DETERMINING THE LONG-TERM MOISTURE CONTENT OF SOILS

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to

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1.0 INTRODUCTION

The design of a cover system to meet the criteria established by the EPA in March, 1983 consists of many factors which include:

- A radon barrier consisting of soils which act to dissipate the gases before they escape into the atmosphere.
- A rock layer to act as an erosion barrier for wind and water erosion.
- Depending on the particle size distribution of the two protection layers, a filter layer may be needed to help protect the radon barrier from erosive forces of water flowing between the radon barrier and the erosion barrier.

The long-term moisture content of soils used in the construction of the cover system is influenced by each of the layers previously described and is of particular importance in determining the thickness of the radon barrier layer.

Several models and empirical solutions have been developed by many researchers to estimate the soil water retention characteristics and the equilibrium water content of the soils based on particle size distribution, density, consolidation properties, infiltration, evaporation and evapotransporation.

This paper deals with the empirical solutions that are being used on the UMTRA project to predict the moisture contents and unsaturated hydraulic conductivity of soils used for the radon barrier. Additionally, the paper discusses analysis that are planned to further define the predictive capability of the long-term moisture content.

2.0 METHODOLOGIES INVESTIGATED

2.1 EMPIRICAL SOLUTIONS

Several different empirical solutions have been evaluated to determine the moisture content of a soil as a function of the negative atmospheric pressure or suction that would be caused by evaporation or evapotransporation. Most of the solutions evaluated were only able to predict the wilting point of the soil, which is commonly referred to as the -15 bar moisture content. However, three solutions, which all use the physical properties of the soil, have the capability of predicting the moisture content over a wide range (0.04 to -15 bar) of soil matric potentials. These relationships are based on the percent sand, silt clay, organic matter and bulk density and a set of regression coefficients which is multiplied times the representative physical property. These solutions all fit the following equation:

$$\theta_p = a \times \text{sand}\ (\%) + b \times \text{silt}\ (\%) + c \times \text{clay}\ (\%) + d \times \text{organic matter}\ (\%) + e \times \text{bulk density} + f$$

where

θ_p = predicted volumetric water content
a, b, c, d, e, f = regression coefficients

$$\text{Bulk density} = \frac{\gamma_d \times e}{6 \times 2.4} \times (1 + \omega)$$

γ_d = dry density
e = void ratio
w = moisture content

To convert the volumetric water content to moisture content on a dry weight basis the following conversion is applied.

$$w = \frac{\theta_p \times e}{n \times G_s}$$

where w = moisture content (dry weight basis)
n = porosity = e/(1 + e)
G_s = specific gravity

The results of these correlations, compared against real data indicate the following:

- The Rawls et al and Brakensiek et al correlations are more suited to sandy and silty material.

- The Gupta & Larson correlation is more suited towards clayey soils.

- For soils that are well graded an average of the three correlations is best suited.

- The correlation by Rogers et al for long term moisture content has a very limited data base and does not apply well to UMTRA sites.

When determining the long-term moisture content of a particular soil we look at the water content vs negative bar suction data, what type of erosion protection layers will be place on top of the radon barrier, what the climate of the area is (i.e., arid, semi-arid, etc.) the optimum moisture content of the material and the moisture content that the material will be placed at.

Based on the above data we normally choose a moisture content that is close to the -2 bar suction. However, there are times when the -15 bar suction moisture content is chosen if the placement moisture content is low.

REFERENCES

Baumer, O.W. and B.R. Brasher, 1982. "Prediction of Water Content at Selected Suctions" American Society of Agricultural Engineers, St. Joseph, Michigan.

Brakensiek, D.L., Rawls, W.J. and B. Soni, 1982. "Infiltration Parameter Values for Transient Soil Conditions," American Society of Agricultural Engineers, St. Joseph, Michigan.

Cambell, G.S., 1974. "A Sample Method for Determining Unsaturated Conductivity from Moisture Retention Data." Washington State University, Pullman, Washington.

Gee, G.W., Nielson, K.K. and V.C. Rogers, 1984. "Predicting Long-term Moisture Contents of Earthen Covers of Uranium Mill Tailings Sites," Pacific Northwest Laboratories, Richland, Washington, PNL-5047.

Gupta, S.C. and W.E. Larson, 1979. "Estimating Soil Water Retention Characteristics from Particle Size Distribution, Organic Matter Percent and Bulk Density," U.S. Department of Agriculture Soil and Water Management Unit, University of Minnesota, St. Paul, Minnesota.

Johnson, T.M., Larson, T.H., Herzog, B.L., Cartwright, K. and C.J. Stohr, 1983. "A Study of Trench Covers to Limit Infiltration at Waste Disposal Sites," Illinois State Geological Survey, Champaign, Illinois.

Rawls, W.J., Brakensiek, D.L. and K.E. Saxton, 1982. "Estimation of Soil Water Properties," American Society of Agricultural Engineers, St. Joseph, Michigan.

Van Genuchten, M.T., 1980. "A Closed-Form ~~Evaluation~~ EQUATION for Predicting the Hydraulic Conductivity of Unsaturated Soils," Soil Science Society of America Journal, 44:892-898.

APPENDIX A

COMPUTER PROGRAM "MOIST"

```
10  ' ***************************************************************************
20  ' **************************** MOIST/BAS *************************************
30  ' ***************************************************************************
40  '
50  '       .   THIS PROGRAM CALCULATES THE 15 BAR MOISTURE CONTENT
60  '             AND LONG TERM MOISTURE CONTENT USING 5 METHODS:
70  '                (1) RAWLS,BRAKENSIEK AND SAXTON METHOD(1982)
80  '                (2) BRAKENSIEK,RAWLS AND SONI METHOD (1982)
90  '                (3) GUPTA AND LARSON METHOD (1979)
100 '                (4) BAUMER AND BRASHER METHOD (1982)
110 '                (5) ROGERS ET AL METHOD (1982)
120 '
130 ' IT WAS WRITTEN BY BERG KESHIAN OF ROY F. WESTON, INC.
140 '
150 ' CONVERTED FOR TRS-80 BY L.C. PEGUES 9/84
160 '                REVISION 3.1      11/27/84   BY B. KESHIAN
170 '
180 CLS : PRINT
190 LPRINT : LPRINT "INPUT INFORMATION:"
200 INPUT"  INPUT SITE ID";S1$
210 INPUT"  INPUT SAMPLE ID";S2$
220 INPUT"  INPUT %SAND,%SILT,%CLAY,%ORGANICS";SD,ST,CL,OM
230 LPRINT:LPRINT "     SITE ID =";S1$
240 LPRINT "     SAMPLE ID =";S2$
250 LPRINT
260 LPRINT "     % SAND =";SD
270 LPRINT "     % SILT =";ST
280 LPRINT "     % CLAY =";CL
290 LPRINT "     % ORGANICS =";OM
300 PRINT : LPRINT
310 INPUT"  INPUT DRY DENSITY,SPECIFIC GRAVITY";DD,GS
320 LPRINT "      DRY DENSITY =";DD
330 LPRINT "      SPECIFIC GRAVITY =";GS
340 PRINT : LPRINT
350 INPUT"  INPUT PRECIPITATION(INCHES),LAKE EVAPORATION(INCHES)";P,E2
360 LPRINT "      PRECIPITATION =";P;"INCHES"
370 LPRINT "      LAKE EVAPORATION =";E2;"INCHES"
380 PRINT : LPRINT
390 LPRINT : LPRINT "OUTPUT INFORMATION:"
400 E=((62.4/DD)*GS)-1
410 N=E/(1+E)
420 REM  ******** RAWLS ET AL(1982) METHOD ********
430 READ BAR1,A1,B1,C1,D1,E1
440 IF A1=999 GOTO 610
450 W2=.1
460 WV=A1+B1*SD+C1*ST+D1*CL+E1*OM
470  SAT=(1/N)*WV
480  W=(SAT*E)/GS
490 IF INT(100*W)<>INT(100*W2) GOTO 500ELSE 520
500 W2=W
510 GOTO 460
520  PRINT : LPRINT
530 PRINT"          ";:PRINT USING "##.";BAR1;
540 LPRINT"          ";:LPRINT USING "##.";BAR1;
550  PRINT" BAR MOISTURE CONTENT BY RAWLS ET AL=";
560  LPRINT" BAR MOISTURE CONTENT BY RAWLS ET AL =";
570  W1=W*100
580  PRINT USING " ###.## ";W1;:PRINT" %"
590  LPRINT USING " ###.## ";W1;:LPRINT" %"
600 GOTO 430
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610  PRINT"          ---------------------------------------------------"
620  LPRINT "          -----------------------------------------------------"
630 PRINT :LPRINT
640 REM ******* BRAKENSIEK ET AL (1982) METHOD *************
650 READ A2,B2,C2,D2,E3,BAR2
660 IF A2=999 GOTO 830
670 W3=.1
680 WV15=A2+B2*SD+C2*CL+D2*OM+E3*(DD/62.4)*(1+W3)
690 SAT=(1/N)*WV15
700 W=SAT*E/GS
710 IF INT(100*W) <> INT(100*W3) GOTO 720ELSE 740
720 W3=W
730 GOTO 680
740 PRINT : LPRINT
750 W1=W*100
760 PRINT"        ";:PRINT USING "##.";BAR2;
770 LPRINT "        ";:LPRINT USING "##.";BAR2;
780 PRINT"  BAR MOISTURE CONTENT BY BRAKENSIEK  ET AL. =";
790 LPRINT "  BAR MOISTURE CONTENT BY BRAKENSIEK  ET AL. =";
800 PRINT USING " ###.## ";W1;:PRINT " %"
810 LPRINT USING " ###.## ";W1;:LPRINT " %"
820 GOTO 650
830 PRINT"          -------------------------------------------------------"
840 LPRINT "          -------------------------------------------------------"
850 REM   ********  GUPTA AND LARSON (1979) METHOD *********
860 PRINT : LPRINT
870 READ A,B,C,D,E1,BAR
880 IF A=999 GOTO 1070
890 W2=.1
900 WV15=(A*SD+B*ST+C*CL+D*OM+(E1*(DD/62.4)*(1+W2)))/1000
910 SAT=(1/N)*WV15
920 W=(SAT*E)/GS
930 IF INT(100*W)<>INT(100*W2) GOTO 940ELSE 960
940 W2=W
950 GOTO 900
960 PRINT : LPRINT
970 PRINT"        ";:PRINT USING "##.";BAR;
980 LPRINT "        ";:LPRINT USING "##.";BAR;
990 PRINT" BAR MOISTURE CONTENT BY GUPTA & LARSON =";
1000 LPRINT " BAR MOISTURE CONTENT BY GUPTA & LARSON =";
1010 W1=W*100
1020 PRINT USING " ###.## ";W1;
1030 LPRINT USING " ###.## ";W1;
1040 PRINT " %"
1050 LPRINT " %"
1060 GOTO 870
1070 PRINT"          ---------------------------------------------------"
1080 LPRINT "          ---------------------------------------------------"
1090 REM  ********  BAUMER AND BRASHER (1982) METHOD **********
1100 PRINT : LPRINT
1110 PRINT : LPRINT
1120 IF CL<=10 GOTO 1310
1130 REM  **** KAOLIN DOMINATED ******
1140 A=-3.26
1150 B=.31
1160 D=.13
1170 PV=(1-(((DD*(1+W))/62.4)/GS))*100
1180 WK=A+B*CL+D*PV
1190 IF INT(WK)<>INT(100*W) GOTO 1200ELSE 1220
1200 W=WK/100
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1210 GOTO 1170
1220 REM *****  MONTMOR DOMINATED *******
1230 A=-4.19
1240 B=.38
1250 D=.13
1260 PV=(1-(((DD*(1+W))/62.4)/GS))*100
1270 WM=A+B*CL+D*PV
1280 IF INT(WM)<>INT(100*W) GOTO 1290ELSE 1410
1290 W=WM/100
1300 GOTO 1260
1310 REM *********  CLAY CONTENT LESS THAN 10%  *************
1320 A=-1.48
1330 B=0.9
1340 C=-0.03
1350 D=0.08
1360 PV=(1-(((DD*(1+W))/62.4)/GS))*100
1370 WC=A+B*CL+C*SD+D*PV
1380 IF INT(WC)<>INT(100*W) GOTO 1390ELSE 1410
1390 W=WC/100
1400 GOTO 1360
1410 PRINT"          15 BAR MOISTURE CONTENT BY BAUMER & BRASHER  "
1420 LPRINT "          15 BAR MOISTURE CONTENT BY BAUMER & BRASHER  "
1430 PRINT : LPRINT
1440 IF CL<=10 GOTO 1580
1450 PRINT"                    FOR KAOLIN DOMINATED =";
1460 LPRINT "                    FOR KAOLIN DOMINATED =";
1470 PRINT USING " ###.## ";WK;
1480 LPRINT USING " ###.## ";WK;
1490 PRINT" %"
1500 LPRINT " %"
1510 PRINT"           FOR MONTMORILONITE DOMINATED =";
1520 LPRINT "           FOR MONTMORILONITE DOMINATED =";
1530 PRINT USING " ###.## ";WM;
1540 LPRINT USING " ###.## ";WM;
1550 PRINT" %"
1560 LPRINT " %"
1570 IF CL>10 GOTO 1640
1580 PRINT"             FOR CLAY CONTENT LESS THAN 10 %=";
1590 LPRINT"             FOR CLAY CONTENT LESS THAN 10 %=";
1600 PRINT USING " ###.## ";WC;
1610 LPRINT USING " ###.## ";WC;
1620 PRINT " %"
1630 LPRINT " %"
1640 PRINT"         ----------------------------------------"
1650 LPRINT "         ----------------------------------------"
1660 PRINT : LPRINT
1670 PRINT : LPRINT
1680 PRINT : LPRINT
1690 REM  **********  ROGERS ET AL. (1982) METHOD  ************
1700 W1=3.1*P^.5-.03*E2+(3.9*((CL+ST)/100))-1
1710 PRINT"          LONG TERM MOISTURE CONTENT BY ROGERS =";
1720 LPRINT "          LONG TERM MOISTURE CONTENT BY ROGERS =";
1730 PRINT USING " ###.## ";W1;
1740 LPRINT USING " ###.## ";W1;
1750 PRINT " %"
1760 LPRINT " %"
1770 PRINT"        -----------------------------------------------"
1780 LPRINT"        -----------------------------------------------"
1790 DATA 15,.0260,0,0,.005,.0158
1800 DATA 10,.0205,0,.0005,.0049,.0154
```

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1830 DATA 2,.0281,0,.0011,.0054,.0200
1840 DATA 1,.0349,0,.0014,.0055,.0251
1850 DATA 0,999,0,0,0,0
1860 DATA .0854,-.0004,.0044,.0122,-.0182,15
1870 DATA .1005,-.0004,.0044,.0133,-.0218,10
1880 DATA .1155,-.0005,.0045,.0143,-.0253,7
1890 DATA .1426,-.0007,.0045,.016,-.0315,4
1900 DATA .1837,-.0009,.0044,.0181,-.0407,2
1910 DATA .2352,-.0012,.0043,.0202,-.0517,1
1920 DATA 999,0,0,0,00,0
1930 DATA -.059,1.142,5.766,2.228,26.71,15
1940 DATA .076,1.334,5.802,2.653,21.45,10
1950 DATA .214,1.536,5.908,2.855,15.3,07
1960 DATA .483,1.943,6.128,2.925,-2.04,04
1970 DATA .932,2.643,6.636,2.717,-22.14,02
1980 DATA 1.563,3.620,7.154,2.388,-57.59,01
1990 DATA 999,0,0,0,0,0
2000 SYSTEM "T
2010 SYSTEM "T
2020 SYSTEM"T" : END
```

APPENDIX B

EXAMPLE OUTPUT

15 BAR MOISTURE CONTENT BY BAUMER & BRASHEF

FOR KAOLIN DOMINATED = 7.32 %
FOR MONTMORILONITE DOMINATED = 7.81 %

LONG TERM MOISTURE CONTENT BY ROGERS = 9.41 %

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15 BAR MOISTURE CONTENT BY BAUMER & BRASHER

FOR KAOLIN DOMINATED = 15.68 %

FOR MONTMORILONITE DOMINATED = 17.72 %

LONG TERM MOISTURE CONTENT BY ROGERS = 10.67 %

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15 BAR MOISTURE CONTENT BY BAUMER & BRASHER

FOR CLAY CONTENT LESS THAN 10 %= 3.52 %

LONG TERM MOISTURE CONTENT BY ROGERS = 9.11 %
