

STATE OF CALIFORNIA

EARL WARREN
Governor

REPORT
ON THE
**INVESTIGATION OF
LEACHING OF ASH DUMPS**



1952

STATE WATER POLLUTION CONTROL BOARD
SACRAMENTO, CALIFORNIA

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FOREWORD

One of the statutory duties (Section 13024 of the Water Code) of the California State Water Pollution Control Board is that of administering and directing any state-wide program of research in the technical phases of water pollution control. The report presented in this publication has been prepared in conjunction with a research project authorized by the State Board on February 20, 1951.

Location of waste disposal dumps in California, where such a large proportion of the water supply is withdrawn from the underground basins, is a problem of considerable concern and one that has often resulted in no small amount of controversy. The question has arisen as to the possibility of pollution of the underground basins by alkalies and other dissolved salts leached from incinerator-ash, garbage, industrial refuse, and other surface dumps either by rainfall or by movement of ground water through the dump depression if the water table rises above the bottom of the pit. When the water pollution control boards commenced operation early in 1950, it was observed that strong opinions among various interests seemed to prevail, but that there were not very many scientific facts upon which decisions could be based.

Recognizing the need for factual information, the State Water Pollution Control Board entered into an agreement with the University of Southern California, Los Angeles, on March 1, 1951, for an investigation of and report on the extent of pollution of ground water by alkalies and salts leached from incinerator-ash, garbage, industrial refuse, or other dumps, to include, but not necessarily limited to, the following:

- a. Amount of leaching of alkalies and salts from surface dumps either by rainfall or by movement of ground water through the dump depression if the water table rises above the bottom of the pit.
- b. Extent of penetration below dumps of water and dissolved salts for rains of varying intensity and varying runoff conditions.
- c. Extent of lateral movement of leached salts should the water table rise above the bottom of the dump pit.
- d. Findings, conclusions, and recommendations of the contractor on waste-disposal dumps in relation to water pollution.
- e. Recommendations of the contractor for further investigations and/or research.
- f. Bibliography of reference material.
- g. A final report consisting of a manuscript ready for submission for printing.

During the first 16 months of the project the investigators, under the direction of Professor Robert C. Merz, concentrated their time and efforts on an investigation of leaching from ash dumps, and, on June 26, 1952, submitted their report on this subject. To make the findings

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of the investigation available to all interested parties and to stimulate comment and constructive criticism which will be invaluable in planning future research in this and other phases of water pollution control, the state board authorized the printing and distribution of the report.

Although the original contract terminated on June 30, 1952, the state board has approved the continuation of this research project on a more intensive scale during the fiscal year ending June 30, 1953, and has directed that emphasis during this next phase be placed on investigations of leaching from dumps handling garbage, rubbish, and mixed refuse.

While these investigations have been conducted under the sponsorship and direction of the State Water Pollution Control Board, it should be pointed out that the conclusions and recommendations given in the "Report on the Investigation of Leaching of Ash Dumps" are those of the research contractor.

REPORT
ON THE
INVESTIGATION OF LEACHING
OF ASH DUMPS

Prepared for

STATE OF CALIFORNIA
STATE WATER POLLUTION CONTROL BOARD

STANDARD SERVICE AGREEMENT NO. 12C-2

By

SANITARY ENGINEERING RESEARCH LABORATORY
UNIVERSITY OF SOUTHERN CALIFORNIA
LOS ANGELES, CALIFORNIA

June, 1952

LETTER OF TRANSMITTAL

UNIVERSITY OF SOUTHERN CALIFORNIA
3518 UNIVERSITY AVENUE, LOS ANGELES 7

June 10, 1952

State of California
State Water Pollution Control Board
305 Financial Building
Sacramento 14, California

GENTLEMEN: Pursuant to the terms of Standard Service Agreement No. 12C-2 dated March 1, 1951, between the State Water Pollution Control Board and the University of Southern California, we are pleased to submit herewith 35 copies of a final report on the Investigation of Leaching From Dumps.

For reasons set forth in the report, the investigation has dealt only with the leaching of incinerator ash dumps. The report was prepared by the undersigned and is, we believe, one of the most comprehensive presentations of research data available on the subject.

Respectfully submitted,

ROBERT C. MERZ
Project Director

JACK R. SNEAD
Assistant Sanitary Engineer

ACKNOWLEDGMENTS

Whatever success this project has enjoyed to date is due in no small measure to the cooperation and support provided by many individuals. The authors wish to take this means of expressing their appreciation for all assistance rendered. We particularly wish to acknowledge the aid of the Advisory Committee comprised of:

Mr. C. E. Arnold, County Engineer and Surveyor, Los Angeles
Mr. Paul G. Brown, Executive Officer, Regional Water Pollution Control Board No. 8, Santa Ana
Mr. Ray L. Derby, Principal Sanitary Engineer, Department Water and Power, Los Angeles
Mr. Cecil J. Geraghty, Executive Secretary, Assembly Interim Fact-Finding Committee on Air and Water Pollution, Oakland
Dr. Roy O. Gilbert, County Health Officer, Los Angeles
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Mr. Linne C. Larson, Executive Officer, Regional Water Pollution Control Board No. 4, Los Angeles
Dr. J. E. McKee, California Institute of Technology, Pasadena
Mr. A M Rawn, Chief Engineer and General Manager, Los Angeles County Sanitation Districts, Los Angeles
Mr. Warren A. Schneider, Waste Disposal Engineer, Department of Public Works, Los Angeles
Dr. George M. Uhl, City Health Officer, Los Angeles
Mr. David B. Willets, Senior Hydraulic Engineer, Division of Water Resources, Los Angeles

At the risk of omitting mention of those equally deserving, we wish to extend our sincere thanks to the following persons: Mr. Arthur Pickett, Division Engineer, Industrial Waste Division, Office of County Engineer, Los Angeles; Mr. E. L. Bettannier, Superintendent Power and Light Department, Pasadena; and Mr. H. J. Scott, Superintendent of Public Works, Beverly Hills, for their assistance in the selection of test sites; Dr. William Lea, Director, Division of Industrial Hygiene, Wisconsin State Board of Health, and Dr. M. Starr Nichols, Assistant Director, Wisconsin State Laboratory of Hygiene, for their aid in formulating analytical procedures; Professor David Eye, Virginia Polytechnic Institute, for his organization of the Lacy Street investigation, while a member of the research personnel; Dr. Arthur Adamson, Associate Professor, Department of Chemistry, University of Southern California, for his advice and counsel on matters of radio chemistry; Dr. Richard Pomeroy, Consulting Chemist, Pasadena, for his review of and suggestions relative to the interpretation of test data; and Professor David M. Wilson, Head, Department of Civil Engineering, University of Southern California, for his guidance in matters of direction and policy.

INTRODUCTION

In the following pages we present a factual report, a report which attempts to set forth simply an accounting of the various individual studies conducted in connection with this "Investigation of Leaching From Ash Dumps." Included are descriptions of materials and equipment used, methods of operation, discussions of results obtained, and, finally, statements of conclusions and recommendations.

Much has been written by many agencies and individuals regarding the dependence of the State of California on its vast underground water basins for its agricultural economy. It is not our purpose to review or reiterate such matters of fact. However, it should be emphasized that any potential threat to those underground water basins, no matter how remote it may appear, must be investigated as thoroughly as time and funds will permit in order that it may be proven real or false.

One such potential threat to the groundwaters is the entrance of leach into them from incinerator ash dumps, whether that leach be derived from precipitation falling on the dump and percolating down through it, or from an actual rise of the groundwater itself into the dump and subsequent lateral movement through it.

When water passes through an ash dump, it undergoes many changes in quality. Leaching of soluble minerals begins, and unburned organic wastes begin to undergo biological decomposition. The object of our investigation was to investigate the physical and chemical phenomena taking place within ash, either in place or after transportation to the laboratory. The heterogeneity of the ash and the complexity of the problem made it desirable and necessary to secure much basic information before reasonable conclusions could be drawn. Because of the time required to obtain a complete picture of the problem, particularly of the effects of partly burned organic material, this report is primarily concerned with the physical and chemical aspects of leach water only from ash deposits.

As the number of communities turning to incineration of their refuse as a means of disposal increases, the problem will become more acute, for every incinerator requires an ash disposal site. Further, the owners of worked-out gravel deposits will request permission to utilize such lands in their possession as dump sites, in order that they may derive additional revenue. And there will be others. It is hoped that this report will assist those in authority to formulate rules or standards governing the use of lands for ash disposal.

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Engineering

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University of Southern California
June, 1952

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CHAPTER I

SUMMARY OF INVESTIGATION

Summary of Conclusions

1. The percolation of natural precipitation or the movement of ground-water through an incinerator ash dump will leach soluble salts and alkalis from the dump.

2. The rate of leaching will be very slow, even when water volumes far in excess of those derived from maximum precipitation or normal groundwater flow are applied to the ash surface.

3. The maximum amount of any cation that may be reasonably expected to be leached from an incinerator ash dump over a period of at least five years will be 2.9 pounds per cubic yard (sodium). This value will decline considerably over subsequent five-year periods.

4. The maximum amount of any anion that may be reasonably expected to be leached from an incinerator ash dump over a period of at least five years will be 5.3 pounds per cubic yard (chloride). The chloride content of the ash will very likely be exhausted within that time. There will be a simultaneous leaching of 5.0 pounds of sulfate per cubic yard, but this value, too, will decline considerably over subsequent five-year periods.

5. Chlorides and nitrates will be rapidly and completely removed by leaching. Sulfates will be leached at a slightly lower rate. Calcium and magnesium will be leached very slowly, while the rate for sodium and potassium will be the fastest of the cations. It is unlikely that all the cations would ever be removed.

6. The annual precipitation in this area will penetrate an ash dump approximately six feet. Subsequent years may be expected to produce equal increments of penetration, assuming normal precipitation.

7. The average rate of penetration through a uniform ash during a period of greatest rainfall will be in the magnitude of 0.20 feet per day.

8. A typical incinerator ash may be expected to exhibit ion exchange properties, and to have exchange capacities approaching one-tenth to one-twentieth that of commercial cation exchangers, and one-half that of glauconite.

Summary of Recommendations

There are many aspects of the subject covered by this report which have not been investigated for they were not considered to be within the province of the basic assignment. Chief among them would be extended research, or perhaps study and computation, which would settle the long-standing contention that any addition of salts to the groundwater, whether dilution is available or not, is detrimental, because any salt added is salt contributed to the coastal basins which are the concentration areas for most groundwater flows. These are matters for engineers expert in groundwater conditions of the area to consider in the light of the findings here disclosed.

Strictly on the basis of the information gained through the field and laboratory studies made, coupled with what are thought to be reasonable assumptions of groundwater volume, the authors make the following recommendations.

1. It is recommended that incinerator ash dumps be located preferably in an area where they will be subject only to percolation by precipitation, without regard to the nature of the underlying soil strata. Caution should be exercised in the selection of the dump site to prevent the funneling of leach waters into an inadequate volume of groundwater dilution. The effect of the entrance of the leach into the groundwater will be negligible.

2. It is recommended that incinerator ash dumps be located only when necessary in an area where they will be subject to the passage of groundwater through them. This statement is made notwithstanding the fact that the evidence of the investigation indicates such location to be safe practice, because of the many variables involved.

3. It is recommended that incinerators be operated with a view toward keeping the percentage of unburned or partially burned organic matter at the very minimum. The production of carbon dioxide within a dump due to the decomposition of the organic matter still in the ash, under aerobic or anaerobic conditions, will directly affect the dissolution of the soluble salts, especially lime, thereby increasing hardness as well as providing the anion necessary for the greatest removal of sodium and potassium.

CHAPTER II

THE FIELD INVESTIGATION

The location of incinerator ash dumps in areas where a large proportion of the underground water supply is put to large and varied use has been a problem of vital concern to various agencies charged with the responsibility of the protection of water quality. The question of how much these ash deposits might pollute the underground basins by their being leached of alkalies and soluble salts, by reason of the movement of water through them, has been one of much controversy. Further, few known facts exist to substantiate one belief or another. To determine some of these facts, the study here being reported was begun with an actual field investigation under conditions deemed to be representative of most ash deposits.

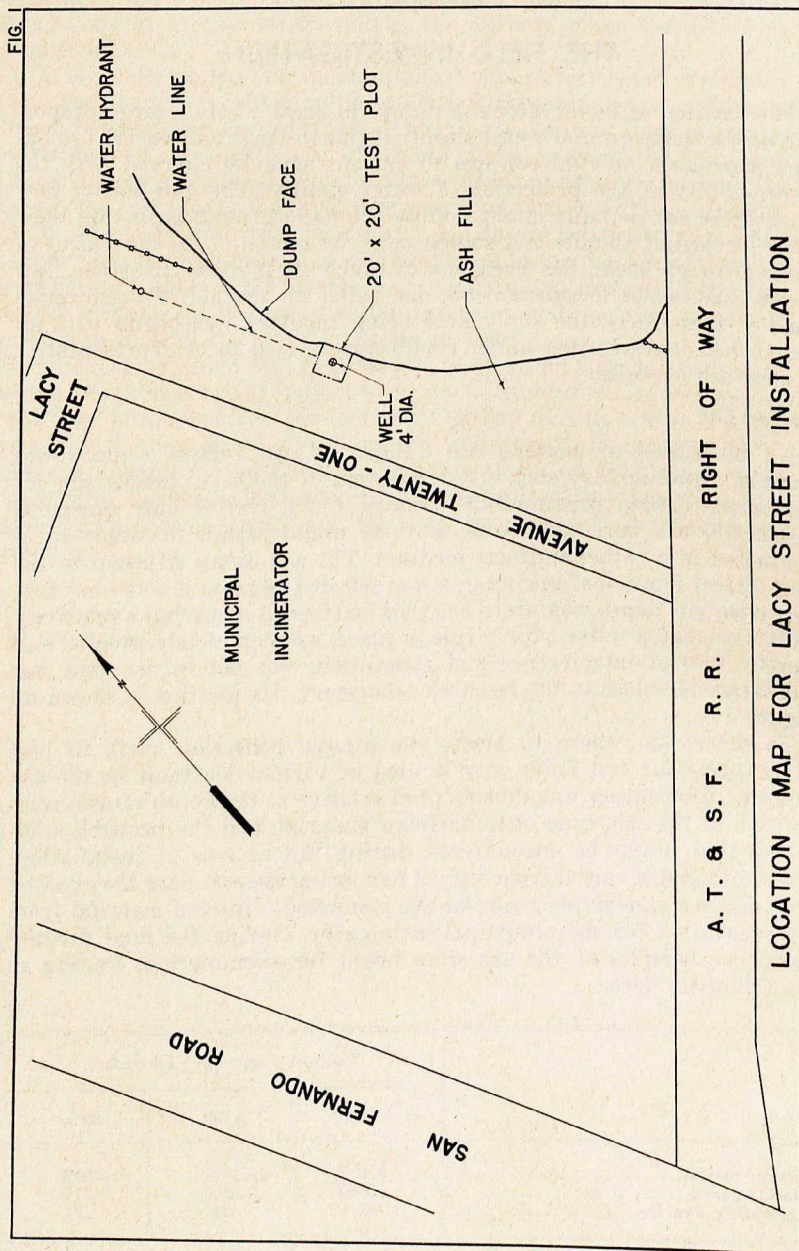
The Test Site

An inspection of existing ash dumps in Los Angeles County was made as a preliminary step in the selection of the best possible site for the proposed field investigation. Dumps which receive only quenched incinerator ash were considered, as these would permit the study to be conducted in a rather uniform medium. The ash dump adjacent to the Lacy Street municipal incinerator was selected because it was known to have adequate depth, contained ash that had been in place but a relatively short time, had a water supply line in place, was completely isolated and thereby free of interference and congestion, was not in use, and was comparatively close to the research laboratory. Its location is shown on Figure 1.

To determine where to locate the sample collection shaft to best advantage, four test holes were drilled at various locations in the ash deposit. Information was thus secured relative to the depth of ash, composition of the ash, type of underlying material, and the probable difficulties that might be encountered during the process of installation. The depth of ash varied from 5 to 12 feet, being deepest near the exposed face, and the underlying material was composed of placed material from the excavation for the municipal incinerator. During the final drilling operation, samples of the ash were taken for examination, leading to the following data:

	Depth of sample below ash surface		
	1 foot	5 feet	10 feet
Moisture content.....	8.10%	10.40%	11.90%
Soluble material.....	0.80%	0.67%	0.74%
Temperature, Deg. C.....	29	33	37

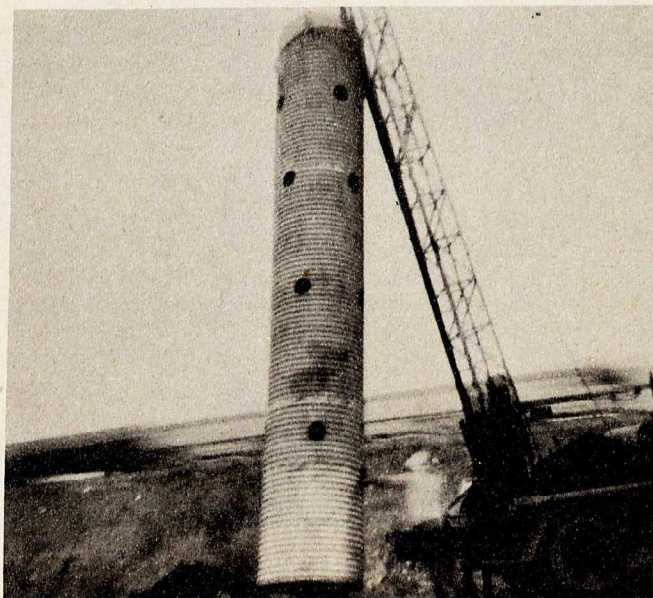
The soluble content of the ash was determined by leaching one part of dry ash in 10 parts of distilled water, by weight, for 48 hours.





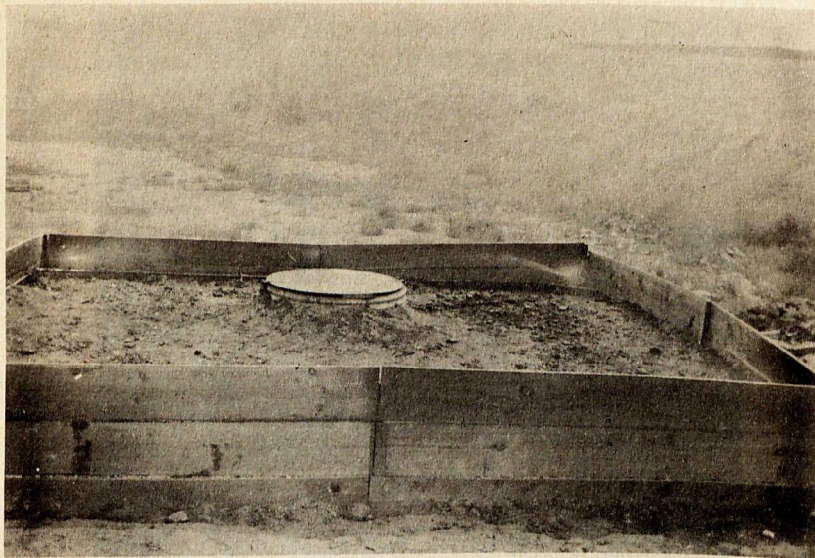
PHOTOGRAPH 1

View of Lacy Street ash dump and test plot



PHOTOGRAPH 2

View of well for collection of leach being lowered into place
at Lacy Street test plot



PHOTOGRAPH 2A

View of fenced test site with spray water being applied to surface



PHOTOGRAPH 2B

View of corner of test site following application of spray water to surface

Equipment for Collection of Leach

The collection well was installed where a 12-foot depth of ash existed, and was sunk an additional 11 feet in order that the collection of leach that had passed through the dirt fill would be possible. The total depth of the 48-inch drilled hole was 23 feet. The well lining consisted of a 48-inch diameter corrugated metal pipe, with holes cut in sides before it was placed to receive four collection laterals at each depth of 3, 7, 12, and 18 feet. In Photograph 1 is pictured the casing being lowered into place.

The collection laterals were 8-inch iron pipes, full diameter from the casing to a distance of approximately one foot into the ash and then half round over the rest of their length. In this manner, the entrance into the laterals of any water moving down the side of the casing was prevented. As indicated by Photograph 1, the positions of the laterals at the various depths were staggered so that no two were directly in line vertically. Where possible, the laterals were installed by jacking into the undisturbed ash. In two instances, actual excavation into the ash was necessary to obtain proper placement of the lateral. A diagram of the complete collection well is shown in Figure 2.

Selection of Spray Nozzles

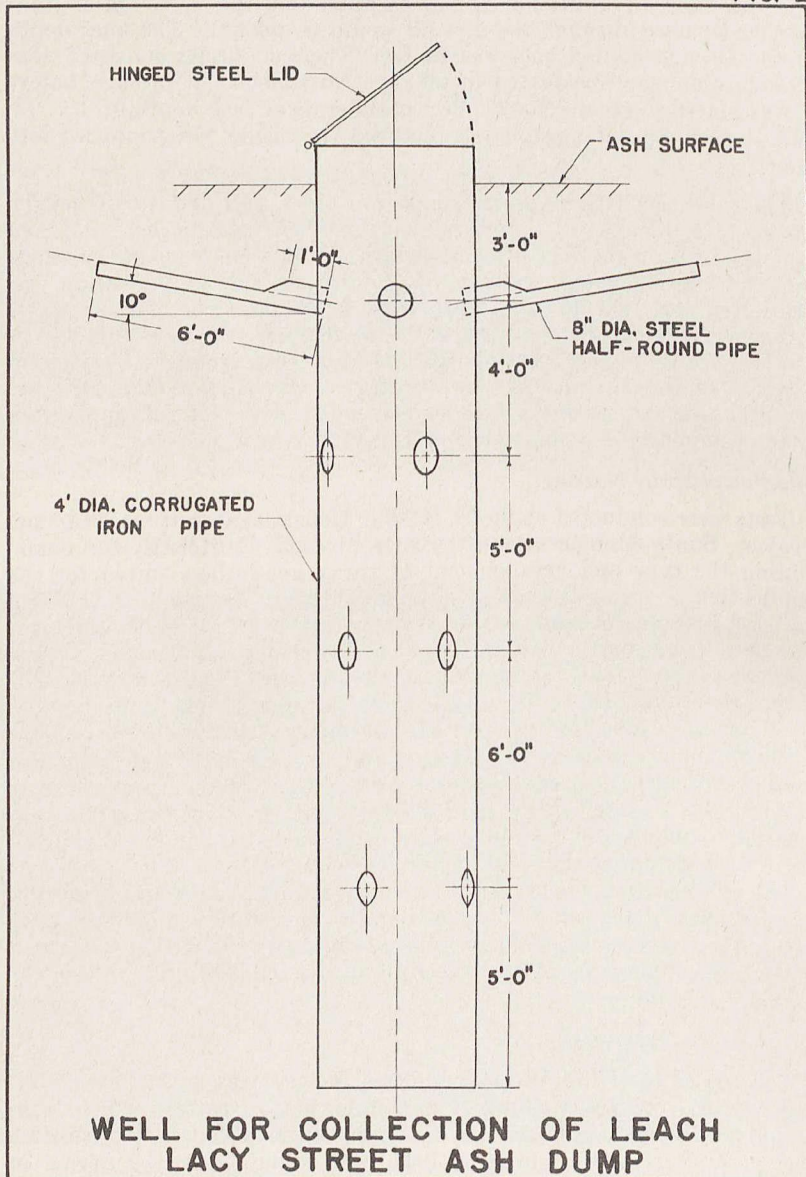
Tests were conducted at the U. S. War Department Airport Drainage Project, Santa Monica Airport, Santa Monica, California, for determining the type and arrangement of spray nozzle best suited for the application of water to the test site. Every effort was made to obtain a uniform coverage of water at the required rates of flow, and under conditions imposed by the proposed field arrangement. The common, lawn-sprinkler type nozzles of the Moody design were finally selected. The coverage obtained led to the selection of a test plot 20 feet square, served by a one-inch pipe line around the periphery fitted with one-quarter circle sprinkler heads at the corners, and two one-half circle sprinkler heads per side spaced equidistant between the corners. By using these nozzles, and a water meter calibrated to read to 0.125 gallon, it was possible to obtain any desired amount or intensity of simulated rainfall up to a maximum of about 10 inches per hour.

The test area was enclosed with a two-foot high, board siding to protect the spray from wind. The fencing also served to confine the spray within the test area, since the sprinkler heads were elevated one foot and the outermost portions of the half-circle sprays tended to fall outside the limits of the plot.

The Method of Operation

Records of the U. S. Weather Bureau for the area encompassing the test site were studied to obtain a maximum rainfall pattern which could be followed in the application of the spray water, or simulated rainfall. The precipitation of February, 1941, was found to be the period of maximum conditions, and was therefore followed for this investigation as well as those later described. Also taken into account were the important rains leading up to and following the maximum period. The amounts of spray water applied to the test plot as simulated rainfall are compared with the actual precipitation record for February, 1941, in Table 1.

FIG. 2



It will be noted that the unusually long waiting periods between some of the rains of lesser intensity were shortened to save time, and that very light rains were combined to afford better coverage of the site. Since this investigation was made in midsummer, it is certain that losses due to evaporation were higher than those that existed during the 1941 rainfall period. The days were, for the most part, hot, dry and sunny, with variable breezes.

Table 1, referred to above, lists the daily quantities of simulated rainfall applied to the surface of the test plot. The application of August 10th brought forth the first sign of water within the sample well. A full quart of sample was obtained from one of the four collection laterals at the seven-foot depth, the water having bypassed the laterals at the three-foot depth. The logical explanation for this was that the dump had cracked at the surface (near the slope) over the contributing lateral, thus providing the water with an easier access to the seven-foot depth.

It should be noted here that settlement of about one-third the test plot, adjacent to the slope, had been gradually taking place since the beginning of operations. A drop of about 18 inches between the original dump surface and the settled portion existed by the time the simulated rainfall period was reached. The rest of the surface of the test plot remained at the original elevation. This settlement was apparently due to consumption of material by a deep-seated fire which had been smoldering continuously since the completion of the installation, not only

TABLE 1
COMPARISON OF MAXIMUM RAINFALL CONDITIONS OF FEBRUARY, 1941, WITH
SIMULATED RAINFALL APPLIED TO LACY STREET TEST PLOT

Date	Inches of natural precipitation over general area	Date	Inches of applied spray water to test site
1-21-41	0.30	7-17-51	0.46
22	0.07		
23	0.46		
24	0.73	18	1.14
26	0.27	19	0.80
2- 6-41	0.86	23	0.85
8	0.13		
11	0.44	24	0.57
14	1.49	26	1.54
15	0.58	27	0.62
16	0.68	28	0.73
17	0.33	29	0.39
19	0.64	31	0.64
20	1.95	8- 1-51	1.98
21	1.89	2	1.87
22	0.19	3	0.28
24	0.45	5	0.51
28	2.78	9	2.80
3- 1-41	0.76	10	0.82
2	0.45	11	0.50
3	0.76		
4	1.25	12	2.01
Totals	17.46		18.51

within the test area but for 50 to 60 yards along the edge of the dump. As far as the test plot was concerned, the fire seemed to confine itself to one corner of the site.

On August 11th, the sample jars were again checked before application of any spray water and another two-thirds of a quart had been obtained from the same lateral. Water was also just beginning to flow from the lateral diametrically opposite.

Following application of the 0.50 inch on August 11th, the jars were checked on August 12th. It was found that the application was not of sufficient magnitude to create a large flow in any of the laterals, but coupled with what had previously been applied, there was about one-half inch of sample in three of the jars at the seven-foot depth. The fourth lateral at the seven-foot depth and all laterals at the three-foot depth remained dry.

Following application of the 2.01 inches on August 12th, the jars were checked on August 13th. Again, the same lateral at the seven-foot depth was contributing flow, but now there was also flow in one of the laterals at the three-foot depth, that under solid fill extending in the direction of the incinerator plant.

Thus, the conclusion of the simulated rainfall application yielded just four samples for initial laboratory study, samples which proved difficult to study because of their high color and because of a lack of information as to the probable ion concentrations which necessitated more than one determination in several instances. The initial analyses are not considered sufficiently reliable for detailed reporting.

It is of interest to note that the color of the initial samples ranged from a yellow-green to a turbid strong tea. The odor was characteristically that of quenched ash or wood. The pH varied from 6.8 to 7.3. The temperature of the samples at collection varied from 104 to 111 degrees F.

On August 20th an effort was made to bring about complete saturation by applying a large quantity of spray water to the test plot. It was believed that complete saturation would represent a condition similar to that obtained by a rise of groundwater into a dump. Over a period of five hours and 20 minutes, 3,074 gallons of water were applied, representing 12.28 inches. This resulted in flow in all laterals at the three-foot depth with all jars full, and flow in three of the laterals at the seven-foot depth with two jars full. The color of the samples from the laterals which had previously contributed was much lighter, but typically dark from the laterals newly contributing. By the following morning, August 21st, all jars at the three-foot depth were again full, three jars at the seven-foot depth were full, and one jar at the 12-foot depth was full. There was no flow at the 18-foot depth.

The foregoing detailed information is summarized in Table 2. Also shown are subsequent floodings of the dump, together with amounts of water applied, number and depths of laterals contributing flow, and sample reference numbers. The total volume of spray water applied up to the time of collection of each group of samples is also shown, for these volumes provide the basis for the plotting of Figures 3, 4, 5, and 6.

It is also of great interest to note that at no time during the entire field investigation did any visible water appear on the exposed dump slope, the top of which was one boundary of the test site. Apparently little lateral capillary movement took place.

TABLE 2
APPLIED WATER DATA FOR LACY STREET ASH DUMP

Date of application	Spray water applied		Total spray water applied up to taking of samples (Gallons)	Number and depth of laterals contributing flow	Composite sample number
	Gallons	Inches			
7-17-51 to 8-10-51		16.00	4,031	1 @ 7 foot depth	
11	127	0.50	4,158	1 @ 7 foot depth	
12	507	2.01	4,665		
13			4,665	1 @ 7 foot depth	
15			4,665	1 @ 3 foot depth	
8-20-51	3,074	12.28	7,739	3 @ 3 foot depth	L-3
				3 @ 7 foot depth	L-6
				1 @ 12 foot depth	L-7
27	2,497	9.87	10,236	3 @ 3 foot depth	L-8
				3 @ 7 foot depth	L-9
				3 @ 12 foot depth	L-10
				2 @ 18 foot depth	L-12
9-5-51	2,822	11.30	13,058	3 @ 3 foot depth	L-13
				3 @ 7 foot depth	L-14
				3 @ 12 foot depth	L-15
				3 @ 18 foot depth	L-16
12	2,672	10.70	15,730	3 @ 3 foot depth	L-17
				2 @ 7 foot depth	L-18
				2 @ 12 foot depth	L-19
				3 @ 18 foot depth	L-20
18	3,497	14.00	19,227	3 @ 3 foot depth	L-21
				4 @ 7 foot depth	L-22
				3 @ 12 foot depth	L-23
				3 @ 18 foot depth	L-24
25	2,948	11.77	22,175	3 @ 3 foot depth	L-25
				4 @ 7 foot depth	L-26
				3 @ 12 foot depth	L-27
				2 @ 18 foot depth	L-28
10-2-51	3,501	14.0	25,676	3 @ 3 foot depth	L-29
				3 @ 7 foot depth	L-30
				4 @ 12 foot depth	L-31
				2 @ 18 foot depth	L-32
8	2,758	11.0	28,434	3 @ 3 foot depth	L-33
				4 @ 7 foot depth	L-34
				4 @ 12 foot depth	L-35
				2 @ 18 foot depth	L-36

Sample jars were removed immediately following the application of the spray water, or as long thereafter as necessary to obtain an adequate sample for laboratory analysis. Samples were collected in open mouth quart jars rather than the special type of apparatus described in Chapter III. Consequently, the pH values reported do not reflect the true character of the leach at the time it entered the sample jar.

Analytical Procedure

The following analytical procedures were adopted for use in this investigation and those subsequently described:

- pH—Beckman Glass Electrode pH Meter
- Total Hardness and Calcium—Volumetric (Sodium Versenate)
- Magnesium—Spectrophotometer (Titan Yellow)
- Sodium—Gravimetric (Uranyl Zinc Acetate)
- Potassium—Spectrophotometer (Sodium Cobaltinitrite)
- Chloride—Mohr
- Sulfate—Spectrophotometer (Turbidimetric)
Gravimetric (Barium Chloride Separation)
- Phosphate—Spectrophotometer (Ammonium Molybdate)
- Silica—Spectrophotometer (Molybdate)
- Nitrogen—Spectrophotometer (Kjeldahl)
- Alkalinity—Volumetric

In the latter stages of the work, some potassium and sodium determinations were made by flame photometer by other laboratories. Spot checks on the rare metals were also made by other laboratories.

Discussion of Results

On Figures 3, 4, 5, and 6 have been graphed the analytical data for the Lacy Street ash, consideration being given only to data obtained from leach samples at the 12- and 18-foot depths. These depths were selected because they represent (1) the conditions at the bottom of the dump which is the important zone as far as this study is concerned (12-foot depth), and (2) the possible changes in the character of the leach following its passage through several feet of earth (18-foot depth). The analytical data for the other levels is included, and appears in Tables 3 and 4.

It will immediately be noted that the curves are very erratic, that in most cases their exact location on the graphs was a highly speculative matter due to the wide spread of points, and that they follow no definite trend as they do with the other ashes investigated and discussed in Chapter III. The explanation lies in the fact that no controls were possible in the field. The test site was extensive, making it possible for the collection laterals to be in different types of materials. The sub-surface fire meant widely varying temperatures in the collected samples which would affect solubilities. Some of the initial samples collected had temperatures of 110 degrees F., whereas by the end of the test sample temperatures had dropped to 70 to 80 degrees F. Cracks developed in the dump, permitting channeling for at least a part of the way down, and settlement occurred on the slope side, all due to the reduction of material by the deep-seated fire.

In general, the behavior of the curves illustrating the data for the 12-foot depth is not much different from those graphed for the laboratory leach column study, and the reader is referred to Chapter III for a detailed discussion. For clarity, however, it should be pointed out here that the sulfate and chloride ion concentrations again decreased rapidly at first, but then leveled off at comparatively constant values. While this

TABLE 3
ANALYSES OF LEACH SAMPLES FROM LACY STREET ASH DUMP
THREE-FOOT DEPTH

Sample number	L-3	L-8	L-13	L-17	L-21	L-25	L-29	L-33
pH.....	7.42	7.30	6.70	7.35	7.50	7.25	7.50	7.90
Total dissolved solids.....	16,550	18,830	10,800	6,980	5,160	4,290	4,215	2,375
Calcium.....	670	720	545	315	380	510	500	395
Magnesium.....	405	565	435	240	300	125	115	88
Sodium.....	1,310	1,380	1,330	1,045	470	355	260	125
Potassium.....	750	1,280	480	595	315	270	340	110
Total hardness as CaCO ₃	3,590	3,930	3,000	2,495	2,275	1,950	1,840	1,300
Alkalinity as CaCO ₃	815	1,120	940	800	645	480	520	410
Chloride as Cl.....	3,400	4,000	1,675	725	290	330	190	110
Sulfates as SO ₄	7,800	7,000	5,000	4,000	2,700	1,750	1,850	1,300
Phosphate as PO ₄	00	1.8	00	3.0	0.38	6.3	0.31	00
Total iron.....	2.1	12.0	0.84	0.60	0.38	0.20	1.1	1.3
SiO ₂	19	37	18	33	30	32	43	31
Total CO ₂ (Calc.).....	72	115	270	82	65	58	45	26
Total Org. N.....	2.1	4.4	NR	1.9	3.0	1.2	2.1	1.3
NH ₄ -N.....	3.5	4.1	0.74	00	0.50	0.40	00	0.20
NO ₂ -N.....	1.9	3.4	0.45	0.08	00	0.11	0.27	0.08
NO ₃ -N.....	42	114	36	10	7.2	6.4	4.8	5.0

Results in ppm

NR = No Result

TABLE 4
ANALYSES OF LEACH SAMPLES FROM LACY STREET ASH DUMP
SEVEN-FOOT DEPTH

Sample number	L-6	L-9	L-14	L-18	L-22	L-26	L-30	L-34
pH	7.10	7.20	6.60	7.25	7.35	7.20	7.50	7.70
Total dissolved solids	7,300	7,755	6,990	3,295	4,140	4,055	2,425	3,940
Calcium	650	545	530	335	370	410	280	340
Magnesium	155	210	120	5	120	96	62	115
Sodium	1,100	1,255	1,185	575	655	595	275	255
Potassium	00	520	250	195	195	90	200	105
Total hardness as CaCO ₃	2,305	2,090	1,970	1,080	1,370	1,440	1,000	1,320
Alkalinity as CaCO ₃	615	645	800	595	540	545	470	430
Chloride as Cl ⁻	800	900	790	235	435	365	130	205
Sulfates as SO ₄ =	5,300	5,800	3,900	2,000	2,100	1,700	1,300	1,300
Phosphate as PO ₄ =	00	1.8	1.5	1.5	0.31	0.06	0.25	00
Total iron	1.6	6.0	1.3	1.5	1.8	1.7	1.1	2.0
SiO ₂	23	40	29	40	40	34	50	34
Total CO ₂ (Calc.)	90	81	295	73	57	73	42	31
Total Org. N	3.2	9.9	NR	0.95	1.9	3.8	2.7	3.2
NH ₄ -N	4.9	3.1	10	5.0	3.3	2.5	1.1	0.62
NO ₂ -N	0.70	1.1	0.05	0.16	0.47	1.4	0.63	0.35
NO ₃ -N	26	74	32	4	5.3	7.4	7.5	12

Results in ppm

NR = No Result

TABLE 5
ANALYSES OF LEACH SAMPLES FROM LACY STREET ASH DUMP
TWELVE-FOOT DEPTH

Sample number	L-7	L-10	L-15	L-19	L-23	L-27	L-31	L-35
pH.....	7.38	7.30	6.50	7.30	7.35	7.30	7.65	7.80
Total dissolved solids.....	8,745	11,300	8,060	3,085	4,950	5,710	4,720	4,455
Calcium.....	495	595	560	415	485	455	410	400
Magnesium.....	185	200	200	40	70	104	75	90
Sodium.....	1,250	1,385	1,310	480	825	1,080	740	815
Potassium.....	00	550	255	60	120	1,180	220	270
Total hardness as CaCO ₃	1,715	2,540	2,023	1,200	1,540	1,560	1,350	1,340
Alkalinity as CaCO ₃	835	845	760	510	555	715	750	565
Chloride as Cl.....	1,100	1,700	915	130	320	455	285	295
Sulfates as SO ₄	5,200	5,500	4,000	1,600	2,350	2,350	2,000	2,270
Phosphate as PO ₄	00	2.5	2.3	0.20	0.38	0.13	6.0	00
Total iron.....	7.8	3.2	3.2	00	0.38	0.40	0.90	0.64
SiO ₂	NR	32	26	39	40	47	63	34
Total CO ₂ (Calc.).....	410	425	640	265	275	355	355	960
Total Org. N.....	2.0	2.9	NR	00	0.91	1.9	2.4	1.2
NH ₄ -N.....	0.60	0.60	2.7	1.5	0.70	0.26	0.92	0.59
NO ₂ -N.....	00	0.70	00	0.04	0.12	0.35	0.20	0.29
NO ₃ -N.....	42	96	43	7	22	11	16	12

Results in ppm

NR = No Result

TABLE 6
ANALYSES OF LEACH SAMPLES FROM LACY STREET ASH DUMP
EIGHTEEN-FOOT DEPTH

Sample number	L-12	L-16	L-20	L-24	L-28	L-32	L-36
pH.....	6.95	6.70	7.43	7.45	7.70	7.80	7.60
Total dissolved solids.....	23,000	9,370	9,315	7,280	6,520	10,250	10,170
Calcium.....	775	660	590	640	580	585	570
Magnesium.....	640	275	125	210	155	150	150
Sodium.....	1,435	1,270	1,245	1,015	800	1,325	1,390
Potassium.....	1,100	200	420	160	320	290	700
Total hardness as CaCO_3	4,735	2,800	2,405	2,340	2,240	2,350	2,190
Alkalinity as CaCO_3	880	715	810	435	485	660	445
Chloride as Cl^-	4,125	890	885	510	360	1,100	1,300
Sulfates as SO_4^{--}	4,875	4,800	3,900	4,400	3,000	4,150	5,375
Phosphate as PO_4^{--}	3.5	00	0.10	0.75	0.07	0.06	00
Total iron.....	8.0	00	0.40	0.38	0.20	1.7	0.64
SiO_2	39	35	42	43	34	50	28
Total CO_2 (Calc.).....	475	495	395	210	225	305	210
Total Org. N.....	4.2	NR	4.6	1.8	4.5	4.7	3.2
$\text{NH}_4\text{-N}$	4.4	11	0.22	00	0.11	0.65	0.28
$\text{NO}_3\text{-N}$	2.7	1.2	0.86	0.14	0.40	0.57	0.55
$\text{NO}_2\text{-N}$	535	174	90	130	55	93	130

Results in ppm

NR = No Result

is in marked contrast to the behavior of the curves for the laboratory leach columns, where the sulfate was leached out at a slower but more uniform rate, the final concentrations were all of approximately the same magnitude. The alkalinity curve demonstrates reasonable, slight variation in concentration since the dissolution of lime will be continuous and proportional to the amount of carbon dioxide produced by decomposition of the organic material in the ash.

The cation concentrations, Figure 3, indicate less sodium removal than might be expected, the reduction of potassium at about the same rate as the sodium, but in lesser quantity, and the expected hold-up of calcium. The removals of sodium and potassium is obviously not a case of simple dilution, perhaps because of the ion exchange properties of the ash (see Chapter V). The potassium curve has an unaccountable rise at the completion of the test. Magnesium shows an over-all decrease of about one-half the original concentration, again possibly due to the exchange mechanism taking place.

The very erratic and peculiar behavior of the curves for the variations in ion concentrations at the 18-foot level are thought to be due primarily to channeling. The following explanation is suggested:

Assume that the overlying ash had a constant leachable salt content and that the soil below the ash had a constant leachable salt content lower than that of the ash. If samples are collected and analyzed at a depth of six feet below the bottom of the ash, with no channeling taking place, the concentration of ions in solution will remain constant until the volume of water in the soil has been displaced by an equal volume of water moving down from the ash. After the volume of the water in the soil has been displaced by the volume that was originally in the ash, the ion concentrations in solution will have increased and become constant. The ion concentrations will remain constant until the "through-put" volume of water from the entire overlying mass of ash has been displaced. From then on, the ion concentrations in solution will show the effect of leaching by a gradual decrease. If this theory is presented diagrammatically, it will be represented closely by Figure A.

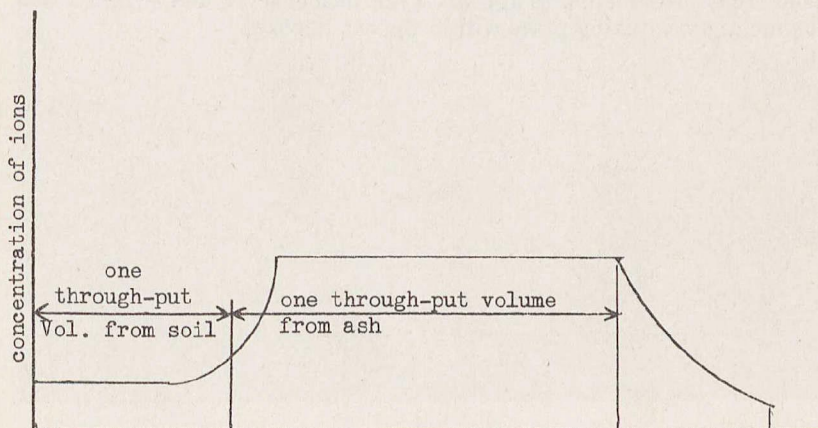


FIGURE A
Volume eluted

If channeling of the applied water took place in the ash deposit, some of the water would not have reached an equilibrium between the dissolved and undissolved salts as compared with the water that did not channel. Therefore, the total ion concentration of the leach would be less when it reached the bottom of the ash deposit. As the amount of channeling increased with an increase in the amount of water applied, the ion concentration would decrease. The conditions of the above diagram must then be altered to appear as in Figure B.

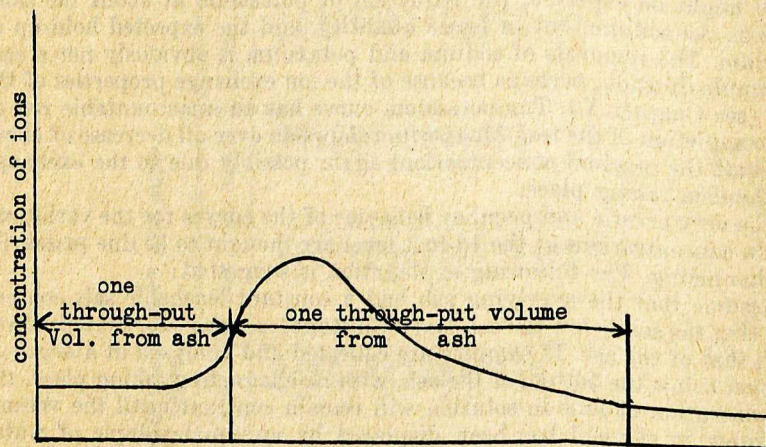
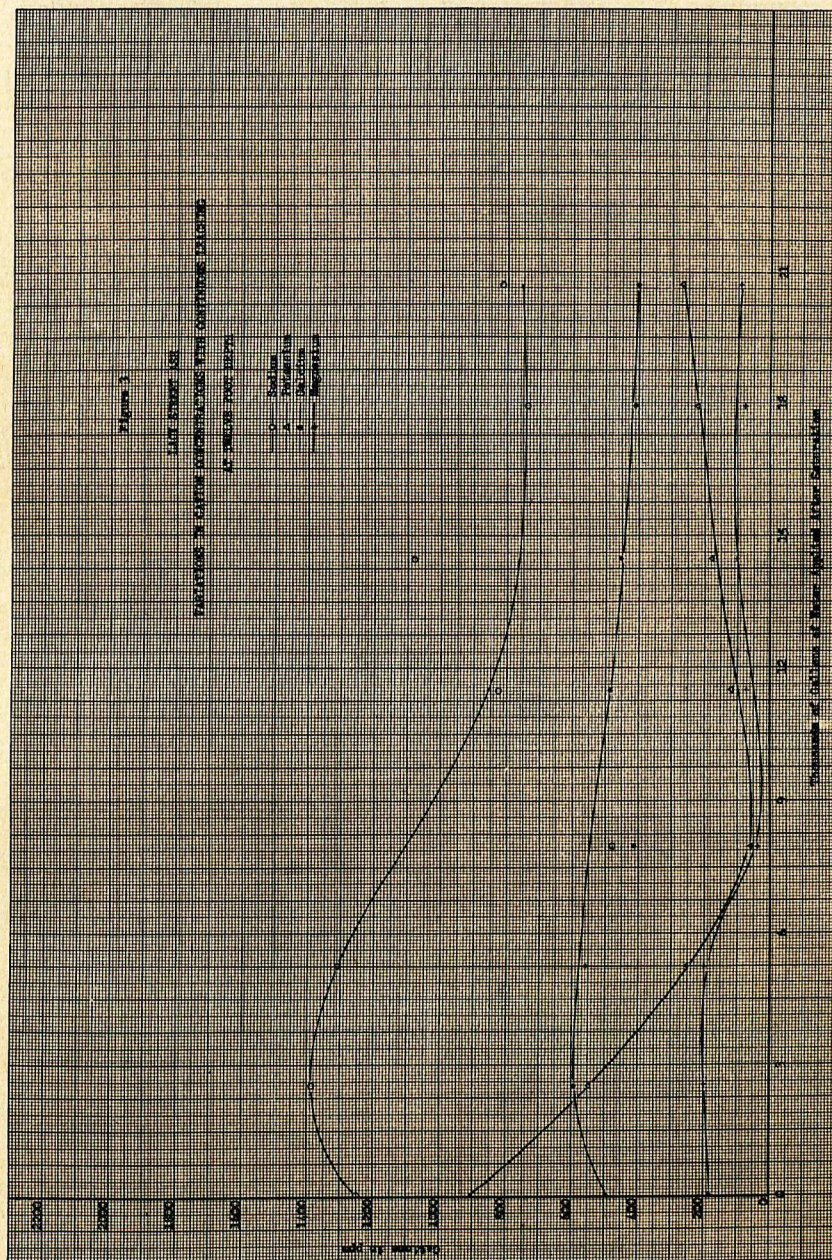
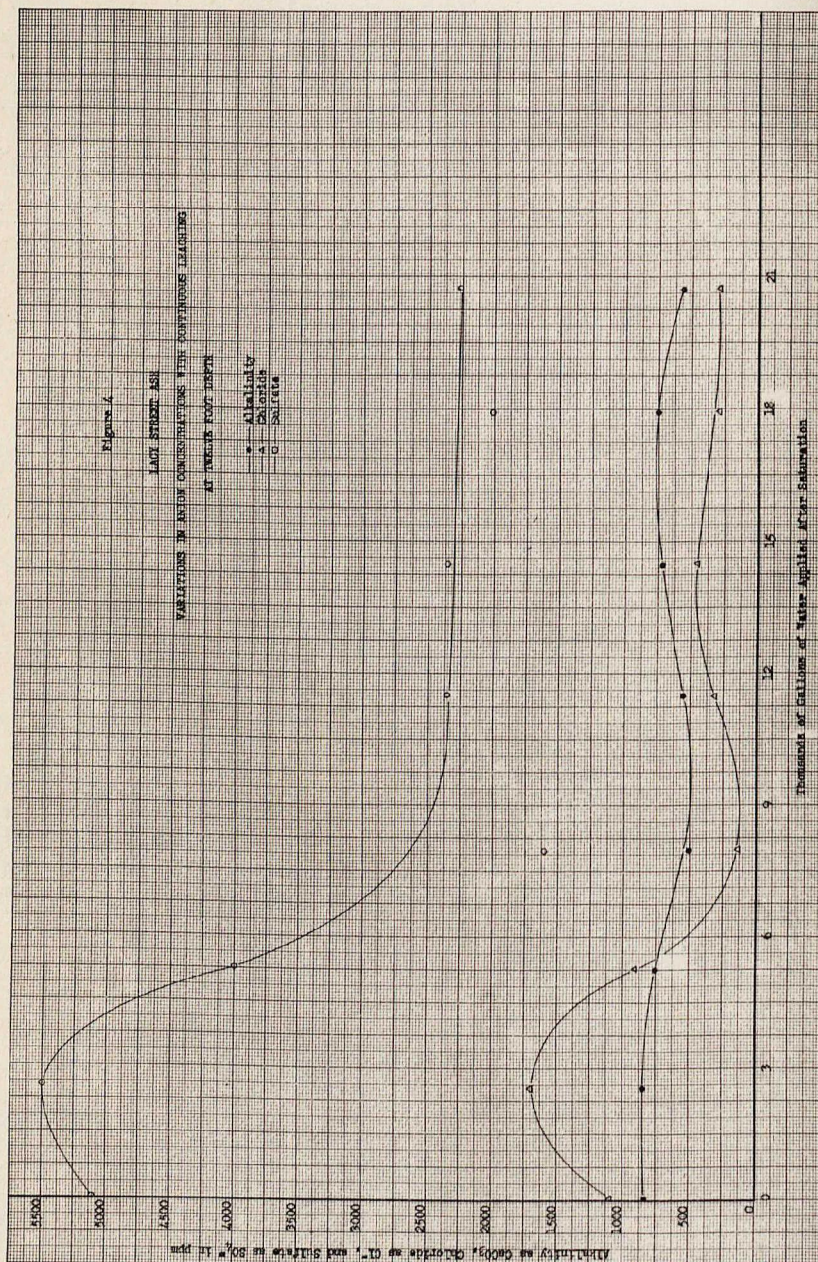
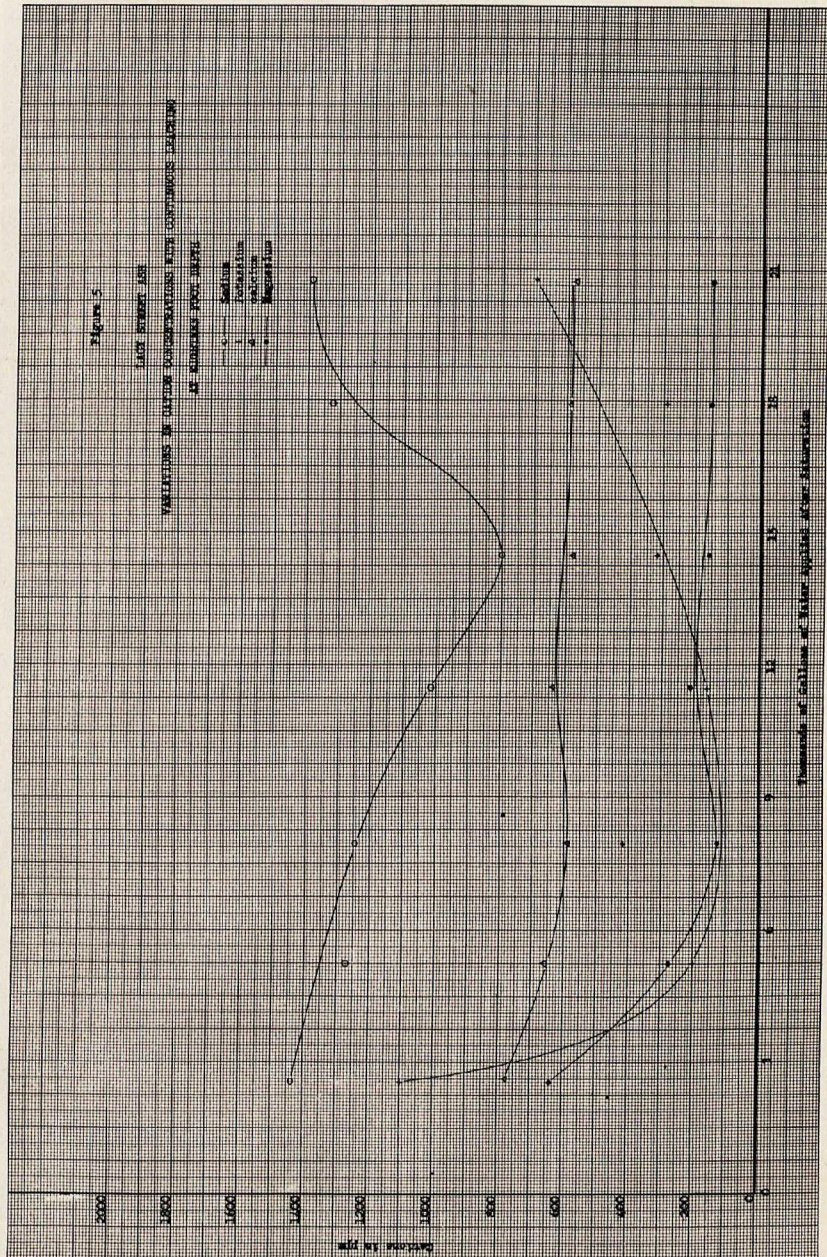


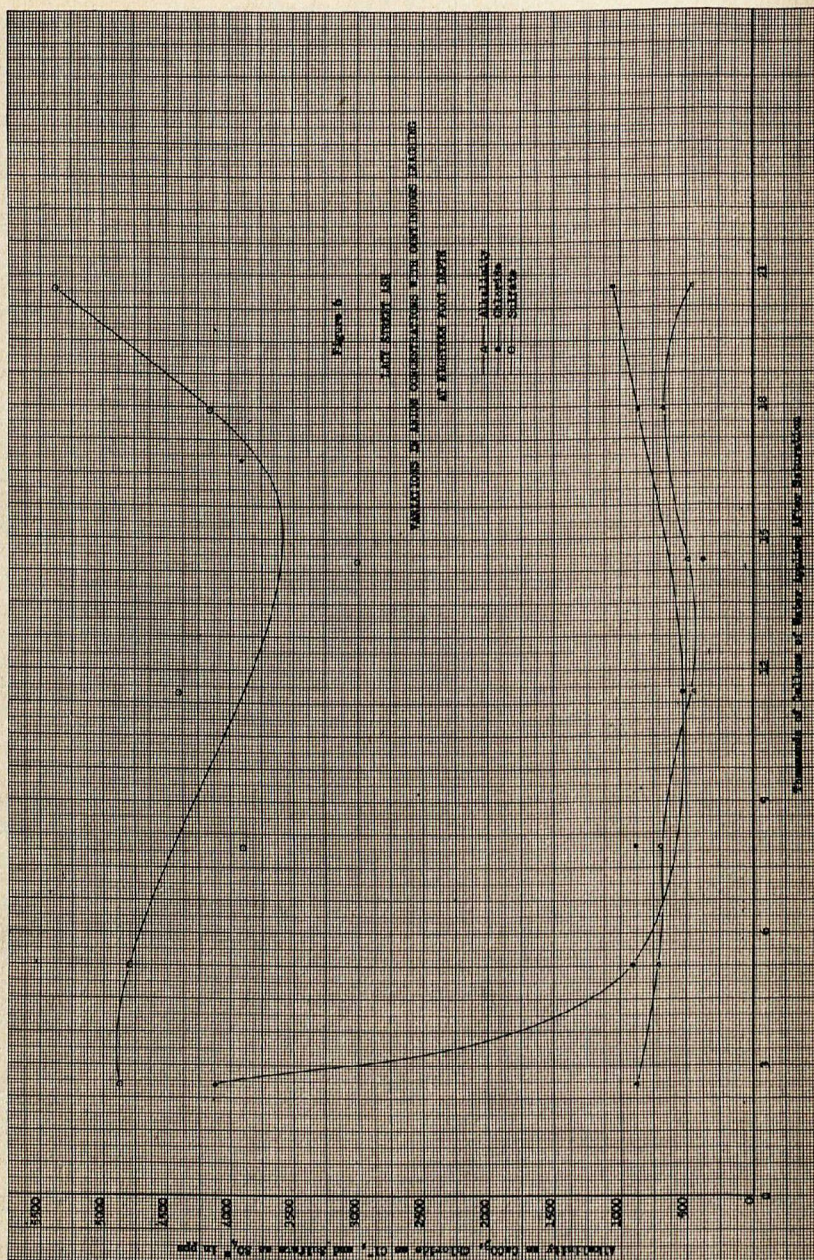
FIGURE B
Volume eluted

By positioning Figure 4 so that it forms a continuation of Figure 6 (the 18-foot anion curves followed by the 12-foot anion curves) it will be observed that the curves match closely and give what is believed to be a close approximation of what the curve for the 18-foot level would have looked like if more water had been applied. This shows the wave or band front just starting to appear at the 18-foot level, and suggests that channeling was taking place within the ash deposit.









CHAPTER III

THE LABORATORY LEACH COLUMN STUDY

The Lacy Street field investigation proved to be a greater technical problem than was anticipated in the beginning. Except for information obtained from three test holes, little was known of the conditions that existed below the ash surface. One especially troublesome development was the formation of fissures that permitted channeling of the percolating water. The ash deposit was found to be heterogeneous in nature and, as expected, had a varying density and porosity.

To eliminate as many of the variables as possible, and thus obtain necessary basic information for a complete understanding of the problem, it was decided to augment the field study with a laboratory study. The Beverly Hills incinerator ash dump, situated on Colorado at 26th Street in Santa Monica, was selected as representative of the quenched incinerator ash type of dump. Other factors leading to its selection were its accessibility to the laboratory and a water connection located immediately adjacent to the proposed test site. Plans were made to run a pilot plant study parallel to a field study, so that a direct comparison could be made between field and laboratory data. However, circumstances prevented the installation of a field sample collection system. The laboratory leach column had been packed and made ready when it became impossible to install a leach well in the field. Hence, only the laboratory study was made using Beverly Hills ash.

Description of Leach Columns

A total of three laboratory leach columns were constructed. Each consisted of three sections of five-inch O.D. acrylic plastic tubing joined together by means of "Ceramicweld" mechanical compression joints to provide a total length of 13 feet. The bottoms of the columns were sealed with plastic plates, six inches square, in which were drilled one-inch diameter holes. To provide an outlet for the leach, a 1½-inch O.D. by three-inch long plastic tube was cemented to the plate and connected to the sampling apparatus. The sampling apparatus consisted of two glass bottles. The larger bottle had a volume 10 times as great as the smaller one, and the two were interconnected so that the small sample collected for pH determination was the result of a tenfold volume displacement. The small sample was considered truly representative of the leach within the column. The laboratory leach columns were wrapped with heavy light-proof paper to discourage algal growths. Plastic covers were also provided to reduce evaporative losses at the surface. The leach column is diagrammed on Figure 7, and the complete laboratory installation is shown in Photographs 3 and 4.

Selection and Preparation of Ash

A variety of near-surface samples were selected from the Beverly Hills ash dump, ranging from one day to two years in age. The samples were picked free of large pieces of clinker, glass, metal, and other foreign materials which were considered detrimental to satisfactory operation

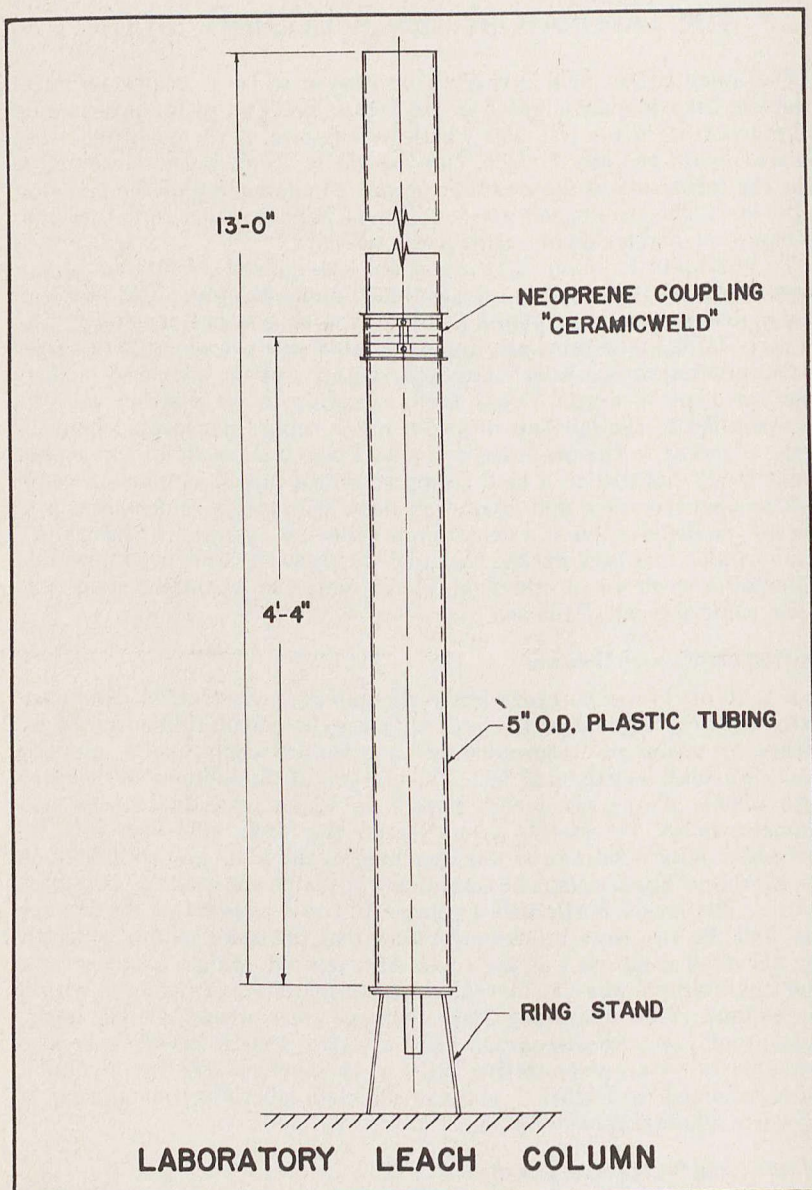
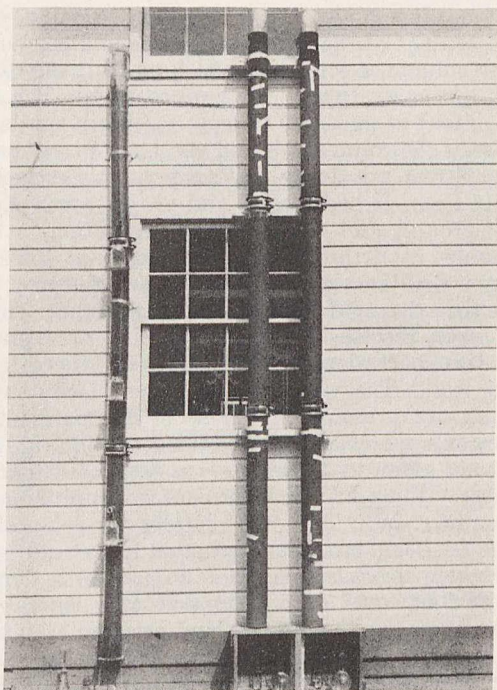


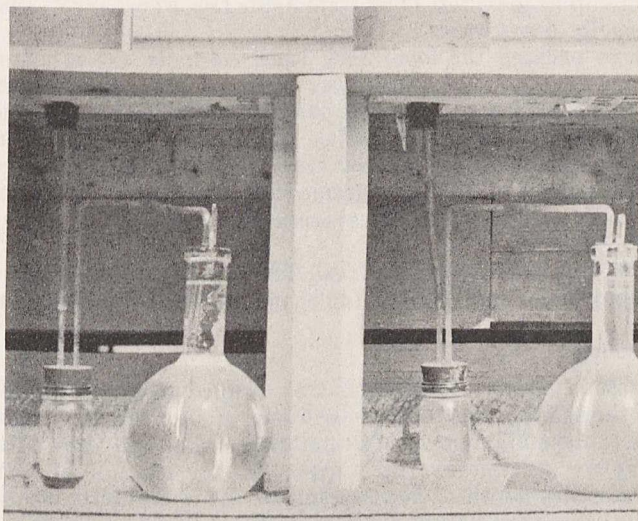
FIGURE 7

INVESTIGATION OF LEACHING OF ASH DUMPS



PHOTOGRAPH 3

General view of ash columns erected for laboratory study



PHOTOGRAPH 4

View of sampling apparatus used with laboratory ash columns

of the leach column. It was also found necessary to reduce the 25-percent initial moisture content of the ash in order to avoid condensation on the side of the leach column, a condition which made it impossible to determine the depth of penetration of the applied water. The ash was dried to a moisture content of about 10 percent to obtain similarity in initial conditions between the column ash and the Lacy Street ash.

The Marengo Street ash dump in Pasadena was estimated to be upwards of 60 feet deep. It had a sand and gravel cover of five feet, was located on high ground, and was devoid of vegetation. A representative sample was obtained by drilling a test hole vertically downward through the bed. A rotary drilling rig was used for this purpose, and a sample was taken from the excavated ash at each foot of depth. The temperature of each sample was recorded, and the samples were placed in sealed containers for transportation to the laboratory where moisture determinations were made. The variations in moisture content and temperature with depth are presented in Table 9. Estimates of the amounts of unburned organic material were obtained through ignition tests, the data for which are given in Table 10. It is estimated that the ash from the Marengo Street dump had been in place for approximately 12 years.

In similar manner, individual ash samples for compositing were obtained from the La Loma ash dump, situated below and north of the La Loma Street Bridge in Pasadena. This dump had a depth of only 10 feet, with a two-foot cover of dirt topped with thick grass, but was selected because of its location on low land between a high bank and the flood control channel. The ash was thus subject to receiving runoff from the bank in addition to direct precipitation. Samples were taken at each foot of depth and the data obtained from them also appear in Tables 9 and 10. It is estimated that the ash from the La Loma Street dump had been in place approximately five years.

It is to be noted that these test holes were drilled on February 4, 1952, following unusually heavy rains.

Preparatory to packing the laboratory leach columns, the ash from both the Marengo and La Loma dumps was air-dried to 6.1 and 10.8 percent, respectively. The ashes were then passed through a one-half-inch mesh screen to remove all foreign materials which might otherwise cause channeling in the columns. The ash was then packed in the laboratory leach columns to a depth of 12 feet, extreme care being taken to obtain a compaction as close as possible to the average initial density of the ash deposit in the dumps.

Samples of the ash were also oven-dried. The dry ash was determined to weigh 69.6 pounds per cubic foot and to have a void ratio of 57 percent.

Method of Operation

In the interest of conserving time, it was decided to apply distilled water daily to the ash columns in three-inch increments (781 ml.) rather than to adhere to the maximum rainfall pattern used on the Lacy Street test plot. Complete information with regard to the amount of water applied, the resulting depth of penetration of the water into the ash, and the volume of leach collected appears in Tables 7, 11, and 13.

As indicated in the tables, the application of three-inch increments of water was continued, following saturation of the columns, and the resulting samples were collected for laboratory analysis. The analytical

data for the three ash columns are reported in Tables 8, 12, and 14. The data are graphically presented in Figures 9 to 16, inclusive.

Leaching of the ash in the columns was continued until there was but a slight decrease in the concentrations of the ions. This is indicated by a leveling-off of the reduction curves, Figures 9, 12, 14, and 15, at which time further leaching was considered to be of little value.

The analytical work on these samples was performed in the manner described under Chapter I.

TABLE 7
APPLIED WATER DATA FOR BEVERLY HILLS ASH

Date	Amount applied in ml.	Depth of penetration in inches	Sample collected		Total volume of water applied up to taking of sample, in ml.
			Volume in ml.	Number	
12-17-51	781	21.0			
18	781	31.5			
19	781	36.0			
20	781	52.0			
21	781	67.0			
22	781	84.0			
23	781	89.0			
24	781	94.0			
25	781	119.0			
26	781				
27	781				
28	781	Sat.	50		
30	781		1,000	1	9,372
31			1,000	2	10,153
1- 1-52					
2	781				
3	781				
4	781		800	3	11,715
5	781		800	4	12,496
6					
7	781				
8			800	5	14,058
9	781				
10	781		800	6	14,839
11	781				
12					
13			800	7	16,401
14					
15	781				
16	781		800	8	17,182
17					
18	781		800	9	17,963
19					
20					
21					
22			800	10	18,744
23	781		800	11	18,744
24	781				
25	781				
26			800	12	21,087
27					
28	781		800	13	21,087
29	781				
30	781		575	14	22,649
31					
2- 1-52			575	15	23,430
4			575	16	23,430
6			575	17	23,430
7			575	18	23,430

Discussion of Results

From Table 7, it is seen that 33 inches of applied water was required to obtain saturation of the Beverly Hills column. From Tables 11 and 13, the requirements for the La Loma and Marengo columns are shown to be 39 and 36 inches, respectively. These quantities are approximately 25 percent of the void volume of the ash.

Figure 8 is a plotting of depth of penetration of the applied water versus time for each of the columns. The slopes of the lines represent the rate of movement of the percolating water through the ash. For the Beverly Hills column, this rate is computed to be 0.48 inch per hour; for the Marengo column 0.45 inch per hour; and for the La Loma column 0.43 inch per hour. These values are in rather close agreement and average 0.44 inch per hour. However, they are simply the result of visual observations of the leach columns and make no allowance for what may have been taking place within the interior of the column. They were also determined by uniform additions of water to the columns, far in excess of natural precipitation rates. Therefore, the investigation discussed in Chapter IV was undertaken.

On Figures 9 and 10 have been graphed the analytical data for the Beverly Hills ash. These curves illustrate the leaching effect of the water on the ash, as evidenced by the decrease in ion concentrations with continued applications of water. Similarly, Figures 11 and 12, 14, and 15 have been prepared to present similar pictures with respect to the La Loma and Marengo ashes.

It is of interest to note that all the Beverly Hills curves except the sulfate and bicarbonate ions showed an increase in concentration before the gradual decrease began to take place. This is very probably due to the variable amounts of soluble salts at any level and the rate at which they will go into solution. As has been pointed out, the ash used to pack the Beverly Hills leach column consisted of near-surface samples from several locations in the dump. Being of different ages, they very likely differed widely in their original mineral composition and produced varying concentrations of salt at the various levels within the column. Since the concentration of salt at any level in the leach is directly proportional to the product of the mass of salt at any level in the column times a constant for the rate at which the mass of salt will go into solution, it follows that the ion concentrations in the leach would build up until the rates throughout the deposit became constant, or reached equilibrium. This was not the case in the other leach columns due, no doubt, to the securing of an "in place" column already in equilibrium.

In general, the cation reduction curves are seen to level off as they approach comparatively low concentrations, particularly in the case of sodium and potassium. The fact that the calcium ion is held up to a greater extent than any of the other cations is traceable to the exchange properties of the ash (see Chapter V). As further substantiation of this statement, the sodium and potassium ions are seen to be leached out much faster and in greater quantity.

The anion curves, except for the Marengo ash, do not exhibit similar behavior. The chloride ion has been promptly and effectively leached out, as was to be expected since all hypothetical combinations present of the sodium and potassium are highly soluble, but the alkalinity remains at high level. This, too, is to be expected since the alkalinity is dependent

TABLE 8
ANALYSES OF LEACH SAMPLES FROM BEVERLY HILLS ASH COLUMN

Sample number	1	2	3	4	5	6	7	8	9
pH.....	7.85	7.95	7.70	7.80	7.80	7.75	7.80	8.00	8.05
Total dissolved solids.....	33,540	38,960	42,060	41,060	40,840	37,660	33,780	28,920	26,340
Calcium.....	925	975	870	1,025	895	1,045	790	510	275
Magnesium.....	1,075	1,270	1,295	1,205	1,135	7,500	925	775	735
Sodium.....	6,760	7,180	8,150	7,500	7,750	7,500	7,000	6,160	5,515
Potassium.....	3,650	4,160	4,550	4,320	4,260	3,900	4,050	3,650	3,650
Total hardness as CaCO ₃	6,740	7,680	7,500	7,540	6,900	6,500	5,780	4,450	3,750
Alkalinity as CaCO ₃	2,210	2,450	2,070	2,750	2,460	2,670	2,850	2,370	1,950
Chloride as Cl ⁻	9,200	12,350	13,600	13,200	12,300	11,500	10,000	7,240	5,960
Sulfates as SO ₄ =	11,100	8,130	9,220	7,470	8,800	8,380	8,940	9,240	9,450
Phosphates as PO ₄ =	5.8	4.2	1.3	2.5	2.1	0.75	3.3	2.8	3.8
Total iron.....	00	00	00	00	00	00	00	00	00
SiO ₂	34	40	18	20	24	26	26	34	34
Total CO ₂ (Calc.).....	1,015	1,110	960	1,250	1,130	1,235	1,300	1,075	880
Total Org. N.....	0.94	0.85	2.3	1.9	2.2	1.4	1.3	3.4	6.4
NH ₃ -N.....	4.3	4.8	4.0	3.4	2.2	3.1	3.3	4.0	4.4
NO ₃ -N.....	0.24	0.32	2.6	2.4	2.6	1.8	0.70	0.50	0.60
NO ₂ -N.....	50	60	54	64	64	54	48	38	52

Results in ppm

TR = Trace NR = No Result

(Table 8 continued on page 44)

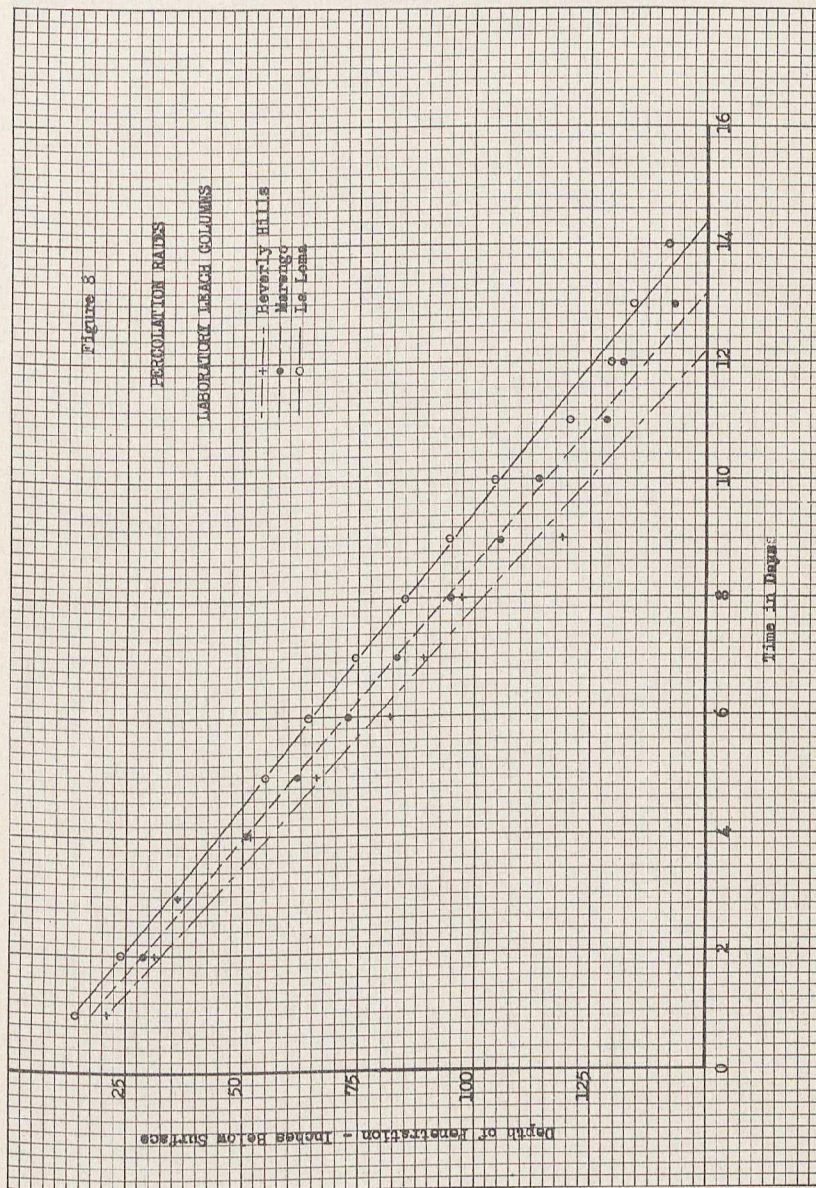
INVESTIGATION OF LEACHING OF ASH DUMPS

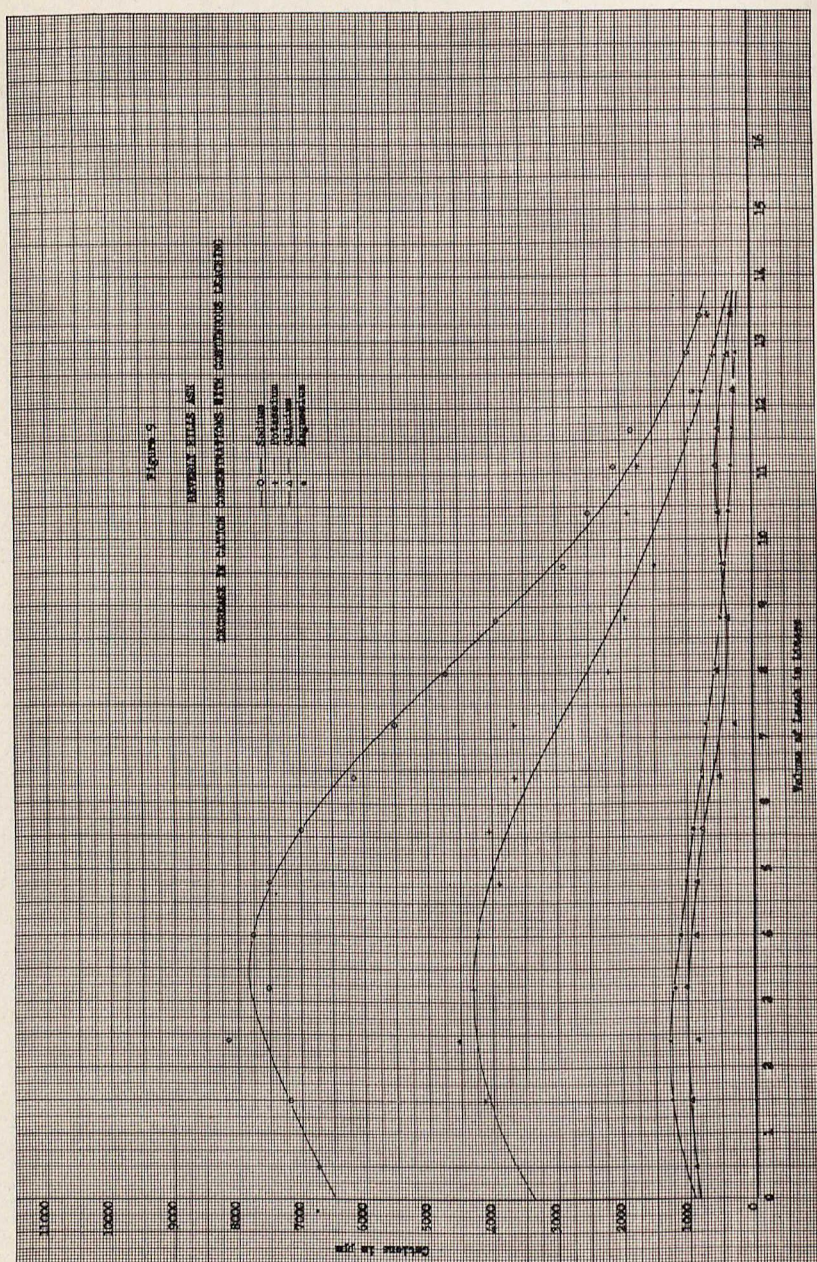
TABLE 8—Continued
ANALYSES OF LEACH SAMPLES FROM BEVERLY HILLS ASH COLUMN

Sample number	10	11	12	13	14	15	16	17	18
pH	8.10	8.10	8.10	8.00	7.60	7.50	7.95	7.85	7.80
Total dissolved solids	21,100	18,780	15,420	12,420	11,050	9,580	7,360	6,480	6,150
Calcium	565	380	465	505	550	485	260	350	290
Magnesium	590	310	450	360	320	300	265	220	275
Sodium	4,710	3,910	2,880	2,595	2,110	1,820	875	950	790
Potassium	2,200	1,850	1,500	2,400	2,250	1,450	750	570	655
Total hardness as CaCO ₃	3,840	3,040	3,020	2,740	2,700	2,440	1,770	1,790	1,860
Alkalinity as CaCO ₃	2,690	2,230	2,400	2,330	2,390	2,260	1,470	1,620	1,640
Chloride as Cl ₋	4,400	2,965	1,890	1,010	650	450	340	280	260
Sulfates as SO ₄	7,520	7,480	6,700	7,200	6,500	5,090	2,540	2,450	2,220
Phosphates as PO ₄	2.8	4.0	3.8	2.5	3.5	1.5	TR	TR	TR
Total iron	00	00	00	00	00	00	00	00	00
SiO ₂	43	34	36	47	50	47	43	43	40
Total CO ₂ (Calc.)	1,215	1,025	1,080	1,060	1,140	1,120	670	775	765
Total Org. N	5.5	4.4	5.1	0.44	4.9	3.7	3.2	3.1	3.8
NH ₄ -N	2.7	2.0	3.9	1.6	1.5	0.93	2.0	2.0	0.68
NO ₃ -N	0.65	0.45	0.12	0.16	0.16	0.02	TR	TR	TR
NO ₂ -N	38	26	10	6.0	1.0	9.0	4.3	4.3	3.3

TR = Trace NR = No Result

Results in ppm





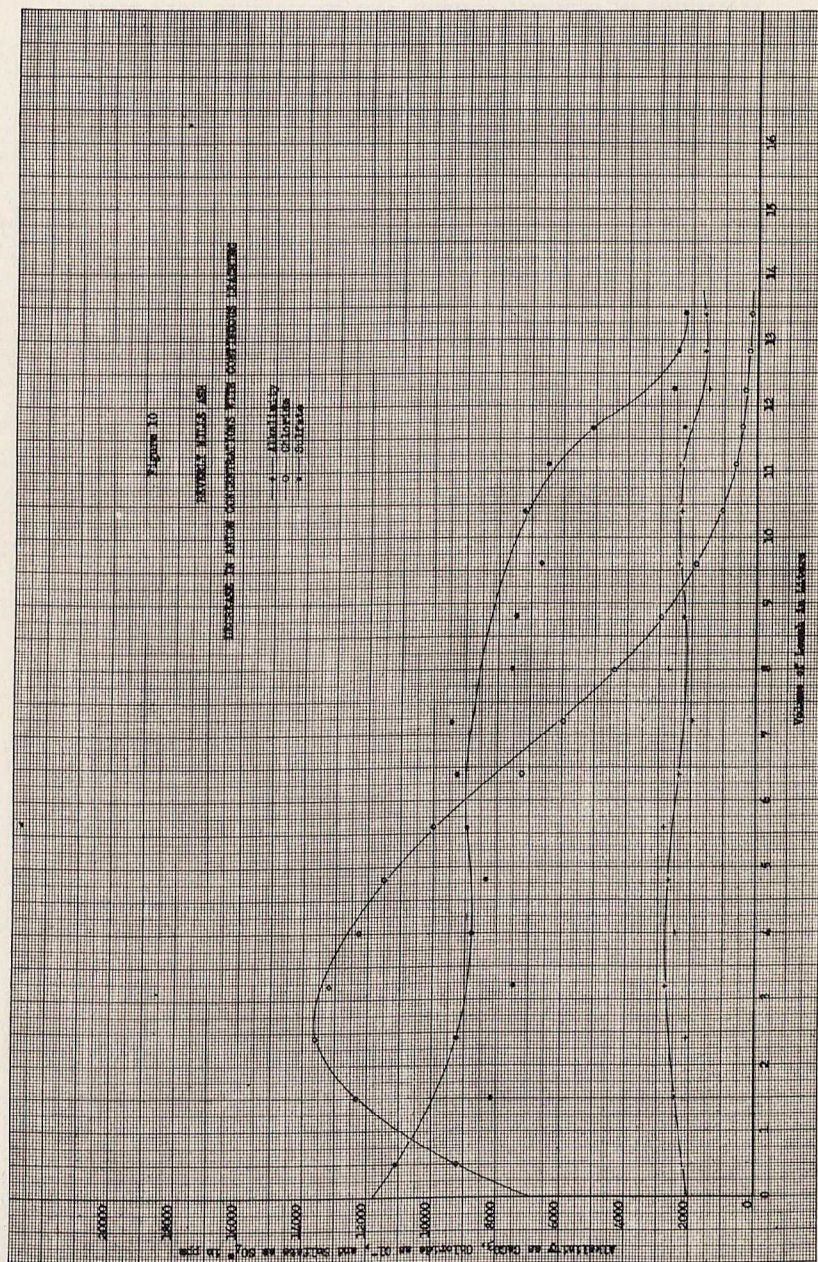
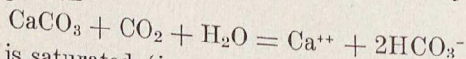


TABLE 9
VARIATIONS IN MOISTURE CONTENT AND TEMPERATURE WITH DEPTH

Marengo ash (5-foot sand and gravel cover)			La Loma ash (2-foot dirt cover)		
Depth in feet	Percent moisture	Temp. Deg. C	Depth in feet	Percent moisture	Temp. Deg. C
6	22.5		2	25.1	15
7	31.9	19	3	24.9	12
8	25.5	20	4	32.0	13
9	22.1		5	23.2	12
10	21.6	23	6	24.4	15
11	21.6	24	7	17.5	15
12	22.7	29	8	22.7	16
13	20.3	31	9	27.2	16
14	17.0	31	10	40.4	
15	19.6	35.5	11	Bottom of ash	
16	25.2	39			
17	20.5	38			
18	19.9	39			
19	19.2	40			
20	18.4	42.5			
21	15.3	42			
22	15.0	42			
23	16.6	42			
24	18.5	44			
25	18.7	43			
26	17.3	42			
27	16.6	42			
28	17.8	42.5			
29	18.7	41			
30	Bottom of ash				

to a large extent on production of carbon dioxide, by aerobic or anaerobic decomposition of organic matter, which, in turn, places carbonates in solution as the bicarbonates. And there must be such decomposition taking place if the alkalinity concentrations are to reach the high values found.

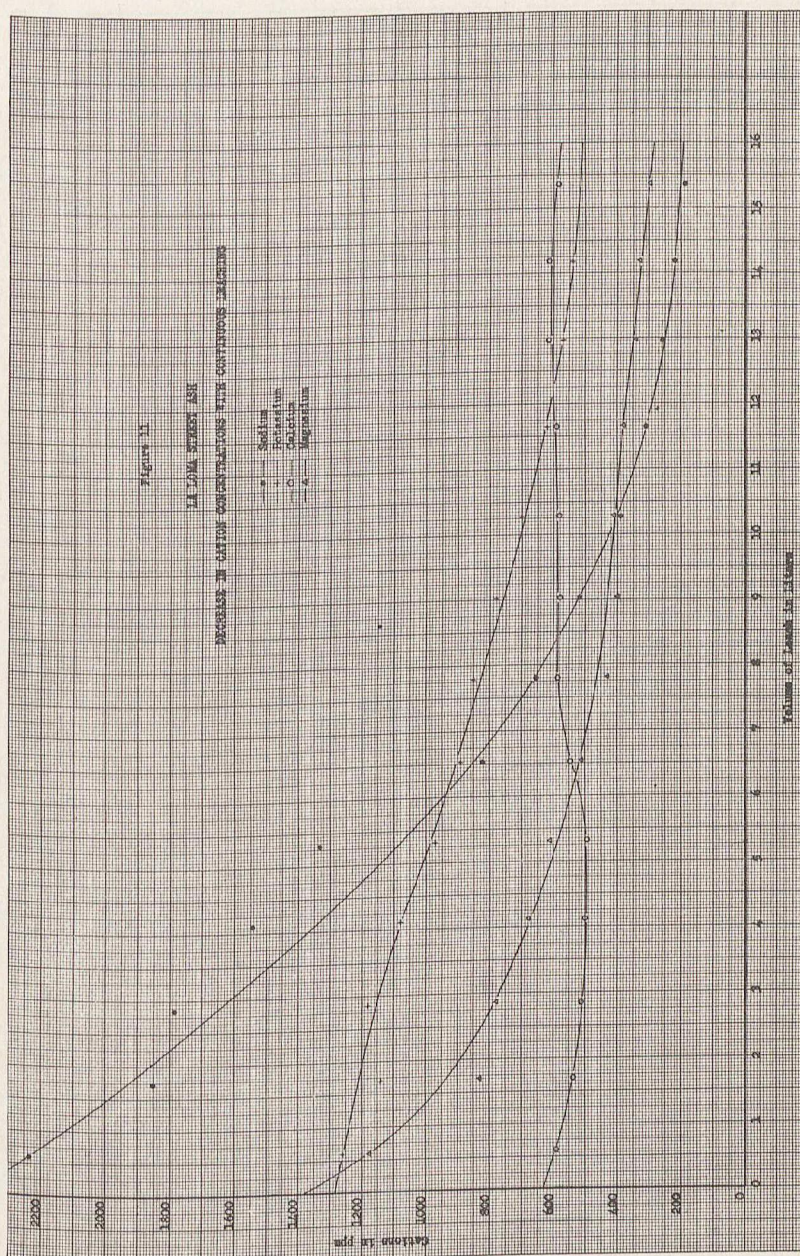
The dissolution of the lime, which is present in the ash, by the carbon dioxide released by the aforementioned decomposition may be represented by the simple equation

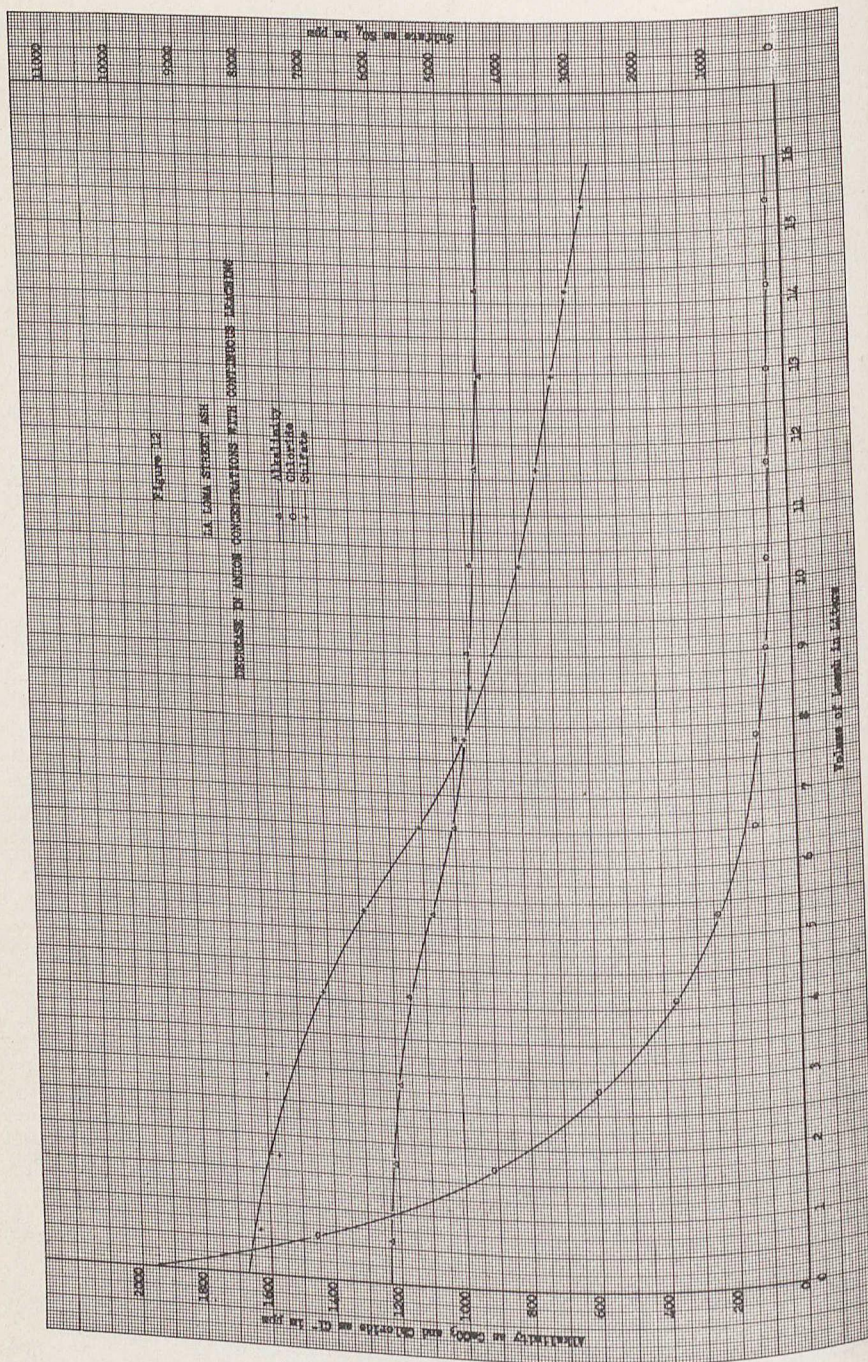


When water is saturated (in equilibrium) with solid CaCO_3 , mathematical relationships exist between the concentrations of the reactants according to the well-established laws of mass action. The interrelations of Ca^{++} , HCO_3^- , and pH are expressed in nomographs which are widely used for calculating Langelier "saturation indices," measuring the extent of oversaturation or undersaturation of a water with lime. For the purposes of this study, it is convenient to set up the relationship between Ca^{++} , HCO_3^- and CO_2 on the basis of the above equation as follows:

$$\frac{[\text{Ca}^{++}] [\text{HCO}_3^-]^2}{[\text{CO}_2]} = C$$

The quantity C varies slightly with temperature and is greatly influenced by the presence of other dissolved mineral matter. The ions of other mineral matter reduce the effective concentrations or activities of the ions participating in the equilibrium. Thus, the actual concentrations, in





order to attain equilibrium, must be greater than in the absence of other salts. In other words, the solubility is increased by the presence of the other salts.

For example, a water at 20 degrees C. containing one ppm. of CO_2 , in equilibrium with lime, will hold in solution 75 ppm. of calcium bicarbonate, expressed as CaCO_3 , if no other salts are present. The value of C in the above equation, with concentrations expressed as ppm. and the bicarbonate expressed as CaCO_3 , is 1.7×10^5 . If the water contains other salts sufficient to raise the total mineral content to 800 ppm., the amount of lime in solution will be about 97.5 ppm., and the value of C in the above equation will be about 3.7×10^5 . This value is for an average mixture of salts occurring in natural waters. If the ions are mostly monovalent, the effect is smaller; if they are divalent, the effect is considerably greater.

At mineral concentrations higher than 800 ppm., such as exist in the leach waters examined, the solubility cannot be calculated with any assurance, but it is known that it will continue to increase with higher mineralization.

The high mineralization of the leach water, particularly the high sulfate concentration, allows quite large amounts of lime to be dissolved with only moderate concentrations of unreacted carbon dioxide remaining to maintain the equilibrium. Thus, in the early stage of the leaching of the Marengo ash, the quantity C had a value of 2.7×10^7 . At the termination of the test, the decline of concentration of other mineral matter permitted less lime to dissolve, with the quantity C dropping to 9.0×10^6 .

It is evident from this discussion that the rate of dissolution of lime from the ash is determined primarily by the rate of formation of carbon dioxide, but with the solubility of the lime being materially increased by the simultaneous dissolution of the other salts.

On Figures 13 and 16 is shown the relationship of total carbon dioxide to hardness for the La Loma and Marengo ashes, respectively. The values plotted for total carbon dioxide represent the addition of the half-bound carbon dioxide computed from the alkalinity, and the free carbon dioxide computed as outlined in Appendix A. The manner in which the alkalinity (carbonate hardness) is held up by production of carbon dioxide is again plainly shown. The rapid reduction of noncarbonate hardness—principally magnesium sulfate—is indicated by the steep slope of the total hardness curve compared with the slight slope of the carbonate hardness curve. Reference to the cation reduction curves will disclose a corresponding decrease in the magnesium ion over the same volume of leach. Reference to the anion reduction curves will show a corresponding decrease in the sulfate ion.

The high concentration of sulfate in the leach column, and its retarded rate of leaching in comparison with chloride, points to the presence of calcium sulfate as a solid base. The solubility of calcium sulfate in pure solution at 20 degrees C. is 2,100 ppm. and the solubility product, $(\text{Ca}^{++})(\text{SO}_4^{--})$ is 2.37×10^{-4} , with concentrations expressed in ppm. Again using the Marengo ash figures, the ion concentration product at the beginning of the test was 2.29×10^{-3} . The fact that this was so much higher than the solubility product does not mean that the water was supersaturated with calcium sulfate, but merely illustrates the increase

INVESTIGATION OF LEACHING OF ASH DUMPS

TABLE 10
LOSS ON IGNITION

Marengo ash		La Loma ash	
Depth in feet	Percent loss	Depth in feet	Percent loss
6.....	9.83	4.....	10.1
12.....	8.53	8.....	12.5
18.....	8.19		
24.....	7.54		

TABLE 11
APPLIED WATER DATA FOR LA LOMA ASH

Date	Amount applied in ml.	Depth of penetration	Sample collected		Total volume of water applied up to taking of sample, in ml.
			Volume in ml.	Number	
2-27-52.....	880				
28.....	880	14			
29.....	880	24			
3- 1-52.....	781				
2.....					
3.....	880	55			
4.....	781	64			
5.....	880	74			
6.....	880	85			
7.....	880	94			
8.....	781	104			
9.....	880	122			
10.....	781	130			
11.....	781	138			
12.....	781	144			
13.....	781		few ml.		
14.....	781				
15.....			1,200	LL- 1	12,507
16.....	781				
17.....	781				
18.....	781				
19.....	781				
20.....	781		1,020	LL- 2	15,631
21.....	781		1,250	LL- 3	16,412
22.....	781				
23.....	781		1,260	LL- 4	17,974
24.....	781				
25.....	781		1,150	LL- 5	19,536
26.....	781				
27.....	781		1,300	LL- 6	21,098
28.....	781				
29.....	781		1,250	LL- 7	22,660
30.....	781		1,180	LL- 8	23,441
31.....	781				
4- 1-52.....	781		1,350	LL- 9	25,003
2.....	781				
3.....	781				
4.....	781		1,380	LL-10	27,346
5.....	781		1,240	LL-11	28,127
6.....					
7.....			1,200	LL-12	29,689
8.....			1,200	LL-13	29,689

TABLE 12
ANALYSES OF LEACH SAMPLES FROM LA LOMA ASH COLUMN

Sample number	LL-1	LL-2	LL-3	LL-4	LL-5	LL-6	LL-7	LL-8	LL-9	LL-10	LL-11	LL-12	LL-13
pH.....	7.38	7.70	7.70	7.70	7.30	7.30	7.30	7.30	7.30	7.40	7.80	7.50	7.50
Total dissolved solids.....	13,350	13,700	13,700	12,450	11,150	10,780	10,830	8,740	8,340	7,010	6,790	6,410	6,000
Calcium.....	590	510	510	500	495	545	585	580	580	590	615	615	585
Magnesium.....	1,175	830	780	680	610	510	430	400	410	380	340	330	295
Sodium.....	2,235	1,850	1,782	1,545	1,335	820	660	520	390	310	290	220	185
Potassium.....	1,260	1,140	1,180	1,080	970	890	850	780	700	620	570	540	NR
Total hardness as CaCO ₃	5,420	4,750	4,475	4,060	3,730	3,470	3,220	3,090	3,140	3,040	2,940	2,890	2,680
Alkalinity as CaCO ₃	1,230	1,210	1,185	1,150	1,075	1,000	990	950	940	915	895	900	895
Chloride as Cl ⁻	1,455	915	595	365	235	110	106	78	64	57	50	42	42
Sulfates as SO ₄ ====	8,160	7,850	7,980	7,070	6,430	5,530	4,820	4,400	3,950	2,680	3,400	3,190	2,800
Phosphate as PO ₄ ====	TR	0.88	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR
Total iron.....	00	00	00	00	00	00	00	00	00	00	00	00	00
SiO ₂	12	21	27	28	30	31	31	34	35	37	35	35	36
Total CO ₂ (Calc.).....	615	565	555	540	560	515	510	490	485	460	415	440	440
Total Org. N.....	10	6.0	4.3	3.8	4.0	4.3	3.5	3.7	3.6	2.4	2.5	2.3	1.8
NH ₄ -N.....	0.43	1.8	2.2	1.1	2.5	3.0	2.5	2.5	2.0	1.6	1.4	0.55	0.51
NO ₃ -N.....	0.26	0.12	TR	TR	TR	00	00	00	00	00	00	00	00
NO ₂ -N.....	20	10	3.5	2.5	4.3	00	00	00	00	00	00	00	00

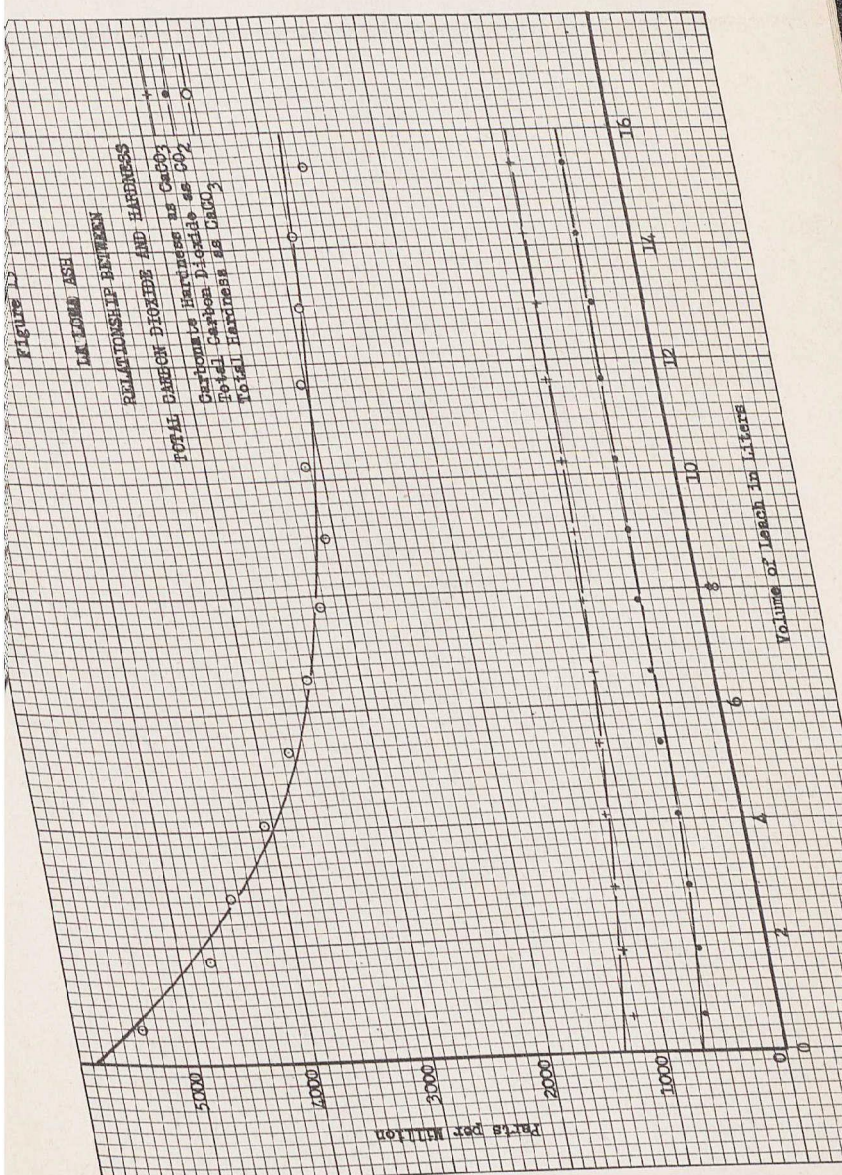
Results in ppm

TR = Trace NR = No Result

Depth of penetration in inches	Sample collected		Total volume of water applied up to taking of sample, in ml.	
	Volume in ml.	Number		
13				
28				
64				
73				
83				
95				
106				
113				
128				
134				
143	few ml.			
781		1,200	M- 1	
781		1,030	M- 2	12,507
781				13,288
781		1,250	M- 3	
781				14,850
781		1,260	M- 4	
781		1,000	M- 5	16,412
781		1,050	M- 6	17,193
781				17,974
781		1,150	M- 7	
781				19,536
781		1,300	M- 8	
781				21,098
781		1,200	M- 9	
781		1,160	M-10	22,660
781				23,441
781		1,380	M-11	
781				25,003
781				
781		1,420	M-12	
781		1,270	M-13	27,346
781				28,127
		1,260	M-14	
				29,689

due to the presence of other salts, just as in the case of lime. Simultaneous presence of lime and calcium sulfate permits the reaction product of each to be higher than it would be if alone.

Gradual elimination of sulfate will allow the solubility of calcium to decline until it reaches a level which is only moderately affected by other salts. Lime will continue to dissolve at rates comparable with carbon dioxide production. In this respect, the ash bed will behave in the same manner as any other soil containing lime and organic matter.



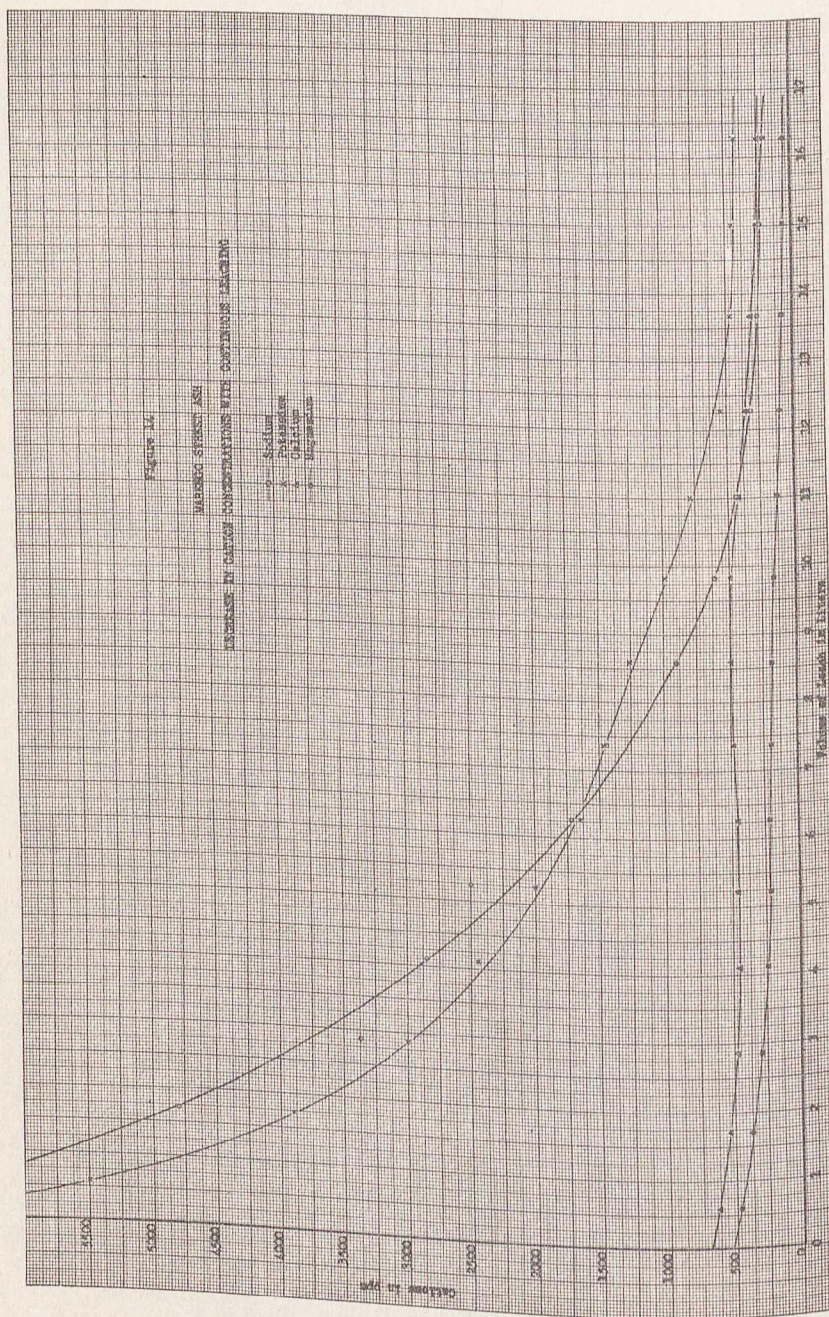
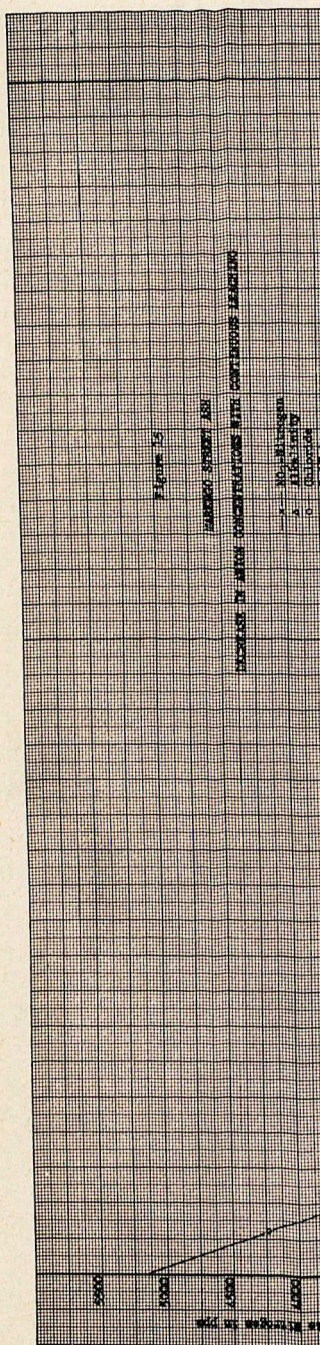
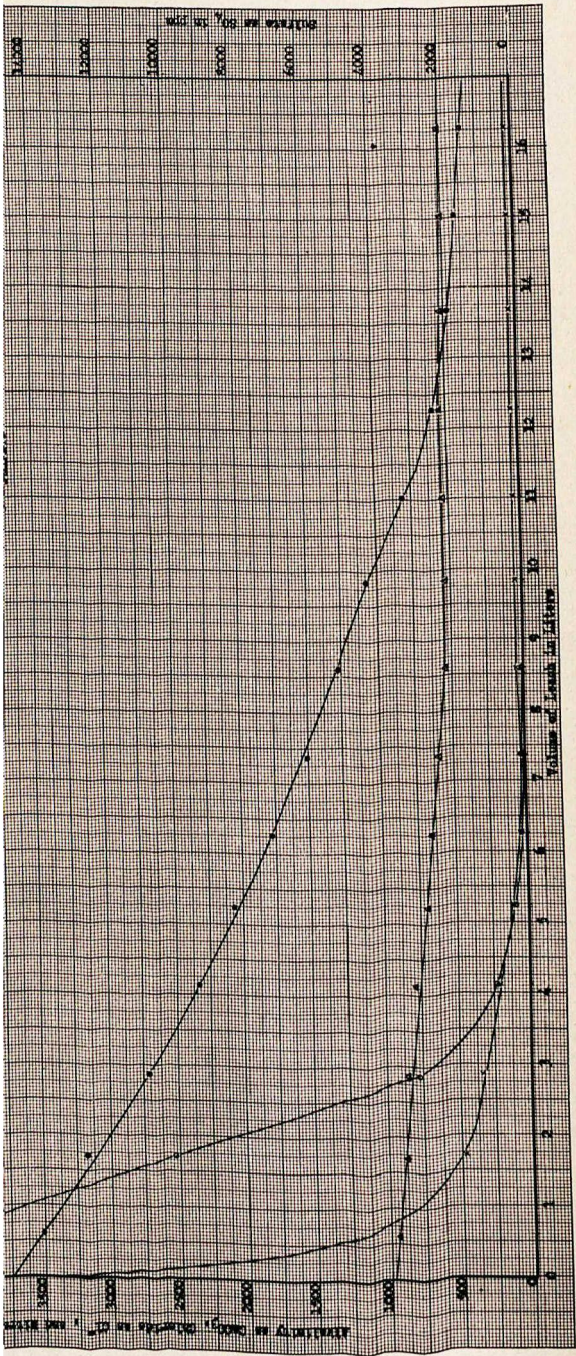


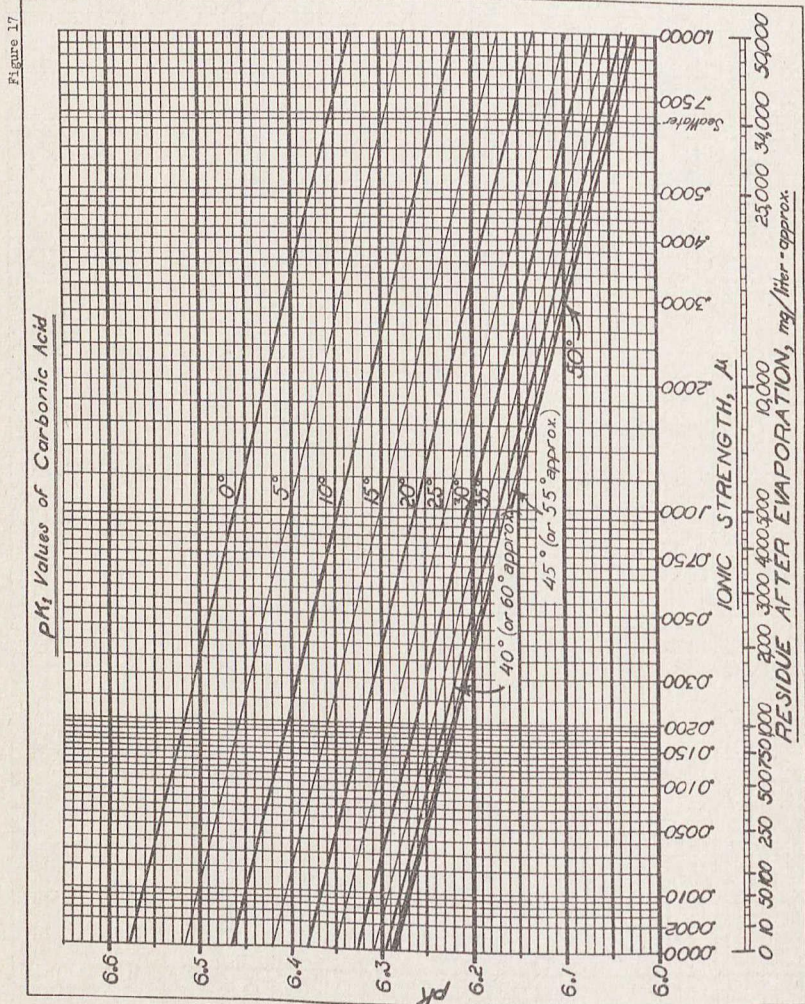
TABLE 14
ANALYSES OF LEACH SAMPLES FROM MARENGO ASH COLUMN

Sample number	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	M-9	M-10	M-11	M-12	M-13	M-14
pH	7.75	7.95	8.00	7.90	7.85	7.90	8.00	7.85	7.75	8.00	8.00	8.00	8.00	8.10
Total dissolved solids	33,460	23,580	22,240	16,980	13,980	10,890	10,140	9,380	7,970	6,070	4,640	3,750	3,230	2,890
Calcium	630	540	475	460	465	450	480	490	490	425	350	310	255	240
Magnesium	470	375	290	245	220	215	190	180	165	130	100	72	59	49
Sodium	6,360	4,800	3,370	2,850	2,500	1,715	1,440	900	610	435	315	260	230	195
Potassium	5,500	3,900	3,000	2,450	2,000	1,650	1,450	1,260	990	780	550	470	450	420
Total hardness as CaCO ₃	3,510	2,890	2,390	2,155	2,080	2,015	1,985	1,960	1,905	1,600	1,300	1,065	880	805
Alkalinity as CaCO ₃	640	875	850	790	700	660	590	540	535	535	535	525	500	515
Chloride as Cl ⁻	4,925	2,535	775	230	80	30	25	2.0	2.0	1.0	1.0	1.0	00	00
Sulfates as SO ₄ =	14,050	12,700	10,840	9,360	8,270	7,165	6,060	5,100	4,300	3,230	2,330	1,935	1,650	1,400
Phosphate as PO ₄ =	1.5	1.0	1.0	1.1	0.81	0.88	0.56	TR	TR	TR	TR	TR	TR	TR
Total iron	00	00	00	00	00	00	00	00	00	00	00	00	00	00
SiO ₂	20	20	18	30	30	34	34	46	46	48	40	43	48	46
Total CO ₂ (Calc.)	435	400	385	360	320	300	270	250	250	245	245	240	230	235
Total Org. N	5.6	11.6	8.7	6.5	4.4	3.4	3.0	6.7	5.3	5.6	5.2	1.3	1.8	0.75
NH ₄ -N	0.74	0.23	0.68	0.59	0.54	0.90	1.3	TR	TR	TR	TR	TR	TR	TR
NO ₂ -N	1.12	6.7	5.6	4.0	3.6	2.6	0.6	TR	TR	TR	TR	TR	TR	TR
NO ₃ -N	1,230	475	340	210	90	30	5.0	44	35	35	35	38	38	38

TR = Trace
Results in ppm







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CHAPTER IV

THE LABORATORY PERCOLATION STUDY

The following study was made in the laboratory for comparison with the field study on rainfall penetration presented in Chapter II. As was described therein, many variables exist in the field such as the heterogeneity of the ash, the varying densities and porosities of the ash, fissures in the ash leading to short-circuiting of the flow, and climatic conditions. Further, there is no practical means of controlling these variables if the test is to be performed on the ash in place. Therefore, to gain such control, a percolation study was made in the laboratory, caution being taken to (1) use a uniform ash, (2) eliminate channeling, and (3) obtain a uniform density. To obtain these conditions, several representative samples from the Lacy Street dump were air-dried to a moisture content of about 6 percent. The composite ash was then passed through a No. 10 U. S. sieve to remove the large particles of clinkers, glass, wood and other material that would cause short-circuiting or channeling of the percolating water. The ash was then ready for packing in the permeameter designed and built for this study.

The Permeameter

The operation of the permeameter used is based on the principle that the flow of a liquid through a medium will cause an increase in the conductance of an electrical current through the medium. Thus, by knowing the electrical resistance of the dry medium at any point and by measuring the decrease in the electrical resistance of the medium caused by the movement of the liquid past this point at any time, the rate of percolation of the liquid through the medium can be determined. In this particular study, the medium was ash, and the liquid was distilled water.

The permeameter was constructed of a six-foot length of one-inch I. D. acrylic plastic tubing. The inside of the tube was coated with paraffin and then packed with the previously prepared ash described above. The bottom of the tube was plugged with cotton to hold the dry ash in place. The tube was then gently heated until the paraffin melted. This formed a thin admixture of ash and paraffin on the inside wall of the tube. This treatment, it was believed, produced an interior tube roughness approximately the same as existed between the ash particles. A pair of diametrically opposed electrodes extending through the sides of the tube and into the ash, with a gap of three-eighths of an inch between them were spaced at six-inch intervals along the tube, beginning one-half inch below the ash surface. This arrangement is indicated schematically on Figure 19.

Instrumentation for Recording Water Movement

The apparatus used to measure and record the conductivity at each increment of depth in the ash as the water moved past the electrodes consisted of a motor-driven selector switch, a battery, dropping resistors,

and a recording voltmeter. The selector switch was built especially for this work and consisted of an 11-inch diameter bakelite disc fitted flush with 15 $1\frac{1}{4}$ - by 2-inch copper bars, called commutator bars, and 15 $\frac{1}{2}$ - by 2-inch copper bars, called identification bars, alternately spaced around its periphery.

A brush connected to the slow speed shaft of a speed reducer, in turn directly connected to an electric motor, revolved around the circle of copper bars, just as the minute hand of any clock passes over the hour numerals. The brush speed was 0.67 rph. The contact time of the brush with each commutator bar was four minutes, and with each identification bar two minutes. These readings were recorded on a recording voltmeter of the "smoke chart" type. Twenty-four-hour charts were used and were fixed permanently by passing them through a mixture of alcohol and shellac. A typical chart from the meter is shown in Figure 20.

Each pair of electrodes was connected in series with a commutator bar and a dropping resistor (i.e., the first pair of electrodes was connected to the first $1\frac{1}{4}$ -inch commutator bar, the second pair to the second $1\frac{1}{4}$ -inch commutator bar, and so on). The identification bars, connected to known resistors, served as reference and identification points for interpretation of the recorded data. The resistors altered the range of the recording voltmeter during the time the brush contacted the identification bars, the result being the recording of three different types of identification points. Through the use made of the resistors, point or bar number one (starting at the top of the disc and proceeding in a clockwise direction) indicated a larger voltage than bars 6 and 11, and these bars in turn indicated a larger voltage than bars 2, 3, 4, 5, 7, 8, 9, 10, 12, 13, 14, and 15. The effect was to produce a reference impulse pattern as shown in Figure 20. The wiring diagram for the system is shown in Figure 19. The installation is further illustrated by Photograph 5.

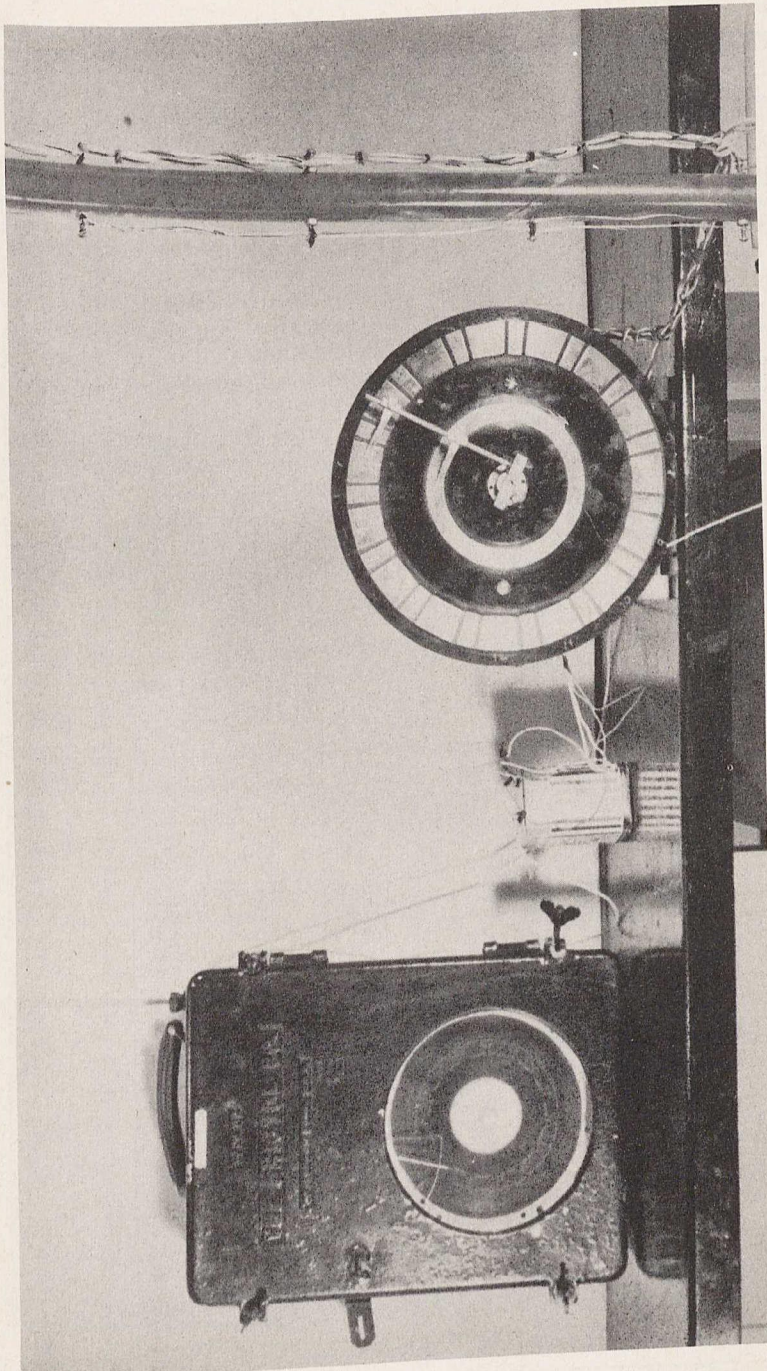
Method of Operation

The first addition of water to the permeameter was made on April 29th, and at intervals thereafter according to the manner in which spray water had been applied to the Lacy Street test plot (see Table 1). In other words, the maximum rainfall pattern was again followed. To simplify the laboratory procedure, the daily additions were made in milliliters, since the quantities could easily be measured with a graduate. The smoke charts on the recording voltmeter were changed daily at the time the water addition was made, and the movement of the water down through the ash was traced by means of interpretation of the impulse patterns on the charts.

Discussion of Results

In Table 15 the complete data are given for the applications of water, both the incremental and the cumulative amounts. The resulting depth of penetration of water into the ash is also tabulated, as is the time schedule for the entire duration of the test.

All data are graphically shown in Figure 18. The course of the water downward is indicated by the single line connecting the six-inch increment depths. The movement of the water has been correlated with the water additions, shown by the vertical bars. The solid portion of the bar



PHOTOGRAPH 5
General view of permeameter and electrical equipment used for percolation study

INVESTIGATION OF LEACH

ents the increment addition; an al volume of water added to the examination of the data in Tab did not reach a depth of five and on May 27th, 684 hours after ed to reach intermediate depths lear picture of the actual mov ed from Figure 18. The incre at lines for lack of additional da points might be connected by : slopes being dependent upon th ations. Equal applications at ed to produce a straight line sin ver, the actual rate of movement s not of paramount importance t in referring to Figure 18, it w slope when the time interval bet esely, a steeper slope when the w e and spaced closer together. rement of the velocity of the ty of the water through the ash

TABLE 1
PERCOLATION STUDY OF

te	Time	Elapsed time, hours	Incremen appli	
			Mls.	
	10:00 AM	0	10.5	
	10:00 AM	24	13.0	
	12:00 N	26		
	10:00 AM	120	11.1	
	10:00 AM	144	7.4	
	10:00 AM	192	19.2	
	10:00 AM	194		
	12:00 N	216	7.5	
	10:00 AM	216		
	10:00 AM	240	8.8	
	10:00 AM	264	4.3	
	10:00 AM	268		
	2:00 PM	312	8.3	
	10:00 AM	336	25.0	
	10:00 AM	345		
	7:00 PM	360	24.4	
	10:00 AM	369		
	7:00 PM	384	2.4	
	10:00 AM	417		
	7:00 PM	432	5.8	
	10:00 AM	528	35.8	
	10:00 AM	549		
	7:00 AM	552	9.8	
	10:00 AM	576	5.8	
	10:00 AM	585		
	7:00 PM	600	9.8	
	10:00 AM	624	16.1	
	10:00 AM	636		
	10:00 PM	684		
	10:00 PM			

d the total bar length represents indicated hour.

le 15 shows that the percolating one-half feet below the ash until the test was begun. The times are also shown.

ement of the water can best be ement depths are connected by ta. Actually, any two consecutive a series of shorter straight lines, the volume and interval of water uniform time intervals could be nilar to those shown on Figure 8. from one set of electrodes to the o this study.

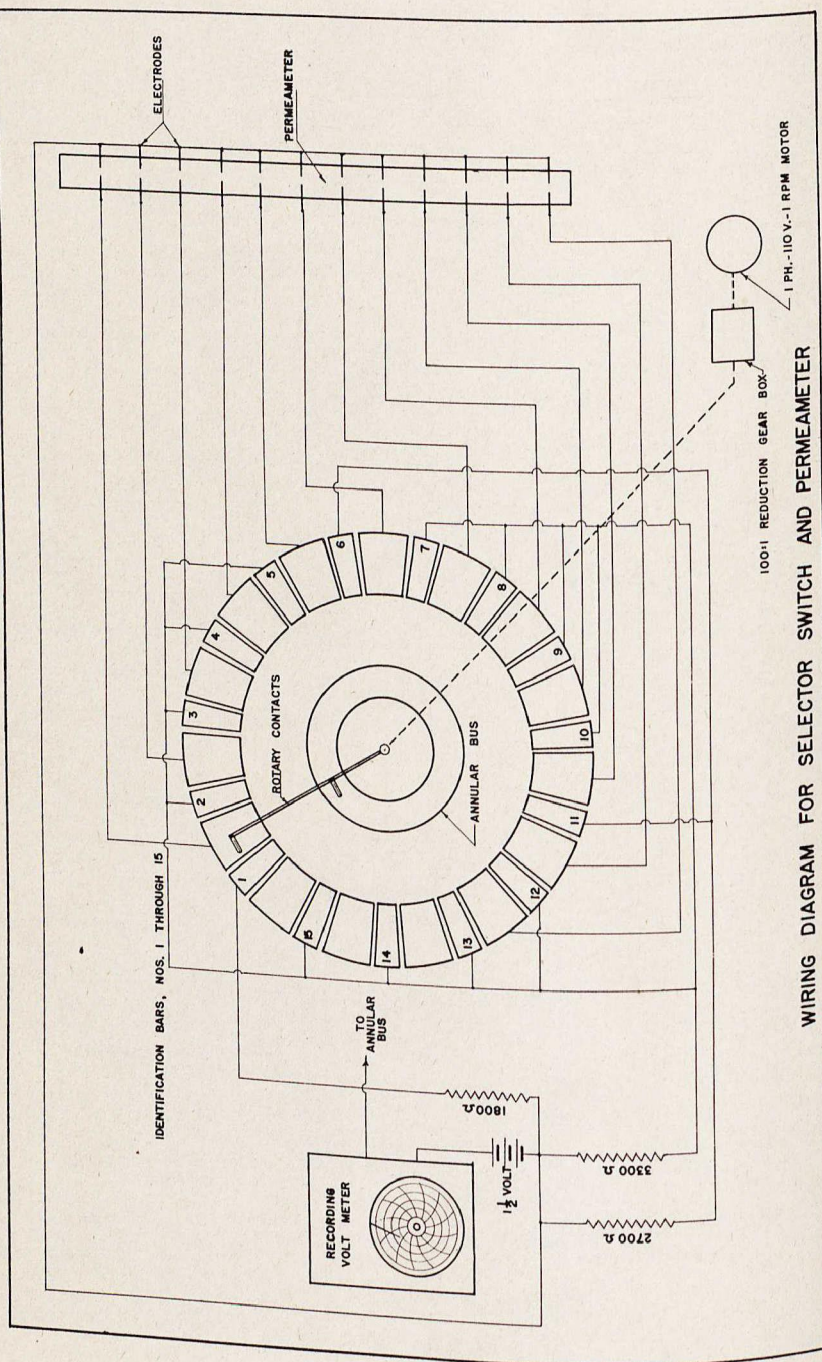
ll be noted that the graph has a ween applications is greatest and, ater applications were in greater The slope is, of course, a direct percolating water. The average for this test was 0.096 inch per

5

LACY STREET ASH

Total water applied Inches	Total water applied		Total depth of penetration in inches
	Mls.	Inches	
0.83	10.5	0.83	
1.00	23.5	1.83	
			6
0.86	34.6	2.69	
0.57	42.0	3.26	
1.49	61.2	4.75	
			12
0.58	68.7	5.33	
			18
0.68	77.5	6.01	
0.33	81.8	6.34	
			24
0.64	90.1	6.98	
1.95	115.1	8.93	
			30
1.89	139.5	10.82	
			36
0.19	141.9	11.01	
			42
0.45	147.7	11.46	
2.78	183.5	14.24	
			48
0.76	193.3	15.00	
0.45	199.1	15.45	
			54
0.76	208.9	16.21	
1.25	225.0	17.46	
			60
			66

FIG. 19



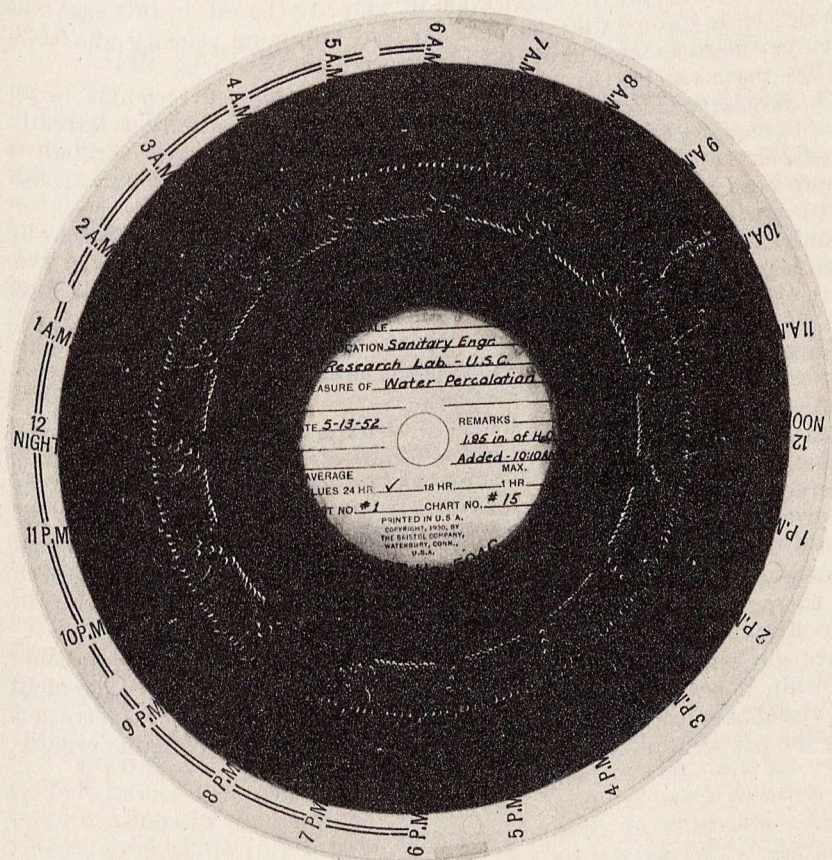


Figure 20

Typical Smoke Chart from Recording Voltmeter
Used for Percolation Study

Notice the water reached a depth in the ash of 30 inches at 7:15 PM as indicated by the swing of the recording needle from the inside band of points to a new position toward the outer periphery of the chart. The previously recorded point for the same electrodes may be seen still in the inside band of points, indicating dry ash, at 5:40 PM. Note also the change in conductance at the six inch depth as the freshly applied water passes by.

ur, about one-fifth that found in the leach columns. I
ed, however, that the application of water to the as
ried on in quite a different manner. The minimum
h per hour, the maximum 0.25 inch per hour.

The permeameter, by reason of its construction, c
initely large field area, for there could be no losses ra
e to capillary movement. The rate of movement of
ould correspond very closely to movement of rainfa
mp because of the imposed boundary conditions.

In April, 1947, a percolation test was reported on
andards, Department of Public Works, City of Los
t, a plastic tube two inches in diameter by eight fo
th ash. Water was applied at the top in the amount
e first 24 hours and then one inch per 24 hours fo
lume of water was selected as being the equivalent o
y storm ever recorded in this area.

As a result of this 12-inch addition of water over a
al penetration of 29 inches was obtained after eigh
netrated no further, and the test was terminated a
erage rate of percolation was 0.151 inch per hou
proximately 60 percent over the average rate of 0.
ove. In the laboratory percolation study, only 3.20
ded after eight days, and the penetration was 12 in
average rate of percolation of 0.063 inch per hour.

A direct comparison between the two tests, howev
ice the rates of application were far different. Als
fficult, if not impossible, to determine the exact dep
visual observation alone. Neither is any information
g the preparation of the ash or the tube for this tes

It must be remembered in this case was velocity was 0.036

corresponds to an radially or laterally water through it all through an ash

by the Bureau of s Angeles. In this set long was filled of eight inches for or four days. This the heaviest five-

five-day period, a t days. The water after 14 days. The tr, an increase of 0.096 inch reported 0 inches had been aches, resulting in

er, is not possible so, it is extremely pth of penetration a available regard- t.

THE

The possi thought to interpretati metal as a laboratory s active mate installation

Description of

A chroma with a stop was plugged layer of La No. 40 sieve been thorough glass wool v hole rubber front of tw horizontally monitor the

Method of O

The mate to 1.7 years properties of concentrati potassium of 0.40 ml. of a was introdu

An atten an applicat washes wer the column down in fro the addition found at ea It will be no indicating water would by the curv attributed of shown migh themselves

A solutio tration of grams of (F

INVESTIGATION OF LEACHING OF ASH

TABLE 16
BAND DESORPTION WITH DISTILLED V

Depth in ash of activity measurement	Total throughput volume in				
	10	35	85	135	
	Activity in milliroentge				
surface-----	1.20	1.10	1.10	0.95	
0.5-----	1.10	1.00	1.05	0.95	
1.0-----	0.45	0.65	0.60	0.55	
1.5-----	0.20	0.40	0.45	0.45	
2.0-----	0.15	0.25	0.20	0.20	
2.5-----	0.15	0.15	0.15	0.10	
3.0-----	0.15	0.10	0.15	0.15	
3.5-----	0.10	0.10	0.10	0.1	
4.0-----	0.10	0.10	0.10	0.1	
4.5-----	0.10	0.10	0.10	0.	
5.0-----	0.10	0.10	0.10	0.	
5.5-----	0.10	0.10	0.10	0	
6.0-----	0.10	0.10	0.10	0	
6.5-----	0.10	0.10	0.10	0	
7.0-----	0.10	0.10	0.10		
Total volume					
	10	25	50		

TABLE
BAND DESORPTION WITH
(5770 p

Depth in ash of activity measurement	To	
	50	
Surface-----	0.38	
0.5-----	0.50	
1.0-----	0.60	
1.5-----	0.70	
2.0-----	0.70	
2.5-----	0.55	
3.0-----	0.40	
3.5-----	0.35	
4.0-----	0.20	
4.5-----	0.15	
5.0-----	0.15	
5.5-----	0.10	
6.0-----	0.10	
6.5-----	0.10	
7.0-----	0.10	

DUMPS

WATER

milliliters

210	490	1690
-----	-----	------

ns per hour

	0.95	0.90
	0.95	0.95
	0.75	0.80
	0.45	0.60
	0.30	0.45
	0.15	0.40
	0.10	0.20
	0.15	0.10
	0.10	0.10
	0.10	0.10
	0.10	0.10
	0.10	0.10
	0.10	0.10
	0.10	0.10
	0.10	0.10
	0.10	0.10

collected in milliliters

50	75	280	1200
----	----	-----	------

7
POTASSIUM CHLORIDE
 (m K)

total throughput volume in milliliters

75	100	125	155
----	-----	-----	-----

Activity in milliroentgens per hour

0.20	0.20	0.15	0.15
0.35	0.30	0.15	0.15
0.45	0.30	0.20	0.15
0.55	0.40	0.30	0.20
0.60	0.40	0.30	0.30
0.55	0.40	0.35	0.25
0.55	0.45	0.35	0.30
0.45	0.45	0.40	0.35
0.40	0.45	0.40	0.35
0.30	0.45	0.40	0.40
0.20	0.35	0.40	0.40
0.20	0.30	0.40	0.40
0.15	0.25	0.30	0.40
0.10	0.20	0.25	0.35
0.10	0.15	0.25	0.30

Net volume collected in milliliters

50	25	25	25	30
----	----	----	----	----

down into the bed by applications of this potassium chloride solution. If the ash had any exchange capacity, the cesium would be displaced into solution by the potassium and would thus be able to move down the bed to greater depths. The fact that there was an exchange of ions and that the cesium did move down is clearly shown by the data of Table 17 and Figure 22. Referring to the latter, it is seen that the band maximum moved with successive applications of 50, 25, 25, 25, 10, 10, and 10 ml. from a depth of less than two inches to a depth of approximately 5.2 inches. There was a 24-hour lapse between the last two additions of 25 ml.

During the test, the eluent quantities shown in Table 17 were collected and their activity checked at a fixed distance from a Victoreen Thyrode aluminum counting tube connected to a Berkeley Decimal Geiger-Muller Sealer Model 1000-B. An automatic timer was set for three-minute counting periods. Table 18 lists the counts per minute, corrected for background activity. By plotting the activities against the average volumes eluted, there results the elution curve shown in Figure 23. This curve clearly demonstrates the movement of the band maximum, and indicates that the peak radiocesium concentration had passed out of the column with the addition of approximately 200 ml. of the potassium chloric solution—once more illustrating the exchange capacity of the ash.

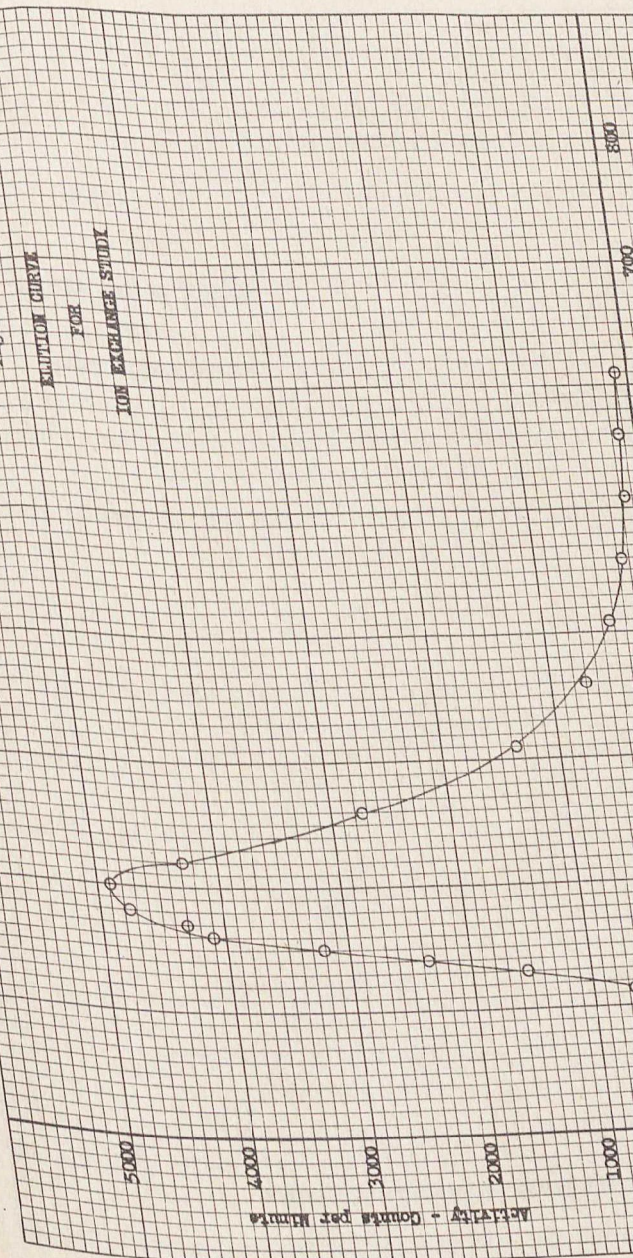
Figure 24 is included to illustrate how, by plotting the position of the band maximum (curve peaks referred to zero activity on Figure 23) against net volume collected, a straight line is obtained which should theoretically intersect the X-axis at the same volume which determines the peak of the elution curve, Figure 23. Actually, the slope of this line is indicative of the velocity with which the displaced radiocesium moves down the bed. For instance, if 100 ml. should be applied in say 30 minutes, the velocity of the cesium band would be 3.5 inches in 30 minutes, or 1.17 inches per minute. If the time of application was 20 minutes, the velocity would be 3.5 inches per minute. Obviously, the reasoning cannot be carried to extremes because the velocity will be infinitely limited by the equilibrium of the process.

TABLE 18
FRONTAL ANALYSIS COUNTING DATA

Activity, counts per minute	Net volume collected in milliliters
0	
17	
632	25
1,515	25
2,364	10
3,225	10
4,101	10
4,324	10
4,756	10
4,913	10
4,294	25
2,714	25
1,357	25
693	25
427	25
258	25
189	25
160	25
114	25

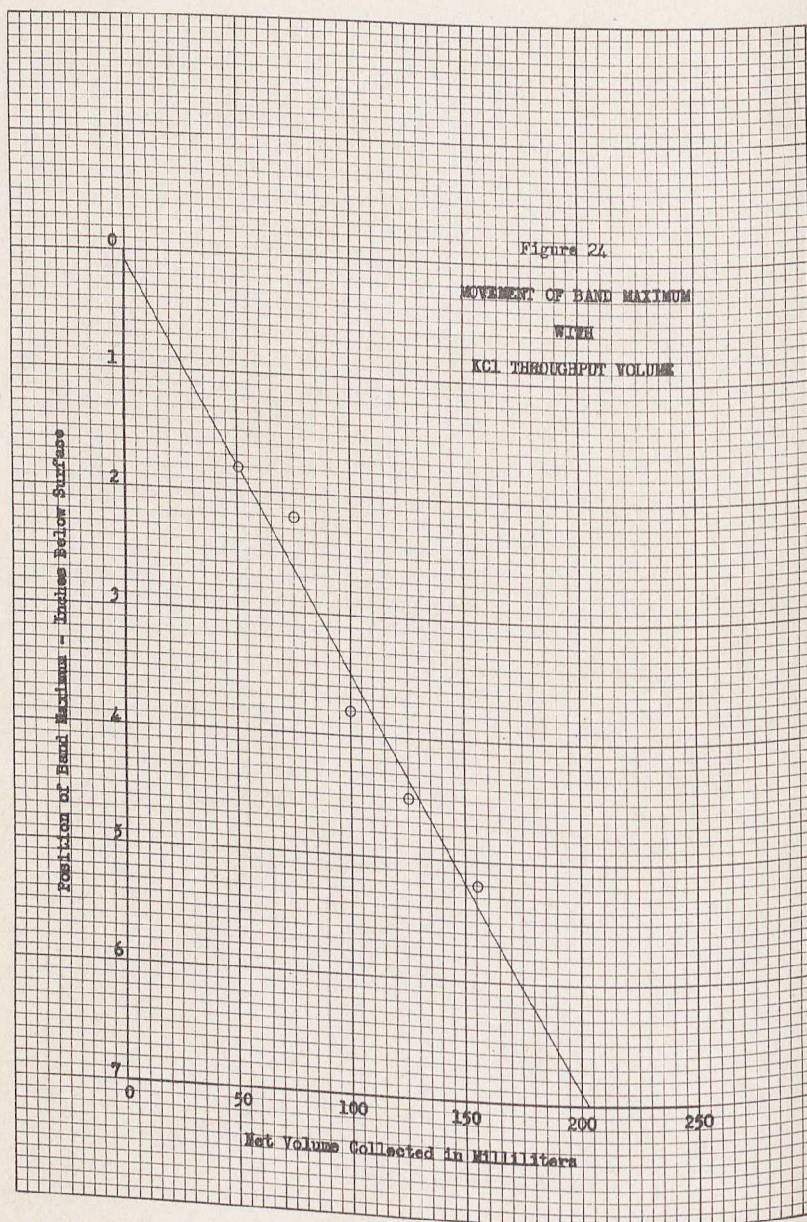
INVESTIGATION OF LEACHING OF ASH DUMPS

Figure 23
ELUTION CURVE
FOR
ION EXCHANGE STUDY



Average
volume in
milliliters

87½
112½
130
140
150
160
170
180
197½
222½
260
310
360
410
460
510
560
610



Calculation of Ion Exchange Capacity

The actual exchange capacity of the ash is calculated as follows:

Let

V = volume of solution put into the column to move the band front out of the column

$$K'_a = \frac{\text{concentration of site ions per cm. depth of bed}}{\text{concentration of solution ions per cc. of solution}}$$

A = area of bed in square cm.

X = depth of bed in cm.

Also

$$V(K^+) = \text{mass of potassium ion put into bed} \quad (1)$$

$$K'_a X(K^+) = \text{mass of site ions in bed} \quad (2)$$

$$faX = \text{volume of water in bed} \quad (3)$$

$$faX(K^+) = \text{concentration of potassium ion in solution} \quad (4)$$

From the law of conservation of mass, the mass of ions put into the bed must equal the amount of ions on sites plus the amount of ions in solution:

$$V(K^+) = K'_a X(K^+) + faX(K^+) \quad (5)$$

from which is obtained the general equation for conservation of mass:

$$V = (K'_a + fa)X \quad (6)$$

Solving for K'_a :

$$K'_a = \frac{V}{X} - Af \quad (7)$$

The substitutional values for the adsorption column used were:

$$V = 200 \text{ ml. (from Figure 23)}$$

$$X = 7 \text{ inches, or } 17.78 \text{ cm.}$$

$$f = 0.801$$

$$A = 5.58 \text{ square cm.}$$

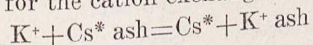
Substituting in (7)

$$K'_a = \frac{200}{17.78} - 0.801(5.6) \\ = 6.7$$

Dividing (7) by 5.6 $\frac{\text{cubic cm. of ash}}{\text{cm. bed}}$, there is obtained:

$$K_a = \frac{\text{concentration of site ions per cubic cm. of ash}}{\text{concentration of solution ions per cc. of solution}} \\ = 1.19$$

The common reaction for the cation exchanger leads to:



The equilibrium constant for the exchange reaction is:

$$(C) = \frac{(Cs^*) (K \text{ ash})}{(K) (Cs^* \text{ ash})}$$

and is equal (approximately) to 0.80 for organolite ion exchangers. Solving for (K^+ ash):

$$(K^+ \text{ ash}) \approx 0.8 \frac{\text{Cs per cubic cm. of ash}}{\text{Cs per cubic cm. solution}} (K^+ \text{ solution})$$

Substituting:

$$(K^+ \text{ ash}) \approx 0.8(1.19)(0.0059)$$

$$\approx 0.005617 \text{ grams } (K^+) \text{ per cubic cm. of ash}$$

Expressing in terms of calcium, the customary basis for reporting exchange capacities:

$$\text{grams of } Ca^{++} \text{ per cubic cm. ash} \approx \frac{0.005617(40)}{39(2)}$$

$$\approx 0.00288$$

Finally, expressing the exchange capacity in terms of grains per cubic foot:

$$\frac{(0.00288)(15.432)(7.48)(3.785)(1000)}{1000} \approx 1260$$

Discussion of Results

As a result of the laboratory study made in the manner described, it is apparent that the ash does have ion exchange properties. Further, it is seen that the exchange capacity of the ash is from one-tenth to one-twentieth that of commercial sulfonated resins, and almost one-half that of glauconite. However, this value applies only to the ash in the adsorption column. The ash in place in the field would undoubtedly have a lesser exchange capacity since per unit volume it would contain less ash due to the presence of large foreign materials.

Although only one carefully selected and prepared ash was used for this study, it is believed to be typical of any ash originally created from similar materials and under similar conditions.

There are several more or less elaborate methods of treating the performance of deep ion exchange beds. While the present exploratory results do not warrant any very extensive treatment, it seems worthwhile to outline the procedure that more extensive results would justify.

A very flexible theory of ion exchange chromatography, and one which is probably most suited to the treatment of data obtained for a relatively indeterminate and variable material such as ash, is that of Mayer and Tomkins (J. Am. Chem. Soc., 69, 2866 (1947)). Their approach consists of a theoretical plate treatment analogous to distillation theory.

Let the following quantities be defined:

p = number of theoretical plates

v = volume of solution associated with one plate

$V = pv$ = volume of solution in column (hold up volume)

n = number of v 's entering a plate up to a given time

$F = n/p$ = number of V 's passed through the column

L = fraction of solute in any v of solution

S = fraction of solute in the solid phase of any plate

$C = S/L$ = distribution constant (the K_d referred to above)

It may be shown that the peak of the elution curve at $F_{\max.} = C$. From Figure 23, the total volume at the peak minus hold up was 120 ml. The column hold up volume was 81 ml., so C becomes 120/81 or 1.5. This value compares well with the alternative calculation of K_d which gave a value of 1.19.

It may be shown moreover that at the peak of the elution curve:

$$L_{\max.} = (2\pi p C (1+C))^{-\frac{1}{2}}$$

The concentration of radiocesium at the peak was 500 counts per minute per ml. or ca. 40,000 counts per minute per V out of an estimated total of 70,000 counts per minute. Thus, $L_{\max.}$ is 40,000/70,000 p or 0.57/ p , and insertion into the above equation yields a value of 7.6 theoretical plates. This number of theoretical plates corresponds to only about one per inch of column, an extremely low value. This could come about either through the use of excessively coarse particles, which was not the case here, or because the ion exchange process itself was slow. This latter seems reasonable.

As has been seen, from a single column experiment it has been possible to estimate the distribution coefficient, the exchange capacity, and to note that the exchange appears to be slow. Under circumstances which would warrant it, the column parameters C and p could be used to predict the distribution in an ash bed, or in the effluent from the bed, for any desired bed depth.

CHAPTER VI

SUMMARY OF RESULTS, CONCLUSIONS AND RECOMMENDATIONS

The work done throughout the investigation of the leaching of ash dumps was always directed towards securing an answer to the question, "Does the leaching of ash dumps either by precipitation or by the passage of high groundwaters through them constitute a major threat to groundwater quality?" Obviously, the second condition can be eliminated by proper selection of the location of the dump, but this solution to the problem may not always be economically feasible.

The Field and Laboratory Leach Studies (Chapters II and III)

In this section of the summary, it is proposed first to examine the actual quantities of materials that may be leached from a dump, and second to consider the effect of these quantities on the groundwater.

Probably the most important contribution of this report is the following table which shows the pounds of the various materials leached per cubic yard from the ashes investigated, by the application of water. Distilled water was used in all cases except for the field study. An analysis of the municipal water supply used at Lacy Street indicated that its effect on the leach samples could be ignored. The values tabulated were computed by planimetry of the areas under the ion concentration curves, without extrapolation.

QUANTITIES OF LEACHED MATERIAL

	Pounds per cubic yard of ash			
	Lacy Street 12-ft. depth	Beverly Hills	La Loma	Marengo
Sodium.....	0.974	2.87	0.586	1.28
Potassium.....	0.274	1.57	0.582	1.22
Calcium.....	0.484	0.424	0.377	0.299
Magnesium.....	0.110	0.385	0.368	0.137
Chloride.....	0.614	5.30	0.202	0.391
Sulfate.....	3.06	4.59	3.57	4.32
Alkalinity.....	0.680	1.33	0.686	0.444
Nitrate nitrogen.....				0.147

The complete extraction of all ions by leaching would never take place; therefore, the curves were not extrapolated to zero concentration. However, if the curves are extrapolated such that the lowest ion concentration in all cases is equivalent to the lowest ion concentration obtained for any one of the leach samples, then all curves are on an equal basis and the values are:

QUANTITIES OF LEACHED MATERIAL

	Pounds per cubic yard of ash			
	Lacy Street 12-ft. depth	Beverly Hills	La Loma	Marengo
Sodium.....	1.17	2.89	0.586	1.28
Potassium.....	0.247	1.57	0.629	1.22
Calcium.....	0.484	0.424	0.377	0.299
Magnesium.....	0.110	0.385	0.425	0.137
Chloride.....	0.690	5.30	0.202	0.391
Sulfate.....	3.58	5.02	3.86	4.32
Alkalinity as CaCO ₃	0.680	1.33	0.686	0.444
Nitrate nitrogen.....				0.147
Total inches of water applied				
	113	90	114	114

No extrapolation was carried out where the change in the magnitude of the leach figure would be insignificant.

The values shown in the above tables must be considered minimum values, for the possibility of prior leaching due to rainfall does exist, however small. It is certain that there has been no movement of ground-water through the dumps from which the ash samples were obtained.

The average quantities received from the ash by leaching are compared with the average quantities (obtained by acid extraction) originally present in the ash in the following table. The latter are based upon a unit ash weight of 70 pounds per cubic foot.

	Average pounds per cubic yard leached from ash	Average pounds per cubic yard originally present in ash
Sodium.....	1.48	5.46
Potassium.....	0.92	7.24
Calcium.....	0.40	48.50
Magnesium.....	0.27	4.61
Chloride.....	1.65	--
Sulfate.....	4.20	5.62
Alkalinity.....	0.79	--
Nitrate Nitrogen.....	0.15	--

With the exception of the sulfate ion it will be observed that only fractions of the ion quantities originally present have been removed by the leaching process. Continued removal of the sulfate ion would mean a lesser removal of the sodium and potassium ion since they can come out only in combination with an anion. If carbon dioxide production continued, then the bicarbonate ion would provide a means for further removal of potassium and sodium. The fact that less potassium has been removed than sodium may be explained by its being more tightly held by the zeolite present.

The maximum amount of any cation leached was 2.89 pounds of sodium per cubic yard of ash. In a dump 25 feet deep, this would correspond to approximately 58 tons per acre. In the case of potassium, there would

be 32 tons per acre of leachable ion present. Although these values appear high on first examination, the amount of water it required to obtain them, and the length of time it would normally take to leach those quantities, with the consequent dilution factor available, must not be overlooked. There seems little doubt but that dilution of leach by ground water would result in concentrations of sodium and potassium which would not in any way adversely affect groundwater quality. If all the sodium and potassium ions could be leached out, and if ideal percolation conditions existed, it might be assumed that normal rainfall over a six year period would accomplish the above noted removals at yearly rates of ten and five tons per acre. Ten tons of sodium leached by 15 inches of rainfall over one acre means a concentration of 20,000 pounds in 1.25 acre feet of water, or 5,900 ppm. A dilution factor of as little as 100:1 will reduce this concentration to a value of no importance, especially when the slow rate at which the pollutant would enter the groundwater is considered. It is expected that it would take several years for ions to be displaced downward by rainfall to a level where they would enter an aquifer.

The lateral movement of groundwater through an ash dump would place a given amount of sodium or potassium in solution much faster than would percolating precipitation, but the volume of water passing through and out of an ash dump, necessarily limited by the permeability and hydraulic gradient, would be but a small fraction of the underground supply, and great dilution would still be available. It is estimated that the groundwater flow through ash would not exceed 0.04 gallons per square foot per day on the basis of the permeability coefficient reported in Appendix B. The average rates at which water was applied to the ash was at least 10 times this rate in all cases.

On the other hand, a well located in close proximity to an ash dump, and receiving drainage directly from the dump, could have its quality seriously impaired, see Appendix C. This represents an extreme condition, and one which can be foreseen in the location of future ash deposits.

Nitrate nitrogen was found in sufficient concentration to be presented graphically only in the case of the Marengo ash (Figure 15), and then only in the amount of 0.147 pounds per cubic yard. Here, again, it appears impossible that impairment of water quality would result, for the full amount would be added gradually over a long period of time to a volume affording tremendous dilution. Even with leaching by groundwater flowing through the dump, its speed and volume would certainly be such as to make the leach process slow and insure the dilution necessary to hold the concentration well below an accepted maximum value of 30 to 40 ppm. In any event, it is unlikely that conditions would exist or be permitted to exist which would mean the addition of the leached nitrate to a limited groundwater volume.

An examination of the data presented indicates that there has been considerable production of carbon dioxide. Principally this will be formed by aerobic and anaerobic decomposition; however a small amount is formed by oxidation of the organic matter present by oxygen which diffuses into the dump from the atmosphere. Upon contact with the lime present in the ash and the leach water, carbon dioxide causes calcium and bicarbonate ions to go into solution according to the physical chemistry laws of mass action.

As is discussed in detail in Chapter III, an excess amount of lime is held in equilibrium with the carbon dioxide, and the leach water appears to be supersaturated with calcium bicarbonate. However, as is pointed out, this is due to the activities of (Ca^{++}) and (HCO_3^-) being depressed by other salts, especially divalent salts in solution.

Most groundwaters in this area are in carbonate equilibrium, therefore pH is equal to pH_s .

A leach entering the groundwater will be diluted, which results in the activity of the ions being increased. With this increase in activity of the ions, the equilibrium of the mixture of leach and groundwater is shifted so that pH is greater than pH_s , resulting in the precipitation of solid calcium carbonate until equilibrium is again established. This results in a very small increase in the total hardness of the groundwater when the large dilution factor is considered.

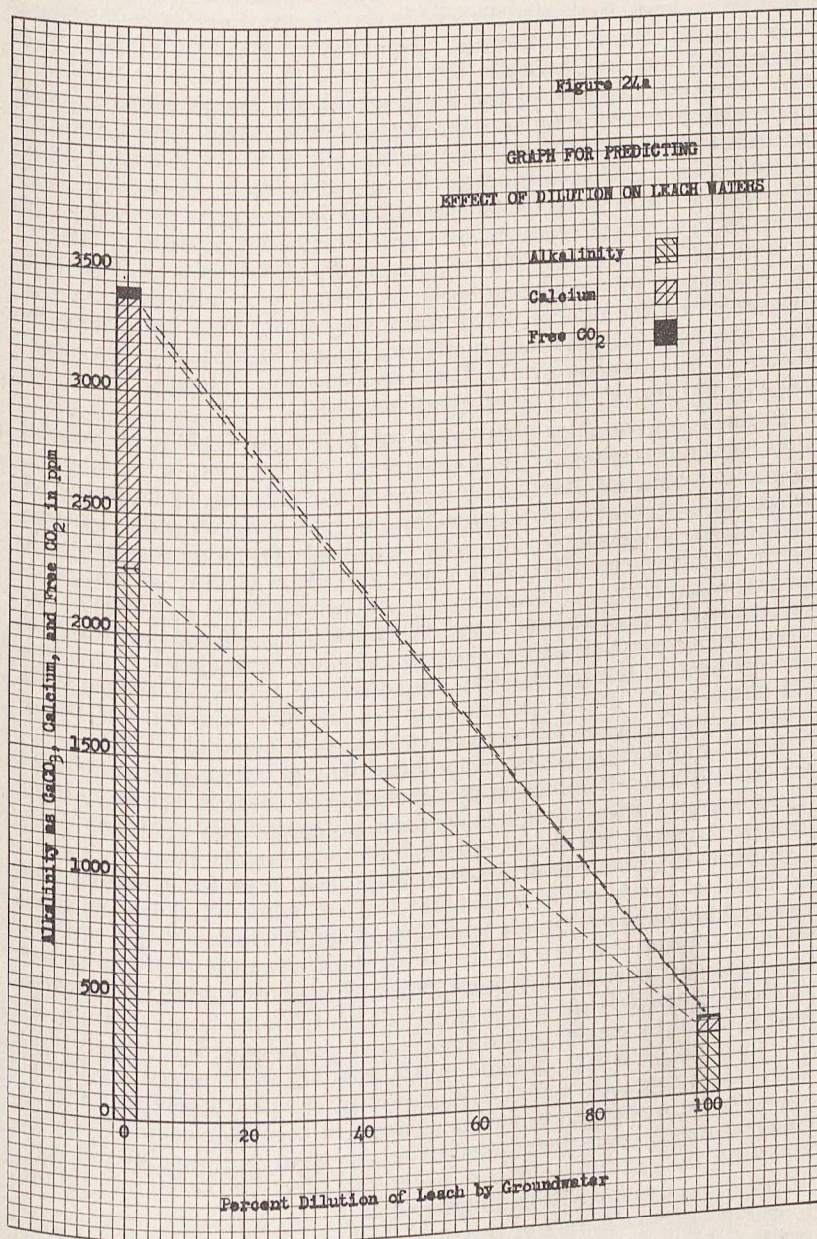
To illustrate how the quality of groundwater might be affected as a result of entrance of Ca^{++} , HCO_3^- , and CO_2 by leach, Figure 24A has been prepared. The figure shows two bars, one representing an average for leach water and the other an average well water in this area. The two bars are located 100 units apart, and the midpoints of the bars at the division lines between ions have been connected by straight lines. The resulting alkalinity, Ca^{++} , and CO_2 of a water can be approximately predicted by erecting a bar at the proper position. This does not, however, take into account any shifting of the equilibrium as mentioned above.

It has been estimated that the Lacy Street incinerator produced a 105 tons of ash per day when in operation. Assume an average rainfall of 15.43 inches per year, that the ash was deposited to a depth of 12 feet, and that the groundwater flow is 2.3 second-feet. Using one year's ash deposit (300 operating days) the resulting dilution of leach would be approximately 1,000 to one. By using this estimate, which has been calculated, and applying it to Figure 24A it can be seen that little change would occur in the groundwater.

Calculations indicate free carbon dioxide to be present in the leach waters analyzed in amounts varying from a minimum of 7.2 (Marengo) to a maximum of 306 ppm. (Lacy Street). The average content was 45 ppm. A comparison of the free carbon dioxide values with the bicarbonate values indicate that the total carbon dioxide produced has reacted so completely that only a very small amount is left.

The important negative ions which would be added to the groundwater are the bicarbonates, sulfates, phosphates, and chlorides. The bicarbonate ion is directly affected by calcium (or magnesium) and carbon dioxide equilibrium which has been discussed. Both chloride and nitrates are highly soluble, and would effectively and rapidly be leached out of an ash. Any possible deleterious effect on the groundwater from these ions would be short-lived due to increasing dilution. Phosphate was found in negligible quantities. Excluding the nitrate, which was found in high concentration in only one of the four ashes examined, the negative ions would have no specific effects of their own, but must be considered jointly with their combining cations, such as sodium chloride, or potassium sulfate.

The effect of the alkali metals and certain of the cations on groundwaters is a subject in itself, and not entirely within the scope of this investigation. Much can be found in the literature on this subject, one



of the best and most recent being Pomeroy's "Report on Probable Ground Water Pollution from Rubbish Dumps" which appears in "Report upon the Collection and Disposal of Refuse in the County Sanitation Districts of Los Angeles County, California" prepared by Mr. A M Rawn, Chief Engineer and General Manager.

Spot checks were made of the leach waters for the rare metals, and copper, aluminum, lithium, manganese and vanadium, were found in quantities less than one ppm., barium one ppm., boron five ppm., and strontium 15 ppm. The boron was considered to be high, so additional analyses were made for this element. A few leach waters from the laboratory leach columns were checked with the following results: BH-1, 14.5 ppm.; M-9, 11.9 ppm.; M-14, 8.9 ppm.; M-16, 8.1 ppm.; LL-14, 11.1 ppm. With many growers being boron conscious, especially those having citrus orchards, the figures noted above may give cause for alarm. To many, therefore, the following comments, prepared especially for incorporation in this treatise by Dr. Richard Pomeroy, Chemical Engineer, Pasadena, California, will be of great interest.

Boron is an essential plant nutrient and is present in all vegetation. The boron content of fruit tree leaves, for instance, is 10-150 ppm. of the dry weight.¹ It must be added as a fertilizer where soils and irrigation waters do not provide for the crop requirements. Turnips and alfalfa are examples of crops with high boron requirements. A boron deficiency usually exists where the boron content of soil solutions is below 0.5 ppm.² Excessive concentrations of boron can be harmful, especially to citrus trees and to walnut trees. A concentration of 0.5 ppm. in irrigation water, which might allow concentrations to reach several ppm in the soil solution, is considered to be the danger level for these crops. But even citrus groves require additions of borax where amounts in the soil are inadequate, as in parts of Florida.³

Like potassium, boron is accumulated in vegetation, particularly in leaves, and like potassium its concentration in ashes is relatively high in comparison with other less common minerals. The relatively high concentration in the leach waters examined results from this fact.

Most of the boron in ordinary soils is held in states of adsorption or chemical combination with other soil components. Boron in solution and boron in solid phase tend toward equilibrium, but this equilibrium is approached very slowly. With short distance of travel in the soil and short periods of contact, much of the boron added in a water of composition foreign to the area will continue to be in solution, so that it might be picked up in wells close to sources of heavy pollution. An increase of boron content might possibly be detected in a well fairly close to an ash dump if such well intercepted leachings in such amounts as to show conspicuous changes in the other components. If this leaching became distributed in a large area and remained in contact with the soil for months or years, the effect on the boron content of the groundwater will be infinitesimal.

In most groundwaters of this area the boron concentrations are generally 0.2 to 0.3 ppm. Even if no fixation of boron occurred in the soil,

¹ Kenworthy, A. L., Proc. Am. Soc. Hort. Science, 55 (1950) 41-46.

² Eaton and Wilcox, "The Behavior of Boron in Soils," U.S.D.A., Bulletin 696, December, 1939.

³ Reuther and Smith, Citrus Industry, 31 (1950), No. 2, 2-7, 20.

dilution of one part of leach with 40 parts of groundwater still would not raise the boron concentration to a level that would damage the sensitive crops, but probably would be beneficial to plants with high boron requirements.

Natural waters of high boron content usually come from hot spring areas, or from waters which have contacted young igneous rocks.

It may be noted that Owens aqueduct water, with 0.5 ppm. of boron, has been used for 35 years for irrigation in the San Fernando Valley. The increase of mineral content in groundwater under irrigated lands occurs because of concentration by evaporation, and this is true in the San Fernando Valley, yet the boron concentration in this groundwater remains at approximately 0.2 ppm.

Conclusions

From the summary presented in the following pages, it is possible to draw several conclusions.

Groundwater may be expected to leach an ash dump of its salts and alkalis. The precise rate at which such leaching will proceed, while known to be slow, remains a matter of strong conjecture, for undoubtedly the answer lies in the volume of water which will percolate or move through the dump. Similarly, the net effect of the leach on a groundwater can only be stated in terms of the volume of groundwater receiving the leach, i.e., the available dilution.

Certainly it may be stated that the use of a site for purposes of incinerator ash disposal constitutes no threat to the groundwater, providing reasonable caution is exercised to prevent direct funneling of the leach into a limited volume of groundwater, such as a well or group of wells.

It is hoped—even anticipated—that the figures presented herein relative to (1) the expected quantities to be leached per cubic foot of ash at flow volumes far in excess of anything possible due to record precipitation or normal groundwater movement and (2) the average quantities of materials originally present in the ash will enable the reader, familiar with his own conditions, to formulate his own opinions relative to ash dump locations.

The Percolation Study (Chapter IV)

Summary of Results. Various rates of percolation of water through ash were determined in the course of the entire study. The rates varied from a minimum of 0.036 to a maximum of 0.48 inch per hour, or 0.072 to 0.96 foot per day, under various test conditions and various rates of water application to the ash surface. It is believed that most credence must be given to the average rate determined through the use of the permeameter described in Chapter IV, viz., 0.096 inch per hour or 0.192 foot per day.

Theoretically, then, an ash dump 25 feet deep would be penetrated by the rainfall of a maximum intensity period in approximately 130 days. However, heavy recurring rains are not frequent enough in this area to extend the curve at the average slope shown in Figure 18 for any such length of time. The tendency would certainly be for the curve to assume a lesser slope, even flatter than that representing the interval

between penetration from 6 to 12 inches, or 42 to 48 inches. The latter stretch of the graph shows very plainly how the rate of percolation slows when the frequency and volume of applied water is lessened. In fact, from observations made, and from a study of Figure 18, it is quite certain that once the application of water ceases the percolation rate rapidly slows down to something approaching a standstill. To illustrate, the water did not penetrate to the five-inch depth, from the $4\frac{1}{2}$ -inch depth, until a heavy application was made at 528 hours. What the slope of the graph would be from the time the water reached the $4\frac{1}{2}$ -foot depth until the water application at 528 hours was made is a matter of conjecture, and in all probability the water would not have reached the five-foot depth without the addition being made. Even as long as eight days following completion of the permeameter test, the cotton plug in the bottom of the permeameter, two inches below the bottom electrodes, remained dry.

If it is assumed that the water will move as much as 12 inches following conclusion of the rainy season, and if ensuing rainy seasons be of normal intensities, the probable time for the rainwater to penetrate the ash will be four years. With a prolonged drought, such as was recently experienced in this area, the time of complete penetration would be considerably greater.

These calculations do not take into account the effect of evaporation at the surface of the dump, nor additional loss of moisture by reason of upward capillary movement as the surface dries, nor lateral capillary movement, all of which would have the effect of prolonging the time interval. They are also based on the ash having an initial moisture content of approximately six percent, a value perhaps half that encountered in the field. Observations made during the percolation study definitely indicate that water will move much faster through an ash previously wetted. Any given application of water to the permeameter was found to move rapidly down through the ash *until* the dry material was reached, although the velocity decreased as the water band widened. A similar situation was experienced at the Lacy Street test site. The last application of water to the surface was made in early October, and the dump at that time was undoubtedly thoroughly saturated. The January rains, while far below the increment additions of simulated rainfall made in October, nevertheless passed rapidly through the dump and produced leach samples at all levels. It is also to be noted that the initial 28-day application of a simulated rainfall of maximum intensity, on the ash known to have a moisture content of 9 to 10 percent, penetrated to a depth of seven feet. This represents a percolation velocity of 0.25 foot per day. However, it is known that some channeling must have taken place.

At the conclusion of the laboratory test, using the permeameter, the ash was found to be uniformly wet from the top to the bottom set of electrodes and to have a moisture content of 23.16 percent. This value agrees closely with the computed value of 23.08 percent.

The effect of hold-over of the water from year to year must be considered. Once wet, the ash will not dry out, and each year's precipitation will penetrate to the driest band, bringing the moisture content up to a value equivalent to that of the overlying ash. How many years that might take is highly problematical.

Conclusions. Because of the many variables involved, particularly the condition of the ash when freshly placed from the standpoint of moisture content, it is difficult to draw any precise conclusions. However, on the basis of the laboratory investigation and other observations, it appears reasonable to conclude that an ash dump having an initial moisture content of 6 to 10 percent and a depth of 25 feet will admit penetration to the bottom in two years, assuming conditions of heaviest recorded rainfalls such as the 1940-41 season. With conditions of average rainfall existing in this area, it appears that complete penetration would be effected only in a period of four years or more.

The Ion Exchange Study (Chapter V)

Summary of Results. The experiments performed on a screened, carefully prepared, representative sample of ash indicated very definitely that it had ion exchange properties. The distribution coefficient determined experimentally checked closely with that developed from theoretical considerations. The ion exchange process appeared to be slow.

Conclusions. The exchange capacity of the ash used for this study, and which is thought to be typical of any ash originally created from similar materials and under similar conditions, was found to be approximately 1,260 grains per cubic foot.

Recommendations. The experiment reported here on the ion exchange behavior of ash has served to indicate the presence of a significant ion exchange capacity, but a considerable amount of additional work is needed if the nature of this capacity is to be known more fully.

It would be desirable, for example, to determine the capacity for divalent ions, through the use of radiocalcium or radiobarium, and also the capacity for anions, through the use of radiochloride. The present experiment was semiquantitative in nature, and was carried out on only one ash sample. More accurate future work would involve batch as well as column experiments on a variety of ash samples, designed to yield more detailed information about the capacity and rate of ion exchange for various ions.

It would be of interest, also, to determine the distribution of exchangeable ions (i.e., what percent of the exchange capacity consists of sodium ions, of potassium ions, of calcium ions, etc.), as would be determined by analyses of column effluent solutions. Additionally, some information about the nature of the ion exchange material itself would be valuable. Experiments might be conducted to determine to what extent the exchange capacity varied with pH (an indication of the acid strength of the functional group of the ion exchanger), and to what extent the capacity could be identified with the organic and with the inorganic fractions of the ash. Thus, the exchange might be due to phenolic, carboxylic and similar acid groups in residues of vegetable origin, or it might be due to silicates and other inorganic components.

One of the prime reasons for undertaking the experiment was to obtain data which might aid in the explanation of the analytical results obtained from the leach samples. Whether the additional work outlined above would have any real, practical value is a question which cannot be answered in the light of the work done so far.