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HCMM Energy Budget Data As A Model Input For Assessing Regions of High Potential Groundwater Pollution

Principal Investigator: Donald G. Moore
Report Authors: J. Heilman, D. Moore, J. Tunheim, V. Baumberger
Remote Sensing Institute
South Dakota State University
Brookings, South Dakota 57007

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16. Abstract

Progress of the investigation is reported. Field measurements in support of HCMM overpasses have begun. The finite-difference heat flow model is being used to simulate soil temperature profiles for a variety of soil moisture profiles. The model is also being used to simulate effects of the presence of shallow water tables on soil temperature profiles.

17. Key Words Suggested by Author	18. Distribution Statement
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A. Problems

None

B. Accomplishments

Collection of ground data in support of HCMM overpasses and for calibration of the finite-difference heat flow model has begun.

The finite-difference model was adapted for use on an Hewlett-Packard 9825 minicomputer (See Appendix A).

A series of model calculations were made to simulate effects of near surface soil moisture (within 50 cm of soil surface) and water tables at deeper depths on the soil depths in soil surface temperature.

During the next reporting period, collection of ground data will continue. Analyses of HCMM data will begin upon receipt of the data.

C. Significant Results

In order to investigate the general relationship between surface temperature and soil moisture profiles a series of model calculations are being carried out. Soil temperature profiles are being calculated during a complete diurnal cycle for a variety of moisture profiles. Preliminary results indicate the surface temperature difference between two sites measured at about 1400 hours is related to the difference in soil moisture within the diurnal damping depth (about 50 cm). The model shows this temperature difference to vary considerably throughout the diurnal cycle.

The presence of a water table below the diurnal damping depth was simulated by fixing the soil temperature at 50 cm depth to be 2^{o} C

cooler than a similar site without water. Model calculations comparing two sites with and without this water were made. Preliminary results show the presence of such a water table results in a surface temperature difference which is constant throughout the diurnal cycle. If the two sites also differ in soil moisture in the top 50 cm layer of soil, the presence of a water table at one site simply alters the surface temperature difference by a constant amount. Thus the model may allow one to distinguish the effects of soil moisture near the surface from those due to a water table below the diurnal damping depth by consideration of surface temperature differences noted by HCMM at its day and night overpasses.

It should be noted that these series of calculations assume the same heat flux into both sites and do not account for crop canopies. These factors may complicate use of the model in actual field conditions.

D. Publications

None at this time

E. Recommendations

None at this time

F. Funds Expended

$29,007.94

G. Data Utility

HCMM data has not been received

APPENDIX A

Soil-Temperature Model Program:

This program is set up to provide a model of soil temperature for 50 cm of soil. This is broken into fifty (50) equally spaced layers.

PARAMETERS:

X(1) is the distance between nodal points in centimeters.
T is the time interval between calculations in seconds.
N is the number of equally spaced nodal points.
P is the time between print-outs in seconds.
M(1) is the initial starting minute.
H(1) is the initial starting hour.
M(2) is the minute when the calculation is to end.
H(2) is the hour when the calculation is to end.
Y(1) is the ending day.
W(1) is the adjusted air temperature.
A(I) is the temperature of Site A at depth I.
B(I) is the temperature of site B at depth I.
O(I) is the moisture of site A at depth I.
P(I) is the moisture of site B at depth I.
Q is the amount of soil.
K(0,1,2) is the conductivity of air, water, and soil respectively.
G(1,2) is the heat capacity of water and soil respectively.
G(0) is a dipolarization factor as defined by deVries

* Program Listing

```
0: 706→r0;gto 76
*11086
```

* Subroutine "QHEAT"
This subroutine is used to calculate the surface heat flux throughout the day.

```
1: "QHEAT":M[1]/60→r21
2: H[1]+r21→r22
3: r22-6.75→r23
*606
```

* Conversion of Temperatures in Degrees Centigrade to Degrees Kelvin.
The adjustment factor (/100) allows for larger precision in the calculation.

```
4: (W[1]+273.16)/100→r24
5: (A[0]+273.16)/100→r25
6: (B[0]+273.16)/100→r26
*12430
```

* Calculation of Surface Heat Loss Term
(.000136 corresponds to the Stefan-Boltzman constant)

```
7: .000136*r24^4→r27
8: -(.000136*r25^4-r27)→r11
9: -(.000136*r26^4-r27)→r12
*1597
```


* Calculation of Surface Heat Flux
This test to determine whether the time is at night or during the day and adds a solar heat flux term for the day.

```
10: if r23<=0;gto "100"
11: if r23>=13;gto "100"
12: rad
13: .0094*sin(r23*π/13)+r11→r11
14: .0094*sin(r23*π/13)+r12→r12
15: "100":ret
*4812
```

* The following subroutines are used for plotting the data.
(for further detail see plotting subroutine package).

```
16: "move":
17: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64),int((p2-Y)V)
18: ret
19: "imove":
20: wtb r0,27,82,int(p1U/64),int(p1U),int(p2V/64),int(p2V)
21: ret
22: "plt":
23: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p2-Y)V/64),int((p2-Y)V)
24: if p3=0;46→p3
25: if p3=46;wtb r0,27,82,0,0,0,6
26: wtb r0,p3;wtb r0,8
27: if p3=46;wtb r0,27,82,0,0,63,-6
28: ret
29: "char":
30: if p2=0;5→p2;0→p3
31: wtb r0,27,46,p1,int(p2/64),p2,p3
32: ret
33: "psiz":
34: p1→H;p2→W
35: wtb r0,27,79,int(p4*120/64),p4*120,int(p3*96/64),p3*96
36: ret
37: "scl":
38: 120W/(p2-p1)→U
39: 96H/(p4-p3)→V
40: p1→X;p3→Y
41: ret
42: "xaxis":
43: wtb r0,27,46,95,0,5,9
44: if p3=0 and p4=0;X→p3;X+120W/U→p4
45: if p2=0;p4-p3→p2
46: wtb r0,27,65,int((p3-X)U/64),int((p3-X)U),int((p1-Y)V/64),int((p1-Y)V)
47: p3→p5;wtb r0,43;wtb r0,8
48: wtb r0,27,114,int(p2U/64),int(p2U),0,0;wtb r0,43,8;jmp (p5+p2→p5)>=p4
49: ret
50: "yaxis":
51: wtb r0,27,46,124,0,3,0
52: if p3=0 and p4=0;Y→p3;Y+96H/V→p4
53: if p2=0;p4-p3→p2
54: wtb r0,27,65,int((p1-X)U/64),int((p1-X)U),int((p3-Y)V/64),int((p3-Y)V)
55: p3→p5;wtb r0,43;wtb r0,8
56: wtb r0,27,114,0,0,int(p2V/64),int(p2V);wtb r0,43,8;jmp (p5+p2→p5)>=p4
57: ret
58: "space":
59: if p1<0;gto +2
60: wtb r0,32;jmp 2((p1-1→p1)=0)
61: wtb r0,8;jmp (p1+1→p1)=0
62: ret
63: "skip":
64: if p1<0;gto +2
65: wtb r0,10;jmp 2((p1-1→p1)=0)
66: wtb r0,27,10;jmp (p1+1→p1)=0
67: ret
68: "form":
69: wtb r0,27,77
70: wtb r0,27,84
71: if p1=0;13.2→p1;11→p2→p3
72: wtb r0,27,87,int(120*p1/64),120*p1
73: wtb r0,27,76,int(96*p2/64),96*p2
74: wtb r0,27,70,int(96*p3/64),96*p3
75: ret
```

* The Main Program Begins Here.
Parameters used are as previously defined and are called for by the computer.

```
5: dim A[0:50],B[0:50],C[0:50],D[0:50],E[0:50],F[0:50],O[0:105],P[0:50]
7: dim X[1],V[0:105],W[1]
8: dim M[0:4],H[0:2],K[0:2],G[0:2],L[0:50],Y[0:1],R[0:50],S[0:51],U[0:105]
9: ent X[1],T,N,P,H[1],M[1],Y[1],H[2],M[2],W[1]
0: -1→L[1]
1: for I=2 to 50;L[I-1]-1→L[I];next I
2: 0→J→M[3]→M[4]→r10
3: H[1]*60+M[1]→M[3]
4: 1→r15
23907
```

* Specification of Initial Temperature Profile
A(0) corresponds to the surface, H(I) 1 cm etc.

```
5: ent A[0],A[1],A[5],A[10],A[25],A[50],B[0],B[1],B[5],B[10],B[25],B[50]
6: for I=2 to 4;(A[5]-A[1])/4*(I-1)+A[1]→A[I]
7: (B[5]-B[1])/4*(I-1)+B[1]→B[I];next I
8: for I=6 to 9;(A[10]-A[5])/5*(I-5)+A[5]→A[I]
9: (B[10]-B[5])/5*(I-5)+B[5]→B[I];next I
1: for I=11 to 24;(A[25]-A[10])/15*(I-10)+A[10]→A[I]
2: (B[25]-B[10])/15*(I-10)+B[10]→B[I];next I
3: for I=26 to 49;(A[50]-A[25])/25*(I-25)+A[25]→A[I]
4: (B[50]-B[25])/25*(I-25)+B[25]→B[I];next I
1: A[1]-B[1]→S[51]
19662
```

* Testing for Calculation of Conductivity and Specific Heats.

```
: "5":J+1→J;if J>1;goto "30"
31264
```

* Specification of Conductivity and Heat Capacity Profiles.

```
: "10":ent O[1],O[8],O[25],O[42],P[1],P[8],P[25],P[42],Q
: ent K[0],K[1],K[2],G[0],G[1],G[2]
: 1-O[1]-Q→U[1]
: 1-P[1]-Q→V[1]
0: 1-O[8]-Q→U[8]
1: 1-P[8]-Q→V[8]
2: 1-O[25]-Q→U[25]
3: 1-P[25]-Q→V[25]
4: 1-O[42]-Q→U[42]
5: 1-P[42]-Q→V[42]
4297
```

```
06: (2/(1+(K[2]/K[1]-1)*G[0])+1/(1+(K[2]/K[1]-1)*(1-2*G[0])))/3→r1
07: (2/(1+(K[0]/K[1]-1)*G[0])+1/(1+(K[0]/K[1]-1)*(1-2*G[0])))/3→r2
08: (O[1]*K[1]+r1*Q*K[2]+r2*U[1]*K[0])/(O[1]+r1*Q+r2*U[1])→C[1]
09: (P[1]*K[1]+r1*Q*K[2]+r2*V[1]*K[0])/(P[1]+r1*Q+r2*V[1])→D[1]
10: (O[8]*K[1]+r1*Q*K[2]+r2*U[8]*K[0])/(O[8]+r1*Q+r2*U[8])→C[8]
11: (P[8]*K[1]+r1*Q*K[2]+r2*V[8]*K[0])/(P[8]+r1*Q+r2*V[8])→D[8]
12: (O[25]*K[1]+r1*Q*K[2]+r2*U[25]*K[0])/(O[25]+r1*Q+r2*U[25])→C[25]
13: (P[25]*K[1]+r1*Q*K[2]+r2*V[25]*K[0])/(P[25]+r1*Q+r2*V[25])→D[25]
14: (O[42]*K[1]+r1*Q*K[2]+r2*U[42]*K[0])/(O[42]+r1*Q+r2*U[42])→C[42]
15: (P[42]*K[1]+r1*Q*K[2]+r2*V[42]*K[0])/(P[42]+r1*Q+r2*V[42])→D[42]
16: Q*G[2]+O[1]*G[1]→E[1]
17: Q*G[2]+P[1]*G[1]→F[1]
18: Q*G[2]+O[8]*G[1]→E[8]
19: Q*G[2]+P[8]*G[1]→F[8]
20: Q*G[2]+O[25]*G[1]→E[25]
21: Q*G[2]+P[25]*G[1]→F[25]
22: Q*G[2]+O[42]*G[1]→E[42]
23: Q*G[2]+P[42]*G[1]→F[42]
24: "11":for I=2 to 24;C[8]-(C[25]-C[8])/17*(8-I)→C[I]
25: D[8]-(D[25]-D[8])/17*(8-I)→D[I]
26: E[8]-(E[25]-E[8])/17*(8-I)→E[I]
27: F[8]-(F[25]-F[8])/17*(8-I)→F[I];next I
28: for I=26 to 50;C[25]+(C[42]-C[25])/17*(I-25)→C[I]
29: D[25]+(D[42]-D[25])/17*(I-25)→D[I]
30: E[25]+(E[42]-E[25])/17*(I-25)→E[I]
31: F[25]+(F[42]-F[25])/17*(I-25)→F[I];next I
32: C[1]→C[0];D[1]→D[0];E[1]→E[0];F[1]→F[0]
33: T/(2*X[1]*X[1])→r1;gto "45"
14479
```

* Call Subroutine to Calculate Surface Heat Flux.


```
34: "30":cll 'QHEAT'
8356
```

* Calculation of Internal Nodal Temperatures.

```
35: for I=1 to N-1;(E[I]/r1-C[I-1]-2*C[I]-C[I+1])*A[I]→r6
36: ((C[I-1]+C[I])*A[I-1]+(C[I]+C[I+1])*A[I+1]+r6)*r1/E[I]→B[I]
37: (F[I]/r1-D[I-1]-2*D[I]-D[I+1])*B[I]→r7
38: ((D[I-1]+D[I])*B[I-1]+(D[I]+D[I+1])*B[I+1]+r7)*r1/F[I]→S[I];next I
9700
```

```
      *    Calculation of Surface Nodal Temperatures.

39: 4*X[1]*r11+(E[1]/r1-2*C[1]-2*C[2])*A[0]+(2*C[1]+2*C[2])*A[1]→R[0]
40: r1/E[1]*R[0]→R[0]
41: 4*X[1]*r12+(F[1]/r1-2*D[1]-2*D[2])*B[0]+(2*D[1]+2*D[2])*B[1]→S[0]
42: r1/F[1]*S[0]→S[0]
21903


      *    Calculation of Lower Boundary Temperatures.

43: A[N]→R[N]
44: B[N]→S[N]
10319


      *    Reassignment of Nodal Temperatures for Next Iteration.

45: for I=0 to N;R[I]→A[I];S[I]→B[I];next I
46: A[0]-B[0]→S[51]
26505


      *    Testing for Print-out Time

47: if M[4]<P;gto "81"
30756


      *    Printing of Pertinent Data

48: "45":r10+1→r10
49: int(r10/2)→r11;r11*2→r12
50: fmt 1,/,/,"TEMPERATURE PROFILE AT ",fz2.0,fz2.0," HOURS"
51: "52":wrt 706.1,H[1],M[1]
52: fmt 2,/,/,/,"SURFACE TEMPERATURE DIFFERENCE =",f6.3
53: wrt 706.2,S[51]
54: fmt 1,/,/,/,4x,3"DEPTH   TEMP A   TEMP B   "
55: wrt 706.1
16789
```

```
        *   Allocation of Three (3) Equal Columns for the Data

156: int(N/3)+1→r2
157: r2*3→r3
158: N-r3+1→r4
159: for I=0 to r2-1;I→r5→r6
160: if r4>=1;r6+1→r6
161: r6+r2→r7→r8
162: if r4>=2;r8+1→r8
163: r8+r2→r9
164: fmt 1,5x,f3.0,4x,f6.3,3x,f6.3,4x,f3.0,4x,f6.3,3x,f6.3,z
165: wrt 706.1,r5,A[r5],B[r5],r7,A[r7],B[r7]
166: fmt 2,4x,f3.0,4x,f6.3,3x,f6.3
167: wrt 706.2,r9,A[r9],B[r9];next I
168: r5+1→r5;r7+1→r7
169: if r4>=2;gto "76"
170: if r4>=1;gto "74"
171: gto "80"
172: fmt 3,4x,f3.0,4x,f6.3,4x,f6.3,z
173: "76":wrt 706.3,r5,A[r5],B[r5]
174: fmt 2,20x,f3.0,4x,f6.3,4x,f3.0,f6.3
175: "74":wrt 706.2,r7,A[r7],B[r7]
*28864

        *   End of Print-Out Routine


176: "80":0→M[4]
177: if r12#r10;gto "81"
*23374

        *   This Portion Plots the Data.

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                                                OF POOR QUALITY

178: cll 'form'(8.5,10,11)
179: cll 'psiz'(7,7,1,.5)
180: cll 'scl'(10,35,-50,0)
181: cll 'xaxis'(-50,5,10,35)
182: cll 'yaxis'(10,10,-50,0)
183: cll 'move'(0,0)
184: for I=0 to 50;cll 'plt'(A[I],L[I],42);next I
185: for I=10 to 35 by 5;cll 'move'(I,-52);cll 'space'(-2)
186: fmt f4.0;wrt 706,I;next I
187: for I=-50 to 0 by 10;cll 'move'(10,I);cll 'space'(-6)
188: wrt 706,I;next I
189: cll 'move'(17,3);wrt 706,"SOIL TEMPERATURE FOR SITE A"
190: cll 'move'(22,-54);wrt 706,"TEMPERATURE"
191: cll 'move'(5,-60);cll 'form'(8.5,10,11);cll 'psiz'(7,7,1,.5)
192: cll 'xaxis'(-50,5,10,35);cll 'yaxis'(10,10,-50,0)
193: cll 'move'(0,0)
194: for I=0 to 50;cll 'plt'(B[I],L[I],42);next I
195: for I=10 to 35 by 5;cll 'move'(I,-52);cll 'space'(-2)
196: fmt f4.0;wrt 706,I;next I
197: for I=-50 to 0 by 10;cll 'move'(10,I);cll 'space'(-6)
198: wrt 706,I;next I
199: cll 'move'(17,3);wrt 706,"SOIL TEMPERATURE FOR SITE B"
200: cll 'move'(22,-54);wrt 706,"TEMPERATURE"
201: cll 'move'(5,-60)
*31492
```

* Testing if Calculations have run for desired time

```
02: "81":if M[1]<M[2];gto "84"
03: if H[1]<H[2];gto "84"
04: if Y[0]<Y[1];gto "84"
05: gto "90"
2210
```

Calculation of Difference every 20 minutes

```
06: "84":M[3]+1→M[3]
07: if M[3]/(r13*20)>=1;gto "203"
08: gto "210"
09: "203":r13+1→r13
10: A[0]-B[0]→U[M[3]/20]
11: A[5]-B[5]→V[M[3]/20]
12: M[3]/60→O[M[3]/20]
31758
```

Calculation of New Time for next iteration

```
13: "210":M[4]+S→M[4]
14: M[1]+T/60→M[1]
15: if M[1]<60;gto "88"
16: M[1]-60→M[1]
17: H[1]+1→H[1];if H[1]<24;gto "88"
18: H[1]-24→H[1];Y[0]+1→Y[0]
19: "88":gto "5"
20: "90":stp
27365
```

```
*   This program allows the differences, previously calculated, to be plotted.
    This portion plots the "surface temperature difference."

: cll 'form'(8.5,10,11)
: cll 'psiz'(7,7,1,.5)
: cll 'scl'(0,30,-4,5)
: cll 'xaxis'(-4,5,0,30)
: cll 'yaxis'(0,1,-4,5)
: cll 'move'(0,0)
: for I=1 to 90;cll 'plt'(D[I],U[I],42);next I
: for I=0 to 30 by 5;cll 'move'(I,-4.4);cll 'space'(-2)
: fmt f4.0;wrt 706,I;next I
: for I=-4 to 5;cll 'move'(0,I);cll 'space'(-6)
0: wrt 706,I;next I
1: cll 'move'(11,5.5);wrt 706,"SURFACE TEMPERATURE DIFFERENCE VERSUS TIME"
2: cll 'move'(17,-4.7);wrt 706,"HOUR"
3: cll 'move'(-3,-6)
32539

*   This portion plots the "5 cm Temperature Difference".

4: cll 'form'(8.5,10,11)
5: cll 'psiz'(7,7,1,.5)
6: cll 'scl'(0,30,-2,3)
7: cll 'xaxis'(-2,5,0,30)
8: cll 'yaxis'(0,1,-2,3)
9: cll 'move'(0,0)
0: for I=1 to 90;cll 'plt'(D[I],V[I],42);next I
1: for I=0 to 30 by 5;cll 'move'(I,-2.2);cll 'space'(-2)
2: fmt f4.0;wrt 706,I;next I
3: for I=-2 to 3;cll 'move'(0,I);cll 'space'(-6)
4: wrt 706,I;next I
5: cll 'move'(12,3.5);wrt 706,"5CM TEMPERATURE DIFFERENCE VERSUS TIME"
6: cll 'move'(17,-2.5);wrt 706,"HOUR"
7: stp
8: end
24560
```