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EVALUATION OF METHODS FOR CALCULATING SOIL THERMAL CONDUCTIVITY--ETC(U)
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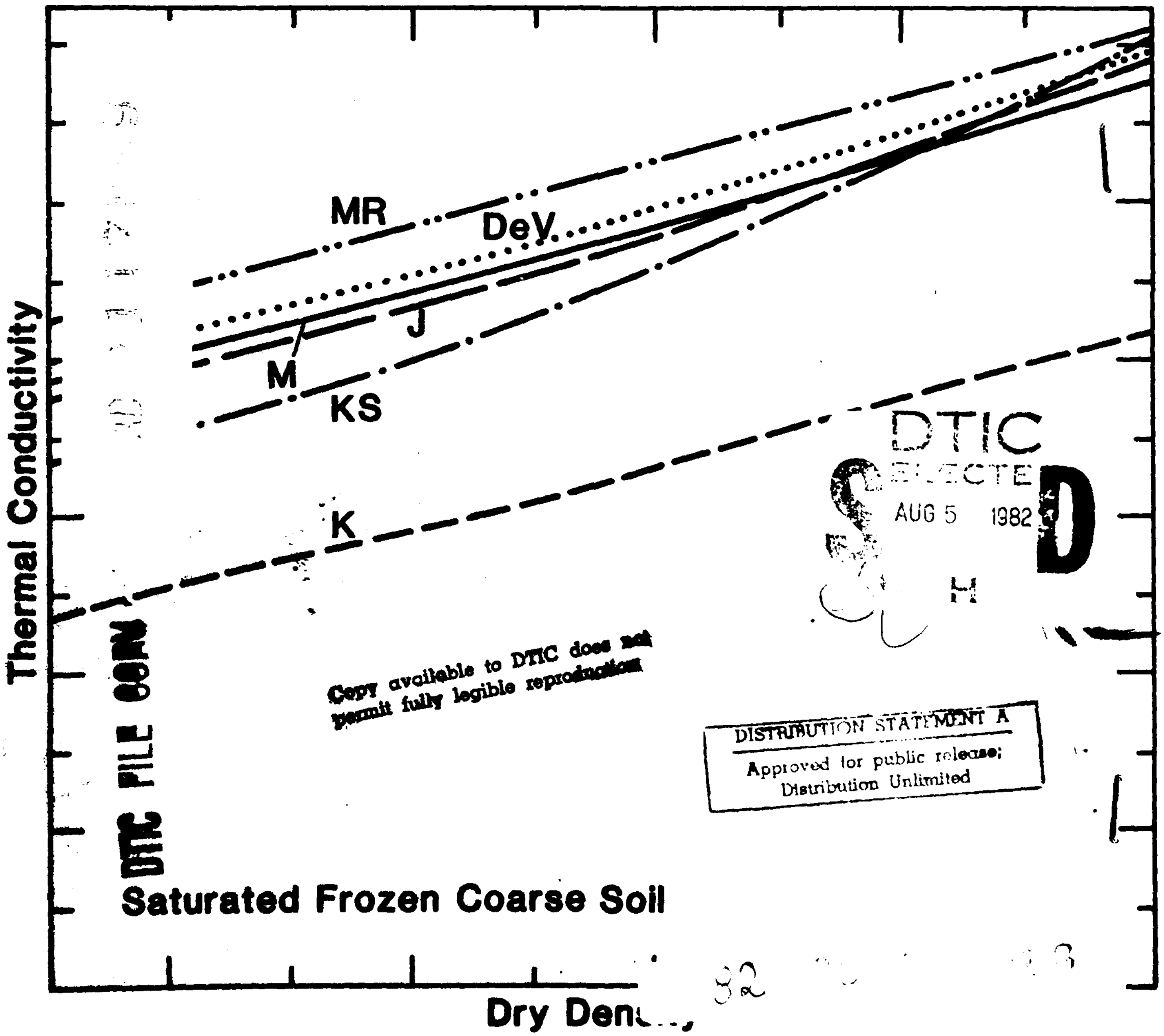
CRREL REPORT 82-8

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Evaluation of methods for calculating soil thermal conductivity



For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Cover: Comparison of thermal conductivity values calculated by various methods (MR—modified resistor, DeV—De Vries, M—Mickley, J—Johansen, KS—Kunii–Smith, K—Kersten).

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CRREL Report 82-8

March 1982

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Omar Farouki

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A detailed analysis of methods for calculating the thermal conductivity of soils is presented, and trends in the predictions of these methods are compared. The influence of changes in the moisture content on the calculated thermal conductivity of a soil (at constant dry density) is shown, as is the sensitivity of this calculated value to changes in dry density or in the soil solids' thermal conductivity.

The methods are evaluated to determine the extent of agreement of their predictions with measured values obtained on soils of known composition and properties. The deviations of the predicted values are determined for soils that are unfrozen or frozen, coarse or fine, unsaturated, saturated or dry. The applicability of each of the methods under various conditions is determined and recommendations are made as to the best method for each condition.

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PREFACE

This report was prepared by Dr. Omar T. Farouki, Senior Lecturer, Department of Civil Engineering, The Queen's University of Belfast, Northern Ireland, United Kingdom. It was started at the U.S. Army Cold Regions Research and Engineering Laboratory while the author was on sabbatical leave from the University.

The work was conducted under Invitational Travel Orders No. 10 (1 February 1977) and No. 298 (12 June 1980) issued by the U.S. Army Research and Standardization Group (Europe). Funding was provided by the CRREL Technical Information Analysis Center (TIAC).

The author is deeply indebted to the late Dr. Hans F. Winterkorn for his encouragement in this project and for general guidance.

The author expresses his gratitude to The Queen's University of Belfast for the sabbatical leave in 1977, during which this project was begun at CRREL. Acknowledgement is due to Dr. Allan A. Wells, then Head of the Department of Civil Engineering, and also to Prof. A.E. Long, present Head, for his continued support. Thanks are given to James Clarke and Albert Smith of the University for developing the computer programs. Thanks are extended to William F. Quinn, Chief, Geotechnical Research Branch, CRREL, for his continuous support and encouragement. Appreciation is also expressed to Albert F. Wuori, Chief, Experimental Engineering Division, CRREL, for initiating the project and to Gregor E. Fellers, Computer Specialist, CRREL, for the pilot computer program.

This report was technically reviewed by Prof. Frederick J. Sanger and Dr. George K. Swinzow. The author thanks them for their efforts and for their comments and suggestions.

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NOMENCLATURE

k — soil thermal conductivity
k_a — thermal conductivity of air
k_f — thermal conductivity of fluid in soil
k_i — thermal conductivity of ice
k_q — thermal conductivity of quartz
k_o — thermal conductivity of soil solids other than quartz
k_s — thermal conductivity of soil solids
k_w — thermal conductivity of water
$k_{\parallel}$ — thermal conductivity of quartz parallel to the c-axis
$k_{\perp}$ — thermal conductivity of quartz perpendicular to the c-axis
n — soil porosity (fractional)
n_c — volume of series fluid in unit soil volume
p — clay content as a fraction of soil solids
S_r — degree of saturation of soil (fractional)
s_w — sensitivity of thermal conductivity of a soil to variations in moisture content at constant dry density
s_γ — sensitivity of thermal conductivity of a soil to variations in dry density at constant moisture content
t — temperature
T — absolute temperature
UWC — unfrozen water content as a fraction by volume of total soil volume
w — moisture content of soil
x_a — volume fraction of air in unit soil volume
x_f — volume fraction of fluid in unit soil volume
x_s — volume fraction of solids in unit soil volume
x_w — volume fraction of water in unit soil volume
α' — thermal structure value (Smith method)
γ_d — soil dry density
$\Delta k/\Delta k_s$ — sensitivity of thermal conductivity of a soil to variation in soil solids thermal conductivity at constant degree of saturation

EVALUATION OF METHODS FOR CALCULATING SOIL THERMAL CONDUCTIVITY

Omar T. Farouki

INTRODUCTION

The U.S. Army Cold Regions Research and Engineering Laboratory monograph entitled *Thermal Properties of Soils* (Farouki 1981) describes the various methods that are available for calculating the thermal conductivity of soils. In chronological order, these are the methods of Smith (1942), Kersten (1949), Mickley (1951), Gemant (1952), De Vries (1952 and 1963), Van Rooyen and Winterkorn (1959), Kunii and Smith (1960), the modified resistor equation (Woodside and Messmer 1961), McGaw (1969) and Johansen (1975).

This report shows in detail the predicted thermal conductivity values given by these methods for appropriate types and conditions of soils. This is done for unfrozen and for frozen soils having a range of moisture contents and dry densities. For each method and each soil condition, the sensitivity of the calculated thermal conductivity value to variations in moisture content and dry density is determined.

These methods are evaluated by comparing their predictions with experimental data from soils of known composition. A computer program is used to calculate the deviations of the predicted values from the experimental values for soils with certain properties. The conditions of applicability and the extent of validity of each of these methods are thus determined. From this follows a recommendation of the method or methods to apply to soils of different types, which may be frozen or unfrozen, range from dry to saturated and have varied dry densities.

Because of the extreme complexity of soils and of their behavior, a semi-empirical approach to calculation of their thermal conductivity is essential and is followed here. Hence the methods mentioned, being either theoretically based with empirical modifications or totally empirical, are tested against experimental data to determine the conditions of their validity in practice and to enhance their trustworthiness under these conditions.

ANALYSIS OF METHODS FOR CALCULATING THERMAL CONDUCTIVITY

Introduction

In order to perform a detailed analysis of the thermal conductivity equations resulting from the various methods, computer programs of these equations were prepared.* The main input parameters were:

1. Specific gravity of the soil solids, taken as 2.70
2. Temperature
3. Thermal conductivity of water k_w and of ice k_i at that temperature
4. Effective thermal conductivity of the air (allowing for moisture migration in the manner suggested by De Vries 1963)
5. Thermal conductivity of the soil solids k_s
6. Moisture content w
7. Dry density γ_d.

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*The programming was done by S.A. James Clarke and Albert Smith on the ICL 1906S computer of the Queen's University of Belfast using FORTRAN language.

The last two properties were varied over a wide range so that their influence on the soil thermal conductivity could be determined.

The computer printout provided the thermal conductivity values predicted by the equations for the given input data. Calculations were made for both the unfrozen and the frozen conditions. In the latter case the unfrozen water content was assumed to be zero for this sensitivity analysis. k_s was set at 8.0 W/m K for coarse soils and at 2.0 W/m K for fine soils.

The moisture content w was varied at constant dry density γ_d to determine the sensitivity of the thermal conductivity to variations in w. In another series of calculations, γ_d was varied at constant w to evaluate the influence of γ_d. The sensitivity of the thermal conductivity to k_s was also determined by varying k_s from 2.0 to 8.0 W/m K, keeping both the degree of saturation S_r and the dry density constant.

For the unsaturated frozen condition, only the methods of Kersten, Mickley, De Vries and Johansen could be applied. For the unsaturated unfrozen condition, these were applied together with the Gemant, Van Rooyen and McGaw methods. In the saturated state, frozen or unfrozen, the method of Kunii-Smith and the modified resistor equation could additionally be applied. For dry soils, the methods of Smith, Mickley, De Vries and adjusted De Vries, Van Rooyen, Kunii-Smith, modified resistor, McGaw and Johansen were applicable.

The results of the sensitivity analysis are given and discussed in the next three sections.

Influence of moisture content on thermal conductivity

Thermal conductivity values were calculated at a constant γ_d for moisture contents varying from the dry to the near saturated condition in increments of 5%. This procedure was repeated for different dry densities in increments of 0.1 g/cm³ from a γ_d of 1.1 g/cm³ to one of 2.1 g/cm³. The results for unfrozen coarse soil (k_s = 8.0 W/m K) at 4°C are shown in Figure 1 while those for unfrozen fine soil (k_s = 2.0 W/m K) are given in Figure 2. Seven methods are applicable to unfrozen soil: Kersten, Mickley, Gemant, De Vries, Van Rooyen, McGaw and Johansen*, except that Kersten and Gemant do not apply for the dry or nearly dry condition. For frozen coarse or fine soil four methods are applicable: Kersten, Mickley, De Vries and Johansen. The resulting curves are shown in Figures 3 and 4.

The sensitivity of the thermal conductivity to w(%) at constant γ_d is given in Tables 1–4 for four representative values of γ_d. These tables give the absolute sensitivity expressed as the absolute increase in the thermal conductivity per 1% increase in w (designated by s_w). By expressing this value as a percentage of the thermal conductivity (taken in the middle of the associated moisture content range) a value for the "relative sensitivity" can be obtained. Except for Mickley and McGaw, s_w decreases as the moisture content increases.

Figures 5–8 compare the absolute and relative sensitivities for the seven methods at a common γ_d of 1.4 g/cm³. With one or two exceptions the pattern of relative sensitivities is similar to that of absolute sensitivities. For unfrozen coarse soil (Fig. 5) Johansen, De Vries and Van Rooyen show comparatively high sensitivities from the dry condition to a w of around 7.5%. Beyond this w, all the sensitivities decrease in a roughly similar manner, except for those from Mickley and McGaw which are small and increase slightly.

In the case of unfrozen fine soil (Fig. 6) all the methods, except Mickley and McGaw, give roughly similar trends. The sensitivities generally decrease appreciably as w increases above 7.5%. It may be noted, however, that Johansen gives a maximum s_w at about w = 7.5%, while Van Rooyen gives a maximum at about w = 15%. As for coarse soil Mickley and McGaw give the lowest sensitivities; these do not vary much with the moisture content.

A comparison of the sensitivities for unfrozen coarse soil to the corresponding values for unfrozen fine soil shows that all the methods give an s_w for coarse soil that is higher than for fine soil, with the exception of Kersten which gives a slightly lower value for coarse soil (compare Tables 1 and 2 at a dry density of 1.4 g/cm³).

For frozen soils both Kersten and Johansen give linear relations between the thermal conductivity and w at constant γ_d, implying a constant s_w for each method. In fact, these two methods give nearly the same s_w for frozen fine soil, Johansen giving slightly larger values at the higher dry densities. For frozen coarse soil, however, Johansen gives an appreciably larger s_w, being about 50% more than that from Kersten at a γ_d of 1.4 g/cm³. De Vries shows the highest s_w at low w but this decreases to become the lowest at high w. Mickley, on the other hand, shows a reverse trend (see Fig. 7 and 8).

It may also be noted that the s_w values for frozen fine soil are less than those for frozen coarse soil. The percentage sensitivites, however, do not differ much, except at low w values where Johansen and De Vries show higher values for frozen coarse soil.

Tables 1–4 show that for Kersten, Johansen, De Vries and Mickley, the effect of increasing γ_d is to increase the value of s_w when moisture content is similar.

Kersten, Mickley, De Vries and Johansen are applicable to both the unfrozen and frozen conditions.

*Mention of the method name in the text implies application of the associated equations.

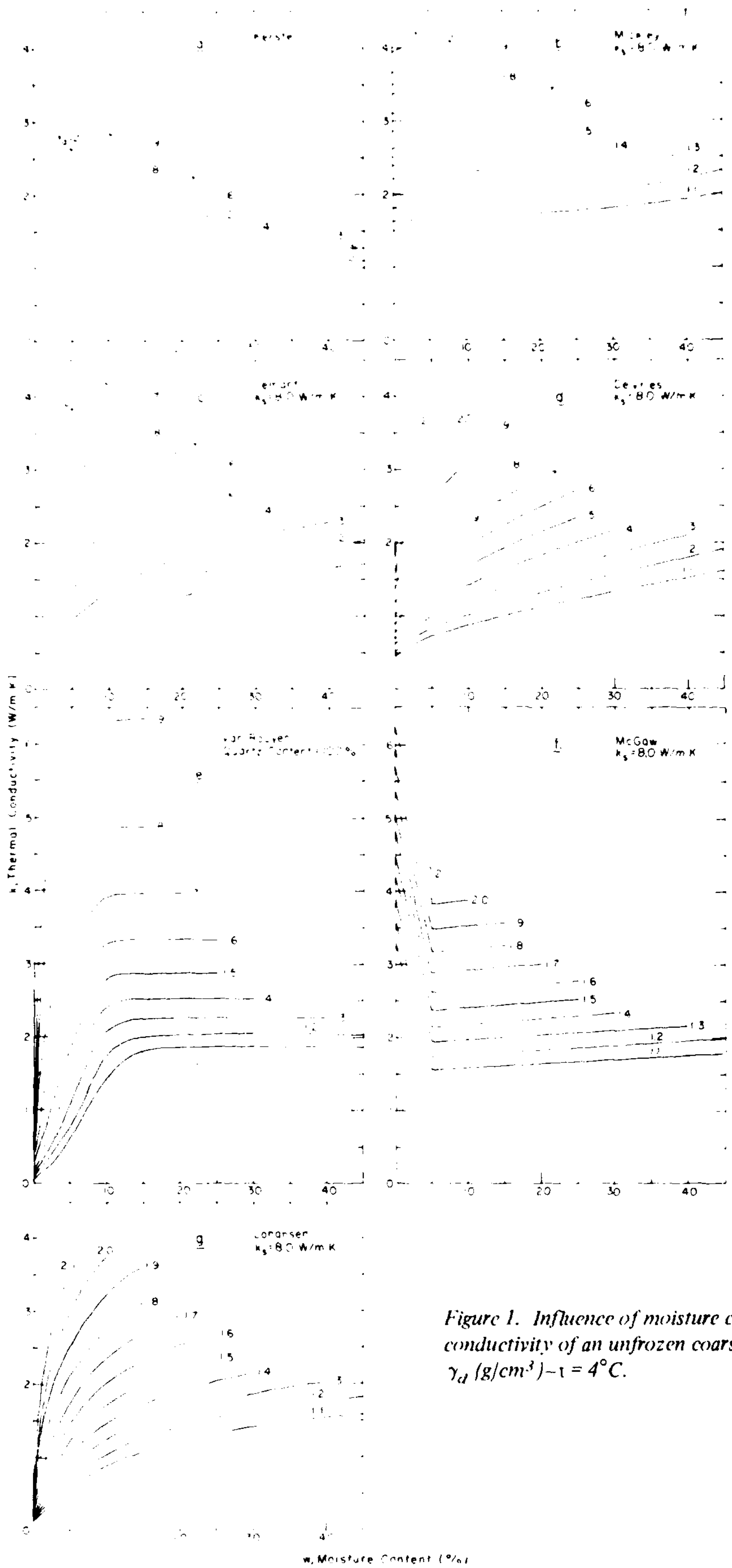

Figure 1. Influence of moisture content on calculated thermal conductivity of an unfrozen coarse soil at constant dry density γ_d (g/cm^3)–t = 4°C.

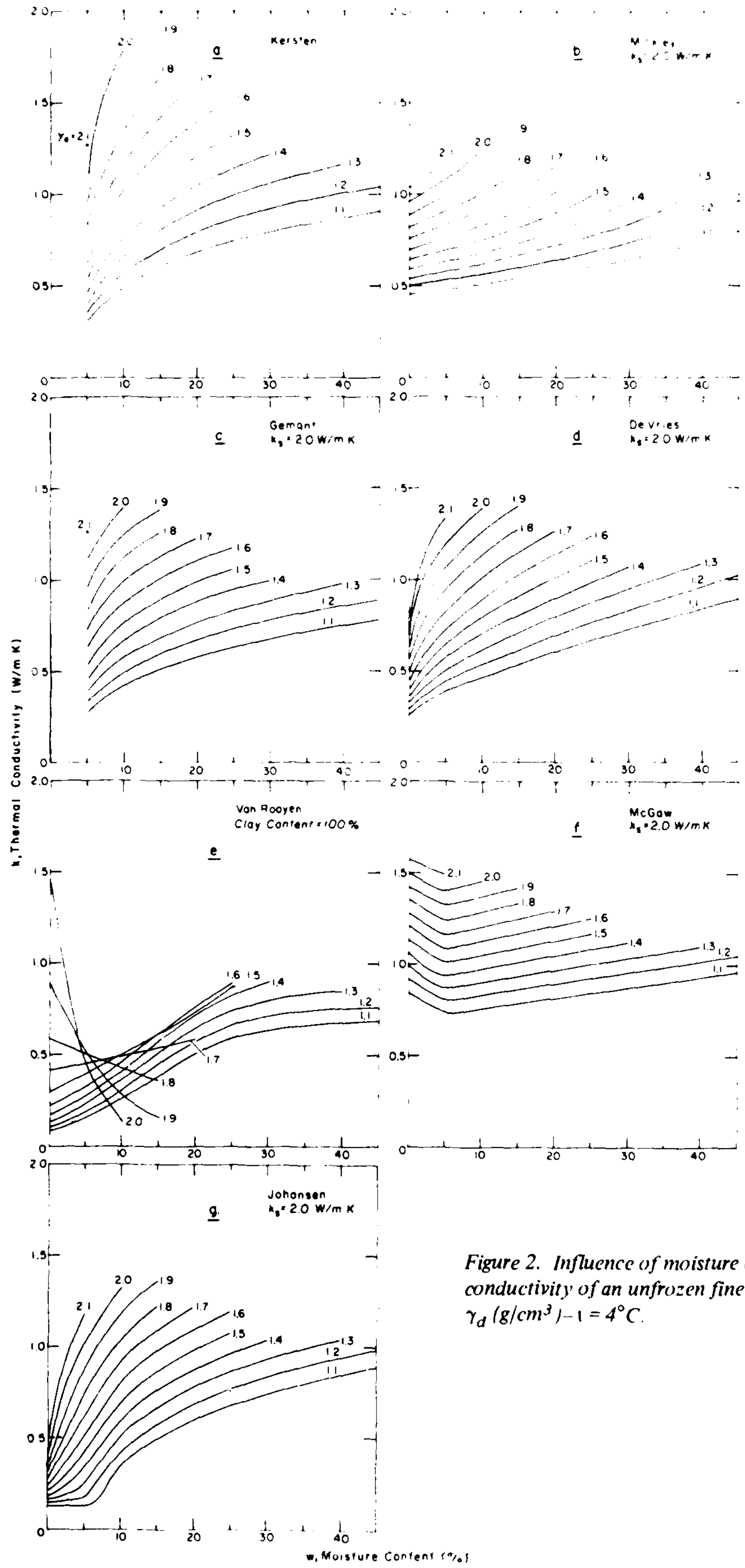

Figure 2. Influence of moisture content on calculated thermal conductivity of an unfrozen fine soil at constant dry density γ_d (g/cm³)–ι = 4°C.

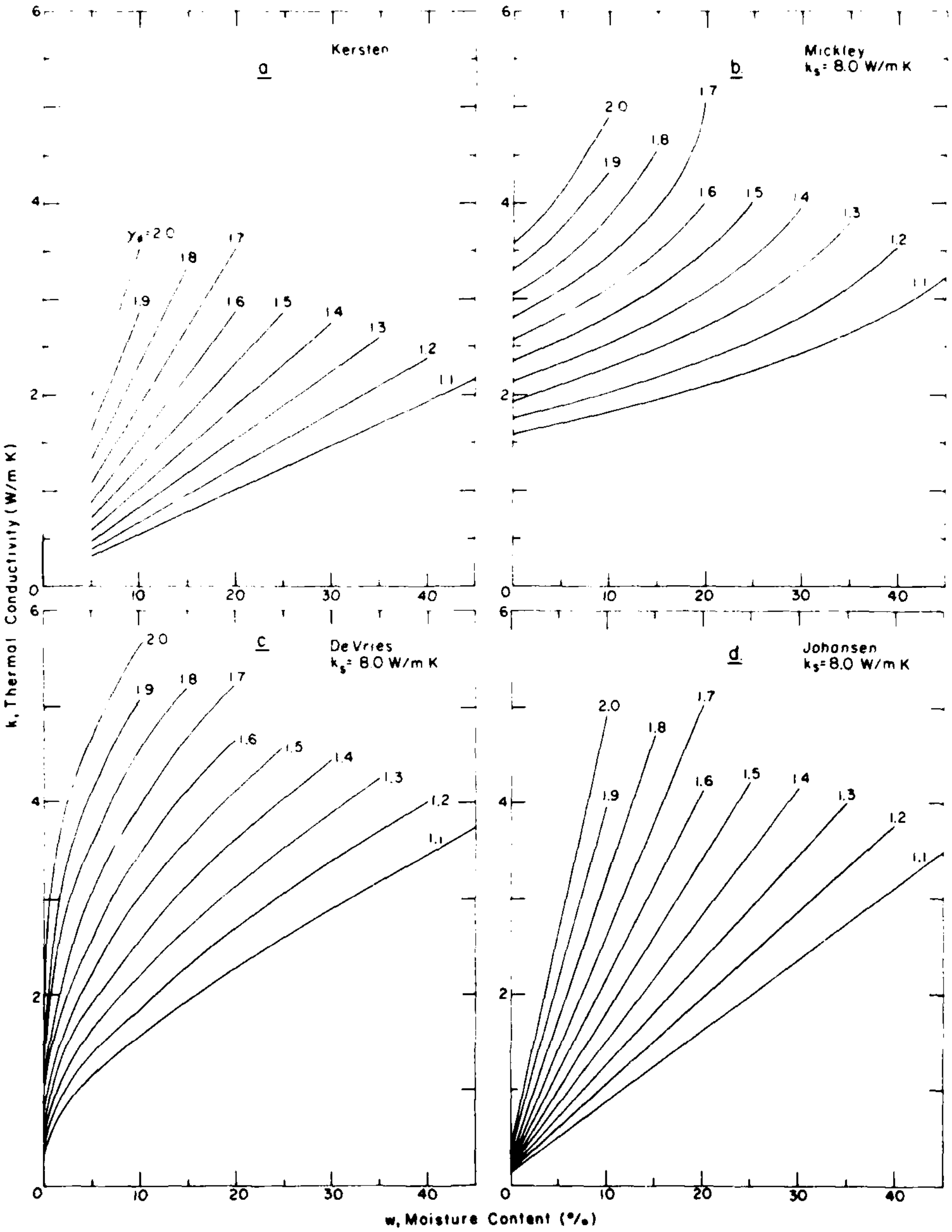

Figure 3. Influence of moisture content on calculated thermal conductivity of a frozen coarse soil at constant dry density γ_d (g/cm^3)—t = −4°C.

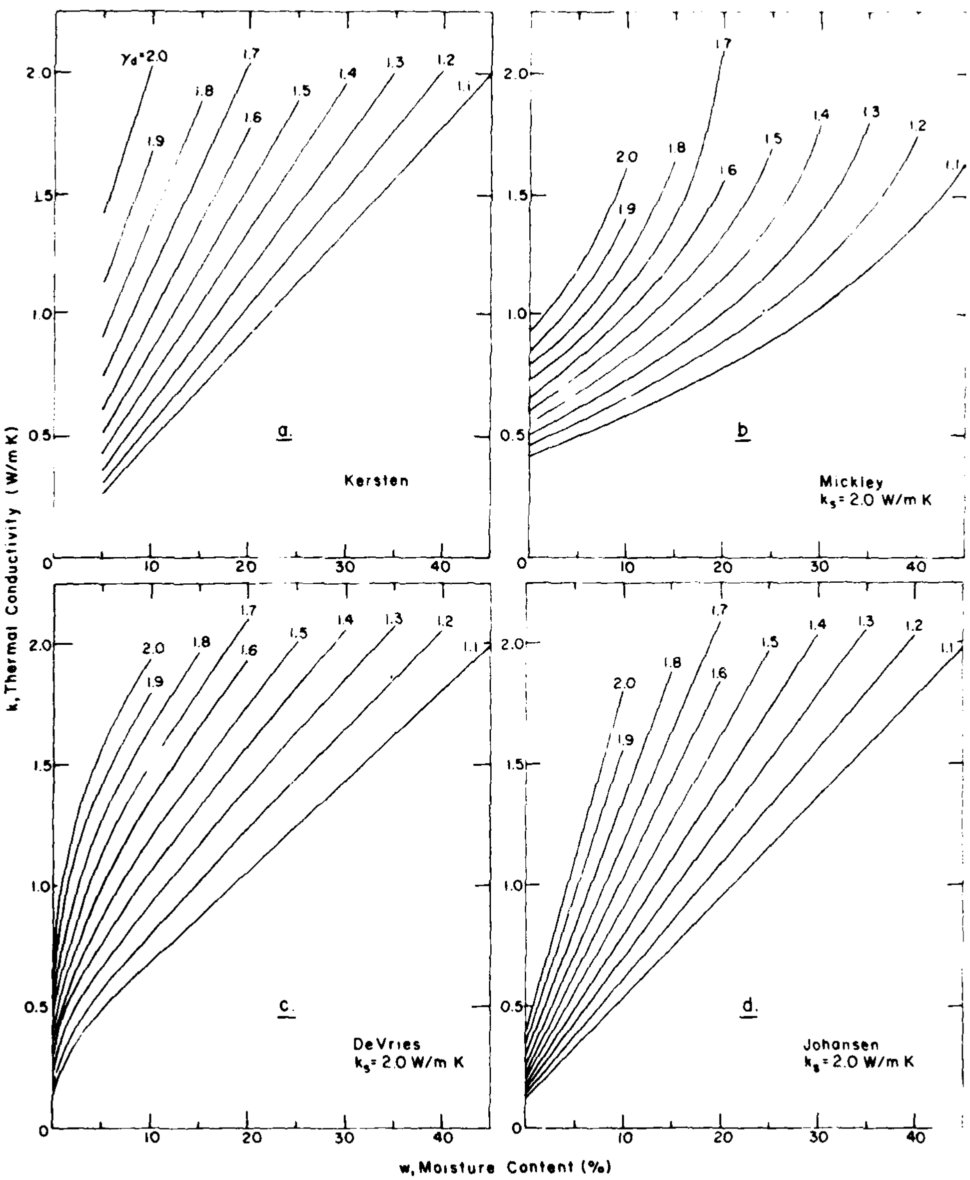

Figure 4. Influence of moisture content on calculated thermal conductivity of a frozen fine soil at constant dry density γ_d (g/cm^3) - t = -4°C.

Table 1. Sensitivity of thermal conductivity k (W/m K) of an unfrozen coarse soil to moisture content w at constant dry density γ_d for different methods of calculating k (s_w is the increase in k per 1% increase in w at constant γ_d).

k_s = 8.0 W/m K

	Kersten	*Johansen*	*De Vries*	*Mickley*	*McGaw*	*Gemant*	*Van Rooyen*
				γ_d = 1.1 g/cm³			
s_w for w = 0 to 5%	-	0.085	0.052	0.007	negative	-	0.097
k at w = 2.5%	-	0.378	0.610	1.625	-	-	0.308
s_w as % of k	-	22.6	8.5	0.4	-	-	31.6
s_w for w = 5 to 15%	0.023	0.051	0.027	0.007	0.006	0.051	0.123
k at w = 10%	0.771	0.881	0.865	1.665	1.586	0.950	1.482
s_w as % of k	3.0	5.8	3.1	0.4	0.4	5.4	8.3
s_w for w = 15 to 45%	0.008	0.017	0.021	0.012	0.007	0.022	0.002
k at w = 30%	1.005	1.395	1.332	1.823	1.700	1.497	1.860
s_w as % of k	0.8	1.2	1.5	0.7	0.4	1.5	0.1
				γ_d = 1.4 g/cm³			
s_w for w = 0 to 5%	-	0.170	0.094	0.011	-	-	0.256
k at w = 2.5%	-	0.683	0.950	2.213	-	-	0.788
s_w as % of k	-	24.9	9.9	0.5	-	-	32.5
s_w for w = 5 to 10%	0.046	0.086	0.053	0.012	0.007	0.096	0.192
k at w = 7.5%	1.078	1.280	1.300	2.263	2.163	1.383	2.070
s_w as % of k	4.2	6.8	4.1	0.5	0.3	7.0	9.3
s_w for w = 10 to 20%	0.023	0.043	0.042	0.014	0.007	0.050	0.010
k at w = 15%	1.320	1.721	1.649	2.344	2.218	1.891	2.525
s_w as % of k	1.7	2.5	2.5	0.6	0.3	2.6	0.4
s_w for w = 20 to 30%	0.013	0.025	0.033	0.019	0.007	0.031	0.000
k at w = 25%	1.487	2.040	2.008	2.500	2.291	2.275	2.532
s_w as % of k	0.9	1.2	1.6	0.8	0.3	1.4	0.0
				γ_d = 1.7 g/cm³			
s_w for w = 0 to 5%	-	0.302	0.160	0.018	-	-	0.565
k at w = 2.5%	-	1.262	1.475	2.870	-	-	2.612
s_w as % of k	-	23.9	10.8	0.6	-	-	21.6
s_w for w = 5 to 20%	0.047	0.077	0.072	0.027	0.009	0.091	0.264
k at w = 10%	1.827	2.357	2.297	3.026	2.921	2.604	3.939
s_w as % of k	2.6	3.3	3.1	0.9	0.3	3.5	6.7
				γ_d = 2.0 g/cm³			
s_w for w = 0 to 5%	-	0.513	0.298	0.033	-	-	-
k at w = 2.5%	-	2.308	2.480	3.720	-	-	-
s_w as % of k	-	22.2	12.0	0.9	-	-	-
s_w for w = 5 to 10%	0.108	0.152	0.119	0.044	0.010	0.181	-
k at w = 5%	2.273	2.984	3.030	3.797	3.829	3.222	-
s_w as % of k	4.7	5.1	3.9	1.2	0.3	5.6	-

Table 2. Sensitivity of thermal conductivity k (W/m K) of an unfrozen fine soil to moisture content w at constant dry density γ_d for different methods of calculating k (s_w is the increase in k per 1% increase in w at constant γ_d).

k_s = 2.0 W/m K

	Kersten	*Johansen*	*De Vries*	*Mickley*	*McGaw*	*Gemant*	*Van Rooyen*
γ_d = 1.1 g/cm^3							
s_w for w = 0 to 5%	-	0.000	0.026	0.006	-0.021	-	0.015
k at w = 2.5%	-	0.131	0.333	0.460	0.777	-	0.116
s_w as % of k	-	0.000	7.7	1.3	-2.7	-	12.6
s_w for w = 5 to 10%	0.038	0.044	0.014	0.006	0.004	0.030	0.022
k at w = 7.5%	0.405	0.200	0.435	0.490	0.740	0.362	0.210
s_w as % of k	9.4	22.0	3.3	1.2	0.5	8.2	10.3
s_w for w = 10 to 20%	0.019	0.025	0.014	0.007	0.006	0.015	0.024
k at w = 15 %	0.602	0.494	0.534	0.536	0.786	0.512	0.392
s_w as % of k	3.2	5.0	2.6	1.2	0.7	2.9	6.2
s_w for w = 20 to 45%	0.009	0.012	0.012	0.056	0.006	0.008	0.007
k at w = 30%	0.792	0.740	0.724	0.645	0.871	0.676	0.634
s_w as % of k	1.1	1.6	1.6	8.7	0.6	1.2	1.1
γ_d = 1.4 g/cm^3							
s_w for w = 0 to 5%	-	0.029	0.043	0.009	-0.025	-	0.022
k at w = 2.5%	-	0.240	0.486	0.610	0.978	-	0.219
s_w as % of k	-	12.2	8.8	1.5	-2.6	-	9.9
s_w for w = 5 to 10%	0.058	0.054	0.025	0.010	0.007	0.041	0.028
k at w = 7.5%	0.636	0.478	0.645	0.659	0.955	0.579	0.342
s_w as % of k	9.2	11.4	3.8	1.5	0.8	7.1	8.3
s_w for w = 10 to 20%	0.029	0.027	0.020	0.012	0.007	0.021	0.030
k at w = 15%	0.926	0.765	0.807	0.740	1.010	0.787	0.576
s_w as % of k	3.2	3.6	2.5	1.6	0.7	2.6	5.2
s_w for w = 20 to 30%	0.017	0.016	0.017	0.016	0.004	0.012	0.018
k at w = 25%	1.142	0.966	0.987	0.873	1.082	0.942	0.827
s_w as % of k	1.5	1.6	1.7	1.9	0.3	1.3	2.2
γ_d = 1.7 g/cm^3							
s_w for w = 0 to 5%	-	0.071	0.064	0.015	-0.023	-	0.008
k at w = 2.5%	-	0.455	0.698	0.796	1.205	-	0.435
s_w as % of k	-	15.6	9.2	1.8	-1.9	-	1.8
s_w for w = 5 to 10%	0.090	0.059	0.038	0.017	0.009	0.005	0.099
k at w = 7.5%	0.972	0.785	0.922	0.872	1.182	0.876	0.473
s_w as % of k	9.2	7.5	4.1	1.9	0.7	0.5	20.9
s_w for w = 10 to 20%	0.045	0.030	0.025	0.025	0.009	0.024	0.009
k at w = 15%	1.426	1.096	1.146	1.016	1.249	1.131	0.540
s_w as % of k	3.2	2.7	2.2	2.4	0.7	2.1	1.7
γ_d = 2.0 g/cm^3							
s_w for w = 0 to 5%	-	0.120	0.098	0.024	-0.018	-	-0.202
k at w = 2.5%	-	0.800	1.057	1.020	1.440	-	0.907
s_w as % of k	-	15.0	9.3	2.4	-1.3	-	-22.3
s_w for w = 5 to 10%	0.138	0.062	0.039	0.033	0.010	0.057	-0.063
k at w = 7.5%	1.563	1.180	1.296	1.165	1.430	1.270	0.265
s_w as % of k	8.9	5.2	3.0	2.8	0.7	4.5	-23.8

Table 3. Sensitivity of thermal conductivity k (W/m K) of a frozen coarse soil to moisture content w at constant dry density γ_d for different methods of calculating k (s_w is the increase in k per 1% increase in w at constant γ_d).

k_s = 8.0 W/m K

	Kersten	*Johansen*	*De Vries*	*Mickley*
		γ_d = 1.1 g/cm^3		
s_w for w = 0 to 5%	-	0.074	0.162	0.024
k at w = 2.5%	-	0.305	0.863	1.630
s_w as % of k	-	24.3	18.7	1.5
s_w for w = 5 to 15%	0.046	0.074	0.076	0.026
k at w = 10%	0.549	0.873	1.541	1.813
s_w as % of k	8.4	8.5	4.9	1.5
s_w for w = 15 to 25%	0.046	0.074	0.067	0.031
k at w = 20%	1.013	1.616	2.273	2.096
s_w as % of k	4.6	4.6	2.9	1.5
s_w for w = 25 to 45%	0.046	0.074	0.057	0.048
k at w = 35%	1.709	2.730	3.179	2.637
s_w as % of k	2.7	2.7	1.8	1.8
		γ_d = 1.4 g/cm^3		
s_w for w = 0 to 5%	-	0.133	0.278	0.039
k at w = 2.5%	-	0.505	1.488	2.453
s_w as % of k	-	26.2	18.7	1.6
s_w for w = 5 to 15%	0.087	0.133	0.123	0.045
k at w = 10%	1.021	1.513	2.591	2.540
s_w as % of k	8.5	8.8	4.7	1.8
s_w for w = 15 to 25%	0.087	0.133	0.089	0.063
k at w = 20%	1.891	2.839	3.617	3.059
s_w as % of k	4.6	4.7	2.1	2.1
s_w for w = 25 to 30%	0.087	0.133	0.082	0.110
k at w = 27.5%	2.538	3.825	4.238	3.655
s_w as % of k	3.4	3.5	1.9	3.0
		γ_d = 1.7 g/cm^3		
s_w for w = 0 to 5%	-	0.238	0.452	0.063
k at w = 2.5%	-	0.858	2.463	2.950
s_w as % of k	-	27.7	18.4	2.1
s_w for w = 5 to 15%	0.163	0.238	0.159	0.085
k at w = 10%	1.897	2.651	3.996	3.475
s_w as % of k	8.6	9.0	4.0	2.4
s_w for w = 15 to 20%	0.163	0.237	0.114	0.220
k at w = 17.5%	3.108	4.418	4.968	4.318
s_w as % of k	5.2	5.4	2.3	5.1
		γ_d = 2.0 g/cm^3		
s_w for w = 0 to 5%	-	0.451	0.689	0.107
k at w = 2.5%	-	0.970	4.063	3.830
s_w as % of k	-	46.5	16.9	2.8
s_w for w = 5 to 10%	0.307	0.450	0.193	0.159
k at w = 7.5%	2.750	3.750	5.238	4.488
s_w as % of k	11.1	12.0	3.7	3.6

Table 4. Sensitivity of thermal conductivity k (W/m K) of a frozen fine soil to moisture content w at constant dry density γ_d for different methods of calculating k (s_w is the increase in k per 1% increase in w at constant γ_d).

k_s = 2.0 W/m K

	Kersten	*Johansen*	*De Vries*	*Mickley*
		γ_d = 1.1 g/cm^3		
s_w for w = 0 to 5%	-	0.041	0.068	0.016
k at w = 2.5%	-	0.230	0.360	0.450
s_w as % of k	-	17.8	18.8	3.6
s_w for w = 5 to 15%	0.043	0.041	0.039	0.018
k at w = 10%	0.481	0.541	0.684	0.579
s_w as % of k	9.0	7.6	5.6	3.2
s_w for w = 15 to 25%	0.044	0.041	0.038	0.022
k at w = 20%	0.915	0.952	1.077	0.779
s_w as % of k	4.8	4.3	3.5	2.8
s_w for w = 25 to 45%	0.043	0.041	0.036	0.036
k at w = 35%	1.567	1.569	1.629	1.181
s_w as % of k	2.8	2.6	2.2	3.1
		γ_d = 1.4 g/cm^3		
s_w for w = 0 to 5%	-	0.062	0.109	0.024
k at w = 2.5%	-	0.337	0.605	0.609
s_w as % of k	-	18.3	18.0	3.9
s_w for w = 5 to 15%	0.061	0.062	0.057	0.029
k at w = 10%	0.734	0.803	1.066	0.808
s_w as % of k	8.4	7.7	5.3	3.6
s_w for w = 15 to 25%	0.061	0.062	0.048	0.043
k at w = 20%	1.347	1.419	1.584	1.152
s_w as % of k	4.6	4.3	3.0	3.7
s_w for w = 25 to 30%	0.061	0.062	0.047	0.078
k at w = 27.5%	1.805	1.880	1.936	1.550
s_w as % of k	3.4	3.3	2.4	5.1
		γ_d = 1.7 g/cm^3		
s_w for w = 0 to 5%	-	0.091	0.161	0.035
k at w = 2.5%	-	0.495	0.870	0.800
s_w as % of k	-	18.5	18.5	4.4
s_w for w = 5 to 15%	0.087	0.091	0.068	0.050
k at w = 10%	1.177	1.187	1.507	1.110
s_w as % of k	7.4	7.7	4.5	4.5
s_w for w = 15 to 20%	0.086	0.091	0.058	0.140
k at w = 17.5%	1.820	1.865	1.951	1.665
s_w as % of k	4.7	4.9	3.0	8.4
		γ_d = 2.0 g/cm^3		
s_w for w = 0 to 5%	-	0.139	0.216	0.053
k at w = 2.5%	-	0.756	1.285	1.045
s_w as % of k	-	18.3	16.8	5.1
s_w for w = 5 to 10%	0.122	0.139	0.076	0.085
k at w = 7.5%	1.715	1.450	1.765	1.375
s_w as % of k	7.1	9.6	4.3	6.2

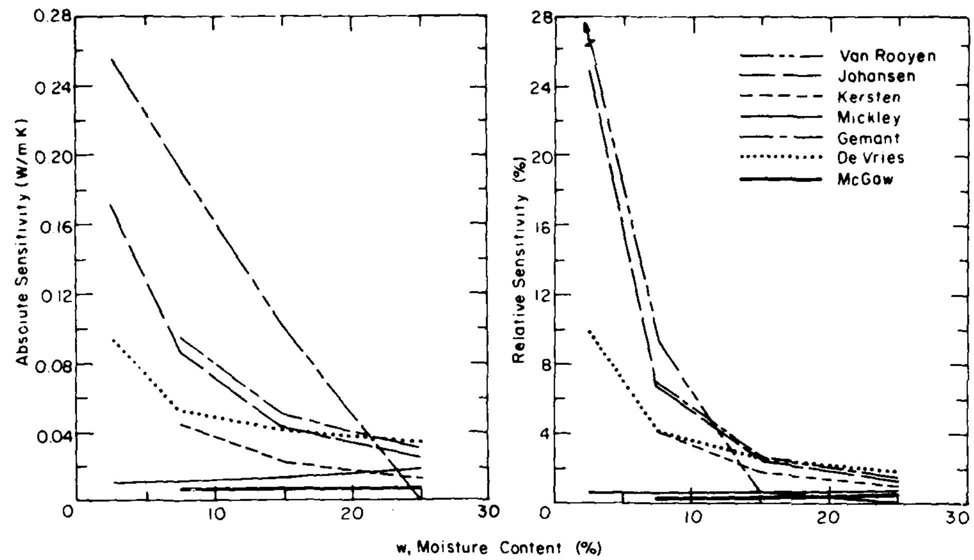

Figure 5. Absolute and relative sensitivities of calculated thermal conductivity of an unfrozen coarse soil vs moisture content (k_s = 8.0 W/m K, γ_d = 1.4 g/cm³). Absolute sensitivity is the change in thermal conductivity (W/m K) due to 1% change in moisture content. Relative sensitivity is the absolute sensitivity expressed as a percentage of the thermal conductivity.

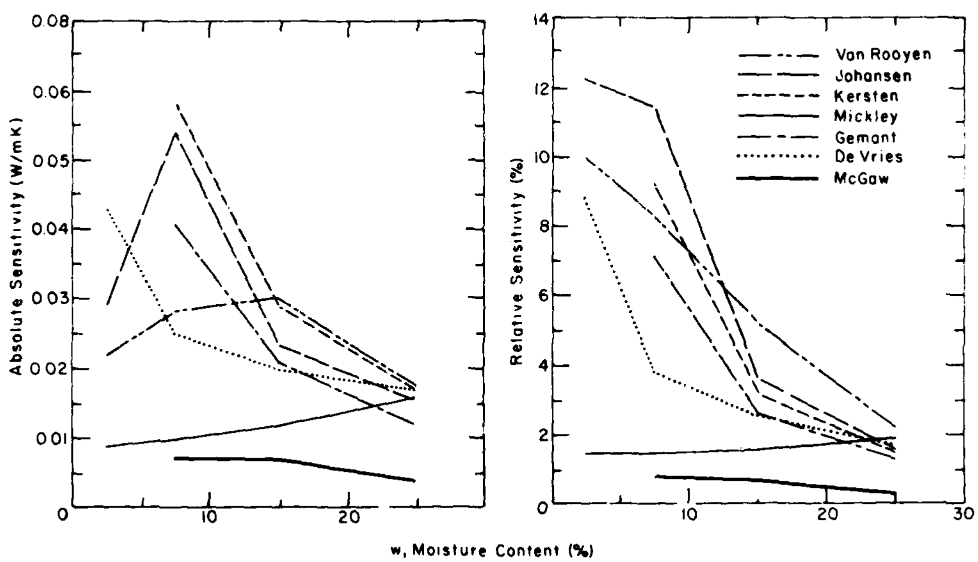

Figure 6. Absolute and relative sensitivities of calculated thermal conductivity of an unfrozen fine soil vs moisture content (k_s = 2.0 W/m K, γ_d = 1.4 g/cm³). Absolute sensitivity is the change in thermal conductivity (W/m K) due to 1% change in moisture content. Relative sensitivity is the absolute sensitivity expressed as a percentage of the thermal conductivity.

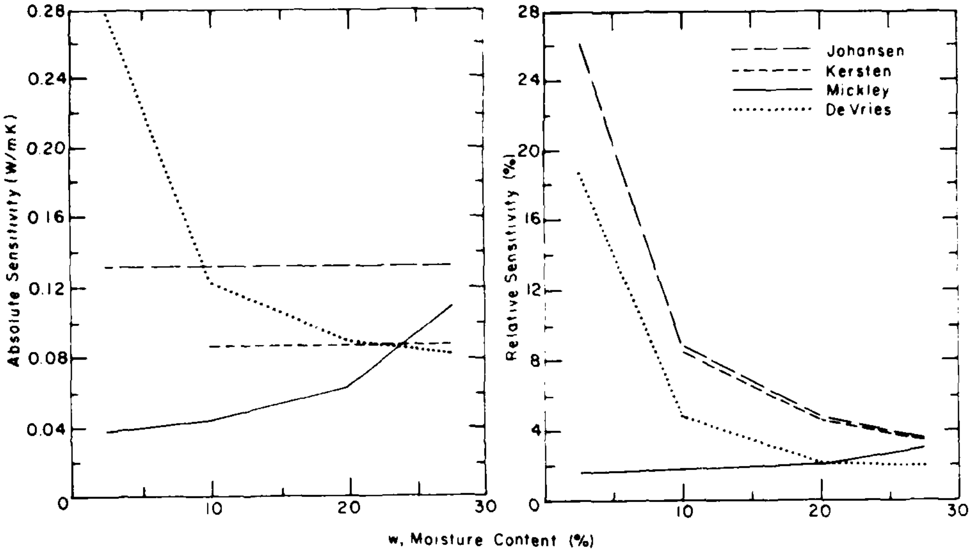

Figure 7. Absolute and relative sensitivities of calculated thermal conductivity of a frozen coarse soil vs moisture content (k_s = 8.0 W/m K, γ_d = 1.4 g/cm^3). Absolute sensitivity is the change in thermal conductivity (W/m K) due to 1% change in moisture content. Relative sensitivity is the absolute sensitivity expressed as a percentage of the thermal conductivity.

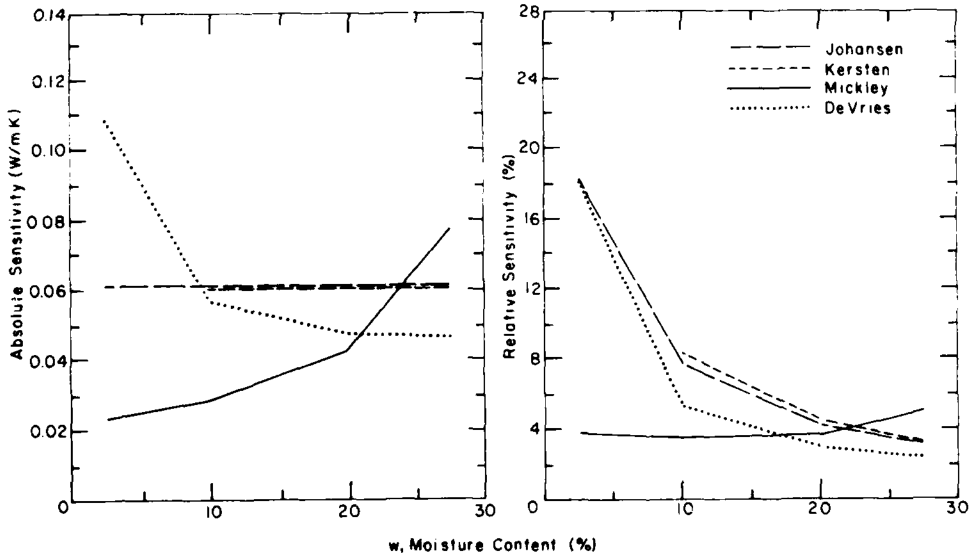

Figure 8. Absolute and relative sensitivities of calculated thermal conductivity of a frozen fine soil vs moisture content (k_s = 2.0 W/m K, γ_d = 1.4 g/cm^3). Absolute sensitivity is the change in thermal conductivity (W/m K) due to 1% change in moisture content. Relative sensitivity is the absolute sensitivity expressed as a percentage of the thermal conductivity.

From a comparison of the results for these conditions, it is evident that each of these common methods gives an s_w value which is appreciably greater for frozen soil than for unfrozen soil. This may be expected because ice has a much higher thermal conductivity than water. At low value of w (0-5% range), Johansen is an exception, giving a higher s_w for the unfrozen condition than for the frozen state.

Influence of dry density on thermal conductivity

To determine the effect of γ_d, thermal conductivity values were calculated at a constant w for values of γ_d varying from 1.1 to 2.0 g cm^3 in increments of 0.1 g/cm^3. This was done for w values from dry to near saturation. At the higher w values, saturation corresponds to lower values of γ_d. As in the previous section, results were obtained from seven methods for the unfrozen state (Fig. 9 and 10) and from four methods for the frozen state (Fig. 11 and 12).

Van Rooyen clearly shows incorrect trends at high values of γ_d or w. Also, both Mickley and McGaw give values for the dry thermal conductivity that are obviously much too high. In Mickley's case, this was expected by him, while for McGaw, the interfacial efficiency ϵ was assumed to be 1.0 in the calculations which is too high for the dry or nearly dry condition.

The sensitivity of the thermal conductivity to γ_d (at constant w) is given in Tables 5-8 for several representative values of w. These tables give the absolute sensitivity s_γ expressed as the increase in thermal conductivity per 0.1 g/cm^3 increase in γ_d at constant w. This increase has also been expressed in relative terms as a percentage of the thermal conductivity value in the middle of the dry density range.

Van Rooyen is considerably out of step with the others for the unfrozen soils (Fig. 9 and 10). For these soils the other six methods give an increased s_γ as γ_d increases at constant w. It is also evident that s_γ increases as w increases for a given γ_d range; however, the values from Mickley and McGaw do not vary much.

For unfrozen coarse soil Kersten gives the lowest s_γ throughout (Table 5). The relative sensitivity given by Kersten is constant at about 14.5% over the whole range of γ_d and w. On the other hand for unfrozen fine soil Kersten tends to give the highest s_γ at the higher values of γ_d (Table 6). The values of s_γ for unfrozen fine soil are lower than the corresponding values for unfrozen coarse soil, as expected, because of the higher k_s value for the latter.

Tables 7 and 8 for frozen soils show the marked increase in s_γ caused by γ_d increasing at constant w. As for unfrozen soils, increased w gives increased sensitivity over a similar range of γ_d. For frozen coarse soil Kersten generally gives the lowest s_γ while Johansen and Mickley give the largest at high values of w. For frozen fine soil, Kersten and Johansen give s_γ values near each other at low γ_d values, but Kersten tends to give higher values in the higher γ_d range.

Because the degree of saturation S_r may be more important than the absolute value of w, especially in affecting moisture migration, thermal conductivity values have been calculated at a constant S_r value but with varying γ_d. The curves corresponding to several S_r values are shown in Figures 13-16. Along a constant S_r curve, varying γ_d implies a varying w; the effect of a varying w is a contributing factor to changes in thermal conductivity.

Apart from Van Rooyen, these curves (at constant S_r) for the unfrozen soils show a more or less constant rate of increase in the thermal conductivity with increasing γ_d. This implies that s_γ (at constant S_r) is approximately constant. For a given method the curves corresponding to different S_r values run roughly parrallel to each other. The same trends are indicated for the four methods applicable to the frozen coarse soil (Fig. 15). With regard to the frozen fine soil, however, the trends shown by these methods are somewhat different (Fig. 16).

The effect of S_r is interesting to note. For the unfrozen soils, the curves given by Kersten, Gemant, De Vries and Johansen show that the sensitivity of the thermal conductivity to S_r at constant γ_d decreases as S_r increases (i.e. the curves become closer together). The opposite trend is shown by Mickley, but this appears to be physically incorrect. For the frozen soils, Kersten, De Vries and Johansen give a nearly constant s_w as S_r increases at constant dry density.

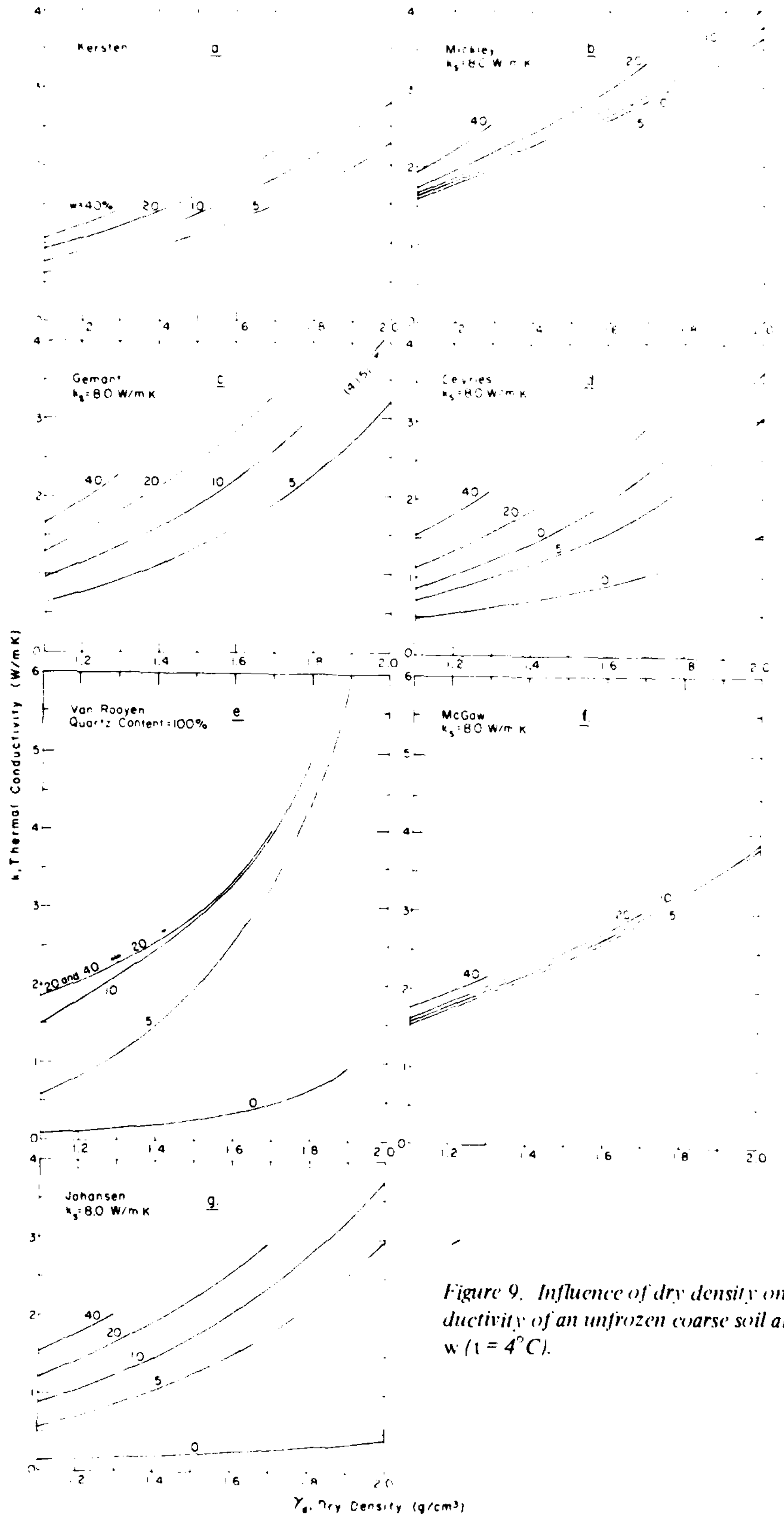

Figure 9. Influence of dry density on calculated thermal conductivity of an unfrozen coarse soil at constant moisture content w (t = 4°C).

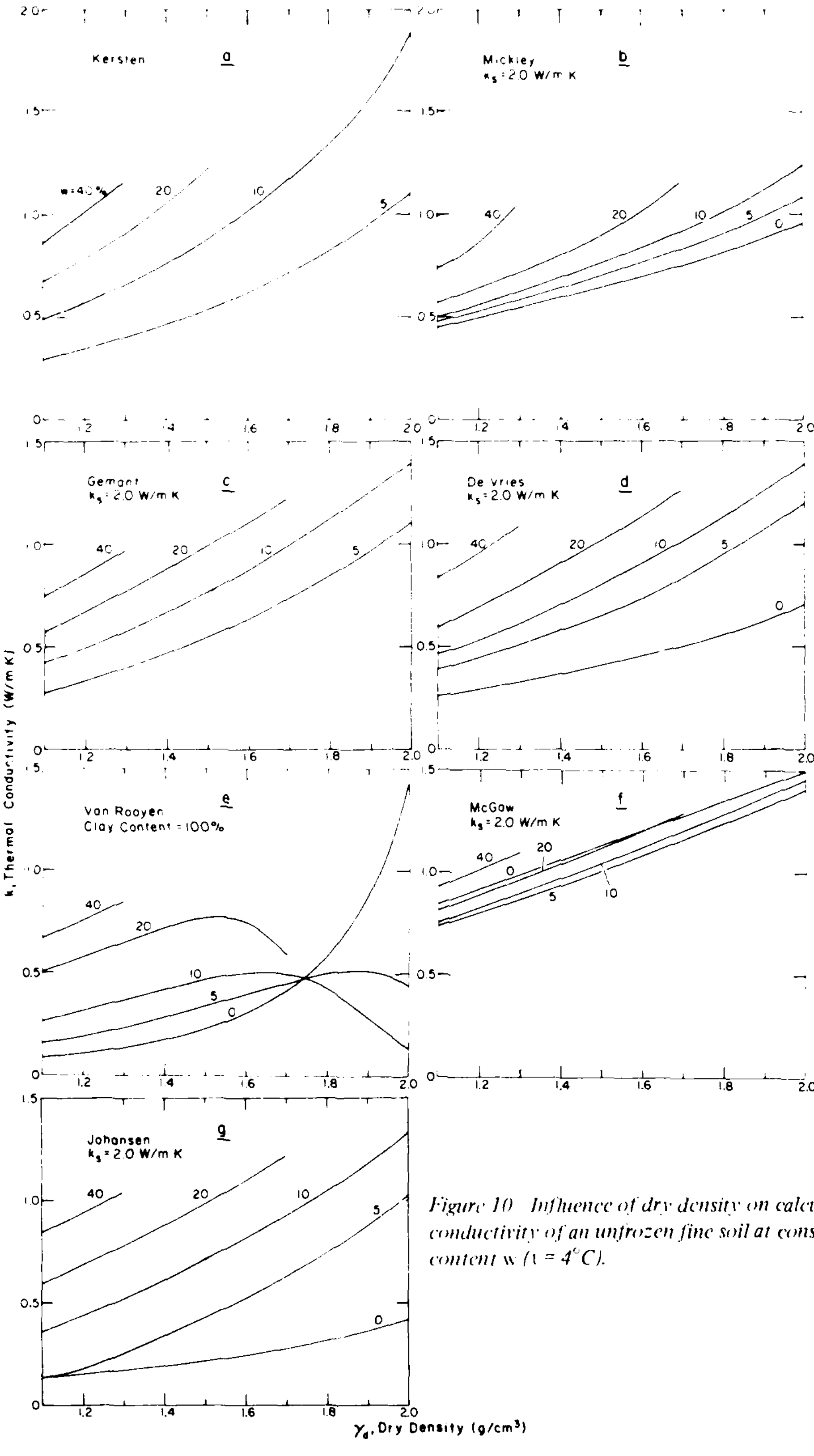

Figure 10. Influence of dry density on calculated thermal conductivity of an unfrozen fine soil at constant moisture content w (t = 4°C).

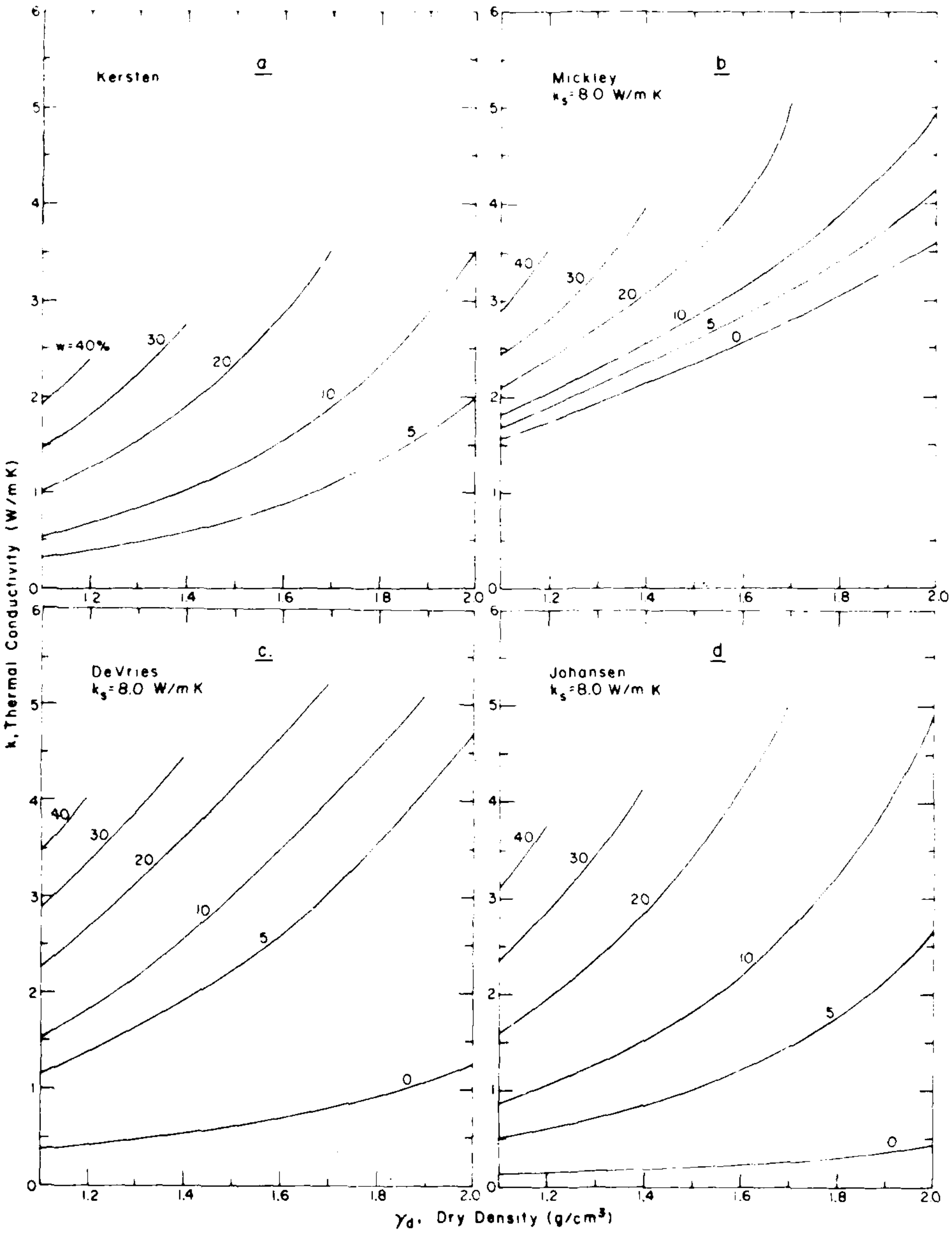

Figure 11. Influence of dry density on calculated thermal conductivity of a frozen coarse soil at constant moisture content w (t = −4° C).

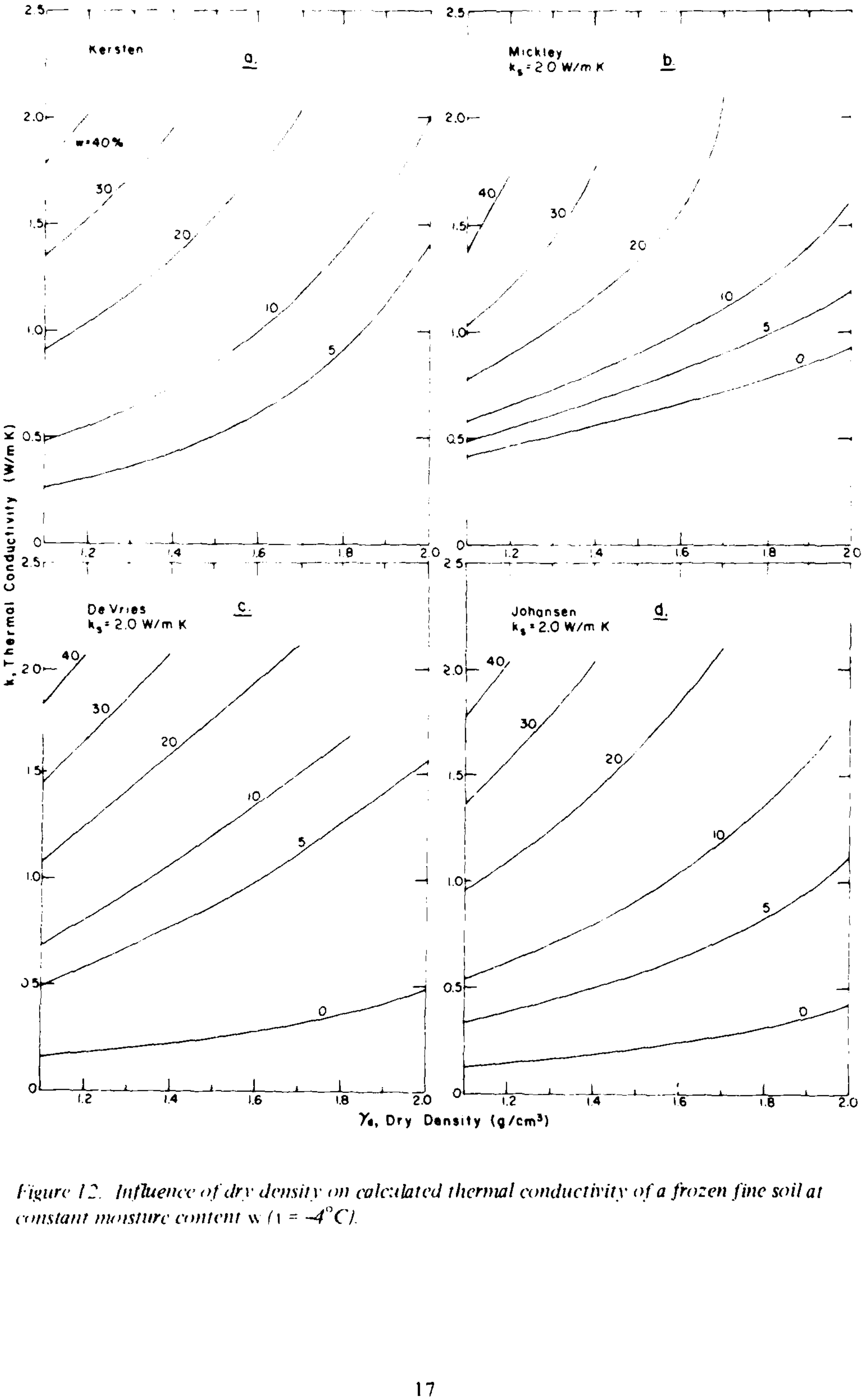

Figure 12. Influence of dry density on calculated thermal conductivity of a frozen fine soil at constant moisture content w (t = −4°C).

Table 5. Sensitivity of thermal conductivity k (W/m K) of an unfrozen coarse soil to dry density γ_d at constant moisture content w for different methods of calculating k (s_γ is the increase in k per 0.1 g/cm^3 increase in γ_d at constant w).

k_s = 8.0 W/m K

	Kersten	*Johansen*	*De Vries*	*Mickley*	*McGaw*	*Gemant*	*Van Rooyen*
				w = 5%			
s_γ for γ_d = 1.1 to 1.5 g/cm^3	0.121	0.173	0.154	0.203	0.203	0.180	0.342
k at γ_d = 1.3 g/cm^3	0.831	0.853	0.995	2.014	1.937	0.937	1.093
s_γ as % of k	14.6	20.3	15.5	10.1	10.5	19.2	31.3
s_γ for γ_d = 1.5 to 1.9 g/cm^3	0.215	0.317	0.307	0.260	0.277	0.341	0.977
k at γ_d = 1.7 g/cm^3	1.477	1.782	1.808	2.922	2.877	1.918	3.291
s_γ as % of k	14.6	17.8	17.0	8.9	9.6	17.8	29.7
				w = 10%			
s_γ for γ_d = 1.1 to 1.5 g/cm^3	0.150	0.211	0.202	0.212	0.206	0.236	0.334
k at γ_d = 1.3 g/cm^3	1.028	1.246	1.209	2.063	1.971	1.354	2.095
s_γ as % of k	14.6	16.9	16.7	10.3	10.5	17.4	15.9
s_γ for γ_d = 1.5 to 1.9 g/cm^3	0.266	0.371	0.362	0.283	0.280	0.414	0.881
k at γ_d = 1.7 g/cm^3	1.827	2.357	2.297	3.026	2.921	2.604	3.939
s_γ as % of k	14.6	15.7	15.8	9.4	9.6	15.9	22.4
				w = 20%			
s_γ for γ_d = 1.1 to 1.5 g/cm^3	0.179	0.249	0.257	0.236	0.223	0.293	0.256
k at γ_d = 1.3 g/cm^3	1.225	1.639	1.568	2.173	2.037	1.800	2.259
s_γ as % of k	14.6	15.2	16.4	10.9	10.9	16.3	11.3
s_γ for γ_d = 1.5 to 1.7 g/cm^3	0.272	0.367	0.372	0.326	0.261	0.414	0.541
k at γ_d = 1.6 g/cm^3	1.885	2.541	2.493	2.979	2.738	2.846	3.333
s_γ as % of k	14.4	14.4	14.9	10.9	9.5	14.5	16.2
				w = 40%			
s_γ for γ_d = 1.1 to 1.3 g/cm^3	0.178	0.247	0.294	0.318	0.204	0.313	0.200
k at γ_d = 1.2 g/cm^3	1.231	1.765	1.800	2.200	1.958	1.957	2.041
s_γ as % of k	14.5	14.0	16.3	14.5	10.4	16.0	9.8

Table 6. Sensitivity of thermal conductivity k (W/m K) of an unfrozen fine soil to dry density γ_d at constant moisture content w for different methods of calculating k (s_γ is the increase in k per 0.1 g/cm^3 increase in γ_d at constant w).

k_s = 2.0 W/m K

	Kersten	Johansen	De Vries	Mickley	McGaw	Gemant	Van Rooyen
				w = 5%			
s_γ for γ_d = 1.1 to 1.5 g/cm^3	0.058	0.073	0.065	0.056	0.068	0.066	0.044
k at γ_d = 1.3 g/cm^3	0.401	0.251	0.509	0.579	0.867	0.396	0.231
s_γ as % of k	14.5	29.2	12.7	9.6	7.8	16.7	18.9
s_γ for γ_d = 1.5 to 1.9 g/cm^3	0.113	0.119	0.109	0.077	0.078	0.113	0.023
k at γ_d = 1.7 g/cm^3	0.713	0.627	0.823	0.832	1.162	0.732	0.451
s_γ as % of k	15.8	19.0	13.3	9.3	6.7	15.4	5.0
				w = 10%			
s_γ for γ_d = 1.1 to 1.5 g/cm^3	0.095	0.088	0.083	0.063	0.073	0.086	0.017
k at γ_d = 1.3 g/cm^3	0.654	0.515	0.613	0.621	0.901	0.577	0.366
s_γ as % of k	14.6	17.1	13.6	10.1	8.1	14.9	4.6
s_γ for γ_d = 1.5 to 2.0 g/cm^3	0.183	0.125	0.119	0.099	0.081	0.125	-0.068
k at γ_d = 1.7 g/cm^3	1.162	0.923	1.014	0.915	1.205	0.993	0.494
s_γ as % of k	15.8	13.5	11.7	10.8	6.7	12.6	13.7
				w = 20%			
s_γ for γ_d = 1.1 to 1.5 g/cm^3	0.132	0.097	0.104	0.082	0.078	0.103	0.065
k at γ_d = 1.3 g/cm^3	0.907	0.779	0.794	0.716	0.968	0.771	0.649
s_γ as % of k	14.6	12.5	13.0	11.5	8.1	13.3	10.0
s_γ for γ_d = 1.5 to 1.7 g/cm^3	0.202	0.117	0.124	0.132	0.083	0.120	-0.090
k at γ_d = 1.6 g/cm^3	1.396	1.097	1.135	1.012	1.209	1.104	0.748
s_γ as % of k	14.4	10.7	10.9	13.0	6.9	10.8	-12.0
				w = 40%			
s_γ for γ_d = 1.1 to 1.3 g/cm^3	0.145	0.098	0.126	0.161	0.086	0.110	0.089
k at γ_d = 1.2 g/cm^3	1.005	0.940	0.961	0.862	1.014	0.858	0.751
s_γ as % of k	14.4	10.4	13.1	18.6	8.4	12.8	11.8

Table 7. Sensitivity of thermal conductivity k (W/m K) of a frozen coarse soil to dry density γ_d at constant moisture content w for different methods of calculating k (s_γ is the increase in k per 0.1 g/cm³ increase in γ_d at constant w).

k_s = 8.0 W/m K

	Kersten	*Johansen*	*De Vries*	*Mickley*
		w = 5%		
s_γ for γ_d = 1.1 to 1.5 g/cm³	0.100	0.129	0.267	0.221
k at γ_d = 1.3 g/cm³	0.477	0.713	1.640	2.100
s_γ as % of k	21.0	18.1	16.3	10.5
s_γ for γ_d = 1.5 to 2.0 g/cm³	0.255	0.332	0.490	0.312
k at γ_d = 1.8 g/cm³	1.325	1.770	3.554	3.411
s_γ as % of k	19.3	18.7	13.8	9.1
		w = 10%		
s_γ for γ_d = 1.1 to 1.5 g/cm³	0.177	0.144	0.371	0.252
k at γ_d = 1.3 g/cm³	0.830	1.260	2.200	2.280
s_γ as % of k	21.3	11.4	16.9	11.1
s_γ for γ_d = 1.5 to 2.0 g/cm³	0.454	0.621	0.525	0.420
k at γ_d = 1.8 g/cm³	2.332	3.227	4.527	3.867
s_γ as % of k	19.5	19.3	11.6	10.9
		w = 20%		
s_γ for γ_d = 1.1 to 1.5 g/cm³	0.329	0.452	0.462	0.346
k at γ_d = 1.3 g/cm³	1.536	2.356	3.140	2.700
s_γ as % of k	21.4	19.2	14.7	12.8
s_γ for γ_d = 1.5 to 1.7 g/cm³	0.600	0.800	0.551	0.787
k at γ_d = 1.6 g/cm³	2.867	4.142	4.653	4.006
s_γ as % of k	20.9	19.3	11.8	19.6
		w = 30%		
s_γ for γ_d = 1.1 to 1.4 g/cm³	0.428	0.602	0.518	0.508
k at γ_d = 1.3 g/cm³	2.242	3.451	3.893	3.285
s_γ as % of k	19.1	17.4	13.3	15.5
		w = 40%		
s_γ for γ_d = 1.1 to 1.2 g/cm³	0.451	0.658	0.561	0.647
k at γ_d = 1.2 g/cm³	2.392	3.760	4.019	3.529
s_γ as % of k	18.9	17.5	14.0	18.3

Table 8. Sensitivity of thermal conductivity k (W/m K) of a frozen fine soil to dry density γ_d at constant moisture content w for different methods of calculating k (s_γ is the increase in k per 0.1 g/cm^3 increase in γ_d at constant w).

k_s = 2.0 W/m K

	Kersten	*Johansen*	*De Vries*	*Mickley*
		w = 5%		
s_γ for γ_d = 1.1 to 1.5 g/cm^3	0.061	0.057	0.094	0.063
k at γ_d = 1.3 g/cm^3	0.361	0.435	0.671	0.610
s_γ as % of k	17.0	13.0	14.0	10.2
s_γ for γ_d = 1.5 to 2.0 g/cm^3	0.181	0.110	0.138	0.090
k at γ_d = 1.7 g/cm^3	0.744	0.730	1.129	0.896
s_γ as % of k	24.4	15.1	12.2	10.0
		w = 10%		
s_γ for γ_d = 1.1 to 1.5 g/cm^3	0.093	0.093	0.132	0.080
k at γ_d = 1.3 g/cm^3	0.635	0.705	0.930	0.726
s_γ as % of k	14.6	13.2	14.1	11.0
s_γ for γ_d = 1.5 to 2.0 g/cm^3	0.235	0.179	0.146	0.144
k at γ_d = 1.7 g/cm^3	1.177	1.187	1.507	1.110
s_γ as % of k	19.9	15.1	9.7	12.9
		w = 20%		
s_γ for γ_d = 1.1 to 1.5 g/cm^3	0.157	0.166	0.170	0.136
k at γ_d = 1.3 g/cm^3	1.181	1.245	1.412	1.010
s_γ as % of k	13.3	13.3	12.0	13.5
s_γ for γ_d = 1.5 to 1.7 g/cm^3	0.251	0.242	0.173	0.387
k at γ_d = 1.6 g/cm^3	1.771	1.841	1.927	1.554
s_γ as % of k	14.1	13.1	9.0	24.9
		w = 30%		
s_γ for γ_d = 1.1 to 1.4 g/cm^3	0.203	0.224	0.203	0.253
k at γ_d = 1.3 g/cm^3	1.728	1.785	1.850	1.426
s_γ as % of k	11.8	12.5	11.0	17.7
		w = 40%		
s_γ for γ_d = 1.1 to 1.2 g/cm^3	0.229	0.260	0.239	0.370
k at γ_d = 1.2 g/cm^3	2.013	2.034	2.049	1.739
s_γ as % of k	11.4	12.8	11.7	21.3

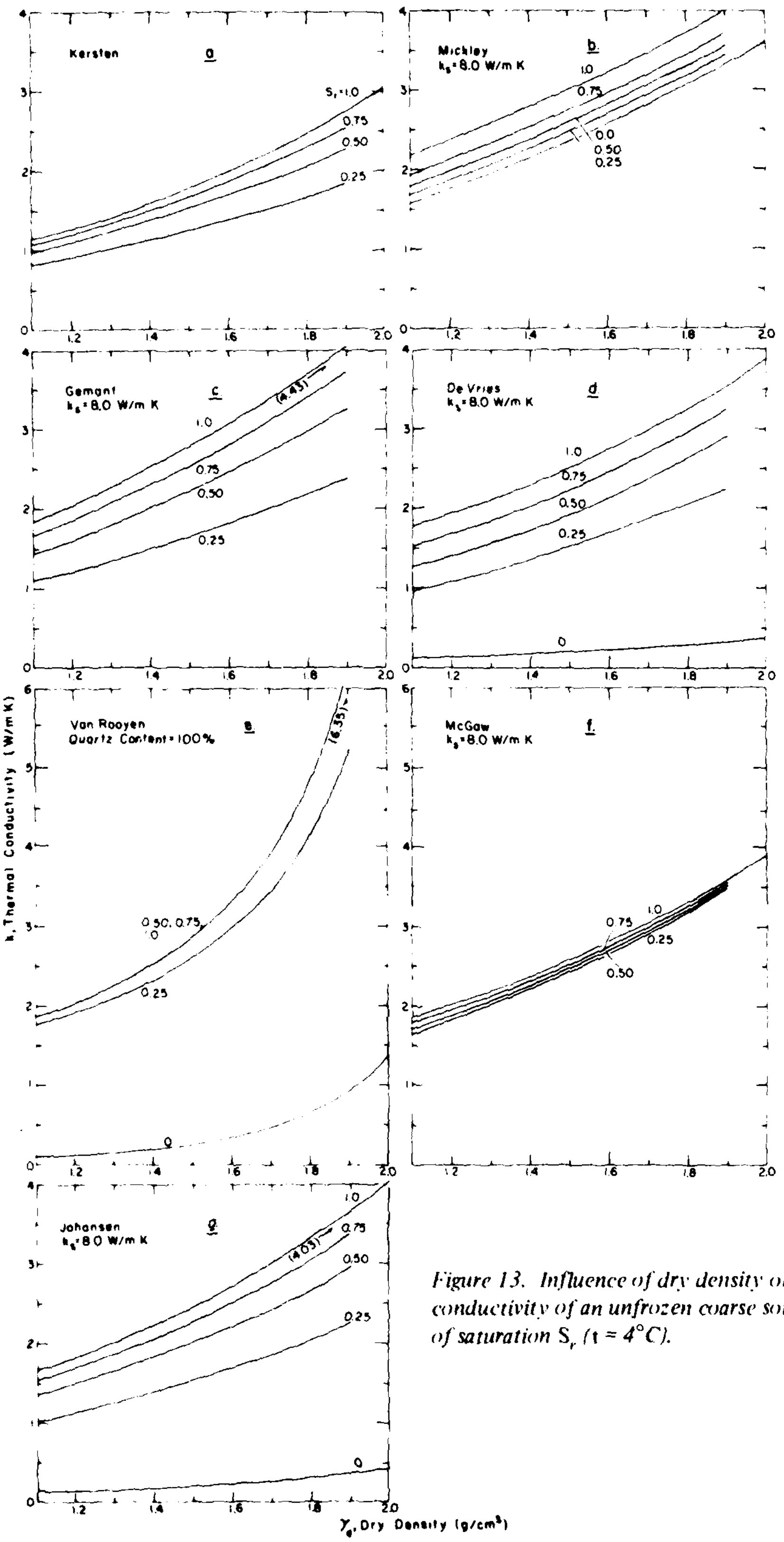

Figure 13. Influence of dry density on calculated thermal conductivity of an unfrozen coarse soil at a constant degree of saturation S_r (t = 4°C).

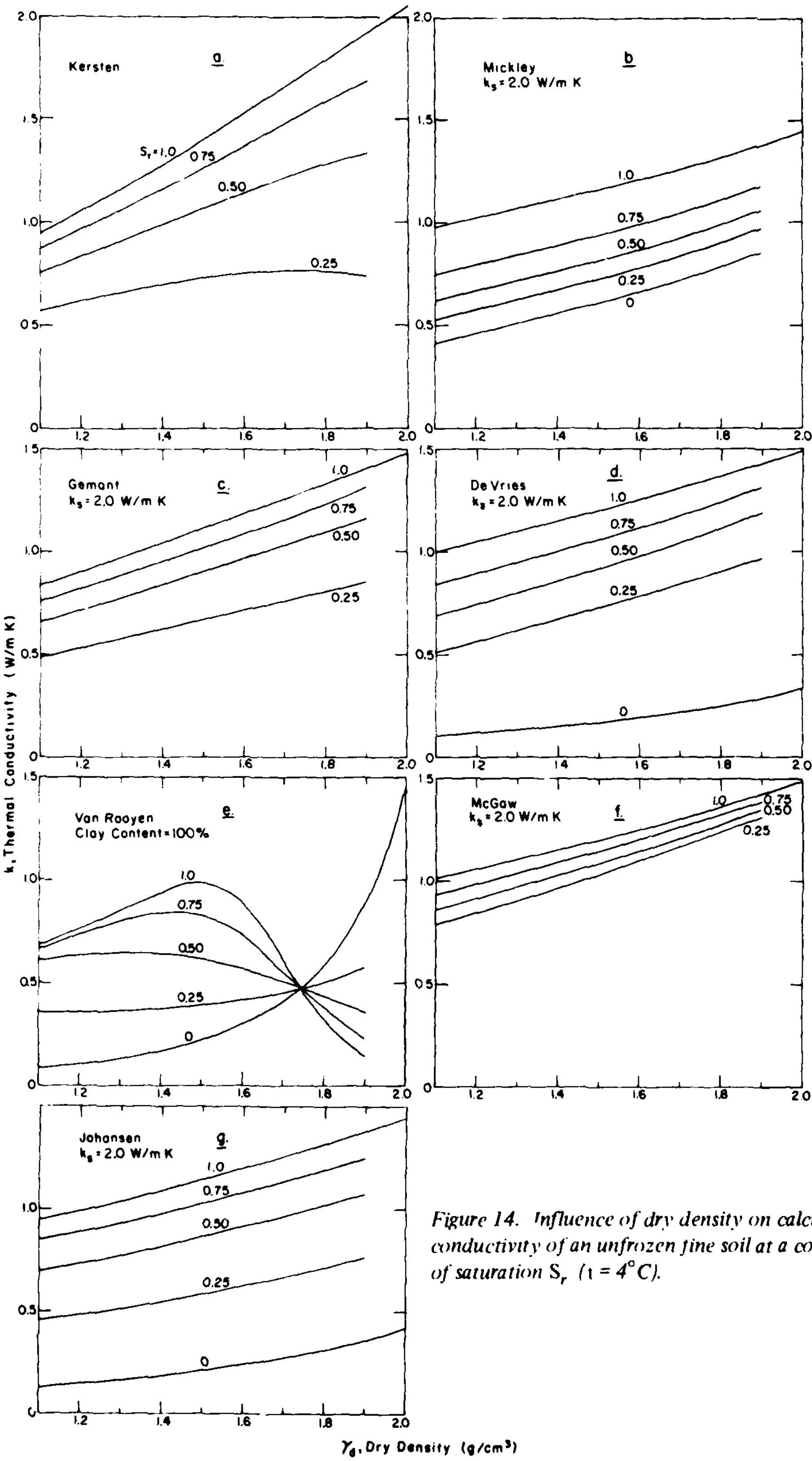

Figure 14. Influence of dry density on calculated thermal conductivity of an unfrozen fine soil at a constant degree of saturation S_r *(t = 4°C).*

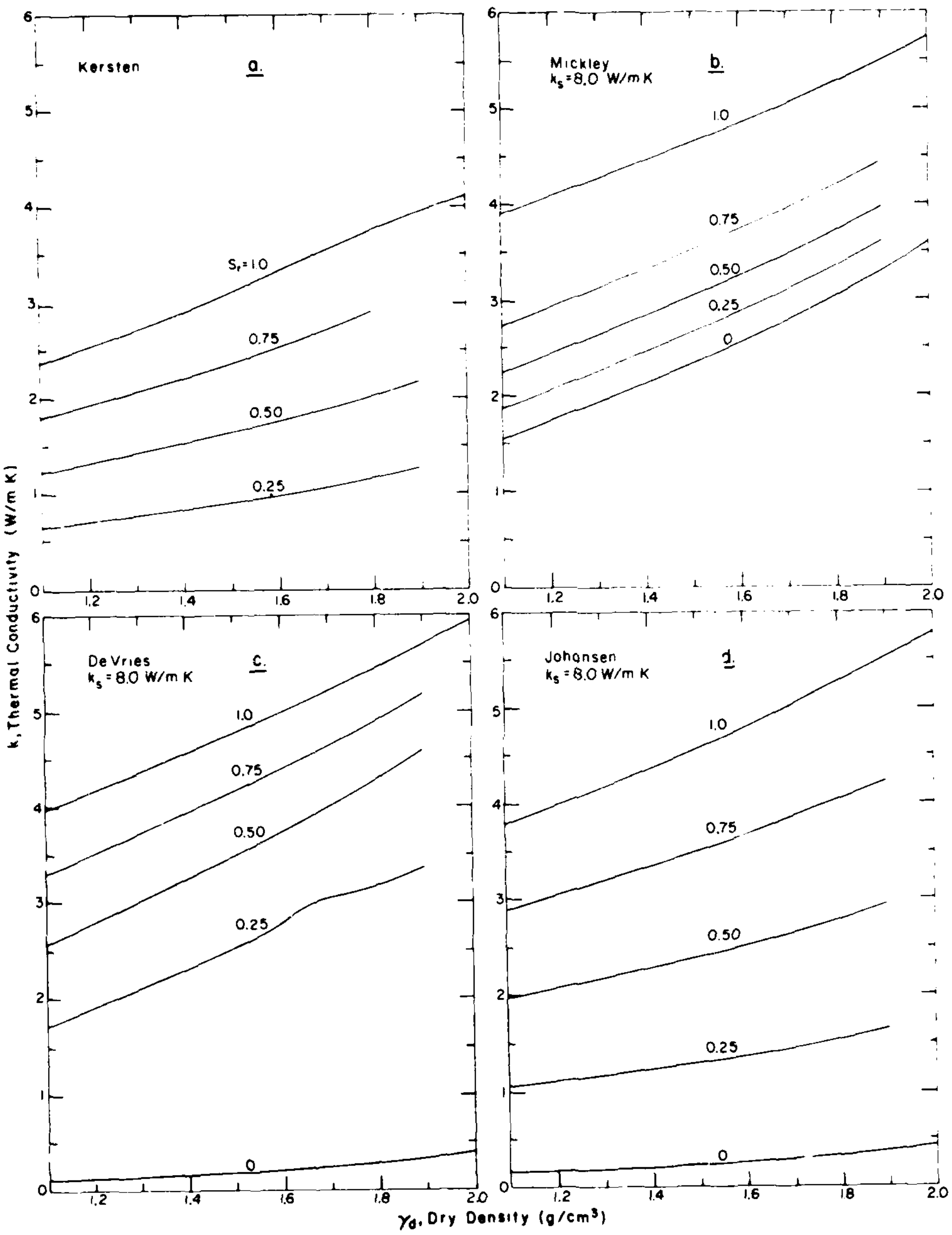

Figure 15. Influence of dry density on calculated thermal conductivity of a frozen coarse soil at a constant degree of saturation S_r *(t = –4°C).*

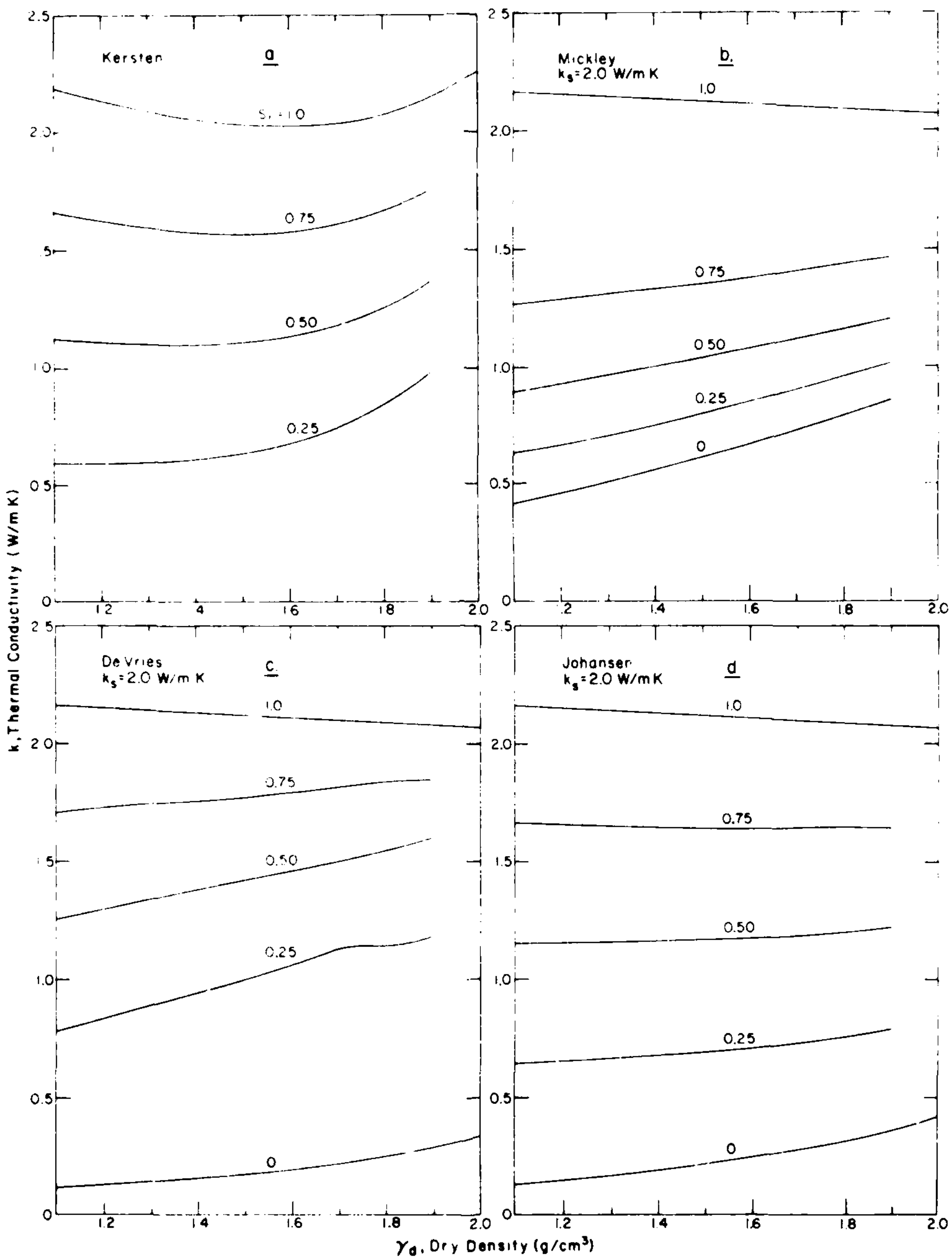

Figure 16. Influence of dry density on calculated thermal conductivity of a frozen fine soil at a constant degree of saturation S_r (t = −4°C).

Table 9. Sensitivity of soil thermal conductivity k (W/m K) of an unfrozen soil to solids conductivity k_s at constant degree of saturation S_r for different methods.

$\gamma_d = 1.6$ g/cm^3

	Johansen Coarse	Johansen Fine	De Vries	Mod. res.	Kunii-Smith	Mickley	McGaw	Gemant	Van Rooyen Coarse
$S_r = 1.0$									
$k_s = 8.0$ W/m K	2.719	-	2.736	3.265	2.270	3.218	2.779	3.066	2.327
$k_s = 4.0$	-	-	-	-	-	-	-	-	0.643
$k_s = 3.0$	1.521	1.521	-	-	-	-	-	-	0.415
$k_s = 2.0$	-	1.197	1.247	1.324	1.129	1.208	1.253	1.181	-
Sensitivity $\partial k/\partial k_s$	0.240	0.324	0.248	0.324	0.190	0.335	0.254	0.314	0.671*
$S_r = 0.5$									
$k_s = 8.0$ W/m K	2.200	-	2.131	-	-	2.811	2.678	2.444	3.327
$k_s = 4.0$	-	-	-	-	-	-	-	-	0.643
$k_s = 3.0$	1.253	1.137	-	-	-	-	-	-	0.415
$k_s = 2.0$	-	0.909	0.973	-	-	0.874	1.149	0.959	-
Sensitivity $\partial k/\partial k_s$	0.189	0.228	-	-	-	0.323	0.255	0.248	0.671*
$S_r = 0.25$									
$k_s = 8.0$ W/m K	1.677	-	1.697	-	-	2.696	2.625	1.823	2.960
$k_s = 4.0$	-	-	-	-	-	-	-	-	-
$k_s = 3.0$	0.982	0.751	-	-	-	-	-	-	0.628
$k_s = 2.0$	-	0.621	0.790	-	-	0.780	1.097	0.716	0.409
Sensitivity $\partial k/\partial k_s$	0.139	0.130	0.151	-	-	0.319	0.255	0.185	0.583*
$S_r = 0$ (dry)									
$k_s = 8.0$ W/m K	0.240	-	0.216	0.302	0.259	-	-	-	0.339
$k_s = 4.0$	-	-	-	-	-	-	-	-	-
$k_s = 3.0$	0.240	0.240	-	-	-	-	-	-	0.198
$k_s = 2.0$	-	0.240	0.193	0.260	0.183	-	-	-	-
Sensitivity $\partial k/\partial k_s$	0.000	0.000	0.0038	0.0070	0.0127	-	-	-	0.0282†

*For k_s varying from 4.0 to 8.0 W/m K

†For k_s varying from 3.0 to 8.0 W/m K

Influence of soil solids' thermal conductivity

A determination was made of the variation in the calculated soil thermal conductivity due to changes in the value of the solids' thermal conductivity k_s at a constant γ_d of 1.6 g/cm^3 and for a constant S_r. Calculations were made for several values of S_r, ranging from dry to saturated. The resulting curves for each S_r value are shown in Figure 17 for unfrozen soil and in Figure 18 for frozen soil. The Kersten method could not be applied as it does not explicitly take k_s into account so that it cannot allow for variation in k_s.

Six methods could be generally applied at all S_r values to unfrozen soils, while only three of these were applicable to frozen soils. In the fully saturated state, two additional methods, Kunii-Smith and the modified resistor equation, were also applicable to both frozen and unfrozen soils. When Johansen was applied at $k_s = 3.0$ W/m K and below, the equation appropriate to fine soil was used. This gives rise to different sensitivities with this method for coarse and for fine soils

Tables 9 and 10 show the values obtained for the absolute sensitivity of the soil thermal conductivity

Table 10. Sensitivity of soil thermal conductivity k (W/m K) of a frozen soil to solids conductivity k_s at constant degree of saturation S_r for different methods.

$\gamma_d = 1.6$ g/cm^3

	Johansen					
	Coarse	*Fine*	*De Vries*	*Mod. res.*	*Kunii-Smith*	*Mickley*
				$S_r = 1.0$		
k_s = 8.0 W/m K	4.793	-	4.996	5.300	4.524	4.837
k_s = 3.0	2.682	2.682	-	-	-	-
k_s = 2.0	-	2.110	2.111	2.113	2.136	2.110
Sensitivity $\Delta k/\Delta k_s$	0.422	0.572	0.481	0.531	0.398	0.455
				$S_r = 0.75$		
k_s = 8.0 W/m K	3.654	-	4.395	-	-	3.724
k_s = 3.0	2.070	2.070	-	-	-	-
k_s = 2.0	-	1.641	1.792	-	-	1.371
Sensitivity $\Delta k/\Delta k_s$	0.317	0.429	0.434	-	-	0.392
				$S_r = 0.5$		
k_s = 8.0 W/m K	2.522	-	3.727	-	-	3.247
k_s = 3.0	1.463	1.463	-	-	-	-
k_s = 2.0	-	1.176	1.463	-	-	1.069
Sensitivity $\Delta k/\Delta k_s$	0.212	0.287	0.377	-	-	0.363
				$S_r = 0.25$		
k_s = 8.0 W/m K	1.381	-	2.792	-	-	2.875
k_s = 3.0	0.851	0.851	-	-	-	-
k_s = 2.0	-	0.708	1.064	-	-	0.845
Sensitivity $\Delta k/\Delta k_s$	0.106	0.143	0.288	-	-	0.338

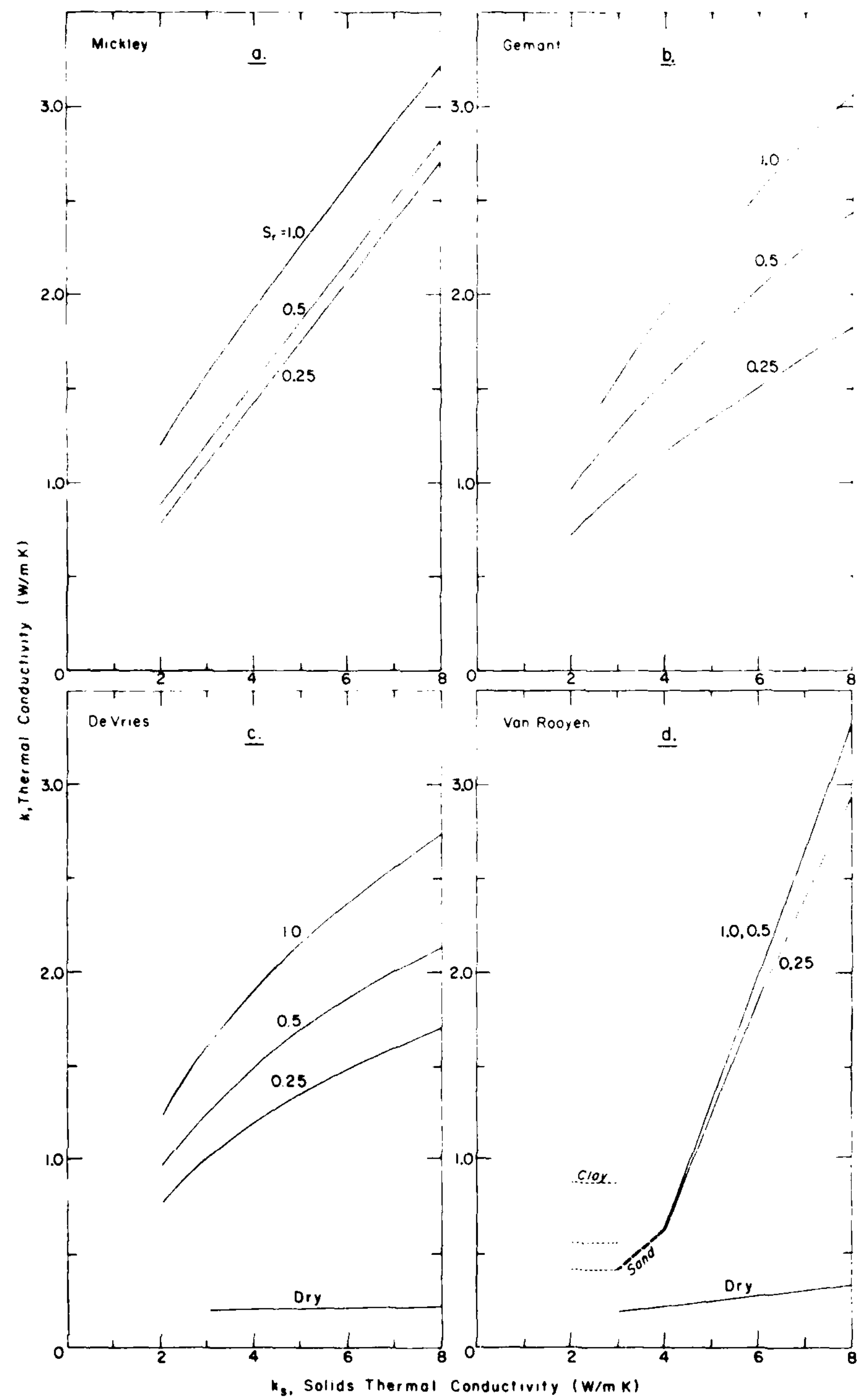

Figure 17. Influence of soil solids' thermal conductivity on calculated thermal conductivity of an unfrozen soil at a constant degree of saturation S_r (t = 4°C, γ_d = 1.6 g/cm^3).

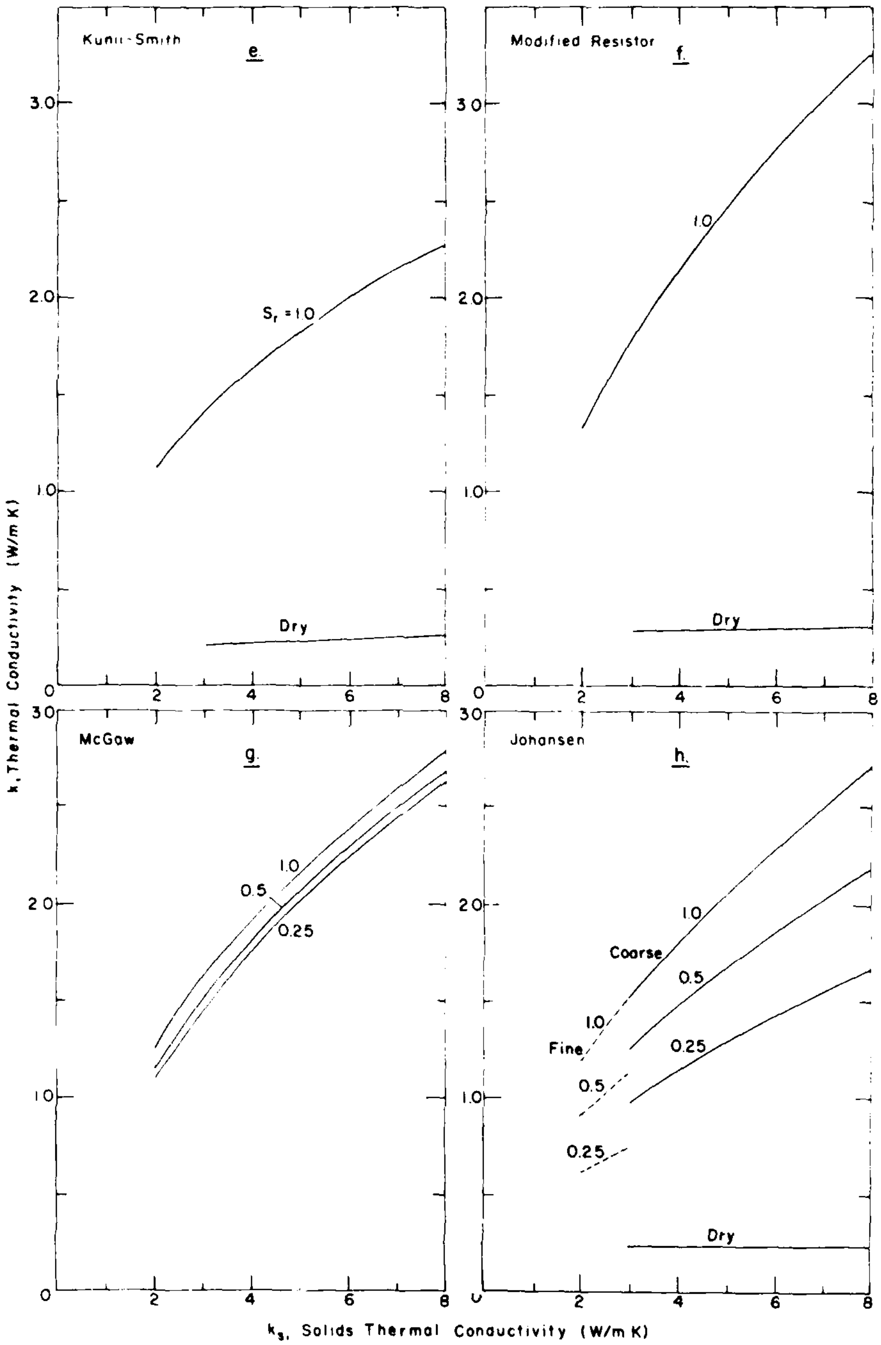

Figure 17 (cont'd).

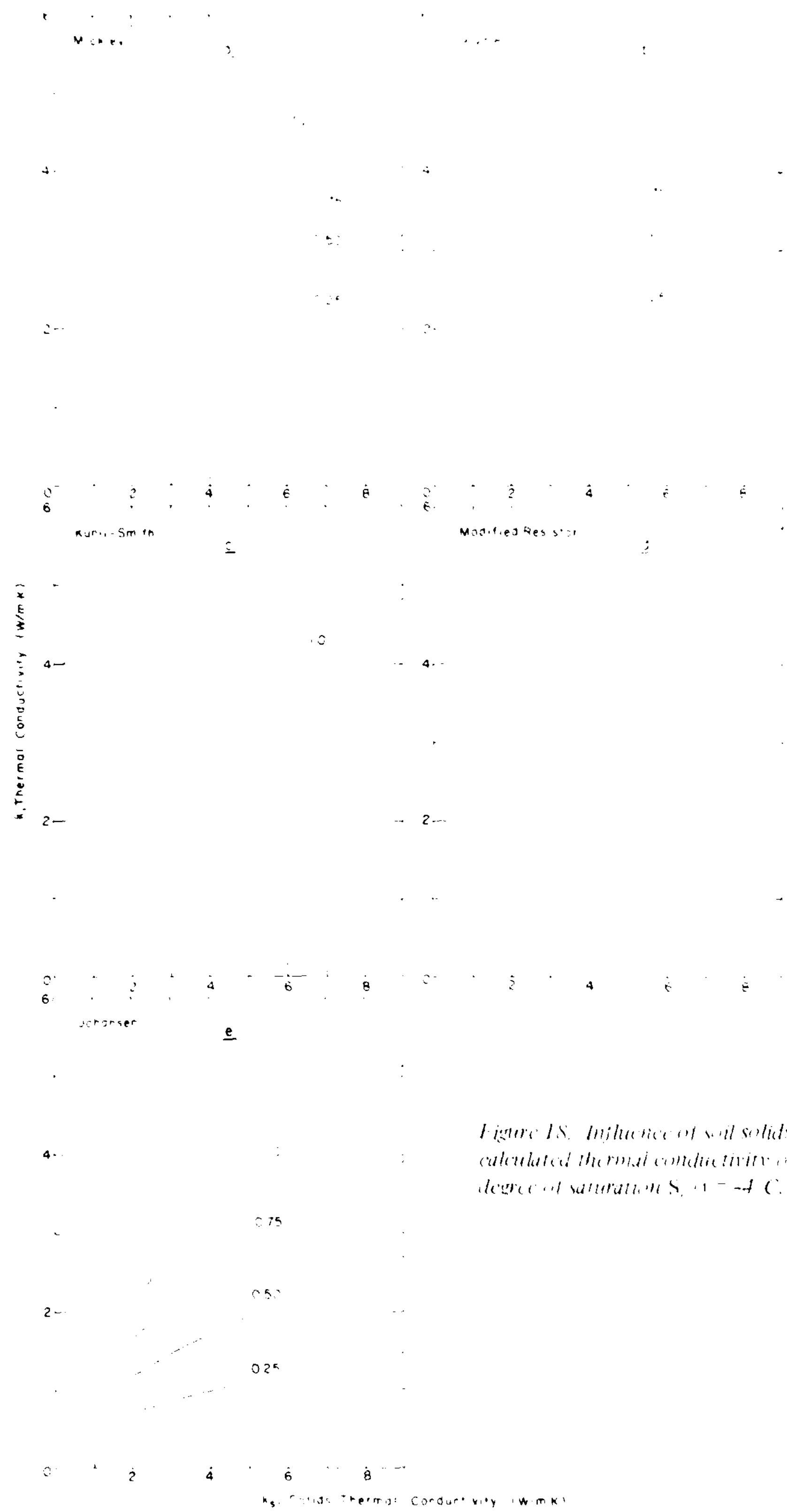

Figure 18. Influence of soil solids' thermal conductivity on calculated thermal conductivity of a frozen soil at a constant degree of saturation S_r (t = -4°C, γ_d = 1.6 g/cm³)

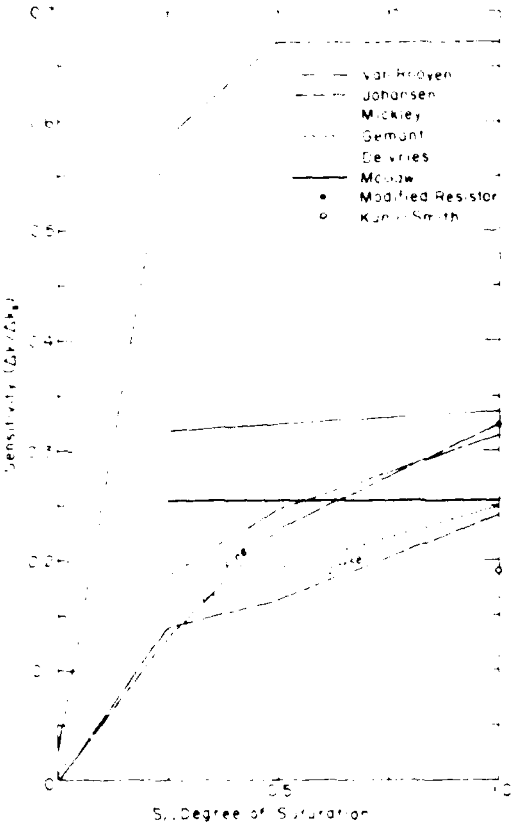

Figure 19. Sensitivity of calculated thermal conductivity to soil solids' thermal conductivity ($\Delta k/\Delta k_s$) of an unfrozen soil as influenced by degree of saturation S_r (γ_d = 1.6 g cm^{-3}).

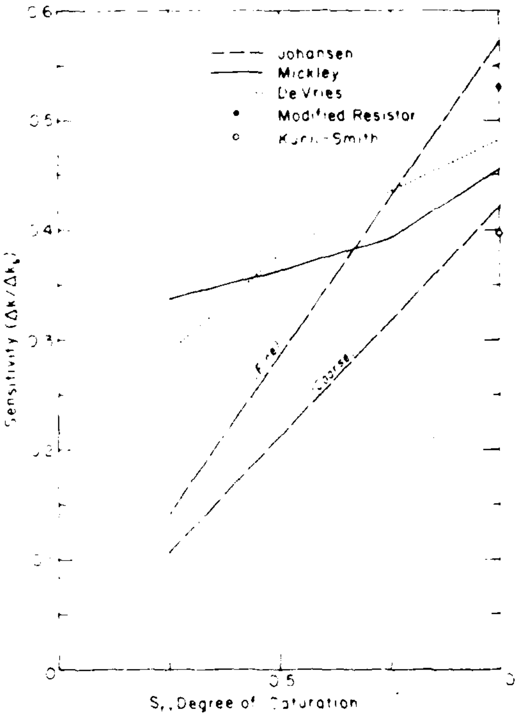

Figure 20. Sensitivity of calculated thermal conductivity to soil solids' thermal conductivity ($\Delta k/\Delta k_s$) in a frozen soil as influenced by degree of saturation S_r (γ_d = 1.6 g cm^{-3}).

to k_s, i.e. the change in the soil thermal conductivity k due to unit change in k_s at constant S_r. The dependence of $\Delta k/\Delta k_s$ on S_r is shown in Figure 19 for unfrozen soil and in Figure 20 for frozen soil.

In the case of unfrozen soil, Van Rooyen gives extremely high sensitivities and differs from the other methods considerably. Johansen, De Vries and Gemant produce sensitivities which increase markedly as S_r increases, while the sensitivities from Mickley and McGaw are almost constant with S_r. For saturated soils Johansen (coarse), De Vries and McGaw give nearly the same sensitivity of about 0.25 while Johansen (fine), Gemant, Mickley and modified resistor give a higher value of about 0.32 (Fig. 19).

For frozen soil Johansen (fine and coarse), De Vries and Mickley give higher sensitivities (i.e. $\Delta k/\Delta k_s$) than for unfrozen soil. Also the rate of increase in the sensitivity with increasing S_r is more marked for the frozen soil. Johansen (fine) shows a particularly large rate of increase (Fig. 20). It is noteworthy that the sensitivities for saturated frozen soil are much higher than the corresponding values for saturated unfrozen soil. This holds for Johansen (coarse and fine), modified resistor, Kunii-Smith, De Vries and Mickley.

Comparison of the various methods

The thermal conductivity values predicted by the various methods are compared for the saturated condition, for S_r = 0.5 and for the dry condition in Figures 21-30. This has been done over a γ_d range from 1.1 to 2.0 g/cm^3. Apart from Kersten the values chosen for k_s were 8.0 W/m K for coarse soil and 2.0 W/m K for fine soil.

The nine methods applicable to saturated unfrozen coarse soil all show a similar trend for the increase in thermal conductivity with increasing γ_d (Fig. 21). Kersten and Van Rooyen give the lowest thermal conductivity values while Mickley, modified resistor and Gemant give the highest values. Johansen, De Vries and McGaw give almost coincident curves.

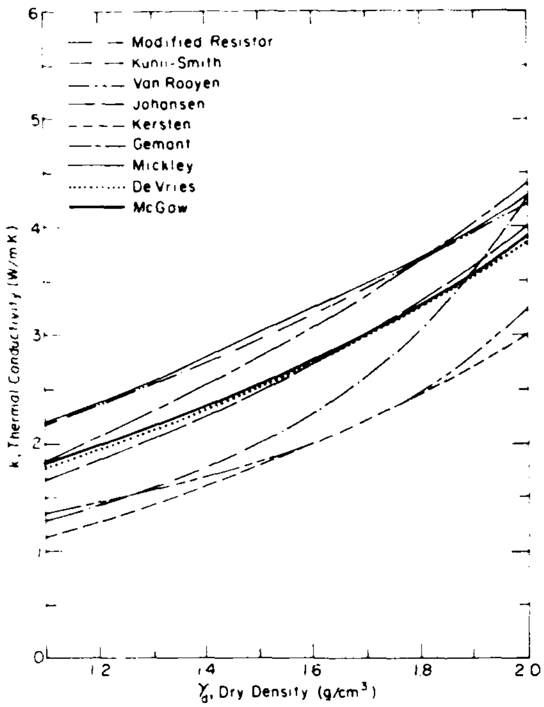

Figure 21. Comparison of thermal conductivity values calculated by the various methods for a saturated unfrozen coarse soil at different dry densities (t = 4°C, k_s = 8.0 W/m K).

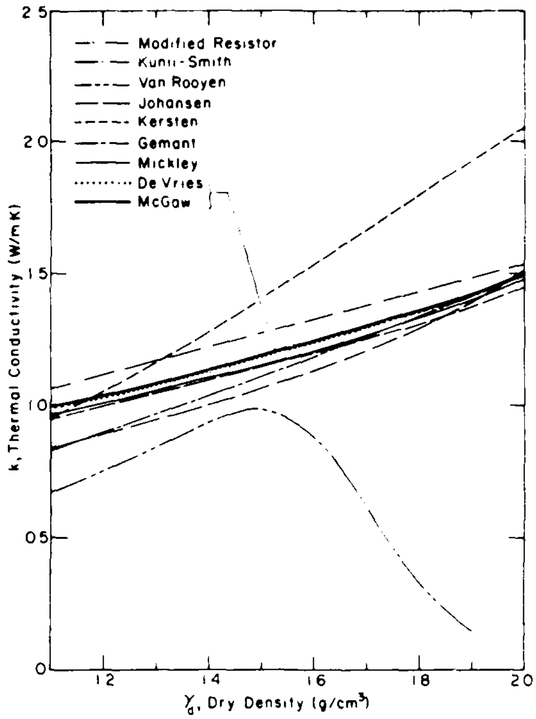

Figure 22. Comparison of thermal conductivity values calculated by the various methods for a saturated unfrozen fine soil at different dry densities (t = 4°C, k_s = 2.0 W/m K).

For saturated unfrozen fine soil (Fig. 22), Kersten gives the highest values above a γ_d of 1.3 g/cm³. Van Rooyen provides the lowest values and is unreliable at values of γ_d over 1.5 g/cm³. Johansen, De Vries, modified resistor, Kunii-Smith, Mickley and Gemant differ noticeably at low γ_d values, but show a similar, almost linear, trend and closely approach each other at high γ_d.

In the case of saturated frozen coarse soil (Fig. 23), Kersten gives much lower values than the other five methods. Modified resistor gives the highest values, showing a linear increase to which De Vries, Mickley and Johansen are approximately parallel.

With regard to saturated frozen fine soil (Fig. 24), the six methods give values which differ little from each other. In fact, Johansen, De Vries, modified resistor and Mickley all give coincident curves. Also, the thermal conductivity does not vary much with γ_d as may be expected because the replacement of ice, having a k_i of 2.2 W/m K, by the mineral solid, having a k_s of 2.0 W/m K, should not make much difference to the overall soil thermal conductivity.

The seven curves for the partially saturated unfrozen sand (S_r = 0.5) all show a similar trend, except for Van Rooyen's, which rises rapidly above a γ_d of 1.4 g/cm³ (Fig. 25). As with the saturated coarse soil, Kersten gives the lowest values while Mickley gives the highest (apart from Van Rooyen, which shows odd behavior). The curves given by Johansen and De Vries are close together and represent roughly average values.

With partially saturated unfrozen fine soil, some opposite trends are apparent (Fig. 26). Van Rooyen and Mickley give the lowest values, with Van Rooyen showing an incongruent decrease at γ_d above 1.3 g/cm³. Contrary to the coarse soil case, Kersten gives one of the highest curves, while De Vries, Gemant and Johansen give curves at intermediate positions.

For partially saturated frozen coarse soil, the four applicable methods give curves which differ by large amounts, although they show similar trends (Fig. 27). Kersten gives the lowest thermal conductivity values while De Vries gives the highest. At high γ_d, De Vries gives values that are more than twice as high as those given by Kersten.

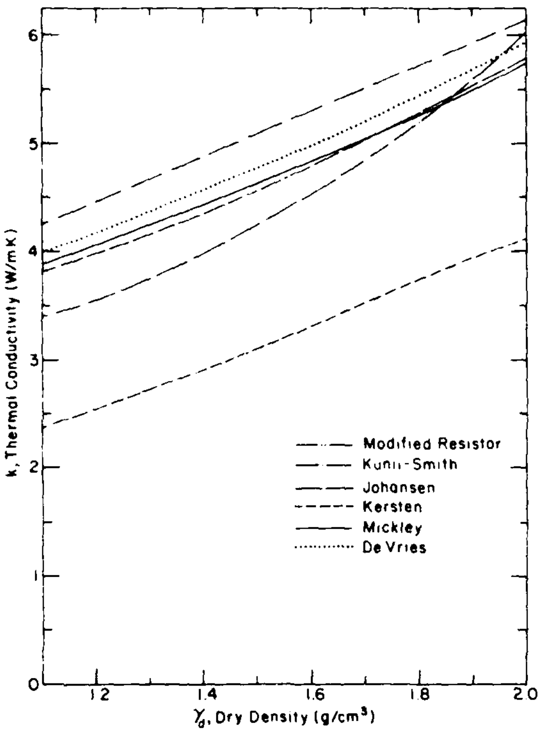

Figure 23. Comparison of thermal conductivity values calculated by the various methods for a saturated frozen coarse soil at different dry densities (t = -4°C, k_s = 8.0 W/m K).

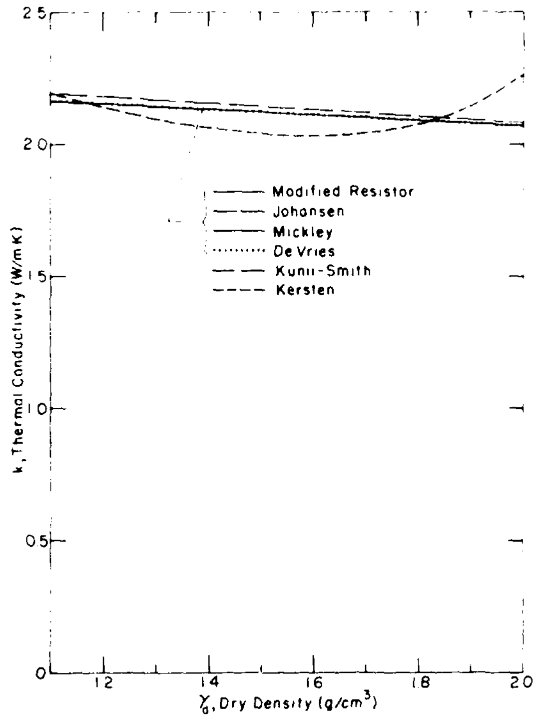

Figure 24. Comparison of thermal conductivity values calculated by the various methods for a saturated frozen fine soil at different dry densities (t = -4°C, k_s = 2.0 W/m K).

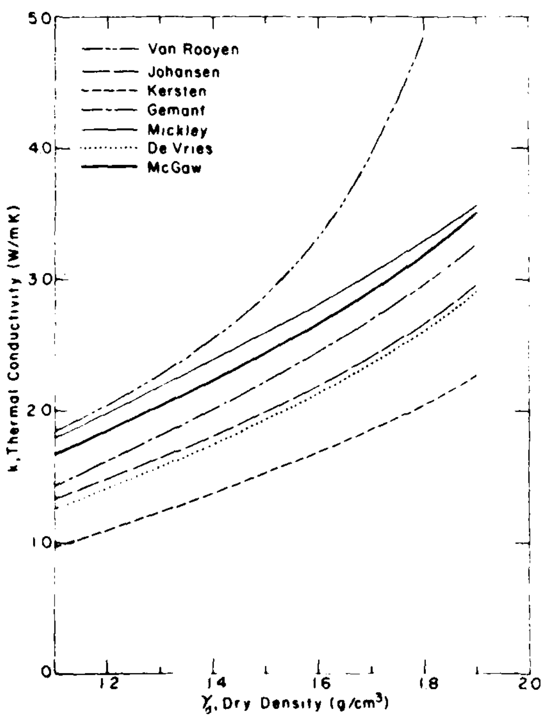

Figure 25. Comparison of thermal conductivity values calculated by the various methods for an unsaturated unfrozen coarse soil at different dry densities with S_r = 0.5 (t = 4°C, k_s = 8.0 W/m K).

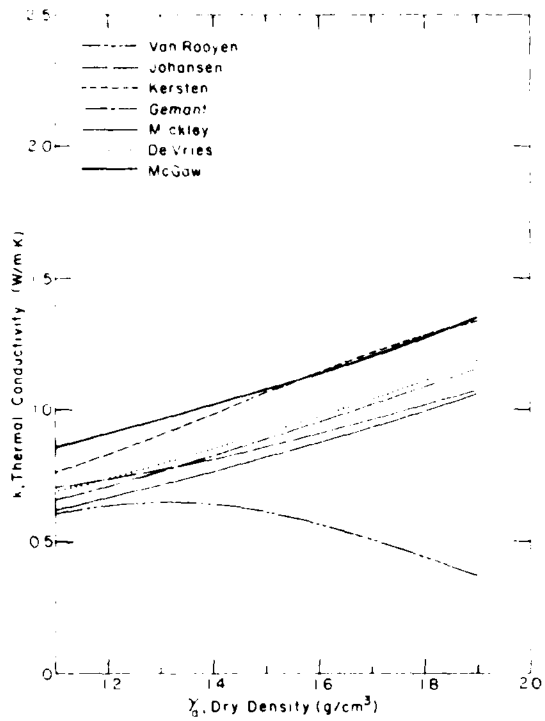

Figure 26. Comparison of thermal conductivity values calculated by the various methods for an unsaturated unfrozen fine soil at different dry densities with $S_r = 0.5$ ($t = 4°C$, $k_s = 2.0$ W/m K).

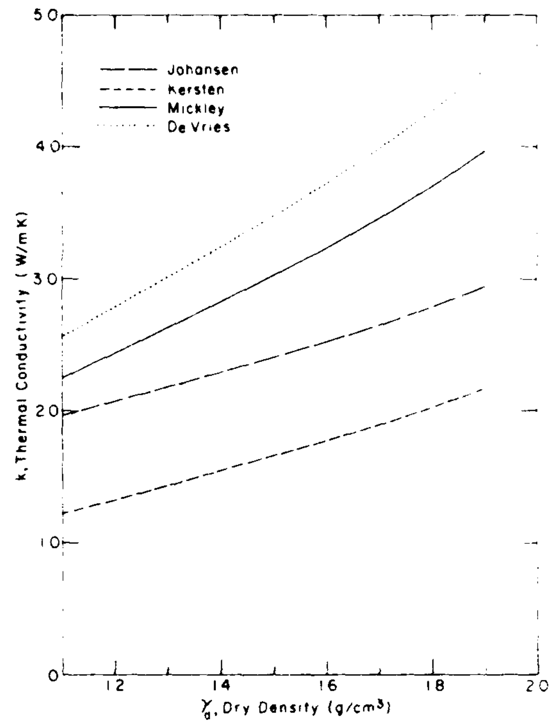

Figure 27. Comparison of thermal conductivity values calculated by the various methods for an unsaturated frozen coarse soil at different dry densities with $S_r = 0.5$ ($t = -4°C$, $k_s = 8.0$ W/m K).

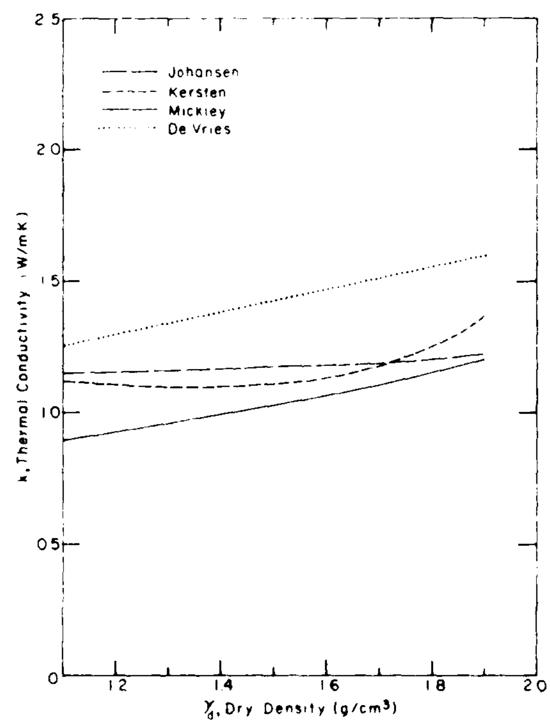

Figure 28. Comparison of thermal conductivity values calculated by the various methods for an unsaturated frozen fine soil at different dry densities with $S_r = 0.5$ ($t = -4°C$, $k_s = 2.0$ W/m K).

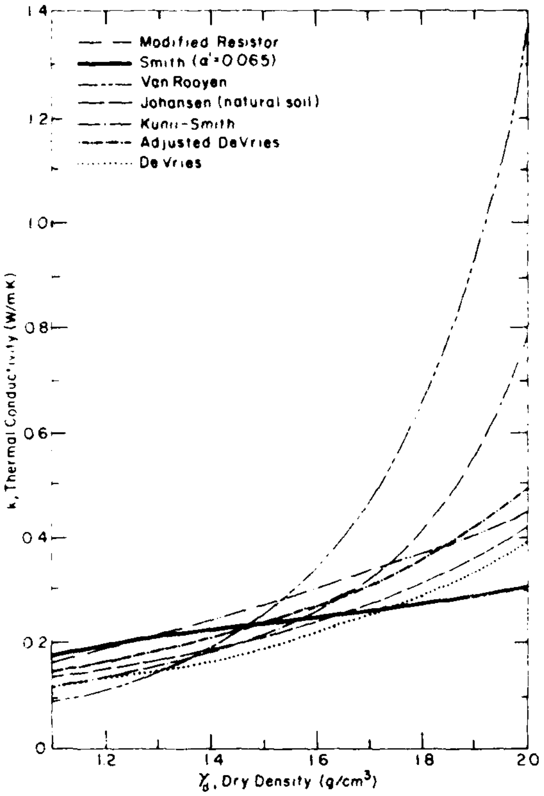

Figure 29. Comparison of thermal conductivity values calculated by the various methods for a dry coarse soil at different dry densities (t = 4°C, k_s = 8.0 W/m K).

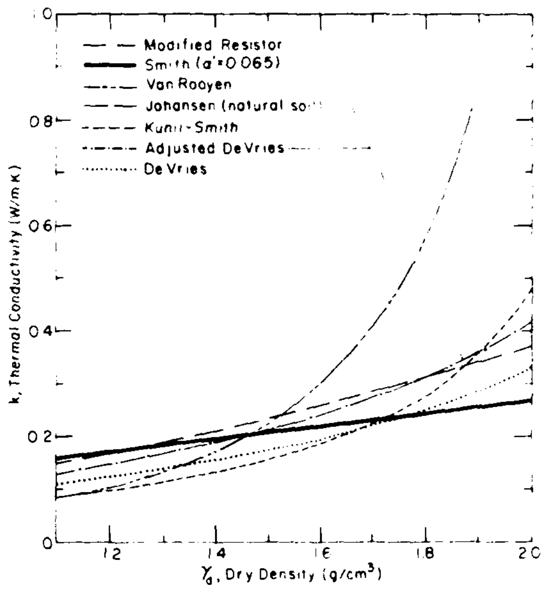

Figure 30. Comparison of thermal conductivity values calculated by the various methods for a dry fine soil at different dry densities (t = 4°C, k_s = 2.0 W/m K).

The differences are less pronounced for frozen fine soil at partial saturation (Fig. 28). Kersten and Johansen do not differ by much over the whole γ_d range, and Mickley approaches them at high γ_d. De Vries gives the highest values, about 15% greater than Kersten and 30% greater than Johansen or Mickley at the highest γ_d (1.9 g/cm³).

For dry coarse soil all the applicable methods show a similar trend, except that the curves of Van Rooyen and Kunii-Smith start to rise quickly above γ_d = 1.5 g/cm³ (Fig. 29). Johansen and De Vries give curves that are close together and nearly parallel, and modified resistor gives a similar curve that is higher. The adjusted De Vries equation gives higher values than the modified resistor equation at the highest γ_d. Smith shows a somewhat different trend, giving the lowest values at high γ_d. For this method the value chosen for α' (thermal structure factor) was 0.065.

In the case of dry fine soil (Fig. 30), Van Rooyen again shows an excessive rate of increase in the thermal conductivity above γ_d = 1.5 g/cm³, but Kunii-Smith appears reasonable up to γ_d = 1.9 g/cm³. The curves from Johansen and adjusted De Vries are practically coincident, while Smith again gives lower values at a γ_d above 1.8 g/cm³.

The temperature difference of 8°C between the frozen and unfrozen dry conditions does not produce appreciable changes in the soil thermal conductivity.

In the next section there is a detailed testing of all the methods against actual experimental data for different soil types and conditions. The methods are evaluated so as to determine under which conditions each method gives good predictions and in order to recommend the best method(s) applicable to soils in various conditions.

EVALUATION OF METHODS FOR CALCULATING THERMAL CONDUCTIVITY

This section presents an evaluation of the various proposed methods for calculating the thermal conductivity of soils. This evaluation was carried out using a computer program which analyzed data obtained by various experimenters on soils with known characteristics. In particular, knowledge of the quartz content was important. The thermal conductivity predicted by each method was then computed at appropriate values of the moisture content and dry density. The deviation of this computed value from the measured value was then obtained. (It should be noted that measured values may not always be accurate).

Comparison of the deviations produced by the various methods indicates which methods give good agreement under the relevant conditions. The evaluation is done for moist coarse and fine soils, unfrozen or frozen, and for dry soils.

Soils data used for evaluation

All the methods for calculating soil thermal conductivity, except Kersten, depend on knowledge of the solids thermal conductivity k_s. The solids component which could have a major influence on the value of k_s is quartz, because quartz has a thermal conductivity appreciably larger than any other possible soil solid component. In order, therefore, to get a reliable value of k_s for use in any of these methods, it is essential to know the quartz content of the soil solids. So the different methods were evaluated by comparing their predictions with the thermal conductivity values measured on soils with known quartz content. The quartz content was supplied by Kersten (1949) and Johansen (pers. comm.) for each of the soils and soil materials they tested.

The evaluation was also carried out on other soils for which values of k_s were either suggested by the respective experimenters (e.g. Penner 1970, Smith and Byers 1938) or could be suitably chosen, depending on the type of soil. In these cases uncertainty about the actual k_s value makes the evaluation inaccurate to some extent. However, such an evaluation should show the main trends in the predictions and deviations, providing at least a general comparison.

Computer program

The computer program* calculates the value of the soil thermal conductivity for the given soil input data. This is done for each of the methods appropriate to the particular soil condtion, frozen or unfrozen, and saturated, unsaturated or dry. The input data consist of the soil sample's dry density, moisture content, unfrozen water content (where applicable) and the thermal conductivity value measured for that sample.

Other basic parameters to be input include the quartz content q (as a fraction of the solids content) and the values of the thermal conductivities of the soil components at the temperature of measurement. These are the thermal conductivity values for the soil air, water and ice, and those for quartz (k_q) and the solid components other than quartz (k_o). From k_o and k_q the program calculates k_s using the geometric mean equation

$$k_s = k_o^{(1-q)} k_q^q .$$

Alternatively, k_s may be input directly if it is known or if a suitable value is assumed.

When Van Rooyen is applied to fine soils, a value for the clay content has to be input as known or as estimated. Van Rooyen also differentiates fine soils into clay and silt. When Smith is applied to dry soils (coarse or fine), a suitable value must be input for the thermal structural factor α'.

The computer program converts the input value of measured thermal conductivity into W/m K if it is not already in these units. It also converts the dry density to metric units. It then calculates the thermal conductivity given by each method selected and determines its deviation from the measured value. This deviation is expressed as a percentage of the measured value. The program also calculates the porosity of the soil, its degree of saturation and its unfrozen water content as a fraction by volume of the total soil volume.

Input parameters

Specific gravity of the soil solids. This was generally taken as 2.70, unless a particular value was given by the experimenter. The program uses this specific gravity and the input soil dry density to calculate the soil porosity.

Temperature. It was necessary to know the temperature at which the measurement was made so that the values of the thermal conductivity of the soil components appropriate to this temperature could be input. In cases where the experimenters had not specified the temperature, a suitable value was assumed.

Thermal conductivity of soil air k_a. For dry soil k_a was taken as 0.024 W/m K at 0°C or below and 0.025 W/m K at 10°C. Where the soil was moist and unsaturated, moisture migration effectively increases k_a, depending upon the temperature. Under these conditions the values of k_a chosen at different temperatures were taken or interpolated from Table 11 which follows from the suggestions of De Vries (1963).

*Available from the author.

Table 11. Apparent thermal conductivity of moist pore air k_a (based on De Vries 1963)*.

Temperature (°C)	k_a *(W/m K)*
0	0.046
5	0.055
10	0.067
15	0.078
20	0.099
25	0.120
30	0.151

*Assuming air is saturated with water vapor.

Thermal conductivity of soil water k_w. The thermal conductivity of the soil water k_w was calculated at different temperatures using the following equation given in the *Thermophysical Properties of Matter* (Touloukian et al. 1970):

$$10^6 k_w = -1390.53 + 15.1937\,T$$

$$- 0.0190398T^2$$

which gives k_w in units of cal/cm s °C, T being the absolute temperature. The resulting values of k_w are given in Table 12. For intermediate temperatures, k_w was interpolated linearly.

Table 12. Thermal conductivity of water k_w*.

Temperature (°C)	k_w *(W/m K)*
0	0.560
5	0.570
10	0.579
15	0.588
20	0.597
25	0.605
30	0.613

*Based on the equation given by Touloukian et al. (1970).

Unfrozen water content UWC. In some cases the unfrozen water content was known from the experimenter's data (e.g. Penner's Leda clay). In other cases a suitable value of UWC was assumed, depending on the soil texture, or the UWC was simply set at zero.

For unfrozen soils the UWC value in the computer printout tables in Appendix B represents the moisture content of the soil expressed as a fraction of the total soil volume.

Thermal conductivity of soil ice k_i. To determine the value of k_i the following formula quoted by Sawada (1977) was used:

$$k_i = 488.19/T + 0.4685 \text{ W/m K}$$

T being the absolute temperature. The resulting values of k_i at different temperatures are given in Table 13. At intermediate temperatures, k_i was linearly interpolated.

Table 13. Thermal conductivity of ice k_i*.

Temperature (°C)	k_i *(W/m K)*
0	2.26
- 4	2.28
-10	2.32
-15	2.36
-20	2.40
-25	2.44
-30	2.48

*Based on the formula given by Sawada (1977).

Thermal conductivity of quartz k_q. Quartz is anisotropic, having a thermal conductivity parallel to the c-axis $k_{\parallel}$ greater than the conductivity at right angles to this axis $k_{\perp}$. The thermal conductivity of a polycrystalline quartz aggregate of random orientation was determined using a geometric mean equation (Farouki 1981).

$$k_q = (k_{\perp}\, k_{\perp}\, k_{\parallel})^{1/3} = k_{\perp}^{\;2/3}\, k_{\parallel}^{\;1/3}.$$

Table 14. Thermal conductivity of quartz k_q*.

Temperature (°C)	k_q *(W/m K)*
30	7.28
25	7.43
20	7.58
15	7.72
10	7.86
4	8.04
0	8.16
- 4	8.29
-10	8.50
-20	8.84
-30	9.18

*Based on the tabulated data for $k_{\parallel}$ and $k_{\perp}$ in Touloukian et al. (1970).

The values of k and k at various temperatures were taken from the *Thermophysical Properties of Matter* (Touloukian et al. 1970). Where necessary these were linearly interpolated and then used in the geometric mean equation to calculate k_q at various temperatures. The results are given in Table 14 and these again were linearly interpolated to arrive at values of k_q for intermediate temperatures.

Thermal conductivity of the soil solids other than quartz, k_o. As suggested by Johansen (1975), the value of k_o was usually taken to be 2.0 W/m K irrespective of temperature. For coarse soils, however, having a quartz content less than 20% of the solids, some calculations were also made with k_o taken as 3.0 W/m K, a value assumed by Johansen for these soils.

Owing to the uncertainty in the value of k_o, there was no point in varying its input value with temperature. It should be noted, however, that the thermal conductivity of feldspar increases as the temperature increases. Feldspar may be the chief component other than quartz. This behavior of feldspar is exceptional among crystalline materials which usually show a decrease in the thermal conductivity as the temperature increases. Variations in k_o with temperature may therefore be somewhat dampened.

Thermal structural value α' *for dry soils.* Where the Smith method is applied to dry soils, a suitable value of α' must be input.

Some program details

When the data for a particular soil were input, the soil had to be specified as being coarse or fine and its condition as being unfrozen or frozen, and unsaturated, saturated or dry. It had also to be specified as natural or crushed so that the appropriate equation in the Johansen method could be applied.

The thermal conductivity methods to be applied in each case are specified. For dry soils, the program automatically calculates the adjusted De Vries value from the value given by De Vries' method. For saturated soils, the computer program calculates the geometric mean value assuming a two-phase material (i.e. solid and water or ice).

Gemant method. This method is inapplicable when the moisture content is below a certain value corresponding to the adsorbed film water. The solids thermal conductivity obtained from the equation suggested by Gemant* was computed by the program and represented as CSOLIDS 2. This was for comparison and it was not used further.

De Vries method. While De Vries' method was not originally intended to apply to frozen soils, Penner (1970) applied it to two frozen clays with good results. It was decided for this analysis to apply De Vries to different conditions of frozen soils, i.e. saturated or unsaturated, and partially or completely frozen.

For saturated frozen soils containing some unfrozen water, this water may be considered as the continuous medium, so the following equation was used for the soil thermal conductivity k:

$$k = \frac{x_w k_w + F_i x_i k_i + F_s (1-n) k_s}{x_w + F_i x_i + F_s (1-n)} .$$

The equation for such soils that are partially saturated is

$$k = \frac{x_w k_w + F_i x_i k_i + F_a x_a k_a + F_s (1-n) k_s}{x_w + F_i x_i + F_a x_a + F_s (1-n)} .$$

If the frozen soils can be considered to have no unfrozen water content (e.g. frozen gravels or sands), the ice is taken to be the continuous medium, giving the equations

$$k = \frac{x_i k_i + F_s (1-n) k_s}{x_i + F_s (1-n)}$$

for saturated soils where $x_i = n$, the porosity, and

$$k = \frac{x_i k_i + F_a x_a k_a + F_s (1-n) k_s}{x_i + F_a x_a + F_s (1-n)}$$

for unsaturated soils.

In the above equations x represents the volume fraction of the soil component corresponding to its subscript (w for water, i for ice, a for air and s for soil solids). The 'F' values are given by

$$F_s = \frac{1}{3} \left\{ \frac{2}{1 + \left[(k_s/k_f) - 1 \right] 0.125} + \frac{1}{1 + \left[(k_s/k_f) - 1 \right] 0.75} \right\}$$

$$F_i = \frac{1}{3} \left\{ \frac{2}{1 + \left[(k_i/k_f) - 1 \right] 0.125} + \frac{1}{1 + \left[(k_i/k_f) - 1 \right] 0.75} \right\}$$

*This equation is $k_s = 5.84 - 0.33p$ W/m K where p is the percent of clay in the soil solids (see Farouki 1981).

and

$$F_a = \frac{1}{3}\left\{\frac{2}{1 + \left[(k_a/k_f) - 1\right] g_a} + \frac{1}{1 + \left[(k_a/k_f) - 1\right] g_c}\right\}$$

in which k_f is the thermal conductivity of the fluid continuous medium (unfrozen water or ice), and the shape factors g_a, g_c for the pore air are given by (De Vries 1963)

$$g_a = 0.333 - x_a \frac{(0.333-0.035)}{n}$$

for $0.09 \leq x_f \leq n$, or

$$g_a = 0.013 + 0.944\, x_f$$

for $0 \leq x_f < 0.09$, and

$$g_c = 1 - 2g_a .$$

Mickley method. Although Mickley's method was originally derived for unfrozen soils it was also applied here to frozen soils simply by considering ice to occupy the place of water in the unit cube soil model (Mickley 1951).

McGaw method. In applying McGaw's conductance equation, the interfacial efficiency ϵ was taken as unity. A value for n_c (the volume of series fluid in unit soil volume) was required and this was calculated using

$$n_c = n(1-n)\,(0.304-0.09 \log k_s/k_w)$$

as suggested by McGaw (pers. comm.). If this equation, however, gave a value for n_c which was greater than nS_r, the magnitude of n_c was limited to nS_r. (The computer printout tables in Appendix B give the n_c value in the form *NC*.)

Van Rooyen method. The equation of Van Rooyen and Winterkorn (1959) is:

$$1/k = A\,10^{-BS_r} + s \text{ cm °C/W} .$$

Where $A = 10^{a_1 - 0.44\gamma_d^2}$,

$$B = b_1 - 5.5\gamma_d$$

$$s = s_1 - s_2\gamma_d$$

S_r = the degree of saturation of the soil (fractional)

and

γ_d is its dry density (g/cm³).

Based on the experimental data and analysis of Van Rooyen and Winterkorn (1959), the value of a_1 was taken as 3.55 and the following values for b_1, s_1 and s_2 were chosen for the different soil types. For cohesionless soil:

$$b_1 = 16.18$$

$$s_2 = 47.5$$

$s_1 = 200 - 94q$ for $q > 0.75$

or $s_1 = 435 - 407q$ for $0.75 > q > 0.20$

or $s_1 = 353.6$ for $q < 0.20$

where q is the quartz content (fractional). For cohesive soils:

silts

$$b_1 = 5.6 \times 10^{-4p} + 9.58$$

$$s_2 = 134.6$$

$$s_1 = 202$$

clays

$$b_1 = 5.6 \times 10^{-4p} + 9.58$$

$$s_2 = 155$$

$$s_1 = 317$$

where p is the clay content (fractional).

Thus the quartz content for cohesionless soils and the clay content for cohesive soils are required as input data. If the latter was not known, the following rough average values for b_1 were used:

$b_1 = 11.8$ for silts

or $b_1 = 9.58$ for clays .

Van Rooyen is the only method which differentiates cohesive soils by subdividing them into clays and silts according to the general description of the soil.

Applicability of the methods

In this section the various methods for calculating thermal conductivity are tested to see under what conditions their predictions agree with measured values of the thermal conductivity and to determine the extent of agreement. The deviations of the predicted values from the measured values are determined at different values of dry density and moisture content. This is done for soils that are unfrozen or frozen, coarse or fine, unsaturated, saturated or dry.

Applicability to unfrozen coarse soils

Figures 31 and 32 show the deviations given by the seven* applicable methods which were tested on data for unfrozen coarse soils and crushed rocks. These data are the result of measurements made by Kersten (1949) on Fairbanks sand, Lowell sand, Northway fine sand, Northway sand, standard Ottawa sand, graded Ottawa sand, Chena River gravel, crushed trap rock, crushed feldspar, crushed granite, crushed quartz and crushed fine quartz; by Johansen (pers. comm.) on sands SA1, SA2, SA4, SA8, SA13 and gravels GR1, GR6, GR7 and GR12, on crushed rocks PU1, PU5, PU6, PU7, PU9 and PU10; and by De Vries (1963) on Wageningen sand (data on these soils are given in Appendix A).

Kersten method. Figure 31a shows the deviations given by Kersten for unfrozen sands. As Kersten himself noted his relevant equation does not apply to the sands he tested that had a low quartz composition, i.e. Northway sand and Northway fine sand. It gives values that are too high, with deviations up to 150% for most of the saturation range (see Appendix Tables B1 and B2). The Kersten equation also gives some high deviations (55%) for several Johansen sands with intermediate quartz content (Fig. 31a).

For the sands tested by Kersten that have medium or high quartz content (Fairbanks sand, Lowell sand, standard and graded Ottawa sand), the Kersten equation generally gives good agreement within ±20%, many of the deviations being negative. Such an agreement may be expected because Kersten fit his equation to these experimental data. However the Kersten equation underpredicts when applied to the data obtained by other workers on sands having high quartz content. Thus for the sands of Johansen and De Vries having high quartz content (Johansen sands SA4 and SA13, De Vries Wageningen sand [$q > 0.65$]), the Kersten equation gives many deviations in the range -25 to -50% at varied values of S_r.

The deviations resulting from the application of the Kersten equation to unfrozen gravels and crushed rocks are shown in Figure 32a. The predictions given by the Kersten equation show similar trends with these gravels and crushed rocks as with the sands considered above. Thus Kersten gives predictions that are much too high for the low-quartz gravel GR7 (Table B3) and the deviations remain substantial at high values of S_r. In the same manner, for all Johansen's crushed rocks which have low quartz content (PU1, PU5, PU6, PU7, PU9, PU10), Kersten gives predictions that are much too high, the deviations reaching 144% (e.g. Table B4). Kersten also gives unacceptably high predictions for the low-quartz crushed rocks tested by him, i.e. crushed trap rock, crushed feldspar and crushed granite (e.g. Table B5). This confirms that Kersten should not be applied to materials with low quartz content.

For the medium-quartz gravels (Chena River gravel and Johansen's GR1, GR6 and GR12 gravels [$0.40 \leq q \leq 0.65$]), Kersten applies well to his own Chena River gravel and to one sample of Johansen's GR12 gravel, but gives some unacceptably high deviations for Johansen's GR1 and GR6 gravels.

As with the high-quartz sands, Kersten gives predictions that are too low for the crushed quartz materials tested by Kersten himself.

To summarize, when applied to coarse soils or soil materials, Kersten overpredicts for those with a low quartz content while it underpredicts for those with a high quartz content. In either case the deviations are too large to be acceptable. Use of the Kersten method should therefore be limited to coarse soils with intermediate quartz content, say around 60% of the soil solids. The expected deviations would then generally be within ±25%, though many may be larger and even unacceptable, particularly for gravels.

Johansen method. Johansen gives good predictions (within ±25%) for coarse soils and crushed rocks of varied quartz content at S_r values above 0.2 (Fig. 31b and 32b). Between $S_r = 0.1$ and $S_r = 0.2$ the predictions are somewhat worse, the deviations showing a marked negative bias extending to -40%. This could be due to the effect of moisture migration, which Johansen does not take into account and which could appreciably increase the measured thermal conductivity. Below about $S_r = 0.1$, Johansen gives large deviations, chiefly negative.

De Vries method. At degrees of saturation greater than about 0.2, De Vries gives deviations within ±20% for sands (Fig. 31c), and within ±30% for gravels and crushed rocks (Fig. 32c). There is a tendency for mainly negative deviations in the range $S_r = 0.1$ to 0.3, but it is less marked than that shown by Johansen, as may be expected because De Vries attempts to take the effect of moisture migration into account.

*These are Kersten, Johansen, De Vries, Gemant, Mickley, McGaw and Van Rooyen which apply to unsaturated (or saturated) unfrozen soils. For saturated soils two additional methods apply: modified resistor and Kunii-Smith.

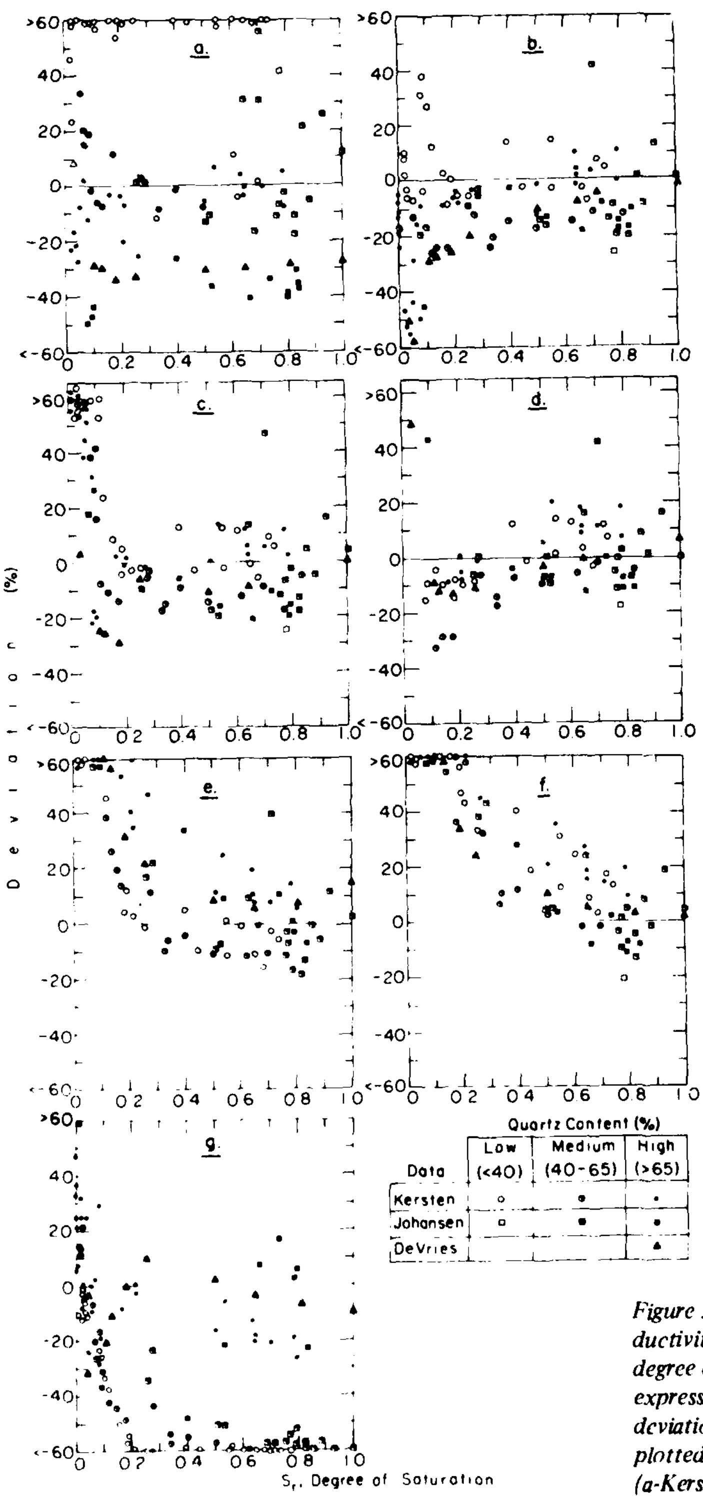

Figure 31. Deviations of calculated thermal conductivity from measured thermal conductivity vs degree of saturation of unfrozen sands. Deviations expressed as a percentage of the measured values; deviations outside the limits of ± 60% have been plotted directly on top or bottom horizontal scales (a-Kersten, b-Johansen, c-De Vries, d-Gemant, e-Mickley, f-McGaw, g-Van Rooyen).

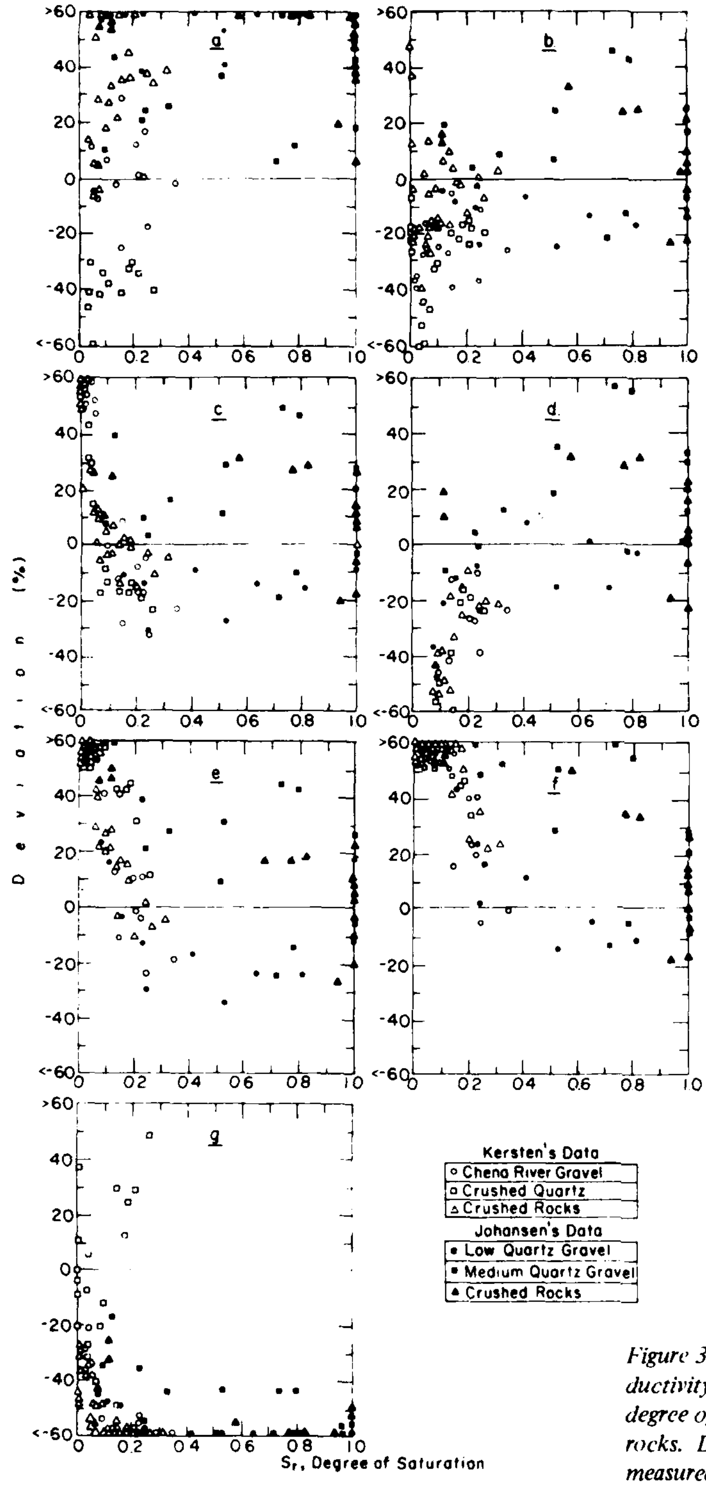

Figure 32. Deviations of calculated thermal conductivity from measured thermal conductivity vs degree of saturation of unfrozen gravels and crushed rocks. Deviations expressed as a percentage of the measured values; deviations outside the limits of ± 60% have been plotted directly on top or bottom horizontal scales (a-Kersten, b-Johansen, c-De Vries, d-Gemant, e-Mickley, f-McGaw, g-Van Rooyen).

Gemant method. By its nature, Gemant is inapplicable below a certain moisture content. It begins to give reasonable results above an S_r value of roughly 0.2 where the deviations are generally within ±20% for sands (Fig. 31d) or within −25 and 35% for gravels and crushed rocks (Fig. 32d). Similarly to Johansen, Gemant shows a marked negative bias in the range S_r = 0.1 to 0.3, which may be attributed to the effect of moisture migration.

Mickley and McGaw methods. These two methods are generally similar in their predictions. In effect both assume good particle-to-particle contact, implying very efficient thermal transfer. Obviously this cannot be the case in the dry condition which therefore gives rise to very large positive deviations from both methods. The presence of some water soon improves the interfacial efficiency and decreases the deviations. However, these deviations remain positive, masking any contribution to heat transfer from moisture migration, which would tend to give negative deviations. For sands Figures 31e and 31f show the marked trend for the deviations to decrease as S_r increases. For gravels and crushed rocks this trend, while still evident, is less consistent at high S_r values (Fig. 32e and 32f).

In the case of sands McGaw shows a roughly linear decrease in the deviations as S_r increases (Fig. 31f). Its predictions can be improved by introducing a suitable value for the interfacial efficiency factor ϵ. Such a value would be appreciably less than unity in the nearly dry condition, increasing linearly to unity at high S_r values.

For sands Mickley gives good agreement (within ±25%, roughly) for S_r values above 0.45, while McGaw does not do so until S_r is greater than about 0.6. With the gravels the threshold of S_r is lower, being about 0.25 for Mickley and 0.5 for McGaw. In the case of the crushed rocks, this threshold is slightly lower still, suggesting that the surface characteristics of crushed materials provide better contact efficiency (Farouki 1981).

Van Rooyen method. Van Rooyen's equation appears to be generally applicable to sands having a high quartz content at S_r values above 0.1 but not for lower S_r values (Fig. 31g). It also appears that Van Rooyen applies well (in fact better than the other six methods) below an S_r value of 0.1 for sands with low or medium quartz content. In this region, if we exclude the nearly dry condition (S_r < 0.015), the deviations for the high-quartz (q > 0.65) sands are not very large, lying within ±35%, which is still much better than Johansen and the other methods.

For gravels and particularly for low-quartz (q < 0.40) crushed rocks, the Van Rooyen equation does not generally apply well. It does, however, give some reasonable predictions for crushed quartz in the range S_r = 0.01 to 0.2 (Fig. 32g).

Summary. Above an S_r of 0.2 Johansen generally gives the best agreement (within ±25%), while De Vries and Gemant are close behind. Mickley and McGaw give good predictions at higher S_r values of 0.45 and 0.6 respectively. Under the stipulated conditions these five methods are applicable to coarse materials of high, intermediate or low quartz content. This is because they take the solids thermal conductivity k_s into account which Kersten's method does not.

In the range of S_r values from 0.1 to 0.2, De Vries appears to be the best method, giving deviations between 10 and −30%. Johansen gives a wider range of variation, between 20 and −40%, thus showing more extensive negative deviations.

Below an S_r value of 0.1 and extending to around S_r = 0.015, Van Rooyen gives the best predictions for sands, but some of the deviations are rather extensive (up to ±35%). For the gravels and low-quartz crushed rocks, however, at such low S_r values, Van Rooyen does not apply well nor does any one of the other methods.

Effect of variation in k_o. The effect on the soil thermal conductivity of variation in k_o is greatest for materials with low quartz content, which implies a high content of the other minerals. Such materials may sometimes have a larger k_o value than the 2.0 W/m K assumed in all the calculations on which Figures 31 and 32 (except 31a and 32a) are based. Johansen (1975) suggested that for his coarse materials with quartz content less than 20%, a k_o value of 3.0 W/m K should be used. Figures 33 and 34 show the deviations resulting from such an assumption as compared with the previous choice of 2.0 W/m K for k_o. Thus these figures show the effect of uncertainties in knowledge of k_o, this effect being greatest for materials with a very low quartz content (less than 20%). These materials include Kersten's two Northway sands, 50% of which is derived from igneous rocks, and Johansen's crushed rocks PU1, PU7, PU9, and PU10. They also include Johansen's sand SA10 and gravel GR7.

Figures 33a and 34a apply to the Johansen method. As expected, the deviations corresponding to a value of 3.0 W/m K for k_o shift upwards compared to the deviations corresponding to k_o = 2.0 W/m K. The ranges covered by these deviations are 10 to 40% for the sands (Fig. 33a) and 20 to −10% for gravels and crushed rocks corresponding to S_r values above

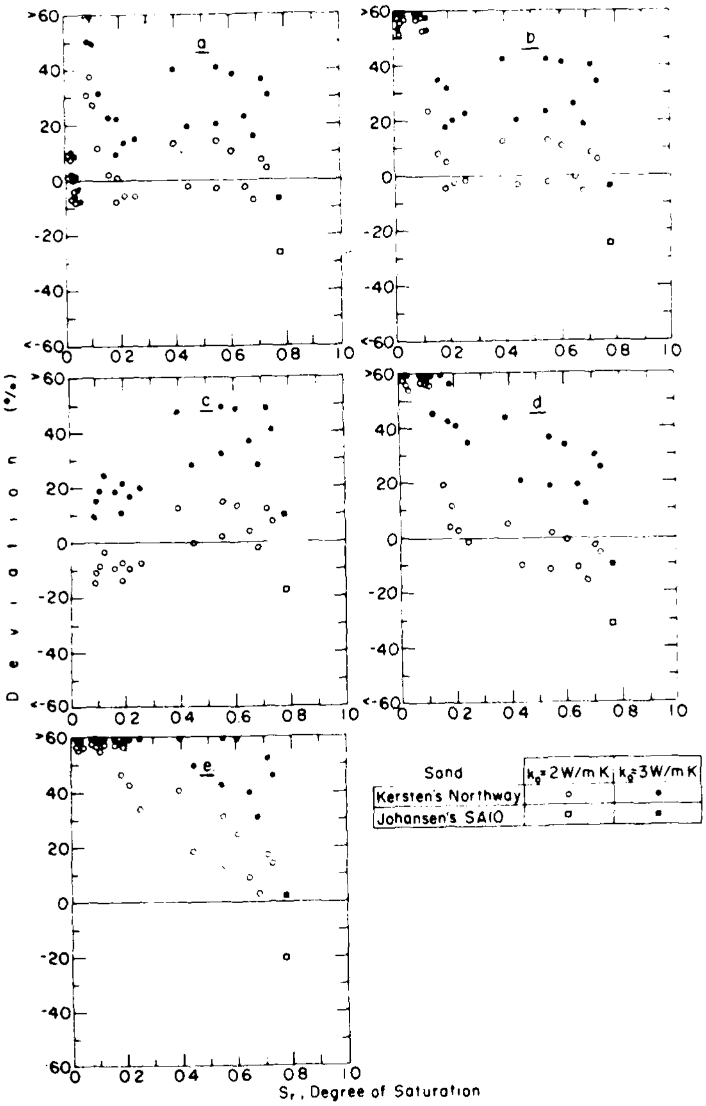

Figure 33. Effect of variation in thermal conductivity k_o of soil solids other than quartz on the deviations of calculated thermal conductivity from measured thermal conductivity of unfrozen low-quartz sands ($q < 0.20$) at various degrees of saturation. Deviations expressed as a percentage of the measured value; deviations outside the limits of ± 60% have been plotted directly on top or bottom horizontal scales (a-Johansen, b-De Vries, c-Gemant, d-Mickley, e-McGaw).

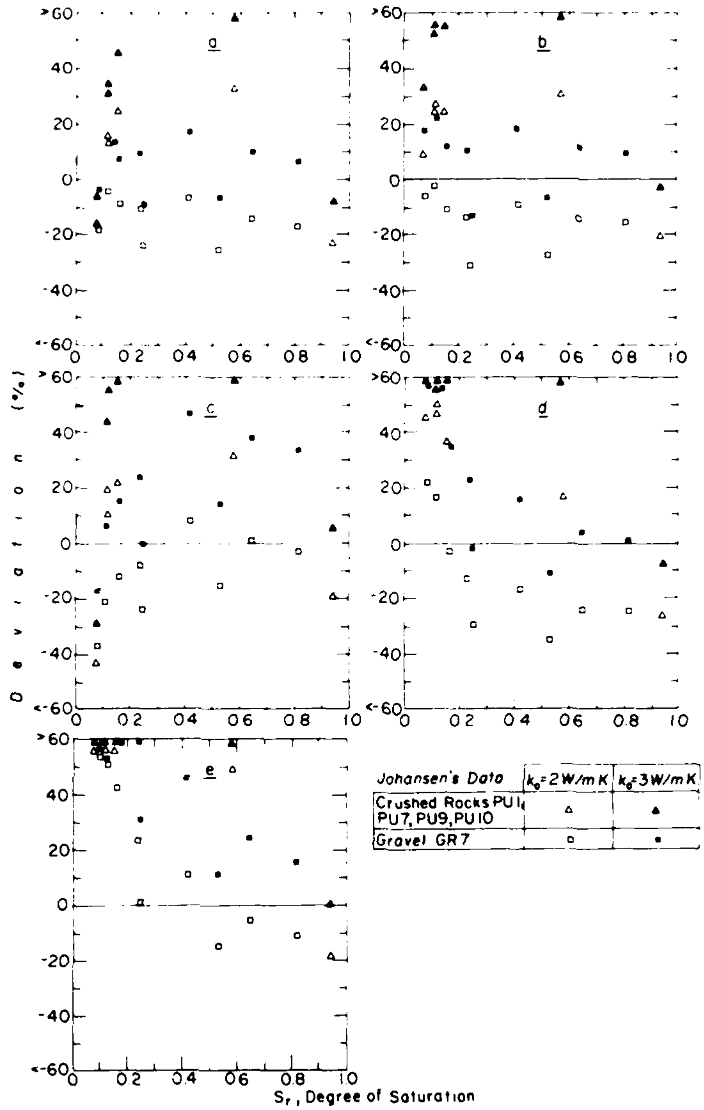

Figure 34. Effect of variation in thermal conductivity k_o *of soil solids other than quartz on the deviations of calculated thermal conductivity from measured thermal conductivity of unfrozen low-quartz crushed rocks and gravels* ($q < 0.20$) *at various degrees of saturation. Deviations expressed as a percentage of the measured value; deviations outside the limits of ± 60% have been plotted directly on top or bottom horizontal scales (a-Johansen, b-De Vries, c-Gemant, d-Mickley, e-McGaw).*

0.2. With a k_u value of 3.0 W/m K and S_r greater than 0.2, De Vries gives deviations in the range 40 to -5% for the sands (Fig. 33b) and in the range 20 to -10% for the crushed rocks (Fig. 34b). For similar conditions, Gemant gives deviations lying in the range 50 to 10% for the sands (Fig. 33c) and 50 to 5% for the crushed rocks (Fig. 34c). Mickley produces deviations in the range 35 to -10% for the sands at S_r values above 0.5 (Fig. 33d), while for the crushed rocks the deviations lie in the range 35 to -10% at S_r values above 0.3 (Fig. 34d). McGaw gives deviations for the sands that are too high (Fig. 33e), but for the crushed rocks (Fig. 34e) the deviations are reasonable at S_r values above 0.5

Applicability to a sandy silt–clay. Where a sand contains a large amount of silt–clay, such as Kersten's Dakota sandy loam with a silt–clay content of 31%, the Kersten equation overestimates considerably at S_r values below about 0.45, giving deviations up to 144% (see Table B6) in spite of the fact that this soil has a medium quartz content. At higher S_r values the Kersten method provides reasonable agreement as does each of the other six methods except Van Rooyen. In particular, Johansen and De Vries, while overestimating at low S_r values, give reasonable agreement from S_r values of 0.24 and 0.32 respectively. Van Rooyen gives good agreement at $S_r \geq 0.24$ and Gemant is generally applicable throughout the range of S_r values.

Applicability to saturated coarse soils. For saturated coarse soils or soil materials (e.g. crushed rocks), nine methods may be applied which, in addition to the seven methods discussed above, include modified resistor and Kunii-Smith. Representative deviations produced by all these methods are given in Tables B7-B11 and also for the seven methods in Figures 31 and 32 for the S_r = 1.0 points.

Kersten gives unacceptably high deviations for the saturated low-quartz crushed rocks (Johansen's PU1, PU5, PU6, PU7, PU9 and PU10) and also for the low-quartz gravel GR7. Excepting Van Rooyen, all the other methods generally give good agreement (within ±25%) for these materials as well as for the medium-quartz saturated gravels (GR1, GR3 and GR6) and the SA2 sand of Johansen. For the GR1 and GR6 gravels, Kersten persists in giving some unacceptably high deviations which, however, are not as bad as in the case of the low-quartz materials. While for the other medium-quartz gravel (GR3) Kersten gives acceptable deviations, these are wider than those given by the other methods. Similarly, while Kersten gives good agreement for the medium-quartz SA2 sand, six other methods give even better agreement. These are Johansen, De Vries, Kunii-Smith, modified resistor, McGaw and Gemant, any of which is preferable to Kersten for calculating the thermal conductivity of saturated coarse soils.

Applicability of methods to unfrozen fine soils

Figure 35 shows the deviations obtained with the seven applicable methods (Kersten, Johansen, De Vries, Gemant, Mickley, McGaw and Van Rooyen) for some unfrozen fine soils at various values of S_r. The evaluated data were for soils tested by Kersten, i.e. Healy clay, Fairbanks silty clay loam, Fairbanks silt loam, Northway silt loam and Ramsey sandy loam. The quartz contents of these soils were known and varied from 0.015 to 0.641* (as a fraction of the total solids content). In the computer program, k_o was set at 2.0 W/m K. In addition to Kersten's soils, data for Russian chernozem given by Kolyasev and Gupalo (1958) were evaluated as well as data given by Mickley (1951) and by Reno and Winterkorn (1967) on fine soils, k_s being taken as 2.0 W/m K.

Kersten method. Below an S_r of about 0.3, Kersten's equation for unfrozen fine soils gives deviations that are either too high, particularly for the chernozem soil, or too low for Kersten's own soils. From S_r = 0.3 to full saturation, the Kersten equation gives deviations that are scattered between 35 and -35%, with some of the highest deviations occurring for Kersten's own soils (Fig. 35a), particularly for his low-quartz Northway silt loam.

Johansen method. At low values of S_r, Johansen gives better agreement than Kersten. Nevertheless, Johansen still gives some excessive deviations below S_r = 0.2, these generally varying between 20 and -45%. At higher values of S_r Johansen gives deviations in the range 35 to -35%, roughly, which is similar behavior to Kersten (see Fig. 35b).

Above S_r = 0.2 Johansen gives positive deviations for most of Kersten's samples, but it tends to give negative deviations for the other soils, possibly because the assumed value of k_s for these (i.e. 2.0 W/m K) may generally be too low.

Other methods. De Vries gives deviations that are much too high at $S_r < 0.3$, but even above this S_r value the deviations for Kersten's samples continue to be unacceptably high (about 50%) and remain so at near full saturation (Fig. 35c). The range of deviations for Kersten's soils is from 50 to -3%, indicating an overprediction for these soils which is similar to that given by Johansen, but greater. For the other soils De Vries gives deviations in the range of 10 to -35% which is again similar to Johansen.

At $S_r > 0.3$ Gemant, Mickley and McGaw show trends generally similar to De Vries, but the deviation

*All these Kersten soils contain a medium amount of quartz ($0.40 < q < 0.65$) except for the low-quartz Healy clay and Northway silt loam.

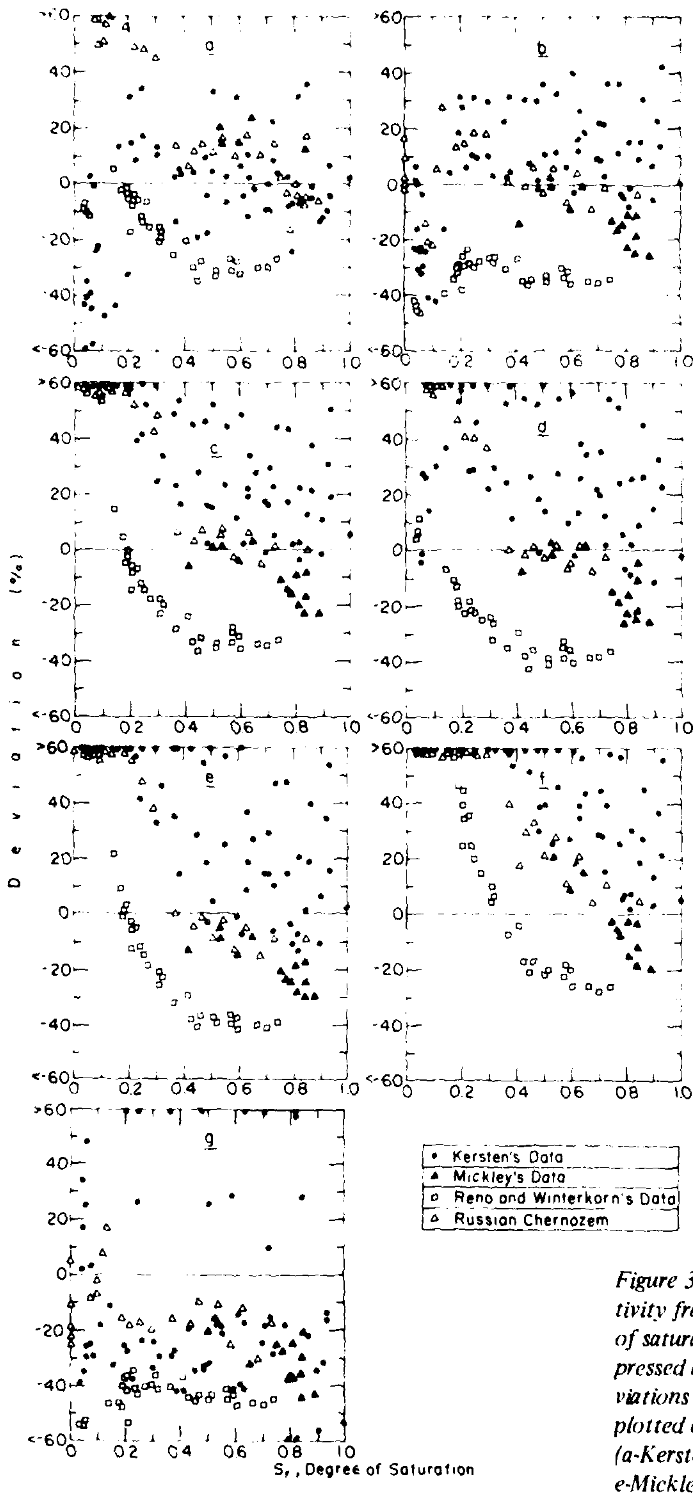

Figure 35. Deviations of calculated thermal conductivity from measured thermal conductivity vs degree of saturation of unfrozen fine soils. Deviations expressed as a percentage of the measured value; deviations outside the limits of ± 60% have been plotted directly on top or bottom horizontal scales (a-Kersten, b-Johansen, c-De Vries, d-Gemant, e-Mickley, f-McGaw, g-Van Rooyen).

ranges are larger (see Fig. 35d-f). Gemant, Mickley and McGaw give mostly positive deviations for Kersten's soils and Gemant and Mickley give mostly negative deviations for the other soils.

As with coarse soils McGaw shows a particularly noticeable trend of decreasing deviation as the S_r value for a particular type of fine soil increases (Fig. 35f). This again suggests that application of a proper value of the interfacial efficiency factor ϵ would give better agreement. As proposed in an earlier section, ϵ would have a small value at low S_r values and it would increase linearly to near unity as full saturation is approached.

Van Rooyen gives a scatter of deviations that is different from all the other methods (Fig. 35g). It produces mostly negative deviations, except for some of Kersten's samples, and the range of deviations is unacceptably extensive. However, for the Russian chernozem, Van Rooyen gives good predictions for a complete range of S_r values from the dry condition to near saturation. For such a range Johansen is the only other method which produces reasonable predictions for the chernozem.

Summary. Kersten should not be used below $S_r = 0.3$ as it would give excessive deviations. Above this S_r value both Kersten and Johansen give deviations within the range 35 to -35%, so that either method is equally applicable. Below $S_r = 0.3$, only Johansen continues to give predictions in this range and does so until S_r reaches about 0.2. It is expected that the accuracy of Johansen would improve with knowledge of a proper value of k_s.

Use of the Johansen method as it stands for S_r values lower than 0.2 may give more excessive deviations. From the trends in the deviations shown in Figure 35b the following suggested scheme could be applied:

1. In the range of $0.1 < S_r < 0.2$, Johansen gives deviations between 30 and -40%, i.e. a rough "average" of -5%. The values given by Johansen could therefore be increased by 5%.
2. In the range $0 < S_r < 0.1$, Johansen gives deviations between 15 and -45%, i.e. a rough "average" of -15%. The values given by Johansen could therefore be increased by 15%.

These specific suggestions are tentative, being based on fairly limited data.

Apart from Kersten and Johansen, the other five methods generally show more extensive deviations, many of which are unacceptable so that use of these methods is not recommended.

Comparison of predictions with tabulated Soviet values. The predictions of the various methods are compared in Table B12 with the values for Soviet clay soils tabulated in the U.S.S.R. Building Code (1960). For these calculations, the value of k_s was assumed to be 2.0 W/m K but it could be greater. Nearly all of the values given by the methods are lower than the U.S.S.R. Code values. Kersten gives differences varying between -5 and -33%, these differences tending to increase as the dry density increases at a given moisture content. Johansen and the other methods generally give lower negative deviations.

Applicability to saturated unfrozen fine soils. The applicability of nine methods was tested for Kersten's *Healy clay* (*Table B13*), Penner's Leda clay (Table B14) and the Dames & Moore (1973) clay or silt (Tables B15 and B16).

The Kersten method gave good predictions, except for Penner's Leda clay, for which it gave values that were too high. All the other methods, except Van Rooyen, gave good predictions overall. Thus seven methods are more or less equally applicable. These are Johansen, De Vries, modified resistor, Kunii-Smith, Mickley, McGaw and Gemant. The Johansen method is suggested as the first choice.

Applicability of methods to frozen coarse soils

For frozen soils only four methods could be used, i.e. Kersten, Johansen, De Vries and Mickley. The predictions of these methods were compared with the thermal conductivity measurements made by Kersten and Johansen on frozen sands, gravels and crushed rocks (Fig. 36 and 37).

Kersten method. As may be seen from Figures 36a and 37a, Kersten gives predictions that are generally much too high for frozen sands, gravels and crushed rocks having low quartz content. On the other hand it gives predictions that are too low for sands or crushed materials with high quartz content. This is in line with the trends shown by Kersten for unfrozen soils.

For frozen materials with intermediate quartz content, Kersten shows conflicting trends. For the sands it gives deviations lying between 35 and -25% at S_r values between 0.2 and 0.6. At S_r values greater than 0.6, the range of deviations is narrower, between 35 and -10%. While, as may be expected, the Kersten equation gives good agreement for Kersten's own Chena River gravel, there are inconsistencies and wide divergencies for Johansen's medium-quartz gravels GR1 and GR6. Thus, even for such materials, Kersten should be used with caution and large deviations expected.

Johansen method. Above an S_r value of 0.1 Johansen generally gives good or adequate predictions (within ±35%) for frozen sands, gravels and crushed rocks of any quartz content (Fig. 36b and 37b). However there are some exceptions, such as

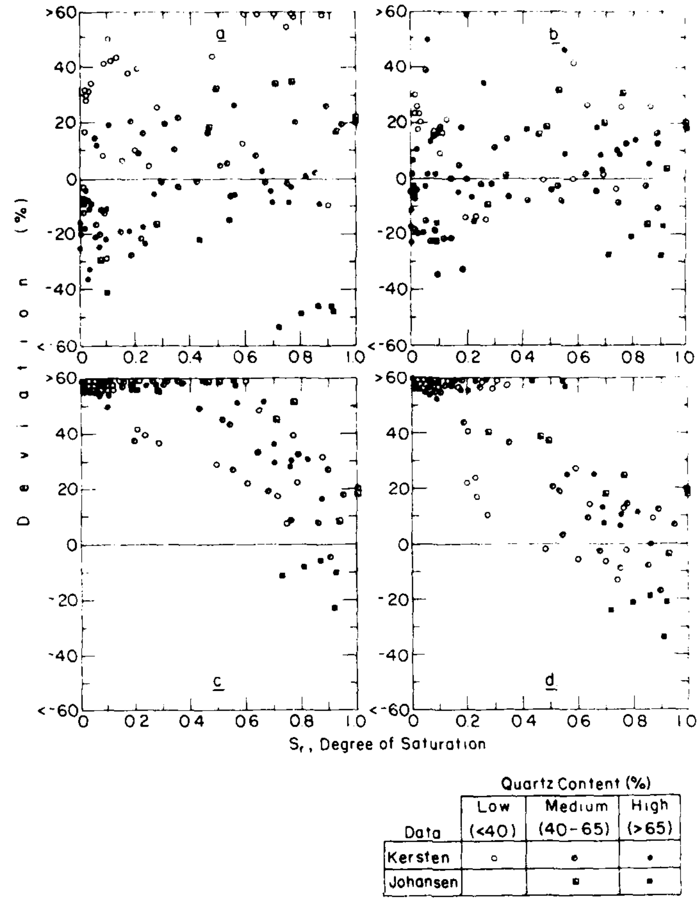

Figure 36. Deviations of calculated thermal conductivity from measured thermal conductivity vs degree of saturation of frozen sands. Deviations expressed as a percentage of the measured value; deviations outside the limits of ± 60% have been plotted directly on top or bottom horizontal scales (a-Kersten, b-Johansen, c-De Vries, d-Mickley).

for several crushed rocks, where deviations that are too large occur at high S_r values.

De Vries method. De Vries generally gives good agreement above an S_r value of 0.8 but even so there are some exceptions (Fig. 36c and 37c).

Mickley method. For gravels and crushed rocks Mickley appears to give good agreement at S_r values greater than about 0.3 (Fig. 37d), while for sands such agreement is not obtained until S_r is greater than 0.6 (Fig. 36d). As with the other methods there are exceptions.

Summary. Johansen is the method giving the best agreement and is generally applicable from an S_r of 0.1 to higher values. De Vries and Mickley apply with good agreement at high S_r values, greater than about 0.8 and 0.6 respectively. Kersten should be used only with medium-quartz materials and, even then, with caution, as it may give large deviations.

Effect of variation in k_o. As with the unfrozen coarse soils, calculations were made to determine the effect of setting k_o equal to 3.0 W/m K instead of 2.0 W/m K (2.0 W/m K was used to obtain Figures 36 and 37 [except 36a and 37a]). This procedure was carried out for the frozen sands and crushed rocks having a quartz content of less than 20% (Kersten's Northway sand and Northway fine sand; Johansen's sand SA10, gravel GR7 and crushed rocks PU1, PU7, PU9 and PU10). The effect of the variation in k_o is shown in Figures 38 and 39. The sensitivity to k_o of the thermal conductivity from each of the three relevant methods is evident from these figures.

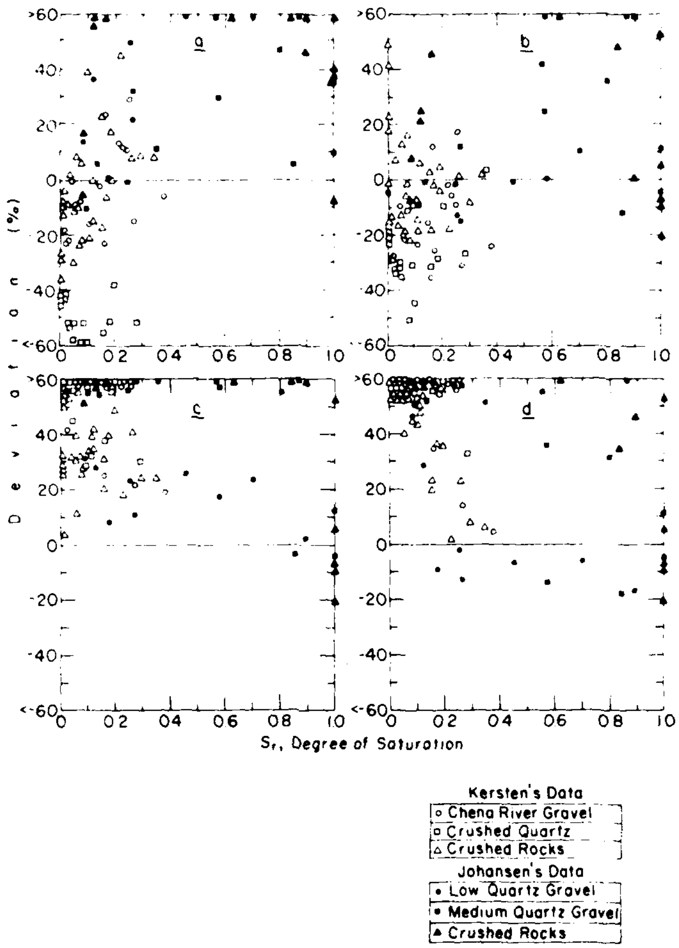

Figure 37. Deviations of calculated thermal conductivity from measured thermal conductivity vs degree of saturation of frozen gravels and crushed rocks. Deviations expressed as a percentage of the measured value; deviations outside the limits of ± 60% have been plotted directly on top or bottom horizontal scales (a-Kersten, b-Johansen, c-De Vries, d-Mickley).

Consider the deviations in Figures 38 and 39 corresponding to a k_o value of 3.0 W/m K. For the frozen sands (Fig. 38a), Johansen gives deviations within the range 40 to 0% provided S_r is less than 0.6. At larger S_r values the deviations become too high. For the frozen crushed rocks at S_r values above 0.2, Johansen gives deviations within the range 25 to -5% (Fig. 39a). De Vries gives deviations that are too high for sands at all S_r values (Fig. 38b) but for the crushed rocks they become reasonable (25 to -5%) at S_r values exceeding 0.9 (Fig. 39b). Mickley also gives deviations that are too high for sands (Fig. 38c) but generally reasonable deviations are obtained for the crushed rocks at S_r values above 0.4 (Fig. 39c).

Applicability to a frozen sandy silt-clay. Where the coarse soil contains a large amount of silt-clay, as in the case of Kersten's Dakota sandy loam, the above conclusions appear to hold. As Table B17 shows, Kersten gives good agreement for this medium-quartz soil, but Johansen gives even better agreement. Again De Vries and Mickley give good predictions only at high S_r values.

Applicability to saturated frozen coarse soils. For the saturated condition, in addition to the four methods used above, modified resistor and Kunn-Smith may be used. Tables B18-B22 give a representative picture of the resulting deviations, as do Figures 36 and 37 for the previous four methods (see values for S_r = 1.0).

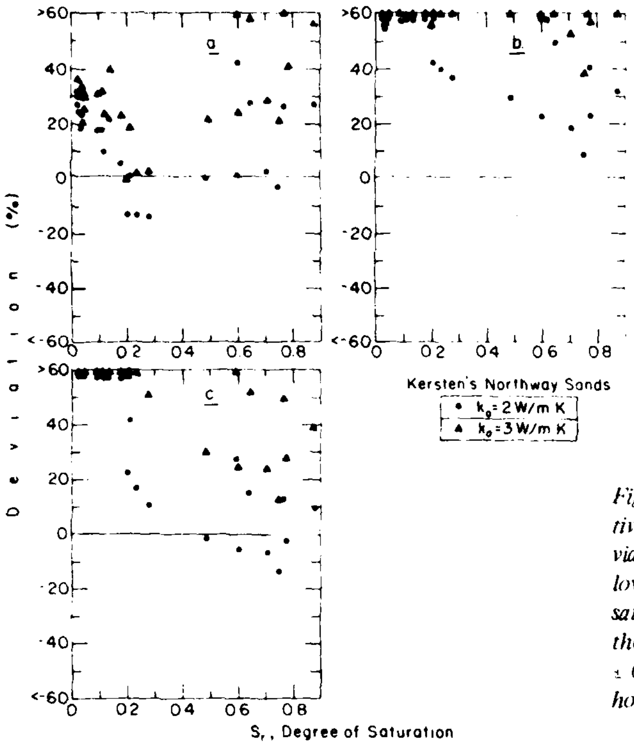

Figure 38. Effect of variation in thermal conductivity k_o of soil solids other than quartz on the deviations of calculated thermal conductivity of frozen low-quartz sands ($q < 0.20$) at various degrees of saturation. Deviations expressed as a percentage of the measured value; deviations outside the limits of ± 60% have been plotted directly on top or bottom horizontal scales (a-Johansen, b-De Vries, c-Mickley).

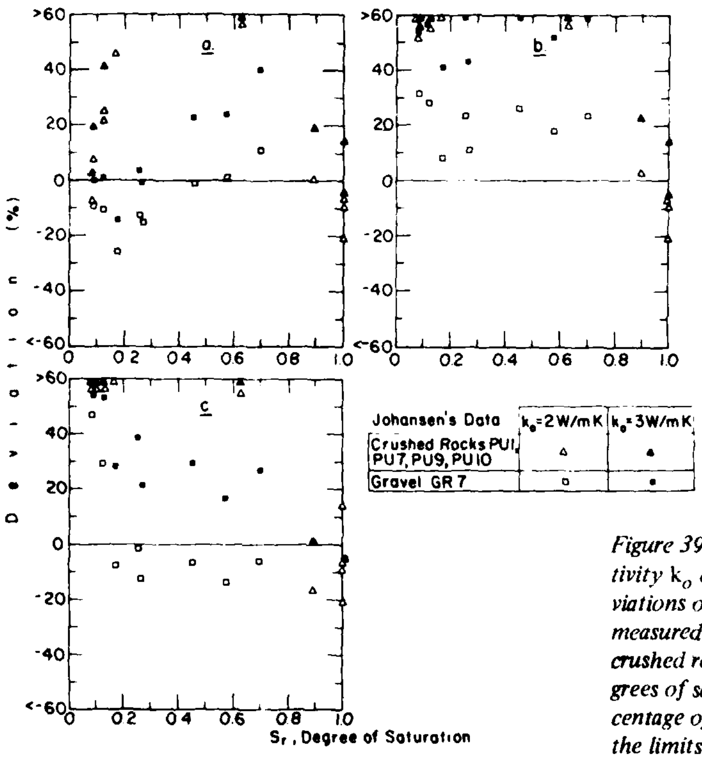

Figure 39. Effect of variation in thermal conductivity k_o of soil solids other than quartz on the deviations of calculated thermal conductivity from measured thermal conductivity of frozen low-quartz crushed rocks and gravels ($q < 0.20$) at various degrees of saturation. Deviations expressed as a percentage of the measured value; deviations outside the limits of ± 60% have been plotted directly on top or bottom horizontal scales (a-Johansen, b-De Vries, c-Mickley).

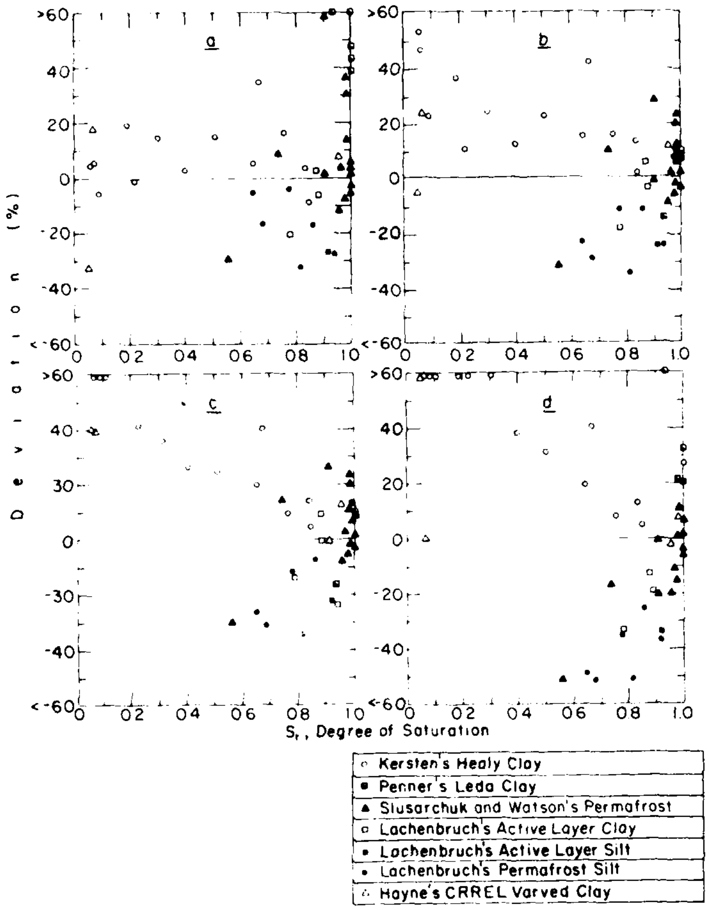

Figure 40. Deviations of calculated thermal conductivity from measured thermal conductivity vs degree of saturation of frozen fine soils. Deviations expressed as a percentage of the measured value; deviations outside the limits of ±60% have been plotted directly on top or bottom horizontal scales (a-Kersten, b-Johansen, c-De Vries, d-Mickley).

Kersten gives predictions that are too high for the low-quartz crushed rocks (except PU7) and high even for the medium-quartz gravel GR1. The best methods to use are Johansen, De Vries, Mickley, modified resistor or Kunii-Smith, any of which generally gives good agreement (except for crushed rock PU6 which is anomalous).

Applicability of methods to frozen fine soils

The four methods applicable to unsaturated frozen soils (Kersten, Johansen, De Vries and Mickley) were tested on Kersten's Healy clay, the CRREL varved clay (Haynes et al. 1980), the active layer silt or clay and the permafrost silt of Lachenbruch (pers. comm.), Penner's (1970) Leda clay, and the undisturbed permafrost of Slusarchuk and Watson (1975). The value of k_s was either that given by the experimenter or, if not known, taken as 2.0 W/m K. In the case of the Leda clay of Penner (1970), the unfrozen water content (UWC) was obtained from his data. For the other soils UWC was taken as zero or a suitable value assumed. The deviations resulting from the application of the four methods are shown in Figure 40.

From these limited results, it is seen that Kersten gives good predictions (generally between 20 and -35% deviations) up to an S_r value of about 0.9, above which it overpredicts considerably for Penner's Leda clay and for Slusarchuk and Watson's permafrost. While Johansen shows a tendency to overpredict below an S_r value of 0.1, it otherwise gives good or adequate agreement (generally within ±35%) up to and including full saturation. Above an S_r value of about 0.4, De Vries gives values very similar to Johansen. Mickley is the worst predictor of all and only gives reasonable results at high values of

S_r (above 0.8 roughly) but even then shows some excessive deviations.

Calculations were made using the data available for soils 4 through 10 of Penner et al. (1975). These were silt–clay materials with little or no sand, except for soil 7 which contained about 40% sand-gravel (but was nevertheless a plastic material). The actual values of k_s are unknown so a value of 3.0 W/m K was assumed. This introduces some uncertainty into the calculated deviations which are given in Tables B23–B29. Three values of UWC were used in each set of calculations, i.e. 0.0, 0.05 and 0.10. Again there is uncertainty about the proper UWC value; UWC will vary from soil to soil depending particularly on the soil's specific surface area. However the UWC value is expected in every case to be greater than zero at -5°C, the temperature to which the measured values are applicable.

Kersten is of course independent of k_s and the UWC value. Tables B23–B29 show that Kersten gives agreement which varies from very good to barely satisfactory (up to 36% deviation). In the case of Johansen, excepting soils 8 and 10, the agreement is generally good, providing the UWC value is taken as 0.05 or 0.10. This shows the importance of assuming a proper value for UWC in the Johansen method. Soils 8 and 10 in fact contain the highest proportion of clay-sized material (> 54%). Thus the assumption of a value of UWC greater than 0.10 for these soils should improve agreement by reducing the calculated values.

De Vries is particularly sensitive to the UWC value, as is evident from Tables B23–B29. Apart from soils 8 and 10, De Vries gives good agreement, with the assumption of a certain value of UWC. Mickley, on the other hand, shows little sensitivity to the UWC value, but gives good agreement at S_r values above 0.5, excepting again soils 8 and 10.

Tables B30–B32 show the deviations obtained by the four methods for Kersten's soils: Fairbanks silty clay loam, Northway silt loam and Ramsey sandy loam. The deviations were calculated at a UWC value of zero, but in the case of the Fairbanks silty clay loam calculations were also made at a UWC value of 0.06 to determine the resulting effect. Kersten generally gives good agreement for these loams, as may be expected because the Kersten equation was fitted to these data, but it gives some high values (around 25%) for Northway silt loam (this loam has low quartz content, whereas the others have medium quartz content). Johansen generally gives values that are too high, although predictions are acceptable for some samples of Ramsey sandy loam and for samples of Northway silt loam at high S_r values. Assumption of a proper UWC value would help to improve agreement when using Johansen, as it does to a certain extent for Fairbanks silty clay loam (Table B30). The effect, however, may not be sufficient, suggesting that Johansen should not generally be applied to frozen loams, i.e. silt–clays.

De Vries and Mickley also give unacceptably high values for these loams, but Mickley tends to give good agreement at high S_r values for Northway silt loam.

Summary. Kersten gives the best agreement up to an S_r value of 0.9; above this it provides many unacceptably high predictions. It also gives high (but acceptable) deviations for a low-quartz loam (Northway silt loam) but not for a low-quartz clay (Healy clay).

Johansen generally gives good predictions from an S_r value of 0.1 up to full saturation, provided a suitable UWC value is used. However this method gives some unacceptably high predictions for the frozen loams. De Vries gives similar results to Johansen for S_r values above 0.4, while Mickley generally gives good predictions at higher S_r values, preferably greater than 0.8.

Comparison of predictions with tabulated Soviet values. The predictions of the four methods were compared with the data for frozen clay soils tabulated in the U.S.S.R. Building Code (1960). The k_s value was taken as 2.0 W/m K and the UWC as zero, the actual values being unknown. The comparative results are shown in Table B33 which gives the differences between the calculated values and the Soviet tabulated data. Below an S_r value of 0.36 (moisture content of 18%), Kersten gives deviations that are too low (extending to -40%), but it agrees well at higher S_r values. Johansen gives somewhat better agreement than Kersten, while De Vries provides the best agreement throughout the saturation range from an S_r value of 0.14 to full saturation. Mickley gives good agreement at high S_r values and also, surprisingly, at S_r values below 0.2.

Applicability to saturated frozen fine soils. The usable data that are available for saturated frozen fine soils are rather limited. However they are sufficient to show some trends.

Table B34 shows the results of calculations on Penner's data for Leda clay at temperatures from -2.5 to -22°C. The values for k_s and UWC were taken from Penner's data (Penner 1970). Kersten's equation gives deviations that are too high, apart from the fact that it cannot allow for the effect of UWC. Johansen and De Vries give very good agreement throughout the temperature range. The other methods, modified resistor, Kunii-Smith and Mickley give adequate or borderline agreement (up to a deviation of 37%).

In the case of Penner's Sudbury silty clay, appropriate values of k_s and UWC were again obtained from

Penner's (1970) data. The calculated values for the various methods are compared with the measured values at temperatures varying from 0 to −20°C in Table B35. Kersten gives a high deviation (43%) at 0°C, but because Kersten's prediction does not change with temperature it agrees well with the larger measured values at −2.5°C and lower. Johansen and De Vries give excellent agreement throughout the temperature range whereas modified resistor, Kunii-Smith and Mickley are satisfactory at −2.5°C and below. These three latter methods show little difference in their predictions from the values given by a geometric mean equation assuming two phases only, i.e. solids and ice.

All the methods give excellent or good agreement for soil 7 (at −5°C) of Penner et al. (1975) and for the undisturbed permafrost (at −6°C) of Slusarchuk and Watson (1975), as is evident from Tables B36 and B37 in which UWC is assumed zero.

Also there is generally good agreement with the U.S.S.R. Building Code (1960) data for saturated frozen fine soils, especially at low dry densities and high moisture (ice) content (again UWC is assumed zero), as shown in Table B38.

It may be concluded that Johansen and De Vries give the best agreement and are capable of taking into account the effect of the unfrozen water content. Modified resistor, Kunii-Smith and Mickley are not as good and may not be quite adequate. Kersten gives some predictions that are too high and it cannot allow for UWC or its variation with temperature.

Applicability of methods to dry soils

The Kersten equations are not applicable to dry soils; nor is the Gemant method. The Mickley equation gives values that are much too high and so does the McGaw equation when the interfacial efficiency e is taken as unity. The other methods that were evaluated on data for dry soils were Johansen, De Vries (and adjusted De Vries), modified resistor, Kunii-Smith, Smith and Van Rooyen.

Applicability to dry coarse soils. The various methods were evaluated by comparing their predictions with the measured values obtained by Johansen (pers. comm.) in his experiments on certain natural gravels and sands as well as on some crushed rocks. These particular data were used because the quartz composition of these materials was known so k_s could be calculated and used in the various methods. Johansen is the only method which specifies different equations for natural soils and for crushed materials. In the case of Smith, an appropriate value for α' was used.

Johansen gives the best agreement for the gravels, mostly within ±25%, followed closely by De Vries (e.g. Table B39). Adjusted De Vries, Smith, Van Rooyen and modified resistor generally give good agreement but there are some inconsistencies, deviations in excess of 25% occur. Kunii-Smith gives many deviations that are too high and should therefore not be applied to gravels.

Analysis of the data for the sands shows that Johansen is the best method, providing good to excellent agreement, with all the deviations being negative (but not below −25%). The adjusted De Vries method also gives good to excellent predictions. Modified resistor and De Vries follow closely behind. The remaining three methods, Kunii-Smith, Smith and Van Rooyen, while showing some good agreement, also give deviations that are excessive (e.g. Table B40 for one of the sands).

For the natural coarse soils, the gravels and sands, Johansen gives the best results (within ±25%). De Vries, adjusted De Vries and modified resistor generally give good or adequate predictions within ±25%, with some values slightly beyond. While Smith and Van Rooyen give some good predictions, they also give some excessive deviations. Kunii-Smith gives unacceptably high deviations for the gravels and should therefore be considered inapplicable.

For the crushed rocks, the modified resistor is the best method, followed by adjusted De Vries. Although Johansen gives some good predictions it also provides a number of excessive deviations, positive and negative. Also Johansen, because it accounts for the porosity only, is insensitive to temperature changes which affect the value of k_s. The other four methods, Kunii-Smith, Smith, Van Rooyen and De Vries, show unacceptable deviations and should therefore be rejected (e.g. Table B41).

Applicability to dry fine soils. Comparisons were made between calculated values and values measured on fine soils by Smith and Byers (1938). Adjusted De Vries and modified resistor give the best agreement, generally well within ±15%. The agreement with Johansen is not as good. It provides negative deviations extending to −25%.

A similar picture holds for Johansen's (pers. comm.) dry silts, i.e. adjusted De Vries and modified resistor are best while Johansen gives negative deviations as low as −33%.

The results for Johansen's (pers. comm.) dry clay are interesting. In this case Smith gives excellent agreement while all the other methods give values that are too low. This may be explained by the formation of secondary aggregations in this clay which would correspond to Smith's derivation and give rise to more effective heat transfer mechanisms. The result would be a greater effective thermal conductivity for the soil.

DISCUSSION AND CONCLUSIONS

The *Analysis of Methods for Calculating Thermal Conductivity* section described the basis of each of the methods for calculating the thermal conductivity of soils. The effect on this calculated value of variations in the soil moisture content and the dry density was determined. The sensitivity to changes in the solids thermal conductivity k_s was also found. In order to determine the predictions of the methods it was necessary to know the soil mineral composition, particularly the quartz content from which k_s could be calculated. These predictions were compared with experimental data in the *Evaluation of Methods for Calculating Thermal Conductivity* section to determine the applicability of the methods to various types and conditions of soils.

For most practical applications it is sufficient to know the thermal conductivity to within about ±25% of its true value. Variation in soil properties from point to point in the field because of a lack of homogeneity could mean variations in the thermal conductivity to a similar extent. It is pointless to attempt to calculate thermal conductivity values to a higher degree of accuracy. Reasonable predictions are therefore considered to be those that do not deviate more than about ±25% from measured values.

Major errors are caused by not taking the soil mineralogical composition into account. According to Johansen (1975) this error could introduce uncertainties of about ±30% into the thermal conductivity value. It is obviously important to use a suitable k_s value in the methods that are based on the mineral composition.

Applicability to unfrozen soils

For unfrozen soils Kersten, Gemant, De Vries and Johansen show roughly similar trends with respect to variation of thermal conductivity with moisture content w at constant dry density γ_d or with γ_d at constant w. Mickley also gives similar trends for fine soil, but for coarse soil the curve of thermal conductivity against w (at constant γ_d) has an opposite curvature, indicating an increasing rate of change of thermal conductivity with increasing w which is contrary to what may be expected. Similar to Mickley, McGaw gives values that are too high in the dry or nearly dry condition, requiring an interfacial efficiency factor of less than unity to be applied. This method also gives a very low sensitivity of the thermal conductivity to variations in w. Van Rooyen shows rather odd thermal conductivity behavior, particularly at high values of w and γ_d where it becomes obviously inapplicable.

A comparison of Tables 1 and 2 reveals that all the methods, except Kersten, show an absolute sensitivity s_w of the thermal conductivity to w (at constant γ_d) that is smaller for the fine soil than for the coarse soil. With respect to the absolute sensitivity s_γ of the thermal conductivity to γ_d (at constant w), Kersten gives the lowest value for unfrozen coarse soils but the highest value for unfrozen fine soils.

Figures 21 and 25, which apply to coarse soils, show that Kersten gives the lowest curve for thermal conductivity as compared with the other methods. Kersten's equation for coarse soil implies a k_s of about 5 W/m K (Farouki 1981). Kersten should therefore not be applied to unfrozen coarse soils having a high quartz content, since it seriously underpredicts for these soils. On the other hand it overpredicts for soils having a low quartz content. It should therefore be applied only to those unfrozen coarse soils with intermediate quartz content, say about 60% of the soil solids.

For degrees of saturation S_r above 0.2, Johansen provides the best agreement with the data for unfrozen coarse soils, giving deviations which are generally in the range ±25%, while De Vries and Gemant generally deviate a little more. As can be seen from Figure 25, which applies to $S_r = 0.5$, De Vries gives a curve parallel and very close to Johansen's, while Gemant's curve is somewhat higher. In the range of S_r values from 0.1 to 0.2, De Vries in fact gives the best agreement, with deviations between 10 and −30%, while Johansen is next, covering a wider range between 20 and −40%. Below an S_r value of about 0.1, none of the methods gives good predictions, except Van Rooyen. This method gives reasonable values for sands and gravels down to S_r values about 0.015. However it underpredicts excessively for the crushed rocks of low quartz content which may be because Van Rooyen's empirical equation is not based on data for such materials.

Figures 22 and 26 show that, for unfrozen fine soils, Kersten gives the highest curve for the thermal conductivity (McGaw gives slightly higher values for unfrozen fine soil [Fig. 26]). The Kersten equation for fine soil implies a k_s of around 3.0 W/m K (Farouki 1981). Johansen, De Vries, Gemant and Mickley all give curves that are quite close together at $S_r = 0.5$ and $S_r = 1.0$ over the whole dry density range. Johansen generally gives the best predictions over the whole range of S_r values. Above $S_r = 0.2$ it gives deviations lying within the range ±35% but below $S_r = 0.2$ they may be as low as −45%. Kersten may be applied above $S_r = 0.3$ where it gives deviations within the range ±35% as does Johansen. However Kersten should not be applied below $S_r = 0.3$ because it then gives excessive deviations.

Applicability to frozen soils

In the case of frozen soils, the four applicable methods (Kersten, Mickley, De Vries and Johansen) show generally similar trends with respect to variation of the thermal conductivity with γ_d at constant w (Fig. 11 and 12). With regard to variation of the thermal conductivity with w at constant γ_d, both Kersten and Johansen give a linear relationship. De Vries shows a lower rate of increase in thermal conductivity with increasing w, while Mickley gives a faster rate. The latter behavior is contrary to expectation (see Fig. 3 and 4).

Above a moisture content of 5%, s_w is greater for frozen soil than for unfrozen soil (compare Tables 3 and 4 with Tables 1 and 2 respectively). This may be expected because the thermal conductivity of ice is considerably higher than that of water. Comparing Table 4 to Table 3 one can see that s_w is greater for frozen coarse soil than for frozen fine soil. At a dry density of 1.4 g/cm^3, Johansen gives a value of s_w for the coarse soil which is slightly more than twice the value for fine soil, while Kersten gives a value only about 40% larger. Both Johansen and Kersten give values of s_w that remain constant with changes in w at a given γ_d. The value of s_w increases with γ_d, particularly so for the coarse soil.

As with unfrozen coarse soils, Kersten overpredicts for frozen coarse soils having low quartz content, while it underpredicts when they have a high quartz content. Figures 23 and 27 show the low values given by Kersten as compared with the other methods in which a k_s value of 8.0 W/m K was used. Also Table 3 shows that Kersten gives a considerably lower s_w value than Johansen.

For unsaturated frozen coarse soils, Johansen gives the best predictions. These are reasonable for S_r values above 0.1 (approximately), while below this value Johansen gives some excessive deviations (though remaining the best predictor). While Mickley and De Vries may be applied with good results at high S_r values (above 0.6 for Mickley and above 0.8 for De Vries), computations can be more easily carried out with Johansen so that its general use is suggested for these soils.

With regard to frozen fine soils at $S_r = 0.5$, Kersten provides a curve of thermal conductivity against γ_d which differs little from the curves provided by Johansen and Mickley, while De Vries' curve is appreciably higher (Fig. 28). Also Table 4 shows that Kersten and Johansen give s_w values that are nearly the same.

While the predictions of the methods were compared with only a limited amount of available data for unsaturated frozen fine soils, certain trends can be seen. Kersten provides good agreement (generally within ± 30%) up to an S_r of 0.9. Beyond this it gives deviations that are too high for naturally occurring frozen soils such as Slusarchuk and Watson's undisturbed permafrost and Penner's Leda clay (Fig. 40a). On the other hand, while Johansen gives a few high deviations at values of S_r below 0.1, it otherwise generally gives good predictions (within ± 35%) up to and including $S_r = 1$ (saturation). Thus, while Kersten may be applied for values of S_r below 0.9, Johansen should be used for higher values of S_r. De Vries gives values close to Johansen at S_r values above 0.4. Both these methods can allow in their equations for the presence of unfrozen water, while Kersten cannot do so.

Applicability to saturated soils

In a saturated soil the ratio of the thermal conductivities of the phases is low. It varies from nearly 15:1 for quartz-water to about 1:1 for clay-ice. Such a low ratio means that application of a geometric mean equation, as in the Johansen method, should give good agreement with measured values (Farouki 1981). In fact, for the unfrozen soils all the applicable methods (Johansen, De Vries, Gemant, Mickley, McGaw, Kunii-Smith and modified resistor, but not Kersten and Van Rooyen) gave good agreement. The resulting deviations were within the range ± 25%. The easiest method to use is Johansen as it reduces to a simple geometric mean equation.

The situation is similar for saturated frozen coarse soils where any of the applicable methods (Johansen, De Vries, Mickley, modified resistor and Kunii-Smith) may be used except Kersten. The Kersten method overpredicts for low-quartz coarse materials, frozen or unfrozen, in the saturated condition just as in the unsaturated condition.

For the saturated frozen fine soils, Johansen and De Vries give the best agreement. Moreover they are capable of taking the unfrozen water content into account which Kersten and the other methods cannot. It is important to know the unfrozen water content present in a given fine-grained soil at temperatures below 0°C. This depends in particular on the specific surface area of the soil.

It should be noted that Johansen assumes that the thermal conductivity of the unfrozen water is the same as that of ordinary water. While this may be true for a large part of the unfrozen water, it has been proposed that the strongly adsorbed unfrozen water (the boundary phase) may have a relatively high thermal conductivity, perhaps even higher than that of ice (Farouki 1981).

Effect of soil mineral composition

In calculating soil thermal conductivity it is important to know the soil mineral composition, particularly its quartz content, as has been stressed. It has been shown that the Kersten method should not be applied to coarse soils having high or low quartz content. For the other methods, the quartz content is required so that the thermal conductivity of the soil solids k_s can be calculated.

There is some uncertainty regarding the "true" value of the thermal conductivity of quartz. In conformity with Lachenbruch (among others) the value used in the *Analysis of Methods for Calculating Thermal Conductivity* section was obtained from a geometric mean equation applied to the thermal conductivity values of the quartz crystal measured along and at right angles to the principal axis ($k_{\parallel}$ and $k_{\perp}$ respectively). Recently Frivik (pers. comm.) reported a quartz thermal conductivity of 10 W/m K which was inferred from measurements on saturated materials. However, it is difficult to see how such a high value can result from the tabulated values of $k_{\parallel}$ and $k_{\perp}$ (Table 14). Further research on this matter is necessary.

Similarly more data are required on the thermal conductivity of minerals, other than quartz, that may be present in soils. In particular measurements of the values for the various clay minerals would be useful. There are indications that the thermal properties of kaolinite, illite, montmorillonite, etc. may be different.

If a coarse soil has a high quartz content, the thermal conductivity of the other minerals present k_o makes little difference to the soil's thermal conductivity. On the other hand, when the quartz content is low, k_o and its variation has a considerable influence on k_s and therefore on the soil thermal conductivity as may be seen from Figures 33, 34, 38 and 39. With Johansen the effect of a change of k_o from 2.0 to 3.0 W/m K is to increase the deviations by 20 or 30% at intermediate S_r values for the unfrozen condition (Fig. 33a) and similarly for the frozen condition (Fig. 38a).

For fine soils a k_s value of 2.0 W/m K has generally been used in the calculations in earlier sections. It would be more accurate to use a value dependent on the type of clay minerals present but further information on these would be required.

Figures 17 and 18 can be used to determine the effect of changes in k_s on the soil thermal conductivity according to the various applicable methods (except Kersten) and for unfrozen or frozen soils. The sensitivity of the thermal conductivity to k_s resulting from Johansen, De Vries and Gemant increases markedly as S_r increases, more so for the frozen condition. This implies that knowledge of a more accurate value of k_s is more important for soils having higher values of S_r.

Assumption of a suitable k_s value in Gemant gives better agreement between its predictions and measured values. The nomogram of Makowski and Mochlinski (1956), which is based on Gemant's equations, should therefore be redeveloped on the basis of a more suitable value for k_s. This could be calculated from the quartz content and its thermal conductivity rather than from Gemant's subsidiary equation for k_s.

The effect of temperature on the value of k_s should be taken into account. The thermal conductivity of quartz increases as the temperature decreases as shown in Table 14. This variation was allowed for in the calculations of the *Evaluation of Methods for Calculating Thermal Conductivity* section. Similarly the thermal conductivity of the other soil minerals, except feldspar, decreases with increasing temperature. Feldspar may be present in coarse or fine soils and, if minerals other than quartz are also present, the effect of the feldspar would be to provide some counterbalance to the variation of k_o with temperature (i.e. k_o would have less sensitivity to temperature variation). Because of the uncertainty in the actual magnitude of k_o, this value was not varied with temperature in the calculations using the various methods. Such an allowance may be made if the amounts and properties of the minerals other than quartz are known.

Applicability to dry soils

Dry soils have a high ratio of thermal conductivity of the two components (solids and air). As a result the region encompassed by the Hashin–Shtrikman bounds is wide and a geometric mean equation does not give good results. The thermal conductivity is highly sensitive to variations in microstructure (see Johansen 1975). This is taken into account by Johansen's method which allows for two different empirical equations, one for natural and the other for crushed materials. The former is a function only of the soil's dry density while the latter is a function of its porosity alone. The implication is that the solids thermal conductivity has little effect.

The analysis of the predictions of the various methods showed that Johansen applies well to dry natural coarse soils (within ± 25%) but not to dry crushed rocks. The thermal conductivity of these was better predicted by the modified resistor or adjusted De Vries methods (the Kersten method is inapplicable). These two methods also applied well for most of the dry fine-grained soils. However, Smith gave the best results for a dry clay. This method allows for structural effects by means of a thermal structure factor. Considerations of structure and contact effects are particularly important in the case of dry soils, fine or coarse.

Summary of applicability of methods

The best methods to apply for different types and conditions of soils are as follows. In most cases these [illegible] within about ±25%, which is [illegible] practical application.

Unfrozen coarse soils	
$0.015 < S_r < 0.1$	Van Rooyen for sands and gravels (not for low quartz crushed rocks)
$0.1 < S_r < 0.2$	De Vries
$S_r > 0.2$	Johansen
Sandy silt clay	Gemant
Saturated	Johansen, De Vries, modified resistor, Kunii-Smith, Mickley, Gemant, or McGaw

Note: Kersten's method should *not* be applied to coarse soils with low or high quartz content.

Unfrozen fine soils	
$0 < S_r < 0.1$	Johansen (increase prediction by 15%)
$0.1 < S_r < 0.2$	Johansen (increase prediction by 5%)
$S_r > 0.2$	Johansen
Saturated	Johansen, De Vries, modified resistor, Kunii-Smith, Mickley, McGaw or Gemant
Frozen coarse soils	
$S_r < 0.1$	Johansen
Saturated	Johansen, De Vries, Mickley, modified resistor or Kunii-Smith

Note: Kersten should *not* be applied to frozen coarse soils with low or high quartz content.

Frozen fine soils	
$S_r < 0.9$	Kersten
$0.1 < S_r < 1$	Johansen (with suitable unfrozen water content)
Saturated	Johansen and De Vries (Kersten should not be used where unfrozen water content is appreciable)
Dry coarse soils	
Natural	Johansen
Crushed rocks	Modified resistor, adjusted De Vries
Dry fine soils	
General	Modified resistor, adjusted De Vries
Clay	Smith

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APPENDIX A: PROPERTIES OF SOME TEST SOILS

Soils of Kersten (1949)

Table A1. General physical properties of soils.

		Mechanical analysis				*Physical constants*						*Textural class*	
Soil no.	*Soil designation*	*Gravel over 2.00*[1]	*Sand 0.05 to 2.00*	*Silt 0.005 to 0.05*	*Clay under 0.005*	*Liquid*[2] *limit*	*Plasticity*[2] *index*	*Modified optimum moisture content*	*Modified max. density*	*Specific gravity*	*Absorption (%)*	*U.S. Bur. of Chem. and soils*	*Unified soil classn.*
P4601	Chena River gravel	80.0	19.4	– 0.6 –		–	N.P.[3]	–	–	2.70	0.75	Gravel	GP
P4703	Crushed quartz	15.5	79.0	– 5.5 –		–	N.P.	–	–	2.65	0.26	Coarse sand	SW
P4704	Crushed trap rock	27.0	63.0	– 10.0 –		–	N.P.	–	–	2.97	0.20	Coarse sand	SM
P4705	Crushed feldspar	25.5	70.3	– 4.2 –		–	N.P.	–	–	2.56	0.75	Coarse sand	SW
P4706	Crushed granite	16.2	77.0	– 6.8 –		–	N.P.	–	–	2.67	0.56	Coarse sand	SW
P4702	20–30 Ottawa sand	0.0	100.0	0.0	0.0	–	N.P.	–	–	2.65	0.17	Coarse sand	SP
P4701	Graded Ottawa sand	0.0	99.9	– 0.1 –		–	N.P.	–	–	2.65	0.19	Medium sand	SP
P4714	Fine crushed quartz	0.0	100.0	0.0	0.0	–	N.P.	–	–	2.65	–	Medium sand	SP
P4709	Fairbanks sand	27.5	70.0	– 2.5 –		–	N.P.	12.0	122.5	2.72	–	Medium sand	SW
P4604	Lowell sand	0.0	100.0	0.0	0.0	–	N.P.	12.2	119.0	2.67	–	Medium sand	SW
P4503	Northway sand	3.0	97.0	0.0	0.0	–	N.P.	14.0	112.8	2.74	–	Medium sand	SW
P4502	Northway fine sand	0.0	97.0	3.0	0.0	–	N.P.	11.4	116.0	2.76	–	Fine sand	SP
P4711	Dakota sandy loam	10.9	57.9	21.2	10.0	17.1	4.9	6.5	138.5	2.71	–	Sandy loam	SM
P4713	Ramsey sandy loam	0.4	53.6	27.5	18.5	24.6	9.3	9.0	127.5	2.68	–	Sandy loam	CL
P4505	Northway silt loam	1.0	21.0	64.4	13.6	27.3	N.P.	15.7	112.0	2.70	–	Silt loam	ML
P4602	Fairbanks silt loam	0.0	7.6	80.9	11.5	34.0	N.P.	15.5	110.0	2.70	–	Silt loam	ML
P4710	Fairbanks silty clay loam	0.0	9.2	63.8	27.0	39.2	12.4	18.0	102.0	2.71	–	Silty clay loam	ML
P4708	Healy clay	0.0	1.9	20.1	78.0	39.4	15.0	17.0	108.0	2.59	–	Clay	CL
P4707	Fairbanks peat	–	–	–	–	–	N.P.	–	–	–	–	Peat	Pt

[1] Size in millimeters. [2] Minus no. 40 mesh fraction. [3] N.P. = non-plastic.

Table A2. Mineral and rock composition of soils (percentage by weight).

			Quartz											
Soil no.	*Soil designation*	*Unified soil classn.*	*By petrogr. exam.*	*By X-ray analysis*	*Orthoclase feldspar*	*Felsite*	*Plagioclase feldspar*	*Pyroxene, amphibole, and olivine*	*Basic igneous rock*	*Kaolinite clay min. and clay coat. min.*	*Hematite and magnetite*	*Mica*	*Coal*	*Others*
P4601	Chena River gravel	GP	43.1		11.6		12.9	27.0				2.1		3.3
P4703	Crushed quartz	SW	95+[1]											
P4704	Crushed trap rock	SM	3.0		10.0		50.0[2]	34.0			2.0			1.0
P4705	Crushed feldspar	SW	15.0		55.0		30.0							
P4706	Crushed granite	SW	20.0		30.0		40.0							10.0
P4702	20–30 Ottawa sand	SP	99+[3]											
P4701	Graded Ottawa sand	SP	99+[3]											
P4714	Fine crushed quartz	SP	95+[1]											
P4709	Fairbanks sand	SW	59.4		3.6	5.0	6.3	8.0	10.0		2.5	0.1		5.1
P4604	Lowell sand	SW	72.2		20.5			3.0				1.3		3.0
P4503	Northway sand	SW	7.5			11.5	9.0	7.5	51.0					13.5
P4502	Northway fine sand	SP	12.0			7.0	18.0	12.0	40.0					11.0
P4711	Dakota sandy loam	SM	59.1		12.9		1.0	12.1		12.4				2.5
P4713	Ramsey sandy loam	CL	51.3		11.8		5.6	12.6		15.9				2.8
P4505	Northway silt loam	ML	1.5				31.5	19.5	4.5	27.5	10.0			5.5
P4602	Fairbanks silt loam	ML	13.3	40.3						28.3		18.1		
P4710	Fairbanks silty clay loam	ML	4.6	59.5				2.2		28.9	1.6	3.2		
P4708	Healy clay	CL	22.5							55.0			22.0	0.5

[1] By visual inspection; impurities less than 5%. [2] Andesine feldspar. [3] By visual inspection; impurities less than 1%.

Soils of Penner et al. (1975)

The grain size distribution curves for soils no. 4 to 10 tested by Penner et al. (1975) are given in Figure A1. The sieve and hydrometer analyses followed ASTM procedures.

The Atterberg limits for soils no. 4 to 10 are given in Table A3. Table A4 shows the relative proportions of minerals in the size fraction smaller than μm.

Table A3. Atterberg limits.

Soil no.	Liquid limit at 25 blows W_L (%)	Plastic limit, W_p(%)	Plasticity index I_p (%)
4	37	21	16
5	25	18	7
6	30	21	9
7	28	14	14
8	43	24	18
9	33	22	11
10	48	23	25

Table A4. Relative proportions of minerals in the < 0.002 mm size fraction.

Soil	Quartz	Illite	Chlorite	Kaolinite	Vermiculite
4	+++	++	++	++	–
5	+	+	–	–	–
6	+	+	+	+	–
7	++	++	+	++	–
8	+++	+++	++	+	–
9	+++	+++	+	+	–
10	+++	+++	++	++	–

+ = small amount present; ++ = moderate amount present; +++ = large amount present.

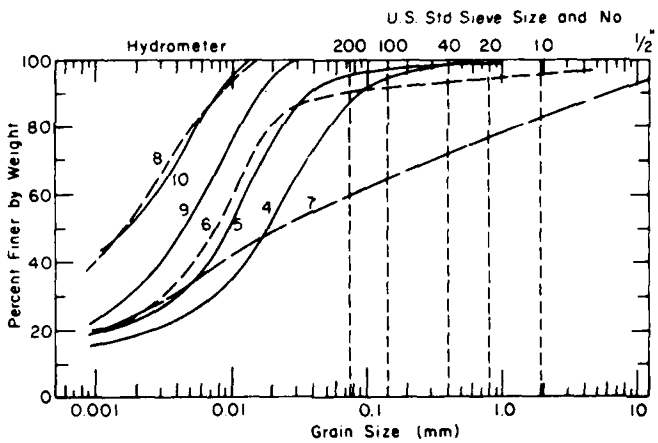

Figure A1. Grain size analysis of soils tested by Penner et al. (1975).

Table A5. Soil materials of Johansen (pers. comm.).

Material	*Quartz content (%)*	*Specific weight (kg/m³)*	d_{60} *(mm)*	d_{10} *(mm)*	*Uniformity coefficient* d_{60}/d_{10}
Sand					
SA1	50	2700	0.69	0.12	5.7
SA2	48	2600	0.27	0.067	4.0
SA3	58	2670	0.15	0.082	1.8
SA4	80	2670	0.16	0.125	1.3
SA5	45	2720	0.26	0.11	2.4
SA7	39	2700	1.5	0.10	15.0
SA8	61	2730	0.20	0.075	2.7
SA10	10	2850	0.52	0.125	4.2
SA13	100	2650	0.70	0.60	1.2
Gravel					
GR1	49	2740	2.0	0.21	9.5
GR3	47	2700	2.0	0.20	10.0
GR6	57	2700	6.1	0.27	22.6
GR7	2	3000	1.4	0.06	23.3
GR12	41	2700	1.8	0.15	12.0
Crushed rock					
PU1	2	3000	31.0	24.0	1.3
PU5	33	2680	6.1	0.25	24.4
PU7	9	2750	35.0	26.0	1.3
PU9	3	2730	8.5	1.0	8.5
PU10	9	3100	17.0	10.5	1.6
Clay					
LE1	22	2800	0.040	0.0035	–

APPENDIX B: COMPARISON OF THERMAL CONDUCTIVITY VALUES COMPUTED BY THE VARIOUS METHODS AND OF THEIR DEVIATIONS FROM THE VALUES MEASURED

Table B1.

KERSTEN NORTHWAY SAND UNSATURATED UNFROZEN

TYPE OF SOIL: SAND NATURAL UNSATURATED UNFROZEN

RHO = 2.760 TEMP = 4.500 Q = 0.975 CL = 0.000 CSOLIDS = * 2.220 ALPHA = -------- KA = 0.056
KW = 0.569 KICE = * 2.200 KQ = 8.920 KO = 2.000 CSOLIDS2 = 3.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR / SAT	NC / UWC
SAMPLE	0.60	1.477	0.202	KERSTEN	0.295	46.1	MICKLEY	0.688	240.6	0.461	0.009
				JOHANSEN	0.205	1.6	MC GAW	1.186	487.4	0.019 *	0.009
				DE VRIES	[illegible]	122.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.180	-10.9		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	0.70	1.600	0.255	KERSTEN	0.419	64.3	MICKLEY	0.764	199.6	0.416	0.011
				JOHANSEN	0.240	-6.1	MC GAW	1.275	399.6	0.027 *	0.011
				DE VRIES	0.523	104.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.225	-12.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	0.80	1.618	0.254	KERSTEN	0.490	93.1	MICKLEY	0.777	206.0	0.410	0.013
				JOHANSEN	0.245	-3.6	MC GAW	1.282	405.2	0.032 *	0.013
				DE VRIES	0.541	113.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.236	-7.1		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	0.60	1.695	0.284	KERSTEN	0.566	99.4	MICKLEY	0.826	186.4	0.382	0.014
				JOHANSEN	0.271	-6.2	MC GAW	1.339	364.4	0.035 *	0.014
				DE VRIES	0.580	104.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.260	-9.7		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	5.80	1.475	0.495	KERSTEN	0.969	95.9	MICKLEY	0.720	45.5	0.462	0.056
				JOHANSEN	0.556	12.5	MC GAW	1.058	113.9	0.121 *	0.056
				DE VRIES	0.619	25.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.477	-3.5		
				RESISTOR	------	------	VAN ROOYEN	0.308	-37.7		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	4.10	1.611	0.681	KERSTEN	1.212	78.1	MICKLEY	0.815	19.7	0.412	0.061
				JOHANSEN	0.697	2.5	MC GAW	1.154	69.6	0.160 *	0.066
				DE VRIES	0.735	8.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.617	-9.3		
				RESISTOR	------	------	VAN ROOYEN	0.340	-50.1		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	6.50	1.691	0.782	KERSTEN	1.386	77.0	MICKLEY	0.876	12.0	0.383	0.059
				JOHANSEN	0.789	1.0	MC GAW	1.222	56.3	0.190 *	0.073
				DE VRIES	0.818	4.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.724	-7.4		
				RESISTOR	------	------	VAN ROOYEN	0.353	-54.8		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	9.20	1.669	0.888	KERSTEN	1.707	92.2	MICKLEY	0.934	5.2	0.391	0.060
				JOHANSEN	1.008	13.5	MC GAW	1.245	40.2	0.393 *	0.154
				DE VRIES	1.000	12.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.998	12.3		
				RESISTOR	------	------	VAN ROOYEN	0.364	-59.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	14.60	1.587	0.932	KERSTEN	[illegible]	[illegible]	MICKLEY	[illegible]	1.8	[illegible]	[illegible]
				JOHANSEN	1.068	14.6	MC GAW	1.221	31.0	[illegible] *	[illegible]
				DE VRIES	1.050	12.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.068	14.6		
				RESISTOR	------	------	VAN ROOYEN	0.359	-61.4		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	15.60	1.696	1.048	KERSTEN	1.971	88.1	MICKLEY	1.041	-0.7	0.381	0.059
				JOHANSEN	1.162	10.8	MC GAW	1.307	24.7	0.606 *	0.231
				DE VRIES	1.162	10.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.185	13.0		
				RESISTOR	------	------	VAN ROOYEN	0.366	-65.1		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	15.50	1.615	1.204	KERSTEN	[illegible]	[illegible]	MICKLEY	[illegible]	[illegible]	[illegible]	[illegible]
				JOHANSEN	1.289	7.1	MC GAW	1.409	17.0	[illegible] *	[illegible]
				DE VRIES	1.309	8.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.342	11.5		
				RESISTOR	------	------	VAN ROOYEN	0.374	-68.9		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	16.50	1.695	1.171	KERSTEN	2.064	76.3	MICKLEY	1.105	-5.7	0.381	0.059
				JOHANSEN	1.221	4.3	MC GAW	1.331	13.7	0.733 *	0.280
				DE VRIES	1.234	5.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.256	7.3		
				RESISTOR	------	------	VAN ROOYEN	0.366	-68.7		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

NOTES:
Moisture content in %.
Dry density in g/cm^3.
All other units W/m K except where noted.
DEVIATION refers to difference between value COMPUTED by respective METHOD and the MEASURED value.
TEMP = test temperature (°C)
ALPHA = parameter in Smith method
Q = Quartz content in soil solids (fractional)
CL = Clay content in soil solids (fractional)
RHO = Specific gravity of soil solids

CSOLIDS = Thermal conductivity of solids (calculated or assumed)
CSOLIDS2 = Value from Gemant's equation
KA, KW, KICE, KQ, KO = conductivities of air, water, ice, quartz and other minerals respectively (values input according to test TEMPERATURE)
POR = Porosity
SAT = Degree of saturation
NC = Parameter in McGaw's method
UWC = Unfrozen water content (fraction by volume of total soil volume)

Table B2.

KERSTEN NORTHWAY FINE SAND UNSATURATED UNFROZEN

TYPE OF SOIL: SAND NATURAL UNSATURATED UNFROZEN

RHO = 2.760 TEMP = 4.500 W = 0.120 CL = 0.000 CSOLIDS = ↑ 2.363 ALPHA = -------- KA = 0.254
KW = 0.569 KICE = ↑ 2.240 KW = 0.020 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UNC
SAMPLE	0.50	1.564	0.208	KERSTEN	0.257	23.8	MICKLEY	0.772	272.0	0.435	0.008
				JOHANSEN	0.228	9.7	MC GAW	1.321	536.3	0.018 +	0.008
				DE VRIES	0.498	140.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.200	-3.6		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	0.50	1.645	0.234	KERSTEN	0.290	24.3	MICKLEY	0.828	254.7	0.404	0.008
				JOHANSEN	0.254	8.7	MC GAW	1.390	495.2	0.020 +	0.008
				DE VRIES	0.546	134.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.228	-2.5		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	0.50	1.767	0.297	KERSTEN	0.346	16.5	MICKLEY	0.914	207.7	0.360	0.009
				JOHANSEN	0.299	0.6	MC GAW	1.489	401.3	0.025 +	0.009
				DE VRIES	0.628	111.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.267	-10.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	2.00	1.651	0.392	KERSTEN	0.946	141.1	MICKLEY	0.853	117.4	0.402	0.033
				JOHANSEN	0.515	31.4	MC GAW	1.300	231.6	0.082 +	0.033
				DE VRIES	0.663	69.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.336	-14.4		
				RESISTOR	------	------	VAN ROOYEN	0.300	-23.6		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	1.90	1.762	0.438	KERSTEN	1.080	146.5	MICKLEY	0.932	112.7	0.362	0.033
				JOHANSEN	0.605	38.1	MC GAW	1.390	217.0	0.093 +	0.033
				DE VRIES	0.747	70.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.391	-10.8		
				RESISTOR	------	------	VAN ROOYEN	0.324	-26.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	2.10	1.759	0.497	KERSTEN	1.130	127.2	MICKLEY	0.933	87.6	0.363	0.037
				JOHANSEN	0.636	27.8	MC GAW	1.376	176.6	0.102 +	0.037
				DE VRIES	0.760	52.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.455	-8.6		
				RESISTOR	------	------	VAN ROOYEN	0.329	-33.8		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	5.10	1.563	0.796	KERSTEN	1.222	53.5	MICKLEY	0.829	4.2	0.434	0.061
				JOHANSEN	0.736	-7.5	MC GAW	1.164	46.3	0.104 +	0.080
				DE VRIES	0.761	-4.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.690	-13.4		
				RESISTOR	------	------	VAN ROOYEN	0.343	-56.9		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	5.20	1.645	0.867	KERSTEN	1.383	59.6	MICKLEY	0.892	3.0	0.404	0.060
				JOHANSEN	0.822	-5.2	MC GAW	1.235	42.6	0.212 +	0.086
				DE VRIES	0.843	-2.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.786	-9.3		
				RESISTOR	------	------	VAN ROOYEN	0.354	-59.2		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	5.20	1.759	0.999	KERSTEN	1.628	63.0	MICKLEY	0.985	-1.5	0.363	0.057
				JOHANSEN	0.943	-5.6	MC GAW	1.336	33.7	0.252 +	0.091
				DE VRIES	0.980	-1.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.922	-7.8		
				RESISTOR	------	------	VAN ROOYEN	0.366	-63.4		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	10.90	1.645	1.087	KERSTEN	1.728	58.9	MICKLEY	0.980	-9.9	0.404	0.060
				JOHANSEN	1.064	-2.2	MC GAW	1.284	18.1	0.444 +	0.179
				DE VRIES	1.052	-3.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.081	-0.6		
				RESISTOR	------	------	VAN ROOYEN	0.363	-66.6		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	11.20	1.767	1.249	KERSTEN	2.074	66.1	MICKLEY	1.108	-11.3	0.360	0.057
				JOHANSEN	1.212	-2.9	MC GAW	1.398	11.9	0.550 +	0.108
				DE VRIES	1.222	-2.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.271	1.8		
				RESISTOR	------	------	VAN ROOYEN	0.371	-70.3		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	11.40	1.860	1.368	KERSTEN	2.381	74.0	MICKLEY	1.221	-10.8	0.326	0.055
				JOHANSEN	1.335	-2.4	MC GAW	1.488	8.7	0.650 +	0.212
				DE VRIES	1.359	-0.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.419	3.7		
				RESISTOR	------	------	VAN ROOYEN	0.377	-72.5		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	13.90	1.765	1.380	KERSTEN	2.189	58.6	MICKLEY	1.169	-15.3	0.360	0.057
				JOHANSEN	1.284	-7.0	MC GAW	1.421	3.0	0.681 +	0.245
				DE VRIES	1.300	-5.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.352	-2.1		
				RESISTOR	------	------	VAN ROOYEN	0.371	-73.1		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B3.

JOHANSEN GRAVEL GR7 MOIST UNFROZEN

TYPE OF SOIL: COARSE NATURAL UNSATURATED UNFROZEN

RHO = 3.000 TEMP = 2.100 U = 0.020 CL = 0.000 CSOLIDS = ? 2.057 ALPHA = -------- KA = 0.044
KW = 0.504 KICE = ? 2.200 KU = 8.100 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	2.50	1.537	0.490	KERSTEN	0.891	81.9	MICKLEY	0.610	24.5	0.488	0.038
				JOHANSEN	0.420	-14.3	MC GAW	0.976	99.2	0.079 ?	0.038
				DE VRIES	0.464	-5.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.265	-45.9		
				RESISTOR	------	------	VAN ROOYEN	0.278	-43.4		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

RHO = 3.000 TEMP = 3.700 U = 0.020 CL = 0.000 CSOLIDS = ? 2.056 ALPHA = -------- KA = 0.048
KW = 0.508 KICE = ? 2.200 KU = 8.040 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	2.50	1.537	0.505	KERSTEN	0.891	76.5	MICKLEY	0.615	21.8	0.488	0.038
				JOHANSEN	0.421	-16.7	MC GAW	0.979	93.9	0.079 ?	0.038
				DE VRIES	0.476	-5.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.319	-36.9		
				RESISTOR	------	------	VAN ROOYEN	0.278	-45.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

RHO = 3.000 TEMP = 25.300 U = 0.020 CL = 0.000 CSOLIDS = ? 2.053 ALPHA = -------- KA = 0.104
KW = 0.605 KICE = ? 2.200 KU = 7.430 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	2.50	1.537	0.649	KERSTEN	0.891	37.4	MICKLEY	0.682	5.0	0.488	0.038
				JOHANSEN	0.428	-34.0	MC GAW	1.016	56.5	0.079 ?	0.038
				DE VRIES	0.618	-4.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.531	-18.2		
				RESISTOR	------	------	VAN ROOYEN	0.278	-57.2		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

RHO = 3.000 TEMP = 3.400 U = 0.020 CL = 0.000 CSOLIDS = ? 2.056 ALPHA = -------- KA = 0.048
KW = 0.508 KICE = ? 2.200 KU = 8.040 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	2.50	1.803	0.653	KERSTEN	1.307	100.1	MICKLEY	0.760	16.4	0.399	0.045
				JOHANSEN	0.623	-4.6	MC GAW	1.140	74.6	0.113 ?	0.045
				DE VRIES	0.638	-2.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.515	-21.1		
				RESISTOR	------	------	VAN ROOYEN	0.340	-47.9		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

RHO = 3.000 TEMP = 25.000 U = 0.020 CL = 0.000 CSOLIDS = ? 2.053 ALPHA = -------- KA = 0.104
KW = 0.605 KICE = ? 2.200 KU = 7.430 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	2.50	1.803	0.778	KERSTEN	1.307	68.0	MICKLEY	0.829	6.5	0.399	0.045
				JOHANSEN	0.633	-18.6	MC GAW	1.173	50.8	0.113 ?	0.045
				DE VRIES	0.786	1.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.770	-1.0		
				RESISTOR	------	------	VAN ROOYEN	0.340	-56.2		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

RHO = 3.000 TEMP = 3.700 U = 0.020 CL = 0.000 CSOLIDS = ? 2.056 ALPHA = -------- KA = 0.053
KW = 0.508 KICE = ? 2.200 KU = 8.040 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	5.40	1.488	0.645	KERSTEN	1.117	73.3	MICKLEY	0.624	-3.2	0.504	0.063
				JOHANSEN	0.591	-8.3	MC GAW	0.919	42.5	0.159 ?	0.080
				DE VRIES	0.576	-10.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.567	-12.1		
				RESISTOR	------	------	VAN ROOYEN	0.330	-48.8		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

RHO = 3.000 TEMP = 25.700 U = 0.020 CL = 0.000 CSOLIDS = ? 2.053 ALPHA = -------- KA = 0.126
KW = 0.606 KICE = ? 2.200 KU = 7.400 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	5.40	1.488	0.806	KERSTEN	1.117	38.6	MICKLEY	0.710	-11.9	0.504	0.064
				JOHANSEN	0.597	-24.8	MC GAW	0.966	19.9	0.159 ?	0.080
				DE VRIES	0.709	-12.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.672	-16.6		
				RESISTOR	------	------	VAN ROOYEN	0.330	-59.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

RHO = 3.000 TEMP = 2.400 U = 0.020 CL = 0.000 CSOLIDS = ? 2.057 ALPHA = -------- KA = 0.050
KW = 0.504 KICE = ? 2.200 KU = 8.100 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	5.40	1.769	0.900	KERSTEN	1.674	86.0	MICKLEY	0.784	-12.9	0.419	0.061
				JOHANSEN	0.806	-10.4	MC GAW	1.107	23.0	0.233 ?	0.096
				DE VRIES	0.777	-13.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.831	-7.7		
				RESISTOR	------	------	VAN ROOYEN	0.365	-59.5		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

RHO = 3.000 TEMP = 27.000 U = 0.020 CL = 0.000 CSOLIDS = ? 2.053 ALPHA = -------- KA = 0.136
KW = 0.609 KICE = ? 2.200 KU = 7.350 KO = 2.000 CSOLIDS2 = 5.840

NOTE:
In plotting the figures the values corresponding to the temperature nearest 4°C were used.

Table B3 (cont'd).

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SAMPLE MOISTURE      DRY   K MEASURED      METHOD K COMPUTED  DEVIATION      METHOD K COMPUTED  DEVIATION    POR,    NC
        CONTENT    DENSITY                                   (PERCENT)                         (PERCENT)    SAT,    UNC
SAMPLE    5,40      1,709      1,087           KERSTEN   1,674      50,9        MICKLEY   0,887      -16,9    0,416   0,062
                                              JOHANSEN   0,842     -22,5         MC GAW   1,155        6,2    0,233 + 0,290
                                              DE VRIES   0,921     -15,0          SMITH   ------    ------
                                          ADJ DE VRIES   ------    ------        GEMANT   0,973       -6,6
                                              RESISTOR   ------    ------    VAN RUOYEN   0,365      -65,0
                                           KUNII-SMITH   ------    ------    GEOM, MEAN   ------    ------

RHO =    3,000 TEMP =    3,000 U =    0,020 CL =    0,000 CSOLIUS = T   2,056 ALPHA = -------- KA =    ?,053
KW =    0,608 KICE = T  2,200 KU =    8,040 KU =    2,000 CSOLIUS2 =     5,840

SAMPLE MOISTURE      DRY   K MEASURED      METHOD K COMPUTED  DEVIATION      METHOD K COMPUTED  DEVIATION    POR,    NC
        CONTENT    DENSITY                                   (PERCENT)                         (PERCENT)    SAT,    UNC
SAMPLE    6,30      1,488      0,920           KERSTEN   1,277      38,8        MICKLEY   0,653      -29,0    0,504   0,063
                                              JOHANSEN   0,704     -23,9         MC GAW   0,941        1,0    0,245 + 0,124
                                              DE VRIES   0,640     -30,0          SMITH   ------    ------
                                          ADJ DE VRIES   ------    ------        GEMANT   0,707      -23,0
                                              RESISTOR   ------    ------    VAN RUOYEN   0,346      -62,4
                                           KUNII-SMITH   ------    ------    GEOM, MEAN   ------    ------

RHO =    3,000 TEMP =   27,000 U =    0,020 CL =    0,000 CSOLIUS = T   2,053 ALPHA = -------- KA =    0,132
KW =    0,608 KICE = T  2,200 KU =    7,370 KU =    2,000 CSOLIUS2 =     5,840

SAMPLE MOISTURE      DRY   K MEASURED      METHOD K COMPUTED  DEVIATION      METHOD K COMPUTED  DEVIATION    POR,    NC
        CONTENT    DENSITY                                   (PERCENT)                         (PERCENT)    SAT,    UNC
SAMPLE    6,30      1,488      1,063           KERSTEN   1,277      20,2        MICKLEY   0,747      -29,8    0,504   0,064
                                              JOHANSEN   0,725     -31,8         MC GAW   0,992       -6,6    0,245 + 0,124
                                              DE VRIES   0,767     -27,8          SMITH   ------    ------
                                          ADJ DE VRIES   ------    ------        GEMANT   0,768      -25,6
                                              RESISTOR   ------    ------    VAN RUOYEN   0,348      -67,2
                                           KUNII-SMITH   ------    ------    GEOM, MEAN   ------    ------

RHO =    3,000 TEMP =    0,100 U =    0,020 CL =    0,000 CSOLIUS = T   2,056 ALPHA = -------- KA =    0,057
KW =    0,572 KICE = T  2,200 KU =    7,980 KU =    2,000 CSOLIUS2 =     5,840

SAMPLE MOISTURE      DRY   K MEASURED      METHOD K COMPUTED  DEVIATION      METHOD K COMPUTED  DEVIATION    POR,    NC
        CONTENT    DENSITY                                   (PERCENT)                         (PERCENT)    SAT,    UNC
SAMPLE    6,30      1,875      1,100           KERSTEN   2,228     102,6        MICKLEY   0,916      -16,7    0,375   0,060
                                              JOHANSEN   1,025      -6,8         MC GAW   1,216       10,5    0,415 + 0,156
                                              DE VRIES   1,001      -9,0          SMITH   ------    ------
                                          ADJ DE VRIES   ------    ------        GEMANT   1,189        8,1
                                              RESISTOR   ------    ------    VAN RUOYEN   0,377      -65,7
                                           KUNII-SMITH   ------    ------    GEOM, MEAN   ------    ------

RHO =    3,000 TEMP =   27,700 U =    0,020 CL =    0,000 CSOLIUS = T   2,053 ALPHA = -------- KA =    0,136
KW =    0,609 KICE = T  2,200 KU =    7,350 KU =    2,000 CSOLIUS2 =     5,840

SAMPLE MOISTURE      DRY   K MEASURED      METHOD K COMPUTED  DEVIATION      METHOD K COMPUTED  DEVIATION    POR,    NC
        CONTENT    DENSITY                                   (PERCENT)                         (PERCENT)    SAT,    UNC
SAMPLE    6,30      1,875      1,219           KERSTEN   2,228      82,8        MICKLEY   1,009      -17,2    0,375   0,060
                                              JOHANSEN   1,047     -14,1         MC GAW   1,252        2,7    0,416 + 0,156
                                              DE VRIES   1,089     -10,7          SMITH   ------    ------
                                          ADJ DE VRIES   ------    ------        GEMANT   1,252        2,7
                                              RESISTOR   ------    ------    VAN RUOYEN   0,377      -69,0
                                           KUNII-SMITH   ------    ------    GEOM, MEAN   ------    ------

RHO =    3,000 TEMP =    3,900 U =    0,020 CL =    0,000 CSOLIUS = T   2,056 ALPHA = -------- KA =    0,053
KW =    0,568 KICE = T  2,200 KU =    8,040 KU =    2,000 CSOLIUS2 =     5,840

SAMPLE MOISTURE      DRY   K MEASURED      METHOD K COMPUTED  DEVIATION      METHOD K COMPUTED  DEVIATION    POR,    NC
        CONTENT    DENSITY                                   (PERCENT)                         (PERCENT)    SAT,    UNC
SAMPLE   12,50      1,752      1,365           KERSTEN   2,090      53,1        MICKLEY   0,890      -34,8    0,416   0,062
                                              JOHANSEN   1,026     -24,8         MC GAW   1,162      -14,9    0,526 + 0,219
                                              DE VRIES   0,992     -27,3          SMITH   ------    ------
                                          ADJ DE VRIES   ------    ------        GEMANT   1,159      -15,1
                                              RESISTOR   ------    ------    VAN RUOYEN   0,370      -72,9
                                           KUNII-SMITH   ------    ------    GEOM, MEAN   ------    ------

RHO =    3,000 TEMP =   26,000 U =    0,020 CL =    0,000 CSOLIUS = T   2,053 ALPHA = -------- KA =    0,132
KW =    0,608 KICE = T  2,200 KU =    7,370 KU =    2,000 CSOLIUS2 =     5,840

SAMPLE MOISTURE      DRY   K MEASURED      METHOD K COMPUTED  DEVIATION      METHOD K COMPUTED  DEVIATION    POR,    NC
        CONTENT    DENSITY                                   (PERCENT)                         (PERCENT)    SAT,    UNC
SAMPLE   12,50      1,752      1,452           KERSTEN   2,090      43,9        MICKLEY   0,983      -32,3    0,416   0,062
                                              JOHANSEN   1,053     -27,5         MC GAW   1,201      -17,3    0,526 + 0,219
                                              DE VRIES   1,068     -26,4          SMITH   ------    ------
                                          ADJ DE VRIES   ------    ------        GEMANT   1,216      -16,2
                                              RESISTOR   ------    ------    VAN RUOYEN   0,370      -74,5
                                           KUNII-SMITH   ------    ------    GEOM, MEAN   ------    ------

RHO =    3,000 TEMP =    5,000 U =    0,020 CL =    0,000 CSOLIUS = T   2,056 ALPHA = -------- KA =    0,055
KW =    0,570 KICE = T  2,200 KU =    8,010 KU =    2,000 CSOLIUS2 =     5,840

SAMPLE MOISTURE      DRY   K MEASURED      METHOD K COMPUTED  DEVIATION      METHOD K COMPUTED  DEVIATION    POR,    NC
        CONTENT    DENSITY                                   (PERCENT)                         (PERCENT)    SAT,    UNC
SAMPLE   12,50      1,894      1,339           KERSTEN   2,563      91,4        MICKLEY   1,021      -23,8    0,369   0,059
                                              JOHANSEN   1,157     -13,6         MC GAW   1,269       -5,2    0,642 + 0,237
                                              DE VRIES   1,148     -14,2          SMITH   ------    ------
                                          ADJ DE VRIES   ------    ------        GEMANT   ?,355        1,2
                                              RESISTOR   ------    ------    VAN RUOYEN   0,379      -71,7
                                           KUNII-SMITH   ------    ------    GEOM, MEAN   ------    ------

RHO =    3,000 TEMP =   20,500 U =    0,020 CL =    0,000 CSOLIUS = T   2,053 ALPHA = -------- KA =    0,132
KW =    0,608 KICE = T  2,200 KU =    7,370 KU =    2,000 CSOLIUS2 =     5,840

SAMPLE MOISTURE      DRY   K MEASURED      METHOD K COMPUTED  DEVIATION      METHOD K COMPUTED  DEVIATION    POR,    NC
        CONTENT    DENSITY                                   (PERCENT)                         (PERCENT)    SAT,    UNC
SAMPLE   12,50      1,894      1,408           KERSTEN   2,563      82,0        MICKLEY   1,107      -21,4    0,369   0,060
                                              JOHANSEN   1,182     -16,0         MC GAW   1,302       -7,5    0,642 + 0,237
                                              DE VRIES   1,206     -14,4          SMITH   ------    ------
                                          ADJ DE VRIES   ------    ------        GEMANT   1,402       -0,5
                                              RESISTOR   ------    ------    VAN RUOYEN   0,379      -73,1
                                           KUNII-SMITH   ------    ------    GEOM, MEAN   ------    ------

RHO =    3,000 TEMP =    4,300 U =    0,020 CL =    0,000 CSOLIUS = T   2,056 ALPHA = -------- KA =    0,053
KW =    0,558 KICE = T  2,200 KU =    8,030 KU =    2,000 CSOLIUS2 =     5,840
```

Table B3 (cont'd).

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por., Sat.	NC, UWC
Sample	15.60	1.894	1.466	Kersten	2.719	85.2	Mickley	1.109	-24.4	0.369	0.249
				Johansen	1.221	-16.8	Mc Gaw	1.300	-11.5	0.812 †	0.249
				De Vries	1.235	-15.9	Smith	------	------		
				Adj De Vries	------	------	Gemant	1.429	-2.7		
				Resistor	------	------	Van Rooyen	0.379	-74.2		
				Kunii-Smith	------	------	Geom. Mean	------	------		

RHO = 3.000 TEMP = 27.000 W = 0.020 CL = 3.000 CSOLIDS = † 2.053 ALPHA = -------- KA = 0.132
KW = 0.608 KICE = † 2.200 KQ = 7.370 KO = 2.000 CSOLIDS2 = 5.840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por., Sat.	NC, UWC
Sample	15.60	1.894	1.682	Kersten	2.719	61.7	Mickley	1.188	-29.4	0.369	0.062
				Johansen	1.250	-25.7	Mc Gaw	1.332	-20.8	0.812 †	0.249
				De Vries	1.279	-23.9	Smith	------	------		
				Adj De Vries	------	------	Gemant	1.474	-12.3		
				Resistor	------	------	Van Rooyen	0.379	-77.4		
				Kunii-Smith	------	------	Geom. Mean	------	------		

Table B4.

JOHANSEN CRUSHED ROCK [illegible] MOIST UNFROZEN

TYPE OF SOIL: COARSE CRUSHED UNSATURATED UNFROZEN

RHO = 3.100 TEMP = [illegible] W = [illegible] CL = 3.000 CSOLIDS = † 2.267 ALPHA = -------- KA = 0.053
KW = 0.568 KICE = † 2.[illegible] KQ = [illegible] KO = 2.000 CSOLIDS2 = 5.840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por., Sat.	NC, UWC
Sample	3.30	1.6[illegible]	[illegible]	Kersten	1.159	144.0	Mickley	0.713	50.1	0.472	0.054
				Johansen	0.537	13.1	Mc Gaw	1.055	122.2	0.115 †	0.054
				De Vries	0.593	24.9	Smith	------	------		
				Adj De Vries	------	------	Gemant	0.567	19.3		
				Resistor	------	------	Van Rooyen	0.321	-32.3		
				Kunii-Smith	------	------	Geom. Mean	------	------		

RHO = 3.100 TEMP = [illegible] W = [illegible] CL = 3.000 CSOLIDS = † 2.266 ALPHA = -------- KA = 0.055
KW = 0.570 KICE = † 2.[illegible] KQ = [illegible] KO = 2.000 CSOLIDS2 = 5.840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por., Sat.	NC, UWC
Sample	3.30	1.636	[illegible]	Kersten	1.159	170.8	Mickley	0.716	67.2	0.472	0.054
				Johansen	0.538	25.7	Mc Gaw	1.057	147.0	0.115 †	0.054
				De Vries	0.590	39.9	Smith	------	------		
				Adj De Vries	------	------	Gemant	0.573	33.3		
				Resistor	------	------	Van Rooyen	0.321	-24.9		
				Kunii-Smith	------	------	Geom. Mean	------	------		

RHO = 3.100 TEMP = [illegible] W = [illegible] CL = [illegible] CSOLIDS = † 2.259 ALPHA = -------- KA = 0.076
KW = 0.586 KICE = † 2.[illegible] KQ = 7.[illegible] KO = 2.000 CSOLIDS2 = 5.840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por., Sat.	NC, UWC
Sample	3.30	1.6[illegible]	0.46[illegible]	Kersten	1.159	150.3	Mickley	0.740	59.8	0.472	0.054
				Johansen	0.542	17.2	Mc Gaw	1.072	131.5	0.115 †	0.054
				De Vries	0.653	41.1	Smith	------	------		
				Adj De Vries	------	------	Gemant	0.668	44.3		
				Resistor	------	------	Van Rooyen	0.321	-30.6		
				Kunii-Smith	------	------	Geom. Mean	------	------		

RHO = 3.100 TEMP = [illegible] W = [illegible] CL = [illegible] CSOLIDS = † 2.267 ALPHA = -------- KA = 0.151
KW = 0.613 KICE = † 2.[illegible] KQ = 7.[illegible] KO = 2.000 CSOLIDS2 = 5.840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por., Sat.	NC, UWC
Sample	3.30	1.6[illegible]	0.655	Kersten	1.159	76.9	Mickley	0.824	25.8	0.472	0.054
				Johansen	0.550	-16.0	Mc Gaw	1.112	69.8	0.115 †	0.054
				De Vries	0.804	22.7	Smith	------	------		
				Adj De Vries	------	------	Gemant	0.748	14.3		
				Resistor	------	------	Van Rooyen	0.321	-50.9		
				Kunii-Smith	------	------	Geom. Mean	------	------		

Table B5.

KERSTEN CRUSHED TRAP ROCK UNSATURATED UNFROZEN

TYPE OF SOIL: COARSE CRUSHED UNSATURATED UNFROZEN

RHO = 2.970 TEMP = 4.500 Q = 0.030 CL = 0.100 CSOLIDS = † 2.085 ALPHA = -------- KA = 0.054
KW = 0.569 KICE = † 2.200 KQ = 8.020 KO = 2.000 CSOLIDS2 = 5.500

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por., Sat.	NC, UWC
Sample	0.20	1.643	0.288	Kersten	-0.137	------	Mickley	0.668	131.7	0.447	0.003
				Johansen	0.230	-20.4	Mc Gaw	1.167	304.5	0.007 †	0.003
				De Vries	0.430	49.0	Smith	------	------		
				Adj De Vries	------	------	Gemant	------	------		
				Resistor	------	------	Van Rooyen	0.209	-27.7		
				Kunii-Smith	------	------	Geom. Mean	------	------		
Sample	0.20	1.922	0.472	Kersten	-0.204	------	Mickley	0.824	74.6	0.353	0.004
				Johansen	0.386	-18.2	Mc Gaw	1.355	187.4	0.011 †	0.004
				De Vries	0.568	20.5	Smith	------	------		
				Adj De Vries	------	------	Gemant	------	------		
				Resistor	------	------	Van Rooyen	0.298	-36.7		
				Kunii-Smith	------	------	Geom. Mean	------	------		

Table B5 (cont'd).

SAMPLE	1.80	1.660	0.382	KERSTEN	0.618	61.7	MICKLEY	0.681	78.8	0.444	0.018
				JOHANSEN	0.232	-39.3	MC GAW	1.131	196.0	0.037 +	0.018
				DE VRIES	0.484	26.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.251	-34.2		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	1.10	1.919	0.647	KERSTEN	0.976	50.7	MICKLEY	0.837	29.2	0.384	0.081
				JOHANSEN	0.517	-20.2	MC GAW	1.381	[illegible]	0.066 +	0.081
				DE VRIES	0.661	[illegible]	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.331	-48.8		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	1.90	1.650	0.567	KERSTEN	0.928	63.3	MICKLEY	0.691	[illegible]	0.444	0.031
				JOHANSEN	0.414	-26.9	MC GAW	1.093	93.0	0.071 +	0.031
				DE VRIES	0.538	-5.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.266	-53.1		
				RESISTOR	------	------	VAN ROOYEN	0.289	-49.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	1.70	1.927	0.672	KERSTEN	1.292	92.2	MICKLEY	0.852	26.8	0.381	0.033
				JOHANSEN	0.650	-3.3	MC GAW	1.277	90.0	0.093 +	0.033
				DE VRIES	0.707	5.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.409	-39.1		
				RESISTOR	------	------	VAN ROOYEN	0.349	-48.1		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	3.00	1.653	0.737	KERSTEN	1.251	69.8	MICKLEY	0.716	-2.8	0.443	0.062
				JOHANSEN	0.614	-16.6	MC GAW	1.038	40.9	0.142 +	0.063
				DE VRIES	0.639	-13.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.599	-18.8		
				RESISTOR	------	------	VAN ROOYEN	0.337	-54.3		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	3.70	1.927	0.992	KERSTEN	1.836	85.0	MICKLEY	0.888	-10.5	0.381	0.050
				JOHANSEN	0.870	-12.3	MC GAW	1.233	24.3	0.203 +	0.071
				DE VRIES	0.851	-14.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.896	-9.7		
				RESISTOR	------	------	VAN ROOYEN	0.373	-62.4		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B6.

KERSTEN DAKOTA SANDY LOAM UNSATURATED UNFROZEN

TYPE OF SOIL: SAND NATURAL UNSATURATED UNFROZEN

RHO = 2.710 TEMP = 4.500 W = 0.591 CL = 0.100 CSOLIDS = + 4.565 ALPHA = -------- KA = 0.094
KW = 0.569 KICE = + 2.200 KM = 6.020 KO = 2.000 CSOLIDS2 = 5.508

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	MC UNF.
SAMPLE	1.90	1.352	0.245	KERSTEN	0.599	144.4	MICKLEY	1.218	396.7	0.501	0.026
				JOHANSEN	0.314	28.2	MC GAW	1.802	635.0	0.051 +	0.026
				DE VRIES	0.660	169.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.304	24.1		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	2.10	1.600	0.460	KERSTEN	0.900	95.6	MICKLEY	1.528	232.2	0.610	0.036
				JOHANSEN	0.648	40.8	MC GAW	2.081	359.4	0.082 +	0.036
				DE VRIES	0.937	103.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.508	10.5		
				RESISTOR	------	------	VAN ROOYEN	0.543	18.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	1.90	1.764	0.554	KERSTEN	1.083	95.6	MICKLEY	1.756	216.8	0.369	0.036
				JOHANSEN	0.844	52.6	MC GAW	2.334	321.5	0.096 +	0.036
				DE VRIES	1.139	105.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.623	12.5		
				RESISTOR	------	------	VAN ROOYEN	0.680	22.9		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	2.10	1.921	0.883	KERSTEN	1.426	61.6	MICKLEY	2.005	127.2	0.291	0.040
				JOHANSEN	1.213	37.5	MC GAW	2.487	181.8	0.138 +	0.040
				DE VRIES	1.443	63.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.019	15.5		
				RESISTOR	------	------	VAN ROOYEN	0.852	-3.6		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	3.40	1.747	0.789	KERSTEN	1.411	78.9	MICKLEY	1.788	126.7	0.348	0.051
				JOHANSEN	1.187	50.5	MC GAW	2.145	172.0	0.173 +	0.060
				DE VRIES	1.326	68.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.169	48.3		
				RESISTOR	------	------	VAN ROOYEN	0.819	3.9		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	3.60	1.927	1.289	KERSTEN	1.817	40.9	MICKLEY	2.055	59.4	0.289	0.048
				JOHANSEN	1.575	22.1	MC GAW	2.443	89.5	0.240 +	0.069
				DE VRIES	1.678	30.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.607	24.6		
				RESISTOR	------	------	VAN ROOYEN	0.937	-27.3		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	3.50	2.084	1.651	KERSTEN	2.232	36.6	MICKLEY	2.352	42.4	0.231	0.060
				JOHANSEN	1.995	20.9	MC GAW	2.766	67.5	0.316 +	0.073
				DE VRIES	2.074	25.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2.056	24.5		
				RESISTOR	------	------	VAN ROOYEN	1.032	-37.5		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	4.00	1.969	1.318	KERSTEN	2.007	52.3	MICKLEY	2.142	62.5	0.274	0.066
				JOHANSEN	1.751	32.9	MC GAW	2.529	91.9	0.288 +	0.079
				DE VRIES	1.832	39.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.815	37.7		
				RESISTOR	------	------	VAN ROOYEN	0.971	-26.3		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	4.90	1.926	1.478	KERSTEN	2.023	36.9	MICKLEY	2.085	41.1	0.290	0.066
				JOHANSEN	1.765	19.4	MC GAW	2.450	65.7	0.375 +	0.094
				DE VRIES	1.911	29.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.875	26.9		
				RESISTOR	------	------	VAN ROOYEN	0.958	-35.2		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B6 (cont'd).

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. / Sat.	NC / UWC
SAMPLE	4,90	2,111	2,271	KERSTEN	2.648	16.6	MICKLEY	2.469	8.7	0.331	0.038
				JOHANSEN	2.325	2.4	MC GAU	2.841	25.1	0.448 +	0.105
				DE VRIES	2.486	9.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2.505	10.3		
				RESISTOR	------	------	VAN ROOYEN	1.059	-53.4		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	6,30	2,196	2,722	KERSTEN	3.264	19.1	MICKLEY	2.766	1.5	0.190	0.036
				JOHANSEN	2.821	3.6	MC GAU	3.049	12.0	0.727 +	0.136
				DE VRIES	2.910	6.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	3.084	13.3		
				RESISTOR	------	------	VAN ROOYEN	1.108	-59.3		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	8,90	1,924	2,166	KERSTEN	2.439	12.7	MICKLEY	2.209	2.1	0.290	0.066
				JOHANSEN	2.148	-0.7	MC GAU	2.489	15.0	0.590 +	0.171
				DE VRIES	2.221	2.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2.357	8.9		
				RESISTOR	------	------	VAN ROOYEN	0.970	-55.2		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	9,30	2,076	2,640	KERSTEN	3.073	16.4	MICKLEY	2.608	-1.2	0.236	0.060
				JOHANSEN	2.659	0.7	MC GAU	2.810	6.4	0.825 +	0.193
				DE VRIES	2.718	3.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2.913	10.3		
				RESISTOR	------	------	VAN ROOYEN	1.043	-60.5		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	13,60	1,914	2,363	KERSTEN	2.696	14.1	MICKLEY	2.388	1.1	0.294	0.066
				JOHANSEN	2.392	1.2	MC GAU	2.517	6.5	0.886 +	0.260
				DE VRIES	2.452	3.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2.621	10.9		
				RESISTOR	------	------	VAN ROOYEN	0.966	-59.1		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B7.

JOHANSEN SAND SA2 SATURATED UNFROZEN

TYPE OF SOIL: SAND NATURAL SATURATED UNFROZEN

RHO = 2,600 TEMP = 4,500 Q = 0.430 CL = 0,000 CSOLIDS = + 5,895 ALPHA = --------+ KA = + 0,025
KJ = 0.569 KICE = + 2,200 KQ = [illegible] KO = 2,000 CSOLIDS2 = 5,840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. / Sat.	NC / UWC
SAMPLE	18,00	1,771	2,109	KERSTEN	2,352	11.5	MICKLEY	2.165	2.7	0.349	0.050
				JOHANSEN	2.110	0.0	MC GAU	2.191	3.9	1.000 +	0.349
				DE VRIES	2.194	4.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2.118	0.4		
				RESISTOR	2.387	13.2	VAN ROOYEN	0.643	-69.5		
				KUNII-SMITH	2.089	-1.0	GEOM. MEAN	2.110	0.0		

RHO = 2,600 TEMP = 22,800 Q = 0.430 CL = 0.000 CSOLIDS = + 5,772 ALPHA = --------+ KA = + 0,025
KJ = 0.601 KICE = + 2,200 KQ = [illegible] KO = 2,000 CSOLIDS2 = 5,840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. / Sat.	NC / UWC
SAMPLE	18,00	1,771	2,145	KERSTEN	2.352	9.6	MICKLEY	2.144	-0.1	0.349	0.050
				JOHANSEN	2.100	-2.1	MC GAU	2.185	1.9	1.000 +	0.349
				DE VRIES	2.188	2.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2.139	-0.3		
				RESISTOR	2.368	10.4	VAN ROOYEN	0.643	-70.0		
				KUNII-SMITH	2.085	-2.8	GEOM. MEAN	2.100	-2.1		

Table B8.

JOHANSEN GRAVEL GR3 SATURATED UNFROZEN

TYPE OF SOIL: COARSE NATURAL SATURATED UNFROZEN

RHO = 2,700 TEMP = 5,100 Q = 0.670 CL = 0.000 CSOLIDS = + 5,839 ALPHA = --------+ KA = + 0,025
KJ = 0.570 KICE = + 2,200 KQ = [illegible] KO = 2,000 CSOLIDS2 = 5,840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. / Sat.	NC / UWC
SAMPLE	14,30	1.944	2,400	KERSTEN	2.881	18.8	MICKLEY	2.286	-4.7	0.278	0.066
				JOHANSEN	2.259	-5.9	MC GAU	2.326	-3.1	1.000 +	0.278
				DE VRIES	2.334	-2.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2.419	0.8		
				RESISTOR	2.491	3.8	VAN ROOYEN	0.661	-72.5		
				KUNII-SMITH	2.361	-1.6	GEOM. MEAN	2.259	-5.9		

RHO = 2,700 TEMP = 22,600 Q = 0.670 CL = 0.000 CSOLIDS = + 5,722 ALPHA = --------+ KA = + 0,025
KJ = 0.601 KICE = + 2,200 KQ = [illegible] KO = 2,000 CSOLIDS2 = 5,840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. / Sat.	NC / UWC
SAMPLE	14,30	1.944	2,615	KERSTEN	[illegible]	10.0	MICKLEY	2.340	[illegible]	0.278	0.067
				JOHANSEN	[illegible]	-7.2	MC GAU	2.316	[illegible]	1.000 +	0.278
				DE VRIES	2.321	-3.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2.436	0.8		
				RESISTOR	2.668	2.2	VAN ROOYEN	0.661	-72.6		
				KUNII-SMITH	2.361	-3.1	GEOM. MEAN	2.262	-7.2		

Table B9.

JOHANSEN GRAVEL GR7 SATURATED UNFROZEN

TYPE OF SOIL: COARSE NATURAL SATURATED UNFROZEN

RHO = 3,000 TEMP = 7,700 Q = 0,330 CL = 0,000 CSOLIDS = + 2,056 ALPHA = -------- KA = + 0,025
KW = 0,575 KICE = + 2,200 KQ = 7,930 KO = 2,000 CSOLIDS2 = 5,840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UNC
SAMPLE	10,20	2,297	1,722	KERSTEN	4,333	151,6	MICKLEY	1,513	-12,1	0,234	0,046
				JOHANSEN	1,525	-11,4	MC GAW	1,566	-9,1	1,000 +	0,234
				DE VRIES	1,565	-9,1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1,930	12,1		
				RESISTOR	1,609	-6,6	VAN ROOYEN	0,409	-76,2		
				KUNII-SMITH	1,628	-5,5	GEOM. MEAN	1,525	-11,4		

RHO = 3,000 TEMP = 16,200 Q = 0,330 CL = 0,000 CSOLIDS = + 2,055 ALPHA = -------- KA = + 0,025
KW = 0,590 KICE = + 2,200 KQ = 7,670 KO = 2,000 CSOLIDS2 = 5,840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UNC
SAMPLE	10,20	2,297	1,743	KERSTEN	4,333	148,6	MICKLEY	1,522	-12,7	0,234	0,046
				JOHANSEN	1,534	-12,0	MC GAW	1,574	-9,7	1,000 +	0,234
				DE VRIES	1,573	-9,7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1,954	12,1		
				RESISTOR	1,615	-7,3	VAN ROOYEN	0,409	-76,5		
				KUNII-SMITH	1,633	-6,3	GEOM. MEAN	1,534	-12,0		

RHO = 3,000 TEMP = 22,000 Q = 0,330 CL = 0,000 CSOLIDS = + 2,056 ALPHA = -------- KA = + 0,025
KW = 0,600 KICE = + 2,200 KQ = 7,3[illegible] KO = 2,000 CSOLIDS2 = 5,840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UNC
SAMPLE	10,20	2,297	1,727	KERSTEN	4,333	150,9	MICKLEY	1,527	-11,6	0,234	0,046
				JOHANSEN	1,536	-10,9	MC GAW	1,579	-8,6	1,000 +	0,234
				DE VRIES	1,578	-8,6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1,946	12,8		
				RESISTOR	1,620	-6,2	VAN ROOYEN	0,409	-76,3		
				KUNII-SMITH	1,639	-5,2	GEOM. MEAN	1,539	-10,9		

Table B10.

JOHANSEN CRUSHED ROCK PJ6 SATURATED UNFROZEN

TYPE OF SOIL: COARSE CRUSHED SATURATED UNFROZEN

RHO = 2,700 TEMP = 2,900 Q = 0,310 CL = 0,000 CSOLIDS = + 3,082 ALPHA = -------- KA = + 0,025
KW = 0,566 KICE = + 2,200 KQ = 8,370 KO = 2,000 CSOLIDS2 = 5,840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UNC
SAMPLE	14,20	1,951	1,759	KERSTEN	2,876	63,5	MICKLEY	1,933	9,9	0,277	0,068
				JOHANSEN	1,929	9,6	MC GAW	1,993	13,3	1,000 +	0,277
				DE VRIES	1,997	13,5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2,036	15,7		
				RESISTOR	2,111	20,0	VAN ROOYEN	0,463	-73,7		
				KUNII-SMITH	2,010	14,3	GEOM. MEAN	1,927	9,6		

RHO = 2,700 TEMP = 21,200 Q = 0,310 CL = 0,000 CSOLIDS = + 3,019 ALPHA = -------- KA = + 0,025
KW = 0,599 KICE = + 2,200 KQ = 7,550 KO = 2,000 CSOLIDS2 = 5,840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UNC
SAMPLE	14,20	1,951	1,807	KERSTEN	2,876	59,2	MICKLEY	1,931	6,9	0,277	0,068
				JOHANSEN	1,929	6,7	MC GAW	1,996	10,4	1,000 +	0,277
				DE VRIES	1,990	10,6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	2,069	14,5		
				RESISTOR	2,104	16,4	VAN ROOYEN	0,503	-72,2		
				KUNII-SMITH	2,008	11,1	GEOM. MEAN	1,929	6,7		

Table B11.

JOHANSEN CRUSHED ROCK PU10 SATURATED UNFROZEN

TYPE OF SOIL: COARSE CRUSHED SATURATED UNFROZEN

RHO = 3,100 TEMP = 6,300 Q = 0,090 CL = 0,000 CSOLIDS = + 2,265 ALPHA = -------- KA = + 0,025
KW = 0,572 KICE = + 2,200 KQ = 7,930 KO = 2,000 CSOLIDS2 = 5,840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UNC
SAMPLE	28,80	1,638	1,157	KERSTEN	2,180	88,4	MICKLEY	1,209	4,5	0,472	0,062
				JOHANSEN	1,183	2,3	MC GAW	1,253	8,3	1,000 +	0,472
				DE VRIES	1,246	7,7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1,402	21,2		
				RESISTOR	1,344	16,1	VAN ROOYEN	0,383	-66,9		
				KUNII-SMITH	1,078	-6,8	GEOM. MEAN	1,183	2,3		

RHO = 3,100 TEMP = 30,800 Q = 0,090 CL = 0,000 CSOLIDS = + 2,260 ALPHA = -------- KA = + 0,025
KW = 0,618 KICE = + 2,200 KQ = 7,280 KO = 2,000 CSOLIDS2 = 5,840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UNC
SAMPLE	28,80	1,638	1,330	KERSTEN	2,180	63,9	MICKLEY	1,239	-6,8	0,472	0,063
				JOHANSEN	1,218	-8,4	MC GAW	1,286	-3,3	1,000 +	0,472
				DE VRIES	1,278	-3,9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1,438	8,1		
				RESISTOR	1,368	2,9	VAN ROOYEN	[illegible]	-7[illegible]		
				KUNII-SMITH	1,115	-16,1	GEOM. MEAN	1,218	-8,4		

Table B12.

USSR BUILDING CODE (1969) CLAY SOIL UNSATURATED UNFROZEN

[illegible]

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K	DEVIATION (PERCENT)	METHOD	K	DEVIATION (PERCENT)	K SAT.	K
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLE	[illegible]	[illegible]	[illegible]	KERSTEN JOHANSEN DE VRIES VAN DE VRIES RESISTOR KERSTEN-SMITH	[illegible]	[illegible]	MICKLEY MC GAW SMITH GEMANT VAN ROOYEN GEOM. MEAN	[illegible]	[illegible]	[illegible]	[illegible]

Table B12 (cont'd).

Sample	Moisture	Density	K measured	Method	K computed	Deviation	Method	K computed	Deviation	Por./Sat.	NC/UWC
[illegible]	27.[illegible]	1.[illegible]	1.?42	KERSTEN	1.?83	-1?.0	MICKLEY	0.810?	-33.3	[illegible] +	[illegible]
				JOHANSEN	1.69?	-2?.5	MC GAW	0.84?	-40.?		
				DE VRIES	1.074	-28.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.651	-30.8		
				RESISTOR	------	------	VAN ROOYEN	0.606	-35.7		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		
[illegible]	27.[illegible]	1.[illegible]	1.331	KERSTEN	1.084	-?5.5	MICKLEY	0.689	-36.2	0.366	0.063
				JOHANSEN	0.782	-27.6	MC GAW	0.919	-15.0	0.575 +	0.324
				DE VRIES	0.776?	-28.5?	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.720?	-38.9?		
				RESISTOR	------	------	VAN ROOYEN	0.680	-37.1		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		
[illegible]	2?.[illegible]	1.?5?	1.?32	KERSTEN	0.96?	-25.2	MICKLEY	0.733	-40.3	0.365	0.063
				JOHANSEN	0.829	-32.7	MC GAW	0.959	-22.2	0.619 +	0.338
				DE VRIES	0.828?	-32.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.820?	-33.1?		
				RESISTOR	------	------	VAN ROOYEN	0.721?	-41.3?		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		
[illegible]	2?.[illegible]	1.?5?	1.39?	KERSTEN	1.09?	-21.7	MICKLEY	0.830	-40.5	0.309	0.066
				JOHANSEN	0.926?	-33.6	MC GAW	1.039	-25.3	0.716 +	0.365
				DE VRIES	0.93?	-32.7?	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.979	-34.8		
				RESISTOR	------	------	VAN ROOYEN	0.808	-42.1		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		
[illegible]	2?.[illegible]	1.?[illegible]	1.?0?	KERSTEN	1.174	-26.6	MICKLEY	0.885	-43.2	0.494	0.066
				JOHANSEN	0.977	-37.3	MC GAW	1.079	-30.7	0.770 +	0.378
				DE VRIES	0.997	-36.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.945?	-38.8?		
				RESISTOR	------	------	VAN ROOYEN	0.852	-45.3		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		
[illegible]	2?.[illegible]	1.?[illegible]	1.?4?	KERSTEN	1.354	-22.3	MICKLEY	1.017	-41.7	0.455	0.063
				JOHANSEN	1.083	-37.9	MC GAW	1.162	-33.4	0.891 +	0.405
				DE VRIES	1.119	-35.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.080	-38.1		
				RESISTOR	------	------	VAN ROOYEN	0.926	-47.0		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		
[illegible]	4?.[illegible]	1.1??	1.1??	KERSTEN	0.876?	-25.9	MICKLEY	0.723	-38.4	0.600	0.061
				JOHANSEN	0.831?	-29.3	MC GAW	0.915	-22.1	0.733 +	0.440
				DE VRIES	0.82?	-26.9?	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.751	-36.1		
				RESISTOR	------	------	VAN ROOYEN	0.670	-42.9		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		
[illegible]	4?.[illegible]	1.?5?	1.32?	KERSTEN	0.94?	-29.4	MICKLEY	0.780	-41.2	0.582	0.062
				JOHANSEN	0.877	-33.8	MC GAW	0.957	-27.8	0.791 +	0.460
				DE VRIES	0.882?	-33.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.833?	-39.6?		
				RESISTOR	------	------	VAN ROOYEN	0.788?	-40.8?		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		
[illegible]	4?.[illegible]	1.2??	1.?3?	KERSTEN	[illegible]	[illegible]	MICKLEY	0.843?	-43.8?	[illegible] +	[illegible]
				JOHANSEN	[illegible]	[illegible]	MC GAW	1.000?	[illegible]		
				DE VRIES	0.?47?	-37.2?	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.858	-42.8		
				RESISTOR	------	------	VAN ROOYEN	0.750	-50.0		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		
[illegible]	5?.[illegible]	1.?0?	1.?0?	KERSTEN	1.166	-30.2	MICKLEY	1.022	-38.5	0.527	0.064
				JOHANSEN	1.02?	-38.4	MC GAW	1.086	-34.7	0.986 +	0.520
				DE VRIES	1.072	-35.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.971?	-41.6?		
				RESISTOR	------	------	VAN ROOYEN	0.847?	-49.1?		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		
[illegible]	4?.[illegible]	1.?5?	1.13?	KERSTEN	1.247	-32.1	MICKLEY	1.036	-43.7	0.560	0.063
				JOHANSEN	1.01?	-44.8	MC GAW	1.073	-41.6	1.000 +	0.560
				DE VRIES	1.064	-42.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.030?	-43.9?		
				RESISTOR	------	------	VAN ROOYEN	0.866?	-53.2?		
				KUNII-SMITH	------	------	GEOM, MEAN	------	------		

Table B13.

KERSTEN HEAVY CLAY SATURATED UNFROZEN

TYPE OF SOIL: CLAY NATURAL SATURATED UNFROZEN

RHO = 1.59 TEMP = 4.0 [illegible] = 0.220 CL = + 0.780 CSOLIDS = + 2.716 ALPHA = -------- KA = + 0.025
KW = 0.568 KICE = + 2.20? [illegible] = 8.040 KQ = 2.000 CSOLIDS2 = 3.253

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	21.?0	1.?63	1.543	KERSTEN	1.576	2.?	MICKLEY	1.572	1.6	0.359	0.0??
				JOHANSEN	1.548	0.3	MC GAW	1.624	5.3	1.000 +	0.359
				DE VRIES	1.622	5.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.510	-2.1		
				RESISTOR	1.745	13.1	VAN ROOYEN	0.726	-53.0		
				KUNII-SMITH	1.491	-3.4	GEOM, MEAN	1.548	0.3		

Table B14.

PENNER LEDA CLAY SATURATED UNFROZEN

TYPE OF SOIL: CLAY NATURAL SATURATED UNFROZEN

RHO = 2.70 TEMP = 1.000 Q = 0.000 CL = 1.000 CSOLIDS = 1.700 ALPHA = -------- KA = + 0.025
KW = 0.564 KICE = + 2.210 KQ = + 8.430 KO = + 2.000 CSOLIDS2 = 2.524

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	MC UWC
SAMPLE	27.60	1.200	0.800	KERSTEN	1.060	32.5	HICKLEY	0.916	14.6	0.571	0.066
				JOHANSEN	0.903	12.9	MC GAW	0.948	18.5	1.000 +	0.571
				DE VRIES	0.941	17.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.813	1.6		
				RESISTOR	0.993	24.1	VAN ROOYEN	0.758	-5.2		
				KUNII-SMITH	0.818	2.2	GEOM. MEAN	------	------		
SAMPLE	35.90	1.380	0.906	KERSTEN	1.285	40.0	HICKLEY	0.985	8.7	0.505	0.067
				JOHANSEN	0.972	7.5	MC GAW	1.018	12.6	1.000 +	0.507
				DE VRIES	1.011	11.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.919	1.7		
				RESISTOR	1.067	18.0	VAN ROOYEN	0.925	2.1		
				KUNII-SMITH	0.892	-1.6	GEOM. MEAN	------	------		
SAMPLE	34.20	1.410	0.920	KERSTEN	1.292	40.5	HICKLEY	1.007	9.4	0.482	0.065
				JOHANSEN	0.997	8.4	MC GAW	1.043	13.3	1.000 +	0.482
				DE VRIES	1.036	12.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.930	1.1		
				RESISTOR	1.092	18.7	VAN ROOYEN	0.948	3.0		
				KUNII-SMITH	0.921	0.1	GEOM. MEAN	------	------		
SAMPLE	34.80	1.430	0.930	KERSTEN	1.337	43.8	HICKLEY	0.990	6.5	0.498	0.065
				JOHANSEN	0.980	5.4	MC GAW	1.026	10.3	1.000 +	0.498
				DE VRIES	1.019	9.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	0.955	2.7		
				RESISTOR	1.075	15.6	VAN ROOYEN	0.962	3.4		
				KUNII-SMITH	0.901	-3.1	GEOM. MEAN	------	------		
SAMPLE	29.10	1.535	0.991	KERSTEN	1.464	47.8	HICKLEY	1.045	5.5	0.447	0.066
				JOHANSEN	1.037	4.7	MC GAW	1.082	9.2	1.000 +	0.447
				DE VRIES	1.076	8.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.010	2.0		
				RESISTOR	1.132	14.3	VAN ROOYEN	0.973	-1.8		
				KUNII-SMITH	0.969	-2.2	GEOM. MEAN	------	------		

Table B15.

DAMES AND MOORE SAMPLES SATURATED UNFROZEN CLAY

TYPE OF SOIL: CLAY NATURAL SATURATED UNFROZEN

RHO = 2.70 TEMP = 20.000 Q = 0.000 CL = 1.000 CSOLIDS = 2.000 ALPHA = -------- KA = + 0.025
KW = 0.597 KICE = + 2.200 KQ = + 8.430 KO = + 2.000 CSOLIDS2 = 2.526

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	MC UWC
SAMPLE	25.70	1.549	1.653	KERSTEN	1.517	-8.2	HICKLEY	1.230	-25.6	0.409	0.062
				JOHANSEN	1.220	-26.2	MC GAW	1.275	-22.9	1.000 +	0.409
				DE VRIES	1.269	-23.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.206	-27.1		
				RESISTOR	1.342	-18.8	VAN ROOYEN	0.603	-63.5		
				KUNII-SMITH	1.153	-30.2	GEOM. MEAN	1.220	-26.2		
SAMPLE	22.90	1.693	1.175	KERSTEN	1.391	18.4	HICKLEY	1.179	0.3	0.446	0.043
				JOHANSEN	1.166	-0.8	MC GAW	1.223	4.0	1.000 +	0.446
				DE VRIES	1.216	3.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.136	-3.3		
				RESISTOR	1.290	9.8	VAN ROOYEN	0.986	-16.1		
				KUNII-SMITH	1.084	-7.8	GEOM. MEAN	1.166	-0.8		
SAMPLE	27.20	1.568	1.486	KERSTEN	1.499	0.9	HICKLEY	1.205	-18.9	0.427	0.063
				JOHANSEN	1.194	-19.6	MC GAW	1.250	-15.9	1.000 +	0.427
				DE VRIES	1.244	-16.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.197	-19.5		
				RESISTOR	1.317	-11.3	VAN ROOYEN	0.939	-36.8		
				KUNII-SMITH	1.120	-24.7	GEOM. MEAN	1.194	-19.6		
SAMPLE	30.00	1.458	1.429	KERSTEN	1.324	-7.4	HICKLEY	1.191	-16.7	0.437	0.063
				JOHANSEN	1.179	-17.5	MC GAW	1.235	-13.6	1.000 +	0.437
				DE VRIES	1.228	-14.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.095	-23.4		
				RESISTOR	1.303	-8.8	VAN ROOYEN	0.977	-31.6		
				KUNII-SMITH	1.100	-23.0	GEOM. MEAN	1.179	-17.5		
SAMPLE	25.00	1.556	1.538	KERSTEN	1.424	-7.4	HICKLEY	1.258	-18.2	0.388	0.061
				JOHANSEN	1.250	-18.7	MC GAW	1.304	-15.2	1.000 +	0.388
				DE VRIES	1.290	-15.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.152	-25.1		
				RESISTOR	1.370	-10.9	VAN ROOYEN	0.957	-37.8		
				KUNII-SMITH	1.192	-22.4	GEOM. MEAN	1.250	-18.7		

Table B16.

DAMES AND MOORE SAMPLES SATURATED UNFROZEN SILT

TYPE OF SOIL: SILT NATURAL SATURATED UNFROZEN

RHO = 2.700 TEMP = 20.000 Q = 0.000 CL = 1.000 CSOLIDS = 2.000 ALPHA = -------- KA = ? 0.026
KW = ?.597 KICE = ? 2.200 KQ = ? 8.430 KO = ? 2.000 CSOLIDS2 = 2.024

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	25.92	1.591	1.481	KERSTEN	1.521	2.7	MICKLEY	1.225	-17.3	0.412	0.062
				JOHANSEN	1.215	-17.9	MC GAW	1.271	-14.2	1.000 +	0.412
				DE VRIES	1.265	-14.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.208	-18.4		
				RESISTOR	1.338	-9.7	VAN ROOYEN	3.555	140.0		
				KUNII-SMITH	1.147	-22.5	GEOM. MEAN	1.215	-17.9		
SAMPLE	25.92	1.591	1.499	KERSTEN	1.521	1.5	MICKLEY	1.225	-18.3	0.412	0.062
				JOHANSEN	1.215	-18.9	MC GAW	1.271	-15.2	1.000 +	0.412
				DE VRIES	1.265	-15.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.208	-19.4		
				RESISTOR	1.338	-10.8	VAN ROOYEN	3.555	137.2		
				KUNII-SMITH	1.147	-23.5	GEOM. MEAN	1.215	-18.9		
SAMPLE	29.42	1.522	1.556	KERSTEN	1.441	-7.0	MICKLEY	1.177	-24.0	0.447	0.063
				JOHANSEN	1.164	-24.9	MC GAW	1.221	-21.2	1.000 +	0.447
				DE VRIES	1.214	-21.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	1.166	-24.8		
				RESISTOR	1.289	-16.9	VAN ROOYEN	5.534	257.0		
				KUNII-SMITH	1.062	-32.2	GEOM. MEAN	1.164	-24.9		

Table B17.

KERSTEN DAKOTA SANDY LOAM UNSATURATED FROZEN

TYPE OF SOIL: SAND NATURAL UNSATURATED FROZEN

RHO = [illegible] TEMP = -4.0 Q = 0.591 CL = 0.100 CSOLIDS = + 4.634 ALPHA = -------- KA = 0.046
KW = [illegible] KICE = [illegible] 2.255 KM = 8.290 KD = 2.000 CSOLIDS2 = 5.508

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	[illegible]	1.352	0.246	KERSTEN	0.287	14.9	MICKLEY	1.271	409.3	0.501	------
				JOHANSEN	0.348	39.4	MC GAW	------	------	0.056	0.000
				DE VRIES	0.826	231.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.4[illegible]	[illegible].459	KERSTEN	0.496	8.2	MICKLEY	1.608	250.7	0.610	------
				JOHANSEN	0.528	15.2	MC GAW	------	------	0.089	0.000
				DE VRIES	1.228	167.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.7[illegible]	[illegible].545	KERSTEN	0.651	19.4	MICKLEY	1.845	238.5	0.349	------
				JOHANSEN	0.645	18.3	MC GAW	------	------	0.105	0.000
				DE VRIES	1.476	170.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.[illegible]	0.883	KERSTEN	0.942	6.7	MICKLEY	2.126	140.9	0.291	------
				JOHANSEN	0.885	0.2	MC GAW	------	------	0.151	0.000
				DE VRIES	1.809	105.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.767	0.763	KERSTEN	0.918	20.3	MICKLEY	1.932	153.2	0.348	------
				JOHANSEN	0.905	18.7	MC GAW	------	------	0.183	0.000
				DE VRIES	1.867	144.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.927	1.265	KERSTEN	1.322	4.6	MICKLEY	2.244	77.4	0.289	------
				JOHANSEN	1.241	-1.9	MC GAW	------	------	0.254	0.000
				DE VRIES	2.340	85.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	2.084	1.647	KERSTEN	1.819	10.4	MICKLEY	2.593	57.5	0.231	------
				JOHANSEN	1.670	1.4	MC GAW	------	------	0.344	0.000
				DE VRIES	2.829	71.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.940	1.293	KERSTEN	1.556	20.3	MICKLEY	2.366	82.8	0.276	------
				JOHANSEN	1.445	11.7	MC GAW	------	------	0.306	0.000
				DE VRIES	2.565	98.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.926	1.377	KERSTEN	1.680	22.0	MICKLEY	2.350	70.6	0.290	------
				JOHANSEN	1.577	14.5	MC GAW	------	------	0.354	0.000
				DE VRIES	2.779	101.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	2.111	2.352	KERSTEN	2.464	4.8	MICKLEY	2.829	20.3	0.221	------
				JOHANSEN	2.269	-3.5	MC GAW	------	------	0.310	0.000
				DE VRIES	3.414	45.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B17 (cont'd).

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. / Sat.	NC / UWC
SAMPLE	[illegible]	2.132	2.428	KERSTEN	2.571	5.9	MICKLEY	2.892	19.1	0.213	------
				JOHANSEN	2.371	-2.4	MC GAW	------	------	0.534	0.000
				DE VRIES	3.486	43.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	2.154	2.924	KERSTEN	3.522	20.4	MICKLEY	3.346	14.4	0.190	------
				JOHANSEN	3.286	12.4	MC GAW	------	------	0.780	0.000
				DE VRIES	3.873	32.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.924	2.483	KERSTEN	2.699	8.7	MICKLEY	2.721	9.6	0.290	------
				JOHANSEN	2.535	2.1	MC GAW	------	------	0.636	0.000
				DE VRIES	3.307	33.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	2.076	3.061	KERSTEN	3.839	26.2	MICKLEY	3.610	12.1	0.234	------
				JOHANSEN	3.565	16.8	MC GAW	------	------	0.890	0.000
				DE VRIES	3.863	26.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	13.3	1.916	3.174	KERSTEN	3.798	19.7	MICKLEY	3.390	6.8	0.296	------
				JOHANSEN	3.576	12.7	MC GAW	------	------	0.945	0.000
				DE VRIES	3.737	17.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.756	3.053	KERSTEN	3.670	20.2	MICKLEY	3.599	17.9	0.352	------
				JOHANSEN	3.609	18.2	MC GAW	------	------	1.000	0.000
				DE VRIES	3.666	20.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B18.

JOHANSEN SAND SA2 SATURATED FROZEN

TYPE OF SOIL: SAND NATURAL SATURATED FROZEN

RHO = 2.600 TEMP = -6.900 W = 0.400 CL = 0.000 CSOLIDS = † 3.996 ALPHA = -------- KA = † 0.025
KW = † 0.570 KICE = 2.310 KU = 8.400 KO = 2.000 CSOLIDS2 = 5.840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. / Sat.	NC / UWC
SAMPLE	18.00	† 1.722	3.111	KERSTEN	3.351	7.7	MICKLEY	3.318	6.7	0.338	------
				JOHANSEN	3.321	6.7	MC GAW	------	------	1.000	0.000
				DE VRIES	3.353	7.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	3.393	9.0	VAN ROOYEN	------	------		
				KUNII-SMITH	3.264	4.9	GEOM. MEAN	3.321	6.7		

RHO = 2.600 TEMP = -28.000 W = 0.400 CL = 0.000 CSOLIDS = † 4.145 ALPHA = -------- KA = † 0.025
KW = † 0.570 KICE = 2.470 KU = 9.130 KO = 2.000 CSOLIDS2 = 5.840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. / Sat.	NC / UWC
SAMPLE	18.00	† 1.722	2.678	KERSTEN	3.351	25.1	MICKLEY	3.478	29.9	0.338	------
				JOHANSEN	3.480	30.0	MC GAW	------	------	1.000	0.000
				DE VRIES	3.510	31.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	3.548	32.5	VAN ROOYEN	------	------		
				KUNII-SMITH	3.421	27.8	GEOM. MEAN	3.480	30.0		

Table B19.

JOHANSEN GRAVEL GR1 SATURATED FROZEN

TYPE OF SOIL: COARSE NATURAL SATURATED FROZEN

RHO = 2.740 TEMP = -7.900 W = 0.490 CL = 0.000 CSOLIDS = † 4.047 ALPHA = -------- KA = † 0.025
KW = † 0.570 KICE = 2.310 KU = 8.430 KO = 2.000 CSOLIDS2 = 5.840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. / Sat.	NC / UWC
SAMPLE	13.20	† 1.967	3.103	KERSTEN	4.210	35.7	MICKLEY	3.448	11.1	0.283	------
				JOHANSEN	3.453	11.3	MC GAW	------	------	1.000	0.000
				DE VRIES	3.484	12.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	3.519	13.4	VAN ROOYEN	------	------		
				KUNII-SMITH	3.445	11.0	GEOM. MEAN	3.453	11.3		

RHO = 2.740 TEMP = -26.400 W = 0.490 CL = 0.000 CSOLIDS = † 4.188 ALPHA = -------- KA = † 0.025
KW = † 0.570 KICE = 2.450 KU = 9.040 KO = 2.000 CSOLIDS2 = 5.840

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. / Sat.	NC / UWC
SAMPLE	13.20	† 1.967	3.584	KERSTEN	4.210	17.5	MICKLEY	3.594	0.3	0.283	------
				JOHANSEN	3.599	0.4	MC GAW	------	------	1.000	0.000
				DE VRIES	3.628	1.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	3.662	2.2	VAN ROOYEN	------	------		
				KUNII-SMITH	3.587	0.1	GEOM. MEAN	3.599	0.4		

Table B20.

JOHANSEN GRAVEL GR3 SATURATED FROZEN

TYPE OF SOIL: COARSE NATURAL SATURATED FROZEN

RHO = 2.700 TEMP = -12.000 W = 0.470 CL = 0.000 CSOLIDS = † 3.968 ALPHA = -------- KA = † 0.025
KW = † 0.570 KICE = 2.340 KU = 8.590 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	14.30	† 1.897	3.572	KERSTEN	3.909	9.4	MICKLEY	3.390	-5.1	0.296	------
				JOHANSEN	3.394	-5.0	MC GAW	------	------	1.000	0.000
				DE VRIES	3.422	-4.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	3.455	-3.3	VAN ROOYEN	------	------		
				KUNII-SMITH	3.372	-5.6	GEOM. MEAN	3.394	-5.0		

RHO = 2.700 TEMP = -30.000 Q = 0.470 CL = 0.000 CSOLIDS = † 4.098 ALPHA = -------- KA = † 0.025
KW = † 0.570 KICE = 2.480 KU = 9.200 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	14.30	† 1.897	3.865	KERSTEN	3.909	1.1	MICKLEY	3.529	-8.7	0.296	------
				JOHANSEN	3.532	-8.6	MC GAW	------	------	1.000	0.000
				DE VRIES	3.559	-7.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	3.590	-7.1	VAN ROOYEN	------	------		
				KUNII-SMITH	3.508	-9.2	GEOM. MEAN	3.532	-8.6		

Table B21.

JOHANSEN CRUSHED ROCK PU5 SATURATED FROZEN

TYPE OF SOIL: COARSE CRUSHED SATURATED FROZEN

RHO = 2.680 TEMP = -9.500 W = 0.330 CL = 0.000 CSOLIDS = † 3.222 ALPHA = -------- KA = † 0.025
KW = † 0.570 KICE = 2.320 KU = 8.480 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	15.10	† 1.861	2.772	KERSTEN	3.812	37.5	MICKLEY	2.912	5.1	0.306	------
				JOHANSEN	2.913	5.1	MC GAW	------	------	1.000	0.000
				DE VRIES	2.923	5.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	2.936	5.9	VAN ROOYEN	------	------		
				KUNII-SMITH	2.886	4.1	GEOM. MEAN	2.913	5.1		

RHO = 2.680 TEMP = -20.000 W = 0.330 CL = 0.000 CSOLIDS = † 3.301 ALPHA = -------- KA = † 0.025
KW = † 0.570 KICE = 2.470 KU = 9.130 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	15.10	† 1.861	2.888	KERSTEN	3.812	32.0	MICKLEY	3.020	4.6	0.306	------
				JOHANSEN	3.020	4.6	MC GAW	------	------	1.000	0.000
				DE VRIES	3.029	4.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	3.039	5.2	VAN ROOYEN	------	------		
				KUNII-SMITH	2.994	3.7	GEOM. MEAN	3.020	4.6		

Table B22.

JOHANSEN CRUSHED ROCK PU9 SATURATED FROZEN

TYPE OF SOIL: COARSE CRUSHED SATURATED FROZEN

RHO = 2.730 TEMP = -10.000 W = 0.030 CL = 0.000 CSOLIDS = † 2.089 ALPHA = -------- KA = † 0.025
KW = † 0.570 KICE = 2.320 KU = 8.520 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	23.60	† 1.603	2.408	KERSTEN	3.368	39.9	MICKLEY	2.181	-9.4	0.412	------
				JOHANSEN	2.181	-9.4	MC GAW	------	------	1.000	0.000
				DE VRIES	2.182	-9.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	2.184	-9.3	VAN ROOYEN	------	------		
				KUNII-SMITH	2.203	-8.5	GEOM. MEAN	2.181	-9.4		

RHO = 2.730 TEMP = -31.400 Q = 0.030 CL = 0.000 CSOLIDS = † 2.094 ALPHA = -------- KA = † 0.025
KW = † 0.570 KICE = 2.490 KU = 9.230 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	23.60	† 1.603	2.494	KERSTEN	3.368	35.1	MICKLEY	2.249	-9.8	0.412	------
				JOHANSEN	2.249	-9.8	MC GAW	------	------	1.000	0.000
				DE VRIES	2.252	-9.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	2.255	-9.6	VAN ROOYEN	------	------		
				KUNII-SMITH	2.287	-8.3	GEOM. MEAN	2.249	-9.8		

Table B23.

[illegible] UNSATURATED FROZEN

TYPE OF SOIL: [illegible] NATURAL UNSATURATED FROZEN

RHO =	[illegible]	[illegible] =	-5.0	[illegible] = +	[illegible] CL = +	1.000 PSOLIDS =	3.000 ALPHA =	--------	KA =	0.024	
KW =	[illegible]	[illegible] =	2.2[illegible]	[illegible] = +	8.430 KQ = +	2.000 PSOLIDS2 =	2.524				

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. / SAT.	NO. UNF.
SAMPLE	[illegible]	1.611	[illegible]	KERSTEN	.701	-10.3	MICKLEY	1.221	56.4	0.403	------
				JOHANSEN	.870	12.4	MC GAW	------	------	0.260	0.000
				DE VRIES	1.452	85.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.726	[illegible]	KERSTEN	1.203	-33.7	MICKLEY	1.564	-13.8	0.368	------
				JOHANSEN	1.528	-15.8	MC GAW	------	------	0.513	0.000
				DE VRIES	2.030	11.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.726	[illegible]	KERSTEN	1.203	-33.7	MICKLEY	1.536	-15.4	0.368	------
				JOHANSEN	1.294	-28.7	MC GAW	------	------	0.480	0.100
				DE VRIES	1.453	-19.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.726	[illegible]	KERSTEN	1.949	-28.0	MICKLEY	2.326	-15.2	0.339	------
				JOHANSEN	2.560	-6.6	MC GAW	------	------	0.927	0.000
				DE VRIES	2.451	-3.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.726	[illegible]	KERSTEN	1.949	-28.0	MICKLEY	2.249	-17.9	0.339	------
				JOHANSEN	2.172	-20.8	MC GAW	------	------	0.900	0.100
				DE VRIES	2.214	-19.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B24.

[illegible] UNSATURATED FROZEN

TYPE OF SOIL: [illegible] NATURAL UNSATURATED FROZEN

RHO =	[illegible]	[illegible] =	-5.0[illegible]	[illegible] = +	[illegible] CL = +	1.000 PSOLIDS =	3.000 ALPHA =	--------	KA =	0.024	
KW =	[illegible]	[illegible] =	2.[illegible]	[illegible] = +	8.430 KQ = +	2.000 PSOLIDS2 =	2.524				

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. / SAT.	NO. UNF.
SAMPLE	[illegible]	1.605	[illegible]	KERSTEN	0.719	-27.1	MICKLEY	1.268	28.6	0.372	------
				JOHANSEN	0.853	-13.6	MC GAW	------	------	0.238	0.000
				DE VRIES	1.447	46.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.605	[illegible]	KERSTEN	0.719	-27.1	MICKLEY	1.257	27.3	0.372	------
				JOHANSEN	0.781	-20.8	MC GAW	------	------	0.224	0.050
				DE VRIES	0.876	-11.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.918	1.316	KERSTEN	1.342	1.9	MICKLEY	1.686	28.1	0.327	------
				JOHANSEN	1.641	24.7	MC GAW	------	------	0.544	0.000
				DE VRIES	2.171	64.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.818	1.316	KERSTEN	1.342	1.9	MICKLEY	1.654	25.7	0.327	------
				JOHANSEN	1.388	5.4	MC GAW	------	------	0.517	0.100
				DE VRIES	1.595	21.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.856	2.367	KERSTEN	1.892	-20.1	MICKLEY	2.199	-7.1	0.312	------
				JOHANSEN	2.427	2.5	MC GAW	------	------	0.863	0.000
				DE VRIES	2.602	9.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.856	2.367	KERSTEN	1.892	-20.1	MICKLEY	2.170	-8.4	0.312	------
				JOHANSEN	2.055	-13.2	MC GAW	------	------	0.835	0.100
				DE VRIES	2.132	-9.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B25.

PENNER ET AL SOIL 6 UNSATURATED FROZEN

TYPE OF SOIL: CLAY NATURAL UNSATURATED FROZEN

RHO = 2.70 TEMP = -5.000 Q = + 0.000 CL = + 1.000 CSOLIDS = 7.000 ALPHA = -------- KA = 0.024
KW = 0.560 KICE = 2.290 KQ = + 8.430 KO = + 2.000 CSOLIDS2 = 2.524

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD K	COMPUTED	DEVIATION (PERCENT)	METHOD K	COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC NUC.
SAMPLE	6.50	1.642	0.840	KERSTEN	0.785	-6.5	MICKLEY	1.281	52.5	0.392	------
				JOHANSEN	0.979	16.5	MC GAW	------	------	0.297	0.000
				DE VRIES	1.567	86.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	6.50	1.642	0.840	KERSTEN	0.785	-6.5	MICKLEY	1.270	51.2	0.392	------
				JOHANSEN	0.899	7.0	MC GAW	------	------	0.285	0.050
				DE VRIES	0.894	6.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	11.20	1.763	1.530	KERSTEN	1.435	-6.2	MICKLEY	1.751	14.4	0.345	------
				JOHANSEN	1.822	19.1	MC GAW	------	------	0.626	0.000
				DE VRIES	2.248	46.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	11.20	1.768	1.530	KERSTEN	1.435	-6.2	MICKLEY	1.717	12.2	0.345	------
				JOHANSEN	1.543	0.9	MC GAW	------	------	0.600	0.100
				DE VRIES	1.688	10.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	14.46	1.826	2.268	KERSTEN	1.911	-15.7	MICKLEY	2.241	-1.2	0.324	------
				JOHANSEN	2.480	9.4	MC GAW	------	------	0.890	0.000
				DE VRIES	2.620	15.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	14.46	1.826	2.268	KERSTEN	1.911	-15.7	MICKLEY	2.177	-4.0	0.324	------
				JOHANSEN	2.102	-7.3	MC GAW	------	------	0.861	0.100
				DE VRIES	2.162	-4.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B26.

PENNER ET AL SOIL 7 UNSATURATED FROZEN

TYPE OF SOIL: CLAY NATURAL UNSATURATED FROZEN

RHO = 2.70 TEMP = -5.000 Q = + 0.000 CL = + 1.000 CSOLIDS = 7.000 ALPHA = -------- KA = 0.024
KW = 0.560 KICE = 2.290 KQ = + 8.430 KO = + 2.000 CSOLIDS2 = 2.524

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD K	COMPUTED	DEVIATION (PERCENT)	METHOD K	COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC NUC.
SAMPLE	4.45	1.973	1.168	KERSTEN	1.290	10.5	MICKLEY	1.639	40.3	0.269	------
				JOHANSEN	1.290	10.5	MC GAW	------	------	0.372	0.000
				DE VRIES	2.058	76.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	4.45	1.973	1.168	KERSTEN	1.290	10.5	MICKLEY	1.626	39.2	0.269	------
				JOHANSEN	1.183	1.3	MC GAW	------	------	0.355	0.050
				DE VRIES	1.299	11.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	8.52	2.074	1.877	KERSTEN	2.151	14.6	MICKLEY	2.272	21.0	0.232	------
				JOHANSEN	2.427	29.3	MC GAW	------	------	0.831	0.000
				DE VRIES	2.672	42.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	8.52	2.074	1.877	KERSTEN	2.151	14.6	MICKLEY	2.208	17.7	0.232	------
				JOHANSEN	2.038	8.6	MC GAW	------	------	0.792	0.100
				DE VRIES	2.196	17.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	13.50 *	1.940	2.582	KERSTEN	2.184	-15.4	MICKLEY	2.780	7.7	0.281	------
				JOHANSEN	2.781	7.7	MC GAW	------	------	1.000	0.000
				DE VRIES	2.787	8.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	13.50 *	1.958	2.581	KERSTEN	2.253	-12.7	MICKLEY	2.765	7.1	0.275	------
				JOHANSEN	2.419	-6.3	MC GAW	------	------	1.000	0.100
				DE VRIES	2.447	-5.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B27.

P[illegible] ET AL SOIL [illegible] UNSATURATED FROZEN

TYPE OF SOIL: [illegible] NATURAL UNSATURATED FROZEN

RHO = [illegible] TEMP = -5.[illegible] = + [illegible].020 CL = + 1.000 ESOLIDS = 3.000 ALPHA = -------- KA = 0.024
KU = [illegible] = 2.[illegible] = + 0.420 KO = + 2.000 ESOLIDS2 = 2.524

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD K	COMPUTED	DEVIATION (PERCENT)	METHOD K	COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NO. [illegible]
SAMPLE	[illegible]	1.757	[illegible]	KERSTEN	0.454	25.8	MICKLEY	0.967	167.0	0.486	------
				JOHANSEN	0.610	68.0	MC GAW	------	------	0.174	0.000
				DE VRIES	1.056	192.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.357	[illegible]	KERSTEN	0.454	25.8	MICKLEY	0.958	165.5	0.486	------
				JOHANSEN	0.558	54.5	MC GAW	------	------	0.165	0.050
				DE VRIES	0.598	65.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.542	[illegible]	KERSTEN	1.293	36.4	MICKLEY	1.573	65.9	0.420	------
				JOHANSEN	1.690	78.3	MC GAW	------	------	0.594	0.000
				DE VRIES	2.057	117.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.542	[illegible]	KERSTEN	1.293	36.4	MICKLEY	1.544	62.9	0.420	------
				JOHANSEN	1.435	51.4	MC GAW	------	------	0.575	0.100
				DE VRIES	1.494	57.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.543	[illegible]	KERSTEN	1.625	-2.1	MICKLEY	1.862	12.1	0.421	------
				JOHANSEN	2.135	28.6	MC GAW	------	------	0.778	0.000
				DE VRIES	2.343	41.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.543	[illegible]	KERSTEN	1.625	-2.1	MICKLEY	1.822	9.8	0.421	------
				JOHANSEN	1.814	9.4	MC GAW	------	------	0.757	0.100
				DE VRIES	1.820	10.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B28.

P[illegible] ET AL SOIL [illegible] UNSATURATED FROZEN

TYPE OF SOIL: [illegible] NATURAL UNSATURATED FROZEN

RHO = [illegible] TEMP = -5.[illegible] = + 0.000 CL = + 1.000 ESOLIDS = 3.000 ALPHA = -------- KA = 0.024
KU = [illegible] = 2.[illegible] = + 0.430 KO = + 2.000 ESOLIDS2 = 2.524

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD K	COMPUTED	DEVIATION (PERCENT)	METHOD K	COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NO. [illegible]
SAMPLE	[illegible]	1.630	0.511	KERSTEN	0.533	4.4	MICKLEY	1.033	102.2	0.470	------
				JOHANSEN	0.706	38.2	MC GAW	------	------	0.209	0.000
				DE VRIES	1.157	126.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.470	0.511	KERSTEN	0.533	4.4	MICKLEY	1.026	100.3	0.470	------
				JOHANSEN	0.647	26.6	MC GAW	------	------	0.200	0.050
				DE VRIES	0.656	28.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	11.4	1.51[illegible]	0.982	KERSTEN	0.995	1.4	MICKLEY	1.340	36.5	0.441	------
				JOHANSEN	1.298	32.2	MC GAW	------	------	0.442	0.000
				DE VRIES	1.741	77.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	11.4	1.51[illegible]	[illegible]	KERSTEN	0.995	1.4	MICKLEY	1.317	34.1	0.441	------
				JOHANSEN	1.100	12.0	MC GAW	------	------	0.422	0.100
				DE VRIES	1.181	20.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	17.2	1.6[illegible]7	1.591	KERSTEN	1.688	6.1	MICKLEY	1.957	23.0	0.394	------
				JOHANSEN	2.224	39.8	MC GAW	------	------	0.806	0.000
				DE VRIES	2.422	52.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	17.[illegible]	1.677	1.591	KERSTEN	1.688	6.1	MICKLEY	1.913	20.3	0.394	------
				JOHANSEN	1.890	18.8	MC GAW	------	------	0.783	0.100
				DE VRIES	1.921	20.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B29.

[illegible] SOIL [illegible] UNSATURATED FROZEN

TYPE OF SOIL: CLAY NATURAL UNSATURATED FROZEN

RHO = [illegible] TEMP = -5.[illegible] CL = [illegible] 1.000 [illegible] KA = 0.026
KW = 0.560 KICE = 2.2[illegible] [illegible] 2.5[illegible]

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	7.[illegible]	1.4[illegible]0	0.4[illegible]7	KERSTEN	.555	11.6	MICKLEY	1.026	106.[illegible]	0.481	------
				JOHANSEN	.73[illegible]	48.1	MC GAW	------	------	0.224	0.000
				DE VRIES	1.168	134.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	7.[illegible]	1.400	0.497	KERSTEN	.555	11.6	MICKLEY	1.017	104.[illegible]	0.481	------
				JOHANSEN	.676	35.7	MC GAW	------	------	0.215	0.650
				DE VRIES	.651	31.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	12.[illegible]	1.461	[illegible].7[illegible]3	KERSTEN	[illegible]	27.7	MICKLEY	1.2[illegible]6	73.[illegible]	0.459	------
				JOHANSEN	1.230	66.7	MC GAW	------	------	0.424	0.000
				DE VRIES	1.662	123.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	12.[illegible]	1.461	0.763	KERSTEN	[illegible]	27.7	MICKLEY	1.2[illegible]1	6[illegible]	0.459	------
				JOHANSEN	1.050	41.3	MC GAW	------	------	0.404	0.400
				DE VRIES	1.111	49.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	16.[illegible]	1.4[illegible]	[illegible]	KERSTEN	1.266	28.7	MICKLEY	1.515	53.[illegible]	0.448	------
				JOHANSEN	1.652	67.0	MC GAW	------	------	0.580	0.000
				DE VRIES	1.992	102.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	16.[illegible]	1.4[illegible]	[illegible]	KERSTEN	1.266	28.7	MICKLEY	1.4[illegible]7	51.[illegible]	0.448	------
				JOHANSEN	1.40[illegible]	42.7	MC GAW	------	------	0.569	0.400
				DE VRIES	1.[illegible]29	45.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	2[illegible].11	1.629	1.9[illegible]	KERSTEN	1.856	-2.5	MICKLEY	2.171	14.2	0.397	------
				JOHANSEN	2.451	28.0	MC GAW	------	------	0.900	0.000
				DE VRIES	2.555	34.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	2[illegible].11	1.629	1.9[illegible]	KERSTEN	1.856	-2.5	MICKLEY	2.111	11.0	0.397	------
				JOHANSEN	2.085	9.7	MC GAW	------	------	0.878	0.400
				DE VRIES	2.102	10.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B30.

KERSTEN FAIRBANKS SILTY CLAY LOAM P4710 UNSATURATED FROZEN

TYPE OF SOIL: CLAY NATURAL UNSATURATED FROZEN

RHO = 2.710 TEMP = -4.000 U = 0.641 CL = 0.270 CSOLIDS = 4.976 ALPHA = -------- KA = 0.046
KW = 0.560 KICE = 2.200 KU = 0.290 KD = 2.000 CSOLIDS2 = 4.945

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	2.40	0.924	0.140	KERSTEN	0.112	-20.0	MICKLEY	0.858	513.6	0.659	------
				JOHANSEN	0.210	50.3	MC GAW	------	------	0.037	0.000
				DE VRIES	0.480	242.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.087	-38.1		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	2.40	0.924	0.140	KERSTEN	0.112	-20.0	MICKLEY	0.855	511.2	0.659	------
				JOHANSEN	0.198	41.8	MC GAW	------	------	0.034 +	0.022
				DE VRIES	0.365	160.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.084	-39.9		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	2.50	1.118	0.189	KERSTEN	0.160	-15.1	MICKLEY	1.080	471.9	0.587	------
				JOHANSEN	0.289	53.0	MC GAW	------	------	0.052	0.000
				DE VRIES	0.677	258.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.130	-31.4		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	2.50	1.118	0.189	KERSTEN	0.160	-15.1	MICKLEY	1.076	469.4	0.587	------
				JOHANSEN	0.270	43.1	MC GAW	------	------	0.048 +	0.028
				DE VRIES	0.[illegible]93	160.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.126	-33.5		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	2.40	1.278	0.235	KERSTEN	0.210	-10.7	MICKLEY	1.276	443.0	0.528	------
				JOHANSEN	0.359	52.9	MC GAW	------	------	0.063	0.000
				DE VRIES	0.855	263.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.180	-23.4		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B30 (cont'd).

SAMPLE	2.40	1.278	0.235	KERSTEN	0.210	-12.7	MICKLEY	1.270	440.5	0.528	------
				JOHANSEN	0.335	42.5	MC GAW	------	------	0.058 +	0.031
				DE VRIES	0.614	161.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.175	-25.6		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	6.60	1.272	0.420	KERSTEN	0.430	2.4	MICKLEY	1.392	231.7	0.531	------
				JOHANSEN	0.699	66.6	MC GAW	------	------	0.172	0.002
				DE VRIES	1.317	213.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.308	-26.7		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	6.60	1.272	0.420	KERSTEN	0.430	2.4	MICKLEY	1.360	228.9	0.531	------
				JOHANSEN	0.624	48.6	MC GAW	------	------	0.102	0.060
				DE VRIES	0.792	88.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.294	-30.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	6.90	1.422	0.522	KERSTEN	0.564	8.0	MICKLEY	1.637	213.6	0.475	------
				JOHANSEN	0.922	76.6	MC GAW	------	------	0.225	0.002
				DE VRIES	1.094	224.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.415	-20.5		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	6.90	1.422	0.522	KERSTEN	0.564	8.0	MICKLEY	1.624	211.0	0.475	------
				JOHANSEN	0.826	58.2	MC GAW	------	------	0.214	0.060
				DE VRIES	0.986	89.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.401	-23.2		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	12.30	1.283	0.632	KERSTEN	0.743	17.6	MICKLEY	1.595	152.5	0.527	------
				JOHANSEN	1.187	87.9	MC GAW	------	------	0.327	0.000
				DE VRIES	1.803	185.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.530	-16.1		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	12.30	1.283	0.632	KERSTEN	0.743	17.6	MICKLEY	1.581	150.4	0.527	------
				JOHANSEN	1.070	69.5	MC GAW	------	------	0.316	0.060
				DE VRIES	0.988	56.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.516	-18.4		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	12.20	1.443	0.870	KERSTEN	0.925	6.3	MICKLEY	1.899	118.4	0.467	------
				JOHANSEN	1.534	76.5	MC GAW	------	------	0.411	0.000
				DE VRIES	2.260	159.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.658	-24.3		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	12.20	1.443	0.870	KERSTEN	0.925	6.3	MICKLEY	1.884	116.6	0.467	------
				JOHANSEN	1.385	59.3	MC GAW	------	------	0.390	0.060
				DE VRIES	1.269	45.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.644	-25.9		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	12.40	1.616	1.201	KERSTEN	1.214	1.1	MICKLEY	2.308	92.2	0.404	------
				JOHANSEN	2.078	73.0	MC GAW	------	------	0.541	0.000
				DE VRIES	2.829	135.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.794	-33.9		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	12.40	1.616	1.201	KERSTEN	1.214	1.1	MICKLEY	2.288	90.5	0.404	------
				JOHANSEN	1.877	56.3	MC GAW	------	------	0.528	0.060
				DE VRIES	1.711	42.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.780	-35.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	17.60	1.286	0.933	KERSTEN	1.031	10.5	MICKLEY	1.795	92.4	0.525	------
				JOHANSEN	1.637	75.5	MC GAW	------	------	0.470	0.000
				DE VRIES	2.185	134.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.693	-25.7		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	17.60	1.286	0.933	KERSTEN	1.031	10.5	MICKLEY	1.780	90.8	0.525	------
				JOHANSEN	1.482	58.9	MC GAW	------	------	0.459	0.060
				DE VRIES	1.210	29.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.684	-26.7		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	17.00	1.438	1.276	KERSTEN	1.277	0.1	MICKLEY	2.170	70.0	0.469	------
				JOHANSEN	2.131	67.0	MC GAW	------	------	0.595	0.000
				DE VRIES	2.687	110.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.851	-33.3		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	17.00	1.438	1.276	KERSTEN	1.277	0.1	MICKLEY	2.151	68.5	0.469	------
				JOHANSEN	1.931	51.3	MC GAW	------	------	0.583	0.060
				DE VRIES	1.614	26.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.841	-34.1		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	17.00	1.634	1.696	KERSTEN	1.681	-0.9	MICKLEY	2.799	65.1	0.397	------
				JOHANSEN	2.964	74.8	MC GAW	------	------	0.708	0.000
				DE VRIES	3.354	97.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	1.025	-39.6		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	17.00	1.634	1.696	KERSTEN	1.681	-0.9	MICKLEY	2.768	63.3	0.397	------
				JOHANSEN	2.686	58.4	MC GAW	------	------	0.785	0.060
				DE VRIES	2.408	42.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	1.013	-40.3		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B30 (cont'd).

SAMPLE	25.00	1.277	1.201	KERSTEN	1.412	17.6	MICKLEY	2.092	74.2	0.529	------
				JOHANSEN	2.221	84.9	MC GAW	------	------	0.658	0.000
				DE VRIES	2.612	117.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.793	-34.0		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	25.00	1.277	1.201	KERSTEN	1.412	17.6	MICKLEY	2.074	72.6	0.529	------
				JOHANSEN	2.017	67.9	MC GAW	------	------	0.648	0.060
				DE VRIES	1.593	32.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.790	-34.2		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	25.30	1.435	1.590	KERSTEN	1.750	9.7	MICKLEY	2.672	67.4	0.470	------
				JOHANSEN	2.931	83.6	MC GAW	------	------	0.841	0.000
				DE VRIES	3.195	100.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.987	-38.2		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	25.30	1.435	1.590	KERSTEN	1.750	9.7	MICKLEY	2.642	65.5	0.470	------
				JOHANSEN	2.663	66.8	MC GAW	------	------	0.830	0.060
				DE VRIES	2.333	46.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.983	-38.4		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	24.70	1.517	1.849	KERSTEN	1.907	3.2	MICKLEY	3.037	64.3	0.440	------
				JOHANSEN	3.289	72.9	MC GAW	------	------	0.928	0.000
				DE VRIES	3.459	87.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	1.099	-40.5		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	24.70	1.517	1.849	KERSTEN	1.907	3.2	MICKLEY	2.991	61.8	0.440	------
				JOHANSEN	2.988	61.6	MC GAW	------	------	0.915	0.060
				DE VRIES	2.788	50.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	1.094	-40.8		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	29.70 †	1.444	1.908	KERSTEN	2.053	7.6	MICKLEY	3.462	81.5	0.467	------
				JOHANSEN	3.455	81.1	MC GAW	------	------	1.000	0.000
				DE VRIES	3.529	85.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	1.035	-45.7		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	29.70	1.446	1.908	KERSTEN	2.061	8.0	MICKLEY	3.340	75.1	0.466	------
				JOHANSEN	3.157	65.5	MC GAW	------	------	0.993	0.060
				DE VRIES	3.131	64.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	1.037	-45.6		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	37.30	1.273	1.948	KERSTEN	2.058	5.7	MICKLEY	3.030	55.5	0.530	------
				JOHANSEN	3.217	65.1	MC GAW	------	------	0.977	0.000
				DE VRIES	3.316	69.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.831	-57.3		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	37.30	1.273	1.948	KERSTEN	2.058	5.7	MICKLEY	2.965	52.2	0.530	------
				JOHANSEN	2.928	50.3	MC GAW	------	------	0.966	0.060
				DE VRIES	2.816	44.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	0.831	-57.4		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B31.

KERSTEN NORTHWAY SILT LOAM UNSATURATEDMFROZEN

TYPE OF SOIL: CLAY NATURAL UNSATURATED FROZEN

RHO = [illegible] TEMP = -4.000 W = 0.015 CL = 0.136 CSOLIDS = 2.063 ALPHA = -------- KA = 0.046
KS = [illegible] KICE = 2.280 KW = 0.290 KO = 2.000 CSOLIDS2 = 5.389

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWP
SAMPLE	1.5[illegible]	1.197	0.143	KERSTEN	0.151	5.6	MICKLEY	0.524	266.6	0.557	------
				JOHANSEN	0.231	62.0	MC GAW	------	------	0.042	0.000
				DE VRIES	0.387	170.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	1.7[illegible]	1.346	0.173	KERSTEN	0.199	15.2	MICKLEY	0.602	247.9	0.502	------
				JOHANSEN	0.273	57.6	MC GAW	------	------	0.050	0.000
				DE VRIES	0.464	168.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	1.4[illegible]	1.446	0.1[illegible]	KERSTEN	0.230	23.7	MICKLEY	0.652	250.8	0.664	------
				JOHANSEN	0.290	56.1	MC GAW	------	------	0.048	0.000
				DE VRIES	0.494	165.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	1.7[illegible]	1.552	0.235	KERSTEN	0.319	35.8	MICKLEY	0.724	208.2	0.625	------
				JOHANSEN	0.355	51.0	MC GAW	------	------	0.068	0.000
				DE VRIES	0.607	158.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	1.70	1.552	0.235	KERSTEN	0.319	35.8	MICKLEY	0.724	208.2	0.625	------
				JOHANSEN	0.355	51.0	MC GAW	------	------	0.068	0.000
				DE VRIES	0.607	158.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B31 (cont'd).

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. Sat.	NC UWF
SAMPLE	[illegible]	1.559	0.526	KERSTEN	0.685	30.1	MICKLEY	0.881	67.3	0.423	------
				JOHANSEN	0.735	39.6	MC GAW	------	------	0.265	0.000
				DE VRIES	1.102	109.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.430	0.937	KERSTEN	1.174	25.3	MICKLEY	1.098	17.1	0.470	------
				JOHANSEN	1.258	34.2	MC GAW	------	------	0.544	0.000
				DE VRIES	1.486	58.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.541	1.087	KERSTEN	1.371	26.1	MICKLEY	1.256	15.5	0.429	------
				JOHANSEN	1.454	33.7	MC GAW	------	------	0.642	0.000
				DE VRIES	1.666	53.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.823	1.526	KERSTEN	1.895	24.2	MICKLEY	1.702	11.6	0.325	------
				JOHANSEN	1.903	24.7	MC GAW	------	------	0.881	0.000
				DE VRIES	1.997	30.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.453	1.286	KERSTEN	1.635	27.1	MICKLEY	1.443	12.2	0.462	------
				JOHANSEN	1.730	34.5	MC GAW	------	------	0.785	0.000
				DE VRIES	1.843	43.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.570	1.539	KERSTEN	1.869	21.4	MICKLEY	1.730	12.5	0.419	------
				JOHANSEN	1.970	28.1	MC GAW	------	------	0.911	0.000
				DE VRIES	2.024	31.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B32.

KERSTEN RAMSEY SANDY LOAM UNSATURATED FROZEN

TYPE [illegible] CLAY NATURAL UNSATURATED FROZEN

RHO = [illegible] TEMP = -4.00 N = 0.513 CL = 0.185 CSOLIDS = + 4.168 ALPHA = -------- KA = 0.046
KW = [illegible] KICE = [illegible] KM = 8.290 KQ = 2.000 CSOLIDS2 = 5.227

Sample	Moisture content	Dry density	K measured	Method	K computed	Deviation (percent)	Method	K computed	Deviation (percent)	Por. Sat.	NC UWF
SAMPLE	[illegible]	1.433	0.247	KERSTEN	0.282	14.3	MICKLEY	1.245	405.0	0.476	------
				JOHANSEN	0.432	75.1	MC GAW	------	------	0.083	0.000
				DE VRIES	0.963	291.5	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	[illegible]	0.519	KERSTEN	0.445	-14.3	MICKLEY	1.513	191.4	0.399	------
				JOHANSEN	0.601	15.8	MC GAW	------	------	0.119	0.000
				DE VRIES	1.311	152.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.743	0.679	KERSTEN	0.602	-11.3	MICKLEY	1.706	150.9	0.350	------
				JOHANSEN	0.740	9.0	MC GAW	------	------	0.147	0.000
				DE VRIES	1.567	130.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.754	1.138	KERSTEN	0.940	-17.3	MICKLEY	1.928	69.5	0.346	------
				JOHANSEN	1.350	18.7	MC GAW	------	------	0.343	0.000
				DE VRIES	2.295	101.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.906	1.507	KERSTEN	1.343	-10.8	MICKLEY	2.292	52.1	0.289	------
				JOHANSEN	1.893	25.6	MC GAW	------	------	0.689	0.000
				DE VRIES	2.814	86.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.594	0.989	KERSTEN	0.927	-6.2	MICKLEY	1.803	82.3	0.405	------
				JOHANSEN	1.427	44.3	MC GAW	------	------	0.394	0.000
				DE VRIES	2.187	121.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.754	1.240	KERSTEN	1.244	0.3	MICKLEY	2.156	73.7	0.346	------
				JOHANSEN	1.912	54.2	MC GAW	------	------	0.526	0.000
				DE VRIES	2.668	115.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.914	1.507	KERSTEN	1.654	9.7	MICKLEY	2.574	70.8	0.286	------
				JOHANSEN	2.515	66.9	MC GAW	------	------	0.686	0.000
				DE VRIES	3.123	107.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	[illegible]	2.020	2.513	KERSTEN	2.056	-18.2	MICKLEY	3.011	19.8	0.246	------
				JOHANSEN	3.133	24.6	MC GAW	------	------	0.858	0.000
				DE VRIES	3.451	37.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B32 (cont'd).

SAMPLE	13.70	1.605	1.379	KERSTEN	1.294	-6.1	MICKLEY	2.093	51.8	0.404	------
				JOHANSEN	2.047	48.5	MC GAW	------	------	0.598	0.000
				DE VRIES	2.614	89.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	13.10	1.770	1.803	KERSTEN	1.618	-10.3	MICKLEY	2.512	39.3	0.340	------
				JOHANSEN	2.596	44.0	MC GAW	------	------	0.756	0.000
				DE VRIES	3.045	68.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	12.70	1.940	2.493	KERSTEN	2.113	-15.3	MICKLEY	3.295	33.7	0.276	------
				JOHANSEN	3.429	37.5	MC GAW	------	------	0.972	0.000
				DE VRIES	3.515	41.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	17.80	1.589	1.869	KERSTEN	1.576	-15.7	MICKLEY	2.352	25.9	0.407	------
				JOHANSEN	2.519	34.8	MC GAW	------	------	0.757	0.000
				DE VRIES	2.876	54.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	15.10	1.753	2.393	KERSTEN	2.036	-14.9	MICKLEY	3.370	40.9	0.346	------
				JOHANSEN	3.372	41.1	MC GAW	------	------	1.000	0.000
				DE VRIES	3.411	42.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B33.

USSR BUILDING CODE (1960) CLAY SOILS UNSATURATED FROZEN

TYPE OF SOIL: CLAY NATURAL UNSATURATED FROZEN

RHO = 2.750 TEMP = [illegible] Q = [illegible] QS = + 1.300 ESOLIDS = 2.700 FLPHS = -------- KA = 0.024
KW = 0.550 KICE = 2.233 KI = + 3.433 KS = + 2.000 ESOLIDS2 = 2.324

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	MC UWC
SAMPLE	8.00	1.000	0.465	KERSTEN	0.344	-26.1	MICKLEY	0.474	1.6	0.636	------
				JOHANSEN	0.397	-14.6	MC GAW	------	------	0.137	0.000
				DE VRIES	0.553	18.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	8.00	1.100	0.531	KERSTEN	0.396	-32.2	MICKLEY	0.536	-8.2	0.620	------
				JOHANSEN	0.458	-33.7	MC GAW	------	------	0.168	0.000
				DE VRIES	0.589	1.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	8.00	1.200	0.593	KERSTEN	0.454	-34.9	MICKLEY	0.507	-14.4	0.564	------
				JOHANSEN	0.519	-25.6	MC GAW	------	------	0.186	0.000
				DE VRIES	0.691	-5.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	8.00	1.300	0.849	KERSTEN	0.525	-38.1	MICKLEY	0.665	-21.7	0.522	------
				JOHANSEN	0.593	-33.4	MC GAW	------	------	0.215	0.000
				DE VRIES	0.803	-5.4	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	8.00	1.400	1.023	KERSTEN	0.611	-40.3	MICKLEY	0.737	-28.0	0.491	------
				JOHANSEN	0.675	-34.4	MC GAW	------	------	0.249	0.000
				DE VRIES	0.925	-9.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	8.00	1.500	1.197	KERSTEN	0.714	-40.2	MICKLEY	0.815	-31.9	0.455	------
				JOHANSEN	0.761	-36.4	MC GAW	------	------	0.288	0.000
				DE VRIES	1.055	-11.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	8.00	1.600	1.383	KERSTEN	0.844	-39.0	MICKLEY	0.900	-35.0	0.418	------
				JOHANSEN	0.865	-37.5	MC GAW	------	------	0.336	0.000
				DE VRIES	1.193	-13.8	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	18.00	1.100	0.872	KERSTEN	0.829	-5.0	MICKLEY	0.726	-17.0	0.600	------
				JOHANSEN	0.861	-1.2	MC GAW	------	------	0.360	0.000
				DE VRIES	0.982	12.6	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	18.00	1.200	1.081	KERSTEN	0.941	-12.9	MICKLEY	0.821	-24.1	0.564	------
				JOHANSEN	0.985	-8.9	MC GAW	------	------	0.418	0.000
				DE VRIES	1.137	5.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	18.00	1.300	1.250	KERSTEN	1.072	-14.6	MICKLEY	0.929	-26.0	0.527	------
				JOHANSEN	1.122	-10.6	MC GAW	------	------	0.484	0.000
				DE VRIES	1.297	3.3	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B33 (cont'd).

SAMPLE	18,00	1,351	[illegible]	KERSTEN	[illegible]	-23.2	MICKLEY	-0,987	-33.6	0,509	------
				JOHANSEN	1,187	-19.6	MC GA	------	------	0,520	0,000
				DE VRIES	1,370	-9.3	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	18,00	1,451	1,335	KERSTEN	[illegible]	-12.3	MICKLEY	1,448	-33.7	0,673	------
				JOHANSEN	1,36[illegible]	-16.3	MC GA	------	------	0,602	0,000
				DE VRIES	1,56[illegible]	-0.5	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	18,00	1,501	[illegible]	KERSTEN	1,40[illegible]	-26.3	MICKLEY	[illegible]	-37.9	0,455	------
				JOHANSEN	1,44[illegible]	-24.5	MC GA	------	------	0,647	0,000
				DE VRIES	1,02[illegible]	-45.3	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	18,00	1,601	[illegible]	KERSTEN	1,01[illegible]	[illegible]	MICKLEY	1,365	-37.5	[illegible]	------
				JOHANSEN	1,06[illegible]	[illegible]	MC GA	------	------	0,751	0,000
				DE VRIES	1,78[illegible]	[illegible]	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	18,00	1,701	[illegible]	KERSTEN	1,87[illegible]	-24.8	MICKLEY	1,602	-35.6	0,382	------
				JOHANSEN	1,879	[illegible]	MC GA	------	------	0,876	0,000
				DE VRIES	1,953	-21.5	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	18,00 *	[illegible]	[illegible]	KERSTEN	[illegible]	[illegible]	MICKLEY	[illegible]	[illegible]	0,350	------
				JOHANSEN	[illegible]	[illegible]	MC GA	------	------	1,000	0,000
				DE VRIES	[illegible]	-24.9	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	27,00	1,101	[illegible]	KERSTEN	1,24[illegible]	-3.8	MICKLEY	0,931	-26.5	0,600	------
				JOHANSEN	1,227	-5.2	MC GA	------	------	0,540	0,000
				DE VRIES	[illegible]	[illegible]	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	27,00	1,201	[illegible]	KERSTEN	[illegible]	[illegible]	MICKLEY	1,077	[illegible]	0,564	------
				JOHANSEN	1,40[illegible]	[illegible]	MC GA	------	------	[illegible]	0,000
				DE VRIES	[illegible]	1.2	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	27,00	1,251	[illegible]	KERSTEN	[illegible]	-15.6	MICKLEY	1,159	-32.6	0,565	------
				JOHANSEN	[illegible]	[illegible]	MC GA	------	------	0,694	0,000
				DE VRIES	[illegible]	-6.9	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	27,00	1,351	[illegible]	KERSTEN	[illegible]	[illegible]	MICKLEY	1,356	-30.6	0,509	------
				JOHANSEN	1,707	-12.6	MC GA	------	------	0,780	0,000
				DE VRIES	1,79[illegible]	-8.3	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	27,00	1,401	[illegible]	KERSTEN	[illegible]	[illegible]	MICKLEY	1,479	-32.7	[illegible]	------
				JOHANSEN	[illegible]	[illegible]	MC GA	------	------	[illegible]	0,000
				DE VRIES	[illegible]	-14.1	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	27,00	1,501	[illegible]	KERSTEN	2,02[illegible]	[illegible]	MICKLEY	1,875	-24.3	0,455	------
				JOHANSEN	[illegible]	[illegible]	MC GA	------	------	0,971	0,000
				DE VRIES	[illegible]	-15.9	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	60,00	1,101	1,102	KERSTEN	1,784	[illegible]	MICKLEY	1,365	-19.4	0,600	------
				JOHANSEN	1,75[illegible]	5.6	MC GA	------	------	0,799	0,000
				DE VRIES	1,79[illegible]	7.7	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	60,00	1,151	[illegible]	KERSTEN	1,895	[illegible]	MICKLEY	[illegible]	-20.7	0,582	------
				JOHANSEN	[illegible]	[illegible]	MC GA	------	------	0,862	0,000
				DE VRIES	[illegible]	[illegible]	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	60,00	1,201	[illegible]	KERSTEN	2,013	-5.4	MICKLEY	1,689	-20.6	0,564	------
				JOHANSEN	[illegible]	-5.5	MC GA	------	------	0,928	0,000
				DE VRIES	2,024	-4.8	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		
SAMPLE	60,00 *	1,251	2,360	KERSTEN	[illegible]	-8.3	MICKLEY	2,168	[illegible]	0,565	------
				JOHANSEN	[illegible]	[illegible]	MC GA	------	------	1,000	0,000
				DE VRIES	[illegible]	[illegible]	SMITH	------	------		
				MOD DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	------	------	VAN ROOYEN	------	------		
				KUNII-SMITH	------	------	GEOM. MEAN	------	------		

Table B34.

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PENNER LEDA CLAY SATURATED FROZEN

TYPE OF SOIL:  CLAY NATURAL SATURATED   FROZEN

RHO =    2.700 TEMP =   -2.500 W =   0.000 CL =   1.000 CSOLIDS =   1.710 ALPHA = -------- KA =   0.024
KW =     0.500 KICE =    2.270 KQ = T 8.430 KO = T 2.000 CSOLIDS2 =  2.524

SAMPLE MOISTURE    DRY    K MEASURED     METHOD K COMPUTED  DEVIATION     METHOD K COMPUTED  DEVIATION   POR.    NC
        CONTENT   DENSITY                                   (PERCENT)                        (PERCENT)   SAT.    UWC
SAMPLE   80.00     0.815     1.570         KERSTEN   2.523      60.7       MICKLEY   2.084      32.7    0.699  ------
                                          JOHANSEN   1.725       9.9        MC GAW  ------    ------    1.000   0.135
                                          DE VRIES   1.754      11.7         SMITH  ------    ------
                                      ADJ DE VRIES  ------    ------        GEMANT  ------    ------
                                          RESISTOR   2.097      33.6    VAN ROOYEN  ------    ------
                                       KUNII-SMITH   2.151      37.0    GEOM. MEAN   2.084      32.8

RHO =    2.700 TEMP =   -5.000 W =   0.000 CL =   1.000 CSOLIDS =   1.710 ALPHA = -------- KA =   0.024
KW =     0.500 KICE =    2.290 KQ = T 8.430 KO = T 2.000 CSOLIDS2 =  2.524

SAMPLE MOISTURE    DRY    K MEASURED     METHOD K COMPUTED  DEVIATION     METHOD K COMPUTED  DEVIATION   POR.    NC
        CONTENT   DENSITY                                   (PERCENT)                        (PERCENT)   SAT.    UWC
SAMPLE   80.00     0.815     1.710         KERSTEN   2.523      47.5       MICKLEY   2.098      22.7    0.702  ------
                                          JOHANSEN   1.823       6.6        MC GAW  ------    ------    1.000   0.100
                                          DE VRIES   1.846       7.9         SMITH  ------    ------
                                      ADJ DE VRIES  ------    ------        GEMANT  ------    ------
                                          RESISTOR   2.113      23.6    VAN ROOYEN  ------    ------
                                       KUNII-SMITH   2.168      26.8    GEOM. MEAN   2.099      22.7

RHO =    2.700 TEMP =  -10.000 W =   0.000 CL =   1.000 CSOLIDS =   1.720 ALPHA = -------- KA =   0.024
KW =     0.500 KICE =    2.320 KQ = T 8.430 KO = T 2.000 CSOLIDS2 =  2.524

SAMPLE MOISTURE    DRY    K MEASURED     METHOD K COMPUTED  DEVIATION     METHOD K COMPUTED  DEVIATION   POR.    NC
        CONTENT   DENSITY                                   (PERCENT)                        (PERCENT)   SAT.    UWC
SAMPLE   80.00     0.815     1.760         KERSTEN   2.523      43.3       MICKLEY   2.122      20.6    0.703  ------
                                          JOHANSEN   1.868       6.1        MC GAW  ------    ------    1.000   0.090
                                          DE VRIES   1.889       7.3         SMITH  ------    ------
                                      ADJ DE VRIES  ------    ------        GEMANT  ------    ------
                                          RESISTOR   2.137      21.4    VAN ROOYEN  ------    ------
                                       KUNII-SMITH   2.194      24.7    GEOM. MEAN   2.122      20.6

RHO =    2.700 TEMP =  -22.000 W =   0.000 CL =   1.000 CSOLIDS =   1.750 ALPHA = -------- KA =   0.024
KW =     0.500 KICE =    2.420 KQ = T 8.430 KO = T 2.000 CSOLIDS2 =  2.524

SAMPLE MOISTURE    DRY    K MEASURED     METHOD K COMPUTED  DEVIATION     METHOD K COMPUTED  DEVIATION   POR.    NC
        CONTENT   DENSITY                                   (PERCENT)                        (PERCENT)   SAT.    UWC
SAMPLE   80.00     0.815     1.820         KERSTEN   2.523      38.6       MICKLEY   2.198      20.8    0.704  ------
                                          JOHANSEN   1.970       8.2        MC GAW  ------    ------    1.000   0.075
                                          DE VRIES   1.989       9.3         SMITH  ------    ------
                                      ADJ DE VRIES  ------    ------        GEMANT  ------    ------
                                          RESISTOR   2.210      21.8    VAN ROOYEN  ------    ------
                                       KUNII-SMITH   2.280      25.3    GEOM. MEAN   2.199      20.8
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Table B35.

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PENNER SUDBURY SILTY CLAY SATURATED FROZEN

TYPE OF SOIL:  CLAY NATURAL SATURATED   FROZEN

RHO =    2.750 TEMP =    0.400 W =   0.000 CL =   1.000 CSOLIDS =   2.930 ALPHA = -------- KA =   0.024
KW =     0.500 KICE =    2.260 KQ = T 8.430 KO = T 2.000 CSOLIDS2 =  2.524

SAMPLE MOISTURE    DRY    K MEASURED     METHOD K COMPUTED  DEVIATION     METHOD K COMPUTED  DEVIATION   POR.    NC
        CONTENT   DENSITY                                   (PERCENT)                        (PERCENT)   SAT.    UWC
SAMPLE   29.00     1.520     1.550         KERSTEN   2.218      43.1       MICKLEY   2.613      68.6    0.441  ------
                                          JOHANSEN   1.414      -8.8        MC GAW  ------    ------    1.000   0.440
                                          DE VRIES   1.499      -3.3         SMITH  ------    ------
                                      ADJ DE VRIES  ------    ------        GEMANT  ------    ------
                                          RESISTOR   2.629      69.6    VAN ROOYEN  ------    ------
                                       KUNII-SMITH   2.559      65.1    GEOM. MEAN   2.613      68.6

RHO =    2.700 TEMP =   -2.500 W =   0.000 CL =   1.000 CSOLIDS =   2.940 ALPHA = -------- KA =   0.024
KW =     0.500 KICE =    2.270 KQ = T 8.430 KO = T 2.000 CSOLIDS2 =  2.524

SAMPLE MOISTURE    DRY    K MEASURED     METHOD K COMPUTED  DEVIATION     METHOD K COMPUTED  DEVIATION   POR.    NC
        CONTENT   DENSITY                                   (PERCENT)                        (PERCENT)   SAT.    UWC
SAMPLE   29.00     1.520     2.130         KERSTEN   2.218       4.1       MICKLEY   2.606      22.3    0.467  ------
                                          JOHANSEN   2.098      -1.5        MC GAW  ------    ------    1.000   0.155
                                          DE VRIES   2.138       0.4         SMITH  ------    ------
                                      ADJ DE VRIES  ------    ------        GEMANT  ------    ------
                                          RESISTOR   2.622      23.1    VAN ROOYEN  ------    ------
                                       KUNII-SMITH   2.548      19.6    GEOM. MEAN   2.606      22.3

RHO =    2.700 TEMP =   -5.000 W =   0.000 CL =   1.000 CSOLIDS =   2.950 ALPHA = -------- KA =   0.024
KW =     0.500 KICE =    2.290 KQ = T 8.430 KO = T 2.000 CSOLIDS2 =  2.524

SAMPLE MOISTURE    DRY    K MEASURED     METHOD K COMPUTED  DEVIATION     METHOD K COMPUTED  DEVIATION   POR.    NC
        CONTENT   DENSITY                                   (PERCENT)                        (PERCENT)   SAT.    UWC
SAMPLE   29.00     1.520     2.220         KERSTEN   2.218      -0.1       MICKLEY   2.617      17.9    0.472  ------
                                          JOHANSEN   2.306       3.9        MC GAW  ------    ------    1.000   0.090
                                          DE VRIES   2.330       5.0         SMITH  ------    ------
                                      ADJ DE VRIES  ------    ------        GEMANT  ------    ------
                                          RESISTOR   2.633      18.6    VAN ROOYEN  ------    ------
                                       KUNII-SMITH   2.559      15.3    GEOM. MEAN   2.617      17.9

RHO =    2.700 TEMP =  -10.000 W =   0.000 CL =   1.000 CSOLIDS =   2.970 ALPHA = -------- KA =   0.024
KW =     0.500 KICE =    2.320 KQ = T 8.430 KO = T 2.000 CSOLIDS2 =  2.524

SAMPLE MOISTURE    DRY    K MEASURED     METHOD K COMPUTED  DEVIATION     METHOD K COMPUTED  DEVIATION   POR.    NC
        CONTENT   DENSITY                                   (PERCENT)                        (PERCENT)   SAT.    UWC
SAMPLE   29.00     1.520     2.340         KERSTEN   2.218      -5.2       MICKLEY   2.643      12.9    0.472  ------
                                          JOHANSEN   2.326      -0.6        MC GAW  ------    ------    1.000   0.090
                                          DE VRIES   2.350       0.4         SMITH  ------    ------
                                      ADJ DE VRIES  ------    ------        GEMANT  ------    ------
                                          RESISTOR   2.658      13.6    VAN ROOYEN  ------    ------
                                       KUNII-SMITH   2.585      10.5    GEOM. MEAN   2.643      12.9
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AD-A117 889 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER NH F/G 8/7
EVALUATION OF METHODS FOR CALCULATING SOIL THERMAL CONDUCTIVITY--ETC(U)
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Table B35 (cont'd).

RHO = 2.700 TEMP = -20.000 W = 0.000 CL = 1.000 CSOLIDS = 3.000 ALPHA = -------- KA = 0.024
KW = 0.560 KICE = 2.430 KQ = ? 8.430 KO = ? 2.000 CSOLIDS2 = 2.524

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	20.00	1.520	2.380	KERSTEN	2.218	-6.8	MICKLEY	2.699	13.4	0.473	------
				JOHANSEN	2.403	1.0	MC GAW	------	------	1.000	0.000
				DE VRIES	2.424	1.9	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	2.712	13.9	VAN ROOYEN	------	------		
				KUNII-SMITH	2.645	11.2	GEOM. MEAN	2.699	13.4		

Table B36.

PENNER ET AL SOIL 7 SATURATED FROZEN

TYPE OF SOIL: CLAY NATURAL SATURATED FROZEN

RHO = 2.700 TEMP = -5.000 W = ? 0.000 CL = ? 1.000 CSOLIDS = 3.000 ALPHA = -------- KA = 0.024
KW = 0.560 KICE = 2.290 KW = ? 8.430 KO = ? 2.000 CSOLIDS2 = 2.524

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	13.30	? 1.934	2.581	KERSTEN	2.160	-16.3	MICKLEY	2.787	8.0	0.272	------
				JOHANSEN	2.422	-6.2	MC GAW	------	------	1.000	0.100
				DE VRIES	2.449	-5.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	2.801	8.5	VAN ROOYEN	------	------		
				KUNII-SMITH	2.777	7.6	GEOM. MEAN	2.788	8.0		
SAMPLE	13.30	? 1.917	2.581	KERSTEN	2.097	-18.8	MICKLEY	2.782	7.8	0.278	------
				JOHANSEN	2.783	7.8	MC GAW	------	------	1.000	0.000
				DE VRIES	2.789	8.1	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	2.796	8.3	VAN ROOYEN	------	------		
				KUNII-SMITH	2.769	7.3	GEOM. MEAN	2.783	7.8		

Table B37.

SLUSARCHUK-WATSON UNDISTURBED PERMAFROST

TYPE OF SOIL: CLAY NATURAL SATURATED FROZEN

RHO = 2.750 TEMP = -6.000 W = 0.000 CL = 0.360 CSOLIDS = 2.000 ALPHA = -------- KA = 0.024
KW = ? 0.570 KICE = 2.300 KQ = ? 8.430 KO = ? 2.000 CSOLIDS2 = 4.646

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	38.90	1.317	2.120	KERSTEN	2.149	1.4	MICKLEY	2.154	1.6	0.530	------
				JOHANSEN	2.154	1.6	MC GAW	------	------	1.000	0.000
				DE VRIES	2.155	1.7	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	2.158	1.8	VAN ROOYEN	------	------		
				KUNII-SMITH	2.188	3.2	GEOM. MEAN	2.154	1.6		
SAMPLE	38.90	1.281	2.230	KERSTEN	2.164	-2.9	MICKLEY	2.158	-3.2	0.543	------
				JOHANSEN	2.158	-3.2	MC GAW	------	------	1.000	0.000
				DE VRIES	2.160	-3.2	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	2.162	-3.1	VAN ROOYEN	------	------		
				KUNII-SMITH	2.193	-1.7	GEOM. MEAN	2.158	-3.2		

Table B38.

USSR BUILDING CODE (1960) CLAY SOILS SATURATED FROZEN

TYPE OF SOIL: CLAY NATURAL SATURATED FROZEN

RHO = 2.750 TEMP = -4.000 W = 0.000 CL = 1.000 CSOLIDS = 2.000 ALPHA = -------- KA = 0.024
KW = 0.560 KICE = 2.200 KQ = ? 8.430 KO = ? 2.000 CSOLIDS2 = 2.524

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	18.00	? 1.749	2.790	KERSTEN	2.012	-27.9	MICKLEY	2.092	-25.0	0.343	------
				JOHANSEN	2.092	-25.0	MC GAW	------	------	1.000	0.000
				DE VRIES	2.093	-25.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	2.095	-24.9	VAN ROOYEN	------	------		
				KUNII-SMITH	2.112	-24.3	GEOM. MEAN	2.092	-25.0		
SAMPLE	40.00	? 1.242	2.360	KERSTEN	2.118	-10.2	MICKLEY	2.147	-9.0	0.541	------
				JOHANSEN	2.147	-9.0	MC GAW	------	------	1.000	0.000
				DE VRIES	2.149	-9.0	SMITH	------	------		
				ADJ DE VRIES	------	------	GEMANT	------	------		
				RESISTOR	2.151	-8.9	VAN ROOYEN	------	------		
				KUNII-SMITH	2.180	-7.6	GEOM. MEAN	2.147	-9.0		

Table B39.

JOHANSEN GRAVEL UPZ DRY

TYPE OF SOIL: COARSE NATURAL DRY

RHO = [illegible] TEMP = [illegible] W = 0.670 CL = 0.000 CSOLIDS = + 3.741 ALPHA = 0.065 KA = 0.026
KW = + 0.570 KICE = + 2.2[illegible] KU = 7.540 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	[illegible]	1.[illegible]5	0.303	KERSTEN	------	------	MICKLEY	1.489	391.6	0.319	0.000
				JOHANSEN	0.315	3.9	MC GAW	2.554	743.[illegible]	0.000	0.000
				DE VRIES	0.308	1.6	SMITH	0.287	-5.4		
				ADJ DE VRIES	0.385	27.0	GEMANT	------	------		
				RESISTOR	0.386	27.4	VAN ROOYEN	0.348	14.5		
				KUNII-SMITH	0.392	29.5	GEOM. MEAN	------	------		
SAMPLE	[illegible]	1.934	0.322	KERSTEN	------	------	MICKLEY	1.459	415.[illegible]	0.270	0.000
				JOHANSEN	0.380	17.8	MC GAW	2.737	750.1	0.000	0.000
				DE VRIES	0.375	16.6	SMITH	0.306	-4.9		
				ADJ DE VRIES	0.469	45.7	GEMANT	------	------		
				RESISTOR	[illegible]	[illegible]	VAN ROOYEN	0.431	33.8		
				KUNII-SMITH	[illegible]	[illegible]	GEOM. MEAN	------	------		
SAMPLE	[illegible]	2.025	0.400	KERSTEN	------	------	MICKLEY	1.787	346.8	0.237	0.000
				JOHANSEN	0.436	9.0	MC GAW	2.862	615.5	0.000	0.000
				DE VRIES	0.436	9.0	SMITH	0.319	-20.2		
				ADJ DE VRIES	0.565	41.2	GEMANT	------	------		
				RESISTOR	0.469	17.2	VAN ROOYEN	0.491	22.7		
				KUNII-SMITH	0.840	109.9	GEOM. MEAN	------	------		

Table B40.

JOHANSEN SAND SAT DRY

TYPE OF SOIL: SAND NATURAL DRY

RHO = [illegible] TEMP = [illegible] W = 0.500 CL = 0.000 CSOLIDS = + 3.914 ALPHA = 0.075 KA = 0.026
KW = + 0.570 KICE = + 2.2[illegible] KU = 7.680 KO = 2.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	[illegible]	1.[illegible]	[illegible]	KERSTEN	------	------	MICKLEY	1.553	358.5	0.320	0.000
				JOHANSEN	0.320	-2.8	MC GAW	2.671	688.0	0.000	0.000
				DE VRIES	0.308	-9.0	SMITH	0.259	-23.7		
				ADJ DE VRIES	0.386	13.7	GEMANT	------	------		
				RESISTOR	0.388	14.3	VAN ROOYEN	0.384	13.3		
				KUNII-SMITH	0.395	16.5	GEOM. MEAN	------	------		

Table B41.

JOHANSEN CRUSHED ROCK DRY DRY

TYPE OF SOIL: COARSE CRUSHED DRY

RHO = [illegible] TEMP = [illegible] W = 0.030 CL = 0.000 CSOLIDS = + 3.085 ALPHA = 0.065 KA = 0.026
KW = + 0.570 KICE = + 2.200 KU = 7.580 KO = 3.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	[illegible]	1.[illegible]03	0.269	KERSTEN	------	------	MICKLEY	0.904	236.0	0.453	0.000
				JOHANSEN	0.223	-17.3	MC GAW	1.699	531.5	0.000	0.000
				DE VRIES	0.187	-30.3	SMITH	0.231	-14.2		
				ADJ DE VRIES	0.234	-13.0	GEMANT	------	------		
				RESISTOR	0.261	-3.0	VAN ROOYEN	0.153	-43.1		
				KUNII-SMITH	0.175	-34.9	GEOM. MEAN	------	------		

RHO = 2.730 TEMP = 24.400 W = 0.030 CL = 0.000 CSOLIDS = + 3.083 ALPHA = 0.065 KA = 0.026
KW = + 0.570 KICE = + 2.200 KU = 7.650 KO = 3.000 CSOLIDS2 = 5.840

SAMPLE	MOISTURE CONTENT	DRY DENSITY	K MEASURED	METHOD	K COMPUTED	DEVIATION (PERCENT)	METHOD	K COMPUTED	DEVIATION (PERCENT)	POR. SAT.	NC UWC
SAMPLE	[illegible]	1.660	0.343	KERSTEN	------	------	MICKLEY	1.045	204.6	0.302	0.000
				JOHANSEN	0.306	-10.7	MC GAW	1.885	449.5	0.000	0.000
				DE VRIES	0.230	-32.8	SMITH	0.254	-25.8		
				ADJ DE VRIES	0.288	-16.0	GEMANT	------	------		
				RESISTOR	0.311	-9.4	VAN ROOYEN	0.203	-40.8		
				KUNII-SMITH	0.237	-30.9	GEOM. MEAN	------	------		

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Farouki, Omar T.
Evaluation of methods for calculating soil thermal conductivity / by Omar T. Farouki. Hanover, N.H.: U.S. Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1982.
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