STUDY OF SOME PUERTO RICAN SOILS AS NATURAL SEALERS OR ATTENUATORS AGAINST GROUNDWATER POLLUTION FROM SANITARY LANDFILL LEACHATES

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INTRODUCTION

Solid wastes are all those wastes generated by human activities that are normally solid and which are wasted to the environment as something useless. Examples of solid wastes are garbage, rubbish, street sweepings, dead animals, tree clippings, ashes, etc.

The adequate disposal of solid wastes is a major urban problem because of the quantities involved. In the United States, for example, it is estimated that 340 million tons of solid wastes were generated in the year 1980. In 1976, the cost of managing the solid wastes in the U.S. was 4.5 billion dollars. Of all government services only public health, highways, and education and welfare spent more money.

In Puerto Rico, the Environmental Quality Board (EQB) reported the production of solid wastes in 1975 to be 2.5 million tons, or 4.5 lbs/person/day. Present estimates for Puerto Rico are 5.5 lb of solid wastes per person per day of which 2.5 lb are disposed of by means of sanitary landfills. The rest is discharged by people into unauthorized dumps or is burnt in backyards. Some material, such as paper, cardboard, and aluminum cans, is recovered from the waste for reuse.

The sanitary landfill is the most widely accepted and used solid waste disposal method in the United States and in Puerto Rico. It is the most economical disposal method without regard to the composition and characteristics of the waste.

It has been reported that in 1975 there were about 14,000 sanitary landfill sites in the United States. In Puerto Rico the practice in the past was to dispose of the solid wastes in open dumps, but new regulations for the protection of the environment have been changing this situation. In the year 1973, the solid waste disposal practices in Puerto Rico were as follows:

17 municipalities were operating sanitary landfills satisfactorily.

9 municipalities were changing from open dump to sanitary landfills,

37 municipalities still used open dumps for their solid waste disposal, and

15 municipalities used waste disposal facilities established in other municipalities.

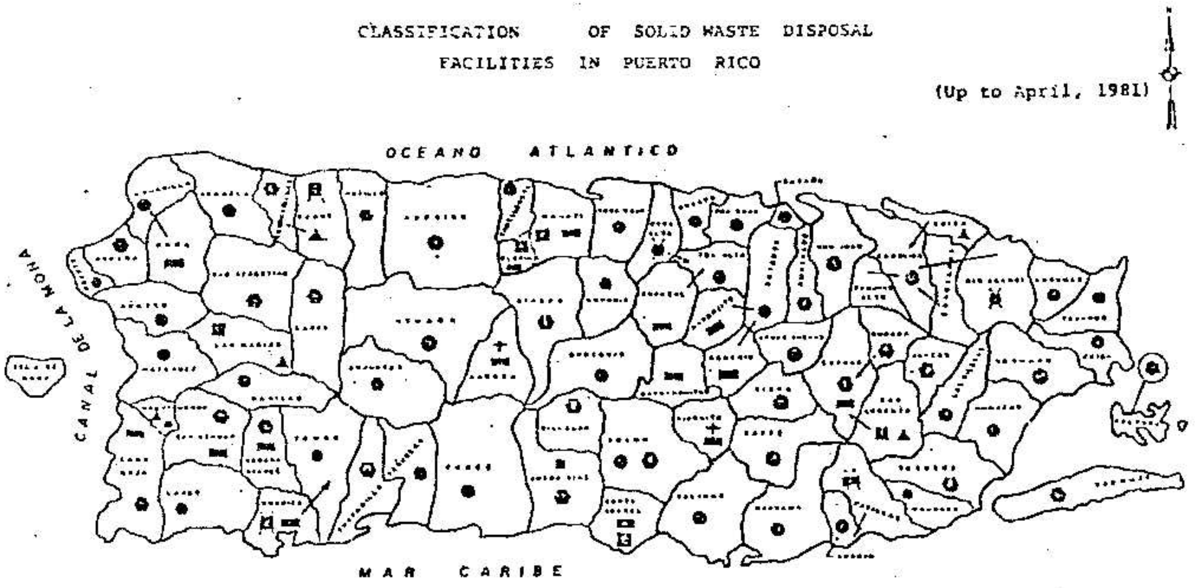
By 1981 the solid waste disposal situation was as illustrated in Figure 1.

Although an acceptable practice, sanitary landfills are not immune to certain environmental pollution problems. As the buried solid waste decompose in the landfill and rainwater percolates through, leachates are liberated which may pollute the underlying groundwater or nearby surface streams. This makes it necessary to select the sanitary landfill site with a view on the adequate protection of the water resources.

An important factor to consider in sanitary landfill site selection is the soil type present at the site. Soil type and characteristics will determine how much rainwater infiltration and runoff will occur. The type of soil will act in two ways with regard to potential pollution of the groundwater sources: a) its permeability will determine how much leachate will reach the groundwater table and b) its physicochemical characteristics will dictate how much of the leachate constituents will be allowed to pass through. In fact, it has been postulated that an impervious soil may be used, both as liner and as cover for the solid waste cell, such as to effectively seal-in the pollutants and prevent their access to surface and groundwater sources. It has been reported in the literature that there are other materials that may be used as liners and sealers for sanitary landfills, such as plastic films, concrete slabs, or asphaltic covers, but

CLASSIFICATION OF SOLID WASTE DISPOSAL
FACILITIES IN PUERTO RICO

(Up to April, 1981)



Legend

- ● Sanitary Landfills
- ⬭ Open Dumps Converted to landfills
- △ Terrains on Study
- ▭ Approved Terrains
- ⧈ Open Burning Dumps
- ↗ Municipalities where Solid Wastes are Dumped
- \+ Non - Authorized Sanitary Landfills
- x Eliminated Landfills

Sanitary Landfills	39
Open Dumps Converted to Landfills	25
Total of Sanitary Landfills	64
Total of Open Burning Dumps	4
Total of Terrain Studies Approved	11
Total of Terrain Studies Pending	5
Total of Non-Authorized Sanitary Landfills	2
Municipalities without Landfills	13

Figure 1

their cost is high.

Object and scope

The specific objectives of this project were:

1. To make a characterization of the leachates from a nearby municipal sanitary landfill and consider their effect on the underlying groundwater.
2. To study the change induced in the leachates when passed through columns containing different types of soils that are common in Puerto Rico.
3. To consider the effect of these soils in reducing or preventing groundwater pollution from leachates when used as base or cover material for municipal refuse cells in sanitary landfills.

The sanitary landfill serving the city of Mayaguez was selected, both for the characterization part of this study and as source of leachate and groundwater samples. The selection of soils for the soil-column studies was based on their relative abundance and wide-spread existence in Puerto Rico.

Literature review

In the past few years, there has been a growing interest in the environmental engineering profession for the characterization of sanitary landfill leachates and for the determination of the potential pollution effect of these leachates on the environment. There are several types of studies that have been conducted with regard to sanitary landfill leachates:

1. Determine the pollution effect of the leachate on the underlying groundwater. (1)(2)(3)(5)(6)(7)(10)(23).
2. Quantities and characteristics of leachates produced in laboratory lysimeters simulating sanitary landfill cells. (4)(8)(15)(16).

3. Characterization of sanitary landfill leachates and the change of these characteristics with the age of the landfill. (3)(4)(5)(8)(12)(17).
4. Relation between water application and leachate production. (11)(19)(20).
5. Analysis of soil samples in sanitary landfills. (10)(24) (30 thru 40).
6. Techniques for the treatment of sanitary landfill leachates. (9)(13)(21)(30 thru 40).
7. Techniques for the analysis of leachates. (14 thru 17).
8. Toxicity of leachates. (18).
9. Use of sanitary landfill leachates for irrigation. (22).
10. Use of natural and synthetic liners and sealers in landfills. (25 thru 41).
11. Laboratory studies of soil columns composed of clays. (30)(31)(32)(40).
12. Movement of leachate components through the soil. (34 thru 39) (61).
13. Damage assessment of specific pollution incidents involving sanitary landfill leachates. (42 thru 47).
14. Evaluation of sanitary landfill practices and regulations. (48 thru 60).

Most of the research work on sanitary landfill leachates and their effect on the environment has been done during the last fifteen years. A comprehensive bibliography on this subject is included at the end of this report for the benefit of those persons interested in finding more detailed information on this subject. Numbers in parenthesis at the end of each item in the above list refer to the specific bibliography cited.

Actually, many of the studies conducted on this subject address more than one of the problems listed.

Procedure

The Mayaguez sanitary landfill was selected for this study. This is a typical municipal landfill of a medium-size city of about 90,000 inhabitants. It is also close to the Mayaguez Campus of the University of Puerto Rico. (See figure 2). This landfill covers about 16 hectareas. It has been in operation since 1974. An average of 600 cubic meters of solid wastes, of domestic and industrial origin, are received at the Mayaguez sanitary landfill each day.

According to the Soil Survey of Puerto Rico (S.C.S.) the soil at this site belongs to the Daguey series of the Ultisol order. This material is used as cover for the refuse cells. The area has slopes between 12 and 20%.

Leachate samples for this study were taken from a horizontal well driven into the refuse and from a small pond excavated at the base of a solid waste cell. Groundwater samples were collected through a vertical well that had been constructed by the U.S. Geological Survey for a previous study.

The selection of the soils for the column studies was based on their relative abundance and wide-spread existence in Puerto Rico and taking into consideration their physical and chemical characteristics. It was desirable that these soils would be representative of major regions of Puerto Rico. At the beginning of the study a preliminary selection of 17 clayey soils was made. These represented about 42% of the Island's surface. Taking into account other factors, the final selection was reduced to five soils. These factors were depth of the groundwater, susceptibility of the area where the soil is found to flooding, the clay content, depth of soil layer to bedrock, presence of wheathered rock near the surface, slope of

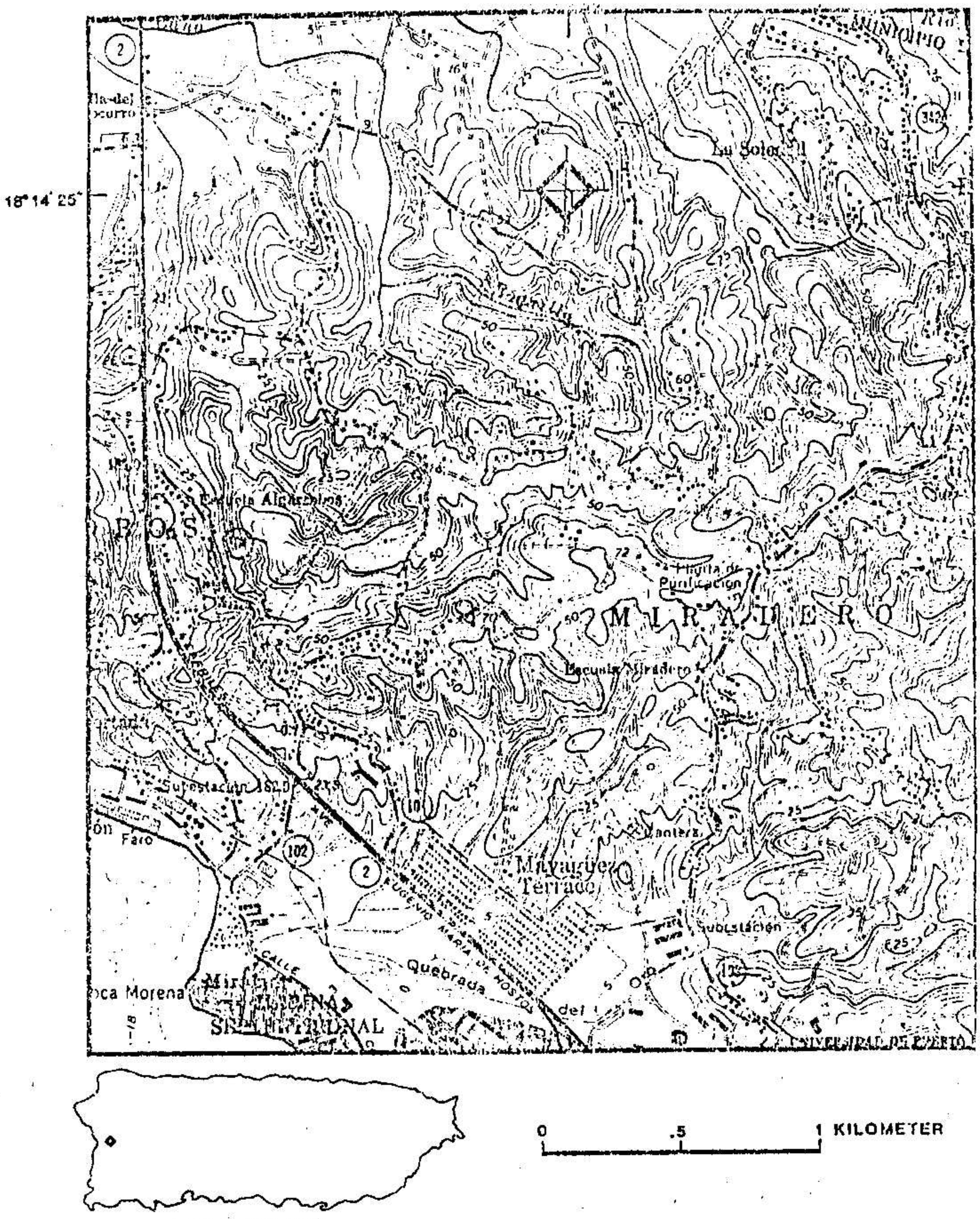


Figure 2 --Mayaguez solid-waste disposal site at Sabanetas.

the ground surface, and ionic exchange capacity of the soils. When two or more soils had similar chemical composition only one of those was selected. Soils with high economical value, because of better use alternatives, were also eliminated from the preliminary list. The five soils selected finally were Daguey, Humatas, Vega Alta, Fraternidad, and Almirante.

All physical and chemical analyses run on leachate and groundwater samples were made according to the Standard Methods for the Examination of Water and Wastewater, 15th edition (APHA, AWWA, WPCF). Soil samples were analyzed using methods developed by the American Society for Testing and Materials (ASTM) or by the U.S. Soil Conservation Service (S.C.S.).

The soil columns were prepared with 20-inch (50 cm) lengths of 2-inch (5.1 cm) diameter PVC pipe. A 12-inch (30 cm) layer of soil was supported by a 2-inch (5.1 cm) layer of glass wool inside the pipe. This arrangement allowed 16-inch (15 cm) freeboard over the soil inside the pipe. A control column was prepared using an empty column with just the glass wool layer in it.

During the preparation of the soil columns it was observed that the Fraternidad soil was very difficult to manipulate. When wet it was very plastic and sticky. When it dried it became very hard and did not break easily. Because of these problems the Fraternidad soil was eliminated from the study at this point.

It was also observed that it was necessary to control carefully the compaction of the soil layer in the columns. These soils are fearly impervious and, therefore, when thorougly compacted very little liquid can percolate through. For the column studies it was necessary to insure that a reasonable amount of leachate would be collected as column effluent in a reasonable amount of time. Because of this, the compaction of the soils in the columns was carried only to the point in which an approximate permeability of 3 x 10^{-5} cm/sec (equivalent to that of fine sand) was obtained. Due to the high clay content of the Almirante soil, it was not possible to obtain the degree of permeability that was demanded by the conditions of the study and, therefore, this soil was eliminated from the study at this point. This left us with three soils to work with.

The leachate was applied to the columns under an approximate head of 6 ft (1.8 m). The leachate reservoir was filled every three to five days as needed with fresh leachate brought from the Mayaguez sanitary landfill. One-liter effluent samples were collected for analysis from the bottom of the columns at the same interval of three to five days. The complete run lasted 35 days.

Results

The results of the Mayaguez sanitary landfill leachate characterization and of the groundwater studies are presented in Table 1. These are based on the analysis of 16 leachate samples collected from March 14 to December 20, 1981 and 7 groundwater samples taken from March 14 to April 30, 1981. Unfortunately, the U.S.G.S. well, from which the groundwater samples were extracted, was buried by soil erosion shortly after the start of this project. That is the reason why it was not possible to collect as many groundwater samples as leachate samples.

This table shows that groundwater characteristics are generally far below the values for the leachate, when the values represent material content. The only exception is in the nickel content, in which case the groundwater concentration of this metal is higher than in the leachate. A possible explanation for this is that the well water may be coming from the area in the landfill where scrap metal and discarded automobiles are deposited. The dissolved oxygen content of the groundwater is also slightly higher than in the leachates, but this may be due to air contamination of

Table 1: Leachate and Groundwater Characteristics at the Mayaguez Sanitary Landfill

Elect. Cond.	µmhos/cm	[illegible]	
Color	Pt-Co.	120 - 3,000	5 - 25
Diss	mg/l	0 - 1.2	0 - 2.5
COD	mg/l	428 - 26,570	19.5 - 61.3
BOD_5	mg/l	49 - >12,000	0 - 2.8
TKN	mg/l	26.6 - 911.7	1.2 - 2.0
Ammonia-N	mg/l	11.7 - 142.5	0 - 0.5
Alkalinity	mg/l as $CaCO_3$	389 - 8,800	116 - 162
Acidity	mg/l as $CaCo_3$	100 - 4,507	122 - 921
Calcium	mg/l	20.1 - 1,262	27.3 - 29.2
Magnesium	mg/l	10.4 - 369	19.9 - 23.1
Sodium	mg/l	40.0 - 4,717	21.7 - 26.9
Potassium	mg/l	16.8 - 250	3.7 - 5.1
Iron	mg/l	0.62- 228	0.8 - 5.0
Manganese	mg/l	0.7 - 215	3.4 - 5.1
Chlorides	mg/l	207 - 3,960	51.7 - 70.7
Sulfates	mg/l	1.6 - 1,075	3.4 - 11.7
Cadmium	µg/l	BDL - 6,100	142 - 180
Chromium	µg/l	BDL - 304	BDL
Lead	µg/l	BDL - 1,115	BDL
Nickle	µg/l	BDL - 478	388 - 1,090
Zinc	µg/l	51.3 - 1,573	BDL - 316
Copper	µg/l	BDL - 237	BDL

BDL = Below Detectable Limit

[redacted]

the water in the well itself. From the results presented, it is evident that there must be a great deal of dilution of the leachate in the groundwater. It is also quite possible that the soil layer below the refuse cells is effectively reducing the transport of materials from the refuse into the groundwater. It must also be pointed out, though, that the groundwater samples were collected during the dry season, when the amount of leachate produced was relatively minor, which could account for the apparent dilution effect.

Table 2 summarizes some of the characteristics of the soils used in the column studies, as well as the initial conditions of the soils in the columns. It is observed that the clay content of these soils is quite high, accounting for their low permeability. The soils in the columns were compacted to a dry density of from 55% to 64% of their maximum value to allow the leachate to percolate through at the desired rate, which was further adjusted at 12.5 to 15.0 ml/hr. by means of a clamp on the effluent tubing.

Figures 3 through 15 summarize in graphical form some of the results of the column studies. In the preparation of these graphs the effluent of the control column was taken as the "corrected" or "adjusted" input to the soil columns. In this form any effect introduced by the column materials or by the glass wool used to support the soil would hopefully cancel out to a great extent. Figures 3 and 4 serve to illustrate how the leachate entering the columns (input) compare with the liquid flowing out of the control column (control) for two parameters: COD and total Kjeldahl nitrogen. It can be seen that the differences are not significant for these two parameters. These was the case for most parameters, with minor exceptions, as shown in figures 16 through 36 included in Appendix A.

Figures 5 and 6 show how the pH and the specific conductance varied during the course of the 35-day run. The specific conductance was plotted

Table 2 : Characteristics of Soils Used in this Study

	SOIL SERIES		
	Daguey	Humatas	Vega Alta
Soil Classification			
ASTM Unified	MH	MH - CL	MH - CL
SCS Comprehensive	Ultisol	Ultisol	Ultisol
Representative region in Puerto Rico	Hills and slopes throughout the Island, except Lajas and Humacao regions.	Hills and slopes throughout the Island, except Lajas region.	Coastal plains of the North.
Characteristics			
pH	5.56	4.75	5.88
Cationic exchange capacity (Ammonium Acetate extraction at pH 7.0), meq/100g	21.0	15.0	15.4
Electrical Conductivity, umho/cm	31	55	72
Surface area, m^2/g	114.3	87.5	60.7
Organic Carbon, %	0.078	0.039	0.438
Chlorides, meq/g	0.09	0.20	0.09
Bicarbonates, meq/g	0.21	0.11	0.21
Nitrogen, %	0.018	0.011	0.091
Composition, %:			
Gravel	0	0	8
Sand	1	3	8
Silt	37	42	31
Clay	62	55	53
Specific gravity	2.85	2.77	2.69
Compaction test:			
Max. dry density, g/cm^3	1.81	1.79	1.90
Optimum humidity, %	49	37	27
Initial Conditions of soils in columns:			
Soil volume, cm^3	620	620	620
Dry density, g/cm^3	1.13	0.98	1.21
Porosity, %	60	65	55
Soil mass, g	700	603	748

COD Input Variation

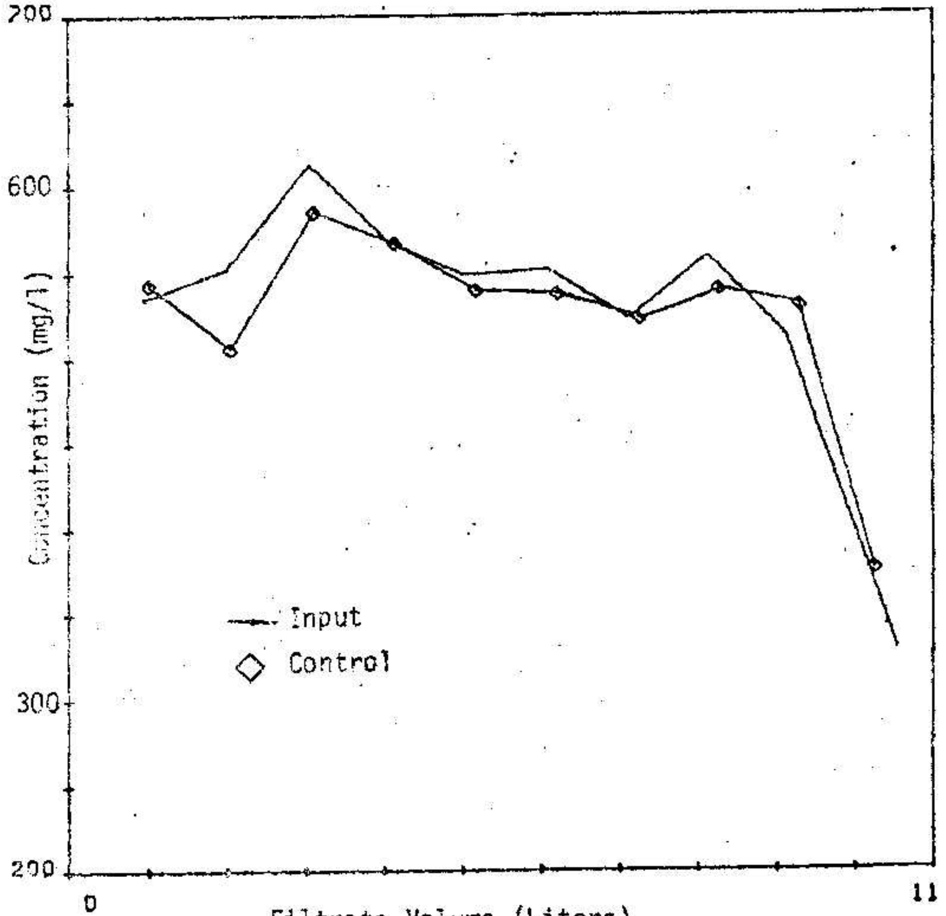


Figure 3

Total Kjeldahl Nitrogen Input Variation

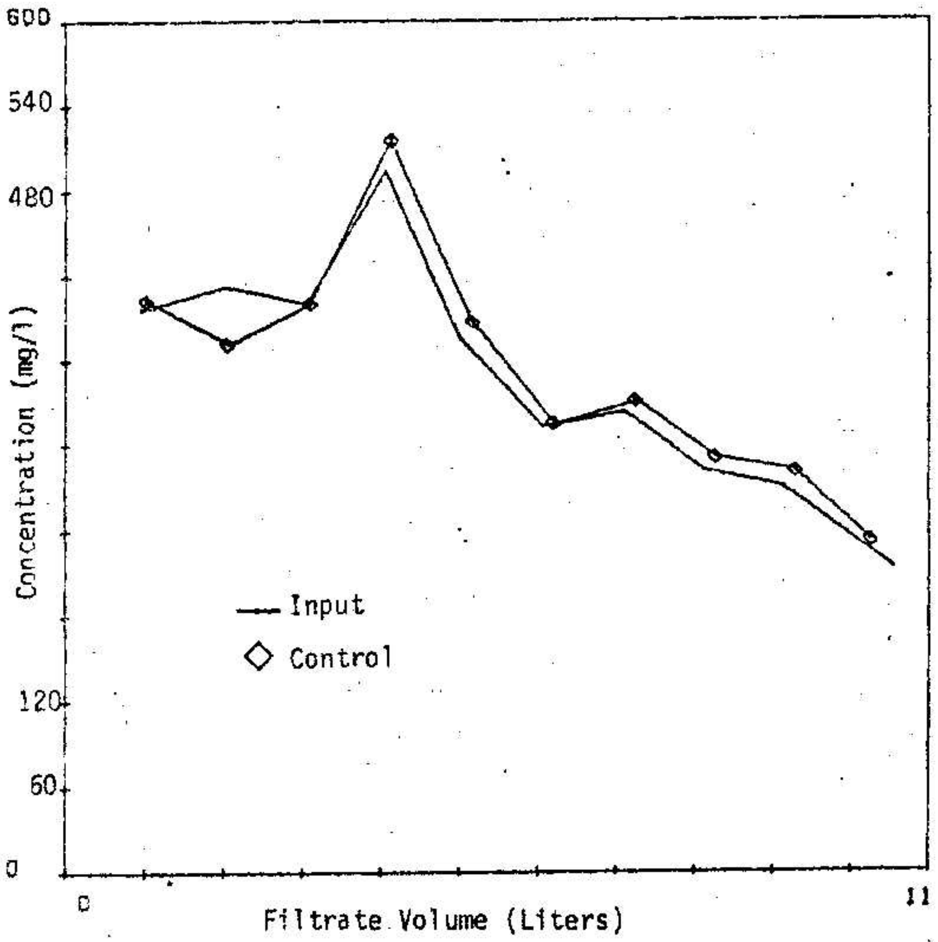


Figure 4

The pH variation during study

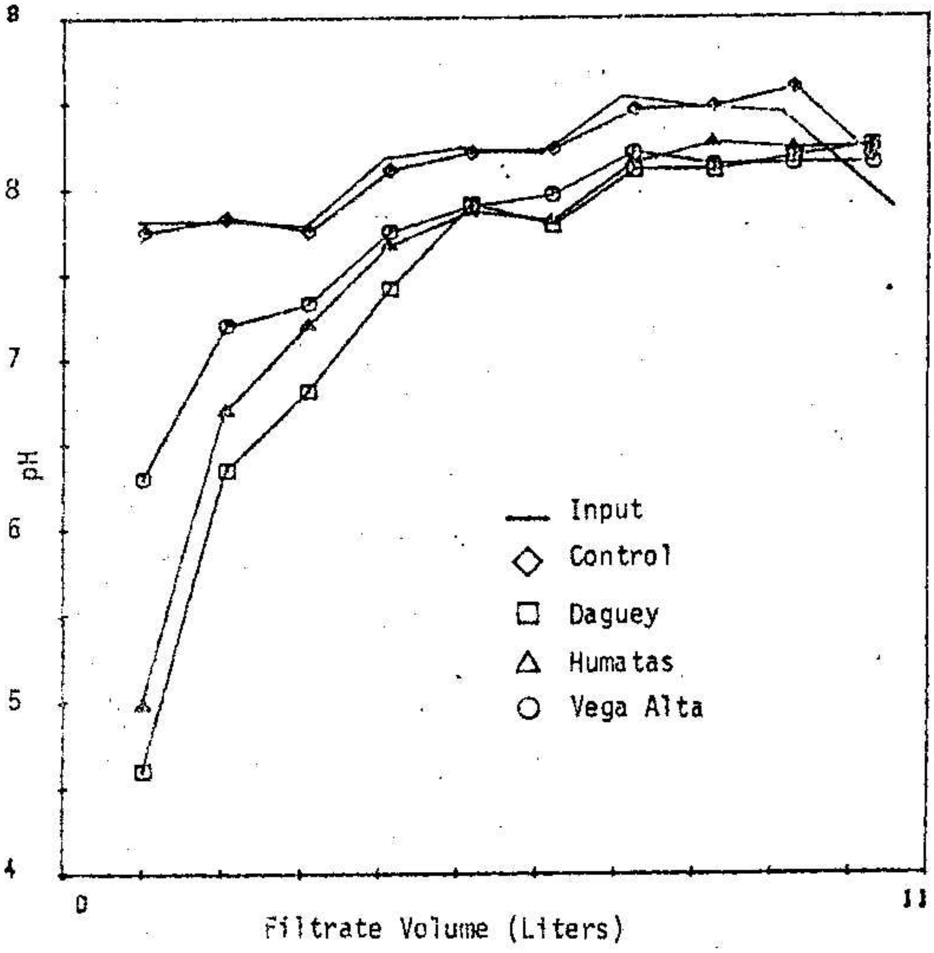


Figure 5

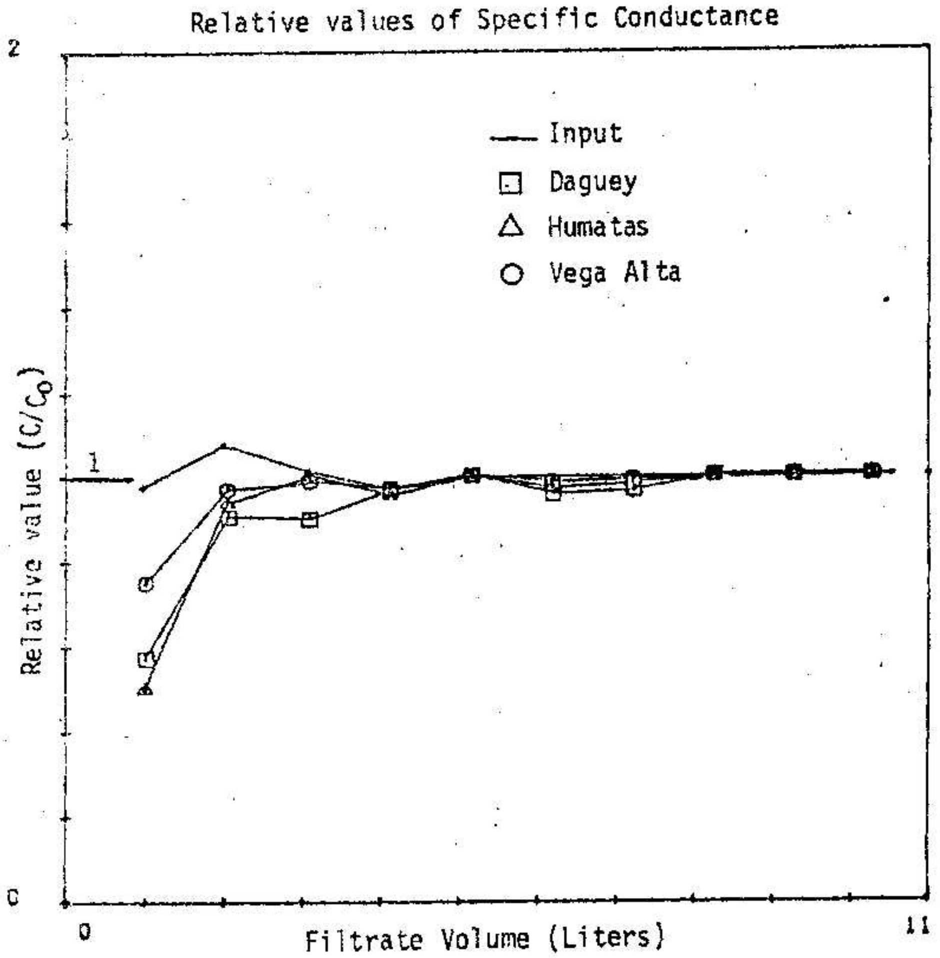

Relative values of Specific Conductance
2
1
0
Relative value (C/C$_0$)
0
11
Filtrate Volume (Liters)
Input
Daguey
Humatas
Vega Alta

Figure 6

in terms of the value of the conductance of the soil column effluent divided by the control column effluent. It is observed that during the initial stages of the run the relative specific conductances for the effluents of the three soil columns were less than 1, indicating that some material was being retained in the columns; but as the run proceeded the values approached unity quite rapidly. This occurred about half way through the course of the run, when about 5 liters of the leachate had been filtered through each column. It is interesting to notice that the three soils behaved in a similar fashion with respect to this parameter, which is a measure of the soluble ions in the leachate. The 5-liter threshhold where the relative specific conductance for the filtered leachates became unity, represents a ratio of about 7 liters of leachate per kilogram of soil mass. At this stage some sort of equilibrium had been reached by means of which no more net soluble material transfer occurred between leachate and soil. This was not the case, though, for individual components of the leachate, as illustrate by figures 7 through 15, and 37 through 51 in Appendix B of this report.

The pH value started in the acid range at the beginning of the run. The lower pH was exhibited by the Daguey soil effluent and the higher pH by the Vega Alta soil effluent. About half way through the run the three column effluents attained a pH of 7.9 and, thereafter, raised slightly together to about 8.2, remaining near that value to the end of the run. For most of the run, the filtered leachates exhibited lower pH values than the input and control leachates (which were alkaline all the time) due to the acidity of the soil samples.

Figures 7 through 15 represent the retained mass in the soil columns for different leachate components, individually or in combination. These are cumulative values and must be interpreted accordingly. Positive values

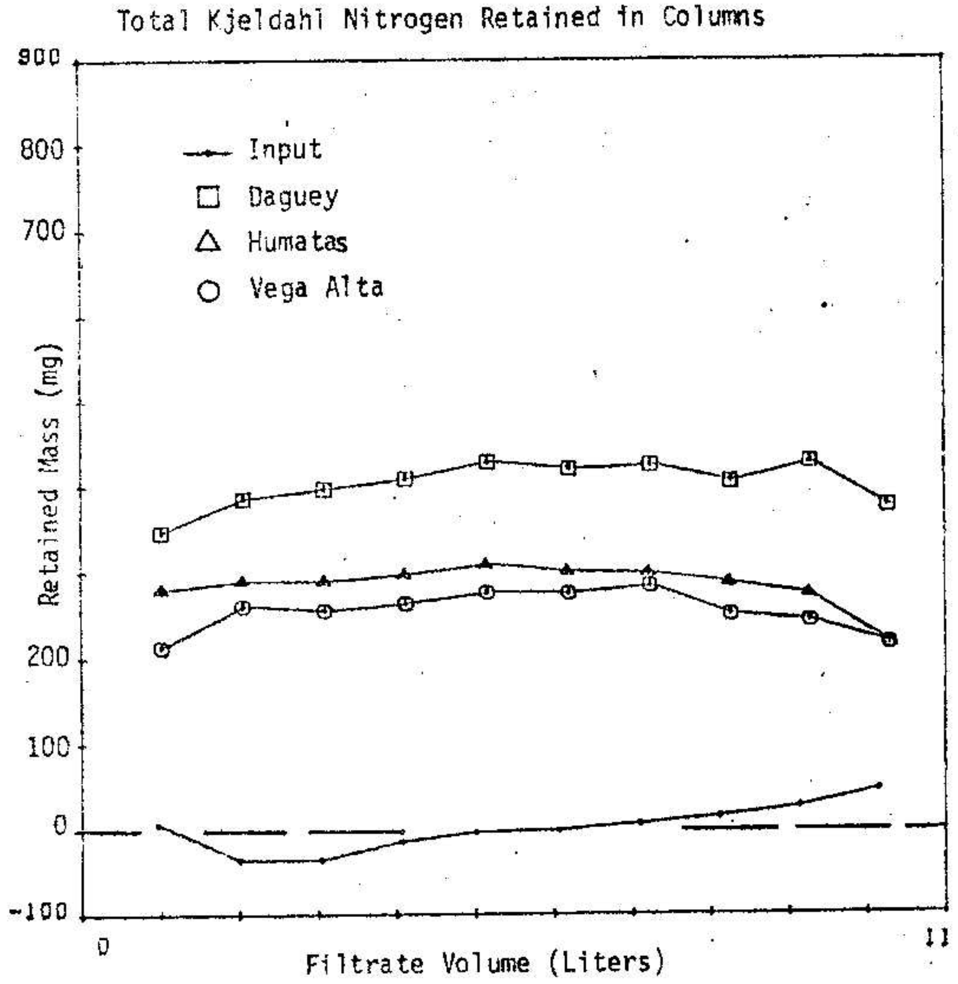

Total Kjeldahl Nitrogen Retained in Columns
900
800
700
200
100
0
-100
Retained Mass (mg)
Input
Daguey
Humatas
Vega Alta
0
11
Filtrate Volume (Liters)

Figure 7

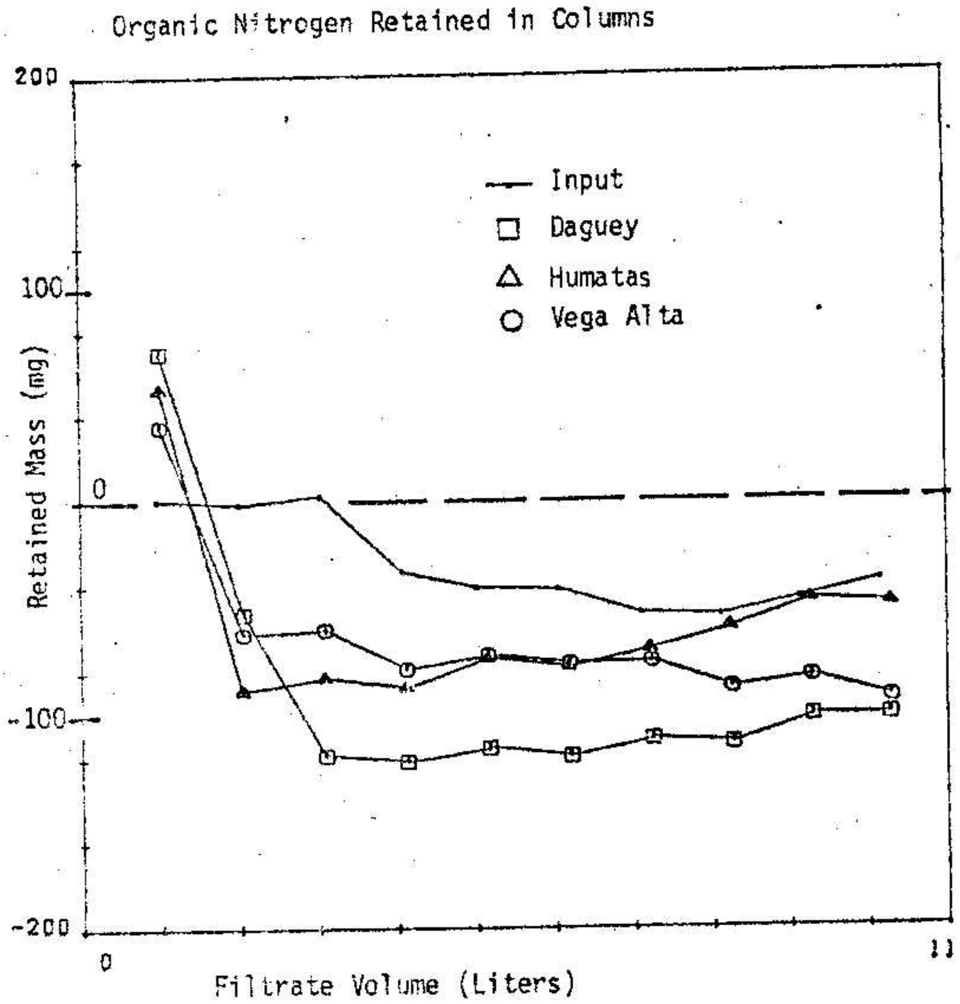

Organic Nitrogen Retained in Columns
200
100
0
-100
-200
Retained Mass (mg)
0
11
Filtrate Volume (Liters)
Input
Daguey
Humatas
Vega Alta

Figure 8

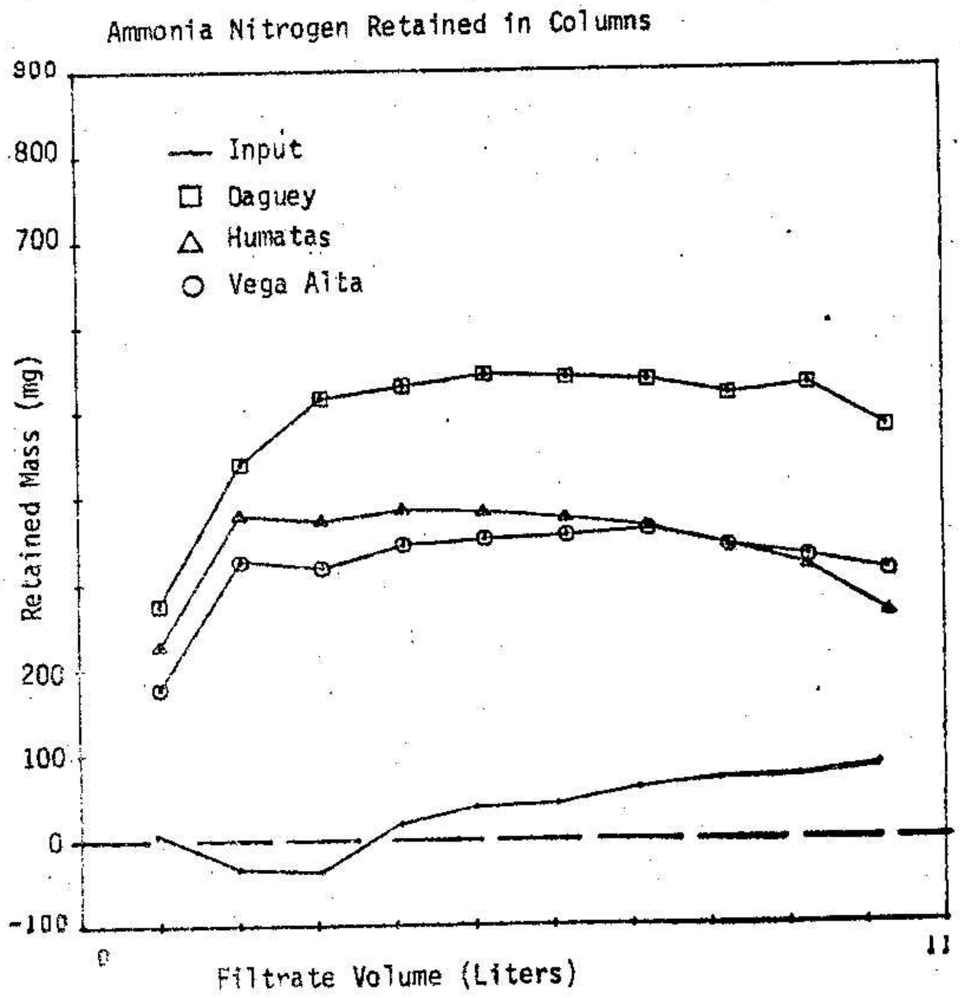

Ammonia Nitrogen Retained in Columns
900
800
700
200
100
0
-100
0
11
Retained Mass (mg)
Filtrate Volume (Liters)
Input
Daguey
Humatas
Vega Alta

Figure 9

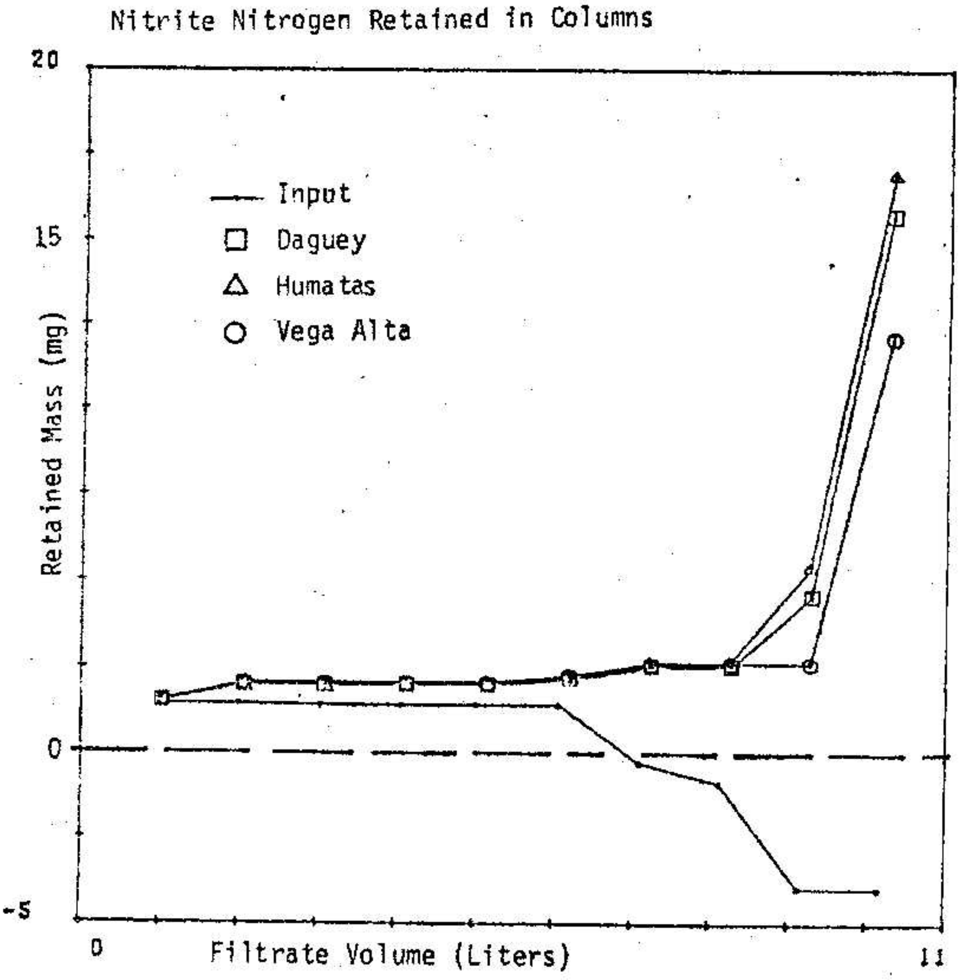

Nitrite Nitrogen Retained in Columns
20
15
0
-5
Retained Mass (mg)
0
Filtrate Volume (Liters)
11
Input
□ Daguey
△ Humatas
○ Vega Alta

Figure 10

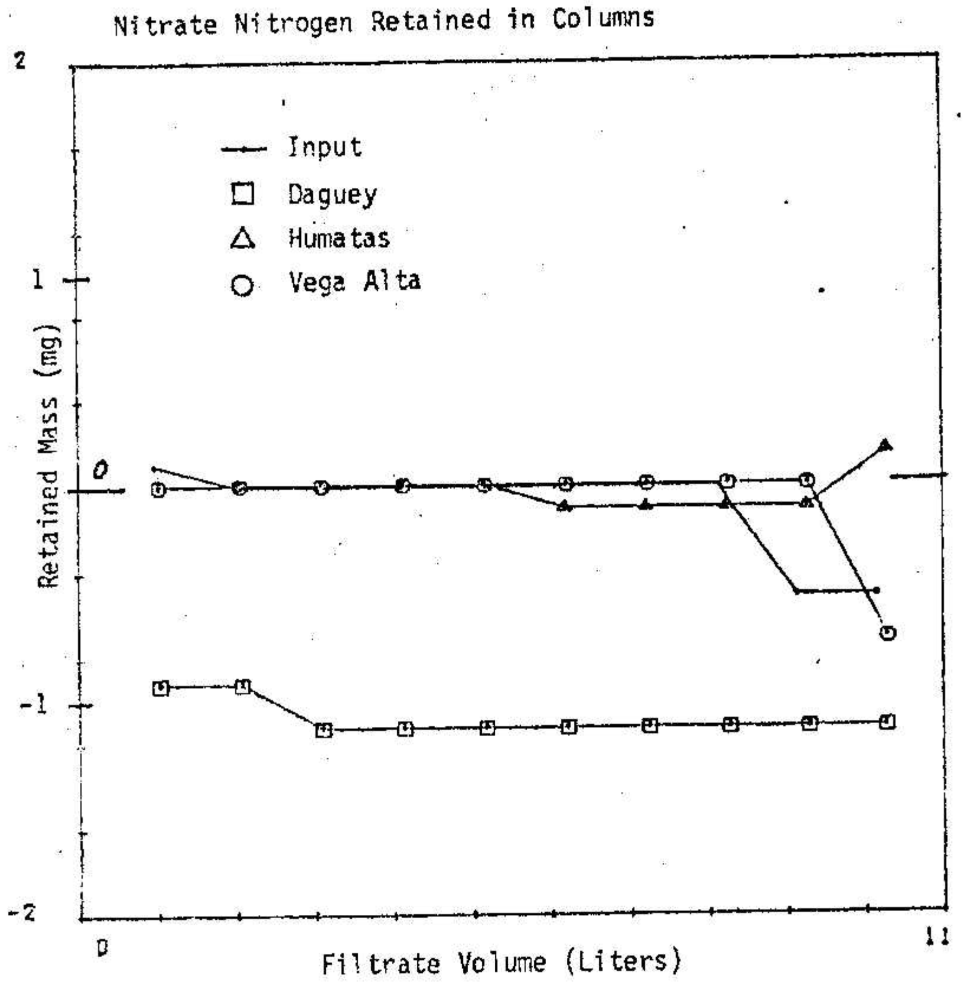

Nitrate Nitrogen Retained in Columns
Input
Daguey
Humatas
Vega Alta
2
1
0
-1
-2
Retained Mass (mg)
0
11
Filtrate Volume (Liters)

Figure 11

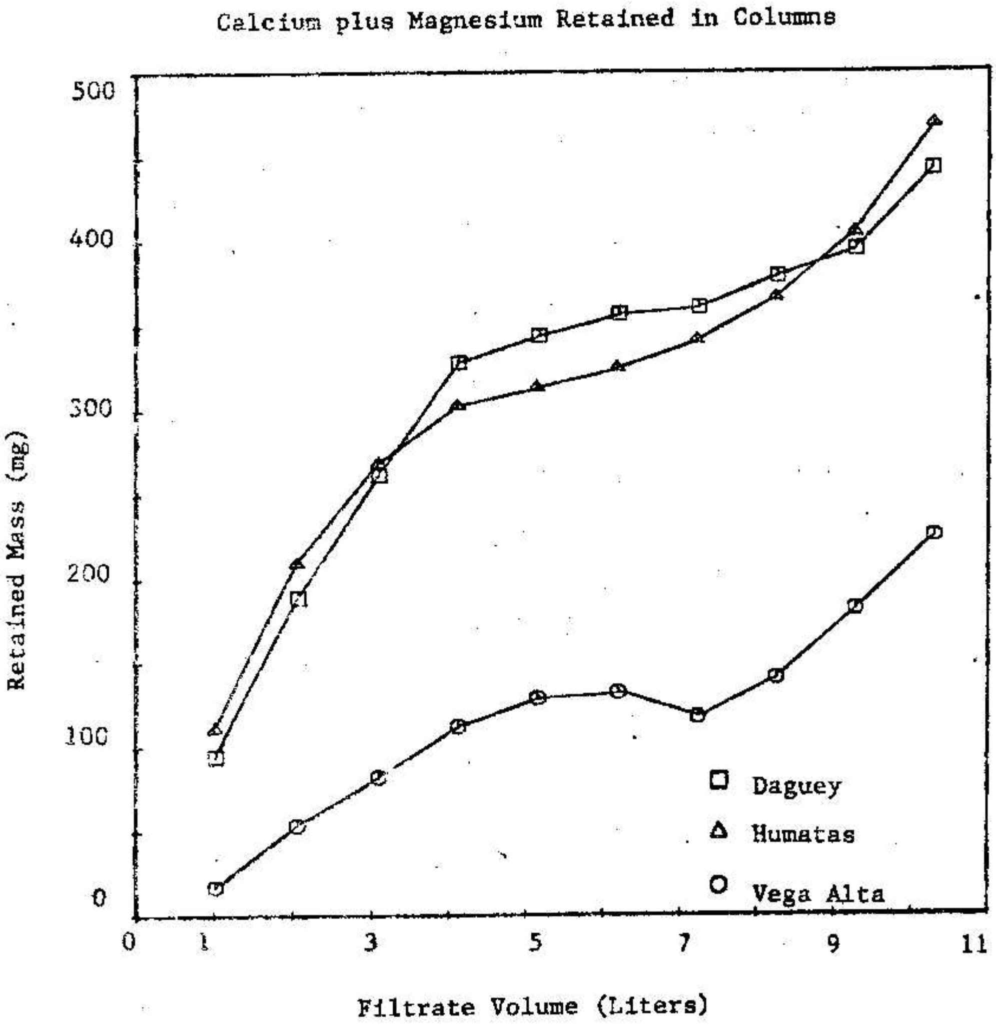

Calcium plus Magnesium Retained in Columns
500
400
300
200
100
0
0
1
3
5
7
9
11
Retained Mass (mg)
Filtrate Volume (Liters)
□ Daguey
△ Humatas
○ Vega Alta

Figure 12

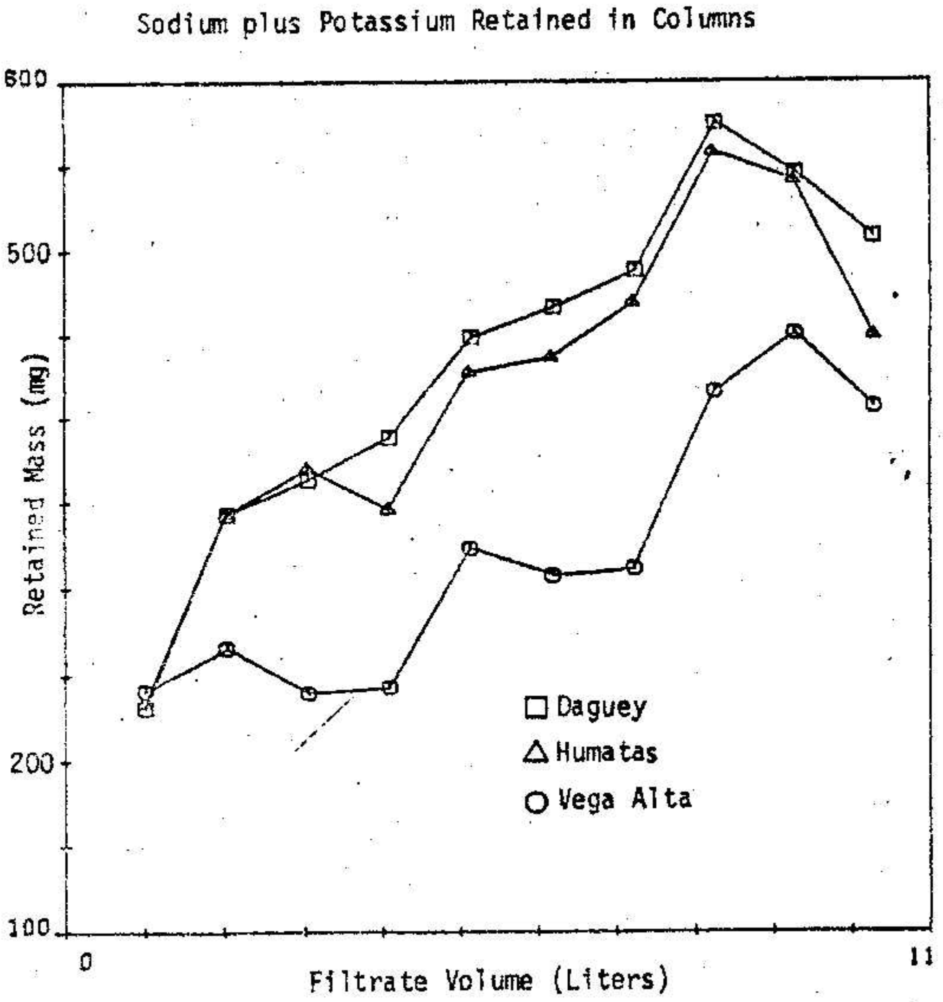

Sodium plus Potassium Retained in Columns

Figure 13

Iron plus Manganese Retained in Columns

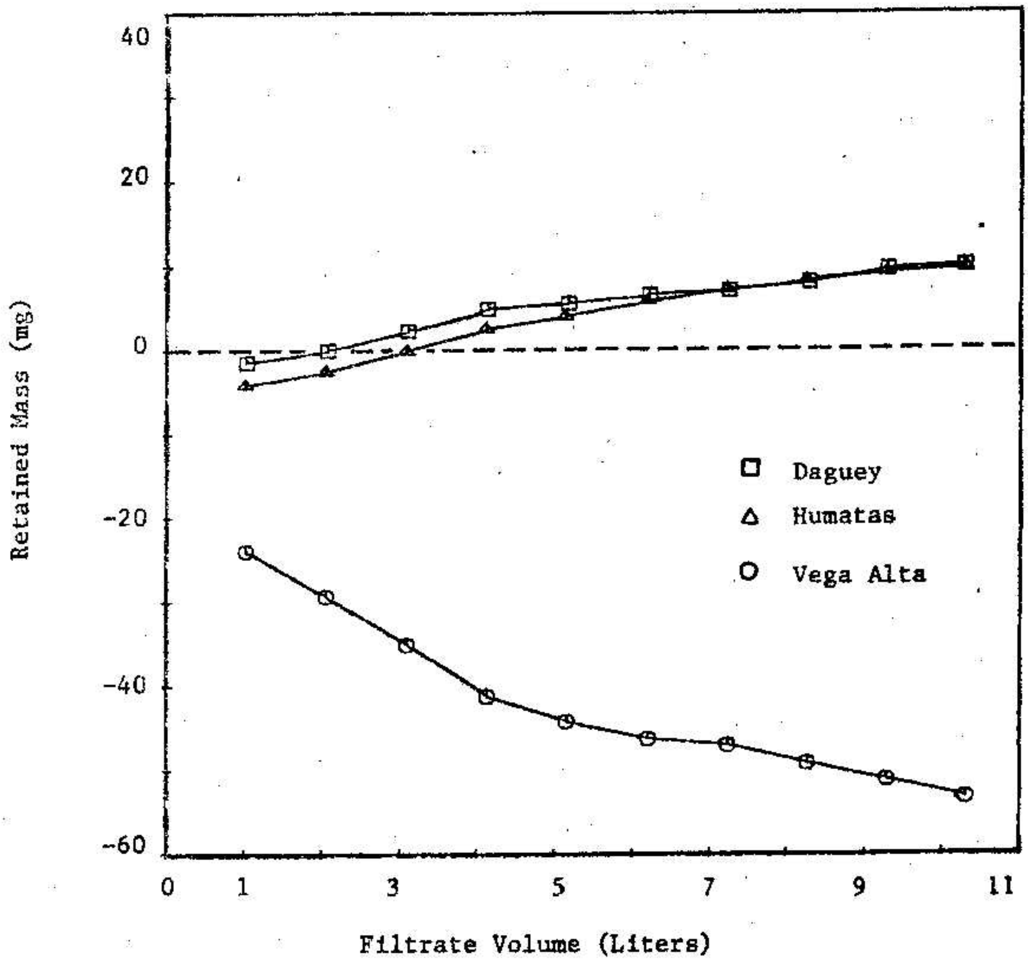


Figure 14

Chromium plus Nickel plus Zinc Retained in Columns

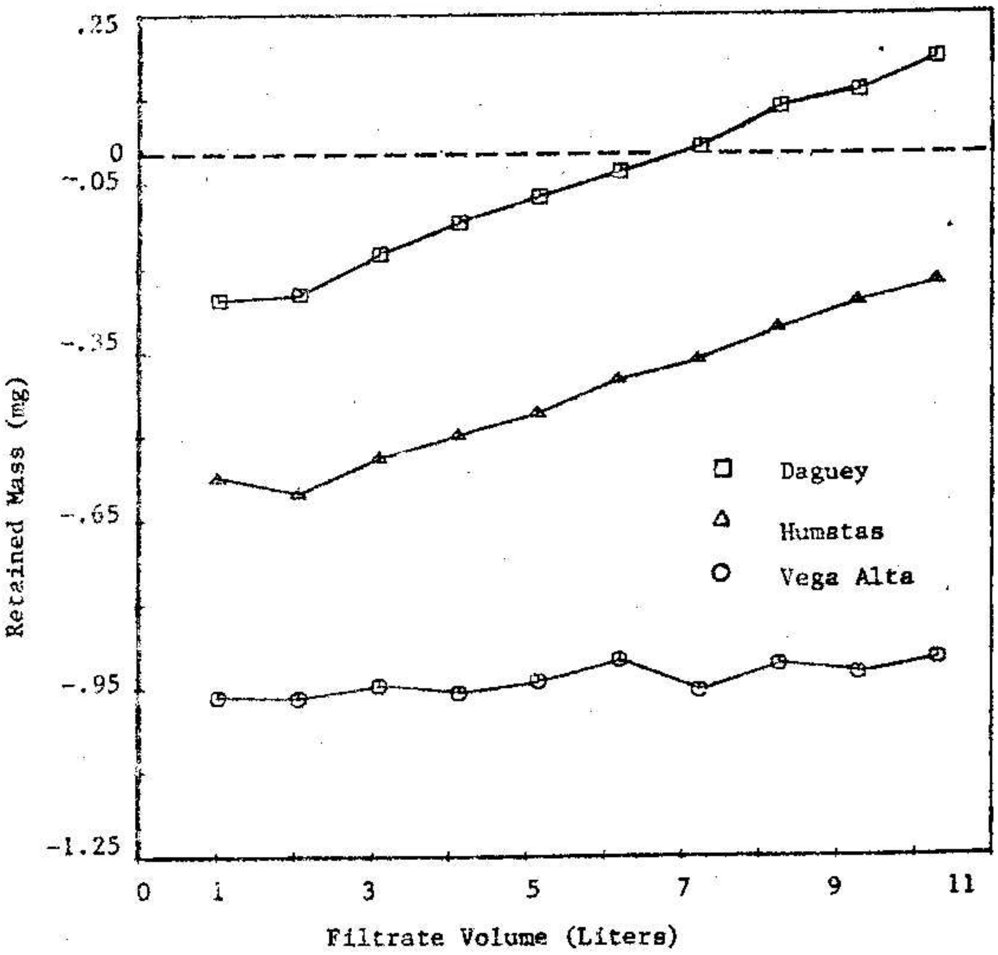


Figure 15

represent a net accumulation in the soil of material extracted from the leachate. Negative values represent a net loss of material by the soil. A positive slope indicates that the soil is removing material from the leachate, while a negative slope means that the soil is transfering material into the leachate. In the case of the nitrogen forms, an exchange between different nitrogen species is also possible, this must be taken into account when interpreting figures 7 through 11. The variation of the nitrogen forms in the input to the columns is represented by a cumulative curve, identified as "input". This is a mass curve reflecting the effect of the control column on the nitrogen forms in the leachate input. This curve, as well as the others in these figures were constructed by considering the effluent of the control columns as the "corrected" input for the soil columns. Because of this, net retention in the control column is given by negative numbers and net release is represented by positive numbers. Figures 12 through 15 represent values of retained mass for combinations of related ions, while figures 37 through 51 in the appendix give analogous information for each individual ion.

Certain components in the leachate, such as calcium and magnesium, were continuously retained in the soil columns throughout the course of this study. Sodium and potassium behaved in a similar fashion, except that near the end of the run there was some release of these ions from the soil columns. Iron and manganese were continuously being retained in the Daguey and Humatas soils, except for a small initial release by Humatas. Vega Alta soil released iron and manganese continuously throghout the run, thus increasing their content in the leachate as it percolated through. Metals, (chromium, nickle, and zinc) were initially released by the soils, but were partially reabsorbed by the Humata and Vega Alta soils, with a net increase in the metals concentration in the filtered leachates. The Daguel soil behaved similarly, but at the end of the run it presented a net retention.

When considered individually, nickel and chromium were retained by the three soils, while zinc evidenced a net release by the soils in the conclusion of the run, the greatest release being from the Vega Alta soil.

In general, Daguey and Humatas soils showed close behavioral patterns for many of the components in the leachate under study, while Vega Alta soil departed markedly from those patterns in many instances. For most leachate components, the Vega Alta soil evidenced a lower retention capacity, when compared with the Daguey and Humatas soils. This is probably due to the fact that the Vega Alta soil has the lowest value of surface area of the three soils used in this study. As it is widely recognized, surface area and adsorption capacity go hand in hand.

Conclusions

From the results of this study the following conclusions may be derived:

1. Sanitary landfill leachate characteristics vary widely even for samples taken at the same site. This makes it quite difficult to talk about a "typical" or "average" leachate.
2. At the Mayaguez sanitary landfill, the concentration of the different components in the leachate appeared greatly diminished in the groundwater under the landfill, except for the nickel content. This is probably due to a large dilution effect or to the effectiveness of the soil layer under the refuse cells in retaining most leachate components or to a combination of both factors. The soil column studies clearly showed that the Daguey soil, present at the Mayaguez landfill, has excellent retention capacity for all measured ions, except zinc which showed a net release. Therefore, the apparent increase in the nickel concentration in the groundwater under the landfill, indicated by the

analyzed groundwater samples as compared with the leachate samples (Table 1), could be due to the contamination of the groundwater sample with leachates coming from the area in the landfill where scrap metal is deposited.

3. Although the three different soils used in this study showed varied behaviors with regard to the retention or release of different materials during the course of this project, the relative specific conductance in the filtered leachates approached a value of unity at about half way through the run. This seems to indicate that some sort of equilibrium was reachdd by means of which no more net transfer of soluble material occurred between the leachate and soil phases. The three soils behaved in identical fashion with regard to this matter and for all of them this equilibrium point was reached when the ratio of filtered leachate volume to soil mass was about 7 liters/kg.
4. In general, the soils used in this study were able to retain many of the leachate components with varying degrees of effectiveness. A major exception was zinc which was released by the soils, thus producing a net increase in its concentration in the leachates filtered through the soils. A similar situation occurred with the iron and manganese in the Vega Alta soil column. Therefore, passage of the leachate through a soil layer does not guarantee an improvement on the leachate quality for all its components. In fact some of the leachate components may be increased in concentration due to their release by the soil.

5. Although it was not possible to run column studies with the Almirante soil, its exceptional imperviousness, when properly compacted, makes it an excellent natural sealer to be used both as base and cover material for the refuse cells in a sanitary landfill to prevent or minimize leachate production and migration into the groundwater.
6. Because of the conditions of this study, it was necessary to run the soil column studies with the soils loosely compacted to a permeability that was about two orders of magnitude greater than that found in nature. Under normal compaction these soils are expected to be far more effective in retaining leachate components as observed in this study.
7. The soils used in this study were all acid and the applied leachates had an alkaline pH which varied between 7.8 and 8.5. Many leachate characterizations cited in the literature tend to indicate that oftentimes leachates are acid in nature rather than basic. It is very difficult to predict the outcome of this study if the leachates would have been acid or if alkaline soils would have been used in the columns. Nevertheless, it must be borne in mind that metals are usually easier to precipitate and be removed under alkaline conditions.

Acknowledgement

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APPENDIX A

GRAPHS SHOWING INPUT TO SOIL COLUMNS

[redacted]

Manganese Input Variation

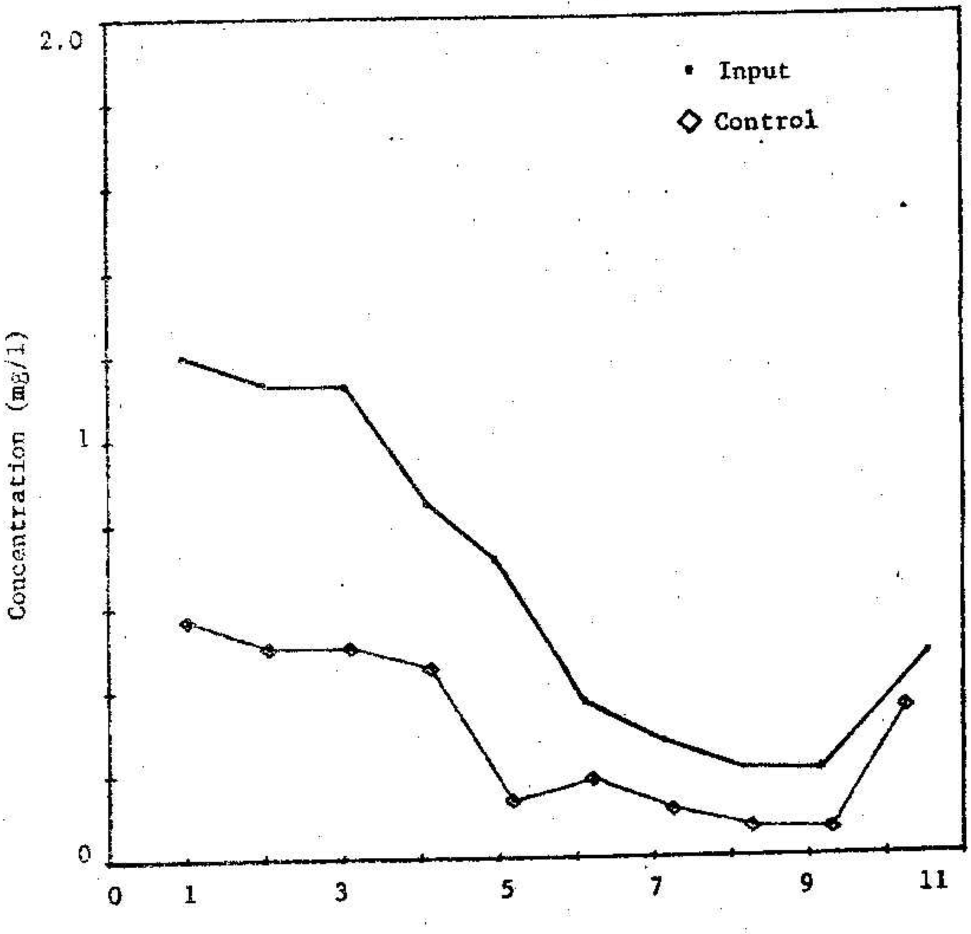


Figure 33

Chromium Input Variation

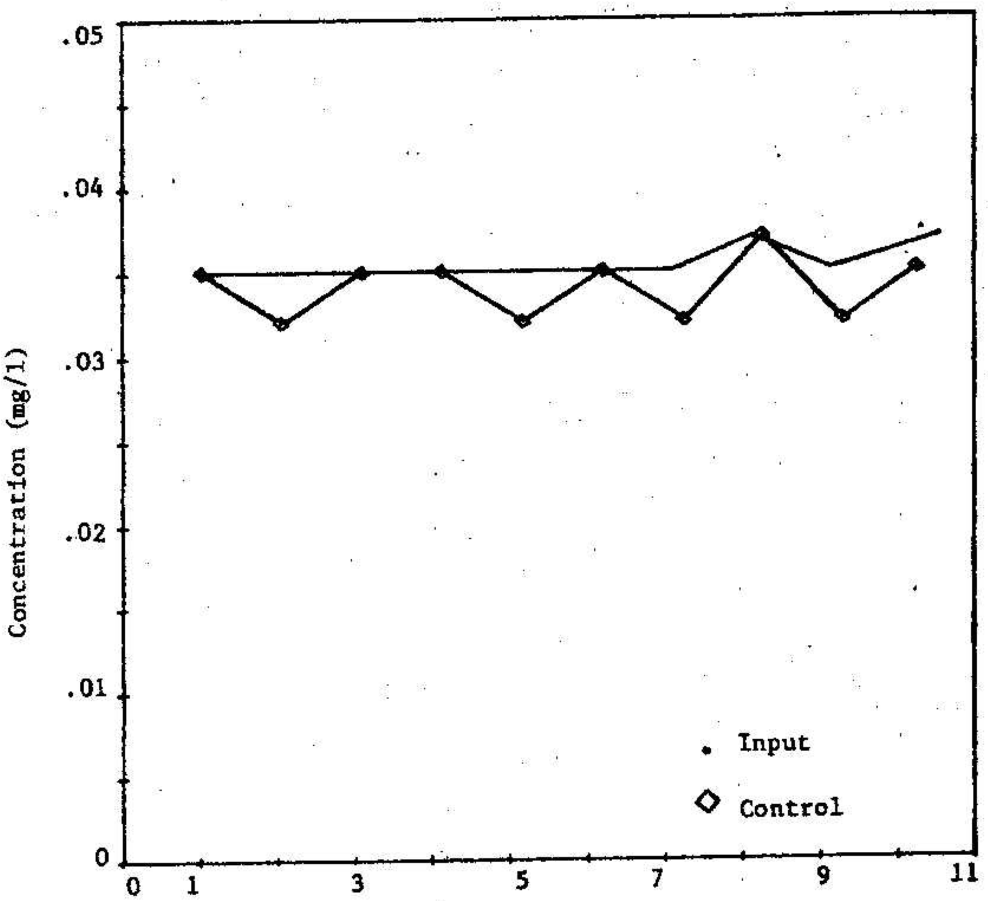


Figure 34

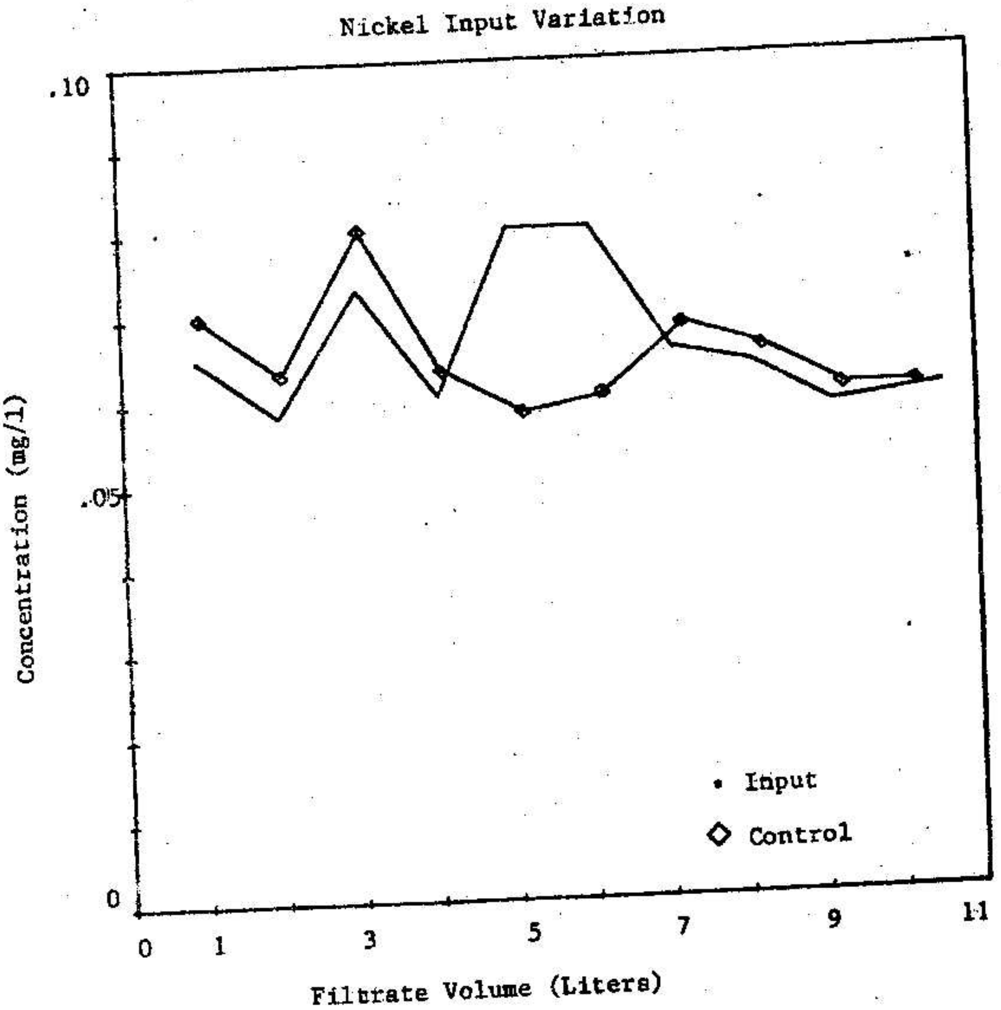
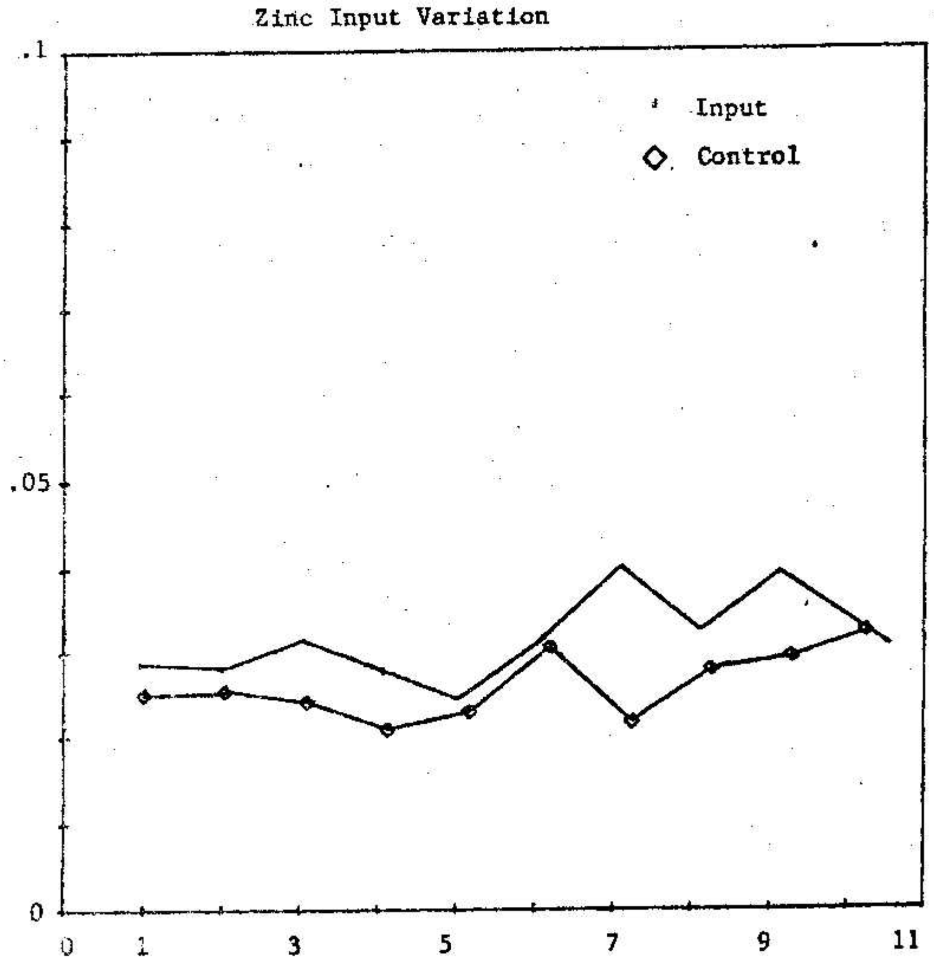

Nickel Input Variation
.10
.05
0
Concentration (mg/l)
0
1
3
5
7
9
11
Filtrate Volume (Liters)
• Input
◇ Control

Figure 35



Filtrate Volume (liters)

Figure 36

APPENDIX B

GRAPHS SHOWING RETAINED MASS IN SOIL COLUMNS

Total COD Removed in Columns

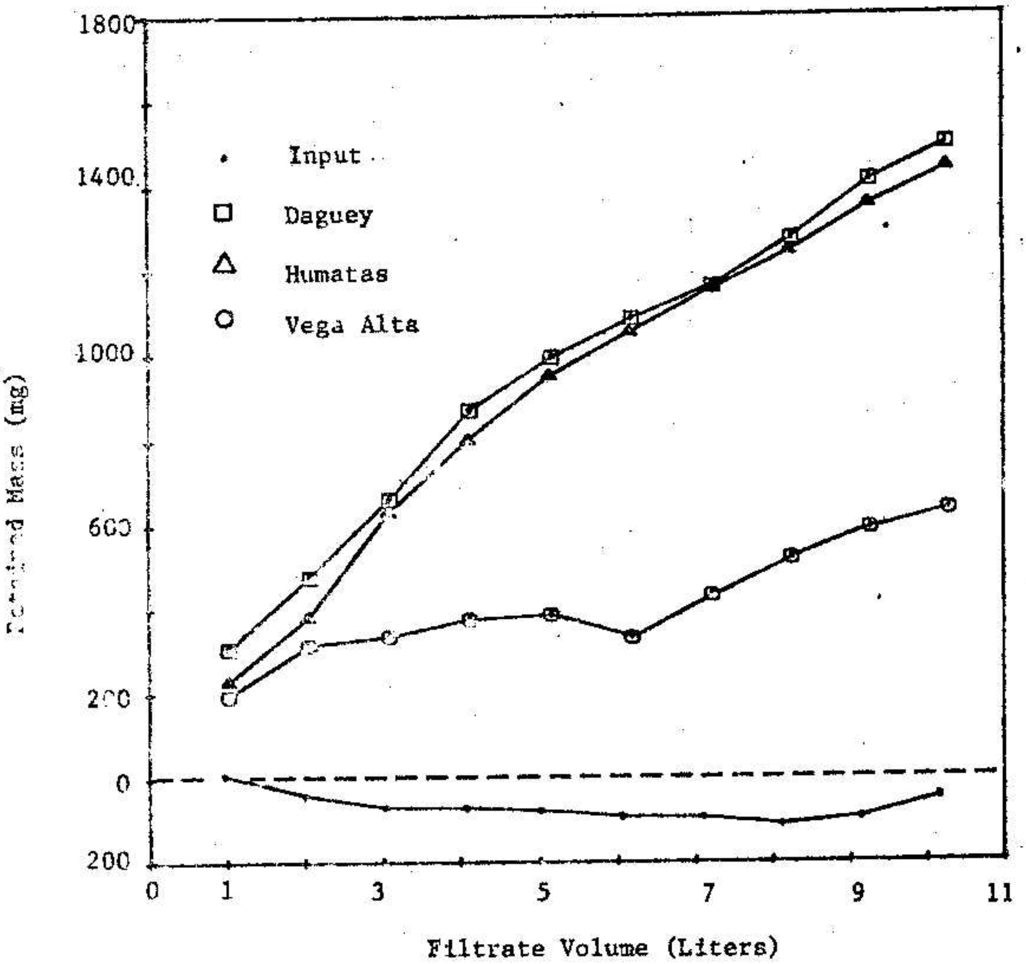


Figure 37

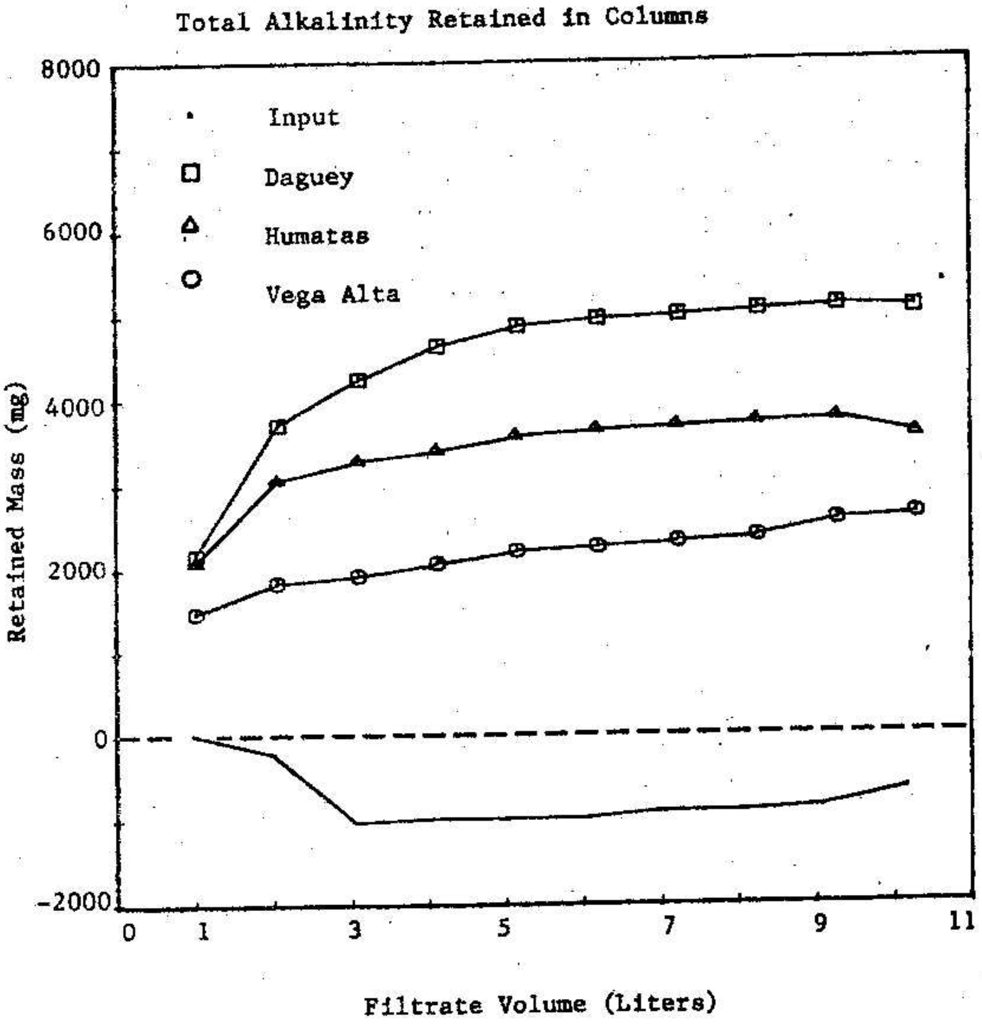

Total Alkalinity Retained in Columns
8000
6000
4000
2000
0
-2000
Retained Mass (mg)
0
1
3
5
7
9
11
Filtrate Volume (Liters)
• Input
□ Daguey
△ Humatas
○ Vega Alta

Figure 38

Calcium Retained in Columns

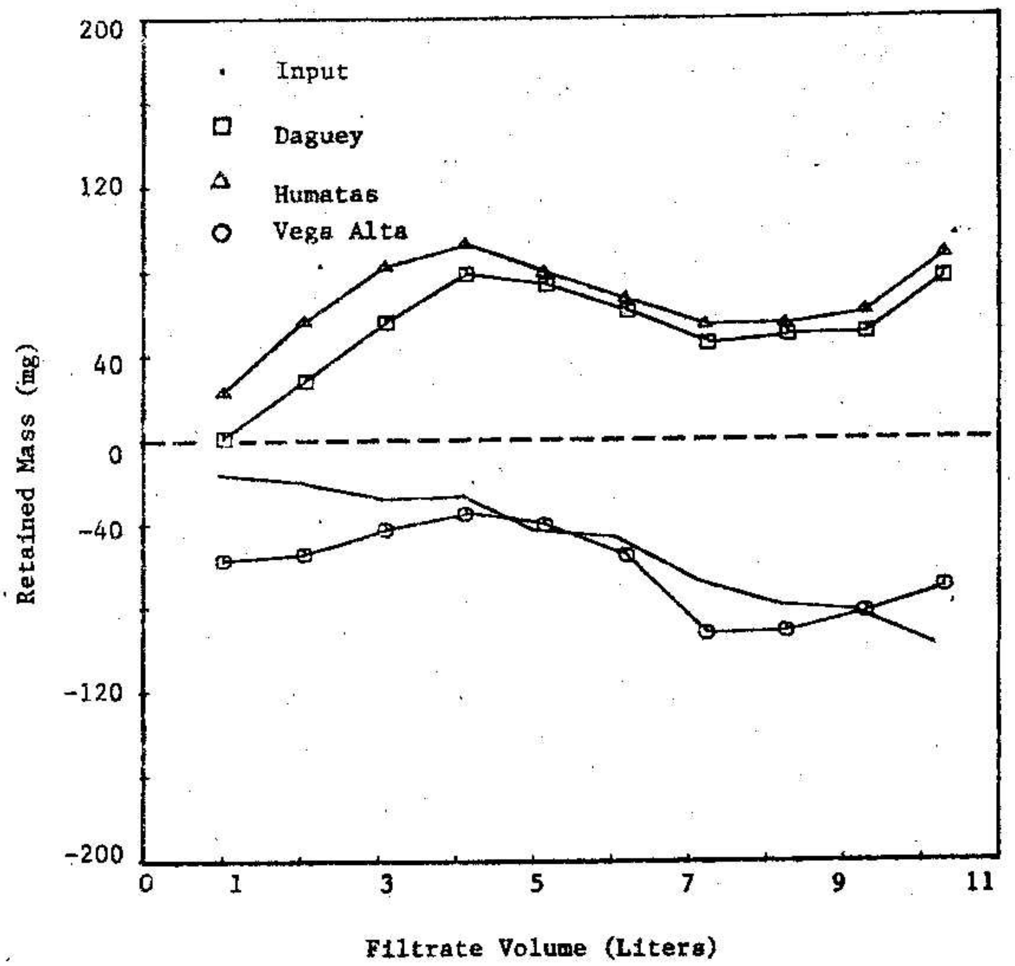
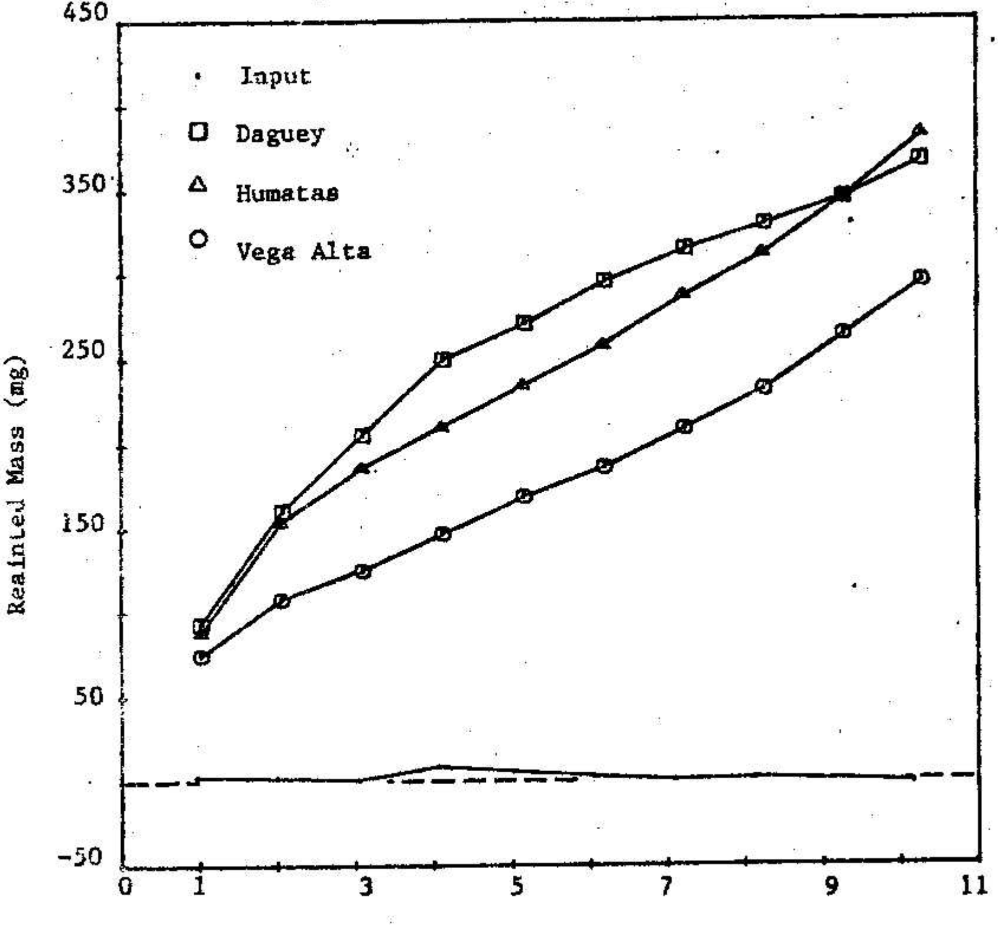


Figure 39

Magnesium Retained in Columns



Filtrate Volume (Liters)

Figure 40

Sodium Retained in Columns

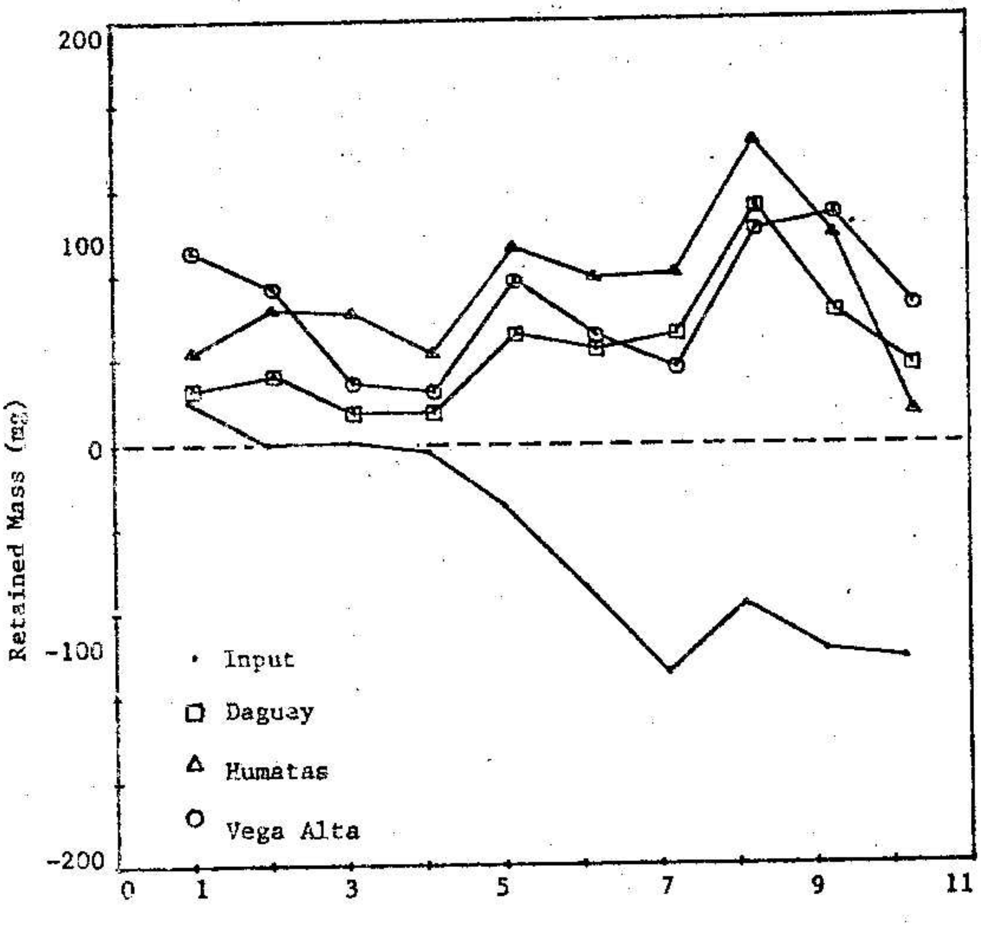


Figure 41

Potassium Retained in Columns

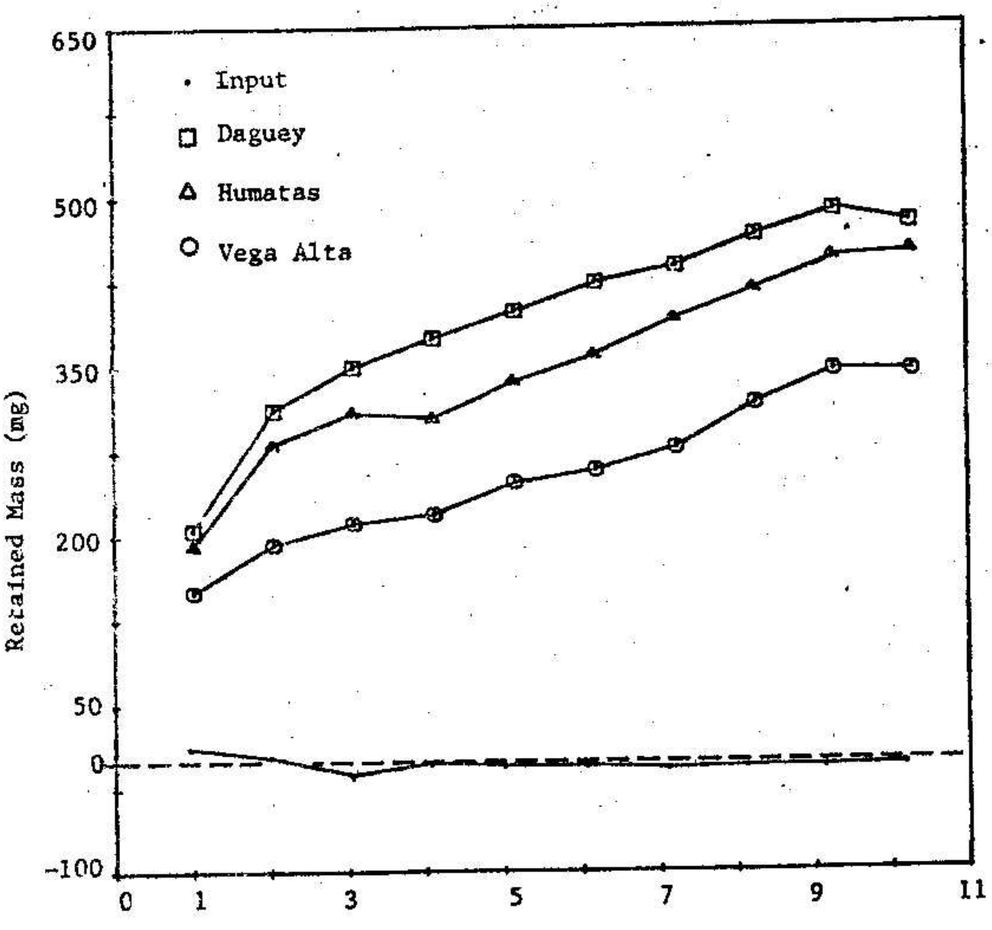


Figure 42

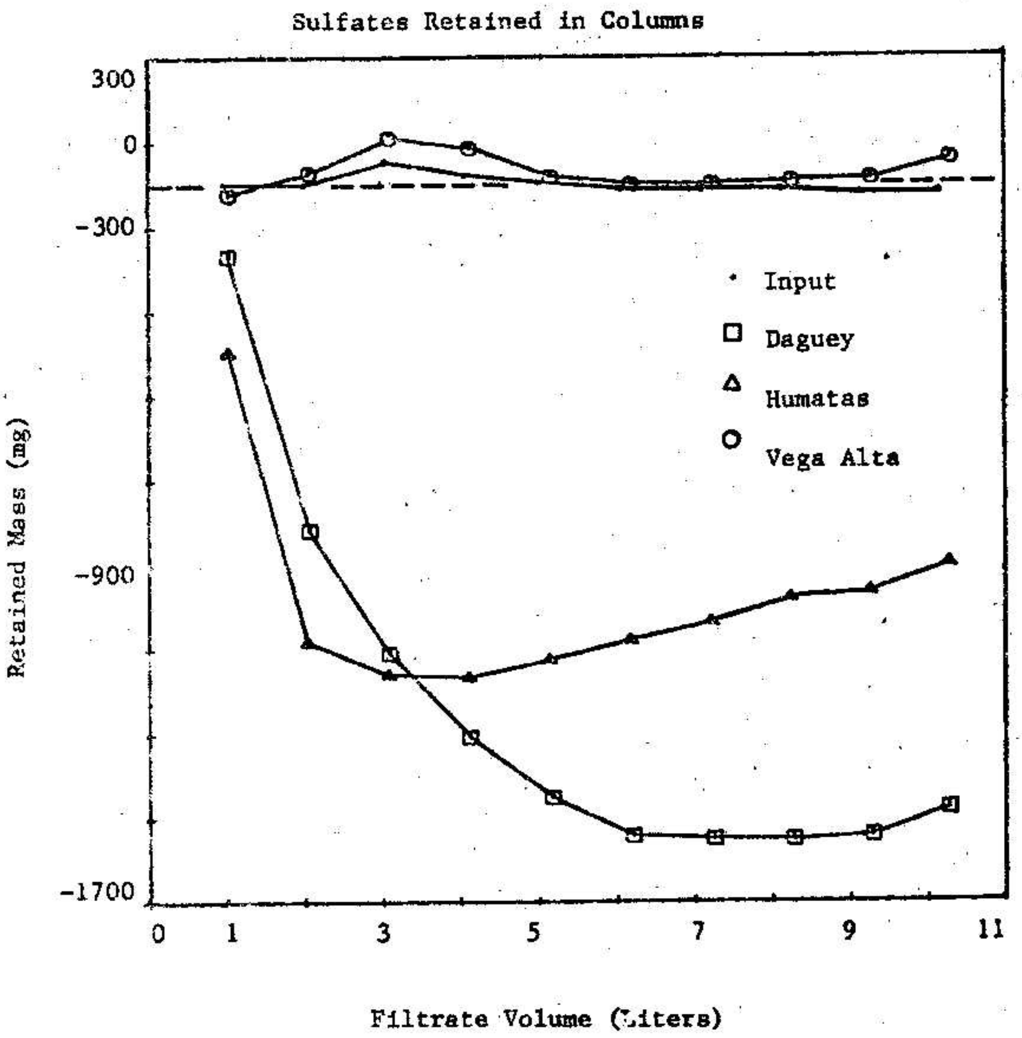

Sulfates Retained in Columns
300
0
-300
-900
-1700
Retained Mass (mg)
0
1
3
5
7
9
11
Filtrate Volume (Liters)
• Input
□ Daguey
△ Humatas
○ Vega Alta

Figure 43

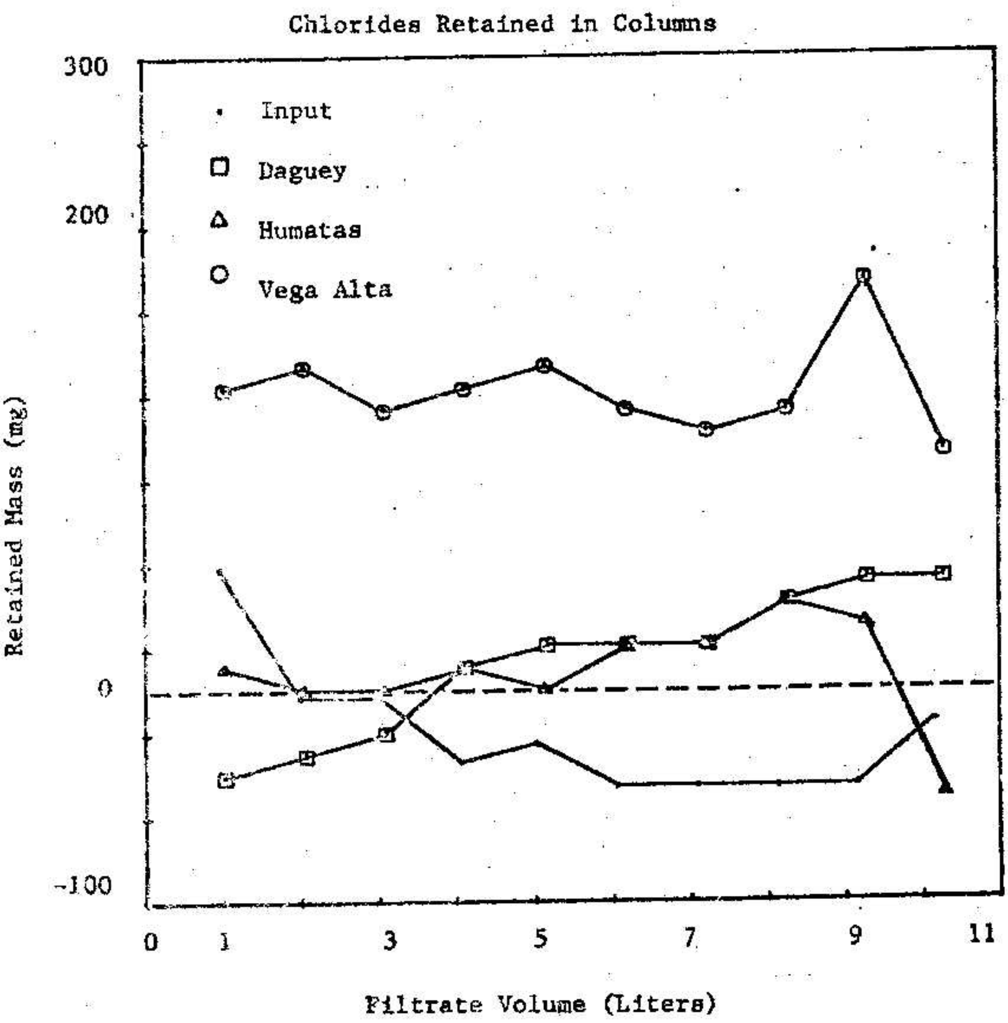

Chlorides Retained in Columns
300
200
0
-100
• Input
□ Daguey
△ Humatas
○ Vega Alta
Retained Mass (mg)
0
1
3
5
7
9
11
Filtrate Volume (Liters)

Figure 44

Total Phosphorus Retained in Columns

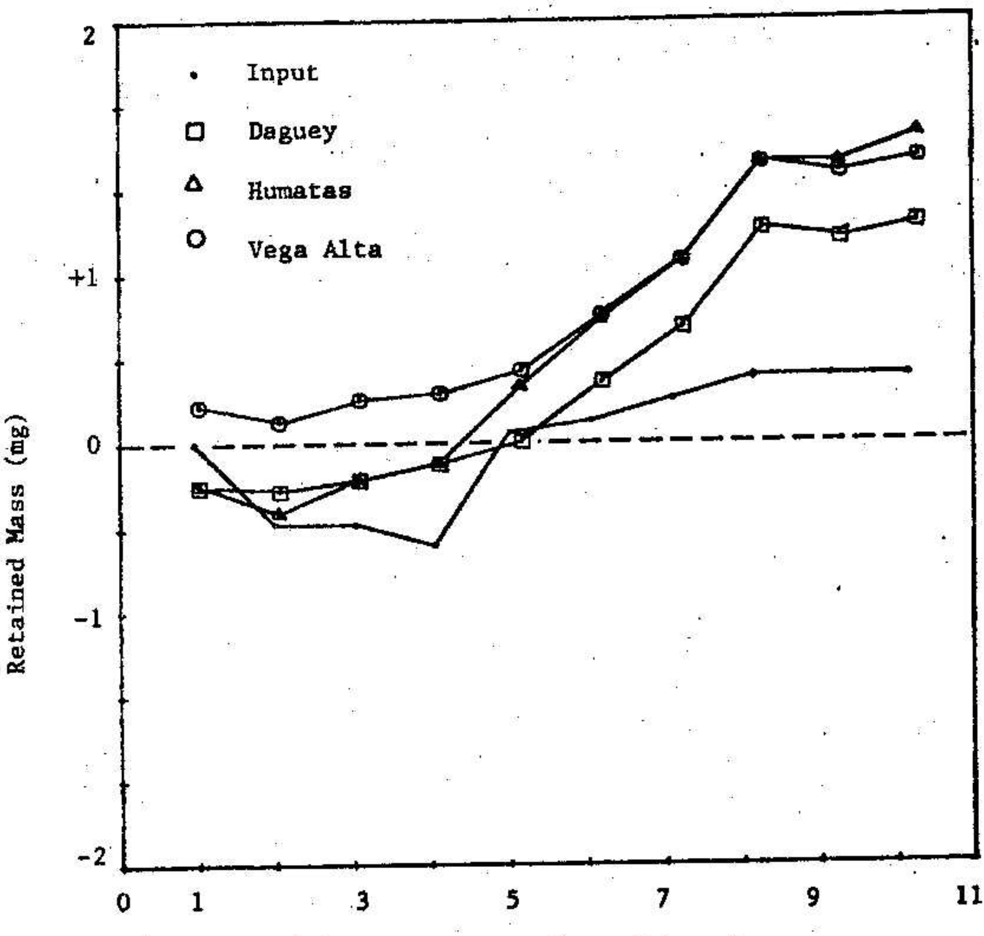


Figure 45

Orthophosfates Retained in Colums

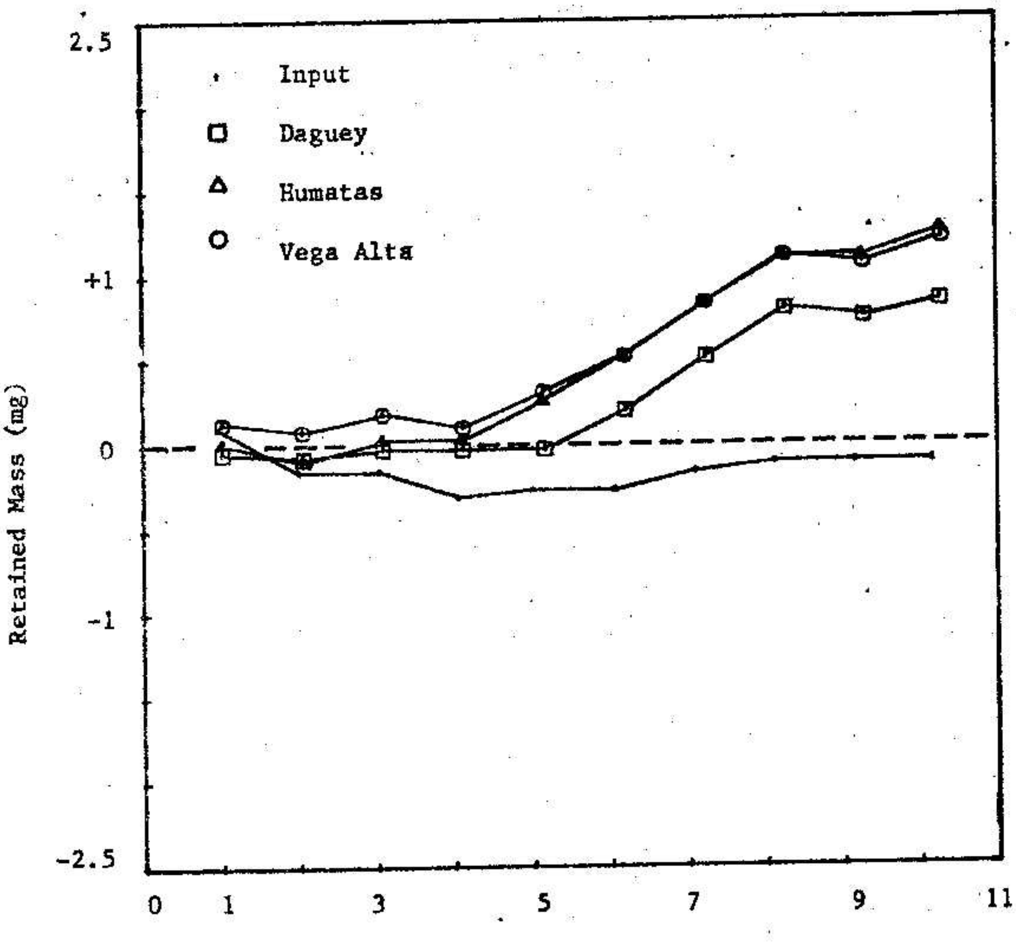


Figure 46

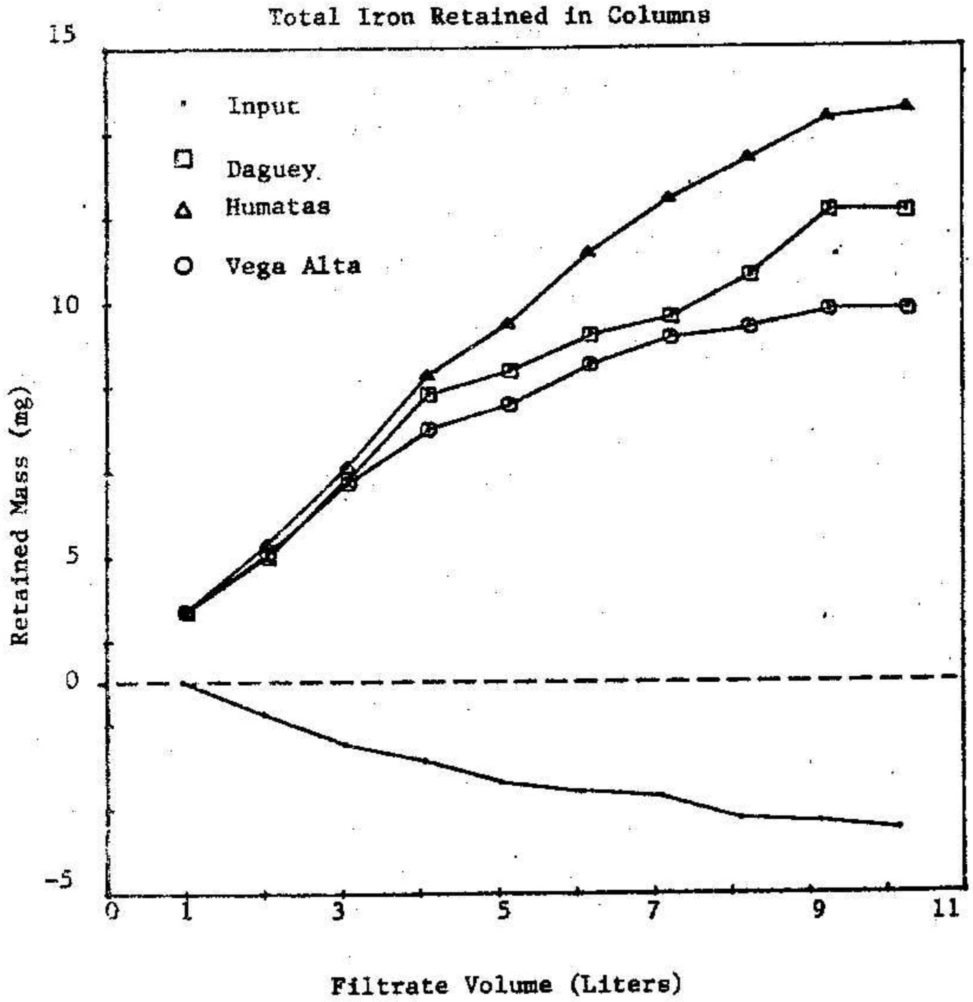

Total Iron Retained in Columns
Input
Daguey
Humatas
Vega Alta
Retained Mass (mg)
15
10
5
0
-5
0
1
3
5
7
9
11
Filtrate Volume (Liters)

Figure 47

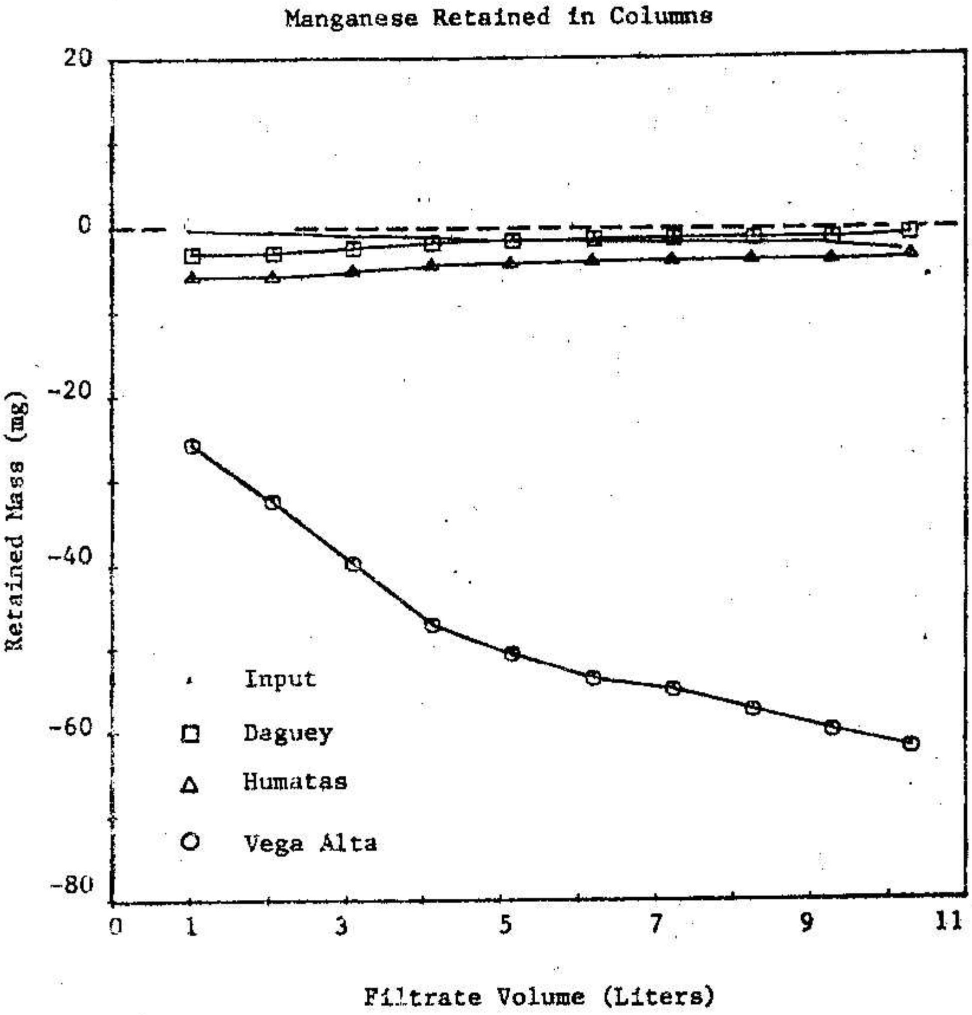
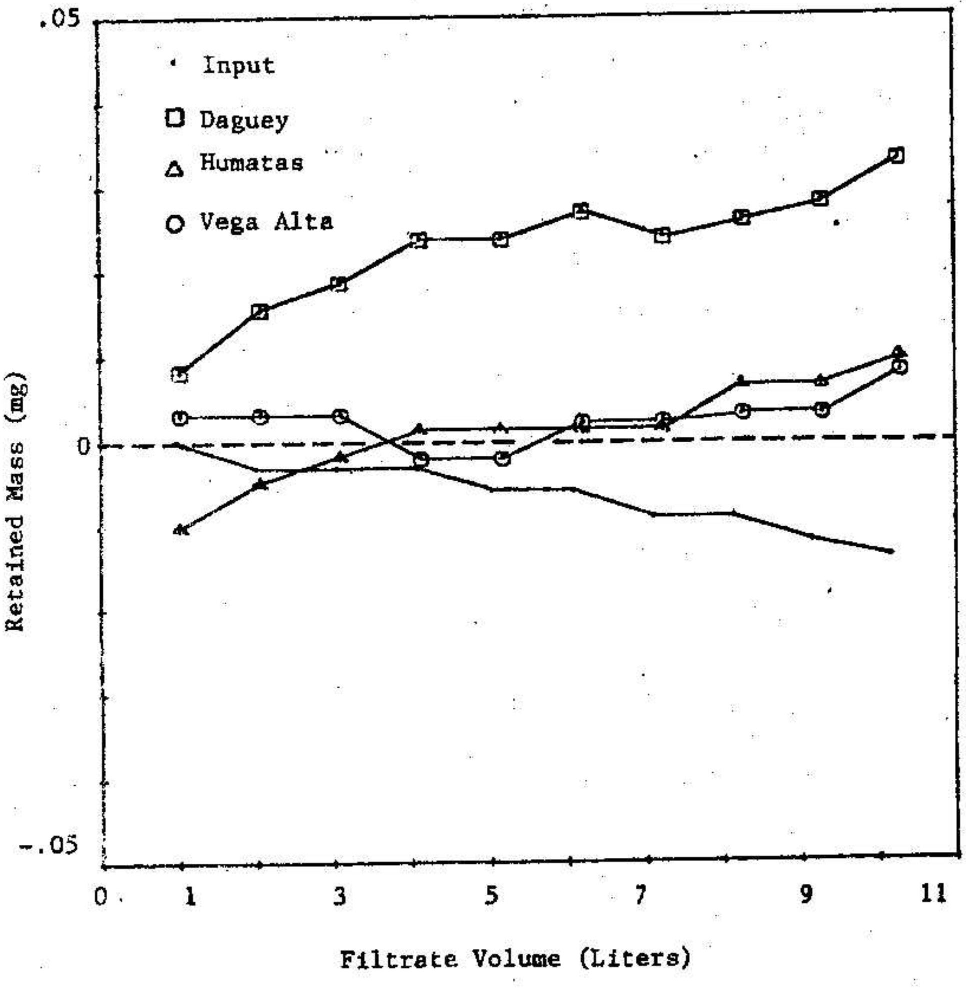

Manganese Retained in Columns
20
0
-20
-40
-60
-80
Retained Mass (mg)
0
1
3
5
7
9
11
Filtrate Volume (Liters)
Input
Daguey
Humatas
Vega Alta

Figure 48



Chromium Retained in Columns

Figure 49

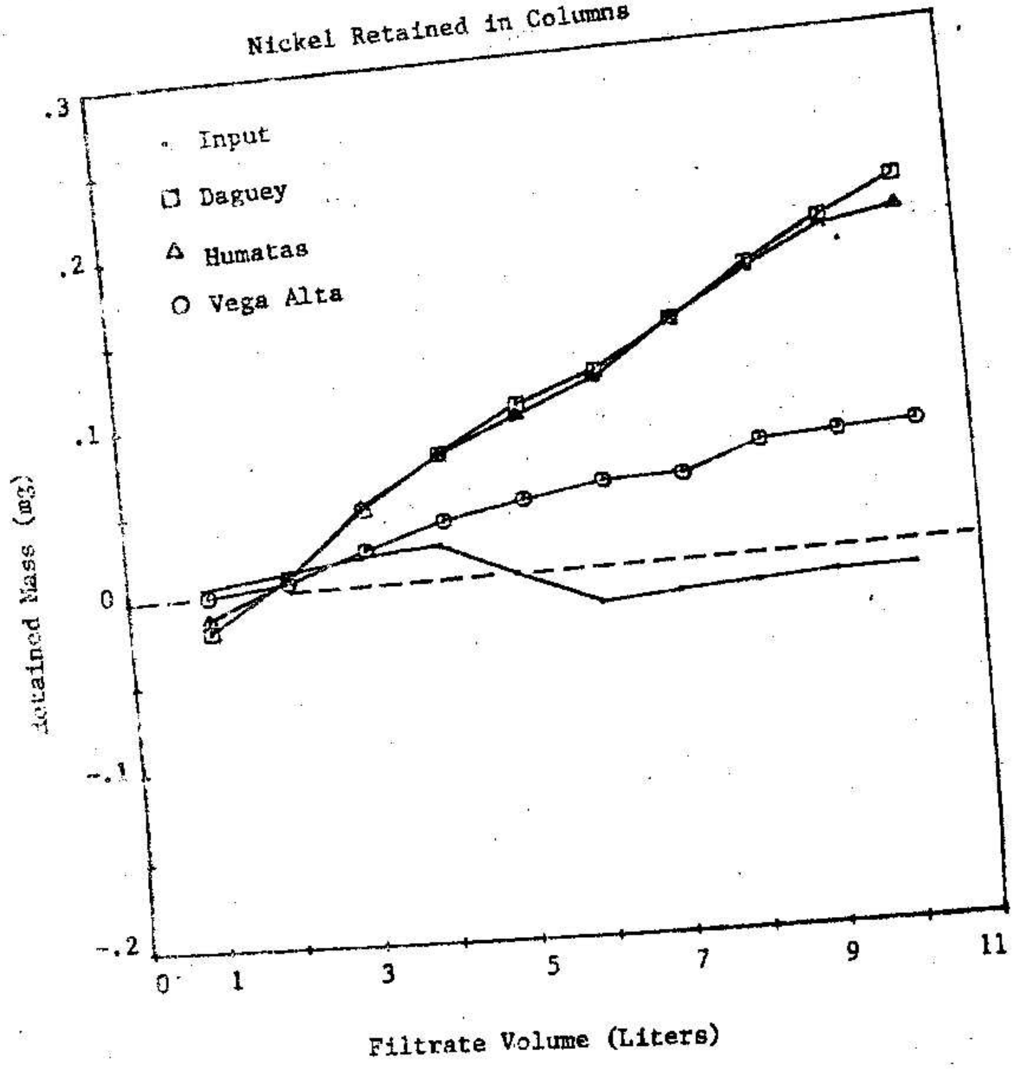

Nickel Retained in Columns
. Input
□ Daguey
△ Humatas
○ Vega Alta
Retained Mass (mg)
.3
.2
.1
0
-.1
-.2
0
1
3
5
7
9
11
Filtrate Volume (Liters)

Figure 50

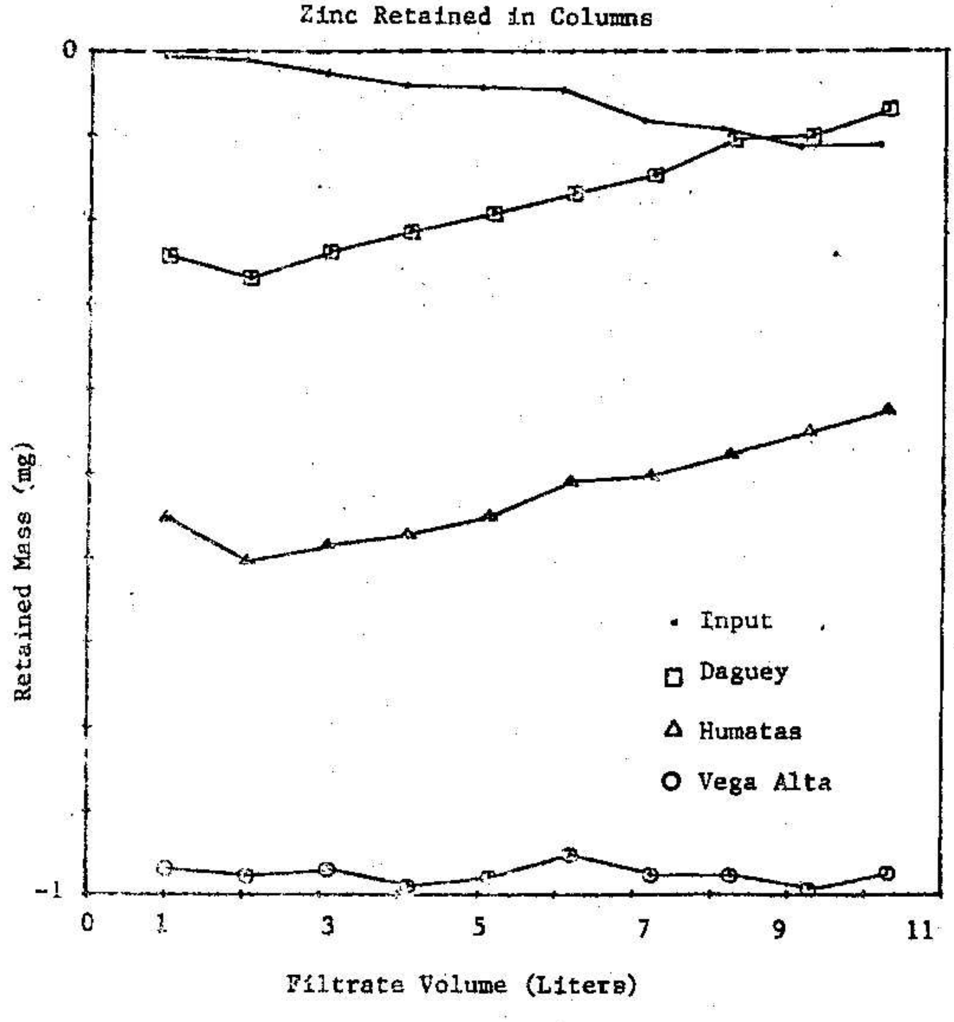

Zinc Retained in Columns
0
-1
Retained Mass (mg)
0
1
3
5
7
9
11
Filtrate Volume (Liters)
• Input
□ Daguey
Δ Humatas
O Vega Alta

Figure 51