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SOIL PARTICLE SIZE DISTRIBUTIONS RELATED TO SUBSURFACE DRAINAGE SYSTEMS IN THE NETHERLANDS, THE UNITED STATES AND CANADA

Ir. L.C.P.M. Stuyt

CONTENTS

INTRODUCTION

In some subsurface drainage systems, clogging of laterals and/or envelopes will occur, giving rise to malfunctioning in due course. Clogging phenomena may be divided into three main categories: chemical clogging, biological clogging and mechanical clogging, plus any combination of these.

Mechanical clogging (that is, clogging due to excessive invasion of soil particles) is currently being investigated at the Institute. In connection to this, the author visited several meetings in the US in December, 1982. Afterwards, a number of soil samples was taken at several drainage sites in the State of Michigan and the Province of Ontario, between 17 and 22 December, 1982. As a reference, some Dutch samples have been taken as well in May, 1983.The majority of the samples was analyzed electronically as regards particle size distribution.

The experimental tour in North America was organized and sponsored by Mr. Lowell E. Kraft (Kraft, Inc., Pigeon, Mich., the Big 'O' Drain Tile Company Limited, Exeter, Ontario, Canada). Kraft's invitation led to a very interesting trip: his co-operation is highly appreciated.

OBJECTIVE

The study tour was organized basically to become familiar with subsurface agricultural drainage systems as installed in North America. Design and lay-out are essentially different from those installed in Europe. Europeans generally use smaller pipe diameters, and will install at shallower depths and with smaller spacing.

Examination of the systems was done visually, mostly at random spots. All systems were located on private farm land; not on trial fields set up by scientific Institutions. A check was made of the rate of sedimentation of fines inside the pipes, pipe deflection, the state of the envelope and the soil surrounding the envelope.

All digups were made incidentally, and no flow and/or groundwater level records were available. Therefore, a quantitative check of drainage performance was not possible. The opinion of the farmers was the only source of information to rely upon.

Still, it was thought worth while to take the samples for two reasons. In the first place, an electronic 'Elzone' particle size analyzer recently installed at the Institute was being started up, and testing material was welcome. Secondly, the performance of envelopes and pipes can be partially judged from the size distribution of the particles inside the pipe. Notwithstanding the fact that it is impossible to assess drain performance from particle size analysis, results are interesting enough to be presented in a report.

ANALYSIS PROCEDURE

Particle size distributions of the samples were determined using the 'Electrozone' concept (Particle Data; 1982). The Electrozone system functioning is described briefly below.

In the Electrozone measurement principle, particles suspended in an electrolyte are caused to flow through a small orifice in a non-conductive material, along with an electric current. Particles traverse the orifice essentially singly, causing electrical pulses at rates from a few thousand to a few hundred per second or lower, depending on flow velocity, orifice size and particle concentration. The amplitude of each pulse is directly proportional to the volume of the particle as sensed by its 'electrical envelope' displacement within the sensing orifice. In all the size distributions presented in this report the particle diameter is the dimension for electrozone size. This is equal to the diameter of a sphere of equal electrozone volume response; the term 'equivalent spherical diameter' is often used, akin to the term 'equivalent Stokesian diameter' for the sizes in sedimentation measurements.

The size span measurable by a given electrozone orifice can exceed

25:1 in diameter, i.e. 1-3% tot 60-80% of the orifice diameter. This represents a signal amplitude range in excess of 16,000:1, for which the Elzone system provides logarithmic conversion. For general use, orifice diameters range from 12 to 1,200 μm, with a total measurable diameter span of 0.15 to 900 μm; at the drainage laboratory of the Institute this span equals 0.5 to 300 μm, depending on the orifice sizes currently available. Soils having size spans greater than this may be handled by artificial extrapolation via Gaussian function-fit in the Elzone software. For narrower distributions, lesser portions of the logarithmic range are expanded to full scale via a selector switch.

Thus, logarithmic conversion is a dominant feature of the Elzone system: it allows selection of log span to suit the breadth of the sample size distribution so that full-scale usage is achieved for all analyses. Because most natural soils have a more or less log-normal size distribution, the log scale is well-suited for presentation of soil size data. Additionally, blending of two or three ranges of size data for wider distributions, incorporated in the Elzone software, is easily done; such blending techniques more or less fail with linear scales.

The following conditions are typical for the Elzone system: flow velocity and current through the sensing orifice are held constant at selected values in the ranges of 1-5 m/sec and 0.03-3 mA, respectively; pulse durations vary from 20 to 30 μsec, with extremes of 5-200 μsec; prior to logarithmic conversion, pulses are amplified by a selectable factor - gain - ranging from 20 to 1,800; for conversion of pulse amplitudes to digital values, 256 channels full-scale is usual, with 128 or 64 channels selectable; orifice diameter is selected to be 50-100% greater than that of the largest particles in the soil sample; the amount of particulate material is 50 mg, usually. As a consequence, it is sufficient to sample very small amounts of soil material during the dig-ups.

The acquisition of size distribution data normally takes less than a minute and consists of transfer of the digitized values for many thousands of particle-pulses to their proper locations in computer memory. The raw data format is thus a frequency histogram or differential distribution, normally having a logarithmic size scale.

Throughout data acquisition and processing, a videoscope display provides interactive, operative monitoring of size distribution data and associated items.

The software includes several data processing means including smoothing, data-set blending, extrapolating, subtracting and ratioing. The output means include graphing of histogram or cumulative data in frequency, area or volume (mass) form, alpha-numeric printing of parameters and channel contents in complete or partial tabulations, transmission of data for storage or further processing in other devices such as the VAX 11/750 computer system of the Institute. The software provides means for forming customized series of processing and output steps, to be performed automatically, in sequence. This feature is used frequently, saving much operator time.

The Elzone system used at the Institute's Drainage Laboratory is functionally organized as shown in Fig. 1. Its physical array, for effective operational convenience, is shown in Fig. 2. The laboratory, and the equipment location in particular is, as much as possible, free of dust and electronic noise sources. Any of these may cause erroneous data and/or troublesome operation,especially when measurements are being done at high sensitivity in small size ranges. Preventive measures include prohibition of smoking, air conditioning and vibration-isolating equipment mountings.

In the field, samples were taken usually in the pipe, immediately outside it and at some distance ($\pm$ 0.5 m). They were packed in plastic bags that could be sealed air-tight. The period between sampling and analysis has been considerable; between one and three months (North American Samples).

All samples were analyzed in triplicate; 3 x 65,000 = 196,000 particles were counted. The three distributions were compared mathematically for equality. In case of sufficient equality, the mean particle size distribution was used. In case a size distribution was significantly different from the other two, it was rejected and a mean particle size distribution was computed from the other two. Generally, the three curves resempled each other sufficiently; a low number of size distributions was rejected.

For each analysis, $\pm$ 200 mg of soil material was taken from the

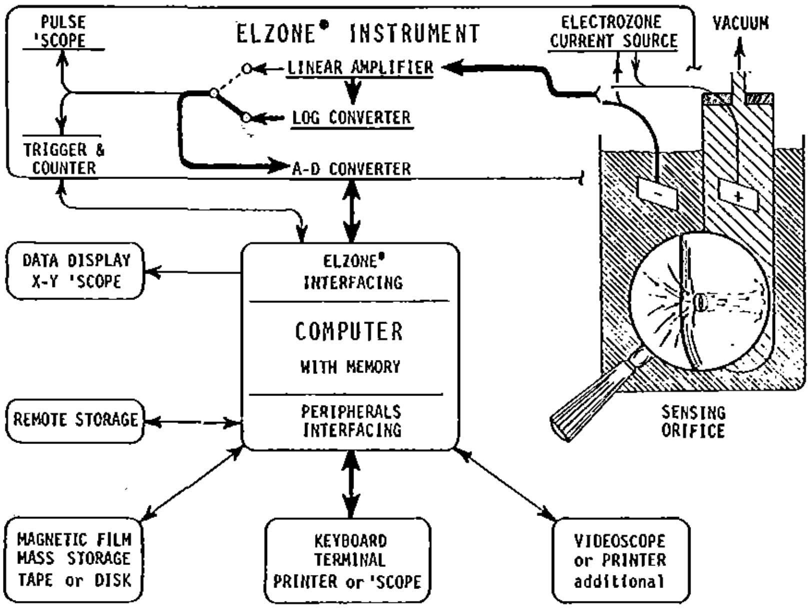


Fig. 1. General schematic of the Elzone system

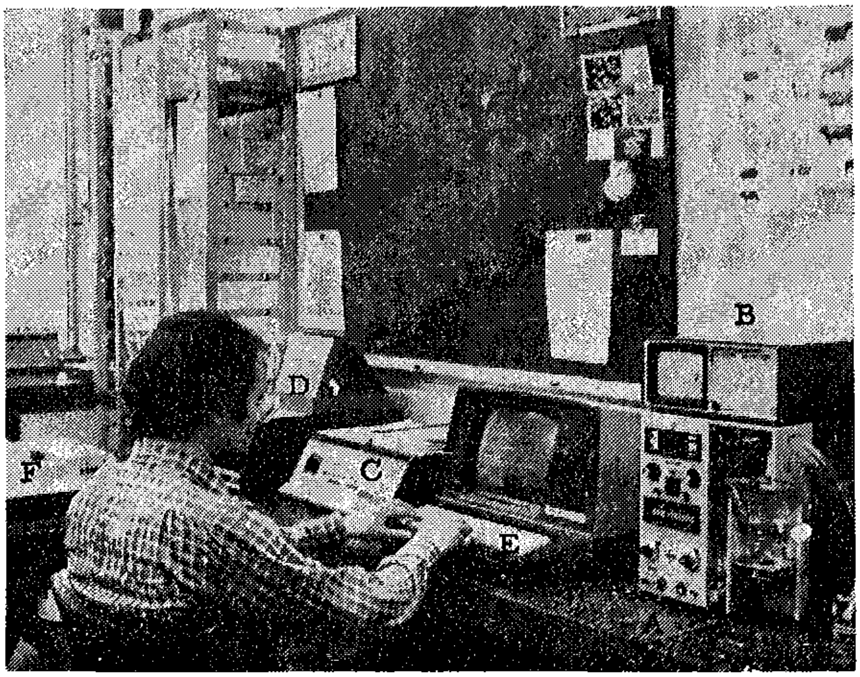


Fig. 2. Particle size analysis rig in ICW's Drainage Laboratory:
a. Elzone unit; b. Video monitor; c. PDP 11/03 computer;
d. Floppy disc unit; e. Video terminal; f. Printer

inside of the sample, and deposited in the sample beaker in which the electrolyte fluid (a weak sodium chloride solution) was gently agitated by means of a stirrer. As soon as a complete suspension state was reached (eye-checked) the sample was analyzed.

A reliable analysis could be made of fourteen soil samples from the US and Canada. Eleven samples had to be rejected, either because they were too coarse or not suited for analysis, like the envelope samples. In addition to that, ten Dutch samples were analyzed.

DATA ANALYSIS

We use statistical methods for making inferences about the particle size distributions. The type of inference we choose is the estimation from the sample's particle size distribution of the value of some relevant parameters. These estimation procedures are based on the assumption that the soil sample is a fair representation of the soil material in which we are interested in the first place. Next, in the second instance we sample once more in the laboratory for electronic size analysis; the reliability of this procedure can, however, be assessed by triplicate analysis. If a bias of unknow extent is present during sampling it is impossible to make reliable inferences about the sample. Suppose that during field sampling a bias operated which gave preverence to high values. If we estimate the mean from this sample, our estimate will be high by an amount which depends on the magnitude of the bias. Such an estimate is of little value unless the bias is known. In all our cases a possible bias is unknown, and therefore all outcomes must be appreciated with reservation.

Three distribution parameters which are commonly used are the mean, the median and the mode; Fig. 3. The mean is the average size value on all the particle size diameters; cf. Fig. 4. It is also called the expected value of the particle size. If the particle size values on all the size channels are arranged into order from smallest to largest, the middle value is the median; 50% of all values is less than it. The most frequently occurring particle size diameter is called the mode: it is the channel size coinciding with the peak of

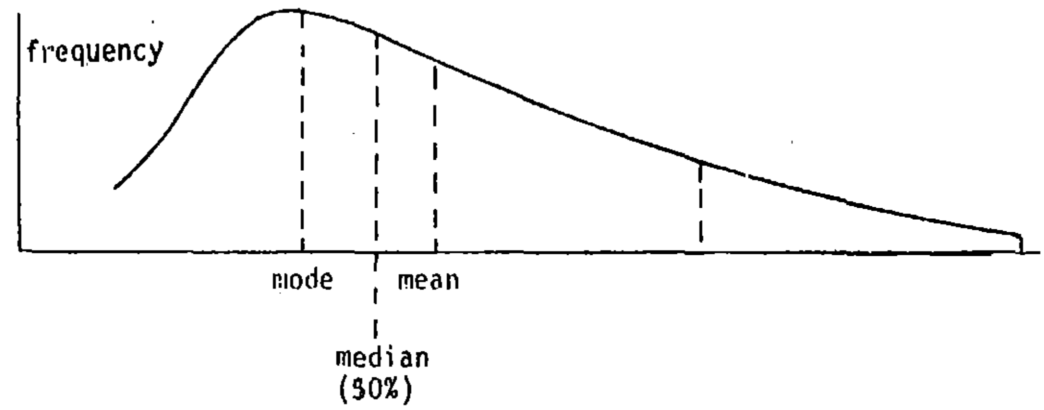


Fig. 3. A skewed particle size distribution with three commonly used parameters for indication of its center

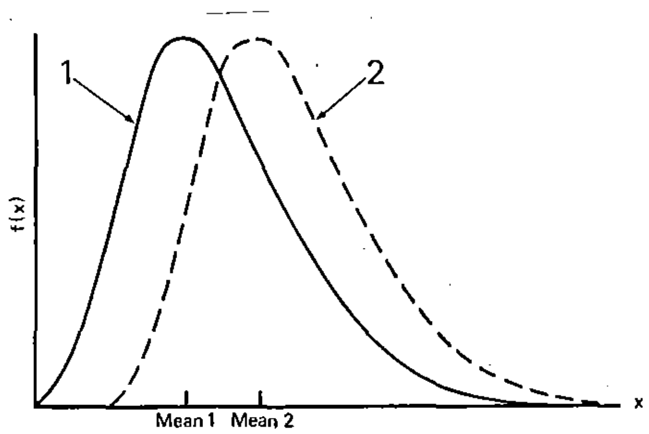


Fig. 4. Particle size distributions of two soil samples equal in all respects except the mean

the distribution. - These three quantities are called measures of location or central tendency because the particle diameter values group around them on the size scale axis. The mean and median values are widely used in practise. The mode is useful occasionally because of its mathematical convenience in a particular case. The mean value is also called the first moment about the origin by analogy with the moment of mass or area as used in mechanics.

The Elzone software provides estimations of both geometric and arithmetic means. The geometric mean is a function of the shape of the particle size distribution, regardless the logarithmic size (diameter) scale used. On the contrary, the arithmetic mean is based upon particle sizes regardless the shape of the curve. - The standard deviation determines the extent of the spread of the particle sizes over the size scale: it is a scale parameter, cf. Fig. 5.

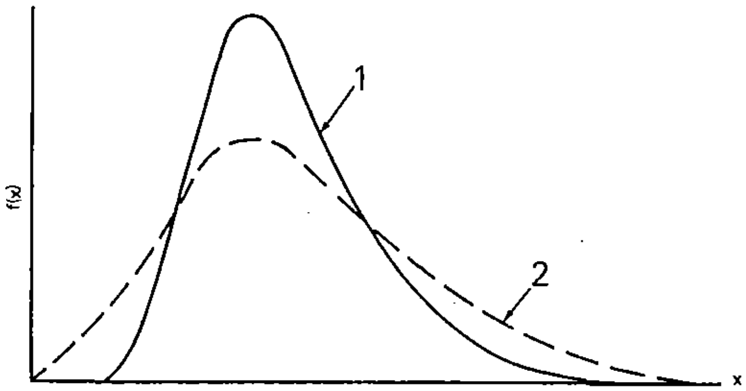
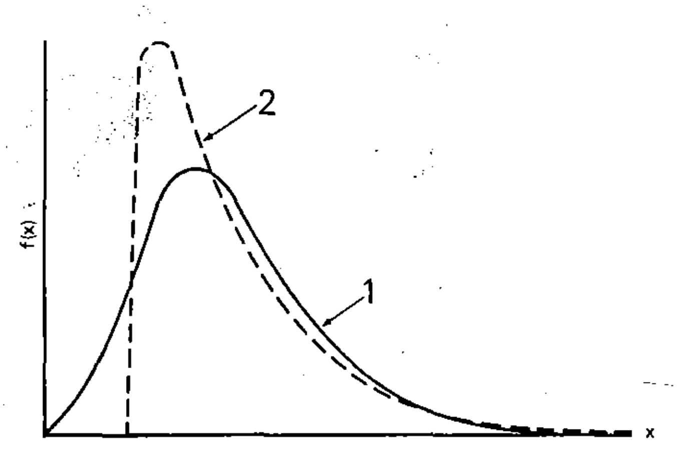


Fig. 5. Particle size distributions of two soil samples equal in all respects except the standard deviation

Most particle size distributions are completely specified by two parameters associated respectively with location and scale: the mean and the standard deviation. An additional distribution parameter is skewness. If a particle size distribution is symmetrical about its mean, its skewness is zero. Generally, the skewness may be considered as a standardised measure of asymmetry; cf. Fig. 6. Most distributions appropriate to soil samples have negative skewness.

In 8 out of 14 cases, the particle size distribution was artificially extrapolated into the lower particle size range; Gaussian extrapolation is available as a software facility. This extrapolation was necessary due to lack of experience in choosing optimal instrument-settings during sample analysis. The extrapolation never exceeded 15% of the total size-span covered (8% typical). Extrapolation has not affected the particle size distributions substantially, but favourably affected some curve shapes in the lower end. The lowest particle diameter included in the extrapolation was 2 μm. If no well-defined downward trend at the lower end of a curve could be detected, no extrapolation was realized for reasons of low credibility.



In Figure 6 population (1) is distributed more symmetrically about its middle than population (2). The latter has a higher value of skewness.

Fig. 6. Particle size distributions of two soil samples equal in mean and variance but differing in skewness

Problem soils. Silts and fine sands are generally regarded as the problem soils in drainage. In Fig. 7 the classification of soils according to the US standard and that of the International Society of Soil Science are given. A range of particle size distributions of

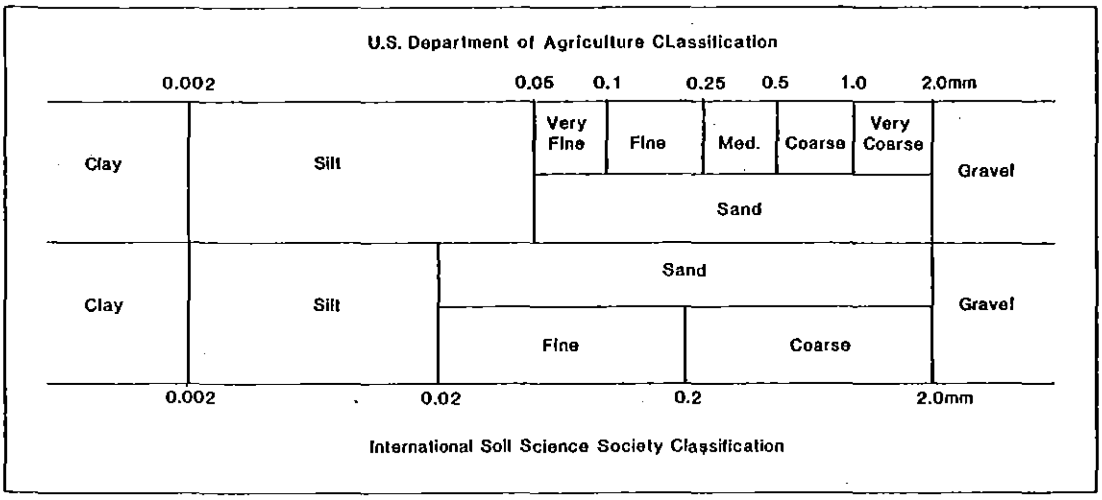


Fig. 7. Two widely used soil classification systems

drainage problem soils is given in Fig. 8. The size distribution of Almere-sand, a well-known problem soil in the Netherlands, is also shown: it is located entirely in the shaded 'problem soil area'. The

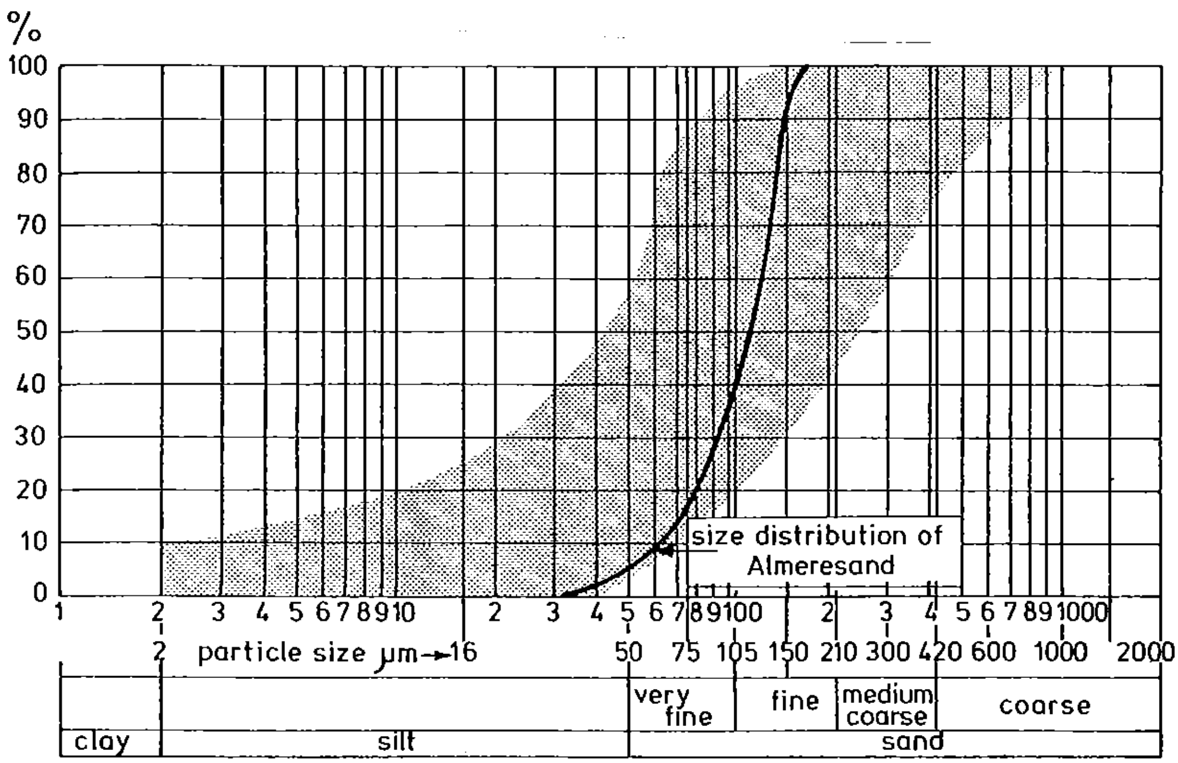


Fig. 8. Range of particle size distributions of drainage problem soils

distribution curve as shown here is drawn on a cumulative basis; the Elzone software produces size distribution graphs on a differential basis as well. All curves discussed in this report are drawn on a differential basis, see e.g. the distribution curve of Almere-sand in Fig. 9. The curves in the last two figures reflect two different analysis procedures. The cumulative curve is based upon sieving results and is less reliable than the differential curve.

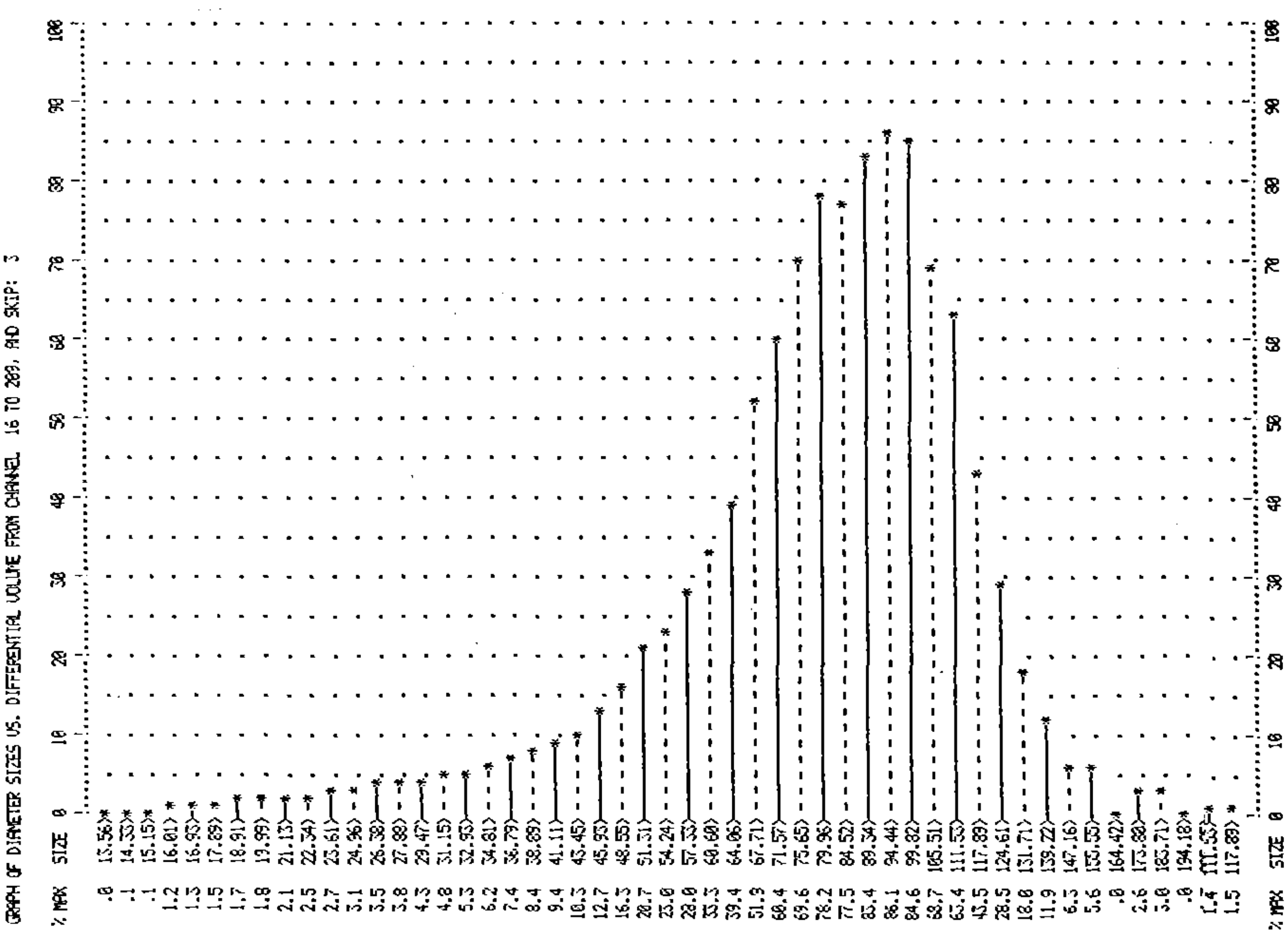


Fig. 9. The particle size distribution of Amere-sand

COMPARISON OF SOIL COMPOSITION IN- AND OUTSIDE DRAINS

Regardless the quantity of soil material which may clog envelope and pipe, particle size analysis of samples taken inside the pipe and at some distance is important because it may give us some insight into selective filtration properties of envelopes. In this respect, not only these properties, but also the catchment conditions after clogging has occurred are important. In the laboratory, the particles are retained in sediment traps, i.e. large glass bottles (contents 10 ℓ). In these traps, upward flow is maintained, and the particles have ample time to settle, except for the very small ones (< 5 μm).

In the field, the water flowrate inside the drains is relatively high during high discharge periods so that the majority of the smaller particles remain suspended and will be washed out of the drain. Relatively large particles stay behind. Apart from individual particles, particle aggregates may also have been analyzed, consisting of small amounts of particles that stick together. The importance of aggregate-size analysis is discussed by LAGACÉ (1983). It is likely that a substantial number of particles analyzed are in fact aggregates, but it is impossible to prove this within the scope of this report.

Regardless the pore size distribution of the envelope and the particle size distribution of the abutting soil, the smallest particles will wash through envelope and pipe most easily, resulting in a particle size distribution of the washed-in material which will be shifted into the direction of the smaller sizes, compared to the distribution of the original soil. A lab-test is therefore a well-suited procedure to assess selective filtration properties of envelopes.

LABORATORY TESTING OF ENVELOPES

In order to investigate envelope properties in terms of permeability and filtration properties, testing conditions must be consistent, that is well-prescribed and invariable, for all tests. The set-up currently used in ICW's drainage laboratory is designed for short term test periods (340-hour) under flow conditions comparable to those in the field. This set-up is shown in Fig. 10. The current testing capacity is eight cylinders instead of four. Two envelopes can be tested simultaneously in four replicates. This number of replicates is necessary for reasons of low reproducibility of this kind of experiments.

Nitrogen gas is fed into the upper head tank in order to fight oxidation inside soil- and envelope samples. The lower constant head tank is fitted with a thermostat and a heating device to keep the water at 24°C (75°F) which is 4°C above the temperature of the air-conditioned laboratory. As the water cools off when passing the columns, the possibility of air coming out of solution is prevented. Water flow through each of the columns is adjusted by means of needle-valves connected to flow-meters, indirectly adjusting the gradient.

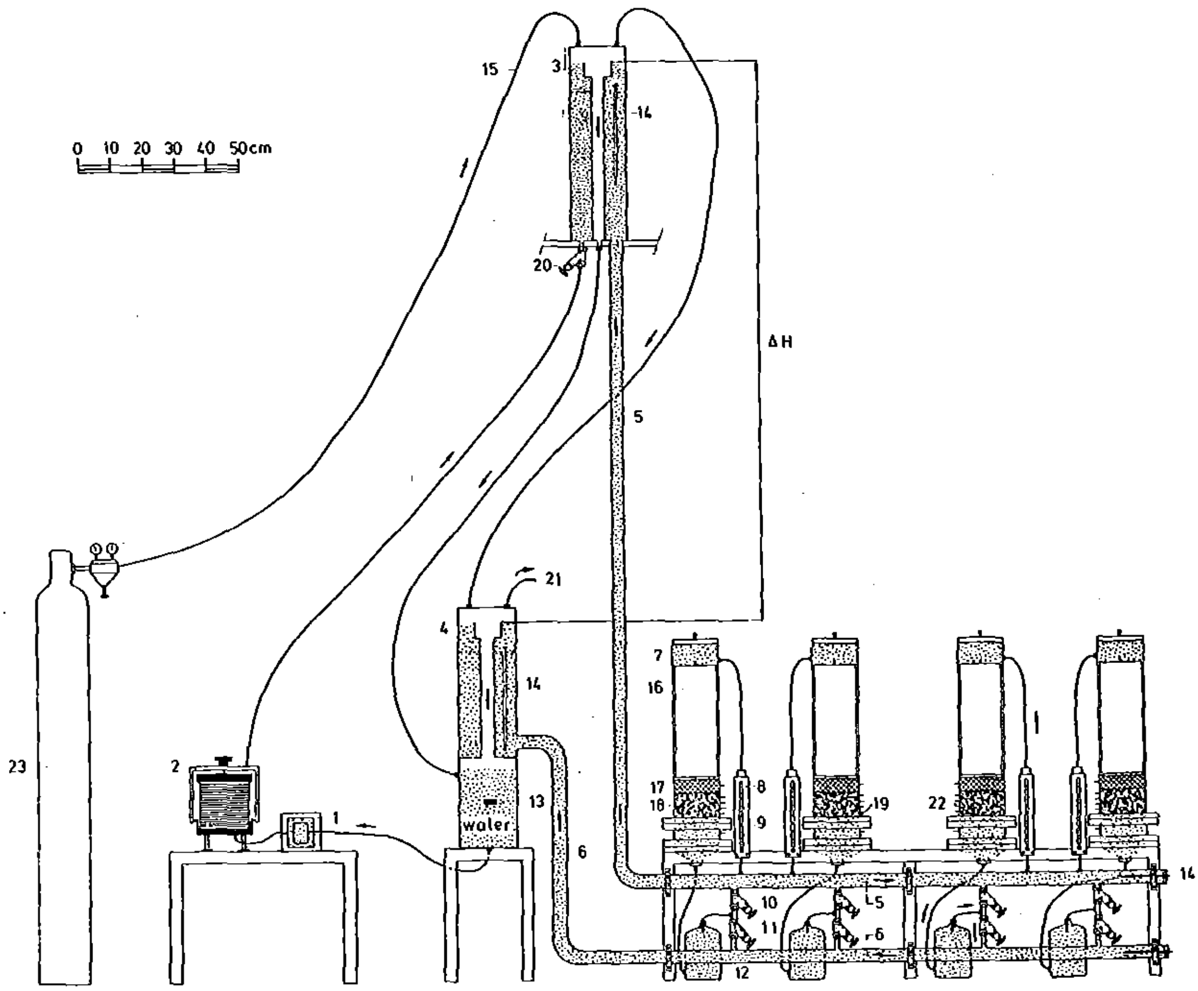


Fig. 10. Laboratory Set Up for Testing Envelopes. 1 = centrifugal pup; 2 = active carbon water filter; 3 = overflow tank; 4 = constant head and water supply tank; 5 = water supply tube; 6 = water discharge tube; 7 = cylindrical plexiglass tank; 8 = flowmeter; 9 = needle valve; 10, 11 = taps regulating flow directions on installing envelope and soil sample; 12 = sediment trap (contents 10 l); 13 = water heating device (60 watts); 14 = thermometer; 15 = supply valve nitrogen gas; 16 = metal weights in PVC cylinder casing; 17 = gravel bed diffuser (height 10 cm); 19 = envelope sample disc; 20 = tap regulating pump flow; 21 = outlet nitrogen gas; 22 = piezometer (10 for each vertical cylinder); 23 = nitrogen supply device

Plexiglass cylinders, 150 mm (5.9-in.) inside diameter by 580 mm (22.9-in.) long, built together from three distinct sections, are used. The top section includes a water inlet, an air release valve and nine piezometers at 0, 15, 30, 42, 54, 66, 78, 90 and 110 mm above the envelope's upper surface. This section contains a 100 mm (4-in.) long soil column, a 25 mm (1-in.) long gravel bed diffuser and a PVC container including 34 kg (75.2 lbs) of weights, simulating the soil load. Weights were chosen rather than loading screws as weights allow the load to be transmitted through the soil column and the envelope irrespective of the amount of soil washed out. The middle section contains a cut portion of corrugated pipe resting on a perforated plate. A piezometer is installed just below the bottom plate. The piezometers are connected to multitube manometer boards. The bottom section contains a funnel-shaped outlet draining to the sediment trap bottle.

A test run begins with submerging and deaeration of the envelope sample, the corrugated bottom plate and the support plate. Next, water is removed till 5 mm (0.2-in.) above the envelope. An amount of 2.5 kg (5.5 lbs) of Almere-sand is brought in each cylinder and charged by the weights. Next, the soil is saturated from below in about hour, displacing air pockets. Local piping seldom occurs. - Saturation is complete as soon as the water level reaches the top of the gravel bed diffuser. Then, the water inflow direction is reversed and the water enters the cylinders from the top. Once the cylinder is filled, the air release valve is closed and the water inflow is adjusted. Piezometric heads are allowed to stabilize. After one hour, data collection starts.

Once a test is terminated the cylinders are dismantled. Envelopes are allowed to dry at room temperature. Soil material in the sediment traps is weighed, after which a sample is analyzed for particle size distribution.

Size distributions of the original soil sample and the soil material which has settled in the sediment trap are shown in Fig. 11 and 12 respectively. A shift in distribution parameters is obvious: see the figures printed below.

```
#ALMEREZAND DOOR PP GESPOELD; RUN # 25, KOLOM # 7, DISK ID # 303215; DATA-
 EDITING: GEEXTRAPOLEERD VAN 8.70 TOT 17.40 MICRON. 29 AUGUSTUS 1983, 15:48 UUR

INDICES

VOLUME MODE =  64.95  MEDIAN =  61.45 MICRONS AND LARGER

GEOMETRIC  VOLUME MEAN =  58.42 +/-  20.90 ( 35.77%)  SKEWNESS =  -.31

ARITHMETIC VOLUME MEAN =  60.92 +/-  16.32 ( 26.78%)  SKEWNESS =  -.25
#
GRAPH OF DIAMETER SIZES VS. DIFFERENTIAL VOLUME FROM CHANNEL  1 TO 191, AND SKIP:  3
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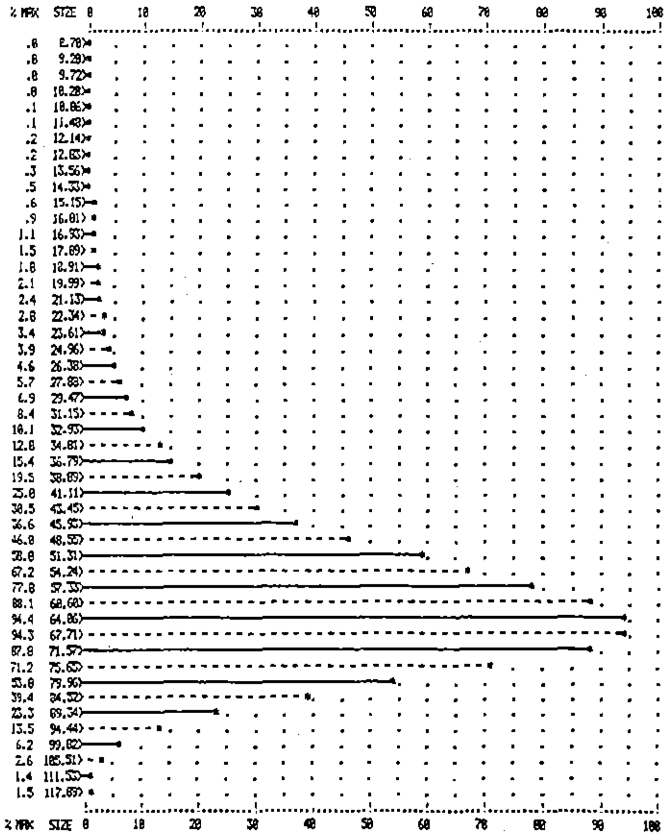


Fig. 12. Particle size distribution of the soil material found in the sediment trap

```
SETTINGS CALIBRATED FOR 301.01  LOG= 13.9636  CURRENT= 5.0  GAIN= 1.0
#ORIGINEEL ALMEREZAND, DISK-ID # 303101, GEEN DATA-EDITING. 29-AUG-83

INDICES

VOLUME MODE =  97.09  MEDIAN =  84.52 MICRONS AND LARGER

GEOMETRIC  VOLUME MEAN =  79.15 +/-  35.24 ( 44.53%)  SKEWNESS =  -.51

ARITHMETIC VOLUME MEAN =  83.97 +/-  26.40 ( 31.43%)  SKEWNESS =  -.50
#
GRAPH OF DIAMETER SIZES VS. DIFFERENTIAL VOLUME FROM CHANNEL  16 TO 209, AND SKIP:  3
```

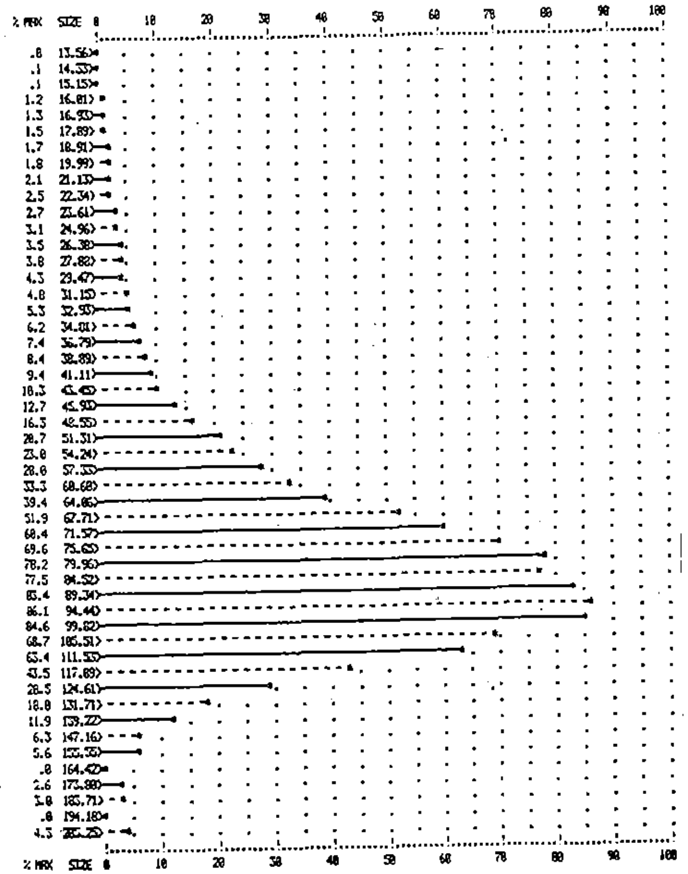


Fig. 11. Particle size distribution of the original soil sample (Almere-sand)

```
#INDICES ALMERE SAND, DISK-ID # 303101, NO DATA EDITING. 29-AUG-83.
INDICES

VOLUME MODE =  97.09  MEDIAN =  84.52 MICRONS AND LARGER

GEOMETRIC  VOLUME MEAN =  79.15 +/-  35.24 ( 44.53%)  SKEWNESS =   -.51

ARITHMETIC VOLUME MEAN =  83.97 +/-  26.40 ( 31.43%)  SKEWNESS =   -.50

ALMERE SAND WASHED THROUGH POLYPROPENE ENVELOPE [VOLUMINOUS]
DATA EDITING: EXTRAPOLATED FROM 8.70 TO 17.40 MICRON , 29 AUGUST, 1983

INDICES

VOLUME MODE =  64.95  MEDIAN =  61.45 MICRONS AND LARGER

GEOMETRIC  VOLUME MEAN =  58.42 +/-  20.90 ( 35.77%)  SKEWNESS =  -.31

ARITHMETIC VOLUME MEAN =  60.92 +/-  16.32 ( 26.78%)  SKEWNESS =  -.25
```

The skewness of the soil sample taken from the sediment trap is lower (less negative, that is) than that of the original soil sample. This indicates that the relative amount of the smallest particles present in the soil sample taken from the sediment trap is smaller than that in the original soil sample: this is visible also when comparing both particle size distribution curve shapes. Obviously, the 'transformation' from one distribution curve to the other is a function of the applied procedure, materials and testing circumstances.

SAMPLE ANALYSIS RESULTS

Graphical output of particle size distributions discussed here are presented in Appendix 2.

1. US and Canadian samples

site No. 1: Lowell E. Kraft, 40 acres North Huron County, Sect. 17, Brookfield, Michigan, USA

Soil material: Tappan loam. This nearly level, poorly drained soil is subject to frequent flooding. Typically, the surface layer is very dark grayish brown, calcareous loam about 30 cm thick. The mottled subsoil is about 45 cm thick. The upper part is friable loam and silt loam; the lower part is firm loam. The substratum, to a depth of about 1.50 m, is mottled loam. In some places the soil is not calcareous within 25 cm of the surface. In some areas there is very firm soil in the substratum.

Permeability of the Tappan soil is moderate or moderately low in the upper part of the profile and low in the lower part. The soil has high available water capacity and slow or ponded runoff. In undrained areas the water table is perched within 30 cm of the surface during the winter and spring months. The soil is suited to cultivated crops; however, wetness and soil compaction are the major concerns. Combined surface and subsurface drainage systems help control wetness. However, the lack of suitable drainage outlets is a problem in some areas. Erosion control structures may be necessary where surface ditches and natural drainageways enter larger ditches.

Working this soil when it is too wet results in clodding and compaction. Additional tillage to break up the surface clods further compacts the lower part of the surface layer and the subsoil. Surface crusting becomes more severe when the natural structure of this soil is destroyed by compaction and by depletion of organic matter. Artificial drainage helps control the high water table and flooding. Undrained areas are sometimes used for pasture. In this case, proper stocking, rotational or strip grazing and restricted use during wet periods helps to keep the pasture and soil in good condition.

A modest shift in particle size distribution parameters has occurred (see Table 1), exept for the mode. The largest particle able to wash through the Big 'O' nylon sock envelope had a diameter of 160 microns. The difference between both size distributions is small, indicating that this envelope is a permeable constaint rather than a filter exhibiting selective filtration. Selective washing-out of suspended materials in the

Table 1. Particle size distribution parameters of the North American soil samples (microns)

No.	Location	Mode	Median	Mean		Standard deviation		Skewness	
				geometric	arithmetric	geometric	arithmetric	geometric	arithmetric
2	Outside drain	76.00	31.59	26.49	44.30	55.31	40.06	- .90	- .79
3	Inside drain	120.64	35.46	19.04	38.91	58.97	40.59	-1.72	-2.01
4	30 cm above drain	65.86	57.33	55.41	60.75	30.80	25.53	- .34	- .20
5	Inside drain	109.99	89.34	83.09	97.90	69.31	52.79	- .39	- .23
6	Outside drain	55.76	60.60	61.79	74.37	51.91	46.77	.12	.40
7	Inside drain	199.64	194.18	186.53	188.43	31.27	23.95	- .42	- .47
8	Outside drain	155.55	102.63	87.59	100.77	70.91	44.76	- .96	-1.22
9	30 cm above drain	196.89	162.16	140.65	151.03	73.83	47.45	- .76	- .97
13	30 cm above drain	129.30	70.91	61.11	78.27	73.55	47.57	- .93	-1.07
16	45 cm above drain	162.91	97.99	83.58	100.55	81.66	51.85	- .97	-1.20
17	45 cm above drain	32.33	30.16	29.40	33.48	20.18	17.08	- .14	.07
20	Outside drain	18.40	12.31	11.41	12.32	6.04	4.26	-1.16	-1.43
24	Inside drain	67.71	64.65	61.67	74.96	56.56	46.08	- .11	.16
25	45 cm above drain	123.46	61.73	58.29	76.08	86.66	68.54	- .95	- .91

pipe is limited, indicating no dramatic seasonal run-off variation, possibly caused by low permeability of the Tappan loam. The washed-in distribution composition is, however, affected by numerous factors, such as sampling site in relation to collector hook-up etc., so it's justified to be reluctant in explanations and conclusions. LOUDIÈRE and FAYOUX (1982) have made many analyses of pipe sediment composition. They concluded that the amount of suspended material is a non-reproducible variable, mainly depending on local conditions. The size of the largest particle washed through an envelope was the only reproducible variable, not very dependent on local conditions.

Site No. 2: Hermand Walker, 756 Charlesina, Rochester, MICH. 80 acres in Tuscalon County, Sect. 1, Elkland

Soil material: Sanilac silt loam. This nearly level and gently undulating, somewhat poorly drained soil is on flats and low hills. Individual areas are irregular in shape and range from four to several hundred acres.

Typically, the surface layer is dark grayish brown, calcareous silt loam about 30 cm thick. The subsoil, 30 cm thick also, is pale brown and brown, mottled, friable very fine sandy loam. The substratum, to a depth of 1.5 metres, is stratified, pale brown, mottled very fine sandy loam and loamy very fine sand; typical drainage problem soils. In some places the soil is not calcareous within 25 cm of the surface, in some other places the lower part of the substratum is loam. The soil has (moderately) low permeability, available water capacity is high, and runoff is slow. In undrained areas the water table is within 30-60 cm of the surface during winter and spring months.

Most areas of this soil are cultivated: it has good potential for crops and pasture. However, wetness and soil compaction are the major concerns. Combined surface and subsurface drainage systems help control wetness. Erosion control structures may be needed where surface ditches and natural drainageways enter larger ditches.

Working this soil when it is too wet results in clodding and compaction. Additional tillage to break up the surface clods may further compact the lower part of the surface layer and the subsoil.

Surface crusting becomes more severe when the natural structure of this soil is destroyed by compaction and by depletion of organic matter. Artificial drainage helps control the water table and flooding.

Particle size distributions of the samples originating from this site indicate the importance of representative sampling. The samples taken 30 cm away from the pipe and from a corrugation printmark in the soil differ considerably, despite the fact that their means are more or less equal. Due to the trenchless installation technique, soil composition in the neighbourhood of the pipe may be less representative for the composition of the original soil, since it is likely to be affected by smearing effects etc. On the other hand, it might be more realistic to use this material in comparing soil outside the pipe with sediment inside it. Obviously, all particles smaller than 19 microns in the immediate vicinity of the pipe have been washed away. This might be an indication of natural filter buildup in the soil abutting the pipe. However, more sampling in this area is required for attaining more consistent results, including solid proof of natural filter buildup. In this respect, Elzone analysis is well-suited since it allows for sampling from well-specified locations on low-dimensional scale. Still, the size distribution parameters of the pipe sediment are shifted to larger values once more. The largest particle washed through the envelope equals 242 microns, but this might have been an aggregate just as well.

Site No. 3: John Fahrner, Owendale, 40 acres on Huron County, Sect. 12, Isant

Soil material: Pipestone sand. This nearly level, somewhat poorly drained soil is on flats, low hills and ridges. Typically, the surface layer is black sand about 5 cm thick. The subsurface layer is light brownish gray sand about 20 cm thick. The subsoil is mottled loose sand about 65 cm thick. The upper part is dark brown. The substratum, to a depth of about 1.5 metres is light yellowish, and pale brown mottled sand. In some places, the soil has a layer of clay accumulation in the subsoil, whereas precipitated iron, aluminium and organic matter have accumulated locally. In some areas there is a loamy soil in the substratum to a depth of 1 to 1.5 metres. Permeability of this soil is high. The available water capacity is low, and runoff is (very) slow. In undrained areas the water table is within 15 to 45 cm of the surface during winter and spring months. Most areas are cultivated or are in woodland. Potential is fair for cultivated crops and good for pasture. Wetness and maintaining organic matter content as well as wind erosion are the major concerns. Combined surface and subsurface drainage helps control wetness. However, the soil is often droughty in the summer. Irrigation will increase production. Tree windbreaks, rye buffer strips, cover crops and crop residue management can help control soil wind erosion.

Three samples taken from this location could be analyzed: No. 7 (inside 100 mm ADS-pipe with Big 'O' envelope), No. 8 (taken from pipe corrugation printmark in the soil) and No. 9 (30 cm above the pipe). The soil material taken 30 cm above the pipe is relative well-sorted with its mode (peak) in the size range around 197 microns. This would not be a typical drainage problem soil. The soil taken from the corrugation printmark, however, has a relatively high amount of fines. It seems that this sample was taken from soil too remote from a pipe slot to be involved in the discharge process, possibly affected by trenchless installation smearing effects. It does not yield information regarding possible natural filter buildup in the soil. These facts prompt multiple sampling near the pipe. In this case there is a significant shift in particle size distribution parameters of the samples taken in- and outside the pipe.

Site No. 4: Burt Visscher Farm, Exeter, Ontario, Canada

No specific information on the soil material was available. Three soil samples and one fiberglass sample were taken. Two samples could't be analyzed with confidence due to the high ochre content. Sample No. 13 (taken 30 cm above the pipe) could be analyzed. This soil is likely to be a real problem soil as far as mechanical clogging is concerned. The drainage system performed satisfactorily, however, and the quantity of sediment found in the pipe was low.

Site No. 5: Ken Campbell Farm, Ontario, Canada

No specific information on the soil material was available. The drainage system was installed in 1982, with 100 mm Big 'O' envelope. No sample was taken from inside the pipe since the amount of solids washed in was negligable. One sample could not be analyzed with confidence since it had a very ochre content. Sample No. 16 was taken 45 cm above the pipe. It contains soil with a median particle diameter near 100 microns, and is therefore classified in the category 'problem soils'. Sample No. 17 was also taken at 45 cm above the pipe, but contains silt. This, generally high-cohesive soil does not give rise to many problems as regards mechanical clogging. The sharp contrast in soil composition stresses once more the need for multiple-site sampling. Ken was very satisfied with his drainage system.

Site No. 6: Bob Hines Farm, Dashwood, Ontario, Canada

No specific information on the soil material was available. Two soil samples were taken at this site. The first one near the ditch, at the metal outlet pipe. This sample appeared to to be clean on arrival in the laboratory and could therefore not be analyzed. The second sample, No. 20, was taken from an apparently 'clayey' intrusion. In fact, the intrusion consists of silt. Soil of this type can be drained without risk with a nude pipe as far as experience in humid climates indicates so far. However, the majority of the soils at the site concerned consists of medium fine sands requiring an envelope. Drains installed at this site (July, 1982) are prewrapped with Big 'O' envelope and the pipe was clean.

Site No. 7: Greg Sadler, Parkhill, Ontario, Canada

No specific information on the soil material was available, but the profile appeared to be a heavy clay soil. Some sediment was sampled from inside a Big 'O' pipe, installed naked in 1974, at a change of grade from steep to slower; sample No. 22. Due to instrument constraints, the minimum particle diameter which can be analyzed currently is 2 microns. The largest particle - of aggregate - diameter analyzed was $\pm$ 36 microns. It was a right decision to install this drain without envelope.

Site No. 8: Michael Lisabeth Farm, Fairground, Ontario, Canada

No specific information on the soil material was available. A 100 mm Big 'O' pipe was installed in 1975, prewrapped with nylon sock. Apparently, the drain was performing well. Minor ochre was present at several spots, but the pores of the envelope were not clogged. Sample No. 24 was taken inside the pipe, No. 25, 45 cm above it. The means of both size distributions do not differ too much; however the skewness of the sample taken outside the pipe equals -1, indicating a relatively high percentage of fines. The skewness of the other sample, taken inside, is about zero indicating a more or less symmetrical size distribution, in which the percentage of fines must be considerably lower. The fines were washed into the drain in the first place and subsequently washed out again since they remained suspended.

To standards, common in the Netherlands, the major part of the soils analyzed consists of problem soils as regards mechanical clogging risk, that is very fine and silty sands. Although no water pressure gradients and other data near the drains could be measured the sand-tightness of the sheet envelopes is obvious. The dig-up sites were particularly interesting since the soils investigated are quite familiar to Dutch problem soils. Taking the success of the sheets into consideration, Dutch reluctance in applying them is to be questioned. This even more so since voluminous envelopes, quite often installed succesfully in Holland give rise to a considerable number of failures as well.

2. Dutch samples

In order to be able to compare the results of the analyses of the North American soils with those of Dutch soils, another five dig-ups were made in the Dutch Rhine Delta area, west of Rotterdam and located in the southwestern part of the country. In this area, the major part of the soils in agricultural use consists of very fine sands of marine and/or fluviatile origin. These digups were scheduled in a vast field research project to investigate coco-fiber behaviour and decomposition rate.

Unlike the rest of Holland, sheet envelopes are commonly installed in this area succesfully, mainly glass fiber sheets. However, at the dig-up sites, coco-fiber envelopes had been installed.

Analysis results are not being discussed separately since they are rather consistent. As far as the mean particle size is concerned, the samples belong to either of two categories (cf. Table 2). The first one (samples 1-6) has a mean particle size of 110 microns, whereas the second group has a mean size of 65 microns. All samples are denoted to be clogging problem soils.

Unlike the North American samples, there is no consistency in shift of the mean particle size towards higher figures inside the drain, compared to the original soil. In all but one cases, however, the skewness (asymmetry) of the samples taken from pipe sediments is lower - less negative, that is - than that of the original soils. This means that the percentage of fines found inside the drains is consistenly lower than that of the original soils. In those cases where the mean particle size made no significant shift, the amount of relative large particles found inside was also lower than that of the original soils. This is notable fact, given the relatively large pores in the voluminous envelope installed.

The mean maximum particle diameter found in the pipe was 182 microns, in the original soil 199 microns. This size difference is not statistically significant, indicating once more that voluminous envelopes like coco-fibres, at least if wrapped to a thickness of 8 mm (3/8 inch) which is familiar, must be considered to be permeable constraints rather than filters.

Table 2. Particle size distribution parameters of the Dutch soil samples (microns)

No.	Location	Mode	Median	Mean		Standard deviation		Skewness	
				geometric	arithmetic	geometric	arithmetic	geometric	arithmetic
1	Inside drain	139.22	117.89	111.81	117.53	42.42	36.60	- .65	- .59
2	Outside drain	152.16	128.11	131.84	158.05	107.27	99.94	-2.60	-2.53
3	Inside drain	133.95	106.98	104.84	110.04	38.48	34.36	- .75	- .68
4	Outside drain	149.22	108.48	101.95	108.86	46.29	37.49	-1.02	-1.08
5	Outside drain	151.30	108.48	103.35	113.69	57.32	50.27	- .84	- .75
6	Inside drain	166.72	137.31	128.22	137.83	62.89	48.76	- .61	- .59
7	Inside drain	75.65	68.65	65.01	68.59	27.14	20.57	- .39	- .34
8	Outside drain	88.11	70.58	64.79	70.79	36.67	27.21	- .64	- .64
9	Outside drain	91.85	70.58	62.74	71.06	44.78	31.83	- .65	- .65
10	Inside drain	106.98	74.61	67.52	75.84	45.88	32.98	- .86	- .94

Sample site id.: 1, 2 = D.J. Geertsema, Middenmeer; 3, 4 = Grootepolder perceel 4, Voorne-Putten;
5. 6 = J. Kruk, Broek op Langedijk; 7, 8 = Oudehoornpolder, Voorne-Putten;
9, 10 = Pancrasgorsedijk, Voorne-Putten

SUMMARY AND CONCLUSIONS

In order to check the state of subsurface drain/envelope combinations, several dig-ups were made in the State of Michigan (United States), the Province of Ontario (Canada) and the southwestern part of the Netherlands. These opportunities were used to sample soil material in the vicinity of the pipe as well as sediment inside. No preparatory moves were made as regards sample containers, sample preservation etc., so all sampling activities have been fully incidental in their nature. Particularly, there was a considerable time-lag between sampling in North-America and analysis in Holland (at least four weeks), due to the fact that the analysis equipment wasn't fully operational untill March, 1983. Moreover, in the majority of cases, not too much attention was paid to selection of the most appropriate sampling sites. This is quite well understandable since the sampling activity was only part of a widely oriented reconnaissance tour. A good deal of reservation in interpreting the results is obviously required.

The results are summarized using the following parameters as a reference: the particle size distribution geometric skewness or assymmetry indicating the relative amount of fines in a sample (the more negative the skewness, the higher the amount of fines), the median particle sizes found in- and outside the drain, and the largest particle (or aggregate) size found in- and outside the drain. Skewness and median particle size are displayed in Fig. 13. The arrows (Dutch samples have dotted arrows) are plotted as follows: the tail ends coincide with parameter values outside the drain and the front ends with the values found on samples taken inside. The majority of the arrows point upward (six to three) indicating less fines in the pipe than around, which is expected. Also, six arrows point to the right which means that the median particle size inside the pipe is larger than around it. If we take into consideration the wide scatter of soil composition at one and the same site, and the stochastic nature ('uncertainty') of sampling as a direct consequence, inside as well as outside the drain, a two to one majority of results we expect to find is not too bad.

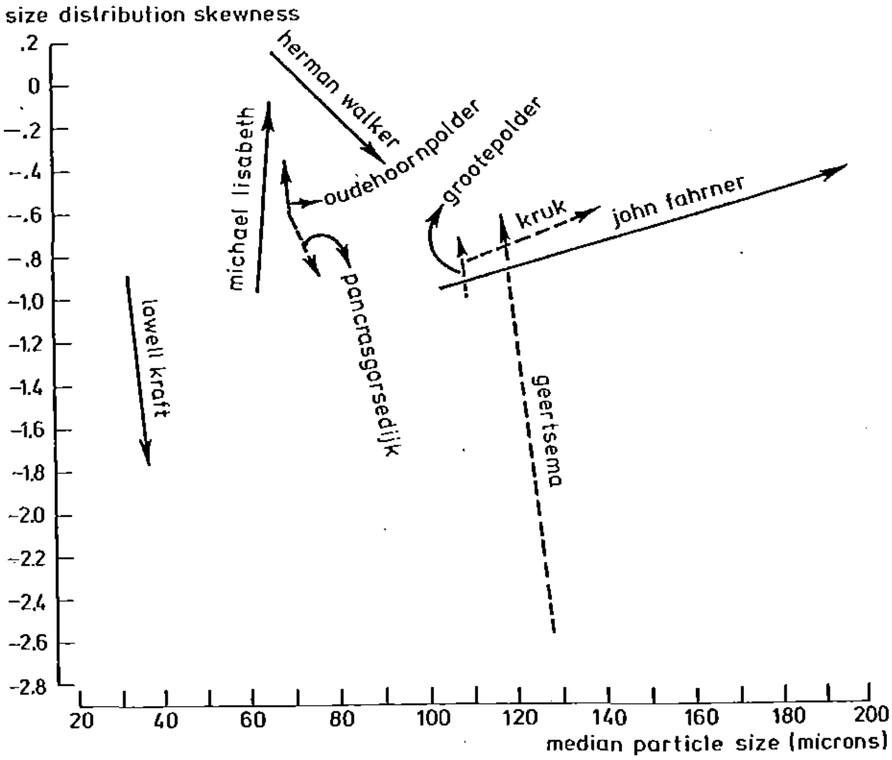


Fig. 13. Skewness and median particle size variations due to soil invasion into the drain (see text)

A notable difference between the Dutch samples on the one hand, and the North American samples on the other hand is observed. In three out of five case, the median particle size found inside is smaller than the corresponding size found outside. This might be due to lower flow velocities inside the pipe than those occurring in large-diameter North American pipes. Moreover, the Dutch samples were analyzed with a time-lag of three days only. It is very well possible that particles in the North-American samples have stuck together into aggregates since they were compacted in their 'containers', i.e. plastic bags. The second suggestion, however, is withspoken if we study a scattergram containing maximum particle diameters in- and outside the pipes, cf. Fig. 14. Whereas in the North-American samples the maximum diameter found inside is larger than outside in all but one cases, in the Dutch samples the reverse is the case. The samples taken at Kruk, Pancrasgorsedijk and Oudehoornpolder are acceptable in this respect, since both sizes are equal, but analyses on Geertsema and Grootepolder cannot be declared. Possibly, sampling- and/or analysis errors have been made.

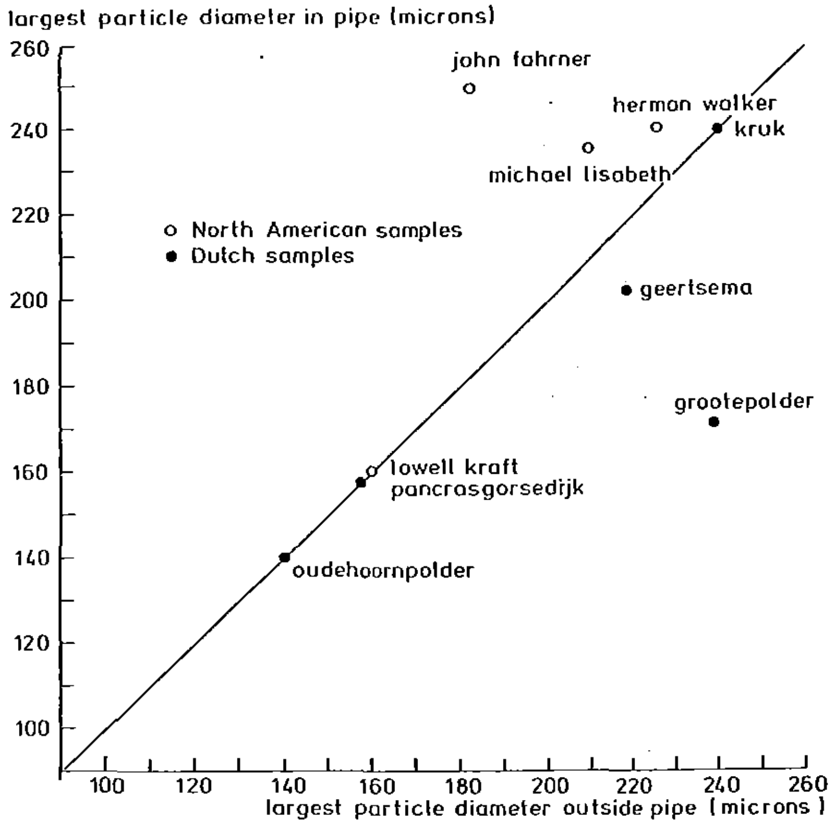


Fig. 14. Maximum particle diameters in- and outside the drain (see text)

What we can learn from this incidental sampling exercise is a couple of things. Firstly, the Elzone method, if applied with consideration, is a useful tool in determining particle size distributions. Secondly, a thorough investigation of the site where sampling is due is a must. Samples must be preserved with care, and the time lag between sampling and analysis is to be minimised. Multifold sampling at one and the same site during the season (pipe outflow etc.) is more informative than incidental sampling. More information regarding the site is necessary in order to be able to draw conclusions that make sense. In this respect, monitoring outflow rates and water table heights during longer periods (pilot areas) can supply more data in order to allow us to learn more about what's really going on at a site. This is generally true for research activities regarding the clogging problem of drain envelopes. We are getting more and more aware of the fact that micro-scale monitoring of soil/water/envelope interactions is inevitable if we really want to dismantle the 'black box' of mechanical clogging which is still fully locked today. Large-

scale field trials are a useful tool for diagnosis only. It is for this reason that ICW has chosen to give high priority to lab-investigations (STUYT, 1983).
Regardless this research philipsophy, it was useful to analyze the samples taken from the field since we have learned that problem soils can be drained successfully, even with sheet envelopes; a fact not yet really accepted in some areas in Europe.

REFERENCES

KARUHN, R.F. and R.H. BERG, 1982. Practical aspects of Electrozone size analysis. Particle Data Laboratories, Ltd., Elmhurst, IL 60126 USA 33 pp.

LAGACÉ, R. and R.W. SKAGGS, 1983. Prediction of Drain Silting and Filter Requirement Criteria. Proc. Sec. Int. Drain. Workshop, CPTA, Carmel, IN, USA: 161-171.

LOUDIÈRE, D. and D. FAYOUX, 1982. Filtration et drainage au moyen de géotextiles: essais et spécifications. Proc. Sec. Int. Conf. Géotextiles, Las Vegas, USA, Vol. 1: 61-66.

STUYT, L.C.P.M., 1983. Drainage envelope research in the Netherlands. Report No. 8, Institute for Land and Water Management Research, Post Box 35, 6700 AA Wageningen, the Netherlands. Reprint from Proc. 2nd Int. Drain. Workshop, Washington DC, 1983. 18 pp.

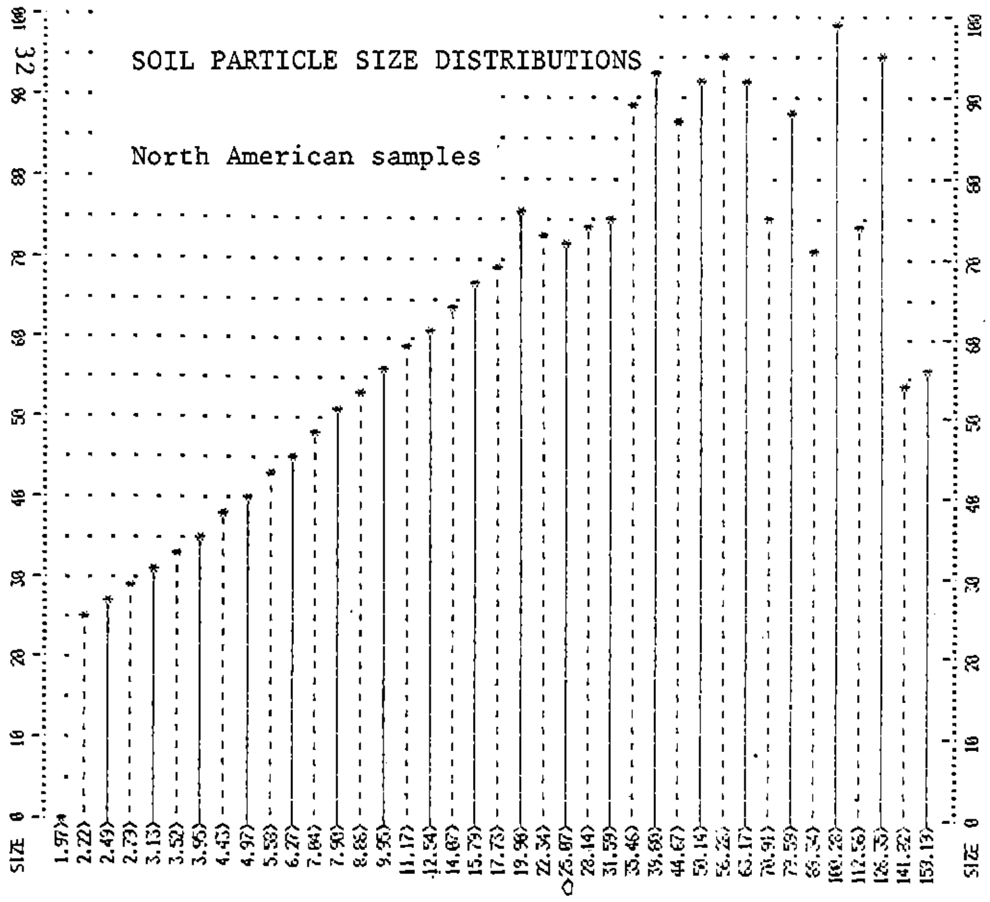
APPENDIX 1

SAMPLE SITE INDENTIFICATION (NORTH-AMERICAN SAMPLES)

Soil samples excavated in the United States and Canada, December 1982, Lowell E. Kraft and Louis C. Stuyt

Sample No.	Date	Description
1	17 Dec. '82	Lowell E. Kraft, North Huron County, sect. 17, Brookfield 30 cm above 75 mm tubing
2	17 Dec. '82	Lowell E. Kraft, North Huron County, sect. 17, Brookfield Sample of soil immediately abutting corrugations of 75 mm tubing
3	17 Dec. '82	Lowell E. Kraft, North Huron County, sect. 17, Brookfield Inside of 75 mm tubing, Big 'O' envelope installed
4	17 Dec. '82	Herman Walker, 756 Charlesina, Rochester, MI 48063 60 acres Tuscalon County, sect. 1, Elkland 30 cm above tubing
5	17 Dec. '82	Herman Walker Inside of Big 'O' 100 mm tubing, Big 'O' envelope installed
6	17 Dec. '82	Herman Walker Sample of soil immediately abutting corrugations of Big 'O' 100 mm tubing
7	17 Dec. '82	John Fahrner, Owendale, 40 acres Huron County, sect. 12, Isant Inside of 100 mm A D S tubing, Big 'O' envelope installed
8	17 Dec. '82	John Fahrner Outside of 100 mm tubing, valley of corrugation
9	17 Dec. '82	John Fahrner 30 cm above 100 mm tubing
10	20 Dec. '82	Muskegon waste water spray field, Muskegon County, Michigan Circle 4 S, subsurface soil 60 cm below surface - 120 cm above second lateral west of Moorland Rd - North of main
11	20 Dec. '82	Muskegon Waste water spray field, circle 4 S, second lateral west of Moorland Road, North of Main, installed 1973. From outside of 6" tubing, near corrugation, cerex envelope installed, tubing still flowing
12	21 Dec. '82	Burt Visscher Farm, Exeter, Ontario, Canada Downstream lateral No. 2. Fiberglass envelope sample from Big 'O' tube, installed 1972. Corrugations had small amount of course sand
13	21 Dec. '82	Burt Visscher Installed 1976. 30 cm above 100 mm Big 'O' tubing (lateral), with Big 'O' envelope installed

Sample No.	Date	Description
14	21 Dec. '82	Burt Visscher Potential ochre, 30 cm above lateral No. 2
15	21 Dec. '82	Burt Visscher Below and outside of 100 mm tubing (Big 'O') with Big 'O' envelope, lateral No. 1
16	21 Dec. '82	Ken Campbell Farm, Ontario, Canada 45 cm above 100 mm Big 'O' tube, installed 1982
17	21 Dec. '82	Ken Campbell 45 cm above Big 'O' tube with Big 'O' envelope, installed 1982, lateral No. 2, small silt intrusion. Some coarser sand in corrugations
18	21 Dec. '82	Jack Riddell Farm, Ontario, Canada Outside and below 100 mm Big 'O' tube with Big 'O' envelope installed. Installed 1976. Tube clean, 25 m downstream from upper end
19	21 Dec. '82	Bob Hines Farm, Dashwood, Ontario, Canada Removed from corrugations of 200 mm metal outlet tube at ditch
20	21 Dec. '82	Bob Hines Clay at interface with sand at tubing centerline (100 mm Big 'O' tube with Big 'O' filter). Tube clean. Installed July 1982
21	21 Dec. '82	Greg Sadler, Parkhill, Ontario, Canada Big 'O' envelope removed from replacement 100 mm Big 'O' tube, perfectly clean inside of tube, installed 1980
22	21 Dec. '82	Greg Sadler Removed from inside Big 'O' tube, installed naked 1974 at change of grade from steep to slower in very heavy clay soil
23	22 Dec. '82	Micheal Lisabeth Farm, Fairground, Ontario, Canada Below and outside next to Big 'O' envelope on 100 mm Big 'O' tube
24	22 Dec. '82	Michael Lisabeth Taken from inside 100 mm Big 'O' tube with Big 'O' envelope, installed 1975. Drain performing very well. Minor ochre present. Pores of envelope not clogged
25	22 Dec. '82	Michael Lisabeth 45 cm above Big 'O' 100 mm tube with Big 'O' envelope installed



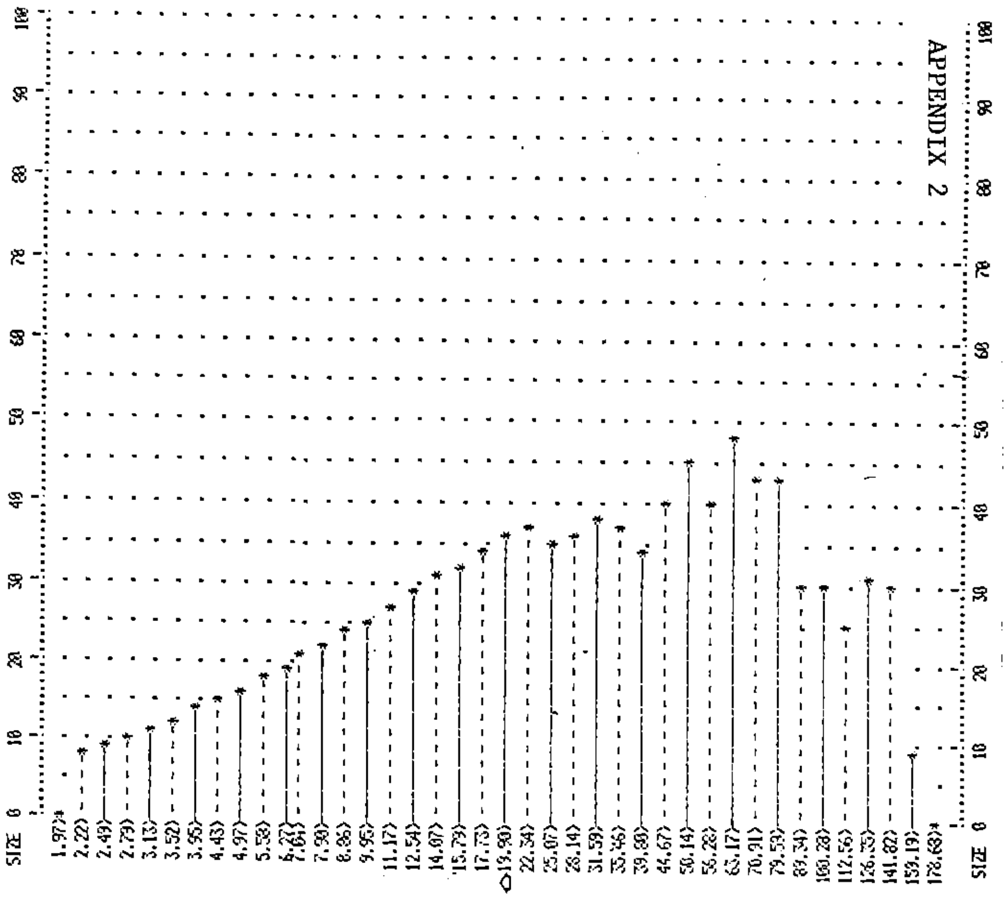


Fig. 1. Lowell E. Kraft, North Huron County, sect. 17, Brookfield
Sample of soil immediately abutting corrugations of 75 mm tubing

Fig. 2 . Lowell E. Kraft, North Huron County, sect. 17, Brookfield
Inside of 75 mm tubing, Big 'O' envelope installed

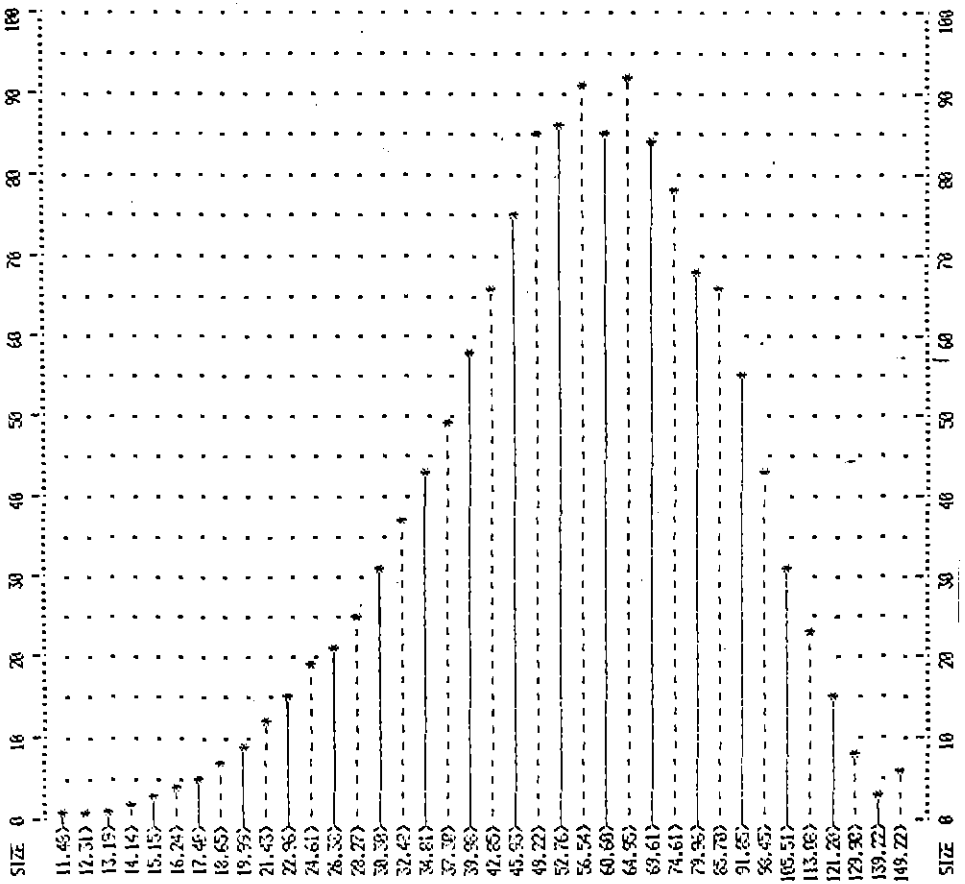


Fig. 3. Herman Walker, 756 Charlesina, Rochester, MI 48063
80 acres Tuscalon County, sect. 1, Elkland
30 cm above tubing

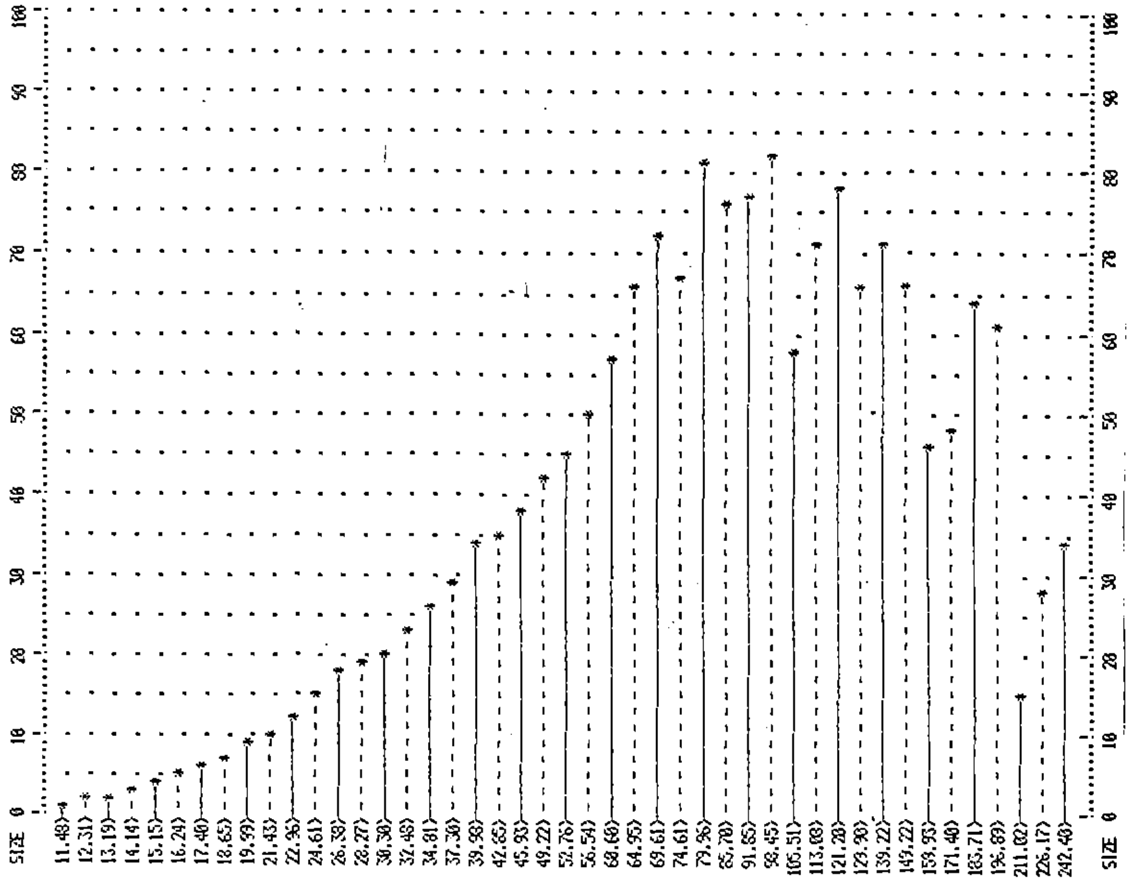


Fig. 4. Herman Walker
Inside of Big 'O' 100 mm tubing, Big 'O' envelope installed

APPENDIX 2-cont'd

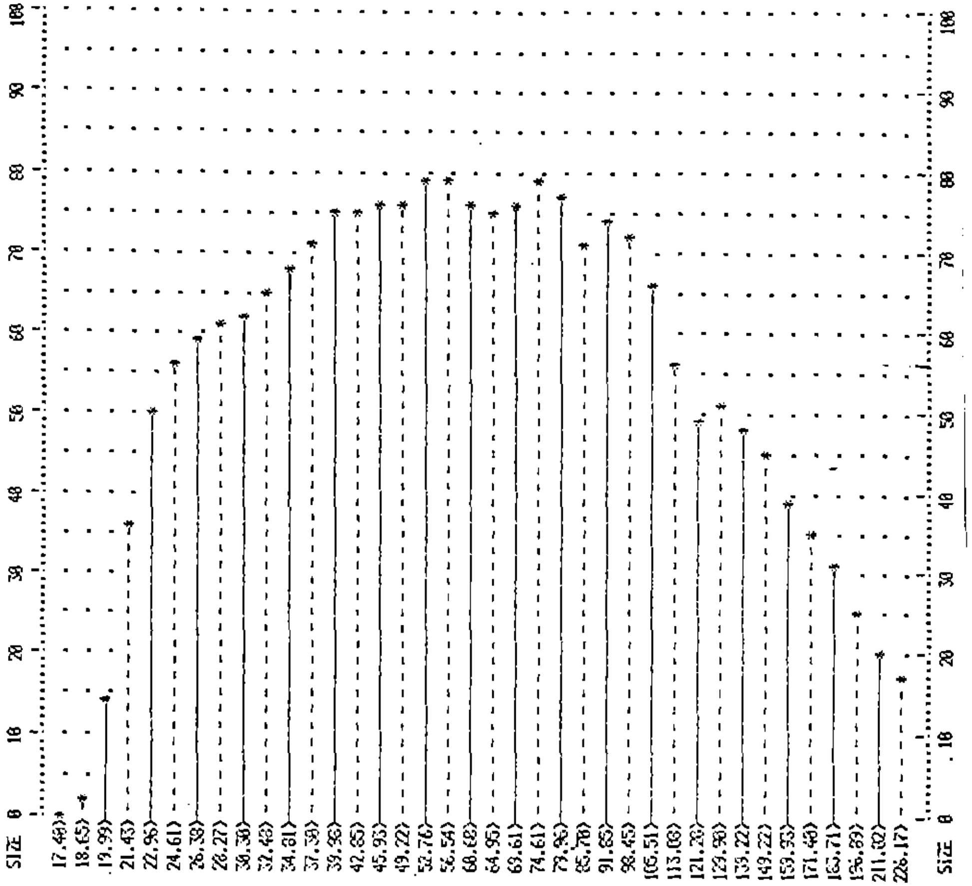


Fig. 5 . Herman Walker
Sample of soil immediately abutting corrugations of Big 'O' 100 mm tubing

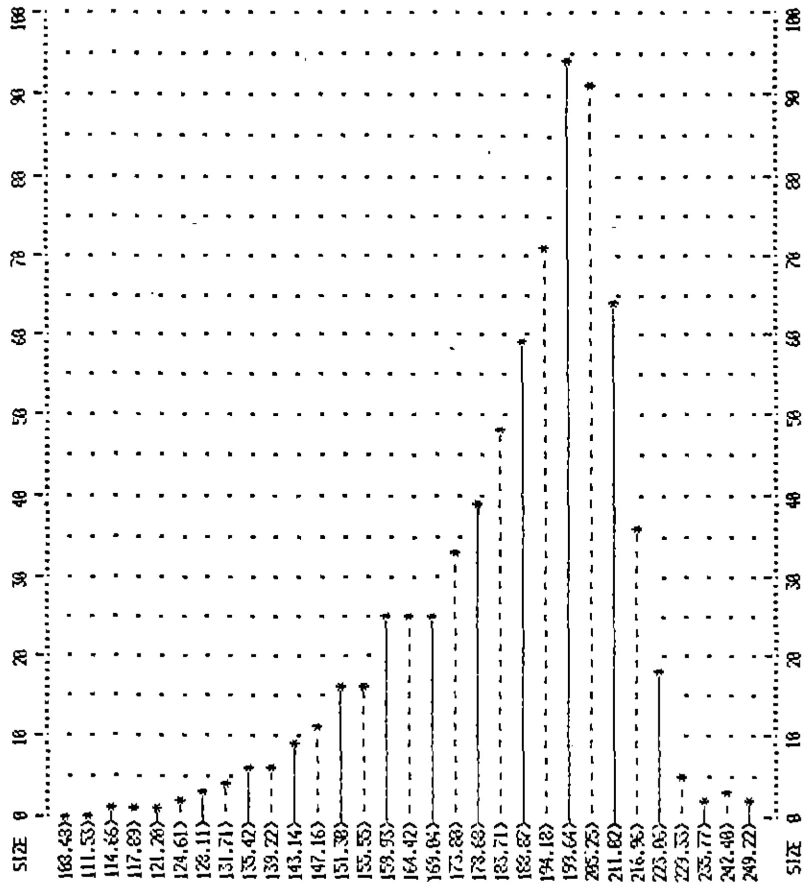


Fig. 6 . John Fahrner, Owendale, 40 acres Huron County, sect 12, Isant
Inside of 100 mm A D S tubing, Big 'O' envelope installed

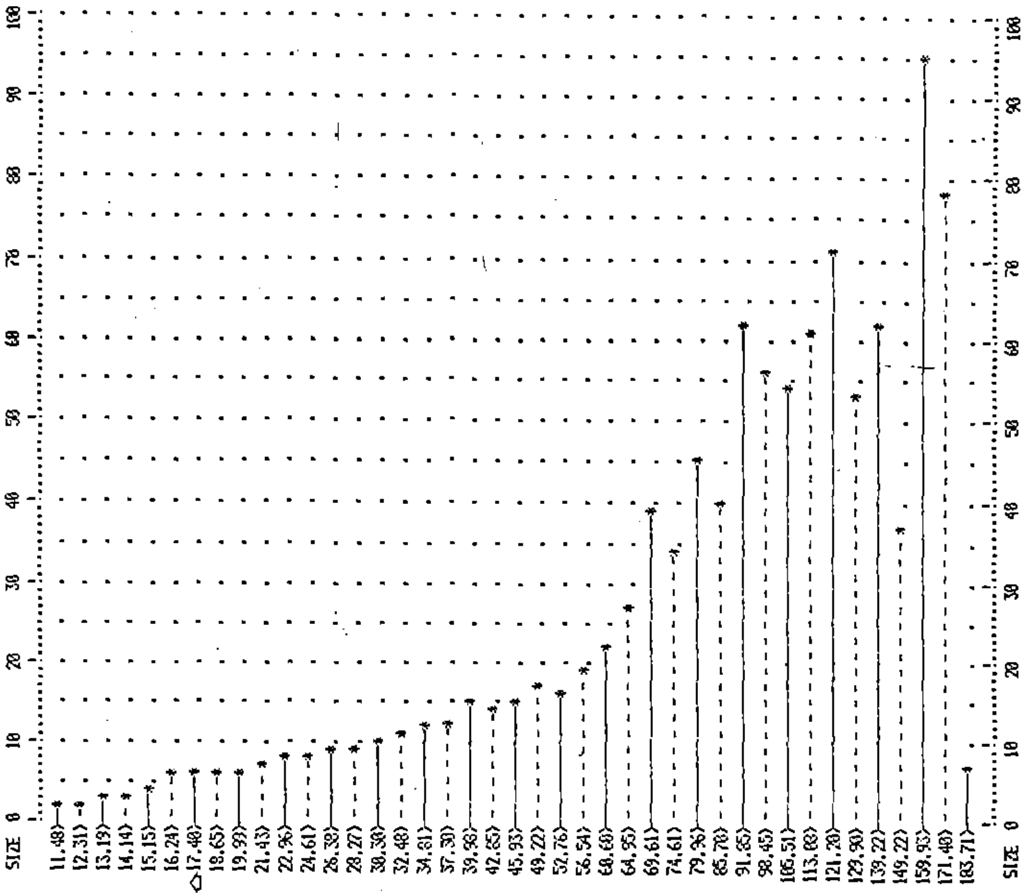


Fig. 7. John Fahrner

Outside of 100 mm tubing, valley of corrugation

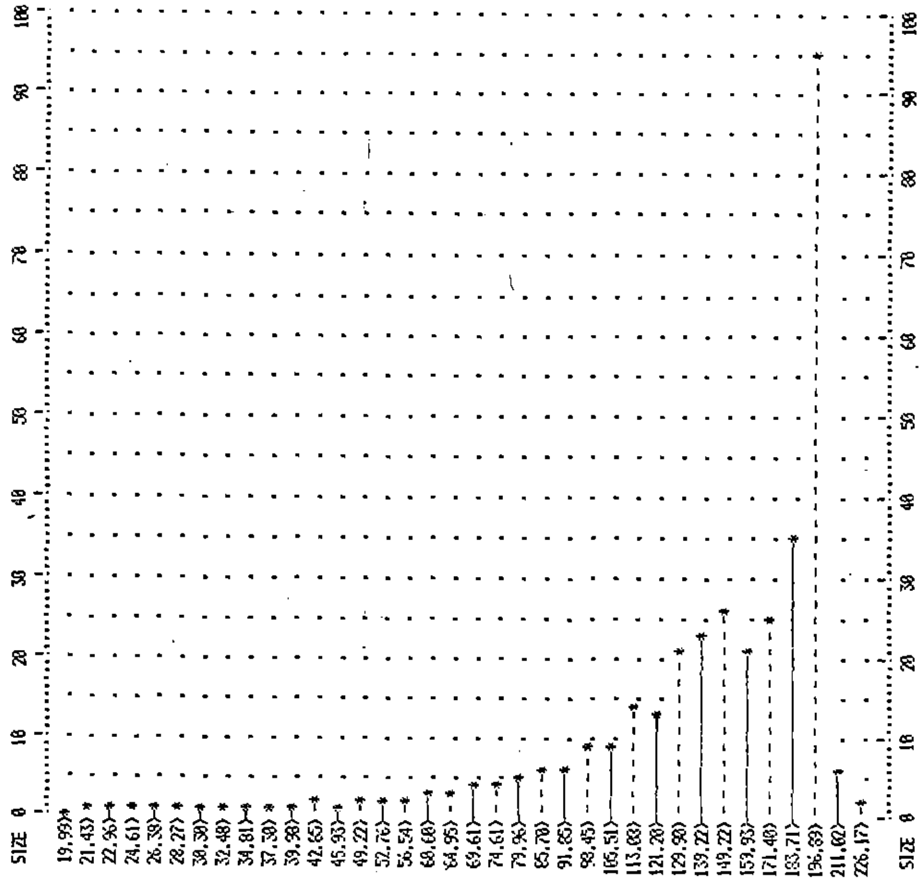


Fig. 8. John Fahrner

30 cm above 100 mm tubing

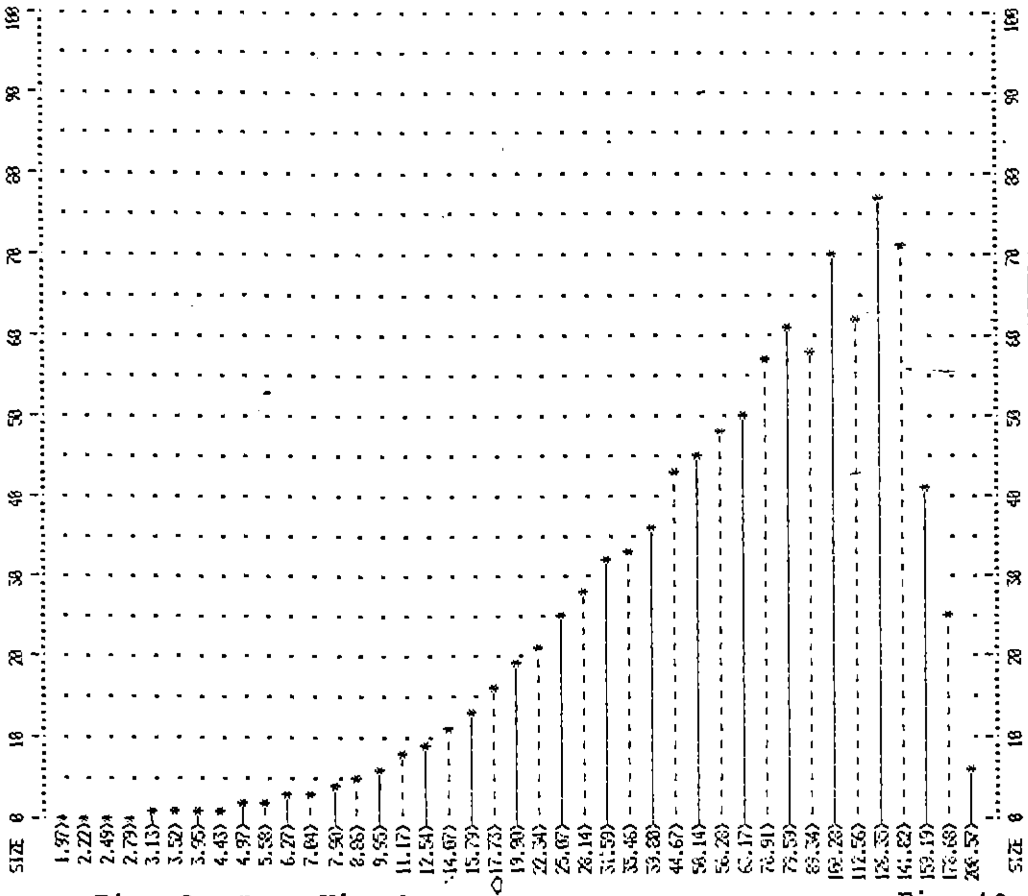


Fig. 9. Burt Visscher
Installed 1976, 30 cm above 100 mm Big 'O' tubing (lateral), with Big 'O' envelope installed

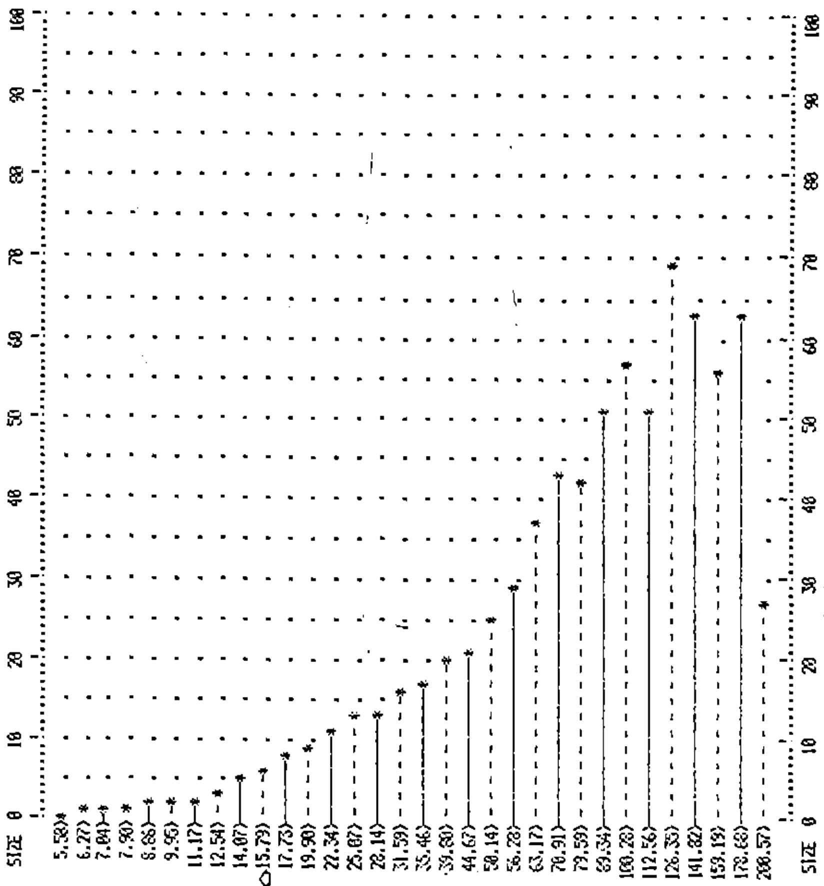


Fig. 10. Ken Campbell Farm, Ontario, Canada
45 cm above 100 mm Big 'O' tube, installed 1982

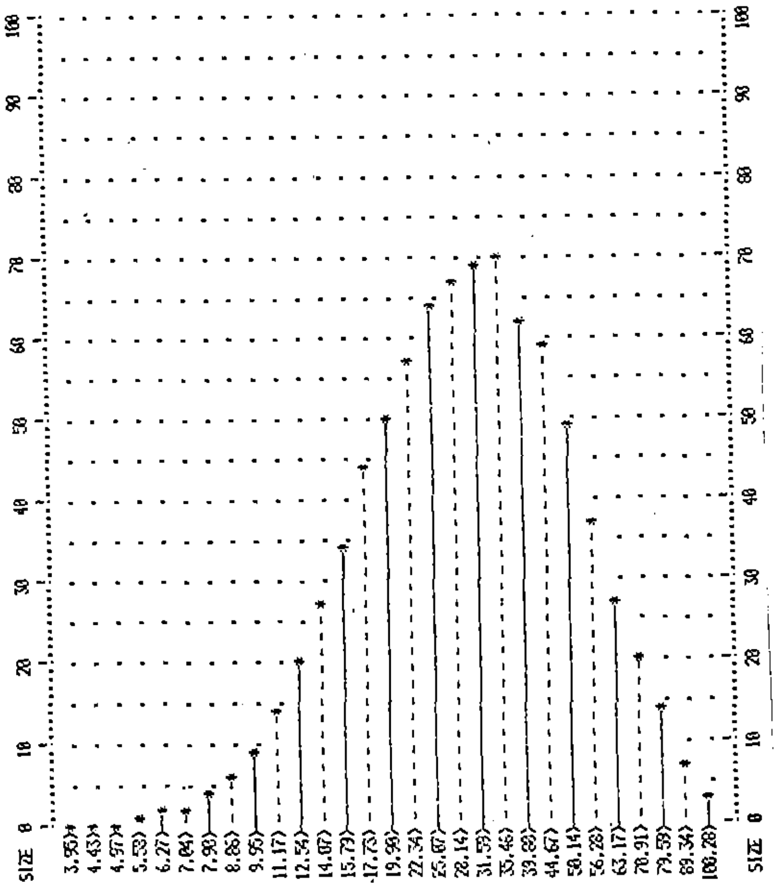


Fig. 11. Ken Campbell
45 cm above Big 'O' tube with Big 'O' envelope, installed 1982, lateral No. 2, small silt intrusion, Some coarser sand in corrugations

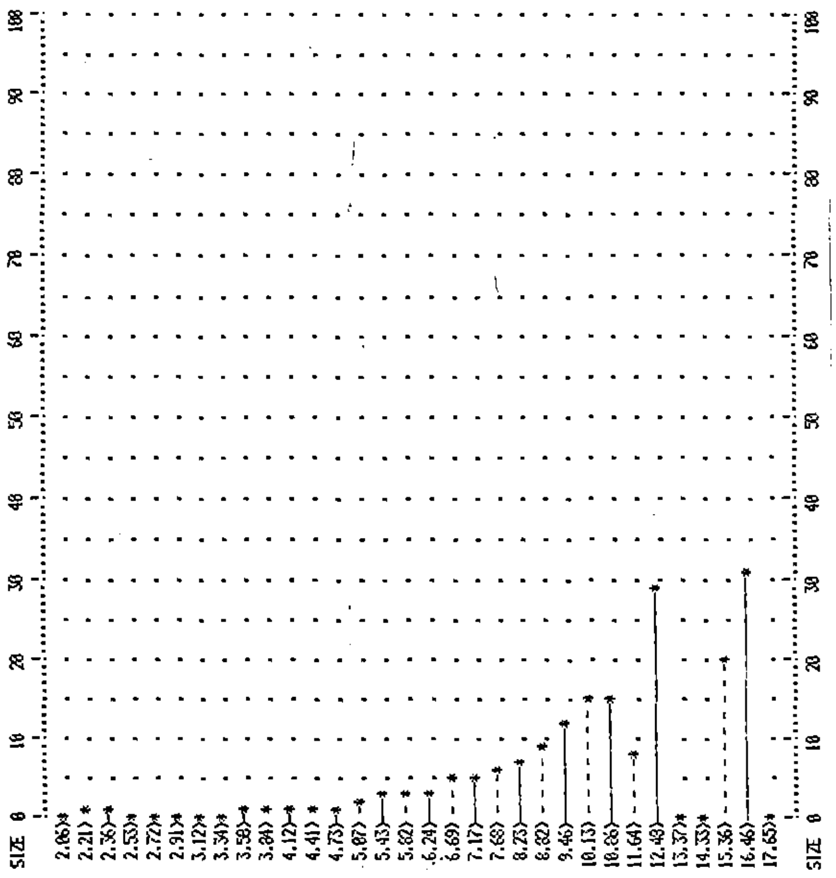


Fig. 12. Bob Hines
'Clay' at interface with sand at tubing centerline (100 mm Big 'O' tube with Big 'O' filter). Tube clean, Installed July 1982

APPENDIX 2-cont'd

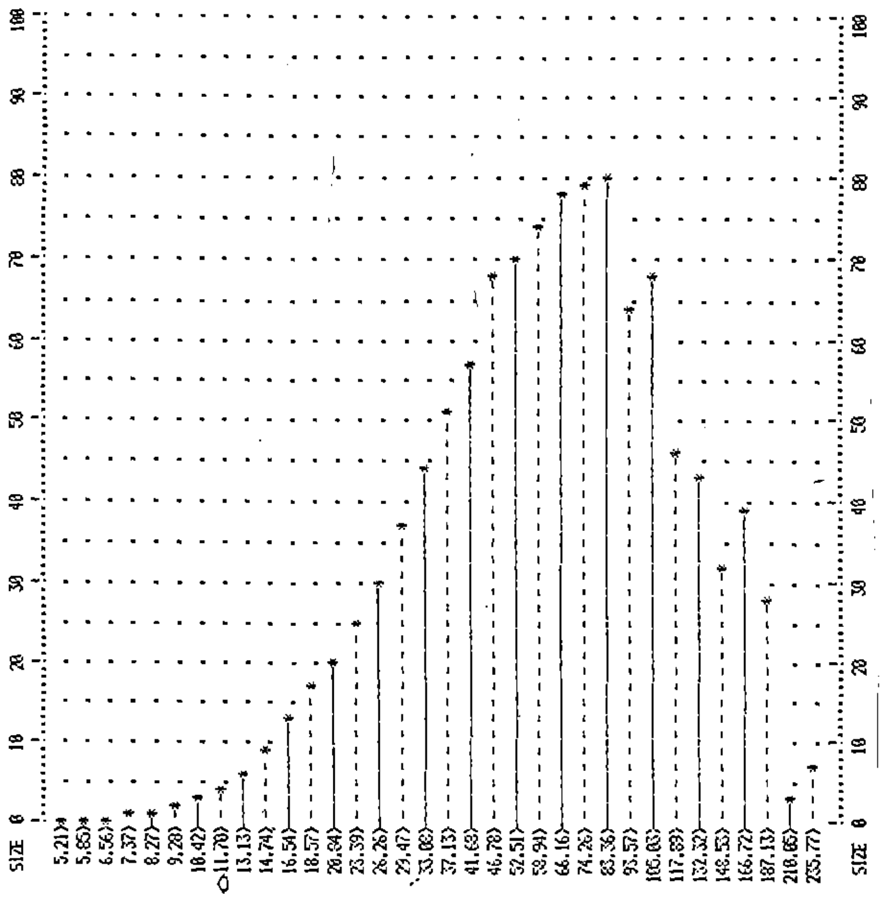


Fig. 13. Michael Lisabeth
Taken from inside 100 mm Big 'O' envelope, Installed 1975. Drain performing very well. Minor ochre present. Pores of envelope not clogged

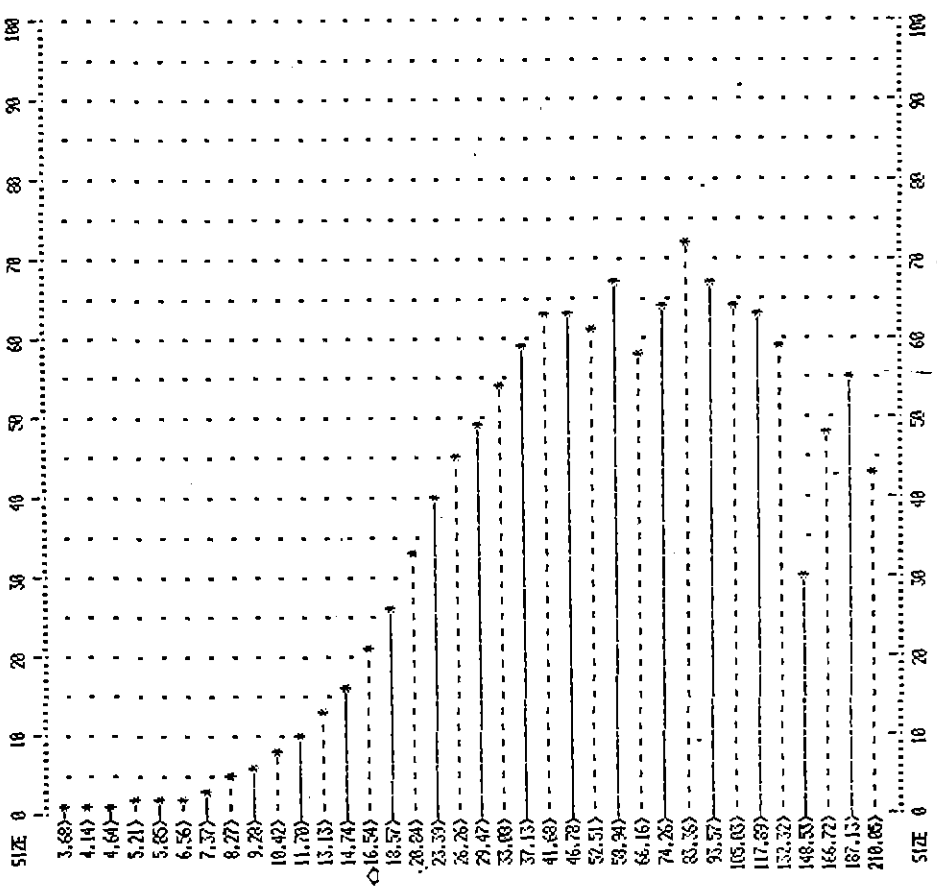


Fig. 14. Michael Lisabeth
45 cm above Big 'O' 100 mm tube with Big 'O' envelope installed

Dutch samples

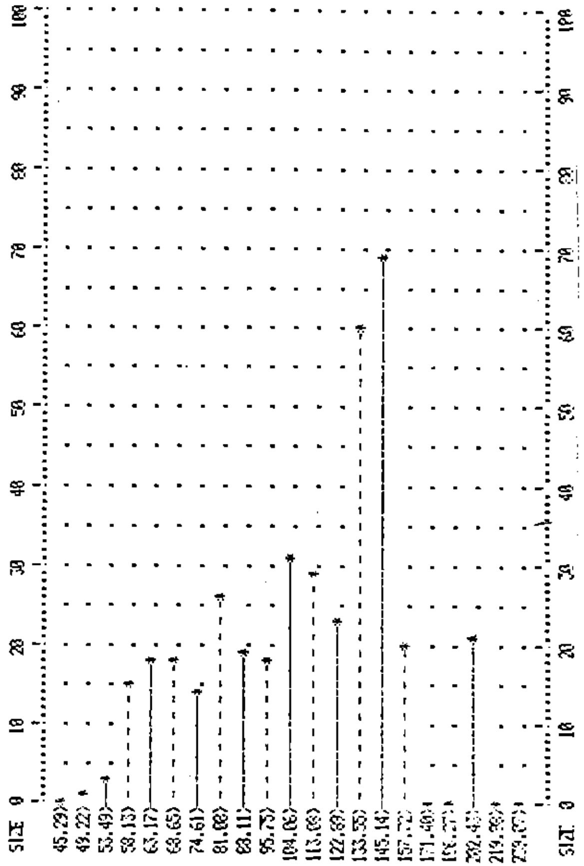


Fig. 1. D.J. Geertsema, Middenmeer, in drain

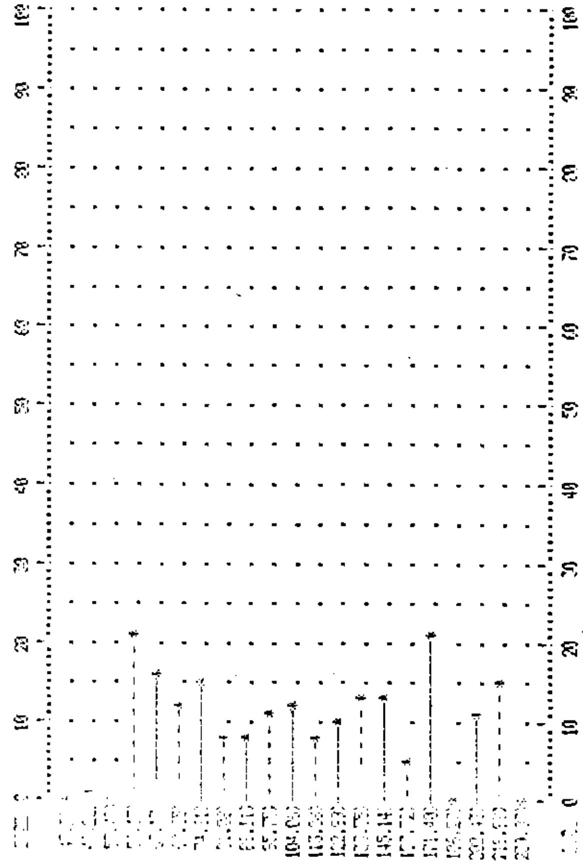


Fig. 2. D.J. Geertsema, Middenmeer, outside drain

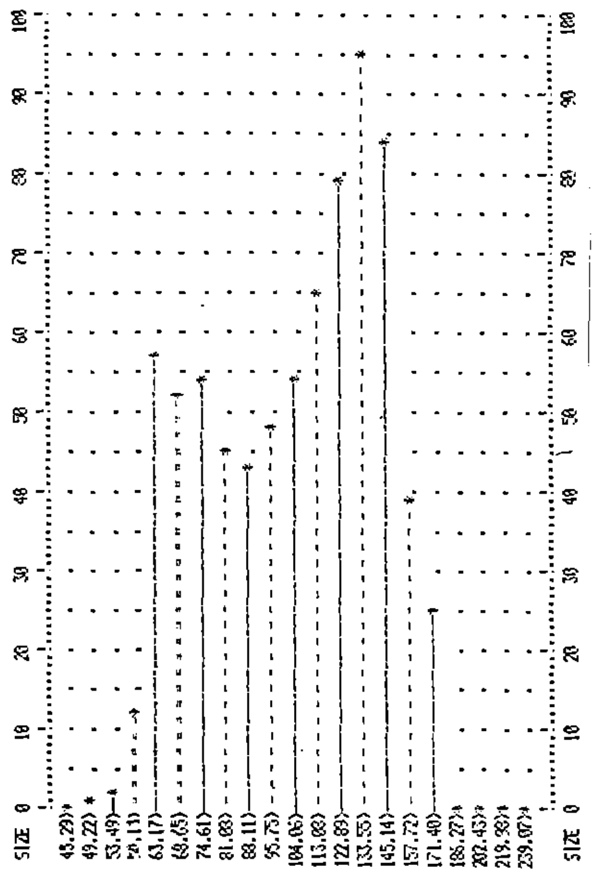


Fig. 3. Province of Zuid-Holland, Voorne-Putten, parcel No. 4, Grootepolder, in drain

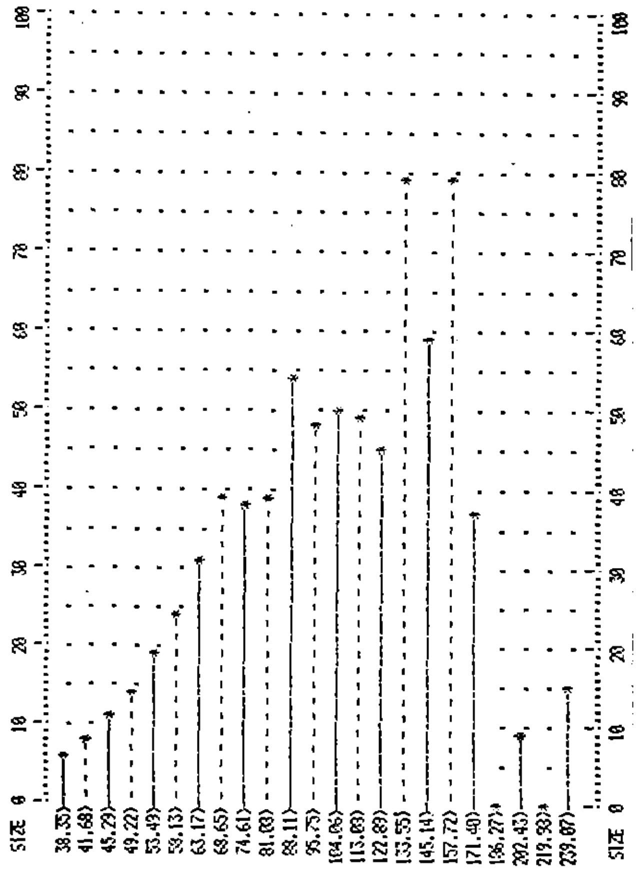


Fig. 4. Province of Zuid-Holland, Voorne-Putten, parcel No. 4, Grootepolder, outside drain

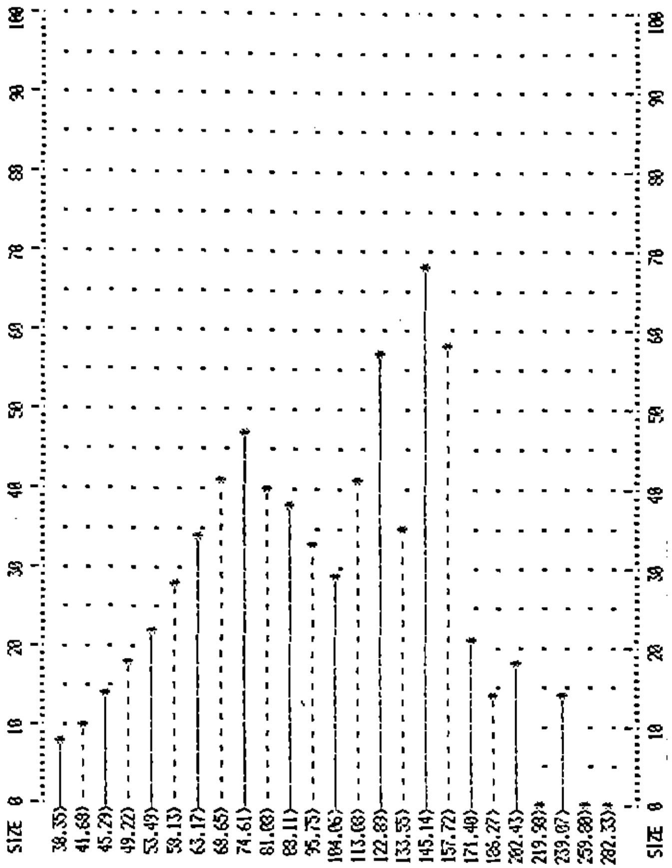


Fig. 5. J. Kruk, Broek op Langedijk, outside drain

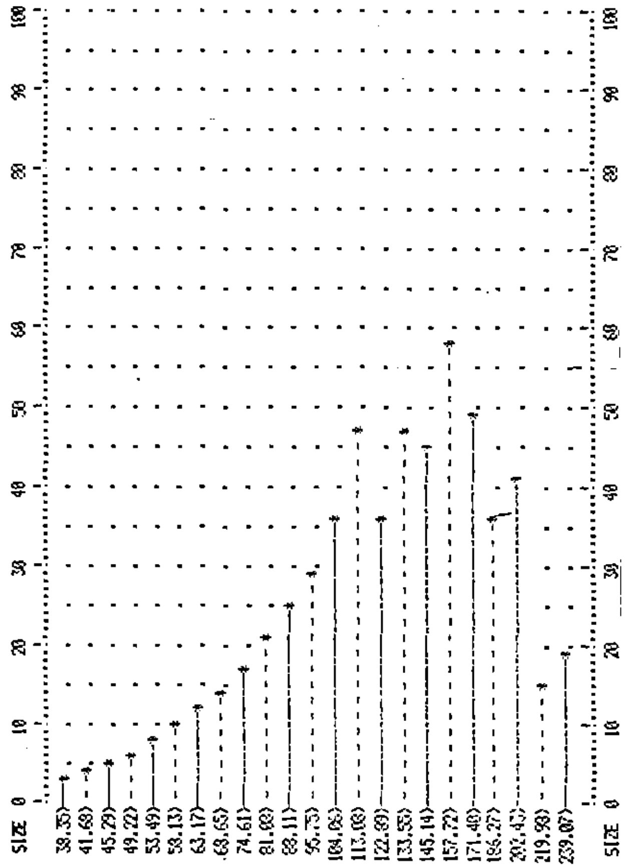


Fig. 6. J. Kruk, Broek op Langedijk, in drain

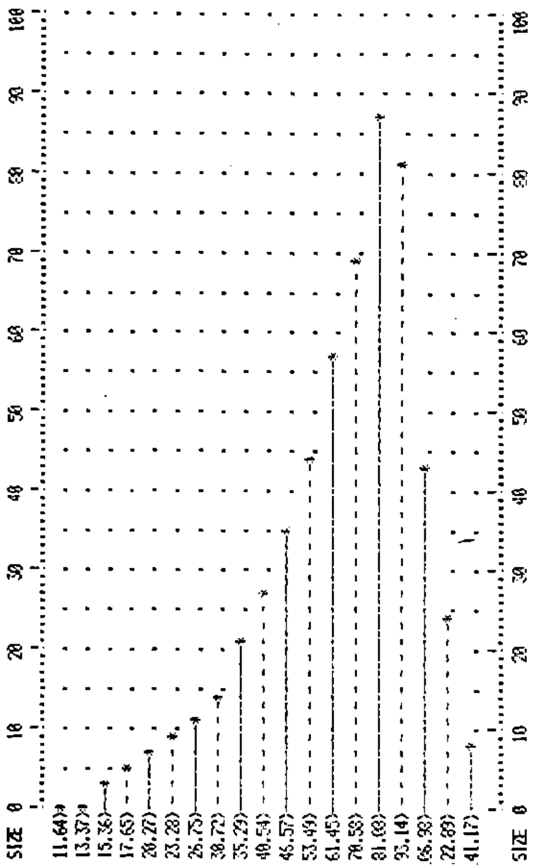


Fig. 7. Province of Zuid-Holland, Voorne-Putten, parcel No. 5, Oudehoornpolder, outside drain

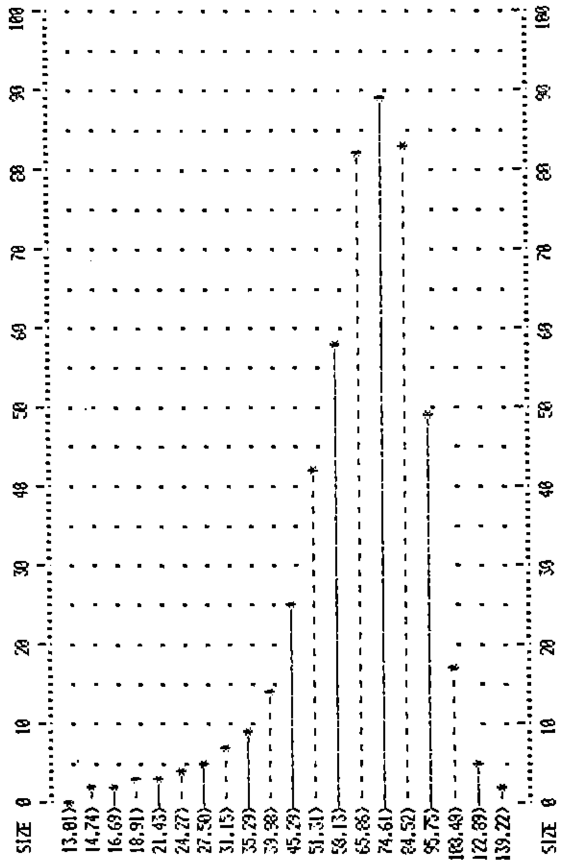


Fig. 8. Province of Zuid-Holland, Voorne-Putten, parcel No. 5, Oudehoornpolder, in drain

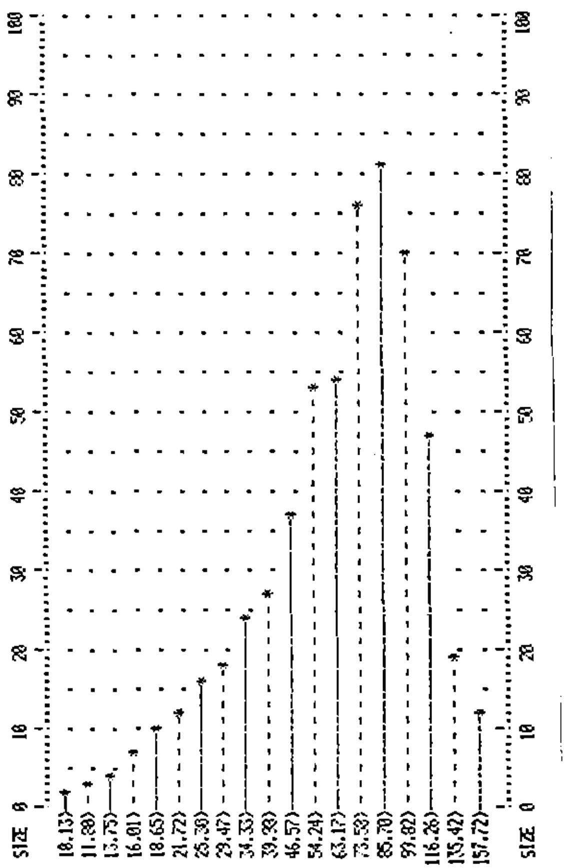


Fig. 9. Province of Zuid-Holland, Voorne-Putten, parcel No. 7, Pancrasgorsedijk, outside drain

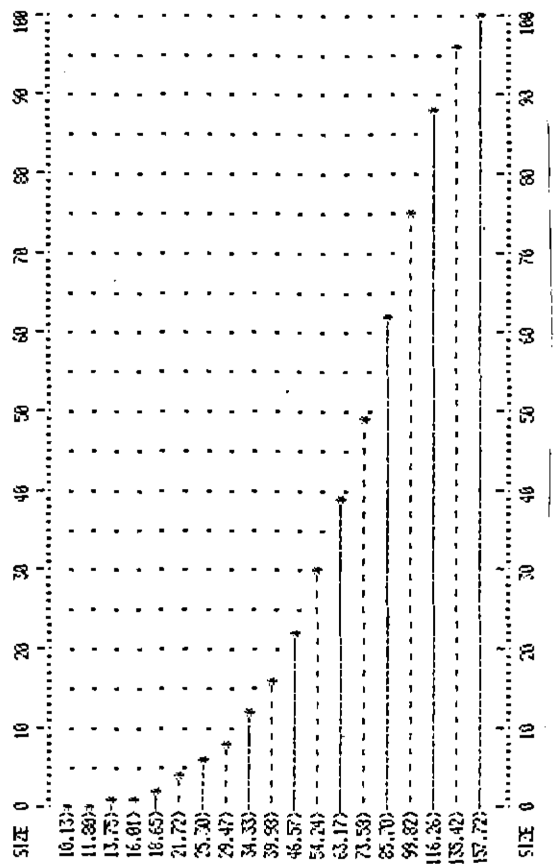


Fig. 10. Province of Zuid-Holland, Voorne-Putten, Parcel No. 7, Pancrasgorsedijk, in drain