Conductivity. Conductivity was measured by means of a Solu-Bridge, model RD-26 manufactured by Industrial Instruments Inc., Jersey City, New Jersey.

14. pH. The pH was measured with a Beckman pH meter, model H2.

15. BOD. The dilution method for determining the five-day 20-degree C. BOD was used.

Reference: "Standard Methods for the Examination of Water and Sewage."

16. Dissolved Oxygen. The DO was determined by the sodium azide modification of the Winkler method.

Reference: "Standard Methods for the Examination of Water and Sewage."

Soil Analysis Methods

1. Organic Nitrogen. See 4 under chemical methods.

2. Organic Carbon. Carbon was determined by a dry combustion method using a standard carbon and hydrogen train apparatus. The weighed sample was ignited in an oxygen train and the evolved carbon dioxide was trapped by Ascarite and weighed. The organic carbon content was then calculated.

Reference: Pregl, F., "Quantitative Organic Microanalysis," 4th English Ed., 1946, Blakiston Co., Philadelphia.

3. Particle Size Distribution. The soil particles were dispersed by blending in a Waring Blendor in the presence of sodium hexametaphosphate. Sand sizes were determined by the usual sieving method whereas distribution of particles finer than 50 microns was determined with a soil hydrometer making use of Stoke's law.

Reference: Day, Paul R., Soil Sci. *70*:363-374, 1950.

4. Permeability. The undisturbed surface soil cores were taken with an impact driven core sampler. The cores were in the form of a cylinder 7.5 cm in diameter and 7.5 cm in length. Distilled water was applied at a constant head of 25 cm of water to the bottom of the upright core. The

amount of water flowing through the core was measured and the permeability, P, calculated from the following expression:

$$P = \frac{V}{J} = \frac{Q}{AT} \cdot \frac{L}{H}$$

V = velocity
J = hydraulic gradient
Q = quantity
A = cross section area
T = time
L = length of core
H = head of water

The steady-rate percolation rate obtained after 30 minutes of percolation was reported. The permeability of disturbed soil samples was measured in the same way. The sample was prepared by packing a column with the screened, dried soil. Water under constant head was applied and the permeability determined.

5. Base Exchange Complex. To measure the base exchange complex the cations adsorbed on the soil particles were displaced and then determined by the chemical methods described above. A neutral solution of 1N ammonium acetate was used to displace the calcium, magnesium, potassium, and sodium.

APPENDIX C

GENERAL BIBLIOGRAPHY

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APPENDIX D

POROUS TUBE DEVICE FOR SAMPLING SOIL SOLUTIONS DURING WATER SPREADING OPERATIONS *

By Ray Krone, H. F. Ludwig, and Jerome Thomas
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July, 1951

1. Introduction

The percolation of water through soil is a phenomenon involved in many sanitary engineering processes, e.g., in the reclamation of sewage by spreading on porous ground areas, so that the water content of the sewage will percolate downwards and augment underground water supplies, and in the disposal of septic tank effluents through subsurface leaching systems. The phenomena which occur along the path of the percolating water are of great importance, and are being increasingly studied. Such studies require that samples of the percolating water or soil solution, be withdrawn at intervals along the soil profile.

Two commonly used sampling methods are (a) the use of pans placed in the soil to catch the downward moving water, and (b) removal of a sample of the soil, from which the soil solution may be displaced in the laboratory. Method (b) involves gross disturbance to the soil and hence is not suited to continuous investigations. Method (a) has been employed extensively in recent years (References 1 and 2), and have been found to have serious disadvantages, as follows: (1) Placement of the pans is difficult without disturbing the overlying soil, and it is difficult to secure a good "bond" with the overlying soil; (2) the method fails when the percolating water is under tension;[1] (3) the flow path, and perhaps the characteristics of the percolating water, are seriously altered; and (4) the size of the pans, if large enough to collect significant samples, limits the number which may be used, and hence makes it difficult to collect samples from enough locations to assure representative results.

This discussion describes an improved sampling method developed by the Sanitary Engineering Research Project, which involves the use of a porous tube or "probe" to which negative pressures or tensions are applied. The method was investigated on the suggestion of Professor P. R. Day of the Department of Soils, University of California, and is being applied to the project's current investigation of sewage reclamation by spreading.

2. The Method

The porous tube or probe is inserted into the soil at the desired sampling depth. The tension or negative pressure necessary to withdraw the liquid may be provided by any means, but usually the most convenient method is to use a "hanging" column of water or siphon, as illustrated in Figures 1 and 2. Prior to sampling, the probe and connecting tubing must be completely filled with water to displace air and to establish the siphon, and the initial yield of the sampling system is discarded until the water initially present in the probe and connecting tubing has been displaced.

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* Soil Science 73:211-219, 1952. (Reprinted by permission.)

[1] These conditions are often found, especially in stratified soils.

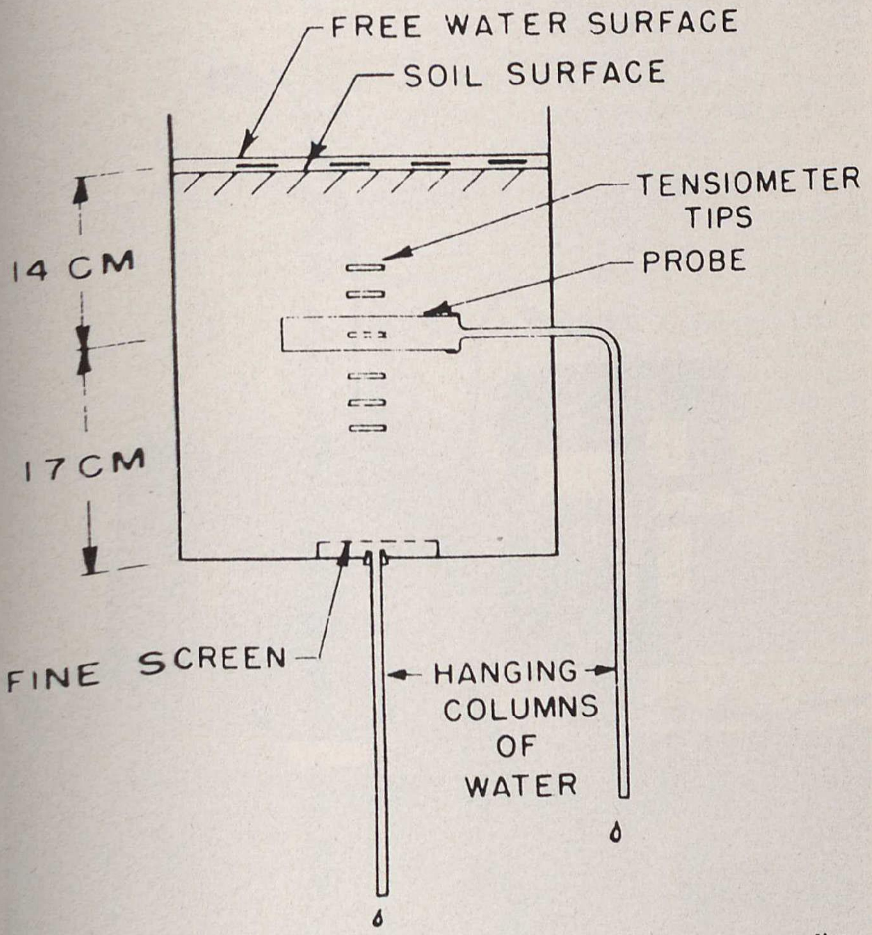

Figure 1. Schematic Drawing of Apparatus Used for Studying Probe Sampling.

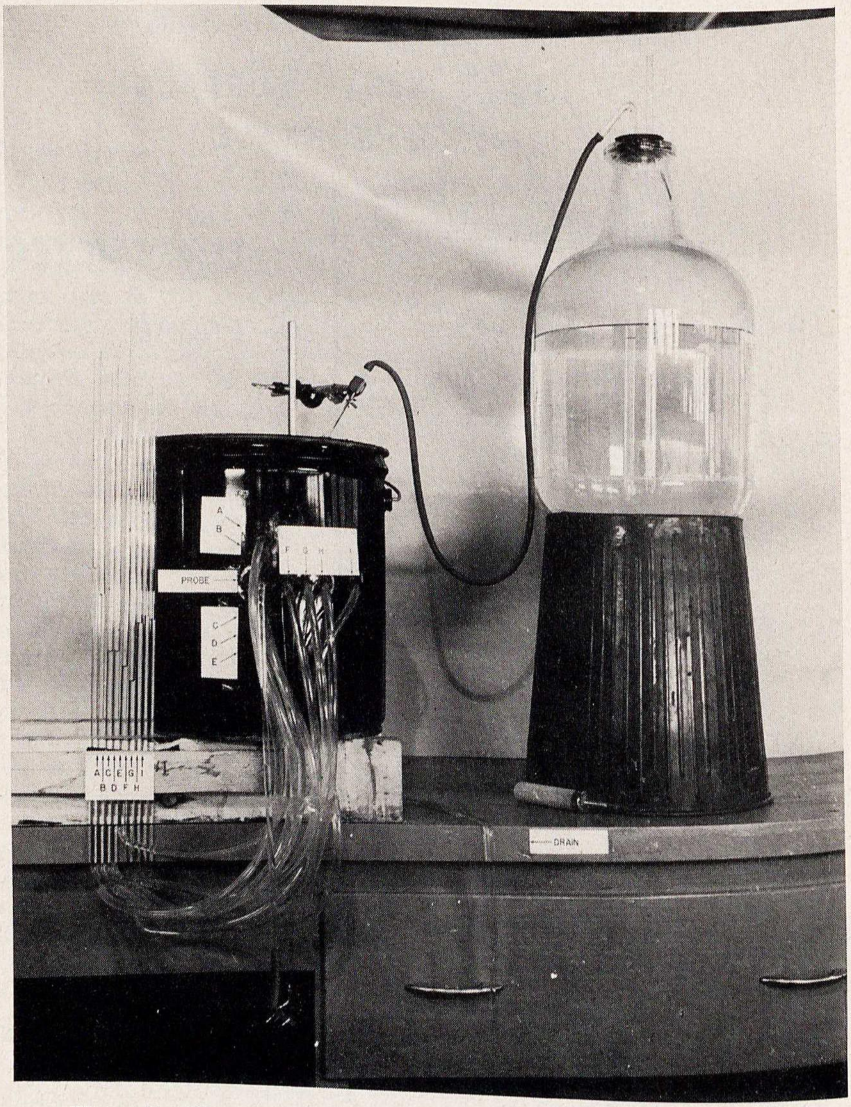

Figure 2. Photograph of Apparatus Used for Studying Probe Sampling.

3. Specifications for Porous Tubes

The type of porous material best suited for probe construction has not been completely ascertained. Various types of probes were studied (see Figure 3) in an attempt to determine what factors are significant in influencing the yield. It was found that the average porosity of the material is the most important criterion, and that the best porosity probably lies in the range of 1μ to 10μ. Smaller pores were found to be readily clogged by fine particles; and large pores are apparently filled in with a densely packed material.[2] The proper pore size may be compared with the proper size of openings in a well screen; what is desired is a permeable and stable packing of the soil particles at the probe surface.

An attempt to minimize or eliminate the effect of clogging was made by surrounding the probe with fine sand. This proved impractical because the sand could not be put into place without admitting air with the sand, which subsequently caused "binding" or interference with the flow.

A second factor influencing probe behavior is its permeability, or ability to transmit water with a minimum of friction. However, permeability is not so important as porosity, because increased frictional resistance may be overcome by applying greater probe tensions. In any case it is necessary to apply to the probe sufficient tension to overcome all of the frictional resistances involved, plus the initial tension if any in the percolating water, such that the particles of water near the probe will flow towards and into the probe instead of continuing downwards.

Permeabilities of porous materials are specified by their capacity to pass a given fluid through a unit area of the surface in unit time at a specified head, e.g., the amount of air at 75 degrees F. and 24 percent humidity passed in one minute through one square foot of the porous material under a head of 2 inches of water. The test data indicate that the porous material having the best permeability characteristics passes 0.2 to 0.4 cubic feet per minute per square foot under the specified conditions.[3]

Another important property of the porous material is its structural strength. The Mandler tube, which is 1 inch in outside diameter and 5 inches long, is the only commercially available type which incorporates an adapter for connecting to rubber tubing. However, it is commercially available only in very fine porosities; and upon continued use it becomes structurally weak and cannot be removed from one location for use at another, without probably breaking. Carborundum tubes are strong and durable, but are not commercially available with adapters, and hence must be specially made up.

A 12-inch length of tube is probably the maximum practical length. Greater lengths can extract water from a greater soil volume or region, but beyond lengths of 12 inches the extra yields are relatively small.

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[2] The degree of clogging at different porosities is indicated by the yields obtained, and also by curves of the type shown in Fig. 4, which are plots of changes in soil solution tension versus distance from the probe on a horizontal plane. Extrapolating such curves to a point representing the surface of the probe gives data indicating the total frictional resistance measured from the probe surface. This becomes greater with greater clogging.

[3] The Mandler filter, such as used in the tests, is rated by the manufacturers on the basis of the pressure in psi on the filter wall necessary to produce air leakage under water. A pressure of 0.5 to 1.0 psi corresponds roughly to a permeability of 0.2 to 0.4 cubic feet per minute.

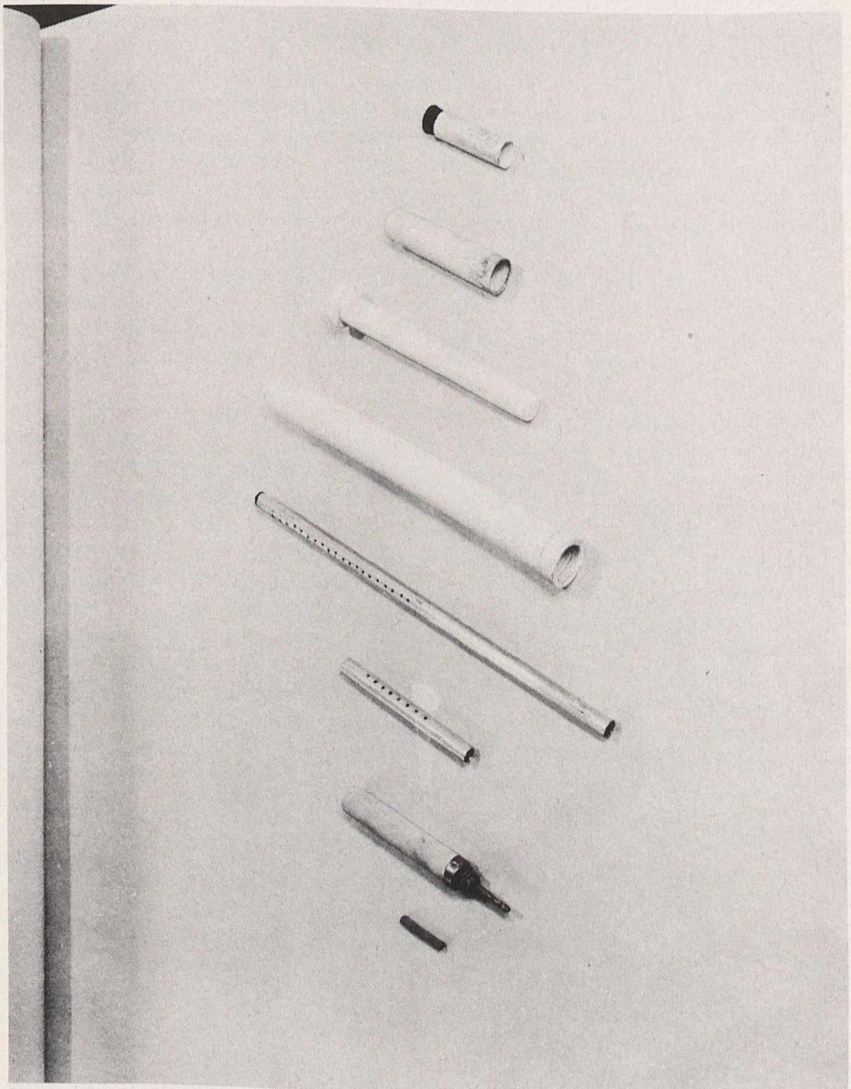

Figure 3. Photograph of Typical Probes Tested.

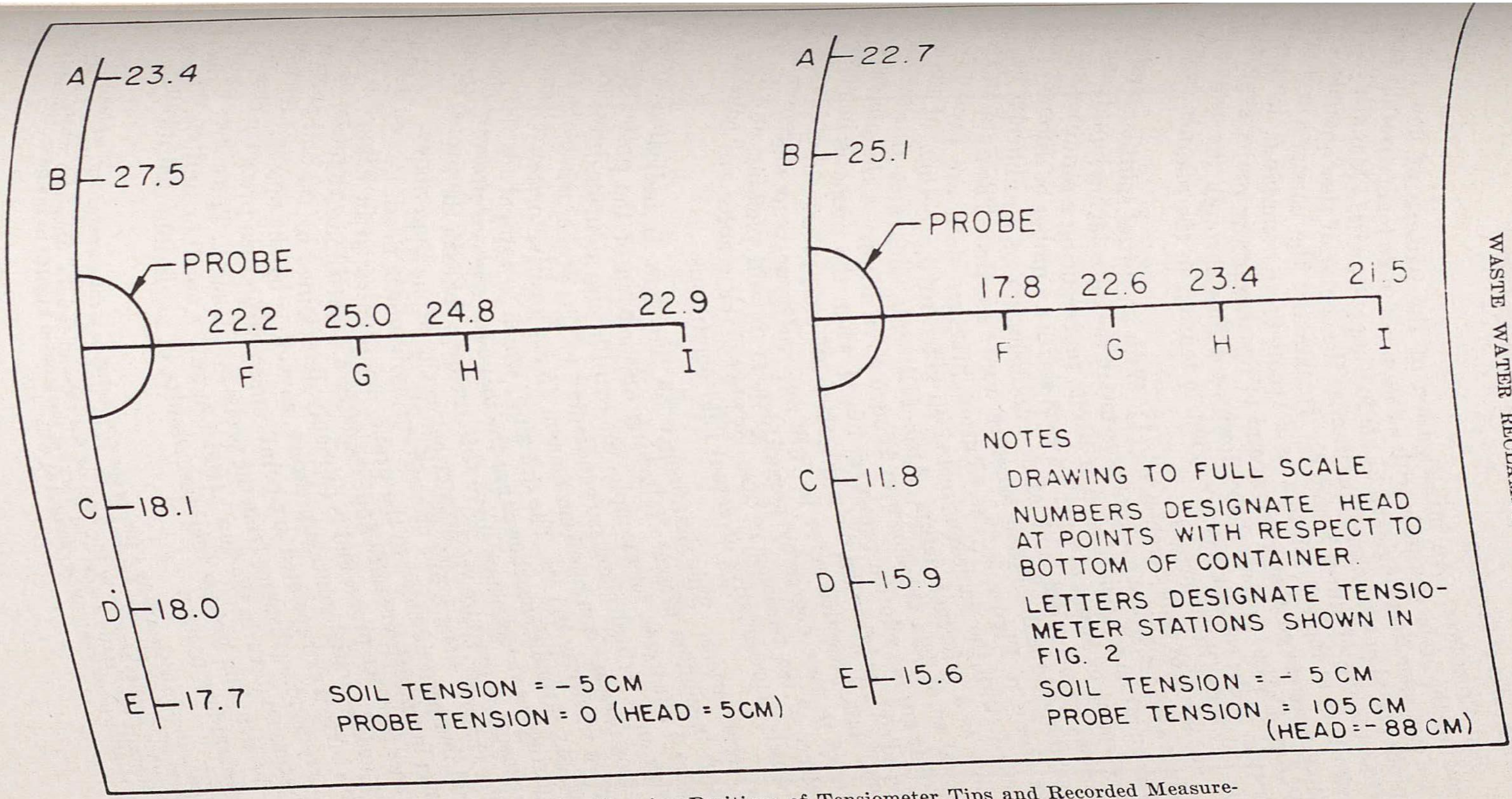

Figure 4. Drawing Showing Positions of Tensiometer Tips and Recorded Measurements.

4. Hydraulics of Sampling

Test Procedure. An investigation of the pattern of flow from the soil into the probe was made with a column of Yolo loam carefully packed in a container 30 cm high and 28 cm in diameter, with a Mandler 2-pound probe placed in a horizontal position at the center of the container, 14 cm from the top (Figures 1 and 2). To measure the changes in pressure occurring in the soil solution as a result of the sampling, tensiometer tips[4] were placed above, below, and to the side of the probe, as shown in Figure 4. Also, to control the downward flow through the column, the bottom of the column was subjected to tension in the manner described by Coleman (Reference 3).[5]

Two series of tests were made: (1) With an initial solution tension of minus 5 cm, i.e., with a positive pressure in the percolating liquid; and (2) with an initial solution tension of 10 cm, representing a condition adverse to sampling by means of pans. In each series a number of different probe tensions were applied, and, after establishment of equilibrium in each case, the yield and solution pressure were recorded. The data on yields are shown in Figure 5. The solution pressure data are presented in Table I, with the values corrected to refer to the bottom of the container as a reference datum. Also, full scale diagrams illustrating a typical set of data are shown in Figure 4. In Figure 4 the numbers on the left are the solution pressures found when the probe is inoperative (closed off), and those on the right when 105 cm probe tension is applied.

The data presented refer to only one soil type, and moreover were affected to some degree by nonuniformity in soil packing and by the presence of the tensiometer tips. However, the results are believed to be closely representative of actual field conditions.

Interpretations. The significance of the data is indicated by the change in solution pressure following application of the probe tension. Figure 6 illustrates, for example, the equilibrium solution pressures occuring on a vertical plane perpendicular to the probe, when the initial solution pressure is minus 5 cm tension (5 cm positive pressure) and the applied tension is 105 cm. The drawing, which is typical for most combinations of conditions, shows that the locus for a given pressure change approximates an egg-shape curve with its apex beneath the probe. Hence, the changes in pressure are greater below the probe than above.

The changes along a line of constant hydrostatic head, i.e., on a horizontal line perpendicular to the probe, are illustrated in Figure 7. The change in solution pressure approximates a logarithmic function of the distance from the probe, and is probably determined by the soil permeability and the initial solution pressure, as well as by the applied tension. If this curve is extrapolated to a point representing zero pressure change, the corresponding distance from the probe is still small. Thus, the applied probe tension disturbs the flow pattern in only a small or limited region, and the sampling process therefore results in negligible disturbance to the general flow pattern.

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[4] A tensiometer tip is essentially a tiny probe connected to a manometer leg, which therefore measures the pressure existing in the soil solution at the location of the tip.

[5] The method applies tension to the base of the column, where otherwise water would accumulate in a "static mound." By varying the tension applied to the base, the initial soil solution pressures may be changed at will.

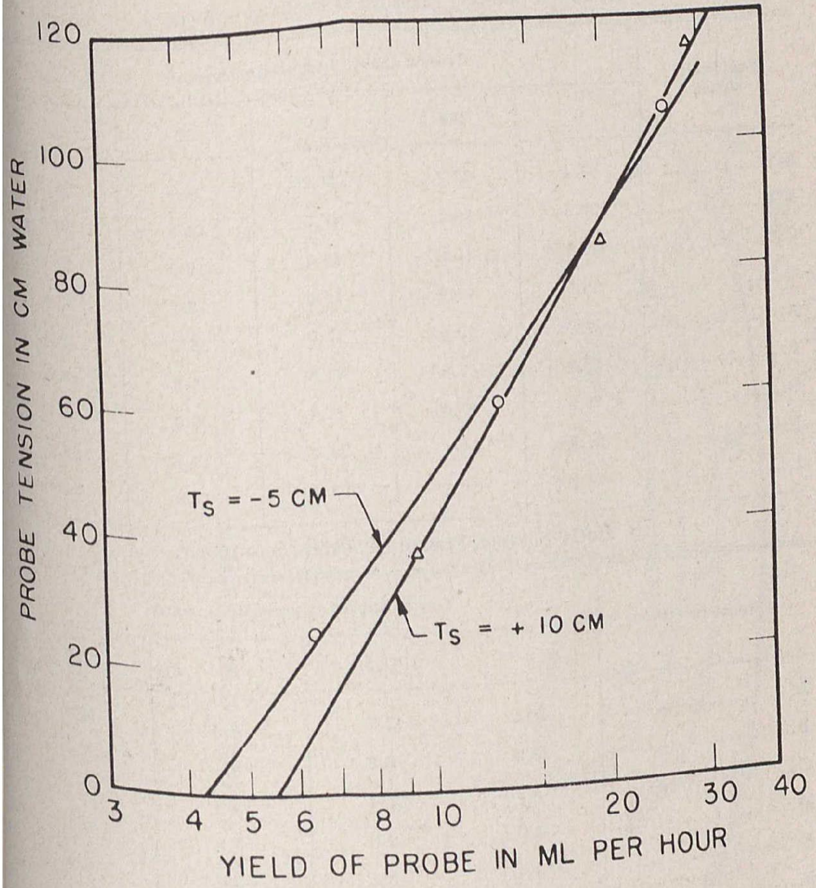

Figure 5. Curves Showing Yields for Various Probe Tensions.

TABLE I
SOIL SOLUTION HEAD AT VARIOUS TENSIOMETER STATIONS IN CM WATER ABOVE BASE OF COLUMN

A. Initial Solution Pressure at Probe = +5 cm

Tensiometer station	Tension applied to probe in cm water				
	0	105	60	25	0
A	23.4	22.7	23.2	23.4	23.7
B	27.5	25.1	27.0	27.3	28.0
C	18.1	11.8	16.7	18.3	20.7
D	18.0	15.9	18.0	18.7	19.6
E	17.7	15.6	17.9	18.7	19.5
F	22.2	17.8	20.6	21.8	23.3
G	25.0	22.6	24.3	25.0	25.7
H	24.8	23.4	24.7	25.1	25.7
I	22.9	21.5	23.4	23.8	24.4

B. Initial Solution Pressure at Probe = —10 cm

Tensiometer station	Tension applied to probe in cm water			
	0	37.5	85	115
A	14.4	12.7	6.3	13.2
B	12.0	8.3	—2.1	—7.0
C	5.9	1.4	—12.4	--------
D	4.3	2.8	—3.9	—9.1
E	3.4	2.1	—3.9	—6.9
F	7.2	—1.2	—20.5	--------
G	9.1	6.1	—3.4	—7.5
H	8.5	7.4	—2.0	—1.4
I	11.0	9.3	4.9	1.4

NOTE. All tests made with a two-pound Mandler filter having an estimated average pore size of 1μ.

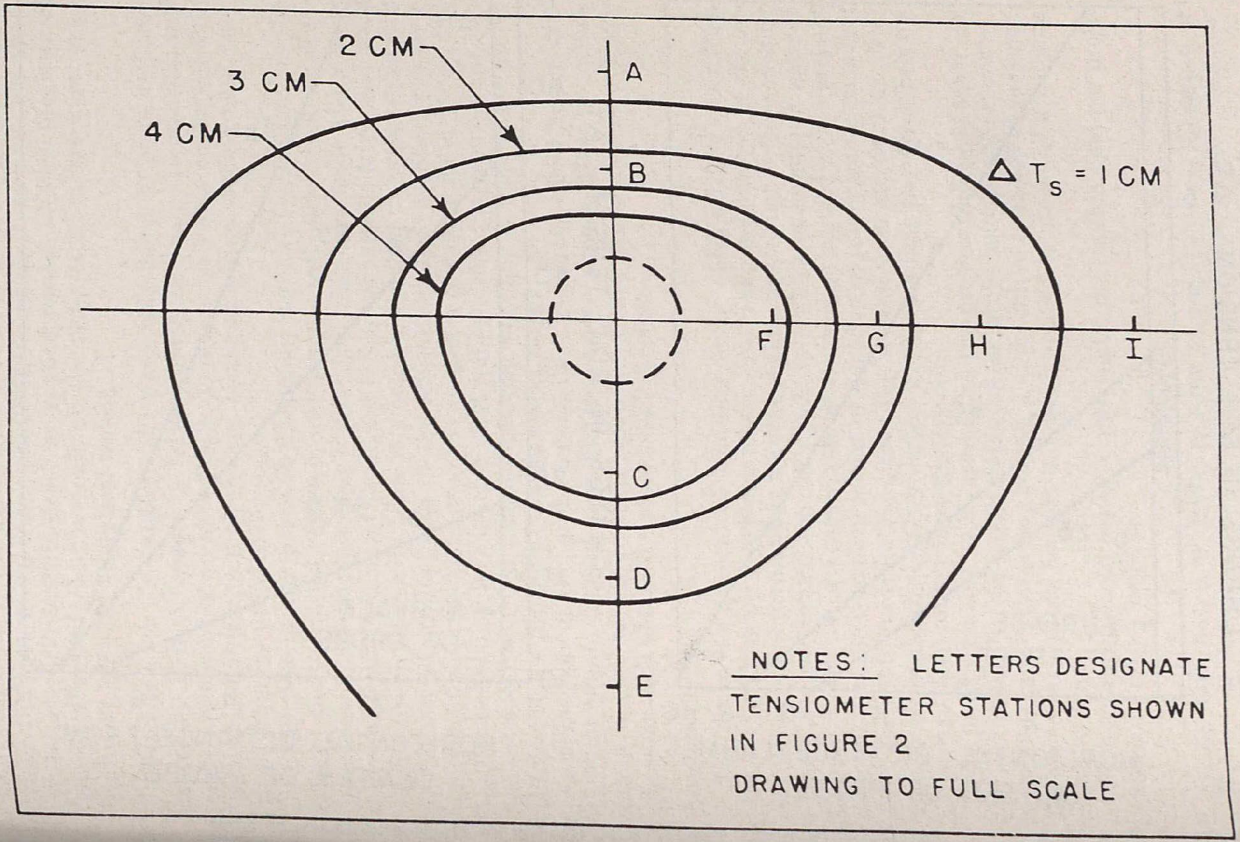

Figure 6. Plot of Changes in Solution Tensions on Plane Perpendicular to Probe.

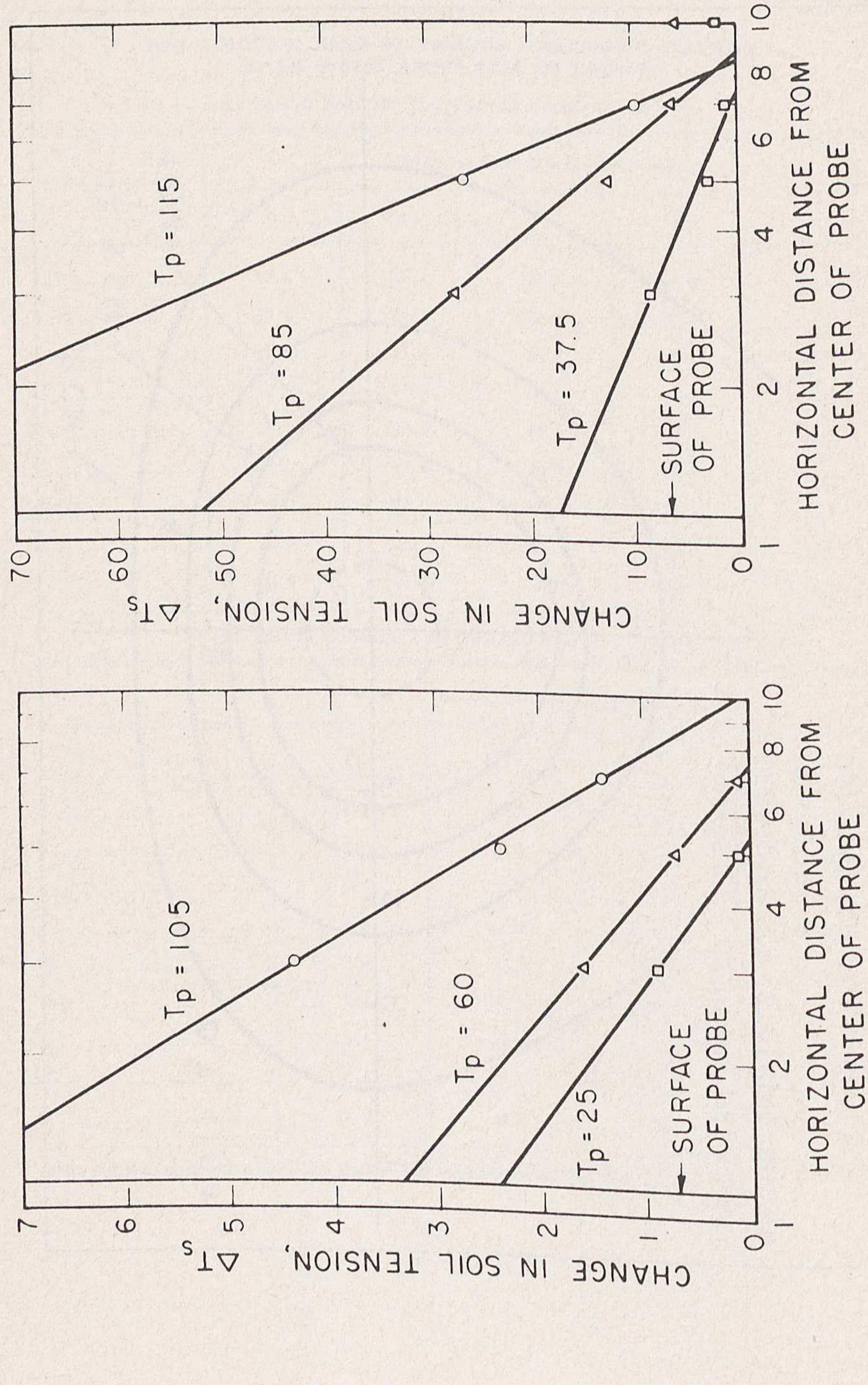

Figure 7. Changes in Solution Tension with Respect to Horizontal Distance from Probes.

The yield of the probe (Figure 5) appears to be a logarithmic function of the applied probe tension, for a given soil permeability and initial solution pressure. The greater the applied probe tension the greater the yield (and the greater the volume of the region disturbed), but the increase in yield with increase in applied tension becomes progressively less. The actual yield is small, on the order of 20 ml per hour, but is sufficient for most analytical testing.

Miscellaneous Techniques. As previously noted, prior to beginning sampling it is necessary to fill the probe and connecting tubing with water, eliminating all air bubbles. This may be readily accomplished by pumping water into the probe by means of a hand syringe, until water flows from the probe to the soil.

After placing the probe in operation, the initial water must be displaced and discarded before proper samples will be delivered. To determine how much displacement is necessary, tests were made with a probe filled with distilled water immersed in sodium chloride brine, and again with a probe filled with brine immersed in distilled water, by measuring the electrical conductivity of the effluent delivered by the probe, with enough applied probe tension to produce a flow of 20 ml per hour. The results are shown in Figure 8, and indicate that the volume to be displaced and discarded before beginning sampling is closely equal to the volume of the probe and its associated tubing.

Application of the probe tension may be accomplished by use of a vacuum pump, instead of a hanging water column. When a vacuum pump is used the flow is irregular but over a period of time averages the same as is obtained with a hanging column.

Conclusions

The probe is a convenient sampling device which extracts water from the soil by forming a hydrodynamic sink. The configuration of the hydraulic flow and pressures in a vertical plane are similar to those existing around the perforated zone of a well into which underground water is flowing. However, the magnitude of the tension applied to the probe is so small that the volume or region of soil affected is very small, extending only about 10 cm from the probe for applied probe tensions of about 100 cm. Thus the disturbance caused by the sampling scarcely affects the general pattern of flow through the soil.

The proper tension to be applied to the probe will depend upon the soil permeability, the permeability of the probe material, the frictional resistance in the connecting tubing, and the initial soil solution pressure. The necessary probe tension is readily applied by means of a hanging water column.

With a proper probe porosity and length, the feasible yield per probe is about 20 ml per hour.

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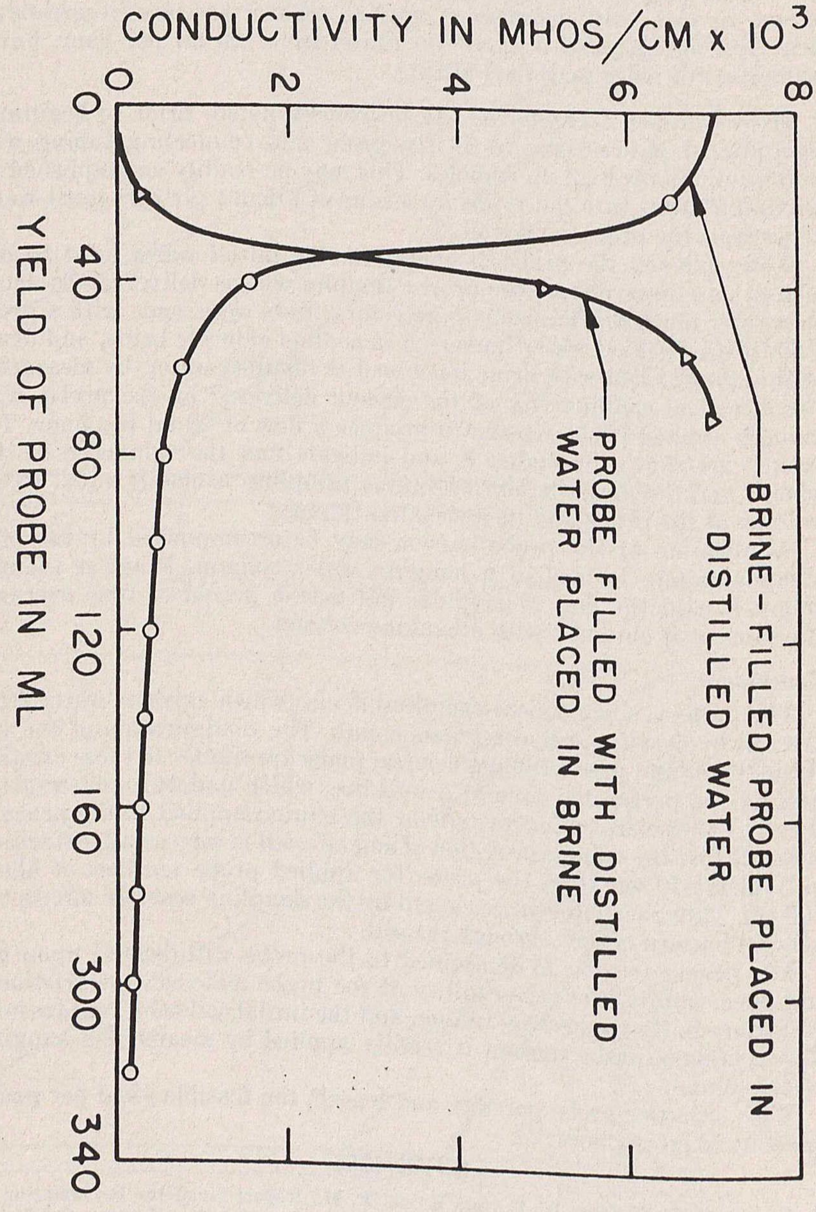

Figure 8. Conductivity Plot Illustrating Displacement of Liquid from Probe.