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USE OF LATEX AS A SOIL SEALANT TO CONTROL ACID MINE DRAINAGE

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USE OF LATEX AS A SOIL SEALANT

TO CONTROL ACID MINE DRAINAGE

by

UNIROYAL, INC.
Research Center
Wayne, New Jersey 07470

for the

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

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ABSTRACT

A study was made to test the feasibility of using latex as a soil sealant to prevent water seepage into subterranean abandoned mines.

A variety of latexes were screened in laboratory tests using reconstructed soil columns. The most promising latex (an SBR rubber latex) was then field tested on selected 1/4 acre plots near Lanse, Pennsylvania. In general the field tests confirmed the laboratory finding that latex does reduce the permeability of soil to water. However, the economics are not attractive and most of the latex is deposited in the top foot of soil where it is subject to damage by microbiological attack, frost and surface vegetation.

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SECTION I

CONCLUSIONS

In laboratory tests using reconstructed soil columns, rubber latex showed good sealing efficiency when applied at a rate equivalent to 4000-5000 pounds per acre. Results of field testing, however, were inconclusive.

The ideal situation in which latex would coagulate in a narrow zone two to three feet below the surface by reacting with acidic or metallic constituents of the soil was not attained. Rather, the latex was deposited progressively as it passed through the soil (most of it remained in the top foot), the rate of deposition being dependent on soil structure and composition as well as on properties of the latex such as particle size and emulsion stability. Latex stability appears to be a more critical property than latex particle size in controlling penetration. Addition of excess anionic or nonionic surfactants to latex improved its penetration into the soil.

A styrene-butadiene (SBR) rubber latex of 2400 Å average particle size with high mechanical stability gave the best balance of penetrating ability and sealing capacity in laboratory tests and this was confirmed in tests on a 5 x 5 foot test plot at Lanse, Pennsylvania. This latex was subsequently applied to three one-quarter-acre plots at Lanse by sprinkler irrigation, and compared to adjacent areas that were sprinkled with water only. Soil moisture measurements did not enable us to judge the effectiveness of the seal because differences between sampling positions were greater than differences between treated and untreated sections, but permeability tests showed that water flow was much slower (90-99% reduction) within the top ten inches of soil in the latex-treated sections. This sealing effectiveness was reduced after wintering. There was no deleterious effect on the vegetation as a result of sprinkling the areas with latex.

A laboratory study conducted in a 5 x 5 x 5 foot box containing uniform reconstructed soil from a New Jersey source suggests that latex penetration into the soil in the field occurs mainly through natural macro openings and not through the capillaries of the soil structure.

Dilute solutions of ammonium hydroxide or sodium carbonate (with no latex present) were found to seal effectively in laboratory soil columns as well as in field applications. However, since these chemicals are water soluble, the seal is temporary.

Raw material costs of latex at the application rates used in the field testing are in the order of $1000 per acre. Equipment and operating costs are \$200-500 per acre depending on size of area and availability of suitable water.

An auger type sampling device was developed for obtaining "undisturbed" samples of soil.

An analytical method to measure latex in soil was developed.

SECTION II

RECOMMENDATIONS

The generally disappointing results obtained in the present study, together with the high material costs involved, preclude any general recommendation for a continuation of the work.

One recommendation arises, however, from some observations on the application of latex to spoil banks. It was found that dilute latex used on a slope of spoil bank material at an application rate of 400 lbs per acre (dry basis) stabilized the soil and made it much more resistant to washout by rainfall. It is recommended that a study be conducted to use latex for temporary stabilization and/or sealing of spoil banks before and during reclamation procedures, on coal slurry ponds and coal refuse piles.

SECTION III

INTRODUCTION

Acid pollution from abandoned mines causes serious contamination of major streams in coal mining areas. In Pennsylvania alone it is estimated that 3000 miles of streams are devoid of fish and plant life because of coal mine effluent.[1] The pollution arises because water and oxygen react with iron sulfide in the mine cavity to produce sulfuric acid and iron sulfate, which later find their way back into surface streams.

Two general approaches to the problem are possible: (1) prevent the acid-forming reaction from taking place, (2) treat the acid mine water after it is formed so that it will not be harmful to the ecology when discharged into streams and other surface waters. The work described in this report belongs in the first category - it was based on the assumption that acid formation in the mine cavity can be prevented by keeping water (one of the reactants) out of the mine. This was to be accomplished by forming a waterproof seal over the mine cavity which would prevent the seepage of surface water into the mine.

It was planned to form such a seal at or near the surface of the ground by applying latex to the soil. Ideally a dilute latex would be applied to the soil and would penetrate to a depth of two to three feet below the surface where it would be coagulated by reacting with a constituent of the soil or by other means. A seal below the surface of the soil would have several advantages over a surface seal - it would not be subject to destruction by traffic, frost or vegetation and, more important, it would allow the use of the top soil for many agricultural purposes.

A preliminary feasibility experiment was performed prior to application for the present grant. It showed that it was indeed possible to form a sub-surface seal by means of latex. A core of soil was obtained locally (Wayne, N. J.) by driving a 6.5 cm inside diameter steel pipe about 100 cm long into subsoil for a distance of 71 cm. The soil was retained within the pipe for this experiment. A part of the free space above the soil in the pipe was charged with water, and the seepage rate of the soil after it had become saturated was 15 ml/min under a total head (wet soil plus supernatant column of water) of 92 cm. After the supernatant water had drained completely, 100 ml of 5% rubber latex was added and allowed to seep into the soil. This was followed by additional water and the seepage rate was found to be 2 ml/min under the same head. This seepage rate remained unchanged when remeasured on the following day. Since there was no visible evidence of the latex in the collected drain water it is presumed to have been retained by the soil.

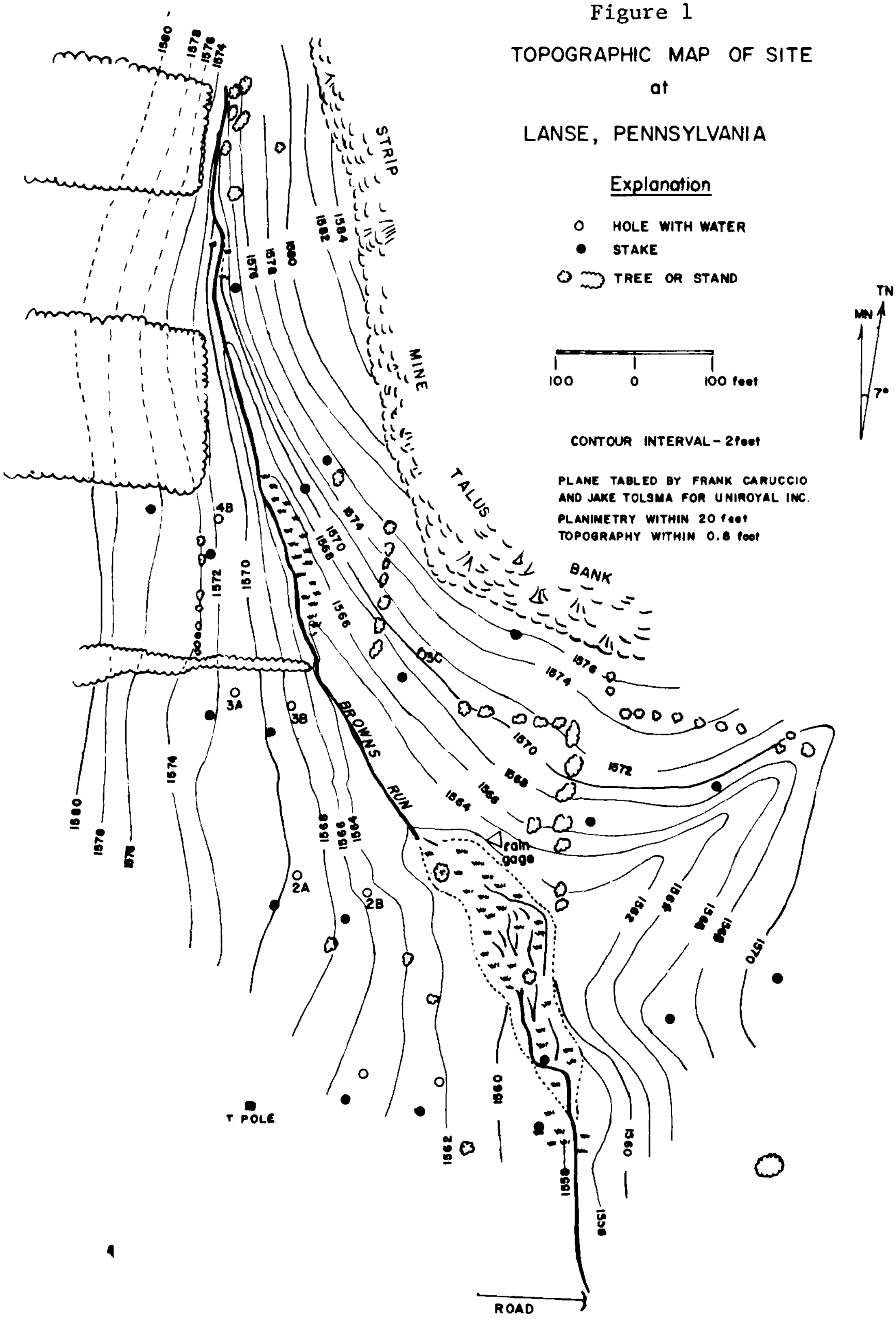
The work described in this report includes:

- Evaluation of the characteristics of the soils of interest,
- Testing of sealing effectiveness of latexes and other materials in reconstructed soil columns in the laboratory,
- Study of field conditions (permeability, etc.) at the selected test site, and corroboration of laboratory results by small scale field tests,
- Application of the latex sealant of choice to the selected test site and evaluation of the seal so obtained,
- Soil box experiments with a uniform soil to interpret penetration and permeability behavior of soil under controlled conditions,
- Projection of cost based on the test results.

The original plan was to conduct all the field tests on a twenty acre plot in Lanse, Pennsylvania (called Lanse site throughout this report). However, easement complications and soil conditions required that the scope of treatment be reduced to three plots of about one-quarter acre each. An alternative site was chosen on State Forest lands northeast of Snowshoe, Pennsylvania, above the abandoned Kato mine (called Kato site throughout this report). Some preliminary testing was carried out at the latter site but the projected large-scale field test was not performed. Topographical maps of the two sites are shown in Figures 1 and 2. Sampling sites referred to throughout this report are shown on these maps.

Figure 1

TOPOGRAPHIC MAP OF SITE
at
LANSE, PENNSYLVANIA



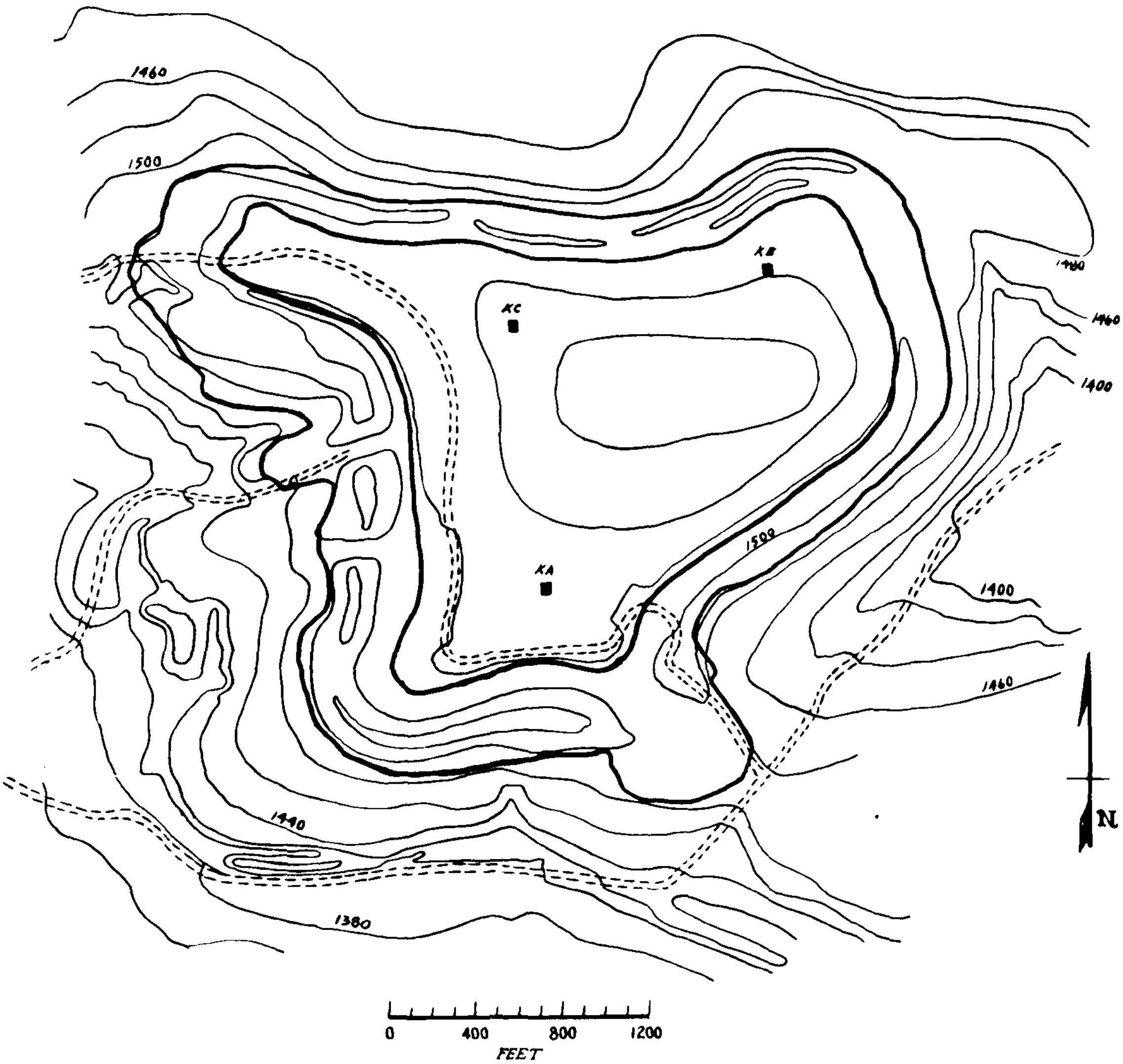


Fig. 2 - Topographic map of site over the abandoned Kato mine near Snowshoe, Pennsylvania

SECTION IV

MATERIALS AND METHODS

Only limited work has been reported in the literature about the use of latex in soil. Unisol 91[2,3] (a 9:1 oil-latex emulsion made by International Synthetic Rubber Company) and Phillips Petroset[4] geotechnic emulsions are surface soil stabilizers which penetrate a maximum of two inches, but do not reduce permeability. Diamond Alkali[5] found that styrene-butadiene rubber latex as a one percent latex-soil mixture reduced permeability to 0.7 from 21 feet per year under a head of twenty feet of brine. We have found no literature reference for use of latex as sealant at depth in the soil, although asphalt has been applied at depth using civil engineering methods[6,7].

Most of the materials investigated as soil sealants in the present work were latexes, although some studies were also conducted with a variety of inorganic and organic chemicals. Of the latexes tested, most were rubber but a few were plastic, e.g. polyvinyl chloride.

Sealants examined in this investigation are listed individually in Table I with supplier, code number, and other pertinent information. The materials consisted of the following general classes with additional details as indicated:

1. Anionic latexes:
   a. styrene-butadiene copolymers and terpolymers (SBR)
   b. butadiene-acrylonitrile copolymer (Paracrils®)
   c. polyvinyl chloride homopolymers and copolymers (PVC)
   d. ethylene-propylene terpolymer
   e. vinyl acetate homopolymers and copolymers (VA)
   f. acrylics (acrylate copolymers)
   g. 2-chlorobutadiene homopolymer (chloroprene) (prepared specially as cationic material coagulated by soil).

2. Water Soluble polymers:
   a. polyvinyl ether
   b. methylcellulose
   c. polyethyleneimines
   d. polyacrylic acid homopolymer
   e. copolymers and terpolymers with acrylic acid types (water soluble as sodium or ammonium salts)
   f. alginates
   g. monomers (for polymerization in soil, e.g. acrylamide)

TABLE I

Sealants Evaluated

Supplier	Code	Type Polymer	Part. Size Å	% Solids	Surface Tension Dynes/cm. Conc. 5%	pH
Naugatuck Chem.	J1405	SBR	1100	41	52.5	10.6
	J1896	SBR - mod.	1500	50	44.2	9.6
	J1925	SBR - mod.	1400	46	64.3	9.6
	J2620	Paracril	800	41	50.4	10.3
	J2714	SBR	1800	51	39.2	11.4
	J2752	SBR - mod.	2000	47	36.5	8.9
	J2768	SBR	1000	46	72.2	9.0
	J3471	SBR	2400	49	35.7	9.8
	J3595	SBR	1300	50	77.	9.5
	J3902	SBR	3000	75	38.	10.5
	Pyratex	SBR - mod.	800	41	56.5	10.3
	-	Natural Rubber	(4000+)	50	52.	
Naugatuck Chem.	BJMM	Paracril®	-	25	51.9	-
	BJLT	Paracril®	-	27	-	10.2
	Marvinol® 8-78-1	PVC	2000	35	45.8	7.5
	5402	PVC	500-1500	38		3.8
	R-8438-20C	SBR - acrylic	-	16	43.	3.1
Uniroyal - R.C.	Royalene® 502	EPDM	(3500+)	55	33.	
	GM-38	EPDM - parafin extended				
	GM-39	EPDM - Aroclor 1242 extended			34.	
	GM-45	EPDM - oil + clay extended				
Borden	2134	VA	-	45	42.	3.5
	2140	VA homo; carboxylated	2000	46	40.	6-7
	2153	VA; acrylic	2000-3000	55	42.	4.5-5.5
	2158	VA	4000	55	44.	4.6
	2635	PVC	-	55	37.	7.

TABLE I (cont'd.)

Supplier	Code	Type Polymer	Part. Size Å	% Solids	Surface Tension Dynes/cm. Conc. 5%	pH
Dow	870	PVC vinylchloride		(50)	36.	8.
	874	PVC vinylidenechloride		50	34-37	8.
Goodrich	2679X6	Acrylic-self thickening		48.5	45.	8.8
Paisley	H-9052-0	Vinylacetate	400-800	50.	46.	4.5
duPont	Neoprene Latex 950	(Cationic surface of 40 ammonium type)	-	50.	-	-
(Water Soluble Polymers)			M.W.			
Dow Methocel	HG	Hydroxypropyl methyl cellulose				
Montrek	12	Polyethyleneimine	12,000	100		
	600	"	40,000-60,000	34		
Goodrich	K714	Polyacrylic acid	200,000			
General Analine & Film Gantrez	M155	Vinylmethylether	-			
(Water Dispersible Organics)						
Phillips Petroset	SB-1	Solprene GEO		-		
Ciba Uvitex	EBC (conc.)	Chem. brightener	-	10		

3. Inorganic dispersions with and without additives
    a. expandable clays (montmorillonite type)
    b. non-expanding clays (kaolin type)
    c. finely divided silica (cabosil)

4. Water soluble inorganics
    a. sodium carbonate
    b. ammonium hydroxide
    c. sodium hexametaphosphate.

A variety of chemicals and latexes were screened at concentrations of about 2-1/2 to 5% for their ability to (a) penetrate soil and (b) reduce the percolation of water through it. Initial laboratory experiments were made with reconstructed soil samples. Effectiveness of the sealant was measured by change in percolation rate. Percolate showing turbidity was evaporated to measure the amount of eluted latex.

To be useful for the present purpose, a latex should be able to penetrate into the soil (ideally, 2 or 3 feet) before forming a seal. Latex which reacts immediately with the soil and forms a seal at the surface is not satisfactory because the seal would be subject to destruction by mechanical forces (traffic, natural movement of ground due to freezing and thawing, growth of vegetation, etc.) and chemical action (atmospheric oxidation, etc.). The amount of latex eluted through a 4- or 8-inch deep column of soil gives some indication of its penetrating ability. In other experiments (referred to herein as "skinning" tests) the extent of sealant penetration was measured by removing soil from the top of the laboratory column in 1.5 to 2.0 cm increments and measuring the corresponding percolation rates.

Some of the more promising sealants were then evaluated in the field by one or more of the following procedures:

1. Permeability tests were performed in situ by pressing eight-inch-diameter, twelve-inch-long, stove pipes into the ground eight to ten inches and measuring the time of disappearance of a measured amount of water. The thin walls of the stove pipes made compaction minimal; stones in some cases created deleterious wall effects. Alternatively eight-inch-diameter permeameter tubes thirty inches long and 1/4 inch thick with a sharp edge at the lower end were driven into the soil twenty-four inches to measure permeability in situ. Less than five percent compaction occurred.

2. Sealant was applied to test areas of five by five feet. Several weeks later core samples were removed in four-inch increments to depths of 8 and 16 inches by means of a thin-walled sampling tube. Samples were examined for presence of sealant. The hole that had been cored was confined by introducing an empty sampling tube of the same diameter and then pressing it to a depth one inch greater than the original sample. Percolation rates were measured in these tubes by the falling head method.

Soil density measurements were made by obtaining the net weight of soil in a given volume. Typical values for reconstructed columns were about 1.40 to 1.45 after draining several days and about 1.34 to 1.38 after air drying about a week. Soil heights in the column sometimes varied 0.5 to 1.0 cm because of preferential redistribution of top-soil on adding make-up water. Less disturbance was evident when a Marriott feed bottle was used to maintain a constant hydraulic head.

Ideally, soil samples tested for permeability in the laboratory should be identical in physical condition to the soil in the field. A commercial split-tube sampler, having a heavy wall to contain the split tube, produced soil samples that were severely compacted. Thin wall sampling tubes were much better in this respect but noticeable compaction occurred if samples longer than four inches were cored. Additional compaction occurred when the soil was removed from the tube.

A jack-type hollow auger modified from a description of similar equipment by Hayden and Heineman[8] was built to take longer samples three inches in diameter. It features an outer sleeve containing a peripheral spiral which, when turned, forces itself into the soil, and an inner sleeve that contains either a metal split sleeve or a Plexiglas tube which is held stationary while filling with soil. (See Figure 3) However, wall effects were evident when permeability tests were performed in the Plexiglas tubes. Undisturbed soil cores are impossible to obtain if stones or strong roots are present. Because of these difficulties most of the laboratory permeability tests were performed on reconstructed soil columns.

One, three, and five foot deep piezometer pipes were placed at the Lanse and Kato field sites. The water from the ground seeps into the tubes and is a measure of the depth of the permanent or perched water-table at that point.

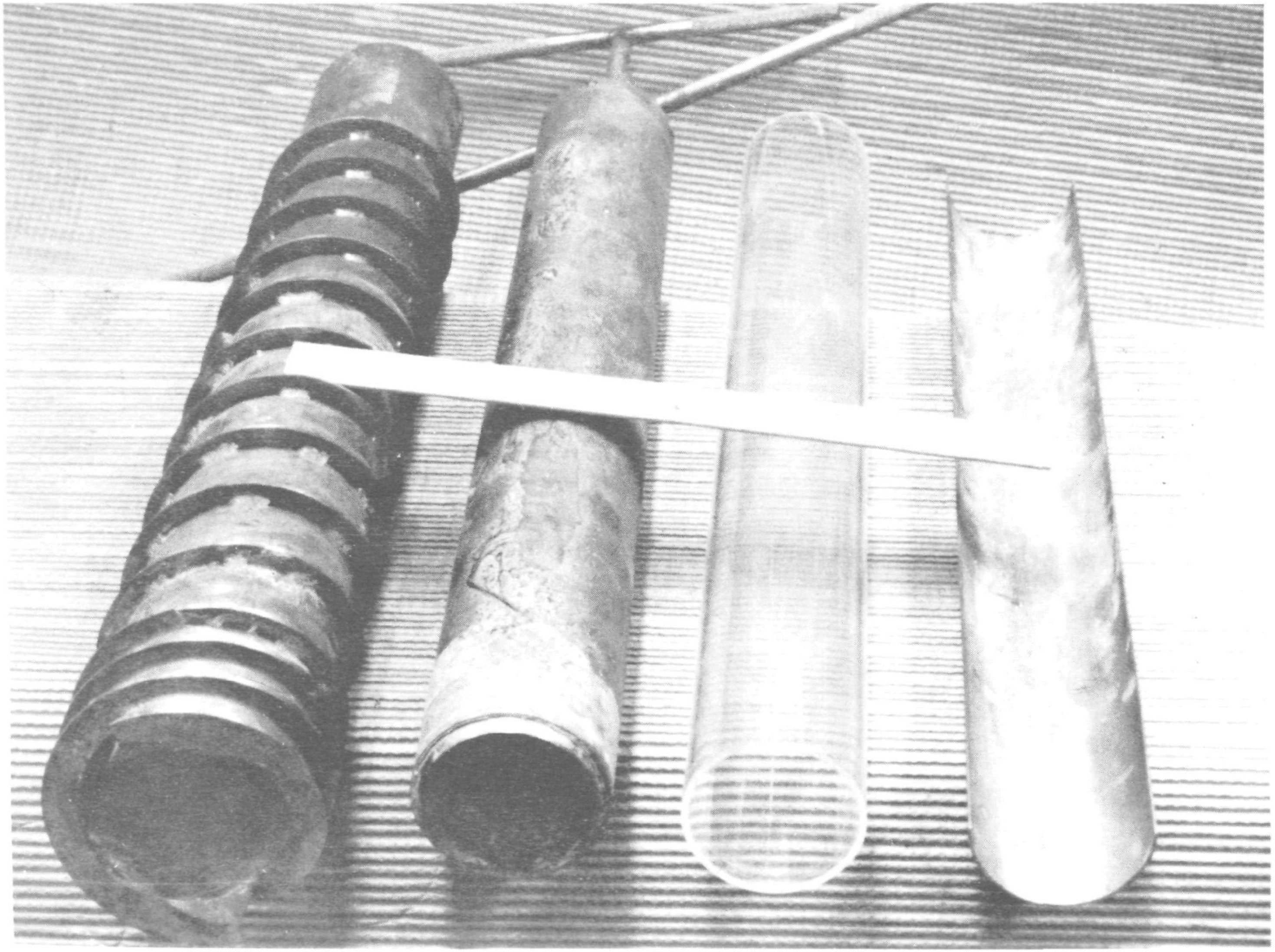


Fig. 3 - UNASSEMBLED UNIROYAL HOLLOW AUGER
(WITH PLEXIGLASS AND SPLIT-TUBE LINER)

SECTION V

SOIL CHARACTERISTICS AND NATURAL FIELD CONDITIONS

This section contains a summary of our investigation of the soil conditions (type, porosity, moisture content, etc.) at the two sites (Lanse and Kato, Pennsylvania) selected for field testing of latex as a soil sealant. Other natural conditions such as rainfall, frostline, depth of the water table, etc., were also measured and recorded for possible later use in assessing the effect of the latex seal on the total environment.

The numbered sites referred to throughout this report are shown on the maps of the Lanse and Kato sites (Figures 1 and 2). KA, KB and KC are positions at the Kato site - all other numbered positions refer to the Lanse site.

Two other terms used throughout the report which should be explained are "horizon" and "profile". These are synonymous terms for soil layer, A horizon (or A profile) referring to topsoil and B horizon (or B profile) referring to subsoil.

The properties that control the flow of water through the soil are of special interest because these will also govern the passage of a sealant into and through the soil. Normally the particle size distribution is a good measure of soil permeability, which is directly proportional to sand content and inversely proportional to silt and/or clay content. Tables II and III show the percentages of gravel or stones, sand, silt and clay of Lanse and Kato soil samples. According to the United States Department of Agriculture classification, the gravel is ignored and the residue separated into sand, silt, and clay fractions. Figures 4 and 5 indicate by means of the USDA soil texture triangle that the variability of composition of Lanse soil ranges from sandy loam in the creekbed to clay loam. The variation is even greater among soil samples from Kato.

Porosity of soil, also known as percent voids, is another indication of how readily water will travel through soils. Soil density usually increases and porosity decreases with depth, and as expected, the porosity of the top soil at Kato, a forest, is exceptionally porous and open (see Table IV).

The pore diameter and length of soil capillaries is extremely variable, and its distribution in the field is impossible to determine. In addition to the capillaries, soil also contains many macro cracks, crevices, and passages around stones and roots. All these affect the flow rate of water through soil. Poiseuille's law states that the rate of flow of a liquid through a narrow tube is proportional to the 4th power of the radius of the tube. Pore size normally decreases with depth and in soil containing appreciable amounts of silt and clay this is especially true. Thus, deeper soils should be less permeable and such was the case at Lanse and Kato.

TABLE II

Particle Size Distribution of Soil Samples fron Lanse Site

Depth Increment (inches):	0-8	8-16	16-24	24-32
Soil Texture of Upper Slope Composite				
% Gravel (+2 mm)	6.3	7.7	13.6	21.5
% Sand (+0.05 - 2 mm)	35.7	34.3	36.4	36.3
% Silt (+0.005 - 0.05 mm)	32.3	31.8	25.0	21.0
% Clay (-0.005 mm)	25.7	26.2	25.0	20.2
U.S.D.A. Classification (without gravel)				
% Sand	39.7	38.8	43.4	48.2
% Silt	31.4	31.2	26.6	25.0
% Clay	28.9	30.0	30.0	26.8
	Sandy Clay Loam	Clay Loam	Clay Loam	Clay Loam
Soil Texture of Creekbed Composite				
% Gravel	4.1	12.6	11.1	32.7
% Sand	47.3	50.5	56.5	40.8
% Silt	35.3	25.1	22.5	19.2
% Clay	13.3	11.8	9.9	7.3
U.S.D.A. Classification (without gravel)				
% Sand	49.3	57.8	63.5	60.6
% Silt	36.8	28.7	25.3	28.6
% Clay	13.9	13.5	11.2	10.8
	Loam	Sandy Loam	Sandy Loam	Sandy Loam
Soil Texture of Pine Woods Composite				
% Gravel	10.0	6.8	13.4	17.3
% Sand	35.7	34.5	32.3	39.3
% Silt	40.8	40.7	35.3	31.6
% Clay	13.5	18.0	19.0	11.8
U.S.D.A. Classification (without gravel)				
% Sand	39.7	37.0	37.3	47.5
% Silt	45.3	43.6	40.8	38.2
% Clay	15.0	19.3	20.9	14.3
	Loam	Loam	Loam	Loam

TABLE II (Cont.)

Depth Increment (inches)	0-8	8-16	16-24	24-32
Soil Texture at Site 03A				
% Gravel	5.1	12.1	36.8	61.1
% Sand	30.3	27.8	19.3	10.2
% Silt	48.6	44.1	31.5	19.5
% Clay	16.0	16.0	12.4	9.2
U.S.D.A. Classification (without gravel)				
% Sand	31.9	31.6	30.5	26.3
% Silt	51.3	50.2	49.9	50.1
% Clay	16.8	18.2	19.6	23.6
	Silt Loam	Silt Loam	Silt Loam	Silt Loam
Soil Texture at Site 3C				
% Gravel	4.4	8.0	1.5	5.8
% Sand	28.4	22.3	20.1	23.2
% Silt	42.2	39.0	42.4	38.4
% Clay	25.0	30.7	36.0	32.6
U.S.D.A. Classification (without gravel)				
% Sand	29.7	24.2	20.4	24.6
% Silt	44.1	42.5	43.0	40.8
% Clay	26.2	33.3	36.6	34.6
	Loam	Clay Loam	Clay Loam	Clay Loam

TABLE III

Particle Size Distribution of Soil Samples from Kato Site

Depth Increment (inches):	0-8	8-16	16-24	24-36
Soil Texture of KA Soil				
% Gravel	21.5	6.6	5.3	14.7
% Sand	37.6	31.2	28.0	33.0
% Silt	28.8	38.5	39.1	29.3
% Clay	12.3	23.7	27.6	23.0
U.S.D.A. Classification (without gravel)				
% Sand	47.6	33.4	29.6	38.6
% Silt	36.7	41.2	41.3	34.4
% Clay	15.7	25.4	29.1	27.0
	Loam	Loam	Clay Loam	Loam
Soil Texture of KB Soil				
% Gravel	20.2	14.5	23.9	18.2
% Sand	50.5	51.1	54.9	46.2
% Silt	15.0	14.4	5.1	12.5
% Clay	14.3	20.0	16.1	23.1
U.S.D.A. Classification (without gravel)				
% Sand	63.3	59.9	72.1	56.5
% Silt	18.8	16.8	6.7	15.3
% Clay	17.9	23.3	21.2	28.2
	Sandy Loam	Sandy Loam	Sandy Clay Loam	Sandy Clay Loam
Soil Texture of KC Soil				
% Gravel	24.6	7.2	14.5	0.4
% Sand	34.0	30.6	26.5	20.4
% Silt	26.8	36.2	33.3	45.9
% Clay	14.6	26.0	25.7	33.3
U.S.D.A. Classification (without gravel)				
% Sand	45.0	33.0	31.0	20.4
% Silt	35.6	39.0	38.9	46.1
% Clay	19.4	28.0	30.1	33.5
	Loam	Loam	Clay Loam	Clay Loam

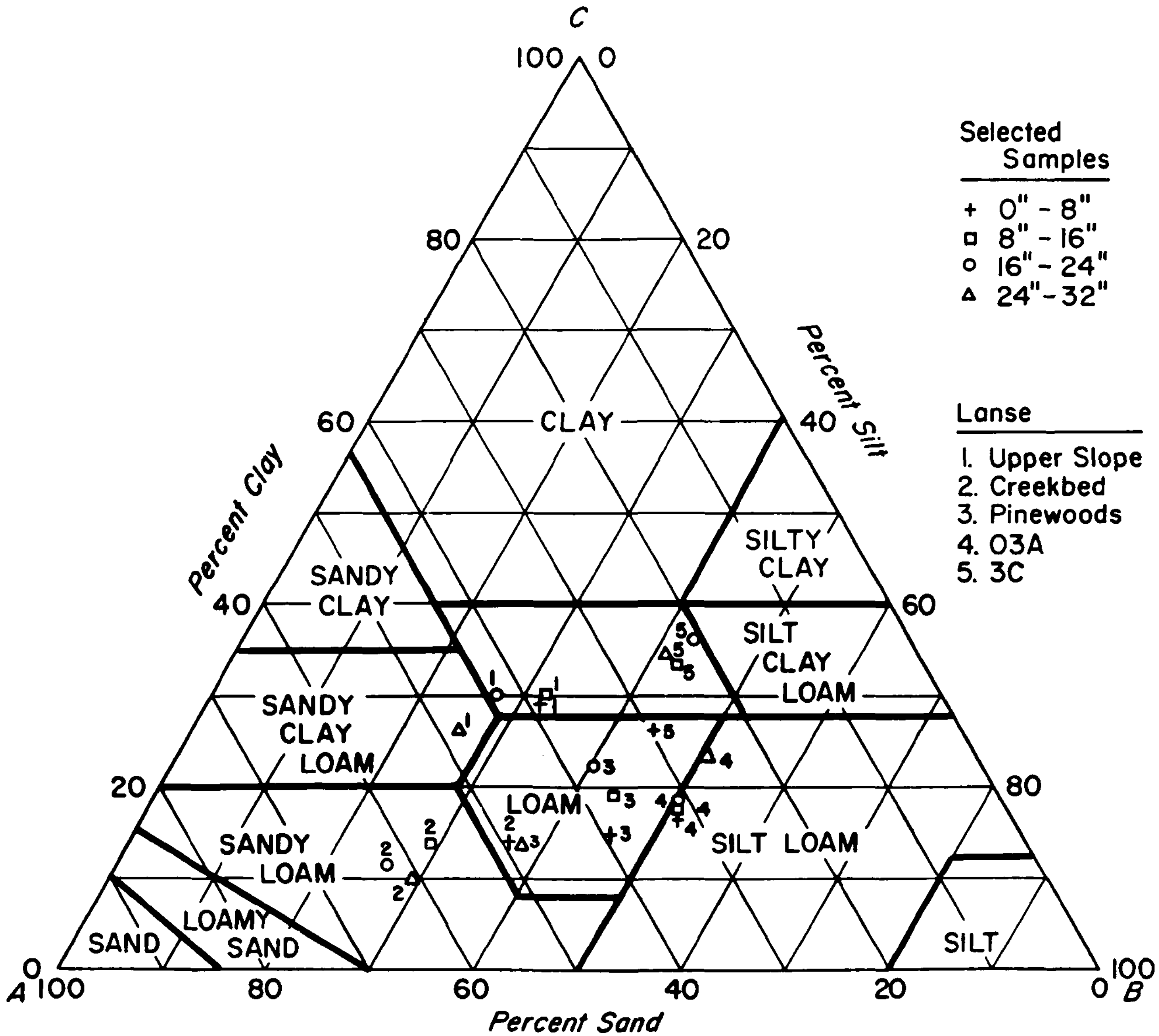


Fig. 4 - USDA soil texture triangle for Lanse soil samples

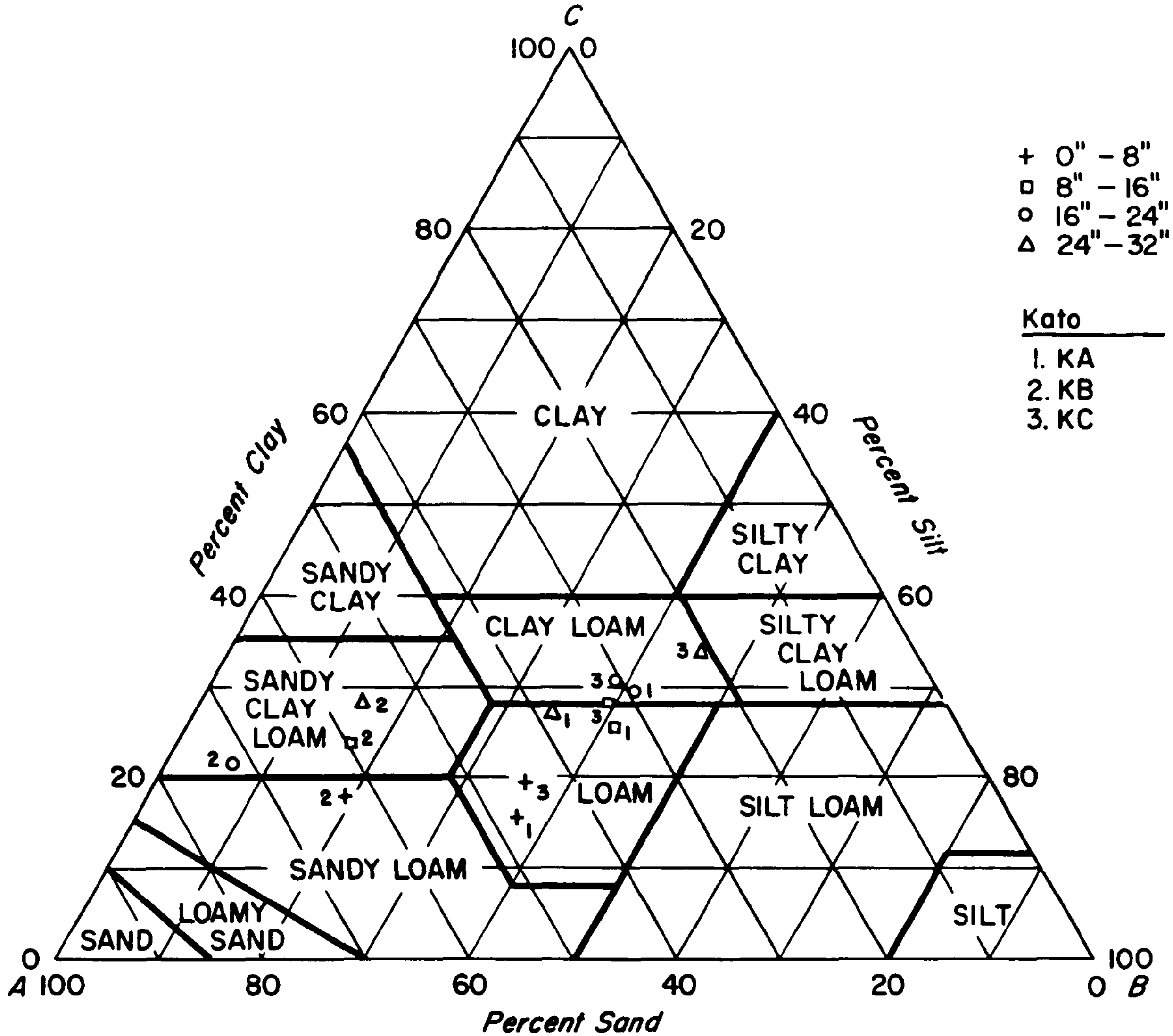


Fig. 5 - USDA soil texture triangle for Kato soil samples

TABLE IV

Physical Properties of Soils at the Lanse and Kato Sites

Depth Increment (inches):	2-4	4-8	8-12	12-16
Soil 2C cored January 29, 1969 (Lanse)				
% Moisture	32.3	24.5	20.8	9.3
Sample volume, cc.	64.33	205.9	205.9	205.9
Dried wt., g.	71.0	261.9	256.2	323.5
Bulk density D_b, g/cc	1.10	1.27	1.24	1.57
Total porosity, $S_T = 100\left[1 - \frac{D_b}{P_p}\right]$, $P_p = 2.65$ g/cc	58.5	52.0	53.2	40.7
Depth Increment (inches):	**0-8**	**8-16**	**16-24**	**24-32**
Soil KA cored July 8, 1969 (Kato)				
% Moisture	21.6	14.0	15.5	12.5
Sample volume, cc	411.6	411.6	411.6	411.6
Dried wt., g.	334.6	603.3	596.6	550.0
Bulk density, g/cc	0.812	1.46	1.45	1.34
Total porosity	69.3	44.9	45.3	49.5
Soil KB cored July 8, 1969 (Kato)				
% Moisture	22.2	14.3	11.5	13.5
Sample volume, cc	411.6	411.6	411.6	411.6
Dried wt., g.	323.8	525.8	59.09	677.6
Bulk density, g./cc.	0.785	1.28	1.44	1.64
Total porosity	70.4	51.7	45.6	38.0
Soil KC cored July 8, 1969 (Kato)				
% Moisture	23.3	16.3	13.5	15.7
Sample volume, cc.	411.6	411.6	411.6	411.6
Dried wt., g.	286.5	558.9	517.0	609.5
Bulk density, g./cc.	0.698	1.36	1.26	1.48
Total porosity	73.7	48.3	52.5	44.1
Depth Increment (inches)	**0-4**	**4-8**	**8-12**	**12-16**
Soil 3D cored November 6, 1969 (Lanse)				
% Moisture	29.8	26.1	23.6	23.7
Sample volume, cc.	205.8	205.8	205.8	205.8
Dried wt., g.	188.2	212.7	245.8	310.4
Bulk density, g./cc.	0.914	1.03	1.19	1.51
Total porosity	65.5	61.0	55.1	43.0

Under saturated conditions, soil water is under no tension but is subject to gravitational forces only. Saturated flow of water in soil is therefore normally downward, unless an impervious lower layer induces lateral flow. This downward gravitational force will carry latex down to the depth of small capillaries where particle blockage can occur.

Elemental analysis of Lanse soil (Table V) combined with crystallographic examination revealed that the major component of < 2 mm fraction of the soil is quartz. The relatively high aluminum and iron concentration indicates the presence of layered hydrated clays.

TABLE V

Mineral Analysis of Upper Slope Composite Soil Samples* at Lanse Site

Depth Increment (inches):	0-8	8-16	16-24
	Composition (%)		
SiO_2	79.5	75.5	75.5
Al_2O_3	10.3	13.8	14.8
Fe_2O_3	6.25	6.16	5.77
MnO_2	0.09	0.05	0.07
MgO	0.35	0.48	0.60
CaO	0.17	0.10	0.09
TiO_2	0.82	0.83	0.86
Na_2O	0.41	0.38	0.38
K_2O	1.60	2.09	2.18
CuO	0.003	0.003	0.005
NiO	0.004	0.004	0.006
CoO	0.008	0.002	0.003
Ignition Loss at 900°C - %	6.96	6.25	5.90

*Analyzed at Penn. State University Minerals Composition Laboratories except for Cu, Ni, and Co.

Dr. Frank Caruccio, our consultant on this project, examined soil samples at sites 03A (Lanse) and KA (Kato) at four depth increments using an optical microscope with polarized light to differentiate between quartz clay and hydrated layered silicate clays. Lanse 03A soil was found to contain a relatively high amount of clay resembling montmorillonite in structure whereas the Kato KA soil has less hydrated clay of different shape that suggests a micaceous structure. The quartz clay particles were stained with iron compounds. X-ray diffraction of clay separated from 03A soil at 24-32 in. depth confirmed the presence of montmorillonite. Cation exchange capacity (CEC) values ranging from 6 to 13 meq/100 g of soil (Table VI) also prove the presence of reactive minerals. Chemically active mineral groups in the soil interact with latex and other additives. Physical interaction with sealant particles can occur by adsorption and surface effects.

It is common among soils developed in the temperate zones to have a lower pH at a two or three foot depth and it was hoped to make use of this difference to effect the coagulation of latex, since latex stability is very dependent on pH. We looked for this effect in the soil of the Lanse and Kato areas but as can be seen in Table VI the pH variation with depth is very small. At sites KB and KC, areas where rotting oak leaves cover the ground, the pH is generally lower.

The Atterberg limits measure the consistency of the soil containing enough water to make a smooth paste. The liquid limit (L.L.) or upper plastic limit is the percent moisture at which soil becomes semi-fluid. The plastic limit (P.L.) is the percent moisture at which the soil crumbles when it is rolled to a 1/8 inch thick thread. The plastic index (P.I.) is the difference between the liquid and plastic limits. All three are directly related to the amount of clay in the soil. Because we added the soil sealant by an irrigation method, the water holding capacity is of interest. Except for the creekbed soil, which is relatively low in clay, all the samples have the desirable positive plastic index.

Lanse Site

The accompanying topographic map (Figure 1) shows the experimental test area at Lanse, Pennsylvania. Brown's Run is a dry creekbed during the summer but a flowing stream in the winter and spring. The area has four distinct topographic features that account for the variability in soil properties. Along part of the creekbed is a boggy area at floodplain level, there are slightly sloping upper plain areas on each side of the stream, there is a stand of pine trees at the northwest corner of the property, and spoil banks from previous strip mining operations both to the northeast and northwest (not shown on map).

From December to June, when the stream was flowing (or frozen), there was a perched water table which we measured occasionally (see Table VII).

TABLE VI

Chemical Properties and Atterberg Limits of Soils at Lanse and Kato Sites

Depth Increment (inches)		0-8	8-16	16-24	24-32
pH					
Upper slope composite (Lanse)		5.9	5.7	5.3	5.1
Pinewoods composite (Lanse)		5.5	5.6	5.5	5.6
Creekbed composite (Lanse)		5.7	6.0	5.8	5.8
03A (Lanse)		5.6	5.5	5.3	5.5
3C (Lanse)		6.2	6.3	6.2	6.0
KA (Kato)		6.4	6.1	5.6	5.9
KB (Kato)		4.8	4.8	4.9	5.0
KC (Kato)		5.2	4.8	4.8	4.9
Cation Exchange Capacity (meq/100 g)					
03A		10.4	7.0	9.9	7.4
KA		9.9	6.9	6.3	11.6
KB		7.8	5.5	4.6	12.8
Atterberg Limits (% moisture)					
Upper slope composite	L.L.*	30	27	28	26
	P.L.*	26	22	22	21
	P.I.*	4	5	6	5
Pinewoods composite	L.L.	27	23	23	22
	P.L.	26	20	18	18
	P.I.	1	3	5	4
Creekbed composite	L.L.	29	22	19	18
	P.L.	26	21	20	19
	P.I.	3	1	-1	-1
3C	L.L.	31	31	35	35
	P.L.	26	25	29	26
	P.I.	5	6	6	9
03A	L.L.	30	26	26	27
	P.L.	26	20	21	21
	P.I.	4	6	5	6
KA	L.L.	30	28	31	33
	P.L.	25	21	21	22
	P.I.	5	7	10	11
KB	L.L.	-	22	22	26
	P.L.	-	18	18	18
	P.I.	-	4	4	8
KC	L.L.	33	29	30	35
	P.L.	31	23	23	24
	P.I.	2	6	7	11

* L.L. = liquid limit; P.L. = plastic limit; P.I. = plasticity index.

TABLE VII

Water Tables and Elevations at Lanse Site

Hole Position	Elevation (ft)	12/3/68	12/11/68	4/7/69	4/11/69	5/2/69
1A	1565	-	-	3	3	
1B	1562	2	-	0	2	
2A	1570	-	-	5	8	
2B	1565	17	21	13	17	
2C	1563	5	16.5	4.5	8.5	14
3A	1571	23	26	20	22.5	
3B	1568	11.5	21	12	17	
3C	1570	17	19.5	15	18	20
4B	1572	11	19	9	11.5	17
4C(N)	1570	-	29	25	28	28.5
4C(S)	1570	-	18.5	13	14.5	19
5C	1572	-	20	-	17.5	21
Creekbed S.	1558					
Creekbed N.	1570					
03A	1574	-	-			

The relative water table depth and position elevations show that the water flows laterally through the soil toward the stream bed. The data from piezometer pipes at site 4B confirms that the perched water table is caused by a relatively impermeable layer between three and five feet from the surface because, while the perched water table is evident in uncast holes, the hydraulic head is much higher at three feet depth than at five feet (Table VIII).

We had expected a soil of moderate permeability from the soil texture, but the presence of a perched water table indicated low permeability, so we asked Mr. William L. Braker, soil scientist from the USDA, Soil Conservation Service, Clearfield Office, to examine and define the soil for us. His report (condensed) with definitions follows:

"A deep soil (which all of these are), is one in which depth to hard bedrock is greater than forty inches. Soil permeability rates as defined by USDA, Soil Conservation Service, are as

TABLE VIII

Hydraulic Head in Piezometer Pipes at Lanse Site

	Depth:	1 ft.	3 ft.	5 ft.
	Date			
Position 4B	12/11/68	0	24	0
	1/29/69	0	19	0
	2/27/69	0	16	5
	4/11/69	0	23.5	2.5
	5/5/69	0	16	3
	5/23/69	0	11.5	3
	6/12/69	0	2	4
	7/7/69	0	0	2.5
	1/29/70	3.5	31	4
	2/12/70	0	27	7
	2/27/70	0	26.5	4.5
	3/18/70	0	23.5	4
	3/30/70	2.5	30	4.5
	4/20/70	1	26	3.5
	5/12/70	0	10.5	4
	6/1/70	0	22	5.5
	6/12/70	0	1.5	6
	6/20/70	0	8.5	5.5
	6/25/70	0	15	5
Position 4CN (placed 4/11/69)				
	5/5/69	0	.5	0
	5/21/69	0	.75	.25
	6/12/69	0	0	0
	1/29/70	0	2.5	0.5
	2/27/70	0	5	5.5
	3/18/70	0	2	5
	3/31/70	0	4	6
	4/30/70	0	2	3.5
	5/12/70	0	0	2
	6/12/70	0	0	3

follows:

Descriptive Term	Range in Inches/Hour	Feet/Year
Slow	less than 0.2	< 146
Moderately slow	0.2 - 0.63	146 - 460
Moderate	0.63- 2.0	460 - 1460
Moderately rapid	2.0 - 6.3	1460 - 4600
Rapid	more than 6.3	> 4600

"The primary reason for the slow and moderately slow permeabilities are the fragipans in the subsoils of the Ernest and Brinkerton soils; and is due to the position in the landscape of the Atkins soil. Ernest is the most extensive soil on this plot. The Atkins is the floodplain soil along the creek. Brinkerton is the wetter upland soil on the southwest side of the plot.

"Ernest are deep, moderately well to somewhat poorly drained soils of the uplands. They have developed in loamy, colluvial material derived from shale and sandstone bedrock. These nearly level to moderately steep soils have a moderately slowly permeable fragipan subsoil. The water table normally rises to within 12 and 18 inches of the surface during wet periods of the year.

"Atkins are deep, poorly and somewhat poorly drained flood plain soils. They have developed in loamy alluvial sediments eroded from higher residual soils derived from gray and brown shale and sandstone. These nearly level soils have a moderately slowly permeable subsoil. The water table normally rises to the surface during much of the year. Most use problems are related to flooding, the high water table, and to the moderately slowly permeable subsoil.

"Fragipan is a subsurface soil structure that seems to be cemented when dry, but is fragile when moist, has a relatively high bulk density and is slowly or very slowly permeable to water. Fragipans may be a few inches to several feet thick."

The Brinkerton soil does not concern the problem because we were unable to obtain an easement for the property in the southwest corner of the plot. The two plots to which latex was applied are Atkins soils. The spoil bank is not a soil in the real sense of the term.

Freezing and thawing changes the structure of soil because of the expansion of ice lenses in the soil[22]. To determine how deeply the ground freezes on the site in the winter, resistance thermometers were placed at 2-inch and 1, 2, 3, and 4 foot depths at site 4B at Lanse and soil temperatures were measured one or two times a week (see Figure 6). At no time did the soil temperature go below 32°F at the one-foot depth. From periodic observations in the field the frost line was determined to be about eight to ten inches deep. The saturated condition of the soil and presence of a water table probably limited the frost-line depth. The implication is that the soil structure is affected only to a depth of 8 to 10 inches. The mean monthly air temperature is included for comparison with the soil temperatures.

A rain gage was obtained from and set up by the Pennsylvania Department of Forests and Waters. Data in Table IX compares rainfall rates at Lanse, Clarence (which is near the Kato site), and Philipsburg FAA-AP. The totals show the variability of rainfall within a thirty-mile span.

Kato Site

We began to investigate the Kato site in June, 1969. The forested mountain top of about 90 acres, of which 70-75 acres are State Forest Land, overlies the abandoned Kato deep mine. Since it is surrounded by an unrestored high wall and spoil banks, vehicular access to the area is available at only one place from the southeast corner. The only water close to the site is acid mine water from drainage holes at the base of the mountain.

Piezometer pipes were placed at one, three, and five foot depths about three hundred feet from the high walls at the south (KA), northeast (KB), and northwest (KC) border of the State Forest land. No water was found in these pipes. Water table measurements were in uncased holes made when coring soil samples contained water.

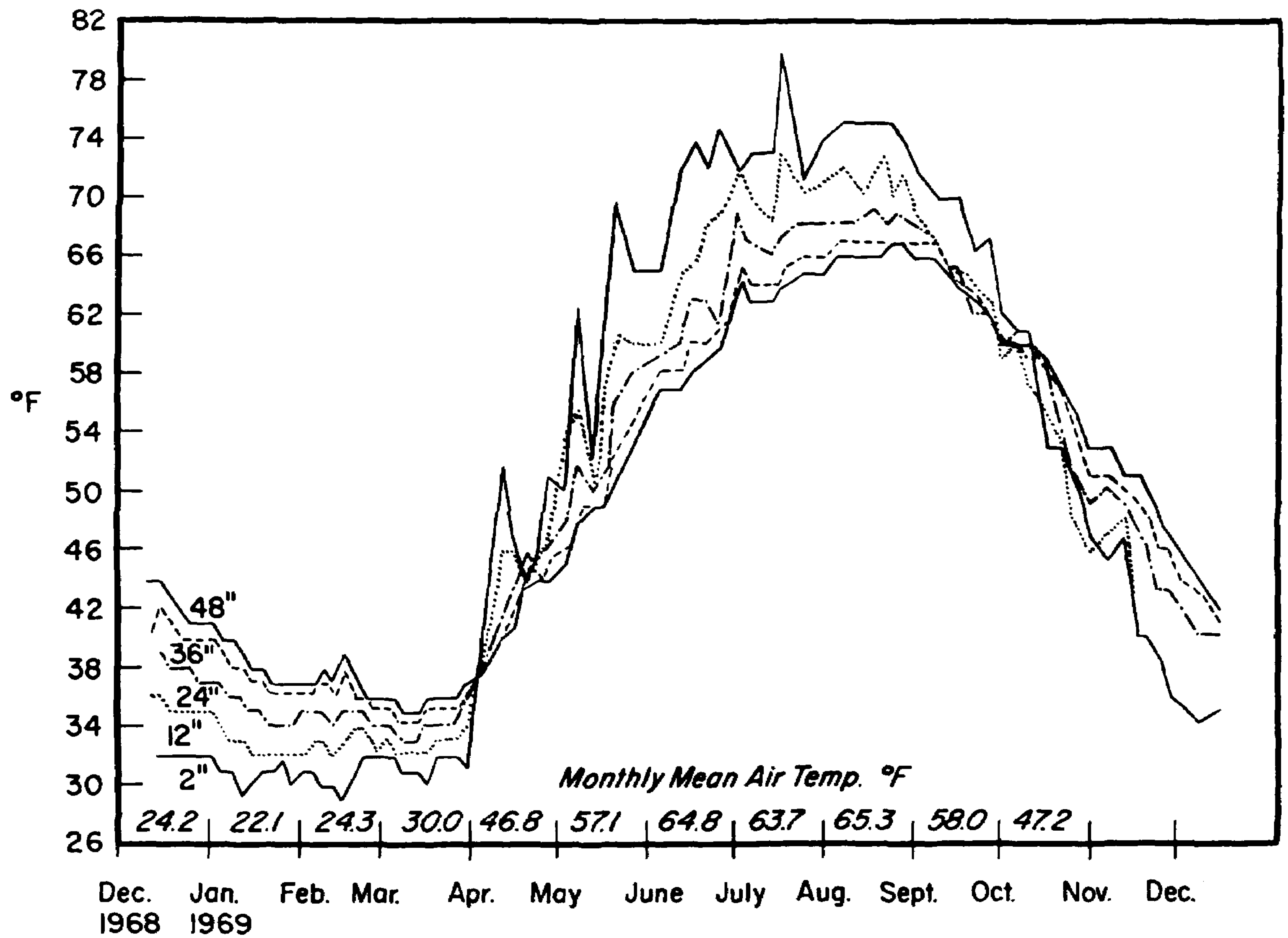


Fig. 6 - Soil temperature at Lanse, Pa. at five depths

TABLE IX

Rainfall Data from November 1968 to October 1970

	Philipsburg, Pa.[1]	Clarence, Pa.[1]	Lanse, Pa.[2]
November 1968	4.01	4.29	
December	2.93	3.32	
January 1969	1.47	1.33	1.35
February	0.67	0.78	0.30
March	1.31	1.23	1.45
April	3.81	2.35	2.85
May	3.91	2.59	2.10
June	5.92	4.55	2.90
July	6.26	5.23	4.70
August	3.14	3.92	2.20
September	1.82	1.34	2.35
October	2.36	2.80	1.35
Annual Total (inches)	37.61	33.73	21.55 (10 months)
November	4.38	3.59	2.80
December	3.82	6.44	2.70
January 1970	1.06	1.09	2.15
February	3.56	3.61	1.30
March	2.39	2.66	2.40
April	4.36	4.08	3.45
May	3.30	4.07	2.95
June	5.02	3.27	2.45
July	6.17	6.78	5.15
August	6.17	6.78	5.15
September	2.40	1.67	1.45
October	4.38	3.95	4.20
Annual Total	45.73	44.14	35.10

(1) Data from U.S. Dept. of Commerce, ESSA, Environmental Data Service.
(2) Data obtained from raingauge on the site.

SECTION VI

EXPERIMENTAL

LABORATORY PROCEDURES

Reconstructed Soil Samples

Most laboratory sealant studies were carried out in 2.0 inch I.D. Plexiglas tubes of 9.0 inches height containing 4.0 to 4.5 inches reconstructed soil from an 0-8 or 8-16 inch soil horizon at the Lanse site. (When soil was used from the Kato site, the top soil horizon was approximately 0-4 inches. The 4-8 inch horizon was somewhat comparable to the Lanse 8-16 inch horizon.) A 20 mesh Saran or steel screen was placed over the rubber stopper with a bottom drain to a 100 ml measuring cylinder. In some earlier experiments a 1/2 inch bed of 1/4 inch pea-gravel was then added, but in later experiments this was eliminated as it showed no particular utility. Field soil samples collected by a shovel were stored in sealed containers and sieved through a 4 mesh screen just before use. (Moisture content was typically about 25% for A horizon soil and about 20% for B horizon soil.) The sieved soil minus roots was then added in increments of about 1 1/4 inches. Compaction was effected by dropping a weighted ramrod (1-7/8 inches O.D.) five times from a height of two inches. If about twenty tamps were used or if the soil columns were rapped vigorously while water-logged, compaction was high with no detectable percolation. Freezing such samples would then usually cause very slow percolation, e.g. 1-2 ml/day.

Using this as a standard procedure, percolation flows were usually stablized after two to three days to rates of about 100 to 200 ml/hour. Percolate was recycled carefully to minimize disturbance of the soil surface.

When percolation flows were about 100 to 200 ml/hour, various additives (sealants) were introduced to the moist column in two to three increments to maintain a slight head. Additive concentrations were usually 2-1/2% with some at 5% in earlier experiments. Typical use of 40 ml of 2-1/2% additive corresponds to 4400 lbs/acre.

When no more additive was present as supernatent liquid, water washes of about 15 ml were then used several times followed by special additives as needed. More water washes were then used to maintain a head of about 1/2 inch. Percolate was collected in 100 ml cylinders to measure percolation rates in ml/hr. Turbid percolate was evaporated to determine amount of eluted latex. Percolate was sometimes checked for pH by Pan-pH Indicator Paper[9,10] reading in 0.5 units. Surface tension measurements were sometimes made by a DuNouy tensiometer[10] in experiments using a surfactant for pretreatment.

Clear percolate wash liquid from latex applications was usually recycled carefully but washes of soluble sealants were discarded, using fresh tap-water as make-up.

Since the hydrostatic head above the soil was usually about 1/2 inch average, Darcy values (K) were calculated by the equation

$$K = \frac{Q\ L}{h\ A}$$

where K = hydraulic conductivity (ft/day)

L = length of column (ft)

h = effective head (ft) = $L + \frac{0.5}{12}$

Q = ft^3/day effluent

A = cross-sectional area (ft^2)

$\frac{h}{L}$ = hydraulic gradient

Percolation flows of 1.00 ml/hour thus correspond to a Darcy value of 0.0346 ft/day or 12.6 ft/year where L = 4 inches and h = 4.5 inches. (Darcy values in this report have been converted to feet/year to avoid fractional numbers.)

Reduction of percolation is frequently used as a measure of sealant efficiency in this report and is defined by the equation

$$\%\ \text{Reduction} = \frac{a - b}{a} \times 100$$

where a = ml/hour before use of sealant

b = ml/hour after use of sealant

"Undisturbed" Soil Samples

Although most of the laboratory work with sealants was done with reconstructed soil samples, some "undisturbed" field cores were also tested for percolation characteristics before and after use of additives (See Table X).

Containment of the soil samples for this work was accomplished by one of two procedures: 1) coating with a cold-molding polysulfide[10, 11] and 2) coating with a polyolefin shrink tubing[10, 12].

TABLE X

Addition of Sealants to "Undisturbed" Soil in Shrink Tubing

	S11	S12	S14	S3	S4	S8	S9
Soil Source	KB	KB	KA	2D	2D	4B	3A
Depth (in.)	0-8	8-16	8-16	0-8	8-16	8-16	0-8
Sealant	NH_4	VA	NH_4	VA	VA	NH_4	3471
lb/acre	4000	2000	4000	750	1150	2700	6200
hr to add	29	29	29	29	29	29	-
Surface Film	No	Yes	No	Some	Yes	No	Low
	Darcy Permeability (Ft/Yr)						
Start	31.2	2.9	15.8	0.73	2.2	2.6	12.8-3.7
6/19-6/26/68	0.73	0.73	0.73	.73	.73	.37	-
6/26-7/3	0.317	2.6	.98	.73	.73	.73	-
Dried out for one month							
8/2-8/9	1.3	2.1	8.7*	-	.30	.73	.34
8/9-8/14	3.5	2.1	1.8	-	.66	1.0	.60
8/14-8/27	2.4	1.5	1.8	0.41	.84	.81	.74
8/27-9/5	3.3	2.0	1.5	.96	.34	.89	.93
9/5-9/15	-	2.0	.74	.92	.96	.91	1.1
9/15-9/20	2.9	2.9	.55	.96	.67	.44	.64
Ave.	2.7	2.1	1.3		.63	.80	.72
Efficiency	91	28	92	Low	71	70	70

* S14 Application of 10,000 lb/acre Na_2CO_3 as 5% solution

VA = Borden vinyl acetate #2140
NH_4 = Calc on NH_3; applied as 2% NH_4OH
S9 = Naugatuck SBR J3471 to thin-walled sampling tube for one month before transfer
Cores of 6.7 inches height; no eluted latex

Perma-Flex CMC Blak-Tufy (a polysulfide) gave excellent adherence to the soil with no wall effects. The three components were mixed as directed and a coating brushed on the vertical soil core resting on a 1/2 inch bed of pea-gravel above a rubber stopper with a hole for a drain. (Modeling clay was used as a seal around the gravel and masking tape was used to extend the core about 3/4 inch.) The soil column was placed in a circular container and then liquid mix was added to the height of masking tape. Setting occurred in about one hour. The following day the firm soil column was used for percolation studies with a head of about 1/2 inch water.

The shrink tubing procedure was recently described by Bondurant[13]. The "undisturbed" soil core was placed inside the tubing above a 1/2 inch bed of pea gravel supported by a one-hole rubber stopper. Shrinkage was effected by a heat gun. No appreciable wall effects were evident when tested with fluorescent additives. Shrink tubing was not useful with reconstructed soil samples.

Soil Characterization

Soil characteristics were determined by standard methods wherever applicable. Samples were prepared according to ASTM Method D421-58[15]. Particle size distribution was determined by the method for "Grain Size Analysis of Soils", D422-63[16] using Apparatus A. Soil particle specific gravity was determined by method D854-58[17]. Oven dry moisture content was measured according to procedure D2216-63T[18]. Liquid and plastic limits were determined by methods D423-61[19] and D424-59[20] respectively. The cation exchange capacity (CEC) was analyzed by the ammonium acetate method described by Bear[21]. Mr. Norman Suhr, assistant director of the Mineral Constitution Laboratories at Pennsylvania State University, analyzed heavy metals content of three soil samples by atomic absorption, and sodium and potassium by flame photometry. Our analytical laboratory made elemental analyses by means of emission spectroscopy. The pH was measured on soil samples that were slurried with an equal weight of distilled water.

FIELD PROCEDURE

Measuring the effectiveness of latex as a soil sealant when applied to test plots in the field was not straightforward. In the present work, since the test area was small compared to the size of the underground mine, the quantity and quality of the mine effluent could not be expected to change appreciably. Thus our method of estimating sealing effectiveness did not involve monitoring of mine effluent, but consisted of measuring soil moisture under the treated area at depths to five feet and comparing the data to those from an adjacent (untreated) area. If the seal was effective, moisture levels would be lower underneath the treated area, although it was recognized that lateral movement of ground water could have an effect on the results.

SECTION VII

RESULTS OF LABORATORY PERMEABILITY AND ELUTION STUDIES

Sealants for A Horizon Soil

The twelve latexes listed in Table XI penetrated A horizon soil as shown by elution through a laboratory soil column and gave good sealing efficiency. See details in Table XII. High elution through laboratory soil columns of 4 to 6 inches depth is desirable because it predicts penetration of latex to a greater depth in the field.

No definite correlation was evident between penetrating ability and particle size, surface tension, or pH. Most of the materials, however, were characterized by low surface tensions in the 36 to 53 dynes/cm range while particle sizes were usually in the intermediate range of about 1500 to 2500 Å.

Naugatex J-3471 (a highly crosslinked styrene-butadiene copolymer) was the most promising of this group for stability, penetrating ability, and sealant efficiency. It also showed utility with B profile soil.

Many of the other latexes tested in this investigation showed good sealing efficiency but were judged unsatisfactory because they gave low penetration or formed surface films with A horizon top soil. In general, latexes containing cationic surfactants were not satisfactory because they formed a heavy surface film. This is due to neutralization of the positive latex charge by the negatively charged soil particles.

Sealants for B Horizon Soil

With reconstructed soil columns, only a few materials gave appreciable penetration of B horizon soil. Most of the sealant is believed distributed through the column with only a fraction appearing as free latex. Part of the sealant was sometimes evident as a surface film, presumably resulting from agglomeration of latex particles. Latexes showing penetrating and sealing activity were: Goodrich 2679X, Borden 2140, Borden 2134, Paisley 71-9052-0, Naugatuck 3471 and Naugatuck R-8438-20C. See Table XIII for further details.

Latex Stability

Laboratory soil column experiments demonstrated the need for greater penetration of latex into the soil. Indeed if the chemical stability of a latex is defensive, surface films result.

Chemical stability can be determined in one of two ways by adding a coagulating salt, such as calcium chloride or aluminum sulfate. One way is to measure how much salt is needed to form a bulk precipitate;

TABLE XI

Penetrating Sealants for A Horizon Soil

Supplier	Code	Type	% Latex Eluted	Latex Properties			Sealing Efficiency (%)
				Particle Size Å	Surface Tension Dyne/cm.	pH	
Naugatuck	J1896	SBR-mod.	29	1500	53	10.6	89
	J1925	SBR-mod.	17	1400	64	9.6	81
	J2752	SBR-mod.	27	2000	37	8.9	79
	J3471	SBR	74	2400	36	9.8	80
Dow	870	PVC	50		36	8.	78
	874	PVC-Vinylidene Chloride	50		36	8.	54
Borden	2134	Vinyl Acetate (VA)	18		42	3.5	86
	2140	VA copolymer	32	2000	40	7.2	94
	2153	Vinyl Acrylic	47	2000-3000	42	5.	95
	2158	Vinyl Acetate	27	4000	44	4-6	94
	2635	PVC Copolymer + plasticizer	43		37	7.	88
Goodrich	2679x6	Acrylic	33		45	8.8	79

TABLE XII

Penetrating Sealants for A Horizon Soil

Sealant	Code	Lb/Acre	Percolation Rate - ft/yr Start	Percolation Rate - ft/yr After Sealing	Efficiency of Sealant	% Latex Eluted	Soil Source	Surface Film
Latexes								
Naugatuck	1896	5500	710	77	89	29	2C	Mod.
	1925	5500	925	180	81	17	2C	Low
	1925	+3300 R	180	26	86	-		
	2752	5500	610	145	79	27	2C	Low
	2752	+3300 R	145	52	96	-		
	2768	5500	775	310	60	33	2C	Low
	2768	+3300 R	310	153	50	-		
	3471	5500	520	104	80	74	2C	Low
	3471	+3300 R	101	41	62	-		
Incremental Additions								
Naugatuck	3471	5500	1610	14	99	25	KB	Mod.
	3471	5500	530	42	92	22	KB	Low
Naugatuck	3471	5500	1060	5.5	99	0	KB	Mod.
+ TEPA Coagulant		5500						
	3471	4400	2240	177	91	20	03A	Low
Dow	870	5500	1060	230	78	50	2C	Low
Dow	874	5500	848		54	50	2C	Low
Borden	VA 2140	5500	252	88	65	18	03A	Low
	2140	5500	1040	64	94	32	2C	Low
	PVC 2635	6600	1320	164	88	43	KB	Some
	VA 2134	8800	1240	173	86	67	KB	No
	VA 2153	4400	1065	56	95	47	KB	
	VA 2158	4400	1240	78	94	27	KB	
Goodrich	2679X6	5500	228	48	79	33	03A	No
Acrylamide + Amm. persulfate		4400	721	218	70	34	2C	No

R = re-used column.

TABLE XIII

Penetrating Sealants for B Profile

Sealant	Code	Lb./Acre	Percolation Rate - ft./yr. Start	Percolation Rate - ft./yr. After Sealing	Efficiency of Sealant	% Latex Eluted	Soil Source	Surface Film
Latexes								
Goodrich	2679x6	3500	472	15	97	9	0A3	Some
	2679x6	5500	570	25	95	16	2C	Some
Borden	2140	4800	665	10	98	13	0A3	Some
	2134	2750 R	88	2	97	73	KB	Low
	2134	1670	1010	91	91	0	KB	Low
	2134	1670 R	91	20	78	0		
Naugatuck	3471	1670	12	1.4	89	0 Sk.	KB	Low
	3471	4400	55	11	80	12	KB	Some
	R-8438-20C } Na_2CO_3 }	4400 } 5400 }	1680	3.8	99	0 Sk.	KB	None
	Na_2CO_3	5400	1720	3.4	98	0 Sk.	KB	None
Paisley	71-9052-0	4400	1510	94	87	34	KB	None
Solutions of Polymers and Monomers						Inches Penetrated		
Goodrich	K714	2800	202	16	93	(1-2)		
+ Tergitol	15-S-12	31						
Dow Montrek	12 }	4400	335	265	22			
	600 }	3100 R	265	28	90			
	600	4400	204	138	32			
NH_4OH		19400	478	18	99.8		0A3	
		Froze	1	3	-			
Sod. hexametaphosphate		4400	1260	10	97		KB	
Hydrazine		6600 R	1700	3.0	97	(1-2)	KB	

Sk = skinned (removed top half inch of soil). R = re-used column a second way is to add a very small amount of coagulant to a dilute latex solution and measure the optical density at 700 mμ in a Cary spectrophotometer to determine how much the particles have grown by insipient coagulation. Both these methods were used on a series of latexes with and without added anionic or nonionic surfactants.

It was found that:

1) The addition of surfactant before adding electrolyte increased chemical stability,

2) Tergitol 15-S-12 (a nonionic) was more effective than Aquarex G and Nacconol 90 (anionics), and

3) 800 Å particle size latex required more electrolyte than 400 Å latex to cause instability.

These results confirm the behavior of latex in soil columns where the highest elution has occurred when latex was stabilized with excess Tergitol 15-S-12.

To further corroborate these observations with respect to reaction with the soil, a series of experiments was carried out by shaking 10 g air-dried Lanse soil for 0.5 to 1.5 hours with 20 ml 2 1/2% latex by itself and with 10 parts added surfactants. Samples were then settled overnight, centrifuged for separation of soil and coagulated latex, and decanted for measurement of solids in the supernatant liquid. The data show that stability of latex to soil is increased by the addition of surfactants, particularly Tergitol. (The latter is more effective with 10 parts than with 5 parts per 100 parts rubber.)

Although this vigorous shaking of latex and soil in a bottle is a more drastic condition than latex percolation, the results show that the addition of surfactants to the latex will reduce coagulation by chemicals in Lanse soil, i.e., increase the penetration of the latex into the soil.

<u>Water Soluble Inorganics as Soil Sealants</u>

Dilute aqueous ammonium hydroxide (2 1/2%) was found to be an effective soil sealant (see Table XIV). This effect was checked a number of times with both A and B profile soil from Lanse or the Research Center.

Use of 2-1/2 or 5% aqueous sodium carbonate was also found to be a very effective sealant for all classes of soil tested (Table XIV). The mechanism of this sealant action is believed to involve swelling resulting from montmorillonite type clays.

TABLE XIV

Inorganic Chemicals as Soil Sealants

Sealant	Lb/Acre	Percolation Rate - ft/yr Start	After Sealing	Efficiency of Sealant	% Latex Eluted	Soil Source	Surface Film
NH_4OH	4400	605	8	99		03A	None
NH_4OH	11000	1580	1.6	99.9	1-2	RC	None
NA_2CO_3	11000	1420	6	99.5	1-2	RC	None

Ammonium carbonate and bicarbonate were found to be ineffective.

The effectiveness of ammonium hydroxide and sodium carbonate as soil sealants is of interest but is of very limited value because of the water solubility of the reagents and the resulting temporary nature of the seal.

Work by Agey[29] reports effective sealant activities with sodium carbonate as well as a variety of lithium salts. With a western type of soil, Agey did not obtain effective sealant action with ammonium hydroxide, however. Letey[30] has reported that soil and sand can be made water repellent by treatment with ammonium hydroxide. He also noted that a certain type of humic acid produced by microbiological action was a very effective sealant in the form of Fe^{+++} or Al^{+++} salts. Phillips[31] reports that mixtures of sodium humate with alkali metal carbonates or polyphosphates are effective soil sealants.

Work of Puri[32] in India notes that calcium saloids in clays are quantitatively converted to sodium saloids by action of sodium carbonate. The fine clay particles produced fill up interstices and make the soils impervious to water. This technique was used on a 13 mile length of canals in India to reduce seepage very effectively.

Clays as Sealants

Since commercial bentonite clays cost about two cents per pound, Montmorillonite BP was investigated as a sealant in very dilute (0.25 to 0.50%) dispersion and as an extender in several latexes. The clay was kept suspended by the addition of a surfactant. Pore blockage occurred, but most seals were made at the surface and in no case was penetration greater than two inches, in laboratory soil columns. It was concluded that no further work was warranted.

SECTION VIII

FIELD PERMEABILITY STUDIES

Natural Permeability

To determine the relative permeability of the soil a series of percolation tests were performed at the three locations of interest at Lanse, i.e., 3C, O3A and strip bank, and KA and KB at Kato. Soil cores were removed to 2, 8, 16, 24 and 32 inch depths with the thin wall sampler tube, each core separated from the next by about fifteen feet. Then two-foot-long thin-wall tubes were inserted into the 2, 8, and 16 inch deep holes and three-foot long tubes were inserted into the 24 and 36 inch deep holes. Each tube was tamped down about one inch further to assure a bottom seal; the tubes were filled with water and the rate of fall was measured.

The test is similar to those done for septic tank percolation studies[36], but is not quantitatively related to Darcy's coefficient of hydraulic conductivity because the water can flow in three dimensions from the bottom of the tube. The measurements are dependent on the length of test, since the rate of fall is a function of the head. Therefore, it should be noted that the 24 and 32 inch deep tubes should give faster percolation rates because of the one foot greater head. At locations O3A and 3C the data show a sharp decrease in percolation at increasing depth, Table XV. However, the percolation at O3A and 32 inch depth is much higher than at 3C (0.2 vs. 0.01 inches/hour); the fragipan layer must be deeper at the 3C location since this area does experience a perched water table. On the strip bank the rates of falling head are randomly variable, appearing to be as much dependent on the particular location of insertion as on depth of placement. For example, water drained from the 16 inch tube as fast as it was added, probably into a sub-surface cavity or crevice.

At Kato the tubes were more difficult to place because of interference of tree roots. For this reason 2 inch deep tubes were not inserted. These short tests at Kato were inconclusive, varying extensively when the tubes were moved.

Field permeability tests were also performed in two (previously described) eight-inch diameter permeater tubes at Lanse and one at Kato. Because the soil is confined inside the tube, hydraulic conductivity can be calculated according to Darcy's flow equation.

The high values reported in Table XVI experienced when the tubes were rewetted from a dry surface condition, enable us to conclude that infiltration is faster than the saturated permeability of the soil. In contrast to the falling head percolation tests, these permeability results do not show a high variation between locations.

TABLE XV

Falling Head Percolation Tests

5/19 - 5/21

	Depth:	2"		8"		16"		24"		32"	
Location	Test #	Time	Rate*	Time	Rate	Time	Rate	Time	Rate	Time	Rate
Lanse 3C	1	10 min.	9.75	10 min.	2.4	24.3 hrs	0.78	47 hrs	0.01	47 hrs	0.008
	2	3 min.	480	14 min.	5.9	15.1 hrs	0.78	39.4 hrs	0.019	39.5 hrs	0.011
	3	4 min.	360	5.3 hrs	3.5	5.3 hrs	0.81	14.3 hrs	0.017	14.3 hrs	0.009
	4	5 min.	300	14 hrs	4.3	2.6 hrs	1.05	440 hrs	0.0125	440 hrs	0.0054
	5	5 min.	300	16.3 hrs	0.65	16.3 hrs	0.70				
	6	5 min.	300	8.8 hrs	0.54	8.8 hrs	0.70				
	7	5 min.	300	14.4 hrs	0.51	14.4 hrs	0.61				
	8	6 min.	240	1.hr	0.38	1.hr	0.36				
Lanse 03A	1	43 min.	25.	44 min.	23.	11 min.	33.4	46 min.	0.5	41 min.	0.18
	2	15 min.	34.	12 min.	27.5	10 min.	24.	24.6 hrs	0.42	24.5 hrs	0.14
	3	13.5 min.	33.3	12	19.8	2.7 hrs	6.	16 hrs	0.66	16 hrs	0.18
	4	10. min	17.2	10	9.4	10 min.	9.	3 hrs	0.83	3.1 hrs	0.20
	5	15 min	20.	15 min.	6	15 min.	6.	17 hrs	0.73	17 hrs	0.26
	6	1 hr	13.	7.9 hrs	2.7	7.9 hrs	2.4	7.9 hrs	0.81	8 hrs	0.38
	7			1 hr.	2.25	15.4 hrs	1.46	15.4 hrs	0.72	15.4 hrs	0.43
	8					1 hr	0.63	1 hr	0.63	1 hr	0.38
Strip bank (Lanse)	1	20 min.	5.6	20 min.	10.5	drains		20 min.	40.	20 min.	11.2
	2	1 hr	4.25	1 hr	8.5	immediately		20 min.	7.1	1 hr	8.25
	3	3.1 hrs	1.9	3.1 hrs.	5.26			17.9 hrs	1.9	3.9 hrs	2.80
	4	4.4 hrs	1.5	4.4 hrs	5.5			4.3 hrs	3.2	4.3 hrs	2.60
	5	1 hr	0.5	15 hrs	1.23			3.1 hrs	3.7	15 hrs	1.80
	6			1 hr	3.13			15 hrs	2.0	1 hr	2.88
	7							1 hr	3.63		

* Rate is given in inches/hour.

TABLE XV (cont'd.)

	Depth:	8"		16"		24"		32"	
Location	Test #	Time	Rate*	Time	Rate	Time	Rate	Time	Rate
Lanse 3C	1	40 min.	3.2	25 min.	0.20	585 hrs.	0.023	585 hrs.	0.009
	2	10 min.	3.8	16.2 hrs.	0.24	16.7 hrs.	0.052	16.7 hrs.	0.026
	3	-	-	24.6 hrs.	0.47	25.2 hrs.	0.044	25.2 hrs.	0.029
Lanse 03A	1	10 min.	30	20 min.	43	2 hrs.	0.38	2 hrs.	0.25
	2	20 min.	23	10 min.	3.4	19 hrs.	0.38	19 hrs.	0.35
	3	10 min.	13	24.2 hrs.	0.62	24.3 hrs.	0.47	24.3 hrs.	0.53
Kato KA	1	2 min.	180	5 min.	5.25	10 min.	6	19.8 hrs.	0.025
	2	12 min.	117	10 min.	1.25	42 min.	3.1	--	-
Kato KB	1	10 min.	6	10 min.	2.25	10 min.	1.12	11 min.	25
	2	10 min.	1.12	45 min.	2.5	23.2 hrs.	0.04	64 min.	3

*Rate is given in inches/hour.

TABLE XVI

Darcy Hydraulic Conductivity (K) of Field Permeameters

Date	Time of Test (Hrs.)	Lanse Site K (3C) (ft./yr.)	Lanse Site K (4B) (ft./yr.)	Kato Site K (KA) (ft./yr.)
6/12	24	7.67	17.2	
7/8	17.5	20.8		
7/9	24.5	7.67		
9/4	15.2	12.0	29.6	
9/5	24.5	7.67	11.3	
9/19	24.5	*56.9		38.3
10/21	3.5	*52.2	*104.	
10/22	24.	11.3	19.0	
10/23	24.	3.65	3.65	
11/7	19.	nil	4.75	
11/8	24.	nil	3.65	
11/20	288.	1.83	2.56	
11/21	24.	3.65	3.65	

*dry

Effect of Sealant Applied in the Field

Ammonium hydroxide, sodium carbonate, and Naugatex J-3471 latex were found to be effective sealants in laboratory columns. Field tests of these sealants were made by sprinkling dilute solutions of these compounds on three five-by-five foot plots separated about fifteen feet from each other. In each case, directly after the application of the sealant solution, a water flush was sprinkled over the area to abet penetration into the soil.

Two or three weeks later, soil cores were dug in 4-inch increments to 8 inch and 16 inch depths, making two holes into which two-foot-long thin-wall tubes were inserted. Concurrently 8 inch and 16 inch holes were dug and thin-wall tubes were inserted into an adjacent untreated area. Subsequently, falling head percolation rates were measured. The results of the percolation tests are shown in Table XVII. The treatments appear to have been more effective at 16 inches deep than at 8 inches. In the case of the ammonium hydroxide tests, the effectiveness at the 16 inch depth was somewhat delayed and short lived. Although the test time is shorter for the sodium carbonate and latex treatments, the 16 inch deep reduction in percolation is significant. Comparing the untreated area with the treated area results for November 8 only, the percent reduction in percolation is 96.6% for the sodium carbonate and 98.9% for the latex treated area.

TABLE XVII

Falling Head Percolation Tests at Lanse
(Units: Time - minutes, Rate - in./hr.)

	NH_4OH Treated				Untreated											
Depth:	8"		16"		8"		16"		8"		16"		8"		16"	
	Time	Rate	Time	Rate	Time	Rate	Time	Rate	Time	Rate	Time	Rate	Time	Rate	Time	Rate
8/1/69	10	32.25	5	12	10	43.5	5	186.								
	5	25.5	5	12	5	37.5	5	190.								
	5	22.5	15	7.38	5	36.25	15	80.								
	30	15.0	15	9.5	30	23.5	15	68.								
	10	16.25	15	9.5	10	35.5	15	57.								
	15	6			15	21.5										
	30	5			30	20.75										
	15	4	15	8.5	15	22.5	15	47.								
	15	4.5	15	8.	15	22.	15	43.								
	15	4.5	15	8.5	15	22.	15	46.								
	15	4.	15	8.	15	21.5	15	41.								
	NH_4OH Treated				Untreated				Na_2CO_3 Treated				Latex 3471			
10/21	16	60	60	0.625	15	47	15	58	15	44	15	0.5				
	15	66	240	0.375	15	41	15	54	15	45	15	0.5				
	15	74	-	-	15	42	29	35	15	54	115	0.25				
	-	-	-	-	-	-	30	34	15	54	241	0.25				
10/22	-	-	1183	0.2	-	-	30	23	-	-	1188	0.15				
	-	-	120	0.25	-	-	90	13	-	-	120	0.12				
	-	-	60	0.375	-	-	60	10	-	-	60	0.25				
10/23	-	-	1457	0.19	-	-	30	17	-	-	30	0.50				
	-	-	92	0.16	-	-	30	19	-	-	30	0.75				
	-	-	30	0.50	-	-	30	18	-	-	30	0.75				
11/6	8	125	30	2.5	10	20	10	26	10	28	30	0.13				
	10	113	60	0.63	10	18	10	20	10	24	60	0.25				
	10	108	60	0.25	10	18	10	20	10	24	60	0.03				
	-	-	-	-	40	17	40	21	40	20	-	-				
	-	-	-	-	60	16	60	18	60	20	-	-				
11/7	-	-	1077	0.38	-	-	15	18	-	-	1075	0.20	15	14	60	0.38
	-	-	60	0.75	-	-	15	19	-	-	60	0.19	15	12	60	0.25
	-	-	60	0.75	-	-	30	16	-	-	60	0.19	30	12	60	0.13
	-	-	60	0.75	-	-	60	14	-	-	60	0.38	60	10	-	-
11/8	-	-	1301	0.9	-	-	60	8	-	-	1480	0.26	55	4	1360	0.12
	-	-	48	1.9	-	-	60	8	-	-	60	0.19	60	3.5	60	0.06
	-	-	72	2.0	-	-	60	8	-	-	60	0.31	60	3.3	60	0.06
	-	-	60	2.0	-	-	-	-	-	-	60	0.31	-	-	60	0.12

Spoil Banks

The soil aggregate system that composes the spoil banks is not definable because of the intermixture of soil, sub-soil and bedrock components, with resultant large voids. If penetrating sealants are not effective, it may be practical to seal these restored stripped areas with a surface seal. Therefore, to test surface seals on the spoil bank at Lanse, five solutions which had previously given effective surface seals in laboratory soil columns were applied in field tests. Five 8-inch diameter galvanized stove pipe sections 8 inches long were pushed into the rocky soil 1 to 1 1/2 inches deep on the spoil bank in Location 4D. The following sealants were tested:

GM-39: 800 ml. of 2 1/2% EPDM latex containing 40 parts of Aroclor 1242[10] per 100 parts of rubber.

GM-38: 800 ml. of 2 1/2% EPDM latex containing 40 parts of paraffin soap per 100 parts of rubber.

PR-10: 800 ml. of 5% solution of Phillips PR-10 sealant, a latex-oil mixture.[10]

BP-clay: 3500 ml. of water containing 80 g. of montmorillonite BP clay and 40 g. of sodium-hexametaphosphate.

Water Repellant: 250 ml. of water containing 2.5 g. of nonylphenoxyacetic acid dissolved in 20 g. of 28% NH_4OH, followed by 250 ml. of 0.1% HCl.

These short tests indicate that PR-10 is a poor sealant, GM-38 and GM-39 are intermediate and montmorillonite clay and nonylphenoxyacetic acid appear to have sealed well enough to be of further interest. See Table XVIII. The acid became more effective after it was allowed to dry.

TABLE XVIII

Surface Seal Tests on Spoil Bank at Lanse
[Time (in minutes) to Dryness of 500 ml Increment of Water]

Date	GM-39	GM-38	PR 10	BP-Clay	Water Repellant
10/22	105	7	7	105	103
	-	-	62	-	61
10/23	6	3	2	3	21
	35	31	6	30	100
11/7	28	33	2	112	110
	60	37	3	-	-
11/8	59	135	3	223	575

SECTION IX

LATEX IRRIGATION AND EVALUATION AT LANSE

It was decided to demonstrate the use of latex as a soil sealant by irrigating three small plots at Lanse coded 03A on the west of Brown's run, 3C on the east of the stream, and SB, an area on the spoil bank. Earlier plans to sprinkle latex on twenty acres of the side were abandoned because of easement difficulties. On the basis of results from laboratory soil columns and small plot experiments at Lanse, Naugatex J-3471 was the latex of choice. The irrigation system consisted of plastic pipe (two inch size) for the main line from the water meter to the irrigation area because of lower price and ease of handling. Because the municipal water supply was limited to 20 gpm, low-volume 14V-LA-TNT Rainbow sprinklers were specified with low angle 20° 3/32 inch nozzles to reduce wind effects. At the expected nozzle pressure of 50 psig, each sprinkler covers a 56 foot diameter area at a delivery rate of 1.64 gpm. Each of the three test areas was covered with twelve sprinklers, six used with water alone as a control area and six used with latex and subsequent water spraying. One-quarter-turn inlet valves were positioned on the main lines leading to each area. Flow to the treated and untreated areas was set at 10 gpm by Dole flow control valves in the main entry lateral to each of the six sprinklers.

To avoid the use of dilution tanks, a Moyno pump operated by a 1/2 HP, 1140 rpm 5:1 reducing drive was used to deliver 1/2 gpm 48% latex for mixing with 10 gpm water. A 3500 watt gasoline generator provided power for pump and light. Latex was applied at night to take advantage of the lower evaporation and higher humidity.

Neutron gauge access tubes were placed in orthogonal arrangement in the areas that were irrigated, with four tubes in the section that were sprinkled with latex and four tubes in the untreated irrigation section in each of the three locations. Each tube, five and one-half feet long and sealed at one end with a plug welded in place, was inserted five feet into the ground in a cored hole.

In each irrigation area, the left section of six sprinklers spread the dilute latex while the right section sprinkled the same amount of water to serve as a control plot. As shown in Figure 7 each sprinkler has a 56-foot sprinkling diameter at 50 psig design water pressure. The sprinklers are 30 feet apart on the laterals and 35 feet apart between the laterals. The access tubes (coded AT on Figure 7) were placed in comparable spots on the two sections of each area, so that four soil moisture measurements on the two sections could be compared. Bouyoucos resistance blocks (BB) were also placed in areas 03A and 3C at one, two and three foot depths, but not on the spoil bank area.

Fig. 7 - Irrigation system for application of latex at Lanse site

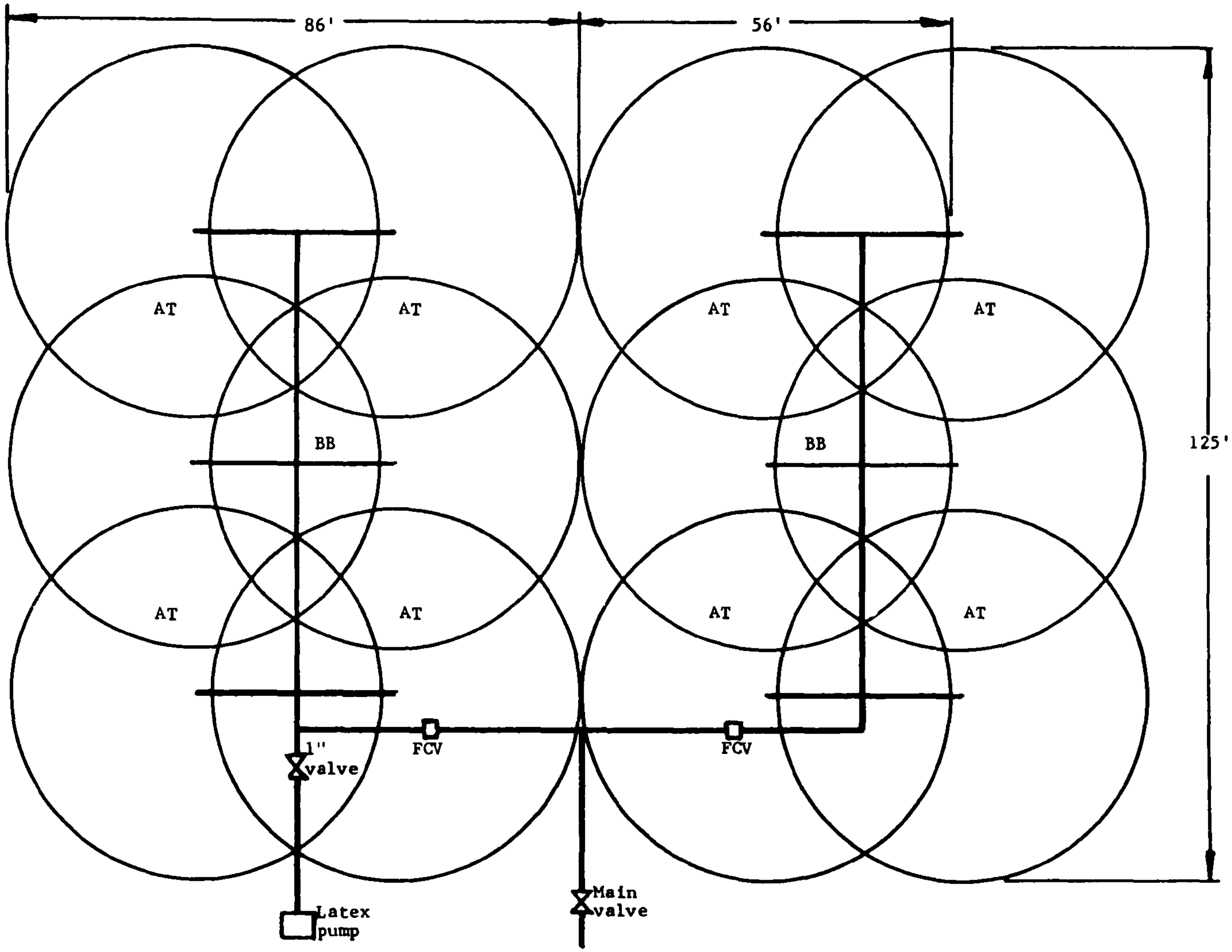


Fig. 7 - Irrigation system for application of latex at Lanse site
AT - access tube; BB - Bouyoucos block; FCV - flow control valve

A service contract was arranged with Pennsylvania State University for thirteen once-a-week neutron gauge measurements of 25 access tubes at 4 depth intervals, extending from June 10 to September 10, 1970. The information was supplied as volume percent water content.

On June 17-18, 18-19, and 19-20 (1970) latex was applied to plots 03A, 3C and the spoil bank (SB), respectively. Table XIX shows the time schedule and the quantities of water and latex irrigation to each area. Latex applications in Areas 03A and 3C were apparently successful, but on the spoil bank appreciable puddling occurred with some latex run-off into the control area. A portion of the SB area had experienced prior compaction and settling; this part of the area showed the greatest run-off.

TABLE XIX

Latex Application Schedule at Lanse

Plot	03A	3C	SB
Date	6/17-18/70	6/18-19/70	6/19-20/70
Pre-Irrigation			
Start	4:00 p.m.	4:10 p.m.	9:15 p.m.
Time	5 hr.	4 hr. 35 min.	1 hr. 37 min.
Gallons of water	4,645	4,000	1,430
Latex Irrigation			
Start	9:00 p.m.	8:45 p.m.	10:52 p.m.
Time	12 hr.	9 hr.	10 hr. 30 min.
Gallons of water	12,485	9,700	10,990
Gallons of Latex (47.8% T.S.)	275	275	275
Latex (solids)	1,052*	1,052*	1,052*
Post Irrigation			
Start	12:00 N	5:52 a.m.	9:25 a.m.
End	2:40 p.m.	2:05 p.m.	3:30 p.m.
Time	2 hr. 40 min.	8 hr. 13 min.	6 hr. 5 min.
Gallons of water	2,230	7,200	4,810
Total water (gal.)	19,370	20,900	17,230
(inches)	1.59	1.71	1.41

*Equivalent to 4,650 lbs/acre

The purpose of the water irrigation before latex application was to provide a wetting front in the soil, whereas the subsequent post-irrigation was needed to rinse the latex from the vegetation, and to flush the latex deeper into the soil. In addition, 5,000 gallons of irrigation water were applied on June 20-21 to Area 03A, June 22-23 to 3C, and June 23-24 to SB to continue the downward movement of moisture into the soil. Almost half an inch of rain fell on June 21 which aided in keeping the ground surface high in moisture.

There was no difference in the appearance of the vegetation between the latex-treated and control areas at any time after application. The grass and legumes were thicker and greener than the year before and the weeds were higher, probably because of the wetter condition provided by the irrigation. No deleterious effects to the trees on the spoil bank has been observed.

Analysis of Soil Moisture Data

It was anticipated that soil moisture measurements taken at intervals of one foot depths would be a valid way to determine the effectiveness of the latex as a soil sealant. Neutron gauge measurements reported by Dr. L. T. Kardos, Environmental Scientist, Pennsylvania State University, as volume percent soil moisture were analyzed in two groups, the first including two weeks before and five weeks after application, and the second involving data taken the subsequent seven week period. The data was treated for analysis of variance and tests of significance.

The analysis divided the sources of variation into the following four factors:

1. Left versus right section of each plot.
2. Depth at which soil moisture was measured, that is 1, 2, 3 and 4 feet.
3. a) Week-to-week variation.
   b) Alternatively, pre-treated weeks versus post-treated weeks.
4. Access tube position. There are four positions in each section.

Each plot was analyzed separately for group 1 data as follows:

Analysis A. All 224 measurements were utilitzed (2 sections x 4 depths x 7 weeks x 4 positions), in which factor 3b (2 levels) was considered.

Analysis B. Pretreatment data only were considered (2 sections x 4 depths x 2 weeks x 4 positions) in which factor 3a compares two weeks under untreated condition.

Analysis C. Post-treatment data only were considered (2 sections x 4 depths x 5 weeks x 4 positions) for the first five weeks after treatment. Factor 1 above is now a measure of treatment significance.

From these three analyses, variances of the main factors and their interactions were calculated.

By comparing the difference based on the latex application to the error variance (the sum of all variances not attributed to treatment), the effect of treatment can be evaluated. On this basis Analysis B determines that there is a difference between the sections in areas 03A and 3C prior to treatment but not for the spoil bank. Analysis C determines that there is also a significant difference between the treated and control sections after treatment for 3C and 03A areas but not for the spoil bank.

Analysis A answers the question whether the difference between the treated and control sections was significantly larger after treatment. The answer is negative for all three plots based on analyses of variance. However, the averaged delta value of the spoil bank (SB) after treatment does show a significantly larger difference at the one-foot level (Table XX, t = 5.88). Figure 8 shows graphically that delta moisture increased after latex application and remained high through the next four weeks.

Table XX explains why Analysis A gives no treatment significance. Although there are wide differences between the control and test sections after treatment, these same differences are evident prior to treatment as well. Table XX shows the soil mositure averages of the four positions in each section prior to (two weeks), and after (five weeks) the latex was applied to the test area. The standard deviation of the means (S.D.) is also given for each set of values. The relatively high standard deviations reflect the wide fluctuation of values from position more than from week-to-week variation. The delta value is the average volume percent soil moisture of the test area minus the control for each depth.

In Figure 8 the delta values are plotted for each of the first seven times soil moisture was measured. It can be seen that except for the one-foot depth in area SB, the delta difference before and after latex treatment is marginal.

The fact that the delta soil moisture decreases with depth at 3C but is a maximum at four feet in area 03A indicates that soil moisture differences are characteristic of section differences. The "Student-t-Distribution" demonstrates that many of the values show very low significance.

For the group 2 data, the difference (delta) in soil moisture between the average (4 positions) of the treated section and the average of the control section for the three areas of interest over the period of July 30 to September 17, 1970, inclusive is shown in Figure 9. Table XXI shows that the soil moisture and delta soil moisture average of the seven measurements differ little from the first five post-treatment data.

TABLE XX

Soil Moisture Data

Depth (feet)	% Moisture Control*	S.D.	% Moisture Test Area**	S.D.	Delta	S.D.	t-dist. (Delta / S.D.)
Plot 3C - Prior to Treatment:							
1	23.67	1.108	25.99	1.623	2.31	1.965	1.17
2	33.85	.973	31.67	3.094	-2.18	3.244	0.67
3	35.45	1.056	32.42	3.201	-3.02	3.370	0.90
4	33.22	2.117	27.04	1.351	-6.19	2.512	2.46
Plot 3C - After Treatment:							
1	29.44	.680	30.94	.899	1.50	1.127	1.33
2	36.21	.480	32.73	1.716	-3.48	1.782	1.95
3	35.71	.691	32.89	1.759	-2.82	1.890	1.49
4	33.56	1.555	26.78	.856	-6.78	1.775	3.82
Plot 03A - Prior to Treatment:							
1	26.27	.618	28.16	.025	1.89	2.117	0.89
2	28.71	.319	28.67	.983	-.04	1.034	0
3	26.01	.710	25.02	.434	-.99	.832	1.19
4	25.09	.529	32.65	2.473	7.56	2.529	3.00
Plot 03A - After Treatment:							
1	30.20	.453	33.71	.892	3.51	1.000	3.51
2	29.06	.448	30.02	.683	.96	.817	1.18
3	27.26	.741	27.34	1.020	.08	1.261	0
4	26.57	.408	37.57	1.906	11.00	1.950	5.65
Plot SB (Spoil Bank) - Prior to Treatment:							
1	18.75	.544	18.39	.583	-.36	.797	0.45
2	15.07	.737	15.40	1.085	.33	1.311	0.25
3	14.41	1.120	15.64	1.145	1.23	1.602	0.77
4	15.25	.903	16.67	.983	1.42	1.335	1.06
Plot SB - After Treatment:							
1	17.86	.143	21.10	.533	3.24	.552	5.88
2	16.98	.584	15.54	.824	-1.45	1.010	1.44
3	15.02	.852	14.74	.808	-.28	1.175	0.24
4	15.73	.545	16.87	.755	1.13	.931	1.21

* Average of 4 positions, 2 weeks
** Average of 4 positions, 5 weeks
S.D. is the standard deviation.

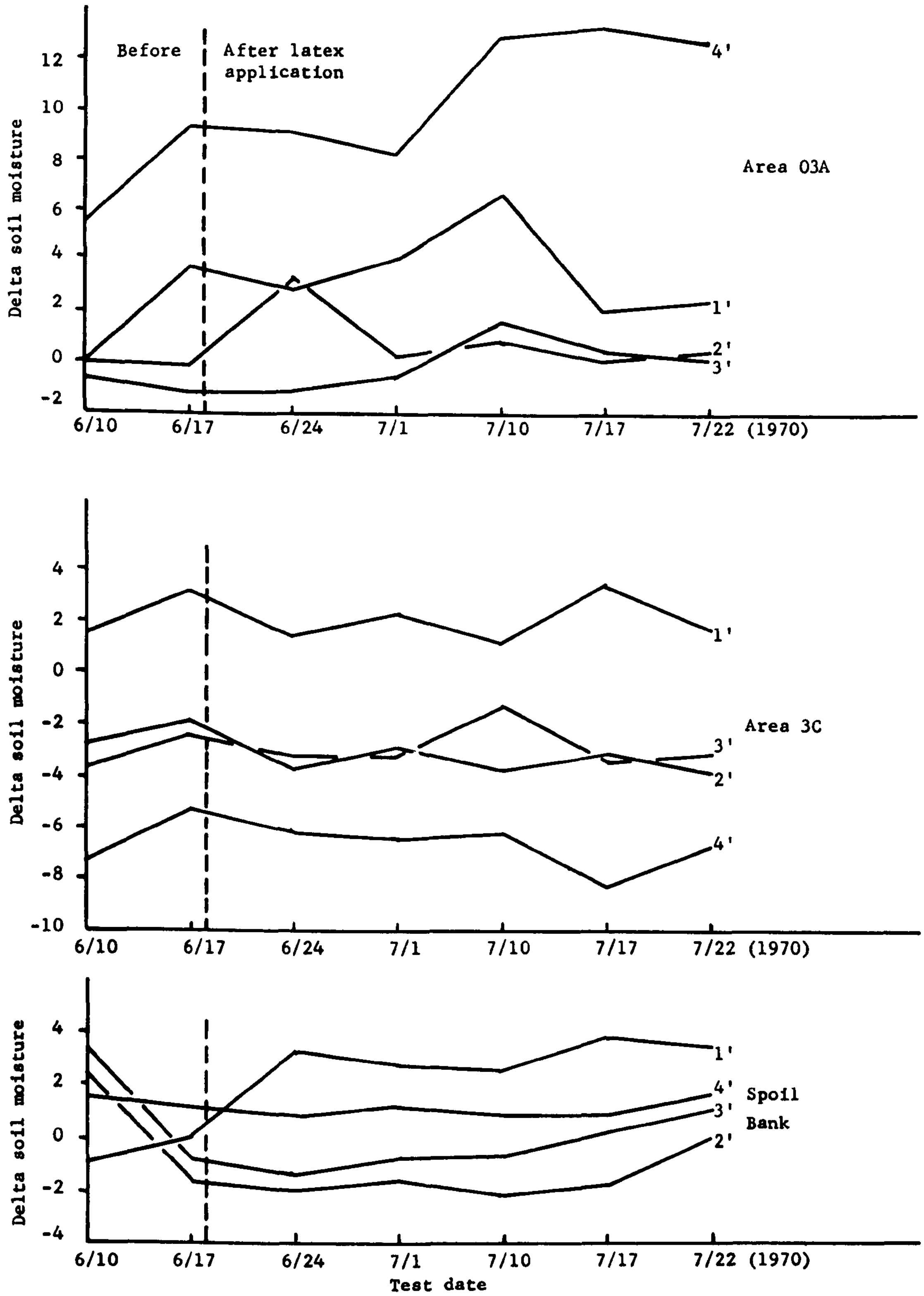


Fig. 8 - Effect of latex on delta soil moisture, i.e., difference in soil moisture between treated and control areas.

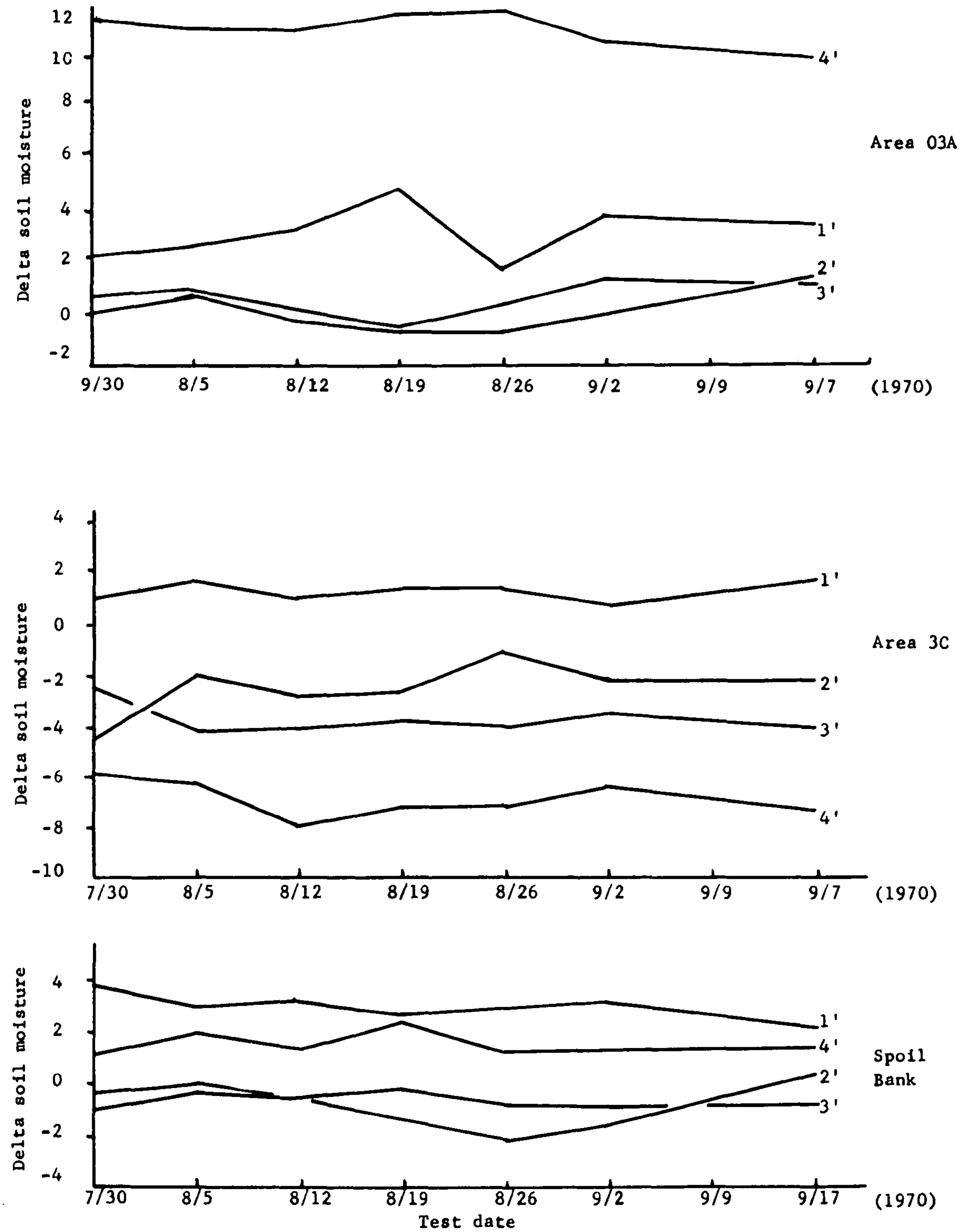


Fig. 9 - Effect of latex on delta soil moisture, i.e., difference in soil moisture between treated and control areas.

TABLE XXI

Soil Moisture Data

Seven weeks combined - 7/30 to 9/17 (1970)

Depth (feet)	% Moisture Control Area	S.D.	% Moisture Test Area	S.D.	Delta	S.D.	t-dist. (Delta / S.D.)
			Plot 3-C				
1	28.31	.653	29.54	.836	1.23	1.061	1.16
2	34.88	.294	32.37	1.422	-2.51	1.452	1.73
3	35.04	.444	31.32	1.467	-3.72	1.532	2.42
4	33.02	1.278	26.15	.656	-6.88	1.436	4.80
			Plot 03-A				
1	28.91	.552	32.03	.783	3.12	.958	3.26
2	28.79	.235	28.92	.600	.14	.644	0.22
3	26.47	.517	27.14	.855	.66	.999	0.67
4	26.04	.341	37.16	1.359	11.12	1.401	7.94
			Plot SB				
1	16.86	.197	19.82	.453	2.97	.494	6.01
2	16.21	.461	15.27	.694	- .94	.833	1.13
3	14.94	.636	14.36	.632	- .58	.897	0.65
4	15.27	.486	16.78	.608	1.51	.778	1.94

Because the results of the in-depth soil moisture were inconclusive, we determined gravimetric soil moisture to a depth of one foot and compared treated and control sections at areas 03A and 3C. As in neutron gauge moisture measurements, position variations were high. Moisture decreased with depth, except where the soil was saturated with free water or was especially stony as noted in Table XXII. In area 03A the soil from the treated section was wetter than the control, whereas the reverse was true at 3C (see average values and L-U values in Table XXII). Evapotranspiration by the vegetation is probably not a factor because it rained the night before the samples were taken. Again, section differences appear to be dominant.

Since soil moisture did not serve as a measure of sealing effectiveness, permeability tests were done on several occasions. Twelve 8-inch diameter by 12-inch long stove pipes were pressed into the ground ten inches, three in comparable positions in each section of Areas 03A and 3C. After sprinkling each area with 12,000 gallons of water,

TABLE XXII

Gravimetric % Soil Mositure of Samples Taken August 31, 1970

	Latex Treated (L)			Untreated Control (U)		
Depth, in.	0-4	4-8	8-12	0-4	4-8	8-12
03A	38.2	26.6	23.8	32.4	26.4	22.6
	41.8	36.5[1]	30.9[1]	29.1	26.5	23.0
	33.6	30.0	34.3[1]	31.2	27.2	21.0
	28.8	26.2	20.7	27.4	28.0	22.8
Av.	35.6	29.8	27.4	30.0	27.0	22.4
Av. Δ (L-U)	5.6	2.8	5.0			
3C	22.4	17.4	10.1[2]	27.3	26.2	23.8
	26.9	23.1	22.0	33.3	30.4	26.8
	25.8	23.0	23.4	28.7	20.7[2]	22.7
	28.2	20.5	21.0	31.3	12.7[2]	16.3
				26.6	23.9	19.0
Av.	25.8	21.0	19.1	29.5	22.8	21.7
Av. Δ (L-U)	-3.7	-1.8	-2.6			

[1]Free water in soil

[2]Soil sample was stony

permeability tests were done on September 16, 1970 in the stove pipes by adding 500 ml increments of water and measuring the time to disappearance of free water from the tubes. Specific permeability was calculated by dividing the infiltration in cubic centimeters per minute (500 cc/t (min.)) by the surface area (324 cm^2) of the tube. The permeability is synonomous with Darcy's hydraulic conductivity K, cm/min. These numbers are recorded in Table XXIII as cc/min. cm^2, as well as percent efficiency, as defined by the permeabilities of the control minus the latex treated tubes divided by the control times 100. The data demonstrate a consistent reduction of permeability in the experimental sections of 90 to 99% efficiency, even though there is significant variability between tubes within each section.

On October 12, 1970 when the tests were repeated, the efficiency remained high except for position 03A-1. For some unexplained reason the 03A-1 tube in the treated area became quite permeable while infiltration of the control at 03A-1 and 2 decreased appreciably. The 03A

TABLE XXIII

Permeability Tests at Lanse on September 16, 1970

Location	Latex Treated (L) Time (min.)	Latex Treated (L) Permeability** (cc./min.-cm^2)	Latex Treated (L) Average	Control (C) Time (min.)	Control (C) Permeability** (cc./min.-cm^2)	Control (C) Average	Efficiency*
03A-1	65	0.0238		3	0.512		
	245	0.0063		6	0.257		
	120	0.0128	0.0143	4	0.386		
				5	0.308	0.366	95.7%
03A-2	> 480	< 0.0032	< 0.0032	2	0.771		
				15	0.103		
				11	0.140		
				16	0.096	0.278	> 98.8%
03A-3	80	0.0193		1	1.54		
	200	0.0077		1	1.54		
	125	0.0123	0.0131	1	1.54	1.54	99.0%
3C-1	250	0.0062	0.0062	5	0.308		
				21	0.0735		
				19	0.0810		
				26	0.0594	0.130	95.0%
3C-2	10	0.154		1	1.54		
	20	0.077		2	0.771		
	22	0.070		2	0.771		
	20	0.070	0.095	2	0.771	0.963	90.0%
3C-3	44	0.0350		1	1.54		
	80	0.0193		2	0.771		
	73	0.0212		2	0.771		
	75	0.0206	0.0240	2	0.771	0.963	97.5%
Overall average			0.0260			0.707	96.4%

* Efficiency $= \frac{C - L}{C}$

** Permeability $= \frac{1.543}{t \text{ (min.)}}$

TABLE XXIV

Permeability Tests at Lanse on October 12, 1970

	Latex Treated (L)			Control (C)			
Location	Time (min.)	Permeability** (cc./min.-cm²)	Average	Time (min.)	Permeability** (cc./min.-cm²)	Average	Efficiency*
03A-1	7	0.220		34	0.0454		
	12	0.129		20	0.0771		
	13	0.119	0.156	19	0.0812	0.0679	negative
03A-2	(contained free water)	nil		70	0.0220		
				100	0.0154		
				80	0.0193	0.0189	~ 100%
03A-3	158	0.0098		1	1.54		
	176	0.0088	0.0093	1	1.54		
				1	1.54	1.54	99.3%
3C-1	165	0.0093		6	0.2570		
	204	0.0076	0.0085	23	0.0670		
				24	0.0643	0.1294	93.2%
3C-2	26	0.0594		2	0.771		
	46	0.0335		3	0.514		
	36	0.0429	0.0453	2	0.771	0.685	93.4%
3C-3	21	0.0734		2	0.771		
	35	0.0440		2	0.771		
	45	0.0343	0.0506	2	0.771	0.771	93.9%
Overall average			0.0450			0.535	91.5%

* $\text{Efficiency} = \frac{C - L}{C}$

** $\text{Permeability} = \frac{1.543}{t\ (\text{min.})}$

treated section was obviously wetter than the adjacent control section with small water puddles in low places and in tube 03A-2. These data are shown in Table XXIV.

To determine the permeability at ten inches depth the tubes were removed from the ground with the enclosed soil and then reinserted in the holes without the soil. When this was done in holes 03A-2 and 3 water flowed into the holes from the thoroughly saturated soil. We may conclude from this that under saturated conditions the sealant induces lateral flow at a higher level in the soil. However, the effect of the latex sealant on permeability from the ten-inch depth down is much poorer than in the top ten inches as the data in Table XXV show.

TABLE XXV

Permeability Tests at Lanse on October 13, 1970
(10 Inches of top soil removed from tubes)

	Latex Treated (L)			Control (C)			
Loc.	Time (min)	Perm** (cc/ min. cm^2)	Ave	Time (min)	Perm** (cc/ min. cm^2)	Ave	Eff.* (%)
03A-1	6	0.257		4	0.386		
	9	0.172	0.215	11	0.140	0.263	18.3
03A	Free water entered hole when soil was excavated			10	0.154		
				26	0.059	0.107	
03A-3	Same as 03A-2			>233	>0.0066	0.0066	
3C-1	>250	<0.0062		6	0.257		
				50	0.0309	0.144	>95.5
3C-2	20	0.0771		6	0.257		
	120	0.0151	0.0461	15	0.103	0.180	74.4
3C-3	34	0.0454		16	0.0963		
	57	0.0271	0.0363	85	0.0182	0.0573	36.7
Overall average			0.0759			0.1263	39.8

* Efficiency $= \frac{C - L}{C}$

** Permeability $= \frac{1.543}{t \text{ (min)}}$

TABLE XXVI

Permeability Tests at Lanse on May 5, 1971

Location	Latex Treated (L) Time(t) (min.)	Permeability cc./min./cm^2	Average	Control (C) Time (min.)	Permeability** cc./min./cm^2	Average	% Efficiency
03A-1	46	0.0336		35	0.0441		
	85	0.0182		106	0.0146		
	93	0.0166	0.0228	84	0.0184	0.0257	11
03A-2	20	0.0772		1	1.54		
	27	0.0571		2	0.772		
	24	0.0644		1	1.54		
	26	0.0594	0.0645	1	1.54	1.368	95
03A-3	10	0.154		5	0.309		
	33	0.0468		6	0.257		
	26	0.0594		4	0.386		
	28	0.0551	0.0813	6	0.257	0.302	73
03A Average			0.0562			0.5652	91
3C-1	2	0.772		1	1.54		
	6	0.257		3	0.515		
	8	0.193		4	0.386		
	9	0.172		4	0.386		
	10	0.154	0.310	3	0.515	0.668	54
3C-2	7	0.221		1	1.54		
	14	0.110		3	0.515		
	17	0.0910		3	0.515		
	18	0.0858		3	0.515		
	16	0.0965	0.121	2	0.772	0.771	84
3C-3	6	0.257		1	1.54		
	12	0.129		2	0.772		
	16	0.0965		2	0.772		
	18	0.0858		3	0.515		
	21	0.0735	0.1284	2	0.772	0.874	85
3C Average			0.186			0.771	75
Overall Average		0.1380			0.668		80

* % Efficiency = $\left(\frac{C - L}{C}\right) 100$ ** Permeability = $\frac{1.543}{t \text{ (min.)}}$

The permeability was still generally lower in the treated than in the control areas in May 1971 (see Table XXVI). For example in Area 03A the average sealing efficiency for the three locations was 91%, while in Area 3C the sealing efficiency was 75%.

In Table XXVII we compare the permeability efficiency as a function of time from September 1970 to May 1971. The results indicate that sealant qualities are retained but at a reduced efficiency after wintering. The overall sealing efficiency for the 03A and 3C has been reduced from 96 to 80 percent from September 16, 1970 to May 5, 1971. The reduction in sealing effectiveness may be caused by the action of freezing and thawing, and/or by increased porosity of the soil by root growth and the action of living organisms - insects, worms, etc. It should be recalled that most of the latex has been found within the top twelve inches of soil.

TABLE XXVII

Comparison of Permeability Efficiency with Time

Location	% Efficiency on September 16, 1970	% Efficiency on October 12, 1970	% Efficiency on May 5, 1971
03A-1	96	negative	11
03A-2	>97	~100	95
03A-3	99	99	73
3C-1	95	93	54
3C-2	90	93	84
3C-3	98	94	85
Overall average for 03A and 3C Areas*	96	92	80

*Based on mean of all the permeability measurements

This confirms our conclusion (previously drawn from soil moisture data) that area differences are at least as large as differences caused by latex treatment. Referring to Table XXVI, it may be pointed out that one inch of water (2.54 cm) at 0.0562 cc/min. cm^2 permeability requires 7 1/2 hours to infiltrate, whereas at 0.186 cc/min. cm^2 one inch of water will infiltrate in 2 hours.

Calculation: @ 03A $\frac{2.54 \text{ cc/min. cm}^2}{0.0562 \text{ cc/min. cm}^2} = 452$ min. = 7 hrs., 32 min.

$$@\ 3C\ \frac{2.54\ cc/min.\ cm^2}{0.186\ cc/min.\ cm^2} = 137\ min. = 2\ hrs.,\ 17\ min.$$

The calculated infiltration times are shorter than the actual observed infiltration rates of the rain because measurements in the stove pipes are affected by wall and disturbance factors as a result of placing the pipes into the soil.

SECTION X

LATEX DISTRIBUTION IN SOIL

Methods

The optimum situation in sealing the soil with latex would be to locate the sealant at the depth where natural permeability is lowest, and to narrow distribution of the latex to a film. To ascertain how closely we were achieving these objectives it was necessary to devise a method to measure the concentration of latex in soil. A number of methods were explored and two were used in actual field tests.

SBR latex tagged with C^{14} was prepared and used to determine the distribution of polymer in the soil. The latex was made by copolymerizing a mixture of radioactive and normal styrene with butadiene in bottles by conventional methods. Average particle size was 600 Å. Diluted aliquots had 1.40 microcuries radioactivity per gram of latex. Tagged latex was mixed with soil in a range of proportions from 0.01 to 0.25% by weight to develop a calibration curve. Analyses of soil in the laboratory and from the field were determined by comparison with this master curve.

Styrene-containing polymers have a characteristic peak at 700 cm^{-1} but crosslinked SBR is not soluble in solvents normally used in infra-red spectroscopy, e.g., carbon disulfide. We developed a method for solubilizing the crosslinked polymer by stirring overnight at room temperature a soil sample in chloroform with t-butyl hydroperoxide and osmium tetroxide. The filtered chloroform residue was dried to constant weight, thoroughly mixed and pressed into a KBr pellet, and concentration was determined by measuring the absorption at 700 cm^{-1}. Details are given in an Appendix.

Results

Concurrent with the sprinkler irrigation of areas 03A and 3C at Lanse, C^{14} tagged latex was applied to soil confined in eight-inch diameter stove pipes twelve inches long which were pressed into the ground ten inches. In another experiment at locations 3A at Lanse, and KA and KB at Kato, a mixture of 160 ml of tagged latex and 480 ml of regular latex was applied followed by a comparable water addition. Sample cores were dug with a one-half inch pipe cover on July 14 and August 20, 1970 and on May 5, 1971. Samples were oven-dried, ground, sieved through 40 mesh screen and the radioactivity was measured. Similarly, cores were dug at Kato on October 14, 1970 and May 3, 1971. Figure 10 is a histogram of the results of the tests at Lanse.

Figure 10 shows that 1) the concentration decreased most in the first month, and 2) it decreased most in the top twelve inches. Interestingly, the shape of the histograms remained similar for each location. For example, all three times of test have the highest concentration

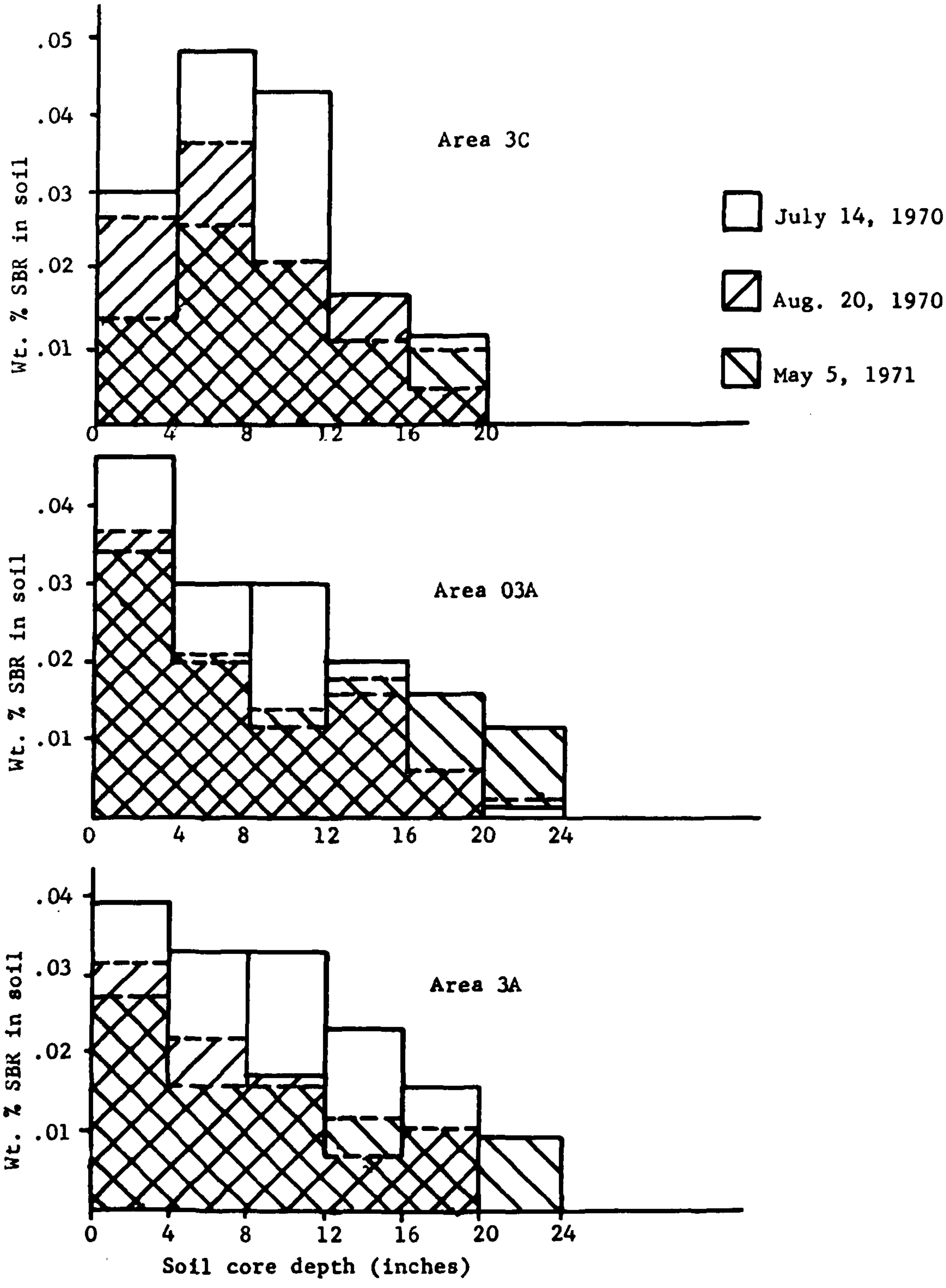


Fig. 10 - Distribution of SBR in Lanse soil

at 4-8 inches in the 3C area, and at 0-4 inches in the 03A and 3A areas. The higher values on May 5, 1971 of 03A and 3A at 16-24 inches may indicate some mobility of the SBR, although sensitivity of the analysis at concentrations below 0.01% is not good enough to draw this conclusion categorically.

The distribution of C^{14} tagged J-1405 SBR at Kato as shown in Table XXVIII indicates very little change between October 14, 1970 and May 3, 1971 soil samples.

TABLE XXVIII

Distribution of Tagged J-1405 SBR in Kato Soil (Wt. %)

Depth (in.)	KA 10/14/70	KA 5/3/71	KB 10/14/70	KB 5/3/71
0-4	0.024	0.018	0.027	0.023
4-8	0.015	0.019	0.045	0.043
8-12	0.009	0.006	0.016	0.012
12-16	0.003	0.007	0.004	0.010
16-20	0.000	0.007	0.000	0.006
20-24		0.008		0.006

The distribution of different average particle diameter latexes applied in eight-inch diameter tubes at locations KA and KB in Kato was investigated by the infra-red analysis of oxidized residues. Latex B-2301-02 is 400 Å average particle diameter, ANJ-27-100K latex is 800 Å and J-1405 is 1200 Å in particle size. The objective of this test was to determine the effect of latex particle size on the distribution of latex in the soil. The results are shown in Table XXIX as percent rubber in soil and as the percent of the total found to a depth of twenty-four inches. There is general similarity among the three latexes of different particle sizes. However, there is significant difference between locations KA and KB. The highest concentration at KA is within the top four inches, whereas at KB the concentration is maximum at the four to eight inch depth. We have reported that soil texture at KB is coarser than at KA. It may be concluded that soil conditions have a major influence on how the latex is distributed within the soil.

From the point of view of a material balance, these results are not quantitative, accounting for only 20-50% of the latex applied. Since the results are obtained against standards done in triplicate, this discrepancy is explained by losses along the walls of the tubes and lateral dispersion from the bottom of the tube walls. The accuracy of the method is as good as the accuracy of the standards, which had less than ± 5% deviation. The precision of the method is very good as demonstrated by comparing Samples J-1405-1 and 2 of the table.

TABLE XXIX

Percent Latex in Kato Soil

Depth (inches)	0-4	4-8	8-12	12-16	16-20	20-24
KA-J-1405	.043	.023	.011	.008	nil	nil
KA-J-1405 (dup.)	.043	.023	.010	.008	-	-
KB-J-1405	.048	.125	.017	.004	.002	.002
KB-J-1405 (dup.)		.117				
KA-B2301-02	.032	.017	.005	.001	.006	.004
KB-B2301-02	.019	.101	.009	.002	.004	.003
KA-ANJ-27-100K	.027	.022	.012	.008	.003	.001
KB-ANJ-27-100K	.022	.035	.013	.007	.003	X stones

Percent of Total Latex for Each Depth

Depth	J-1405-1	J-1405-2	B2301-02	ANJ-27-100K	J-1405	B2301-02	ANJ-27-100K
0-4	50.5	50.5	49.2	37.0	24.2	13.8	27.5
4-8	27.1	28.3	26.2	30.2	63.2	73.1	43.8
8-12	13.0	11.8	7.7	16.4	8.6	6.5	16.3
12-16	9.4	9.4	1.5	11.0	2.0	1.5	8.7
16-20	-	-	9.2	4.1	1.0	2.9	3.7
20-24	-	-	6.2	1.3	1.0	2.2	stones

SECTION XI

SOIL BOX EXPERIMENT

The extrapolation of results from reconstructed laboratory soil columns to field conditions is difficult because of the limitations of laboratory experiments. Permeability and elution tests performed in the laboratory differed from the natural state in that the soil was sieved through 1/4 inch screen to remove large stones and roots, its density was controlled by tamping the soil into two-inch I.D. tubes instead of normal weathering, and water and latex were applied with a constant head of liquid. Tube wall effects are important in interpreting data. Conversely, interpretation of field results were confounded by non-homogeneities within the sample tested, a soil profile with gradation of permeability and density with depth, and uncontrolled weather conditions and seasonal changes that affected the results. Nevertheless, both laboratory and field tests showed that a specific latex did perform as a soil sealant.

In view of these facts a soil box experiment was designed to overcome some of the disadvantages associated with the small laboratory soil columns and the field experiments. Two wood soil boxes 5 ft x 5 ft x 5 ft were built in the greenhouse at the Uniroyal Research Center. They were lined with plastic PVC sheeting provided with tubes every six inches of depth on one side of each box to measure water removal rates under saturated conditions. Tensiometer gauges were placed at depths of 6, 12, 18, 24, 36 and 48 inches and Bouyoucos blocs and resistance thermometers were positioned at 6, 24 and 48 inch depths. Each box was filled with a uniform sub-soil obtained from Ogdensburg, N. J. The texture of this soil was determined to be a sandy loam by the ASTM Hydrometer method, as shown below:

Texture of Ogdensburg, N. J. Soil

	%	USDA
Gravel (+2 mm)	11.6	-
Sand (+0.05 mm -2 mm)	48.0	54.1
Silt (+0.005 mm -0.05 mm)	30.4	34.2
Clay (-0.005 mm)	10.0	11.7

USDA texture classification (without gravel) is sandy loam

The boxes were thoroughly wetted by sprinkling to abet settling and allowed to dry by draining to check seepage ports and functioning of tensiometers.

In preparation for applying latex in the soil box experiments, twelve laboratory soil columns of Ogdensburg soil were reconstructed to 1) test the permeability behavior of this particular soil and 2) to test effects of different particle size latexes and levels and methods of adding surfactant. These tests were carried out by first measuring water permeability for two weeks and then measuring permeability for an additional three weeks after applying 40 ml of 2 1/2% latex (1 g solids). The results are shown in Table XXX. The data show that:

a. Although the soil column permeability was stable for four days before adding the latex (the "before latex" value is an average of 4 days results), continued wetting caused further reduction in permeability (Columns 2, 6, 11).

b. The three latexes which had no surfactant added formed surface films (Columns 1, 3, 10). Surface films cannot be observed with ANJ-27-100K latex but their presence is indicated by the non-wetting behavior of the surface when the first few drops of water are applied to the column soil (for example see Column 10).

c. Surface films were also observed in columns 4 and 5 where 10 phr of Tergitol 15-S-12 was applied to the soil before the latex; however, some latex was eluted.

d. ANJ-27-100K latex seems to become less effective in sealing efficiency with passage of time (Columns 7, 10, 12).

e. Of those columns treated with latex to which 5 phr Tergitol was added, only J-1405 latex was eluted through the column (Column 8). This is probably due to the higher stabilization of the J-1405 latex. It should be noted that percent reduction in permeability is based on the 63.9% latex remaining in the column.

Naugatex J-1405 latex + 5 phr Tergitol 15-S-12 surfactant was selected for the soil box experiment because it had the best balance of elution and permeability with no surface film. This latex was ordered from Uniroyal Chemical for the experiment but was received as Naugatex J-2758, a change in designation only of Naugatex J-1405.

On May 25, 1971, Soil Box #1 was sprinkled with eleven-and-one-half gallons of 2 1/2% solids J-2758 latex containing five phr of additional Tergitol 15-S-12 surfactant. This is equivalent to 4000 lbs. of rubber per acre. Before the latex was applied the soil was pre-wetted with eight gallons of water and after application of the latex eighteen gallons of water was sprinkled on the soil in one gallon increments on the same date. The latex was readily washed in and left no surface residue. Concurrently, twenty gallons of water were sprinkled on Soil Box #2 as a control. Table XXXI is a record of the

TABLE XXX

Latex Experiments in Laboratory Reconstructed Soil Columns* of Ogdensburg, N. J. Soil

Columns #	1	2	3	4	5	6	7	8	9	10	11	12
Latex	J-1405	none	B2301-02	J-1405	B2301-02	none	ANJ-27-100K	J-1405	B2301-02	ANJ-27-100K	none	ANJ-27-100K
Surfactant added	no	no	no	← 10 phr on soil →		no	10 phr on soil	← 5 phr in latex →		no	no	5 phr in latex
Latex added (g)	0.8	0	1.0	1.0	1.0	0	1.0	1.0	1.0	1.0	0	1.0
Latex eluted (%)	0		0	36.4	34.9		41.6	36.1	0	0		0
Surface film	evident		evident	evident	evident							
Permeability in Columns												
Before Latex	85	107	83	69	59	78	57	75	78	82	97	75
After Latex:												
1st week	0.7	88	0.5	6.8	16	64	13	39	32	1.2	76	2.6
2nd week	1.4	69	0.8	5.7	19	53	22	34	31	6.8	63	1.9
3rd week	1.9	63	0.6	3.2	23	46	28	33	34	17	56	21
% Reduction = $\frac{\text{Before - After}}{\text{Before}}$												
1st week	99.1	17.8	99.4	90.2	73.0	18.0	77.2	58.0	59.0	98.5	21.6	96.4
2nd week	97.5	35.5	99.0	91.7	67.9	32.1	61.4	54.7	60.3	91.9	35.0	97.5
3rd week	97.9	41.1	99.2	95.3	61.0	41.0	50.9	56.0	56.5	79.2	42.2	72.0

* Columns are 2" in diameter and contain a 6" column of soil.

TABLE XXXI

Soil Box Water Additions, Soil Tension and Resistance Data

Date	Water Added (gal.)	Tensiometers (Centibars) 6"	12"	18"	24"	36"	48"	Bouyoucos Block (Resistance, Ω) 6"	2'	4'
					Box #1					
5/24	8	72	38	30	30	13	12	930	500	360
5/25[1]	18	0	41	31	25	11	11	620	500	360
5/26	7	0	2	3	7	10	11	660	450	360
5/27	9	0	0	0	2	6	10	690	460	360
5/28	6	0	0	0	3	5	10	690	470	360
5/29	1	0	0	0	5	6	10	-	-	-
6/1	0	0	2	3	5	5	10	700	480	360
6/2	0	3	4	5	6	6	10	680	460	360
6/3	0	5	4	6	6	6	10	680	470	360
6/4	0	11	8	8	8	8	10	-	-	-
6/5		13	8	7	8	8	11	-	-	-
6/7		19	10	10	12	11	12	630	430	340
6/8		31	11	10	10	11	12	620	420	330
6/9		47	15	12	10	11	12	630	410	330
6/10		59	16	10	10	11	12	640	410	330
6/11		64	19	10	10	10	11	650	410	330
6/12		62[2]	33	15	12	10	11	-	-	-
6/14		60	35	16	12	10	11	690	410	330
6/15		60	41	16	12	10	11	750	420	340
6/16		60	43	20	16	12	13	790	440	340
6/17		59	50	25	17	13	14	-	-	-
6/18		58	54	26	17	10	11	760	440	340
6/21	8	0[3]	68	40	28	13	12	820	420	340
6/22	12	50	60	26	26	13	12	820	430	340
6/23	7	8	13	10	16	12	11	770	420	330
6/24	13	2	6	5	8	11	10	740	420	330
6/25	10	0	3	4	8	10	10	640	410	320
6/26		2	5	5	8	9	10			
6/28		21	9	8	9	10	11	600	400	320
6/30		40	12	8	9	10	11	630	410	320
7/2		78	22	13	12	10	11	640	400	320
7/6		-	72	50	40	14	11	820	410	320

1 - 11 1/2 gal. of J-2758 latex was sprinkled on Soil of Box #1 at 2 1/2% Total Solids
2 - At readings between 65 and 85 tensiometers may begin to take in air, making subsequent readings lower.
3 - Refilled with water

TABLE XXXI (Cont.)

Soil Box Water Additions, Soil Tension and Resistance Data

Box #2 (Control)

Date	Water Added (gal.)	Tensiometers (Centibars) 6"	12"	18"	24"	36"	Bouyoucos Blocks (Resistance, Ω) 6"	2'	4'
5/24	1	-	-	-	-	-	960	460	250
5/25	20	0	16	13	10	13	590	460	250
5/26	7	0	6	10	9	11	610	460	250
5/27	9	0	3	4	7	12	600	450	250
5/28	4	0	2	2	7	11	610	450	250
5/29	1	0	0	3	5	10	-	-	-
6/1		3	3	5	5	9	620	450	250
6/2		8	7	7	6	11			
6/3		10	6	7	6	11	660	440	250
6/4		15	10	10	7	12			
6/5		18	10	10	7	13			
6/7		35	14	12	11	16	610	440	240
6/8		43	24	13	2[4]	15	640	400	240
6/9		52	15(?)	12	-	14	680	400	240
6/10		64	17	13	-	14	720	400	240
6/11		74	18	13	10[5]	13	750	400	240
6/12		80	22	15	12	14			
6/14		82	24	16	12	14	940	400	240
6/15		82	24	16	11	13	1060	400	240
6/16		84	24	17	12	15	1110	420	250
6/17		86	26	20	14	16	1360	410	250
6/18		83[1]	28	18	12	14			
6/21	8	77	34	22	5[4]	14	2040	400	250
6/22	12	76	30	22	-	14	1410	400	250
6/23	7	5	17	19	-	15	630	390	250
6/24	13	0	7	14	-	14	490	390	250
6/25	10	0	7	7	-	14	470	390	250
6/26		2	6	8	-	14			
6/28		9	7	8	-	14	550	360	250
6/30		15	8	8	-	14	590	370	250
7/2		28	9	10	-	14	610	370	260
7/6		72	26	15	-	4	930	370	260

4 - Tensiometer water leaked out of tube.

5 - Refilled Tensiometer.

amounts of water applied and the responses of the tensiometers and Bouyoucos resistance blocks to the increase in soil moisture for each box. Water was sprinkled in one gallon increments intermittently to each box for several days to May 29 to keep the surface wet, and then each box was allowed to dry. No significant differences in drying rates nor water elution were observed between the two soil boxes.

A second wetting cycle was begun on June 21 and concluded on June 25, a total of fifty gallons of water being added to each box. Again during the drying cycle the drying and elution rates were similar. Because of its location, Soil Box #1 received at least an hour more exposure to the sun each day; this probably accounts for the somewhat higher tensiometer readings from June 28 to July 7. In Soil Box #2 the 48 inch tensiometer gave no readings because of a water leak and the 24 inch tensiometer gave intermittently spurious results.

Permeability tests were performed in the soil boxes by means of eight-inch diameter, twelve inch long, stove pipes pressed into the soil eight inches deep. These tests, shown in Table XXXII, indicate that the latex did not act as a sealant. On the other hand, in laboratory soil column tests with this soil, J-2758 latex did show sealing action. The explanation of these anomalous results may be that the drying cycles caused shrinkage that opened the latex-containing soil to its natural porosity. High daily temperatures in June caused rapid and severe drying of the soil at and near the surface.

On June 23 samples of soil from Soil Box #1 were cored in four-inch sections to 36 inches depth, were oven dried, sieved through a 40 mesh sieve and oxidized, and analyzed for styrene-butadiene rubber (SBR). Ninety-two percent of the SBR (0.107% in soil) was found in the top four inches, eight percent (0.009% in soil) was found in the four-to-eight inch depth; none was detected below this depth. The Ogdensburg soil used in this experiment is a rather open soil, characterized as a sandy loam, so penetration was expected to be better, i.e. deeper, than the above values. The poorer penetration of the latex in the soil box as compared to field application at Lanse suggests that much of the latex in the field penetrated into the soil by means of macro-cracks, worm holes, etc., and not through the capillaries of the soil. The lack of such macro-paths in the soil box and the method of packing the soil in the box (tamping every two to three inches of soil with a five-foot long 2 x 4 board) evidently restricted the downward flow of latex.

TABLE XXXII

Soil Box Permeability Tests*

Date	Box #1 Location	Box #1 Time (min.)	Box #1 Permeability (cc./min./cm^2)	Box #2 (Control) Time (min.)	Box #2 (Control) Permeability (cc./min./cm^2)
July 16, 1971	1	6	0.257	8	0.193
		7	0.221	8	0.193
		8	0.193	9	0.163
July 19	1	8	0.193	9	0.163
		8	0.193	10	0.154
		8	0.193	10.5	0.147
		8	0.193	10	0.154
		9	0.163	10.5	0.147
July 22	2	5	0.308	9	0.163
		5	0.308	10	0.154
		5	0.308	10	0.154
		5	0.308	10	0.154
		6	0.258	10	0.154
		5.5	0.280	12	0.129
July 23	3	10	0.154	5	0.308
		11	0.141	8	0.193
		11	0.141	8	0.193
		10	0.154	8	0.193
		10.5	0.147	8	0.193
Average		7.7	0.216	9.1	0.174

* 500 cc. water was placed on soil in 8" diameter stovepipe 12" long pressed into soil 8" deep, and time recorded to disappearance of water.

$$\text{Permeability} = \frac{1.543 \text{ cc./cm.}^2}{\text{time (min.)}}$$

SECTION XII

COSTS

Table XXXIII itemizes the cost associated with the installation of an irrigation system and the application of latex and water in the three experimental areas at Lanse. There were no external labor charges (non-Research Center) except for the installation of the water meter. Cost of pipe and fitting are high because long lines were required at each of the three different locations; these costs were minimized by using plastic instead of metal pipe. Fifteen of the seventeen drums of latex received were used, five drums for each area.

TABLE XXXIII

Irrigation Cost at Lanse

Equipment:	
Moyno pump	$ 355.00
Moyno pump (lease spare) 15% of purchase price	53.25
Pipe and fittings	900.00
Flow control valves	22.00
Sprinkler heads	156.60
Garden hose (3/4" heavy) 300 ft	75.60
	1,562.45
Raw Materials:	
Latex J-3471, 3500 lbs @ $0.34/lb (dry basis)	1,190.00
Water, 75,000 gal. - June 1 to July 1	42.50
Other Charges	
Water meter installation	70.71
Deposit on water meter $85.00	
U-Haul rental trailer	26.26
Neutron gauge measurements 6/10-9/10 by P.S.U. personnel	1,836.00

In tank-car lots latex would cost about $0.25/lb so that raw material cost for a 4000 lb /acre application would be in the range of $1,000 per acre. Equipment costs for setting up and irrigation are sensitive to size of area to be irrigated, design of system, and availability and cost of water. A realistic range is estimated to be between $200-500/acre.

SECTION XIII

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SECTION XIV

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SECTION XV

GLOSSARY

A Horizon - the surface layer of a mineral soil having maximum biological activation; commonly referred to as topsoil.

A Profile - the topsoil layer (synonymous with A Horizon)

Atterberg limits - a measure of the workability or consistency of the soil as affected by the water content. The limits are defined by the water contents required to produce specified degrees of consistency that are measured in the laboratory (see liquid limit, plastic limit and plastic index).

B Horizon - the subsoil below the A Horizon topsoil.

Bouyoucos block - an instrument for measuring the water content of soil based on dielectic conductivity.

B Profile - the subsoil (synonymous with B Horizon).

Cation exchange capacity (CEC) - the sum of the chemically exchangeable cations of a soil.

Darcy Value (K) - a coefficient of permeability to correlate effects of column height, head and diameter

$$K = \frac{QL}{hA}$$

where K = hydraulic conductivity (ft/day)
L = length of soil column (ft)
h = effective head (ft)
A = cross sectional area (ft^2)
Q = quantity discharged (ft^3/day)

Fragipan - a type of subsurface soil structure having a relatively high bulk density. It is cement-like when dry and very slowly permeable to water.

Latex - an aqueous dispersion of finely divided rubber or plastic materials of medium to high molecular weight. Stability is controlled by use of surfactants, typically a mixture of anionic and non-ionic materials.

Liquid limit - the water content (%) at which soil becomes semi-fluid, like softened butter, as measured by a standard ASTM procedure.

Mariott feed bottle - a device for maintaining a constant liquid level above a soil column during percolation testing.

Montmorillonite - a specific type of clay soil (hydrous aluminum silicate).

Permeability - a measure of the readiness with which the soil permits the passage of water through a unit cross-section.

Permeameter tube - a thin-walled open-ended tube used to perform in situ measurements of soil permeability. The tube is pressed into the soil for part of its length, a measured amount of water is placed in the tube and the time required for the disappearance of this water is taken as a measure of soil permeability. Eight-inch-diameter, twelve-inch-long stove pipes, inserted eight inches into the soil, were used as permeameter tubes for much of the present work.

Piezometer tube - a tube placed in the ground to establish the location of the water table. An open-ended tube is driven into the ground, then withdrawn, the soil core removed, and the empty tube reinserted in the hole.

Plastic index - the difference between liquid and plastic limits. It gives an indication of the "clayeyness" or plasticity of a soil and is widely used in engineering classification for soils.

Plastic limit - the water content (%) at which soil begins to crumble on being rolled into a thread 1/8 inch in diameter. It represents the lowest water content at which soil can be deformed readily without cracking.

Porosity - the ratio of volume of voids to the total volume of a given mass of soil.

PVC - a homopolymer of vinyl chloride.

SBR - a rubber copolymer of styrene and butadiene.

Surfactant - a chemical which will reduce the surface tension of aqueous solutions. There are three classes, namely, anionic, cationic, and non-ionic.

Tensiometer - an instrument combining a manometer and a porous membrane for measuring soil water suction.

VA - a homopolymer of vinyl acetate.

APPENDIX

ANALYTICAL METHOD TO DETERMINE STYRENE-BUTADIENE RUBBER IN SOIL

Sample Preparation

Soil cores are cut in the field in 4-inch depth increments, dried, ground and sieved through a 40 mesh screen and weighed.

Polymer Oxidation and Separation from Soil

Crosslinked styrene-butadiene rubber (SBR) is insoluble in most solvents. The purpose of oxidizing the SBR in the soil is to render it soluble in chloroform. Twenty grams of soil containing SBR is weighed into a 125 ml erlenmeyer flask. Fifty milliliters (ml) of chloroform, 15 ml of t-butyl hydroperoxide, and 2.5 ml of 1% osmium tetroxide in benzene are added. A one-inch magnetic stirrer is placed in the flask, the flask is stoppered and the contents are stirred overnight on a magnetic stirrer at room temperature. Overnight stirring has proved adequate to give reproducible results.

The oxidized chloroform soluble portion is separated from the soil by filtering through a #1 Whatman filter into a 500 ml vacuum flask. The soil is washed four or five times with additional chloroform. The chloroform filtrate is air dried by evaporating the chloroform in a small beaker in a hood and subsequently dried to constant weight in a vacuum dessicator.

Concurrent with the analysis of samples of unknown SBR concentration, a known amount (for this work 15 mg was used) of the same SBR in 20 g of a soilblank should be run as a standard in triplicate.

Infrared Analysis

A portion of the oxidized, thoroughly dried residue is ground with and pressed into a KBr pellet and the characteristic peak at 700 cm^{-1} is measured. The equivalent optical density (O.D.) of the standard is measured and a specific O.D. per mg is calculated.

Then the mg. of SBR in the sample soil is calculated as follows:

$$\frac{(\text{O.D. of sample})(\text{total mg residue})}{\text{mg of sample in pellet}} + \frac{\text{O.D.}}{\text{mg}} \text{ of standard} = \text{mg of SBR in sample}$$

$$\frac{\text{mg of SBR in sample}}{\text{mg of soil}} (100) = \text{\% SBR in soil.}$$

Comments

It has been found that a very dark or black residue indicates that the oxidation has been too severe and invariably gives low results. It is therefore important to do the drying at room temperature as well as the oxidations.

The soil oxidation products contribute to the residue weight at 0-4" and 4-8" depths, but do not appear to influence the optical density of the styrene peak at 700 cm^{-1}.

The oxidized residue is partially insoluble in carbon disulfide, making necessary the imbibation of solid residue into a well mixed KBr pellet, rather than the less tedious method of infrared analysis in solution.

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27 *Abstract*

A study was made to test the feasibility of using latex as a soil sealant to prevent water seepage into subterranean abandoned mines.

A variety of latexes were screened in laboratory tests using reconstructed soil columns. The most promising latex (an SBR rubber latex) was then field tested on selected 1/4 acre plots near Lanse, Pennsylvania. In general the field tests confirmed the laboratory finding that latex does reduce the permeability of soil to water. However, the economics are not attractive and most of the latex is deposited in the top foot of soil where it is subject to damage by microbiological attack, frost and surface vegetation.

Abstractor G. T. E. Graham	*Institution* Uniroyal, Inc., Wayne, New Jersey 07470

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