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INFLUENCE OF THE AREA SIZE ON THE SPATIAL VARIABILITY OF HYDRAULIC CONDUCTIVITY

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Finally, I would like to dedicate this work to my parents, whose invaluable support has been decisive for it.

ABSTRACT

The present study of the spatial variability of hydraulic conductivity is made on samples collected in an area located at St. Agatha-Rode, Huldenberg, Belgium. Two previous studies had taken place in part of this area. These studies consisted of plots 14x14m and 90x90m respectively. The present study area extends to about one square kilometer. The hydraulic conductivity is measured by using a permeameter, by both the constant and the variable head methods.

A map of contour lines of the logarithm of conductivity is constructed and compared with the geological map of the region. No correlation is detected.

The statistical analysis of the data set is made. The cummulative frequencies of every study are plotted, and it is clear that the variance is growing with the area size.

The variograms for different directional orientations are computed, and the results show that the samples have isotropic property.

The total variogram of the points of the three studies is calculated and plotted, and it is approximated by a linear model. This model is used in the application of the kriging method.

The conductivity values are found to be log-normally distributed, after having applied the Kolmogorov-Smirnov goodness

of fit test.

A proportional effect study was made, in order to coincide the variogram of the present study, with the variograms of the previous studies. It has been successful only for the 14x14m plot study.

The estimation technique of kriging has been applied. The results appear to overestimate the value of the parameter under study, with respect to the observations, but the observations fall into the confidence interval of the kriging results.

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1. INTRODUCTION.

Hydraulic conductivity is one of the basic data required for any study in Hydrosciences. A good knowledge of it increases the reliability of any study concerning the regional flow in an aquifer, groundwater pollution control etc.

Detailed information about hydraulic conductivity is, in general, difficult and expensive to obtain, since it requires wells (pumping test), boreholes etc.

When limited information is available, an accurate deterministic approach of the spatial variability of the hydraulic conductivity is not usually possible. By considering it as a regionalised variable, and determining the statistical characteristics of its spatial variability, one can obtain a stochastic approach to the study, which may give a more accurate probabilistic estimate of it.

In the present study, the main aim is to determine the spatial variability of the hydraulic conductivity at an area of about one square kilometer, as well as to investigate the influence of the area size in this variability. For the second purpose, we use the data of two previous studies in the same area (Nurul, 1984 and Tan, 1986), which cover considerably smaller areas.

The data are collected in the field, and measurements are done in the laboratory. The statistical analysis of the data set is done. Variograms of the conductivity and the logarithm of conductivity data set are computed. The variogram of the logarithm data set is compared with the ones of the previous studies, through a proportional effect study.

The technique of kriging is applied to the observations of the present study, in order to estimate the values of conductivity at points of the previous studies.

2. DATA COLLECTION

2.1 Field sampling

2.1.1 Site description

The study area is located at the countryside next to the village of Sint Agatha Rode, in the province of Brabant, approximately 25 kilometers east-south east of the city of Brussels (fig. 1). The area is generally flat. River Laan is crossing it and river Dijle is flowing beside it. It is mainly countryside, but it includes some countryhouses. Many land pieces are used as grazing land for the animals. Near the centre of the area, there is a small forest with difficult access. The main soil type in the area is loam, with some clayey regions. In the next page, the layout of the field plot can be seen (fig. 2), together with the plots of two previous studies that took place inside the plot of the present study (Nurul 1984 and Tan 1986).

2.1.2 Sampling

Sampling was carried out during the months of September to November 1986. It was done at the points shown in figure 2. The basic idea was to have samples across the roads or across fences dividing land pieces so that the points would be recognisable at the map, having distances of about 90 meters

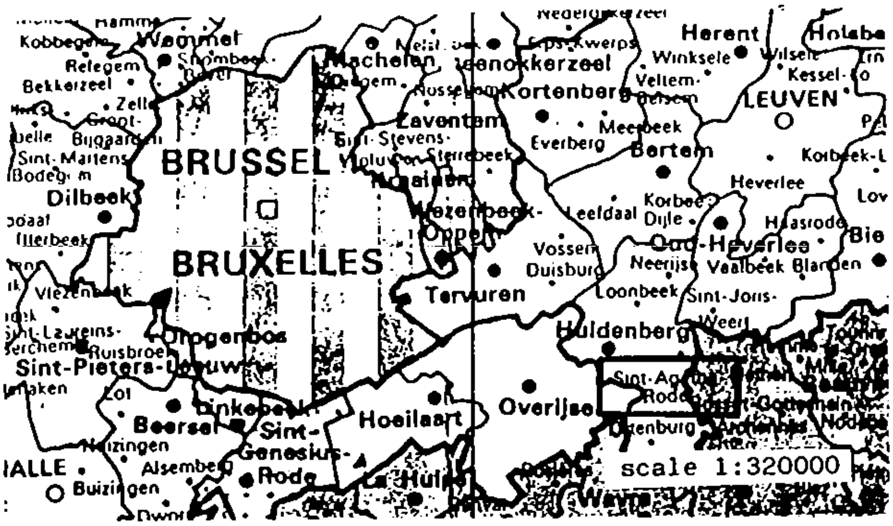


Fig. 1. Location of St. Agatha-Rode.

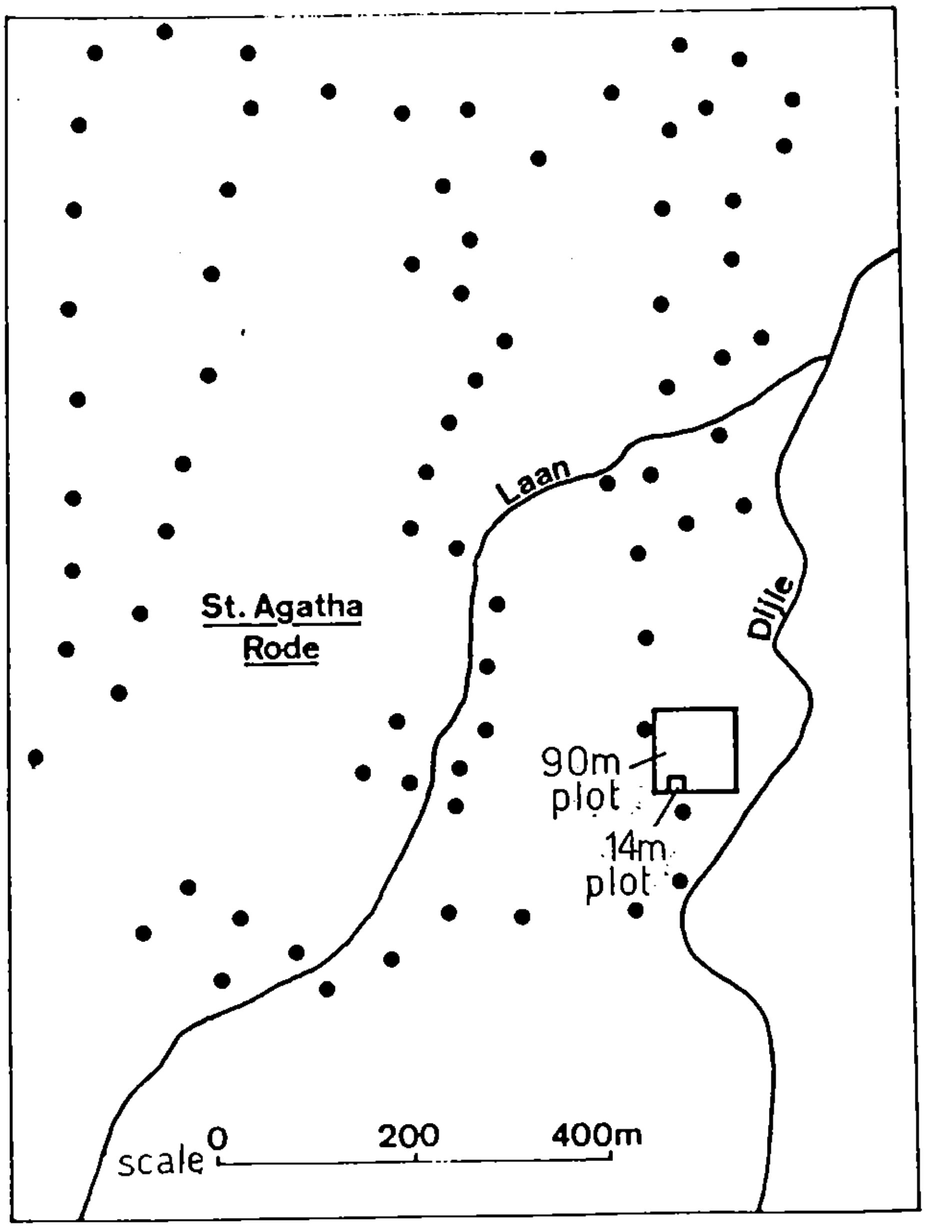


Fig. 2. The layout of the field plot.

(where that was possible).

The equipment that was used for the sampling is shown in figure 3. The sampler was connected to a changeable handle. The cutting head was fixed to the sampler by an adopter. The sample rings were of a length of 5 cm and of the same diameter. They were placed inside the cutting head with the tapering edge on the same side as the cutting edge, as shown in figure 4.

Each sample point was first cleared, by removing the top soil of about 20 cm. In some cases, local conditions demanded higher depth of about 30 cm.

The sampler was then placed vertically over the hole. It was pushed into the soil being turned clockwise at the same time. After having penetrated sufficient depth, it was pulled out, being turned clockwise again. The turning was done just for preventing the breaking of the sample's lower part, by making the retrival easier.

The sample ring, containing the soil sample, was then removed from the cutting head. After removing the soil that was there in excess of the dimensions of the sample ring by using a knife (fig. 4), samples were put into the plastic covers, and were stored in the kit cases.

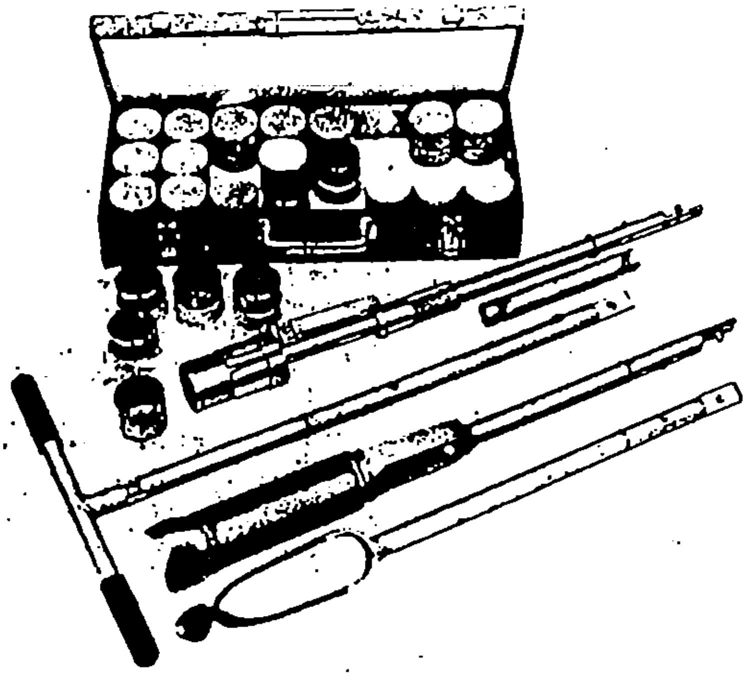
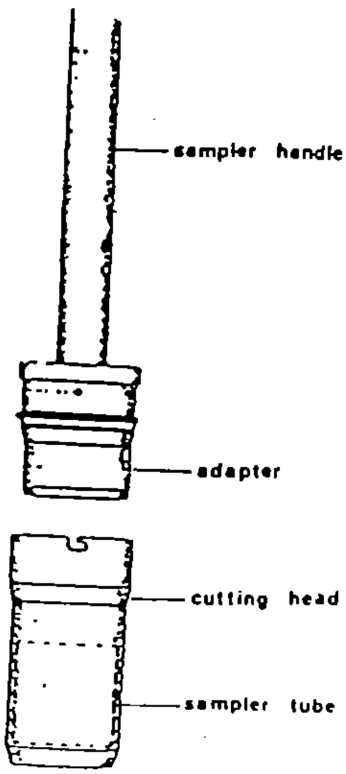


Fig. 3. Sampling equipment.



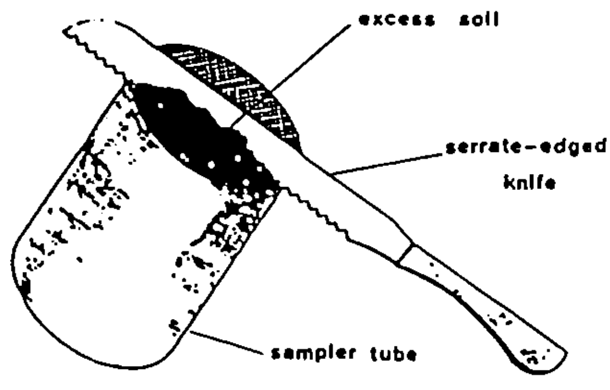


Fig. 4 Set up of sampler and trimming of sample

2.2. Laboratory Measurements.

2.2.1. Laboratory Set Up.

The values of the hydraulic conductivity of the samples were derived from measurements in the laboratory, using a permeameter.

Sample rings were put into ring holders and the ring holders were put into the permeameter. Before putting the sample ring into the ring holder, it was checked whether the surface had been sealed up during transportation from the field. A pin was used to sharp gently the surface, and reopen the sealed surface. This is important especially in cases that the soil has a clayey nature. A piece of rubber band was placed around the ring, to ensure a waterproof seal around the side, when placed into the ring holder. It was then inserted into the ring holder. Two strainer caps were fixed at the bottom side of the sample ring, and the screw was tightened. The set up of the ring holder is shown in figure 5.

Before making the measurements, we have to ensure the full saturation of the samples. Because during the time that they were collected they had the in situ moisture content, they were left inside the permeameter for at least twelve hours for this purpose.

The permeameter could not accomodate more than five samples at the same time. Thus, the measurements took place in groups of five and all of them were kept inside till the end, since, removal of a neighbouring sample holder could cause non-uniform conditions during the measurement.

The measurements were done by using both the constant and the variable head methods, depending each time on the particular sample's conductivity: In case of high conductivity, the constant head method is faster. In low conductivity cases, the constant head method is impossible to be applied, and the variable head method was used. The two different set ups are shown in figures 6 and 7.

When using the constant head method, the water level inside the collector cylinder would remain constant, by using a small siphon that would lead the excessive water into an external pipe on which we could measure water volume, and thus, the flow rate passing through the soil sample. In most cases, one measured the time interval needed for 20 cm^3 to pass through it.

During the use of the variable head method, the water level inside the collector cylinder would change with time, due to the differences in potential, and would be recorded in different times. In most cases the head change was at least 10 mm in order to have as accurate level-difference measurements as possible. The water level outside the collector cylinder, was kept the same, in order to ensure a constant flow rate.

Water temperature was also recorded at each measurement,

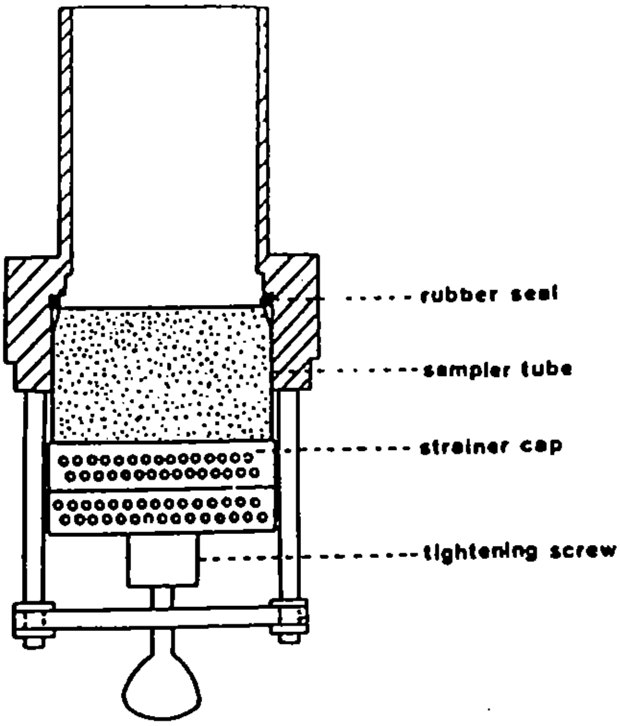


Fig. .5 Set up of the ringholder

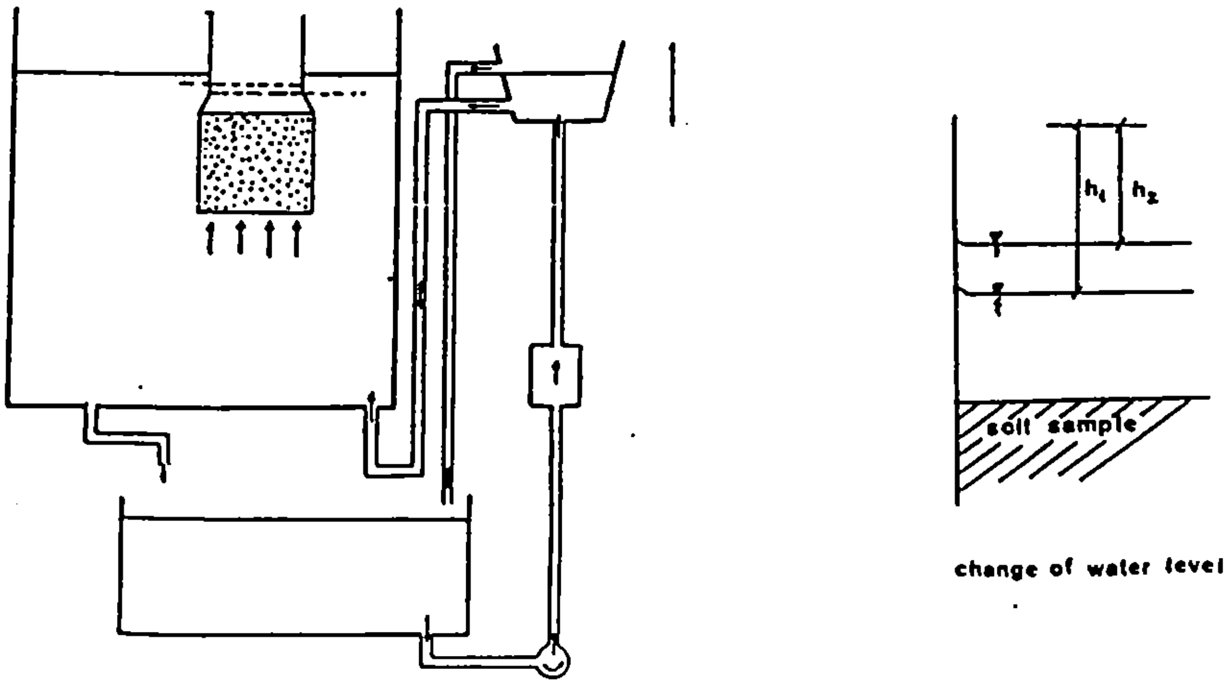


Fig. 6 Set up of permeameter for variable head method

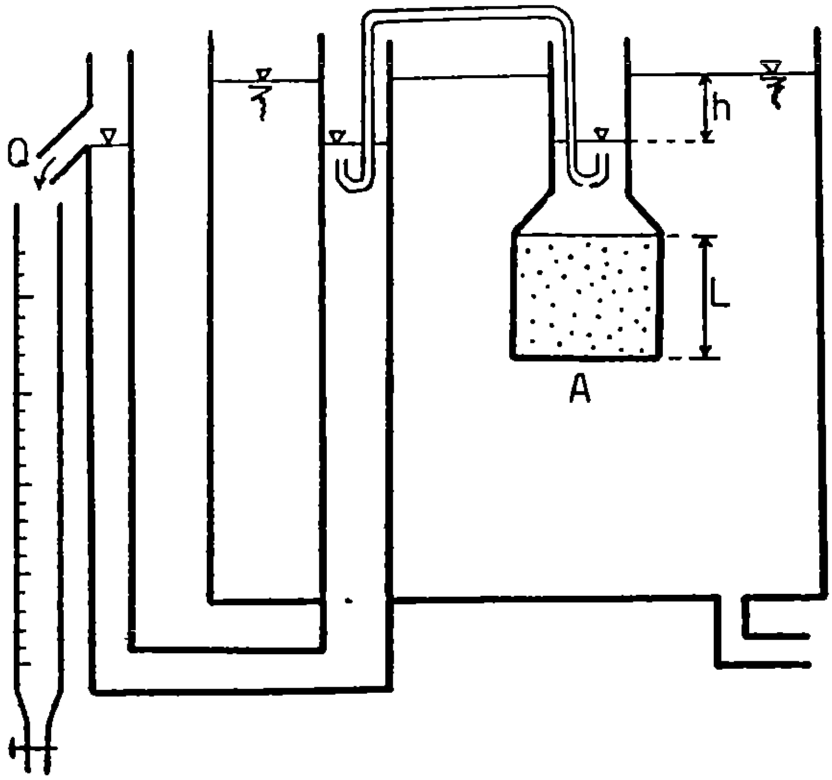


fig. 7. Setup of the permeameter for the constant head method

Table 1. Water viscosity versus temperature.

temperature T (°C)	viscosity (ctpoises)
0	1.79
5	1.52
10	1.31
15	1.14
20	1.01
25	0.89
30	0.80

in order to allow the conversion to the same temperature, since the viscosity and, thus, the conductivity of water changes with temperature.

More than two measurements were taken on every sample, to increase the degree of reliability of them. Averages were then calculated for each point. In some cases (very low values), a second measurement was not possible, since it would demand many days of observation more.

2.2.2. Computation of Conductivity values

In the case of the constant head method, for the calculation of hydraulic conductivity K, the following formula was applied:

$$K=(Q\cdot L)/(h\cdot A) \qquad (2.1)$$

where: Q is the flow rate in cm^3/sec

A is the section in cm^2

h is the level difference in cm

L is the sample length in cm

In the case of the variable head method, the conductivity is given by the formula:

$$K=(L/t)\cdot(F_2/F_1)^2\cdot \ln(h_1/h_2) \qquad (2.2)$$

where: F_2 is the diameter of the collector cylinder in cm

F_1 is the diameter of the P-F ring in cm

h_1 is the initial level difference in cm

h_2 is the final level difference in cm

L is the sample length in cm

Since the most practically used unit of hydraulic conductivity is the meter per day, we transform the formulas (2.1) and (2.2) to the ones that will give us m/day:

$$K=((V\cdot L)/(h\cdot t\cdot \pi\cdot F_1^2))\cdot 3456 \qquad (2.3)$$

$$K=(L/t)\cdot(F_2/F_1)^2\cdot \ln(h_1/h_2)\cdot 864 \qquad (2.4)$$

In the formula (2.3), the flow rate Q is replaced by the observed quantities volume V (in cm^3) and time interval (in sec). Also the cross section A is replaced by $\pi\cdot F_1^2/4$.

Since the normal temperature for groundwater is about 10 degrees centigrade, which is much lower than the temperature under which the measurements were taken (19-22° C), it is practical to convert all K values to this standard temperature, in order to have also a common refference point. This convertion was done by using the formula:

$$K_{10}=(n_T/n_{10})\ K_T \qquad (2.5)$$

where K_{10}, K_T and n_{10}, n_T are the values of conductivity and water viscosity at T and 10 degrees centigrade respectively. Table 1 (p. 10), gives the values of viscosity versus temperature. The program that calculated the K values, made also this convertion, by interpolating the viscosity values.

2.3. Results

2.3.1. Overview of the results

The observations are situated in table 2 for the variable head method, and 3 for the constant head method. Each line represents a measurement. Column "I" shows the sample point, and column "K" the number of the measurement taken at this point.

In the variable head method, H1 and H2 are the initial and final head differences in cm, DT is the time between the occurence of these differences in seconds, and TE is the temperature in degrees centigrade.

In the constant head method, the volume (in cm^3) that passed through the sample during a certain time (in sec) is given, as well as the head in cm and the temperature.

The results for each measurement are given in tables 4 for the variable and 5 for the constant head methods respectively. In the third column, the value of K at the certain temperature that the measurement was taken is situated, and at the fifth one, the K value converted to 10 C.

One can observe the much higher values that were measured with the constant head method. Some of them exceed a lot 100 m/day. The values measured by the variable head method, were, as was expected, much lower, reaching a minimum of .0003 m/day.

Table 6 contains all results brought together. The first

Table 2

OBSERVATIONS WITH VARIABLE HEAD METHOD

I	K	H1	H2	DT	TE
21	1	2.20	1.65	1330.	19.6
49	1	1.65	1.10	215.	19.6
33	1	1.50	0.60	70.	19.6
29	1	2.80	2.20	5312.	20.6
27	1	2.60	1.70	765.	20.9
27	2	1.70	1.20	780.	20.9
37	1	1.40	0.40	1896.	21.0
35	1	2.00	1.00	2678.	20.8
39	1	1.85	.75	73.	20.6
38	1	1.6	.40	38.	20.6
41	1	.95	.45	19.	21.7
43	1	1.26	.50	101.	21.7
45	1	1.40	0.40	160.	21.4
47	1	1.85	1.40	391.	21.9
47	2	1.40	1.00	325.	21.9
48	1	.85	.25	15.5	20.9
34	1	1.80	1.20	61.	20.6
2	1	1.48	0.80	871.	21.4
2	2	0.80	0.30	1321.	21.4
2	3	1.09	0.36	1532.	20.8
1	1	2.42	1.80	3548.	21.5
1	2	1.80	1.31	4472.	21.6
1	3	1.31	0.90	4255.	21.6
3	1	2.05	1.62	2668.	21.6
3	2	1.62	1.42	1615.	21.6
3	3	1.53	1.06	4535.	20.9
7	1	1.53	1.02	742.	20.8
7	2	1.00	0.65	690.	20.8
7	3	0.64	0.36	915.	20.8
9	1	1.43	0.80	892.	21.3
9	2	1.00	0.30	40.	21.3
11	1	2.35	1.70	601.	21.3
11	2	1.70	0.95	1004.	21.3
11	3	0.95	0.29	1100.	21.3
13	1	2.80	2.25	5325.	21.7
13	2	2.25	2.00	3832.	21.7
16	1	2.85	2.05	1110.	21.3
16	2	2.05	1.32	1620.	21.3
46	1	2.20	0.48	86940.	20.2
26	1	2.51	2.39	97080.	20.2
36	1	2.54	0.86	87122.	20.2
40	1	2.70	2.45	87260.	20.2
53	1	2.60	2.20	897.	20.7
54	1	1.32	0.23	92730.	21.0
62	1	2.70	2.11	1718.	21.5
56	1	2.18	1.64	136098.	21.1
61	1	1.80	1.00	442.	21.5
65	1	2.35	1.70	3176.	20.5
65	2	1.60	0.51	14357.	20.5
68	1	1.20	0.27	65730.	21.1
55	1	2.95	2.81	434220.	20.7
75	1	2.38	1.98	2447.	21.8
75	2	1.98	1.70	1798.	21.1
4	1	2.30	1.90	602830.	20.3
5	1	2.50	1.97	602725.	20.3
6	1	2.95	2.75	523440.	20.8
20	1	2.50	0.12	427880.	20.9
70	1	2.68	2.48	55720.	21.1
70	2	2.31	2.21	56310.	21.3
74	1	2.02	1.70	81377.	21.4
77	1	2.24	1.95	2816.	21.4
77	2	1.88	1.40	4139.	21.3
78	1	2.19	1.70	155.	21.4
78	2	1.60	0.90	344.	21.4
78	3	0.80	0.30	621.	21.4
69	1	1.21	1.16	167980.	21.2
80	1	1.26	1.04	1211.	20.3

Table 3

OBSERVATIONS WITH CONSTANT HEAD METHOD

I	K	VOL.	TIME	HEAD	TEMP. (C)
31	1	20.	101.	2.20	20.8
31	2	20.	109.	2.20	20.8
31	3	20.	109.	2.20	20.8
31	4	20.	110.	2.20	20.8
30	1	4.	828.	2.45	20.6
28	1	10.	110.	1.90	20.6
28	2	10.	114.	1.90	20.6
28	3	5.	56.	1.90	20.6
39	1	20.	54.	1.75	20.8
39	2	20.	56.	1.75	20.8
39	3	20.	54.	1.75	20.8
38	1	20.	25.	1.60	20.7
38	2	20.	25.	1.60	20.7
38	3	20.	25.	1.60	20.7
41	1	20.	30.	1.00	21.9
41	2	20.	29.5	1.00	21.9
41	3	20.	30.	1.00	21.9
41	4	20.	30.	1.00	21.9
43	1	20.	120.	1.25	21.9
43	2	20.	119.	1.25	21.9
43	3	20.	111.	1.25	21.8
43	4	20.	107.5	1.25	21.8
43	5	20.	101.	1.25	21.8
43	6	20.	102.	1.21	21.7
43	7	20.	104.	1.21	21.7
43	8	20.	105.	1.21	21.7
45	1	20.	86.	1.32	21.5
45	2	20.	87.	1.32	21.5
45	3	20.	97.	1.32	21.4
45	4	20.	98.5	1.32	21.4
45	5	20.	102.5	1.32	21.4
45	6	20.	104.	1.32	21.5
45	7	20.	108.	1.32	21.5
45	8	20.	109.	1.32	21.5
45	9	10.	54.	1.32	21.5
45	10	10.	55.	1.32	21.5
45	11	10.	54.5	1.32	21.5
45	12	10.	55.	1.32	21.5
45	13	20.	115.	1.40	21.5
45	14	20.	115.	1.40	21.5
45	15	20.	114.	1.40	21.5
45	16	20.	114.	1.40	21.5
44	1	20.	23.	0.70	21.5
44	2	20.	23.	0.70	21.5
44	3	20.	23.	0.70	21.5
44	4	20.	24.	0.70	21.5
44	5	20.	24.	0.70	21.5
44	6	20.	23.5	0.70	21.5
44	7	20.	24.	0.70	21.5
44	8	20.	24.	0.70	21.5
47	1	10.	189.	1.85	21.8
47	2	10.	291.	1.85	21.8
48	1	20.	18.	0.85	20.9
48	2	20.	18.5	0.85	20.9
48	3	20.	18.5	0.85	20.9
48	4	20.	18.0	0.85	20.9
48	5	20.	18.5	0.85	20.9
34	1	20.	64.	1.72	20.7
34	2	20.	64.	1.72	20.7
34	3	20.	65.	1.72	20.7
34	4	20.	65.	1.72	20.7
34	5	10.	45.	1.80	20.6
34	6	10.	44.5	1.80	20.6
8	1	20.	32.5	1.85	20.8
8	2	20.	32.5	1.85	20.8
8	3	20.	32.5	1.85	20.8
8	4	20.	32.5	1.85	20.8
10	1	20.	24.0	1.65	20.8
10	2	20.	24.0	1.65	20.8
10	3	20.	24.5	1.65	20.8
10	4	20.	24.5	1.65	20.8
10	5	20.	25.0	1.65	20.8
10	6	20.	25.0	1.65	20.8
9	1	20.	31.5	1.80	21.3
9	2	20.	30.5	1.80	21.3
9	3	20.	31.0	1.80	21.3
9	4	20.	31.0	1.80	21.3
12	1	20.	76.0	2.12	21.7
12	2	20.	76.0	2.12	21.7
12	3	20.	76.0	2.12	21.7

OBSERVATIONS WITH CONSTANT HEAD METHOD
(CONT.)

I	K	VOL	TIME	HEAD	TEMP. (C)
14	1	20.	44.0	2.02	21.7
14	2	20.	45.0	2.02	21.7
14	3	20.	45.0	2.02	21.7
15	1	20.	22.0	1.58	21.7
15	2	20.	22.0	1.58	21.7
15	3	20.	22.0	1.58	21.7
17	1	20.	33.5	1.89	22.0
17	2	20.	34.0	1.89	22.0
17	3	20.	34.0	1.89	22.0
18	1	10.	866.0	2.55	22.0
18	2	10.	892.0	2.55	22.0
18	3	10.	883.0	2.55	21.9
19	1	20.	20.0	1.45	22.0
19	2	20.	21.5	1.45	22.0
19	3	20.	22.0	1.45	22.0
19	4	20.	21.5	1.45	22.0
22	1	20.	32.5	1.10	19.7
22	2	20.	33.5	1.10	19.7
22	3	20.	33.0	1.10	19.7
50	1	20.	15.0	0.45	20.3
50	2	20.	15.5	0.45	20.3
50	3	20.	15.5	0.45	20.3
32	1	20.	23.0	1.10	19.7
32	2	20.	23.5	1.10	19.7
32	3	20.	22.5	1.10	19.7
23	1	20.	20.0	1.40	21.9
23	2	20.	20.0	1.40	21.9
23	3	20.	20.5	1.40	21.9
42	1	20.	16.0	1.01	19.6
42	2	20.	16.0	1.01	19.6
42	3	20.	16.5	1.01	19.6
25	1	20.	19.0	1.09	19.6
25	2	20.	19.5	1.09	19.6
25	3	20.	19.5	1.09	19.6
51	1	20.	18.0	1.11	20.9
51	2	20.	18.0	1.11	20.9
51	3	20.	18.0	1.11	20.9
52	1	20.	19.0	1.22	20.8
52	2	20.	19.0	1.22	20.8
52	3	20.	19.0	1.22	20.8
58	1	20.	15.0	1.07	21.0
58	2	20.	15.0	1.07	21.0
58	3	20.	15.0	1.07	21.0
57	1	20.	26.5	1.44	21.0
57	2	20.	25.5	1.50	20.9
57	3	20.	26.0	1.51	20.9
59	1	20.	13.5	0.97	21.3
59	2	20.	13.5	0.97	21.3
59	3	20.	13.5	0.97	21.3
60	1	20.	43.0	1.48	21.3
60	2	20.	43.0	1.48	21.3
60	3	20.	35.0	1.83	21.3
63	1	20.	48.5	2.00	21.5
63	2	20.	47.0	2.00	21.5
63	3	20.	46.0	2.00	21.5
61	1	20.	487.0	1.80	21.4
64	1	20.	99.0	2.12	20.5
64	2	20.	99.5	2.12	20.5
64	3	20.	99.5	2.12	20.5
67	1	20.	24.0	1.35	20.4
67	2	20.	24.0	1.35	20.4
67	3	20.	24.0	1.35	20.4
66	1	20.	13.0	0.70	20.5
66	2	20.	13.5	0.70	20.5
66	3	20.	13.0	0.70	20.5
71	1	20.	15.5	1.00	20.5
71	2	20.	16.0	1.00	20.5
71	3	20.	15.5	1.00	20.5
72	1	20.	23.5	1.42	20.8
72	2	20.	23.5	1.42	20.8
72	3	20.	23.5	1.42	20.8
73	1	20.	13.0	0.70	20.8
73	2	20.	13.0	0.70	20.8
73	3	20.	13.0	0.70	21.5
76	1	20.	13.5	0.86	21.5
76	2	20.	13.5	0.86	21.5
76	3	20.	13.5	0.86	21.4
79	1	20.	17.5	1.08	21.4
79	2	20.	17.5	1.08	21.4
79	3	20.	17.5	1.08	21.3
24	1	20.	15.5	1.04	21.3
24	2	20.	15.5	1.04	21.3
24	3	20.	15.5	1.04	

Table 4

CONDUCTIVITY IN RESPECTIVE TEMPERATURE (VARIABLE HEAD METHOD)

I	K	COND. (M/DAY)	TEMP. (C)	COND. IN 10(C)
21	1	.75689	19.6	.58956
49	1	6.59909	19.6	5.14023
33	1	45.80406	19.6	35.67822
29	1	.15886	20.6	.12074
27	1	1.94347	20.9	1.46635
27	2	1.56256	20.9	1.17896
37	1	2.31206	21.0	1.74022
35	1	.90570	20.8	.68501
39	1	43.27828	20.6	32.89150
38	1	127.65582	20.6	97.01842
41	1	137.61330	21.7	101.81283
43	1	32.02145	21.7	23.69099
45	1	27.39793	21.4	20.42087
47	1	2.49431	21.9	1.83627
47	2	3.62272	21.9	2.66698
48	1	276.27323	20.9	208.44920
34	1	23.25907	20.6	17.67690
2	1	2.47148	21.4	1.84210
2	2	2.59812	21.4	1.93649
2	3	2.53036	20.8	1.91380
1	1	.29191	21.5	.21704
1	2	.24864	21.6	.18441
1	3	.30871	21.6	.22896
3	1	.30876	21.6	.22900
3	2	.28550	21.6	.21175
3	3	.28318	20.9	.21366
7	1	1.91213	20.8	1.44622
7	2	2.18463	20.8	1.65232
7	3	2.20034	20.8	1.66420
9	1	2.27847	21.3	1.70242
9	2	105.32354	21.3	78.69518
11	1	1.88518	21.3	1.40856
11	2	2.02815	21.3	1.51538
11	3	3.77462	21.3	2.82031
13	1	.14371	21.7	.10632
13	2	.10755	21.7	.07957
16	1	1.03866	21.3	.77606
16	2	.95085	21.3	.71045
46	1	.06128	20.2	.04702
26	1	.00177	20.2	.00135
36	1	.04350	20.2	.03338
40	1	.00390	20.2	.00299
53	1	.65168	20.7	.49408
54	1	.06594	21.0	.04963
62	1	.50220	21.5	.37339
56	1	.00732	21.1	.00549
61	1	4.65336	21.5	3.45982
65	1	.35674	20.5	.27177
65	2	.27867	20.5	.21230
68	1	.07941	21.1	.05962
55	1	.00039	20.7	.00030
75	1	.26312	21.8	.19419
75	2	.29673	21.1	.22280
4	1	.00111	20.3	.00085
5	1	.00138	20.3	.00106
6	1	.00047	20.8	.00035
20	1	.02483	20.9	.01874
70	1	.00487	21.1	.00366
70	2	.00275	21.3	.00205
74	1	.00742	21.4	.00553
77	1	.17228	21.4	.12841
77	2	.24923	21.3	.18622
78	1	5.71777	21.4	4.26170
78	2	5.85266	21.4	4.36224
78	3	5.52676	21.4	4.11933
69	1	.00088	21.2	.00066
80	1	.55447	20.3	.42445

Table 5

CONDUCTIVITY IN RESPECTIVE TEMPERATURE (CONSTANT HEAD METHOD)

I	K	COND. (M/DAY)	TEMP. (C)	COND. IN 10(C)
31	1	19.80340	20.8	14.97802
31	2	18.34994	20.8	13.87872
31	3	18.34994	20.8	13.87872
31	4	18.18312	20.8	13.75255
30	1	.43383	20.6	.32971
28	1	10.52707	20.6	8.00057
28	2	10.15770	20.6	7.71985
28	3	10.33909	20.6	7.85771
39	1	46.56419	20.8	35.21817
39	2	44.90118	20.8	33.96038
39	3	46.56419	20.8	35.21817
38	1	110.00790	20.7	83.40446
38	2	110.00790	20.7	83.40446
38	3	110.00790	20.7	83.40446
41	1	146.67720	21.9	107.98129
41	2	149.16325	21.9	109.81148
41	3	146.67720	21.9	107.98129
41	4	146.67720	21.9	107.98129
43	1	29.33544	21.9	21.59626
43	2	29.58196	21.9	21.77774
43	3	31.71399	21.8	23.40541
43	4	32.74654	21.8	24.16744
43	5	34.85399	21.8	25.72277
43	6	35.65318	21.7	26.37791
43	7	34.96755	21.7	25.87064
43	8	34.63452	21.7	25.62426
45	1	38.76247	21.5	28.82034
45	2	38.31693	21.5	28.48907
45	3	34.36673	21.4	25.61502
45	4	33.84338	21.4	25.22494
45	5	32.52266	21.4	24.24055
45	6	32.05358	21.5	23.83221
45	7	30.86641	21.5	22.94953
45	8	30.58324	21.5	22.73899
45	9	30.86641	21.5	22.94953
45	10	30.30521	21.5	22.53227
45	11	30.58324	21.5	22.73899
45	12	30.30521	21.5	22.53227
45	13	27.33115	21.5	20.32103
45	14	27.33115	21.5	20.32103
45	15	27.57090	21.5	20.49928
45	16	27.57090	21.5	20.49928
44	1	273.31154	21.5	203.21026
44	2	273.31154	21.5	203.21026
44	3	273.31154	21.5	203.21026
44	4	261.92356	21.5	194.74317
44	5	261.92356	21.5	194.74317
44	6	267.49641	21.5	198.88664
44	7	261.92356	21.5	194.74317
44	8	261.92356	21.5	194.74317
47	1	6.29246	21.8	4.64393
47	2	4.08685	21.8	3.01616
48	1	287.60234	20.9	216.99707
48	2	279.82931	20.9	211.13228
48	3	279.82931	20.9	211.13228
48	4	287.60234	20.9	216.99707
48	5	279.82931	20.9	211.13228
34	1	39.97380	20.7	30.30685
34	2	39.97380	20.7	30.30685
34	3	39.35882	20.7	29.84059
34	4	39.35882	20.7	29.84059
34	5	27.16244	20.6	20.64346
34	6	27.46764	20.6	20.87541
8	1	73.18613	20.8	55.35329
8	2	73.18613	20.8	55.35329
8	3	73.18613	20.8	55.35329
8	4	73.18613	20.8	55.35329
10	1	111.11909	20.8	84.04335
10	2	111.11909	20.8	84.04335
10	3	108.85135	20.8	82.32818
10	4	108.85135	20.8	82.32818
10	5	106.67432	20.8	80.68162
10	6	106.67432	20.8	80.68162
9	1	77.60698	21.3	57.98604
9	2	80.15147	21.3	59.88722
9	3	78.85871	21.3	58.92130
9	4	78.85871	21.3	58.92130
12	1	27.31080	21.7	20.20582
12	2	27.31080	21.7	20.20582
12	3	27.31080	21.7	20.20582

CONDUCTIVITY IN RESPECTIVE TEMPERATURE (CONSTANT HEAD METHOD)
(CONT.)

I	K	COND. (M/DAY)	TEMP. (C)	COND. IN 10(C)
14	1	49.50850	21.7	36.62873
14	2	48.40832	21.7	35.81476
14	3	48.40832	21.7	35.81476
15	1	126.59137	21.7	93.65828
15	2	126.59137	21.7	93.65828
15	3	126.59137	21.7	93.65828
17	1	69.49879	22.0	51.03652
17	2	68.47675	22.0	50.28598
17	3	68.47675	22.0	50.28598
18	1	.99631	22.0	.73164
18	2	.96727	22.0	.71032
18	3	.97713	21.9	.71935
19	1	151.73503	22.0	111.42679
19	2	141.14886	22.0	103.65283
19	3	137.94094	22.0	101.29708
19	4	141.14886	22.0	103.65283
22	1	123.08576	19.7	95.63106
22	2	119.41156	19.7	92.77640
22	3	121.22082	19.7	94.18210
50	1	651.89865	20.3	499.02593
50	2	630.86966	20.3	482.92832
50	3	630.86966	20.3	482.92832
32	1	173.92553	19.7	135.13084
32	2	170.22499	19.7	132.25572
32	3	177.79054	19.7	138.13375
23	1	157.15414	21.9	115.69424
23	2	157.15414	21.9	115.69424
23	3	153.32111	21.9	112.87243
42	1	272.29677	19.6	212.10048
42	2	272.29677	19.6	212.10048
42	3	264.04536	19.6	205.67319
25	1	212.47300	19.6	165.50187
25	2	207.02498	19.6	161.25823
25	3	207.02498	19.6	161.25823
51	1	220.23603	20.9	166.16892
51	2	220.23603	20.9	166.16892
51	3	220.23603	20.9	166.16892
52	1	189.83244	20.8	143.57708
52	2	189.83244	20.8	143.57708
52	3	189.83244	20.8	143.57708
58	1	274.16298	21.0	206.35473
58	2	274.16298	21.0	206.35473
58	3	274.16298	21.0	206.35473
57	1	115.31226	21.0	86.79228
57	2	115.04094	20.9	86.79883
57	3	112.08140	20.9	84.56585
59	1	336.03023	21.3	251.07358
59	2	336.03023	21.3	251.07358
59	3	336.03023	21.3	251.07358
60	1	69.14387	21.3	51.66261
60	2	69.14387	21.3	51.66261
60	3	68.70126	21.3	51.33191
63	1	45.36408	21.5	33.72871
63	2	46.81187	21.5	34.80516
63	3	47.82952	21.5	35.56180
61	1	5.01975	21.4	3.74144
64	1	20.96587	20.5	15.97247
64	2	20.86051	20.5	15.89220
64	3	20.86051	20.5	15.89220
67	1	135.81222	20.4	103.71492
67	2	135.81222	20.4	103.71492
67	3	135.81222	20.4	103.71492
66	1	483.55119	20.5	368.38480
66	2	465.64189	20.5	354.74092
66	3	483.55119	20.5	368.38480
71	1	283.89135	20.5	216.27753
71	2	275.01974	20.5	209.51886
71	3	283.89135	20.5	216.27753
72	1	131.86443	20.8	99.73380
72	2	131.86443	20.8	99.73380
72	3	131.86443	20.8	99.73380
73	1	483.55119	20.8	365.72712
73	2	483.55119	20.8	365.72712
73	3	483.55119	20.8	365.72712
76	1	379.01084	21.5	281.79890
76	2	379.01084	21.5	281.79890
76	3	379.01084	21.5	281.79890
79	1	232.82095	21.4	173.53158
79	2	232.82095	21.4	173.53158
79	3	232.82095	21.4	173.53158
24	1	272.97245	21.3	203.95835
24	2	272.97245	21.3	203.95835
24	3	272.97245	21.3	203.95835

column gives the point number and columns 2 and 3, the values observed with the variable and the constant head method respectively. In the cases where both methods were used for the same sample, one can observe the difference of the results, which are, in general, considerable.

Table 7 contains the coordinates of the points of measurement. Columns 1, 2 and 3, contain the x and y coordinates and the K value in m/day respectively.

2.4. Comparison with the Geological map

A geological map of 1:20000 of the region was used to see whether there is an apparent relation between the geology and the measured K values. The map was first brought in a much bigger scale and is situated in figure 8.

As can be seen in the map, most of the samples were taken inside the area which was coded as "Ap" and represents valley soils of silty nature with no structured soil profile, which means that the depth of sampling has no effect.

A small number of samples has been taken in "Aa" and "La" areas, which represent silt and silt-loam soils respectively. The character "a", means layering in the soil profile, that is, the depth has an effect.

Finally 3 samples were taken in urbanised areas.

Another map, containing the contour lines of logK=0 or

Table 6

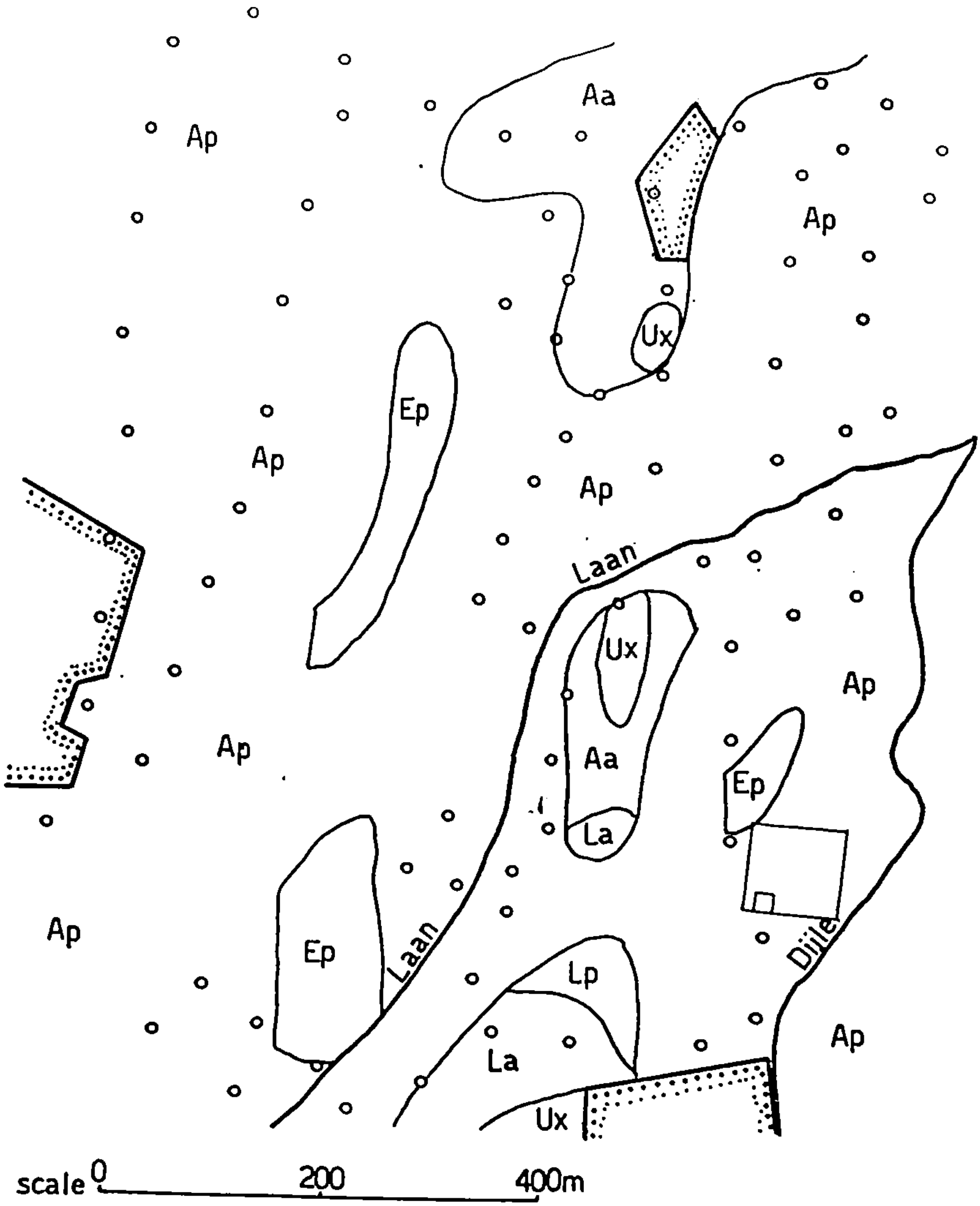
CONDUCTIVITY VALUES WITH BOTH METHODS

1	.21014	******
2	1.89746	******
3	.21814	******
4	.00085	******
5	.00106	******
6	.00035	******
7	1.58758	******
8	******	55.35329
9	40.19880	58.92897
10	******	82.35105
11	1.91475	******
12	******	20.20582
13	.09295	******
14	******	36.08608
15	******	93.65828
16	.74326	******
17	******	50.53616
18	******	.72044
19	******	105.00738
20	.01874	******
21	.58956	******
22	******	94.19652
23	******	114.75364
24	******	203.95835
25	******	162.67278
26	.00135	******
27	1.32266	******
28	******	7.85938
29	.12074	******
30	******	.32971
31	******	14.12200
32	******	135.17344
33	35.67822	******
34	17.67690	26.96896
35	.68501	******
36	.03338	******
37	1.74022	******
38	97.01842	83.40446
39	32.89150	34.79891
40	.00299	******
41	101.81283	108.43884
42	******	209.95805
43	23.69099	24.31780
44	******	198.43626
45	20.42087	23.39402
46	.04702	******
47	2.25163	3.83005
48	208.44920	213.47820
49	5.14023	******
50	******	488.29419
51	******	166.16892
52	******	143.57708
53	.49408	******
54	.04963	******
55	.00030	******
56	.00549	******
57	******	86.05232
58	******	206.35473
59	******	251.07358
60	******	51.55238
61	3.45982	3.74144
62	.37339	******
63	******	34.69856
64	******	15.91896
65	.24204	******
66	******	363.83684
67	******	103.71492
68	.05962	******
69	.00066	******
70	.00286	******
71	******	214.02464
72	******	99.73380
73	******	365.72712
74	.00553	******
75	.20850	******
76	******	281.79890
77	.15732	******
78	4.24776	******
79	******	173.53158
80	.42445	******

Table 7

COORDINATES AND CONDUCTIVITY OF THE SAMPLES

X	Y	K
788.0	1087.0	.21014
777.7	1039.4	1.89746
696.3	1079.1	.21814
487.1	837.0	.00085
456.8	797.6	.00106
429.8	754.3	.00035
405.1	699.4	1.58758
387.4	643.5	55.35329
435.3	621.1	52.68558
476.6	563.1	82.35105
466.1	502.3	1.91475
467.9	439.7	20.20582
437.9	399.8	.09295
436.3	362.0	36.08608
408.1	298.9	93.65828
387.2	382.9	.74326
340.3	394.7	50.53616
375.0	445.4	.72044
518.9	648.1	105.00738
43.2	1049.7	.01874
57.6	1128.2	.58956
38.0	966.5	94.19652
34.3	861.6	114.75364
48.1	770.9	203.95835
40.4	671.1	162.67278
39.1	599.4	.00135
34.6	518.0	1.32266
7.0	409.7	7.85938
671.5	354.3	.12074
635.7	439.7	.32971
630.8	530.6	14.12200
625.5	617.2	135.17344
593.7	692.1	35.67822
544.2	773.2	25.64152
543.6	859.7	.68501
541.7	938.3	.03338
522.0	1025.3	1.74022
448.9	1073.4	86.80795
375.6	1069.4	34.32206
301.7	1093.6	.00299
218.5	1128.8	107.11364
131.9	1164.7	209.95805
621.9	253.7	24.24815
501.8	248.1	198.43626
428.8	252.3	23.21913
368.8	201.8	.04702
302.0	173.9	3.04084
199.4	181.3	212.64003
120.3	232.2	5.14023
222.0	1076.3	488.29419
197.3	991.7	166.16892
182.1	902.1	143.57708
177.4	799.6	.49408
159.0	709.1	.04963
136.8	639.9	.00030
112.3	556.8	.00549
89.2	473.9	86.05232
422.5	998.1	206.35473
389.5	915.3	251.07358
447.1	941.2	51.55238
441.3	884.8	3.60063
597.9	1094.1	.37339
669.9	1140.7	34.69856
733.7	1126.6	15.91896
271.4	210.1	.24204
214.3	244.4	363.83684
162.4	276.6	103.71492
640.1	699.6	.05962
710.7	743.2	.00066
735.3	669.5	.00286
679.0	649.5	214.02464
670.3	281.6	99.73380
659.2	1051.6	365.72712
653.2	970.7	.00553
647.0	877.8	.20850
724.2	923.3	281.79890
726.3	982.1	.15732
755.3	839.8	4.24776
715.6	819.7	173.53158
656.3	789.0	.42445



LEGEND

Ap – silt, valley soils
Aa – silt, plateau soils
Ep – clay-loam, valley soils
Ux – clay, no distinct structure
Lp – silt-loam, valley soils
La – silt-loam, plateau soils
urbanised area

Fig. 8. Geological map of the region under study.

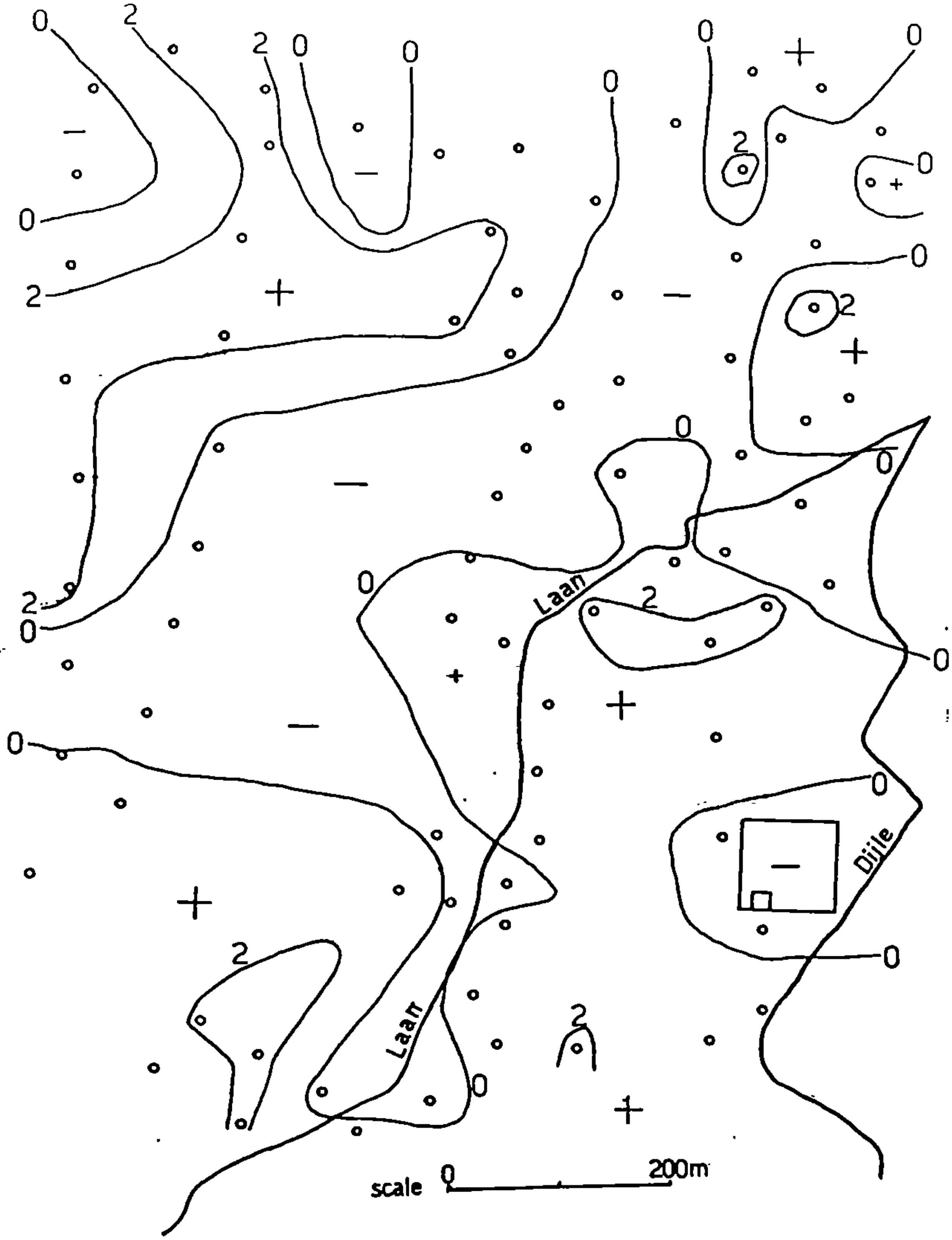


Fig. 9. Contour lines of logK in the region.

K=1m/day, as well as of K=100m/day, derived from the data, is situated in figure 9. Regions of positive and negative logK values are shown there.

The plots of the two previous studies, are located in a negative area, a fact which later will help in explaining the lower values obtained in these studies.

The general conclusion is that the area is mainly uniform and can be classified as silt to silt-loam soils with little structural development. There appears to be no correspondance between soil types and measured K values.