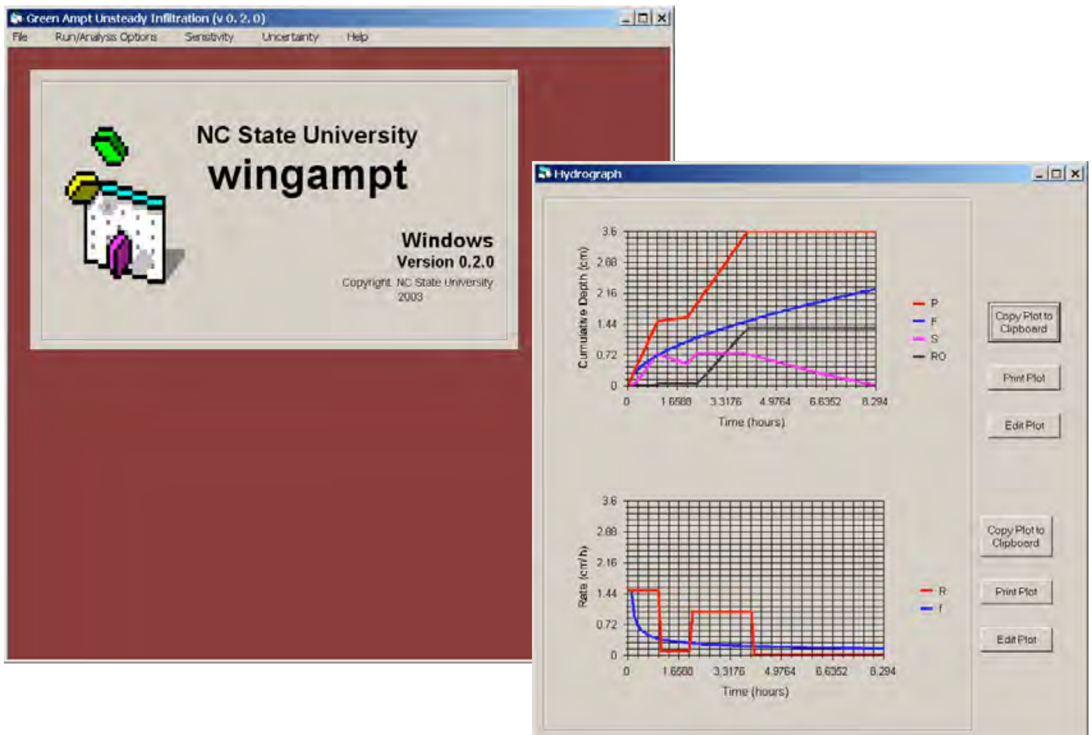
WinGAmpt

A Windows based teaching tool for Green-Ampt Infiltration for Unsteady Rainfall Model



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1.0 Documentation for WinGampt.exe (6/03)

2.0 Green Ampt Model: Background and Derivations

This discussion is a summary from Skaggs and Khaheel (1982). The Green Ampt model for infiltration was originally derived for infiltration from a ponded surface into a deep homogenous soil with a uniform initial water content (Green and Ampt 1911). Green and Ampt applied Darcy's Law by assuming that water enters the soil as slug flow. This assumption implies that there is a sharply defined wetting front which separates a zone that has been wetted from infiltration and a zone that is totally un-wetted (at the initial water content). In other words, as an approximation, they assumed that the transitions zone was very small. Pictorially, we have:

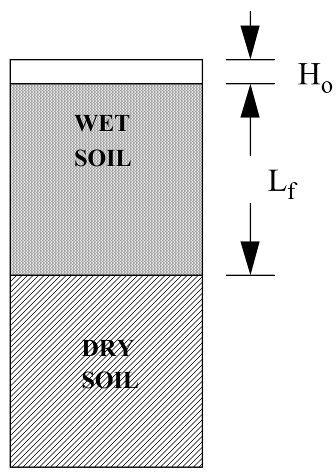


Figure 1 Schematic to illustrate piston flow.

From the figure we assume that $\theta = \theta_s$ in the wet soil zone and $\theta = \theta_i$ in the dry soil zone. Let K_s be the saturated hydraulic conductivity in the tranmission zone (saturated soil).

Recall Darcy's Law, $Q = AK\frac{\mathrm{d}H}{\mathrm{d}z}$ where Q is the flow (L^3/T), A is the area (L^2), K is the saturated conductivity (L/T), H is the total hydraulic head (L), and z is the space coordinate (L). This is equivalent to

$q = K\frac{\mathrm{d}H}{\mathrm{d}z}$ where q is the flux (L/T) per unit area. Applying this form to the Figure 24,

(EQ 1)

$$f_p = K_s\left(\frac{H_o + L_f + S_f}{L_f}\right)$$

where

f_p = infiltration rate (L/T),

K_s = hydraulic conductivity of the transmission zone (wetted zone) (L/T),

H_o = depth of water ponded on the surface (L),

L_f = distance from the surface to the wetting front (L), and

S_f = effective suction at the wetting front (L).

Note that the cumulative infiltration, F (L), is given by

(EQ 2) $$F = (\theta_s - \theta_i)L_f = ML_f$$

where $M = (\theta_s - \theta_i)$.

(EQ 1)The effective suction at the wetting front, S_f, requires some knowledge of the development of the wetting front. This quantity is difficult to determine. This is often replaced by the average suction at the wetting front which is found from the soil water characteristic. The interested reader is referred to Bouwer (1969) and Mein and Larson (1973). For the rest of our discussion we will use the average suction at the wetting front, Sav, as estimated by Mein and Larson (1973). If we assume that the surface has just ponded (that is, $H_o \approx 0$), then

becomes

(EQ 3)

$$f_p = K_s + \frac{K_s\ Sav\ M}{F}$$

and M is called the fillable porosity. This is a direct measure of antecedent moisture conditions which is often estimated indirectly in other methods such as the NRCS (SCS) Curve Number method.

(EQ 3)Now substitute $f_p = \frac{dF}{dt}$ into

. This yields

(EQ 4)

(EQ 4) $\frac{dF}{dt} = K_s + \frac{K_s\ M\ Sav}{F}$ Now we assume that F=0 at t=0, and integrate

with respect to t,

(EQ 5) $$\int_0^t \frac{dF}{dt} dt = \int_0^t K_s dt + \int_0^t \frac{K_s\ M\ Sav}{F} dt$$

This yields the following for ponded conditions with steady rainfall,

(EQ 6)

(EQ 3) $K_s t = F - M\ Sav\ \ln\left(1 + \frac{F}{M\ Sav}\right)$ Now, we need to modify the Green Ampt approach to handle conditions non-ponded, unsteady rainfall. First, for the non-ponded condition, we know that all of the water must be infiltrating. Therefore f_p = R where R is the rainfall intensity. The first step is to determine the cumulative infiltration at the time of ponding (call this F_p). This is found by setting f_p=R and using

. The resulting equation is

(EQ 7) $$R = K_s + \frac{K_s\ M\ Sav}{F_p}$$

Solve for F_p and obtain

(EQ 8)

$F_p = \frac{Sav\ M}{\frac{R}{K_s} - 1}$ Prior to ponding, f=R, so,

(EQ 9)

$$F_p = Rt_p$$

(EQ 10)

$t_p = \frac{F_p}{R}$ where t_p is the time to ponding.

So for steady rainfall, if $t<t_p$, then

(EQ 11)

$f = R$ and for $t>t_p$,

(EQ 12)

$f = f_p = K_s + \frac{K_s\, Sav\, M}{F_p}$ Mein and Larson (1973) derived the following form of the Green Ampt equation,

(EQ 13)

(EQ 6) $K_s(t - t_p + t'_p) = F - M\,Sav\,\ln\left(1 + \frac{F}{M\,Sav}\right)$ where t'_p is the equivalent time to infiltrate the volume Fp under initially ponded conditions which can be calculated directly from

(EQ 13). Application of Green Ampt Model can be made by applying either

(EQ 11) or

(EQ 12) and

(EQ 6) along with using

.

An example is given in the next section, other examples may be added future appendices to this summary.

For analyzing unsteady rainfall, it is helpful to utilize a water balance at the surface. Ignoring evaporation during the rainfall event, this is given by

(EQ 14)

$\Delta P = \Delta F + \Delta s + RO$ where $\Delta P = R\Delta t$, the rainfall during the time period Δt, ΔF is the cumulative infiltration, Δs is change in surface storage, and RO is the surface runoff during the time period Δt. Chu (1978) offered a simplified systematic approach to using the Green Ampt model along with this water balance. This approach is illustrated here and with the FORTRAN program supplied in the WinGampt package.

2.0.1 Steady and Unsteady Rainfall Examples

```
Solution to Spring 1994 Homework Problem:

Important Equations: (Note I will use the numbers similar to those used in
the previous examples)

      Sav*M
Fp = ---------     (Find Cum. Inf. at ponding)
```

(EQ 8) (R/Ks)-1 (EQ

)

```
       Fp
tp = -----         (Eqn to find time to ponding)
```

(EQ 10) R (EQ

)

(EQ 6)Eq. (EQ

```
) to relate infiltration volume to time from the start of infiltration (under
ponded conditions)
                                  F
Ks*t = F - Sav * M * ln(1.0 + --------)
                               M * Sav
```

(EQ 6)To find tp', then we use Eq. (EQ

```
) with Fp,

                                       Fp
Ks * tp' = Fp - Sav * M * ln(1.0 + --------)
                                    M * Sav
```

(EQ 13)Infiltration under ponded conditions after tp, we use (EQ

)

```
                                         F
Ks*(t-tp+tp') = F - M*Sav * ln(1.0 + -------)
                                       M*Sav
```

(EQ 12)Note, the infiltration rate, f, under ponded conditions is always given by Green-Ampt's Equation (EQ

)

```
         M*Sav
f = Ks + -----
           F
```

(EQ 14)The other piece of the puzzle is the water balance,(Eq.

),

```
dP = dF + dS + RO
```

The variables are

```
Ks = vertical saturated conductivity (cm/h)
Sav = average suction across the wetting front (cm)
wcs = water content, theta at saturation (cm^3/cm^3)
wci = initial water content, theta (cm^3/cm^3) at the start
M = wcs - wci (cm^3/cm^3)
ln = natural logarithm function
Fp = cumulative infiltration at ponding (cm)
fp = infiltration rate at ponding (cm/h)
tp = time to ponding (h)
tp' = time required to infiltrate Fp if the system had started in ponded
conditions (h)
F = cumulative infiltration during the event (cm)
f = infiltration rate (cm/h)
t = time (h)
R = rainfall rate (cm/h)
P = amount of rainfall (cm)
S = surface storage (cm)
Smax = maximum surface storage (cm)
RO = runoff (cm)
dP, dS, dF = change in P, S, F since the last time step
```

The problem:

wci=0.0.25, wcs=0.499, Ks = 0.044 cm/h, Sav=22.4 cm, Smax=0.5 cm (Yolo light clay soil)

```
The Rainfall Event:

R = 3.0 cm/h  ; 0h <= t <= 1h
  = 0.1 cm/h  ; 1h <  t <= 3h
  = 1.0 cm/h  ; 3h <  t <= 4h
  = 0.4 cm/h  ; 4h <  t <= 6h

----------------------- The Solution -----------------

PERIOD 1:
```

(EQ 9)First find the time to ponding (EQ

(EQ 10) and

)

```
         22.4*0.249
Fp = ------------------- = 0.083 cm
      (3.0/0.044) - 1.0

      Fp    0.083
tp = ---- = ------ = 0.0277 h
      R      3.0
```

(EQ 6)Find tp’ using EQ

substituting t=tp’ and F=Fp

```
                                Fp
tp’ = (Fp - Sav*M*ln(1.0 + --------) ) /Ks
                               M*Sav
tp’ = 0.01319 h
```

(EQ 13)Now we infiltrate for the rest of the 1st period using EQ

.

(EQ 13)For example, at t=1.0 h, we solve EQ

for F

```
                                          F
Ks*(t-tp+tp’) = F - M*Sav * ln(1.0 + -------)
                                       M*Sav
```

0.044*(1.0-0.0277+0.01391) =

$$F - 0.249*22.4*\ln(1.0 + \frac{F}{0.249*22.4})$$

We iterate the above and find

At t=1h, F=0.7250

The infiltration rate, f, at t=1h

$$f = Ks + \frac{Ks*M*Sav}{F} = 0.044 + \frac{0.044*0.249*22.4}{0.7250} = 0.383 \text{ cm/h}$$

Now we do the water balance, that is,

From t=0.0277h to t=1h ->From tp=0.00277h to t=1h)

dP = dF + dS + RO

First compute dt = (1h -0.0277h)=0.9723h

dP = dt*R = 0.9723 * 3 = 2.9169 cm

dF = 0.7250-0.0831 = 0.6419

So the Excess=dP - dF = 2.9169-0.6419 = 2.275 cm

First we fill storage to the max (Smax=0.5), This leaves

dS = S(t=1)-S(t=tp), S(t=tp)=0.0, so
dS = 0.5 cm, and RO = 2.275 - 0.5 = 1.775 cm

This completes calculations on period 1.

PERIOD 2:

For this period and any period after the start of the event, we need to check if we remain in the current condition. We enter this period ponded, so we check to see if we remain ponded throughout the period.

To not be ponded for the entire period means that we must infiltrate the rainfall and all of the surface storage. Let the time for this to occur be t1, Then at time t1,

F = F(t=1h) + R*(t1-1) + S

```
  = 0.725 + 0.1*(t1-1) + 0.5 = 1.225 + 0.1 * (t1-1)
```

(EQ 13)Substitute this into EQ

for F,

```
                                                F
Ks*(t-tp+tp') = F - M*Sav * ln(1.0 + -------)
                                             M*Sav


0.044*(t1-0.0277+0.01381) =

                                                1.225+0.1*(t1-1)
  1.225+0.1*(t1-1) - 0.249*22.4*ln(1.0 + ----------------)
                                                      0.249*22.4
```

Solve this for t1 by iterating,
t1=4.066 h. Since t1> 4h (the end of the second period) we remain ponded during the entire period.

(EQ 13)We compute F based on EQ

at each desired time in the interval (at least at the ends). For example, at t=3h

```
                                                F
Ks*(t-tp+tp') = F - M*Sav * ln(1.0 + -------)
                                             M*Sav


0.044*(3.0-0.0277+0.01391) =

                                       F
 F - 0.249*22.4*ln(1.0 + ------------)
                                  0.249*22.4
```

We iterate the above and find

F = 1.2998 cm

The infiltration rate, f at t=3h is

```
          Ks*M*Sav           0.044*0.249*22.4
 f = Ks + -------- = 0.044 + ---------------- = 0.233 cm/h
            F                       1.2998
```

Now we do the water balance,

dF = 1.2998 - 0.7250 = 0.0.5748 cm

dP = R*dt = 0.1*2 = 0.2 cm

Note that dP < dF, therefore the dF-dP must come from storage, ie, dP-dF = -0.3748 = dS
Therefore, S = 0.5 + dS = 0.5 - 0.3798 = 0.1252 cm

Period 3:
Period 3 is handled in a similar fashion to period 2. However, since R=1 cm/h and f=0.233 cm/h at the start of the period we will stay ponded throughout the period.

So we find F at t=4h,

$$Ks*(t-tp+tp') = F - M*Sav * \ln(1.0 + \frac{F}{M*Sav})$$

$$0.044*(4.0-0.0277+0.01391) =$$

$$F - 0.249*22.4*\ln(1.0 + \frac{F}{0.249*22.4})$$

We iterate the above and find
F =1.5181 cm

The infiltration rate, f at t=4h is

$$f = Ks + \frac{Ks*M*Sav}{F} = 0.044 + \frac{0.044*0.249*22.4}{1.5181} = 0.206 \text{ cm/h}$$

Now we do the water balance,

dF = 1.5181 - 1.2998 = 0.2183 cm

dP = R*dt = 1.0*1 = 1.0 cm

Add dP - dF = excess = 0.7817 cm

Fill Storage, dS = 0.5 - 0.1252 = 0.3748 cm

Excess = 0.7817-0.3748 = 0.4069 cm which is added to RO

Period 4:

(EQ 13)Again, note that f=0.206 cm/h < R=0.4 cm/h, so we will remain in ponded conditions for the period. So compute F at t=6h the same as last period EQ

```
F = 1.8940 cm

f = 0.1736 cm/h

dF = 1.8940 - 1.5181 = 0.376 cm
dP = 0.4 * 2 = 0.8 cm
Excess = 0.4241 cm, This must all be added to runoff since the surface
storage was at maximum for the entire period.

Final Calculations:  We must infiltrate the remaining water in storage, 0.5
cm, To find the time this occurs, we find the time to infiltrate

F = 1.8940 + 0.5 = 2.394 cm using equation 4.32b (EQ 12)

t = 9.152 h, and f = 0.147 cm/h

NOTE: In this handout the equations are identified by two different numbering
schemes.

Additional Notes and Comments:
```

2.0.2 FORTRAN PROGRAM ILLUSTRATING CHU'S METHOD

The program illustrating Green-Ampt for unsteady rainfall is linked to the course homepage. The source code is given in the appendix.

2.0.3 EXAMPLE USING THE FORTRAN PROGRAM

The program requires two input files: one for the rainfall and one for the soils data.

Rainfall Input file:

Each line of the rainfall consists of: starting time (h), ending time (h) and rainfall amount (cm/h)

```
 0.0 1.0 3.0
 1.0 3.0 0.1
 3.0 4.0 1.0
 4.0 6.0 0.4
```

Soils Input file:

The format of the input file is:

```
line 1: ****> solution time step (h), time offset (h) [usually 0]
line 2: ****> Sat K (cm/h), Sav (cm), Sat. WC (cm^3/cm^3), Init. WC (cm^3/cm^3)
line 3: ****> maximum surface storage (cm)
0.1  0.0   Yolo Clay -- Test Case
0.044 22.4 0.499 0.25
0.75
Output File:

  Working with Soils data    =soils.inp
  Working with Rainfall data =rawrain.inp


          -----------------------------------------------
          |   Green-Ampt Solution for Unsteady Rainfall  |
          |    by J.E.Parsons, v0.3, R.Munoz-Carpena     |
          |    Routines from Papers by Mein and Larson   |
          |    1971 and Chu, 1976. See Reference Sec.    |
          |    Version as of 03/02/00. jep-rmc           |
          -----------------------------------------------

          ----------------------------------------------
          |   INPUT PARAMETERS                         |
          |  Sat. K               =  .0440 cm/h        |
          |  Sav                  =  22.40 cm          |
          |  Sat. Water Content   =   .499 cm^3/cm^3   |
          |  Initial Water Content =   .250 cm^3/cm^3  |
          |  Maximum Surface Stor. =     .8 cm         |
          |  Solution Time Step   =    .10 h           |
          ----------------------------------------------



          ----------------------------
          | Rainfall Distribution    |
          |--------------------------|
          | Start   End        RFi   |
          | Time    Time             |
          | -----   -----      ---   |
          |   h       h       cm/h   |
          |--------------------------|
          |   .00     1.00     1.50  |
          |  1.00     2.00      .10  |
          |  2.00     4.00     1.00  |
          ----------------------------


          Green-Ampt Test Routines
```

Based on work of Mein&Larson and Chu

Time h	tp h	tpp h	R cm/h	P cm	F cm	fp cm/h	f cm/h	S cm	RO cm
.000	.000	.000	1.50	.00	.000	.000	.000	.000	.000
.100	.112	.057	1.50	.15	.150	1.680	1.500	.000	.000
.112	.112	.057	1.50	.17	.169	1.500	1.500	.000	.000
.212	.112	.057	1.50	.32	.282	.914	.914	.037	.000
.312	.112	.057	1.50	.47	.363	.721	.721	.106	.000
.412	.112	.057	1.50	.62	.429	.616	.616	.190	.000
.512	.112	.057	1.50	.77	.487	.548	.548	.282	.000
.612	.112	.057	1.50	.92	.539	.499	.499	.379	.000
.712	.112	.057	1.50	1.07	.587	.462	.462	.481	.000
.812	.112	.057	1.50	1.22	.632	.432	.432	.587	.000
.912	.112	.057	1.50	1.37	.674	.408	.408	.695	.000
1.000	.112	.057	1.50	1.50	.709	.390	.390	.750	.041
1.100	.112	.057	.10	1.51	.747	.373	.373	.722	.041
1.200	.112	.057	.10	1.52	.783	.357	.357	.695	.041
1.300	.112	.057	.10	1.53	.818	.344	.344	.670	.041
1.400	.112	.057	.10	1.54	.852	.332	.332	.647	.041
1.500	.112	.057	.10	1.55	.885	.321	.321	.624	.041
1.600	.112	.057	.10	1.56	.917	.312	.312	.602	.041
1.700	.112	.057	.10	1.57	.947	.303	.303	.582	.041
1.800	.112	.057	.10	1.58	.977	.295	.295	.562	.041
1.900	.112	.057	.10	1.59	1.006	.288	.288	.542	.041
2.000	.112	.057	.10	1.60	1.035	.281	.281	.524	.041
2.100	.112	.057	1.00	1.70	1.063	.275	.275	.596	.041
2.200	.112	.057	1.00	1.80	1.090	.269	.269	.669	.041
2.300	.112	.057	1.00	1.90	1.116	.264	.264	.742	.041
2.400	.112	.057	1.00	2.00	1.143	.259	.259	.750	.107
2.500	.112	.057	1.00	2.10	1.168	.254	.254	.750	.182
2.600	.112	.057	1.00	2.20	1.193	.250	.250	.750	.257
2.700	.112	.057	1.00	2.30	1.218	.245	.245	.750	.332
2.800	.112	.057	1.00	2.40	1.242	.242	.242	.750	.408
2.900	.112	.057	1.00	2.50	1.266	.238	.238	.750	.484
3.000	.112	.057	1.00	2.60	1.290	.234	.234	.750	.560
3.100	.112	.057	1.00	2.70	1.313	.231	.231	.750	.637
3.200	.112	.057	1.00	2.80	1.336	.228	.228	.750	.714
3.300	.112	.057	1.00	2.90	1.359	.225	.225	.750	.791
3.400	.112	.057	1.00	3.00	1.381	.222	.222	.750	.869
3.500	.112	.057	1.00	3.10	1.403	.219	.219	.750	.947
3.600	.112	.057	1.00	3.20	1.425	.216	.216	.750	1.025
3.700	.112	.057	1.00	3.30	1.446	.214	.214	.750	1.104
3.800	.112	.057	1.00	3.40	1.468	.211	.211	.750	1.182
3.900	.112	.057	1.00	3.50	1.489	.209	.209	.750	1.261
4.000	.112	.057	1.00	3.60	1.509	.207	.207	.750	1.341
4.100	.112	.057	.00	3.60	1.530	.204	.204	.729	1.341
4.200	.112	.057	.00	3.60	1.550	.202	.202	.709	1.341
4.300	.112	.057	.00	3.60	1.570	.200	.200	.689	1.341
4.400	.112	.057	.00	3.60	1.590	.198	.198	.669	1.341
4.500	.112	.057	.00	3.60	1.610	.196	.196	.649	1.341
4.600	.112	.057	.00	3.60	1.630	.195	.195	.630	1.341
4.700	.112	.057	.00	3.60	1.649	.193	.193	.610	1.341
4.800	.112	.057	.00	3.60	1.668	.191	.191	.591	1.341

4.900	.112	.057	.00	3.60	1.687	.189	.189	.572	1.341
5.000	.112	.057	.00	3.60	1.706	.188	.188	.553	1.341
5.100	.112	.057	.00	3.60	1.725	.186	.186	.535	1.341
5.200	.112	.057	.00	3.60	1.743	.185	.185	.516	1.341
5.300	.112	.057	.00	3.60	1.762	.183	.183	.498	1.341
5.400	.112	.057	.00	3.60	1.780	.182	.182	.479	1.341
5.500	.112	.057	.00	3.60	1.798	.180	.180	.461	1.341
5.600	.112	.057	.00	3.60	1.816	.179	.179	.443	1.341
5.700	.112	.057	.00	3.60	1.834	.178	.178	.425	1.341
5.800	.112	.057	.00	3.60	1.852	.177	.177	.408	1.341
5.900	.112	.057	.00	3.60	1.869	.175	.175	.390	1.341
6.000	.112	.057	.00	3.60	1.887	.174	.174	.373	1.341
6.100	.112	.057	.00	3.60	1.904	.173	.173	.355	1.341
6.200	.112	.057	.00	3.60	1.921	.172	.172	.338	1.341
6.300	.112	.057	.00	3.60	1.938	.171	.171	.321	1.341
6.400	.112	.057	.00	3.60	1.955	.170	.170	.304	1.341
6.500	.112	.057	.00	3.60	1.972	.168	.168	.287	1.341
6.600	.112	.057	.00	3.60	1.989	.167	.167	.270	1.341
6.700	.112	.057	.00	3.60	2.006	.166	.166	.254	1.341
6.800	.112	.057	.00	3.60	2.022	.165	.165	.237	1.341
6.900	.112	.057	.00	3.60	2.039	.164	.164	.221	1.341
7.000	.112	.057	.00	3.60	2.055	.163	.163	.204	1.341
7.100	.112	.057	.00	3.60	2.072	.162	.162	.188	1.341
7.200	.112	.057	.00	3.60	2.088	.162	.162	.172	1.341
7.300	.112	.057	.00	3.60	2.104	.161	.161	.156	1.341
7.400	.112	.057	.00	3.60	2.120	.160	.160	.140	1.341
7.500	.112	.057	.00	3.60	2.136	.159	.159	.124	1.341
7.600	.112	.057	.00	3.60	2.152	.158	.158	.108	1.341
7.700	.112	.057	.00	3.60	2.167	.157	.157	.092	1.341
7.800	.112	.057	.00	3.60	2.183	.156	.156	.076	1.341
7.900	.112	.057	.00	3.60	2.199	.156	.156	.061	1.341
8.000	.112	.057	.00	3.60	2.214	.155	.155	.045	1.341
8.100	.112	.057	.00	3.60	2.230	.154	.154	.030	1.341
8.200	.112	.057	.00	3.60	2.245	.153	.153	.014	1.341
8.294	.112	.057	.00	3.60	2.259	.153	.153	.000	1.341

```
-----------------------------------------------------------------------------
  Note: npp in tp or tpp means no ponding in period

    Event Statistics
       Cum. Infiltration (cm) =     2.259
       Runoff (cm)            =     1.341
       ----------------------  ----------
       Cum. Inf+ Runoff (cm)  =     3.600
       Total Rainfall (cm)    =     3.600

       Peak Runoff Rate (cm/h)   =     4.836   at time=     2.900 h
       Peak Rainfall Int. (cm/h) =     1.500   at time=      .000 h

-----------------------------------------------------------------------------
```

End of example.

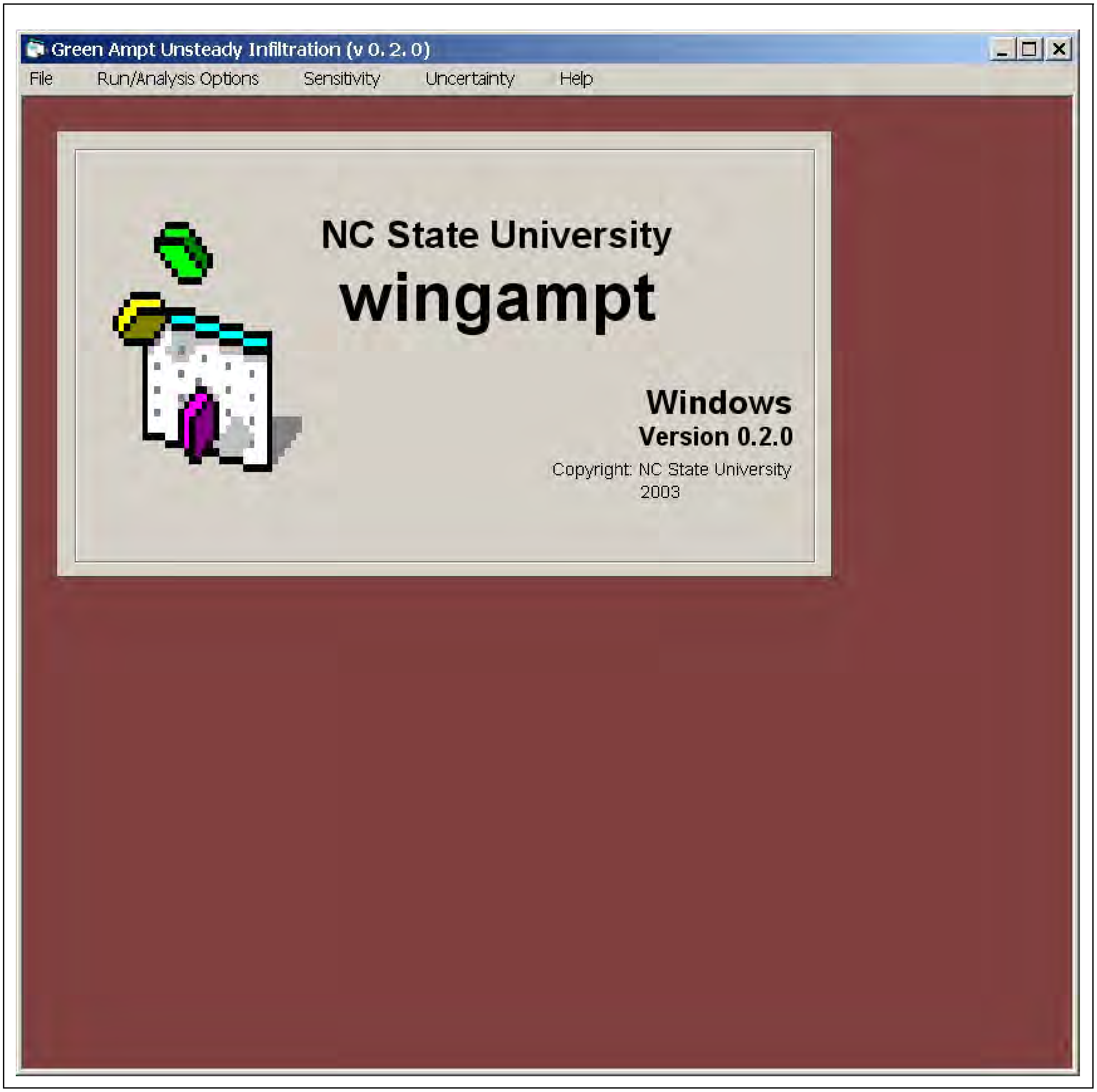
3.0 Documentation for WinGampt

The program consists of a visual front (graphical user interface Figure 2) to enable the user to easily develop input datasets to illustrate the infiltration process. In addition, options are available to investigate and illustrate the concepts of sensitivity of modeling results to changes in input parameters and the effect of uncertainty on modeing results.

The inputs and outputs are organized into project files with soils inputs, rainfall inputs and program outputs. The sample project file is shown below:

```
soils=soils.sin
rainf=rawrain.rin
outpt=sample.out
```

The user selects a project file using the File menu.


Green Ampt Unsteady Infiltration (v 0. 2. 0)
File
Run/Analysis Options
Sensitivity
Uncertainty
Help
NC State University
wingampt
Windows
Version 0.2.0
Copyright: NC State University
2003

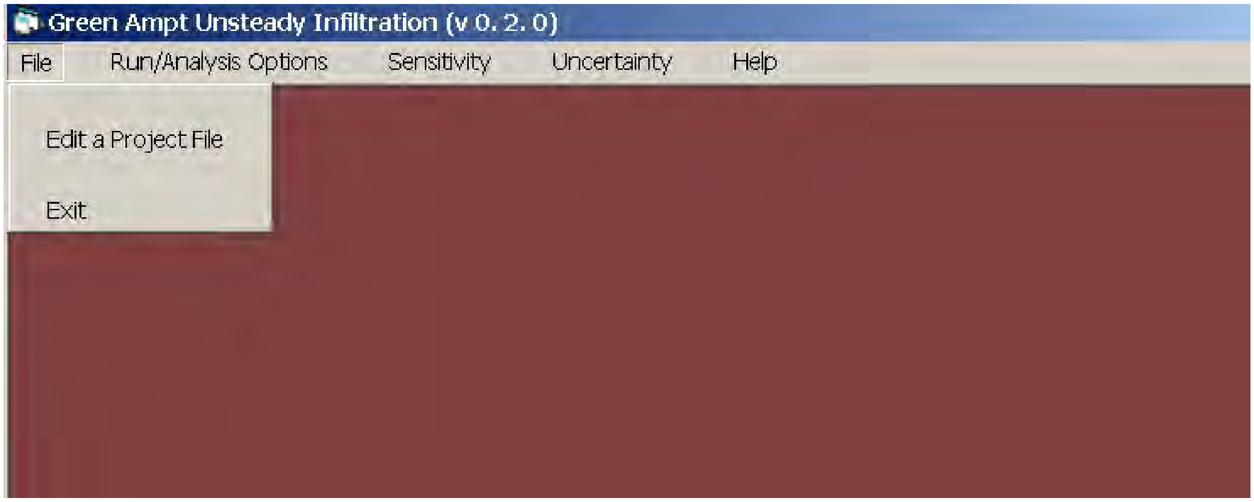
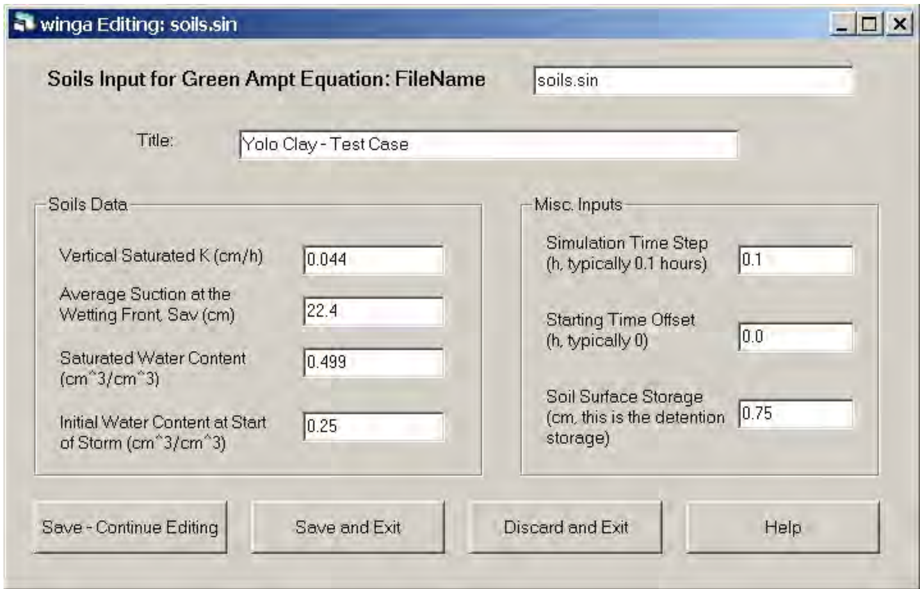


Figure 2. Wingampt startup screen and File menu options

The project file window shows the name of the project and the soils and rainfall input files.

Figure 3. The project window.

Selecting the Edit button, opens the Soils or Rainfall input files.



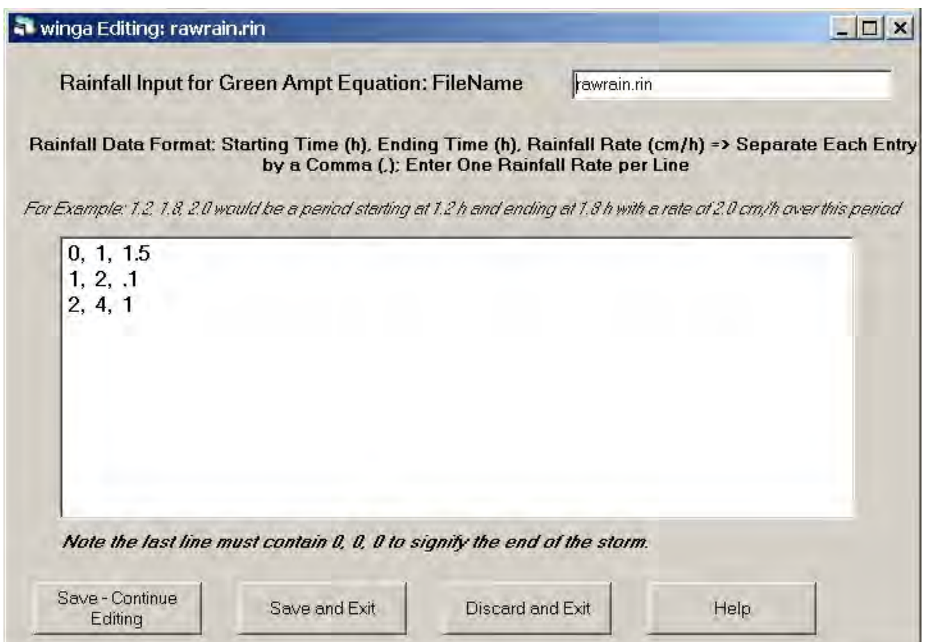
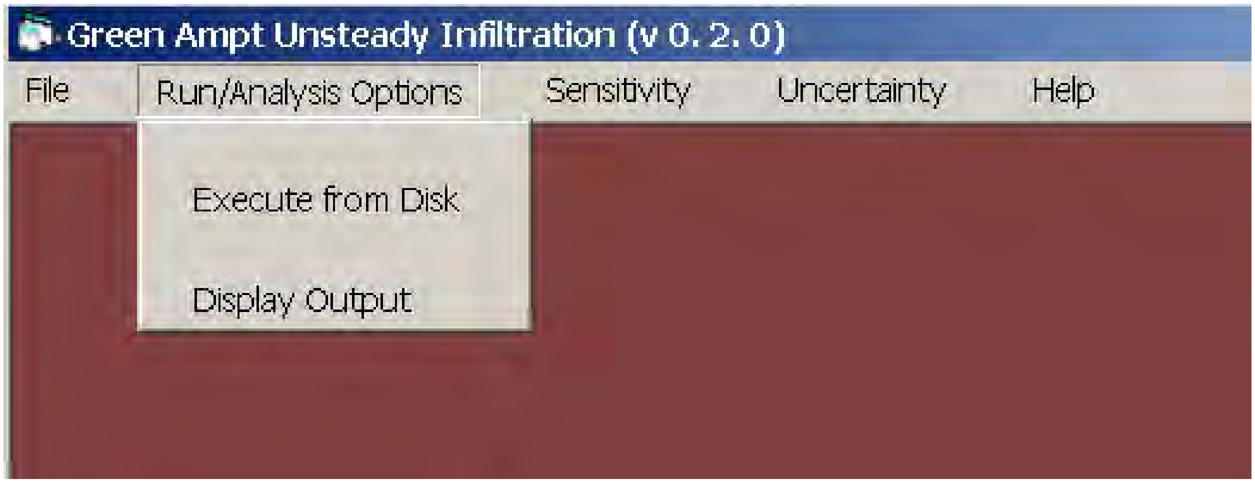


Figure 4. Soils and Rainfall Edit windows.

The user has the option of executing a single project or multiple projects.



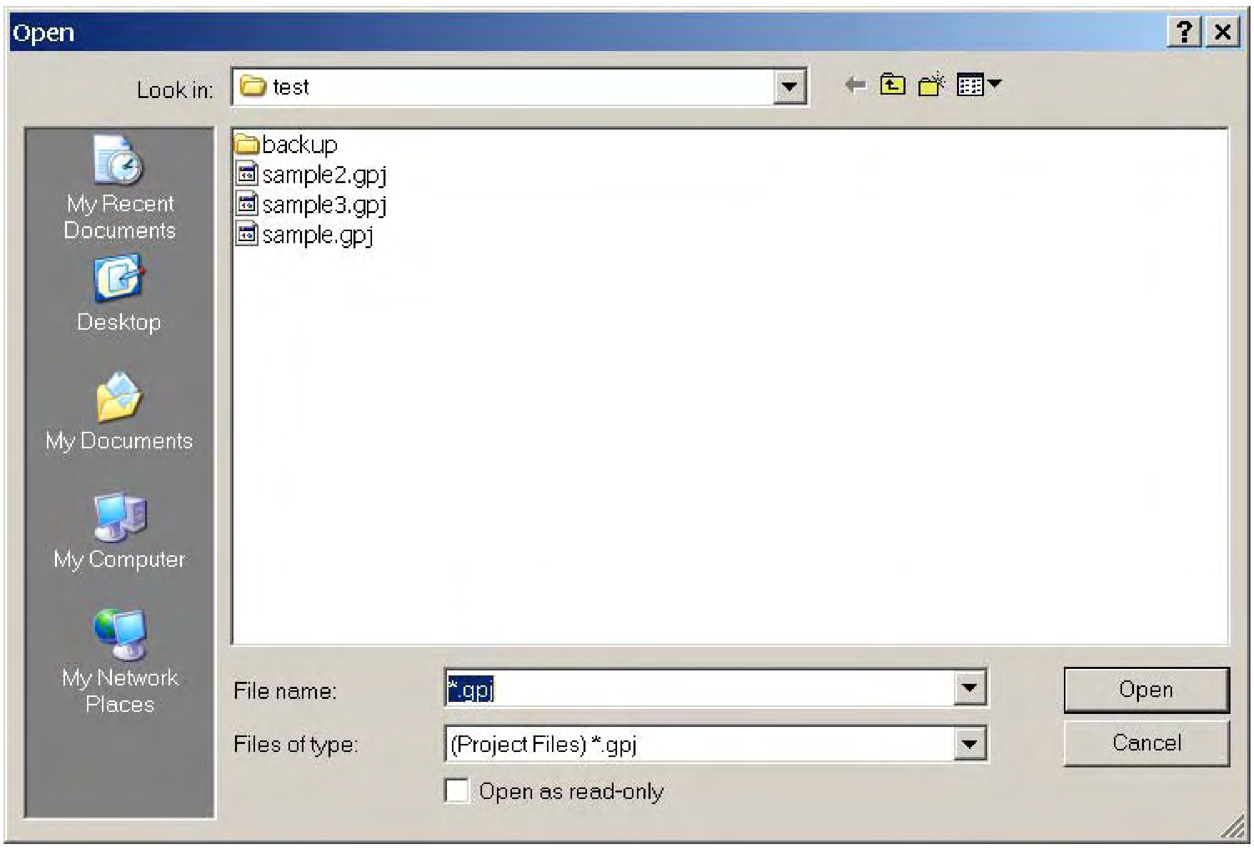


Figure 5. Analysis and Run options.

Selecting the analysis menu option displays the selected output file with an option to graphically see the water balance during the storm.

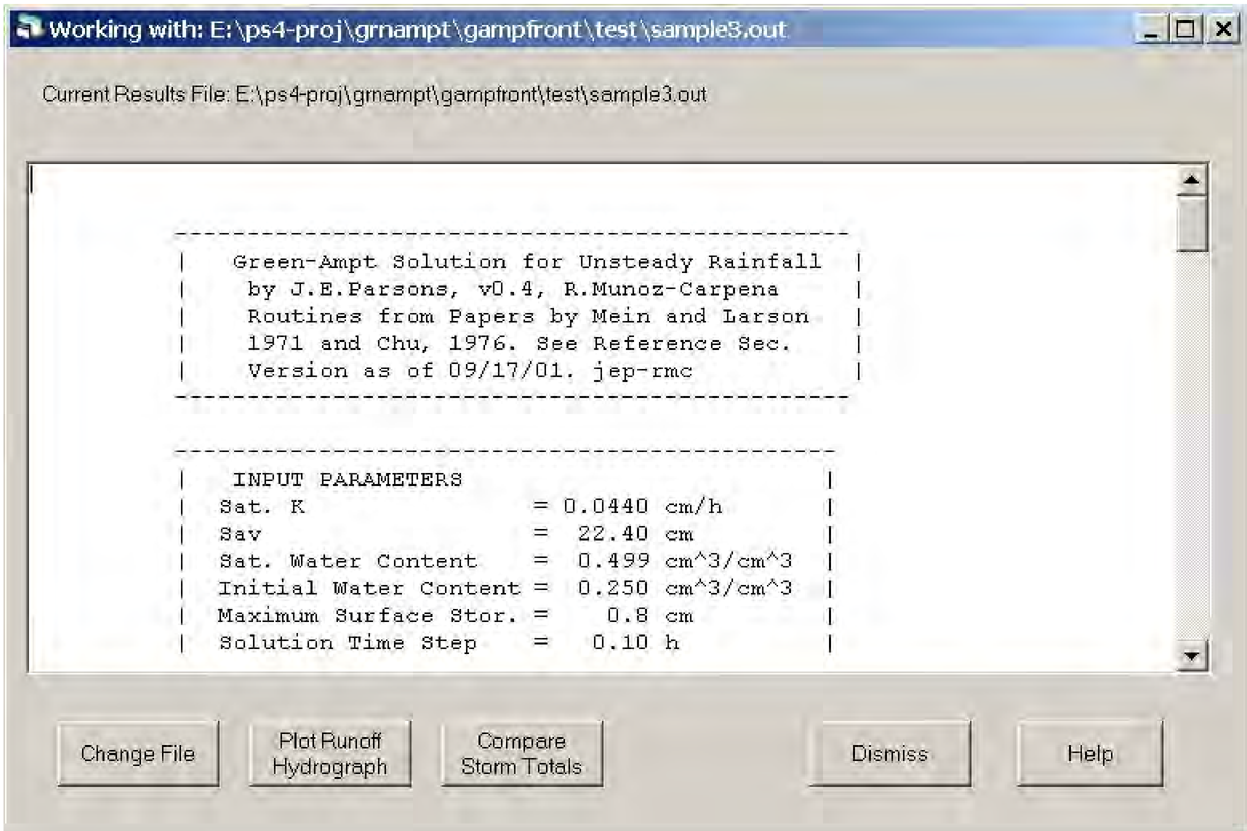


Figure 6. Output window.

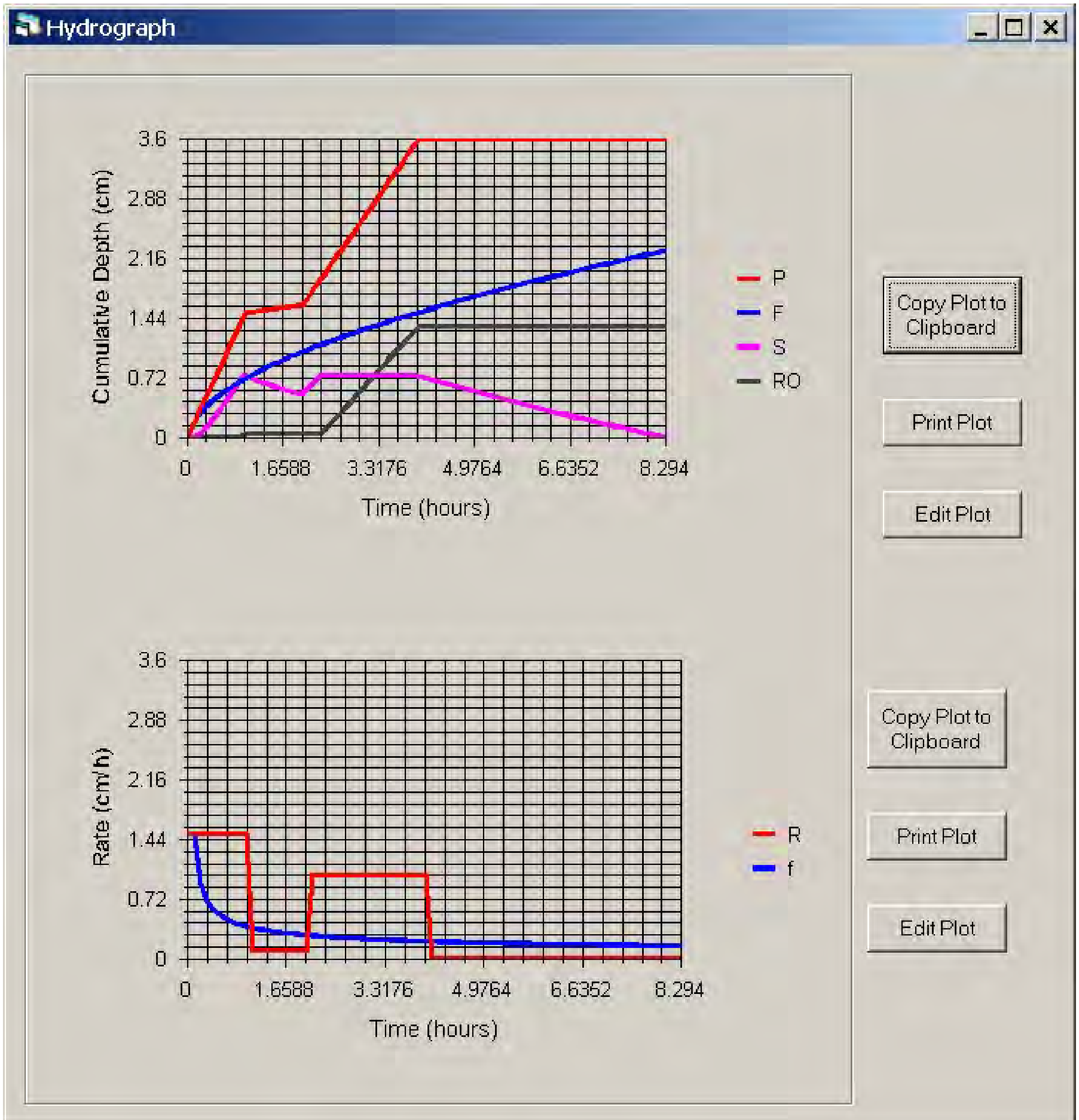


Figure 7. Plot windows showing the water balance during the storm along the infiltration and rainfall rates.

3.0 Advanced Options – Sensitivity Analysis

The user can select a base input dataset and investigate the sensitivity of the inputs parameters on the resulting storm runoff outputs (Figure 8).

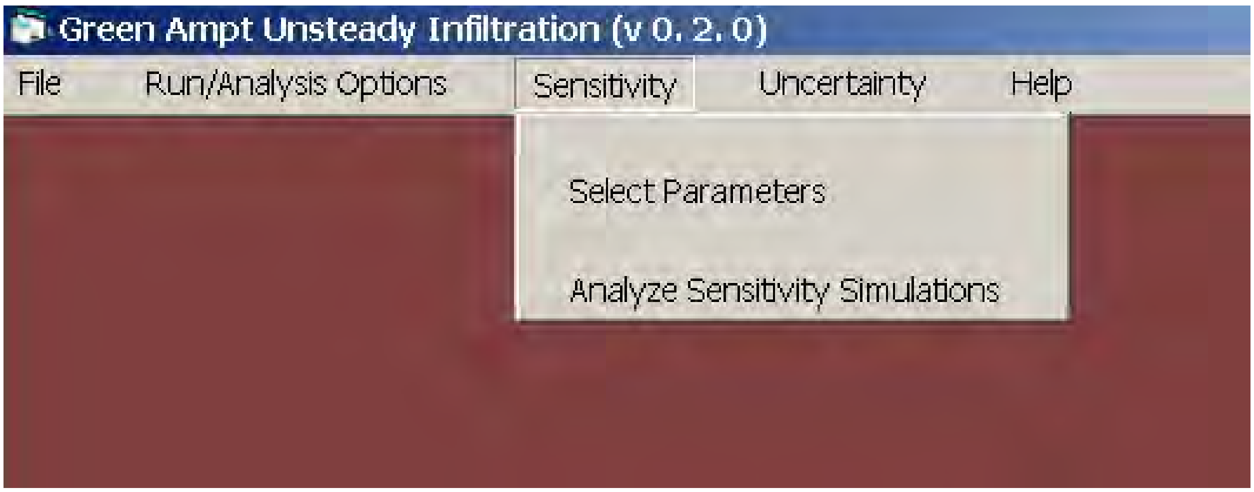


Figure 8. Sensitivity Menu.

After opening a project (Figure 9 shows the initial screen for sample.gpj), sensitivity analysis can be done for saturated vertical conductivity (SatK), the average suction at the wetting front (Sav), the saturated water content (SWC), and the initial water contents (IWC). After selecting the parameters and their ranges, an independent set of simulations for each parameter is done for each parameter with the resulting outputs stored for later analysis. A comma separated file is created with the values for SatK, Sav, SWC, IWC along with the outputs for each run which includes the cumulative infiltration (F), runoff (RO), F+RO, total precipitation (P), Peak runoff rate and the time of occurrence of the peak runoff rate. This file can be easily read into other analysis packages such as spreadsheets.

The multi-dimensional sensitivity option is not available in this version. It will be added to a later release. This option will allow varying all parameters at once to find any interrelationships between the inputs and the outputs.

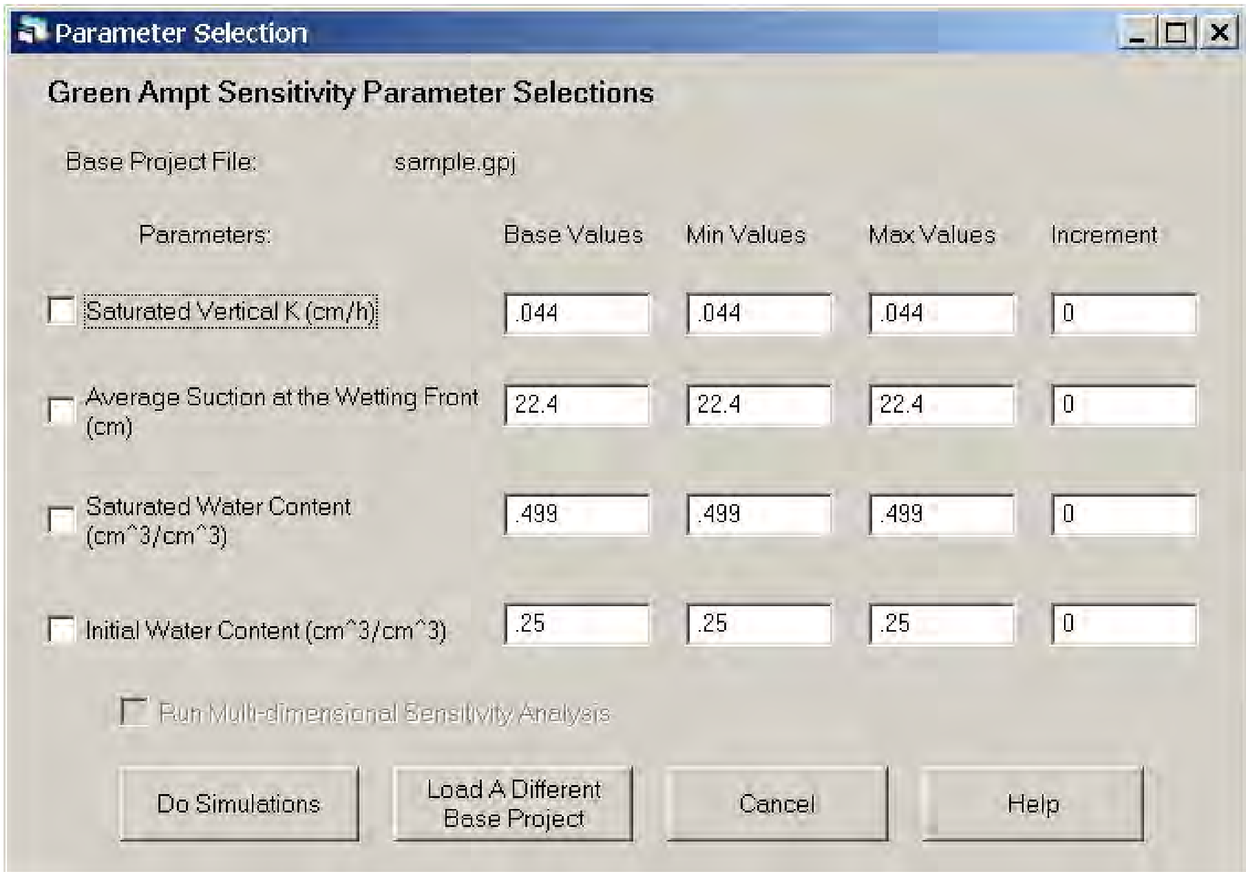


Figure 9. Sensitivity inputs window.

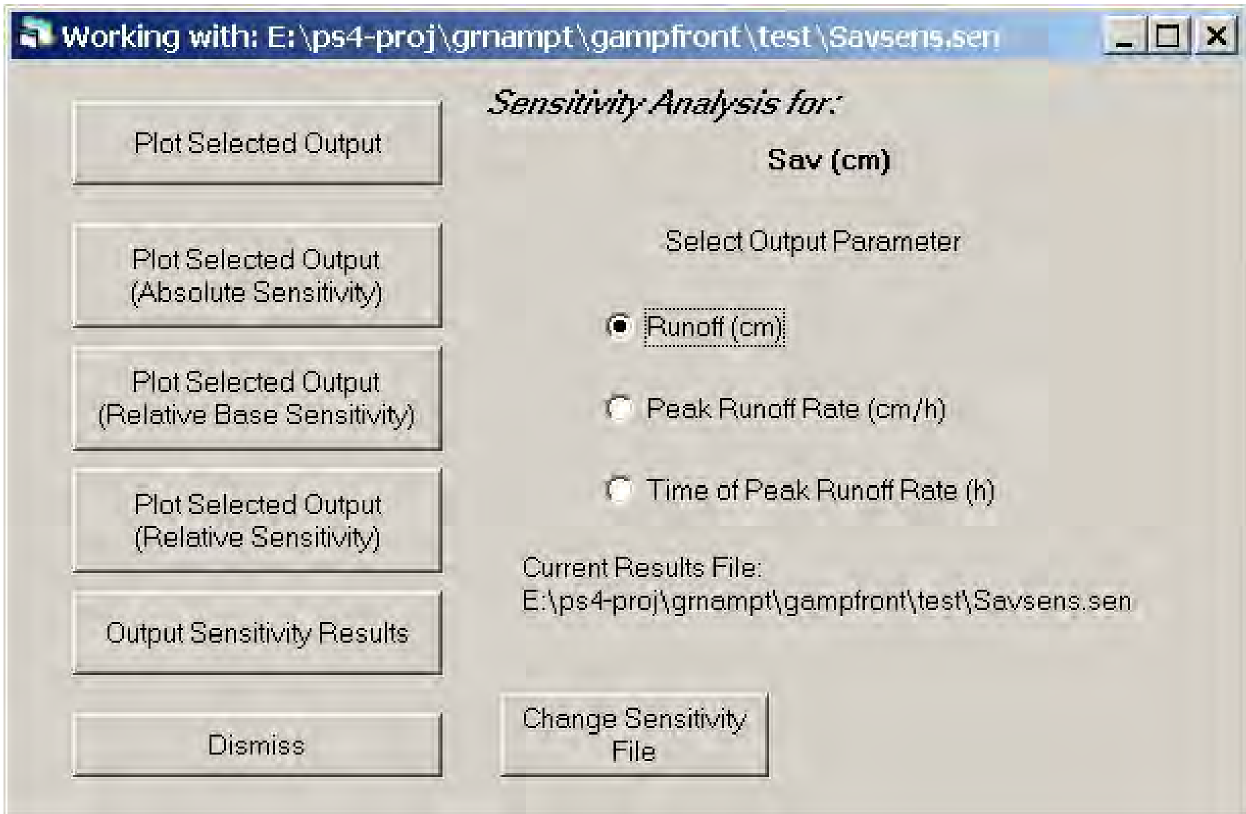


Figure 10.Analysis options for Sensitivity Simulations.

Some analysis are available within the program (Figure 10). The sensitivity analysis screen enables the user to examine the relationship between Runoff, Peak Runoff Rate and Time of Peak Runoff Rate and one of the inputs parameters (saturated hydraulic conductivity (SatK), average suction at the wetting front (Sav), saturated water content (SWC), or the initial water content (IWC). Analysis options include Raw sensitivity, Absolute Sensitivity, Relative Base sensitivity, and Relative sensitivity.

If P_i and O_i are the values of the input and output parameters for each simulation where i ranges from 1 to Nsims (number of simulations), then

$$AS_i = \frac{O_{i+1} - O_i}{P_{i+1} - P_i}; i = 1$$

Absolute Sensitivity at each point is $$AS_i = \frac{O_{i+1} - O_{i-1}}{P_{i+1} - P_{i-1}}; i = 2, Nsim - 1$$

$$AS_i = \frac{O_i - O_{i-1}}{P_i - P_{i-1}}; i = Nsim$$

$$RS_i = \frac{O_{i+1} - O_i}{P_{i+1} - P_i}\left(\frac{P_i}{O_i}\right); i = 1$$

Relative Sensitivity at each point is $$RS_i = \frac{O_{i+1} - O_{i-1}}{P_{i+1} - P_{i-1}}\left(\frac{P_i}{O_i}\right); i = 2, Nsim - 1$$

$$RS_i = \frac{O_i - O_{i-1}}{P_i - P_{i-1}}\left(\frac{P_i}{O_i}\right); i = Nsim$$

Relative Base Sensitivity at each point is: $$RBS_i = \frac{O_i - O_{base}}{P_i - P_{base}}\left(\frac{P_{base}}{O_{base}}\right); i = 1, Nsim$$

P_{base} and O_{base} are the input and output values derived from the selected base project.

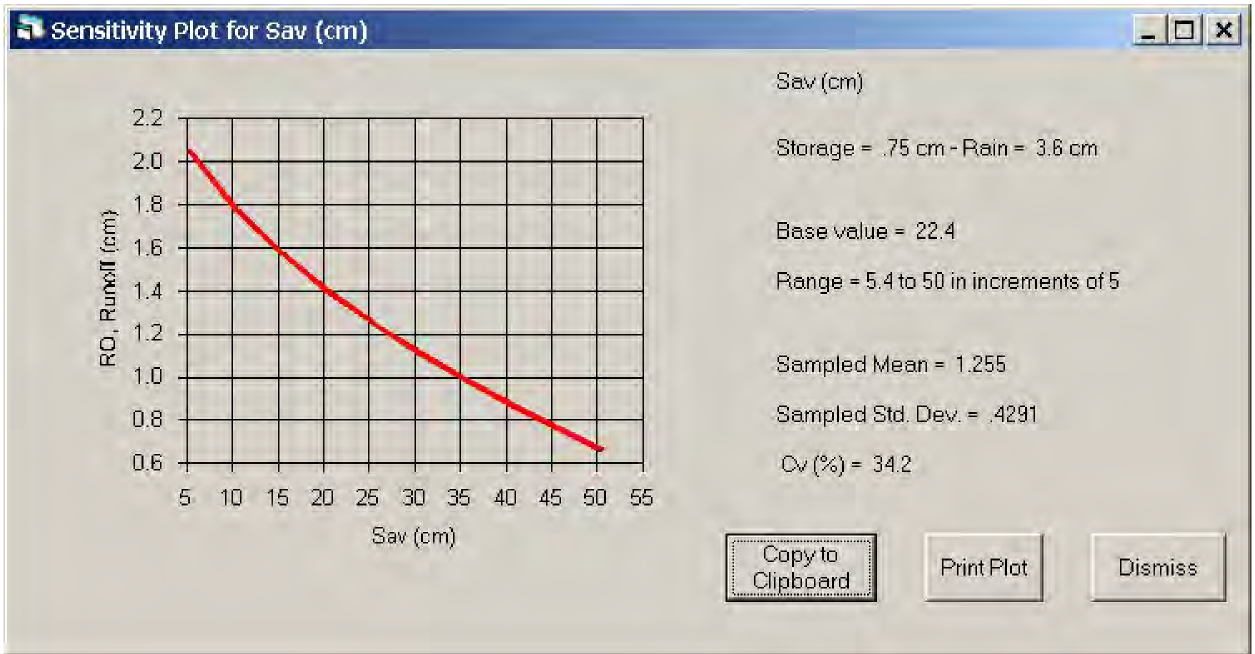


Figure 11. Example of the sensitivity plots and analyses for Runoff versus Sav.

Figure 11 shows a graph of the relationship between Runoff and Sav. In addition, the mean, standard deviation and coefficient of variation are computed for the output variable, runoff.

The user can also select to have the sensitivity results for a set of simulations output to a file for further analysis or incorporation in a spreadsheet for more in-depth comparisons and analyses.

Figure 12 shows a portion of the contents of the file. The outputs include a table of the computed sensitivity parameters along with the statistics and regression analyses of some of the possible functional relationships between the Sensitivity outputs and the input parameter. These functional relationships include linear, exponential and power function fits. Note that these are included but the user should verify these in a spreadsheet or other analysis package since these are “beta” versions and have not been thoroughly checked.

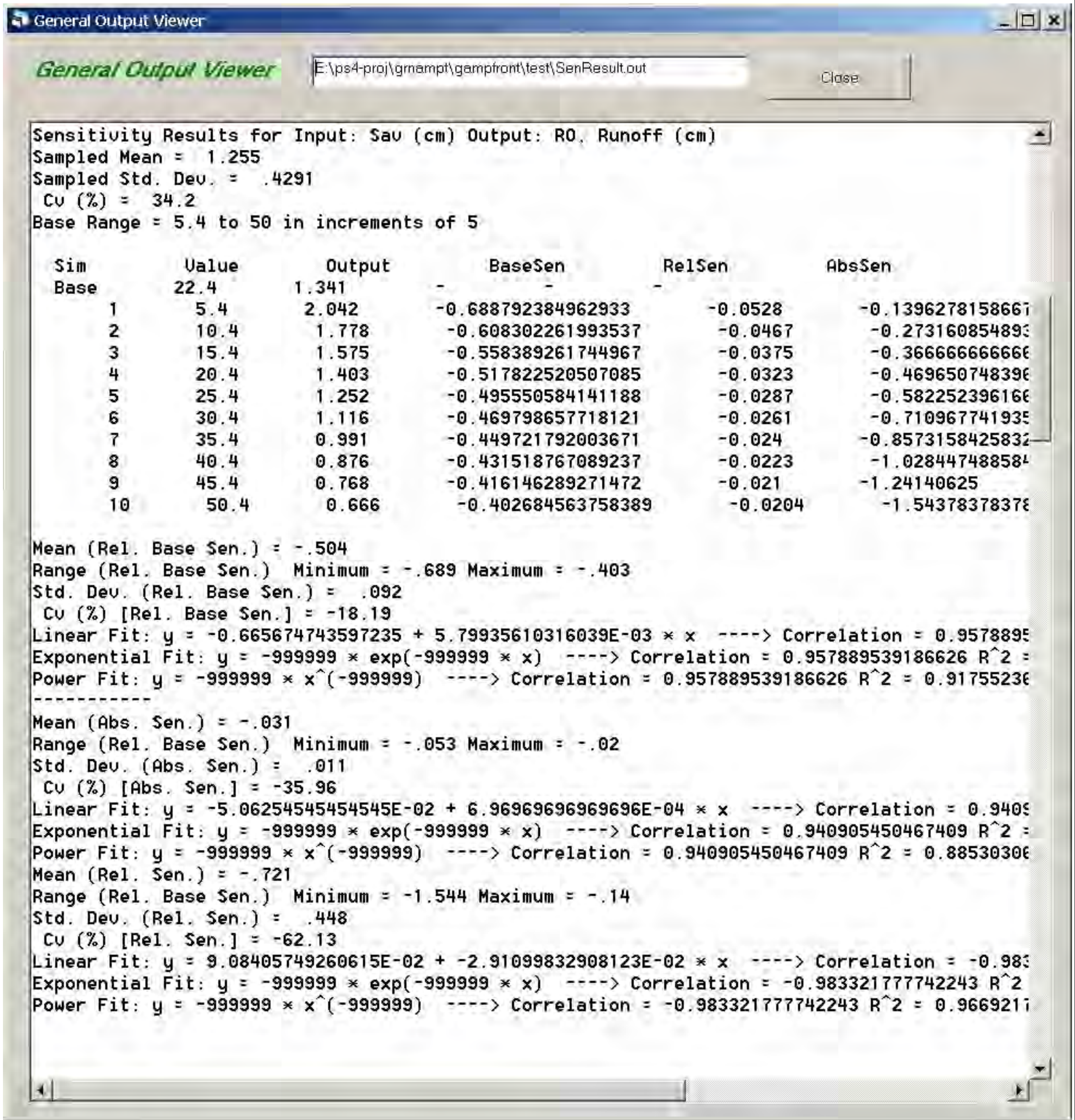


Figure 12. Output window showing the Output file for further analysis of sensitivity results..

The multidimensional sensitivity analysis option produces an output file for later analysis. There are currently no analysis options available within this program. Multidimensional analysis allows the user to simulate every combination of the possible values of the selected input parameters.

The resulting trends and variations in the outputs can be related to interactions among the input parameters (not available in the current release).

3.0 Advanced Options – Uncertainty Analysis

The Uncertainty analysis section enables the user to investigate the effects of uncertainty in the input parameters on the outputs on a storm by storm basis. This section allows the user to set up the necessary probability distributions for the input parameters to do a Monte Carlo simulation experiment with the Green Ampt model. An outline of this procedure is:

1. select the most sensitive input parameters,
2. develop probability distribution functions for each input parameter,
3. randomly generate input parameter datasets based on the probability distributions
4. perform the model simulation with the randomly generated input dataset
5. repeat steps 3 and 4 for a large number of trials
6. generate probability distribution functions for the model outputs of interest
7. use the output probability distribution functions to evaluate uncertainty in the model by placing confidence levels on the outputs

The Wingampt front end automates steps 1-4 (Figure 13). A limited amount of analyses of the results is included to enable the user to visually evaluate the resulting output distributions. Steps 6 and 7 can and should be done more completely with other packages. Examples illustrating the theory are given in Haan et al. (1995) and Haan et al. (1998).

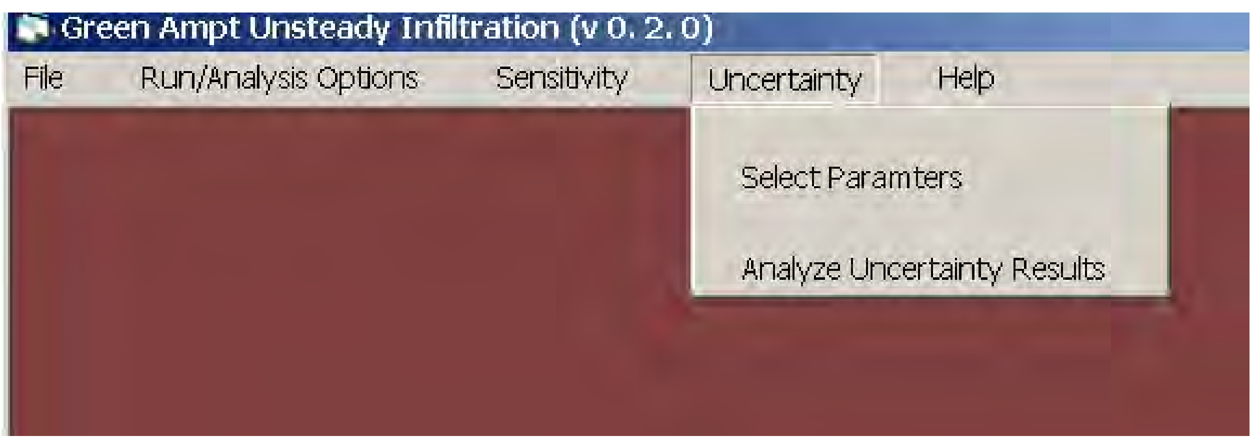


Figure 13. Uncertainty Menu.

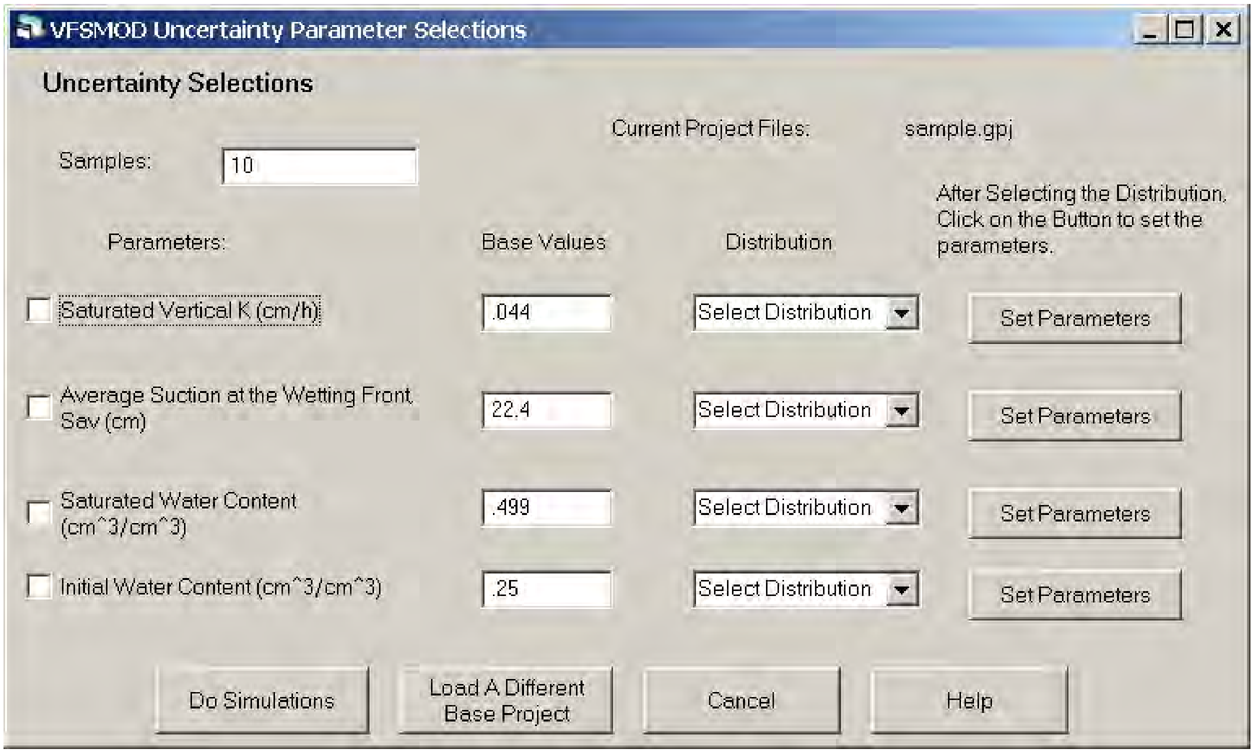


Figure 14. Input options for Uncertainty analysis simulations..

All of the inputs are available for the uncertainty analyses (Figure 14). The base values for each input are the inputs from the soils file in the project selected as a base for the analyses. The user has a choice of distributions shown in Table 1.

Table 1

Distribution	Parameters	Notes/Comments
Normal	Mean Standard Deviation	These can be derived from the literature or from sample data
Lognormal	Mean Standard Deviation	Enter the mean and standard deviation of the data transformed, ie from the log(X) data
Triangular	Minimum	This distribution can be used to emulate a normal. No

	Maximum Mean	samples are below the minimum or above the maximum
Uniform	Minimum Maximum	This distribution is useful for parameters that are equally likely to take on any value within a range.

An output file is created the uncertainty simulations in the comma separated value format. This file contains values for SatK, Sav, SWC, IWC along with the outputs for each run which include the cumulative infiltration (F), runoff (RO), F+RO, total precipitation (P), Peak runoff rate and the time of occurrence of the peak runoff rate. This file can be easily read into other analysis packages such as spreadsheets.

The analysis options are available for any of the simulation sets (Figure 15). The user can examine the frequency and cumulative probability distributions for either the inputs parameters or for the output parameters. Example of the analysis options are given in Figure 16, Figure 17, and Figure 18.

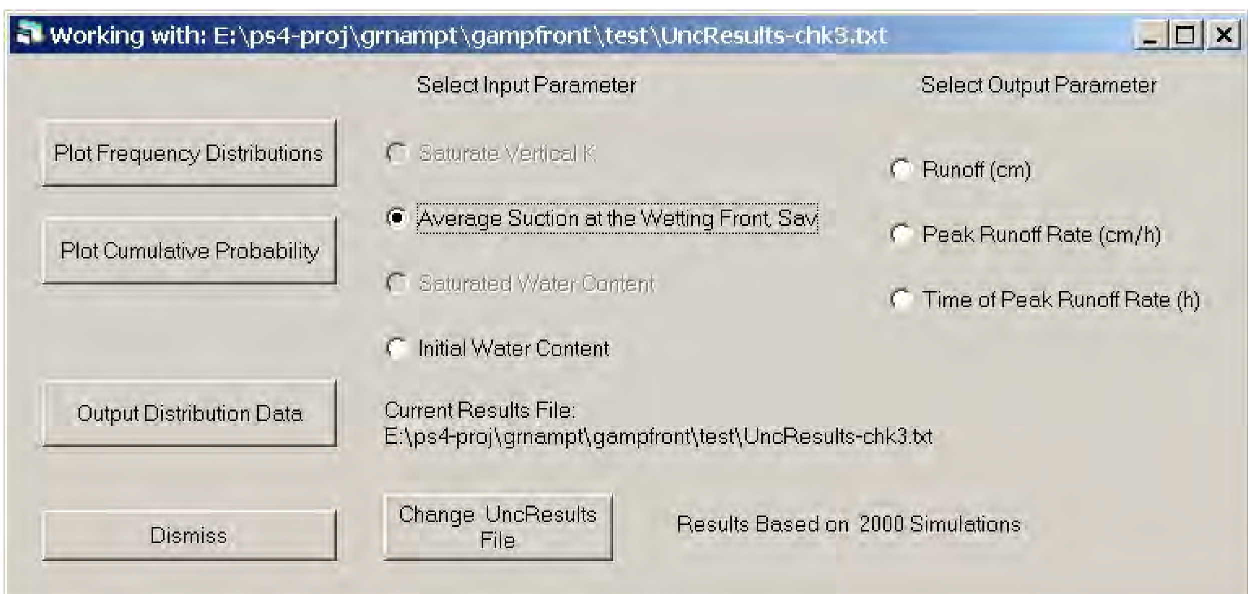


Figure 15. Output analysis option for uncertainty simulations.

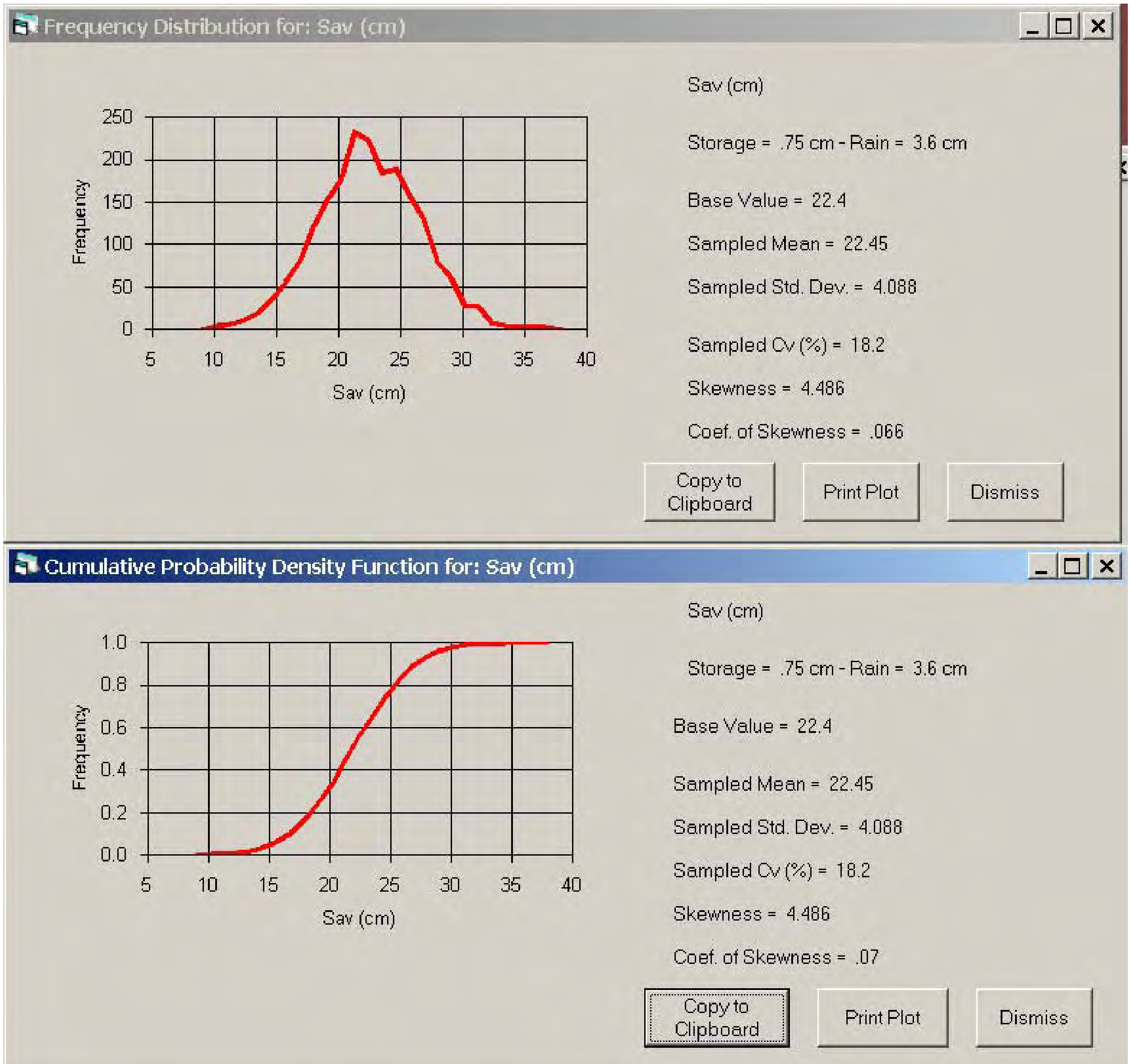


Figure 16. Example analysis window for the probability distributions associated with an inputs, Sav..

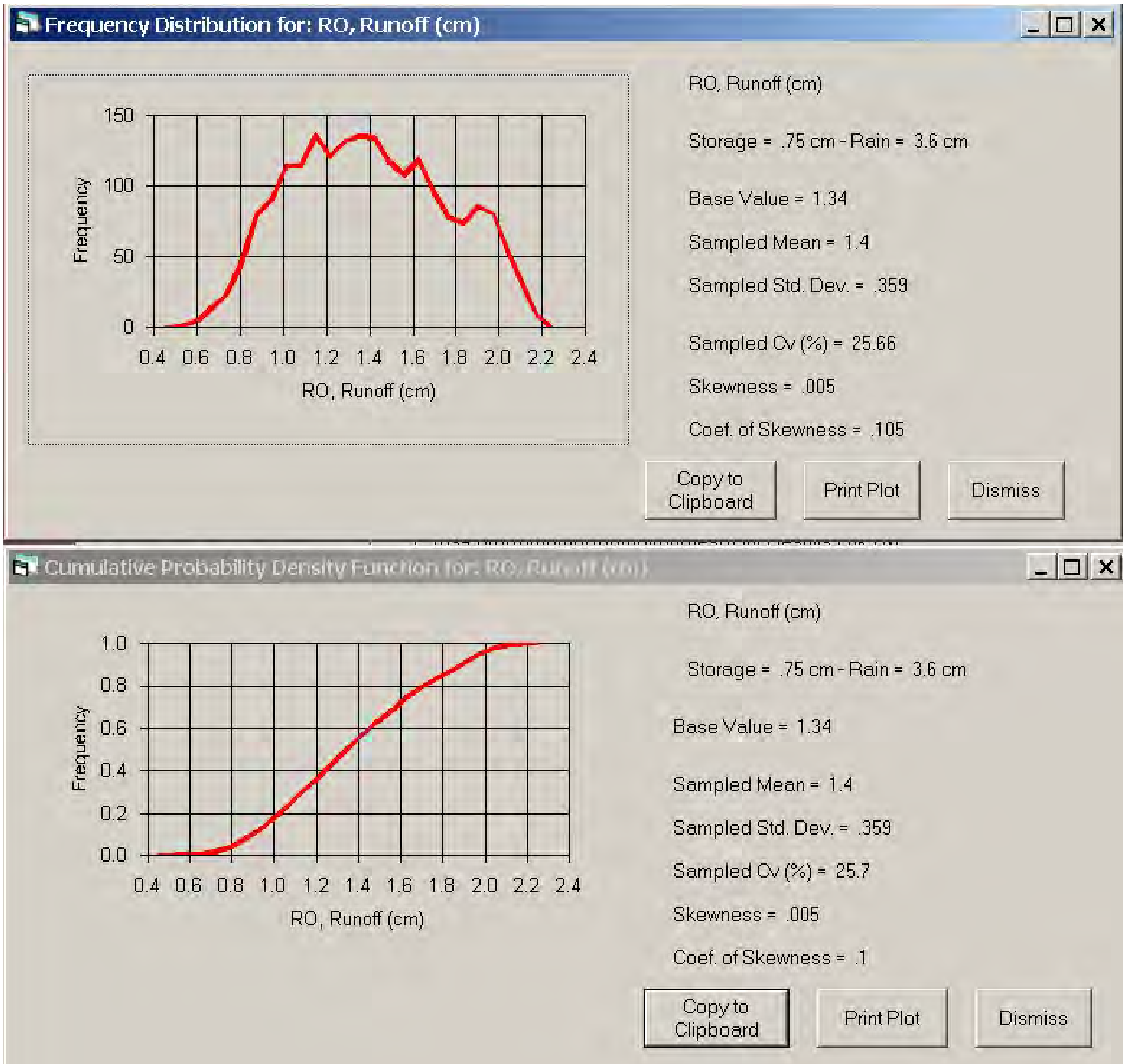


Figure 17. Example analysis window for the probability distributions associated with an output, runoff..

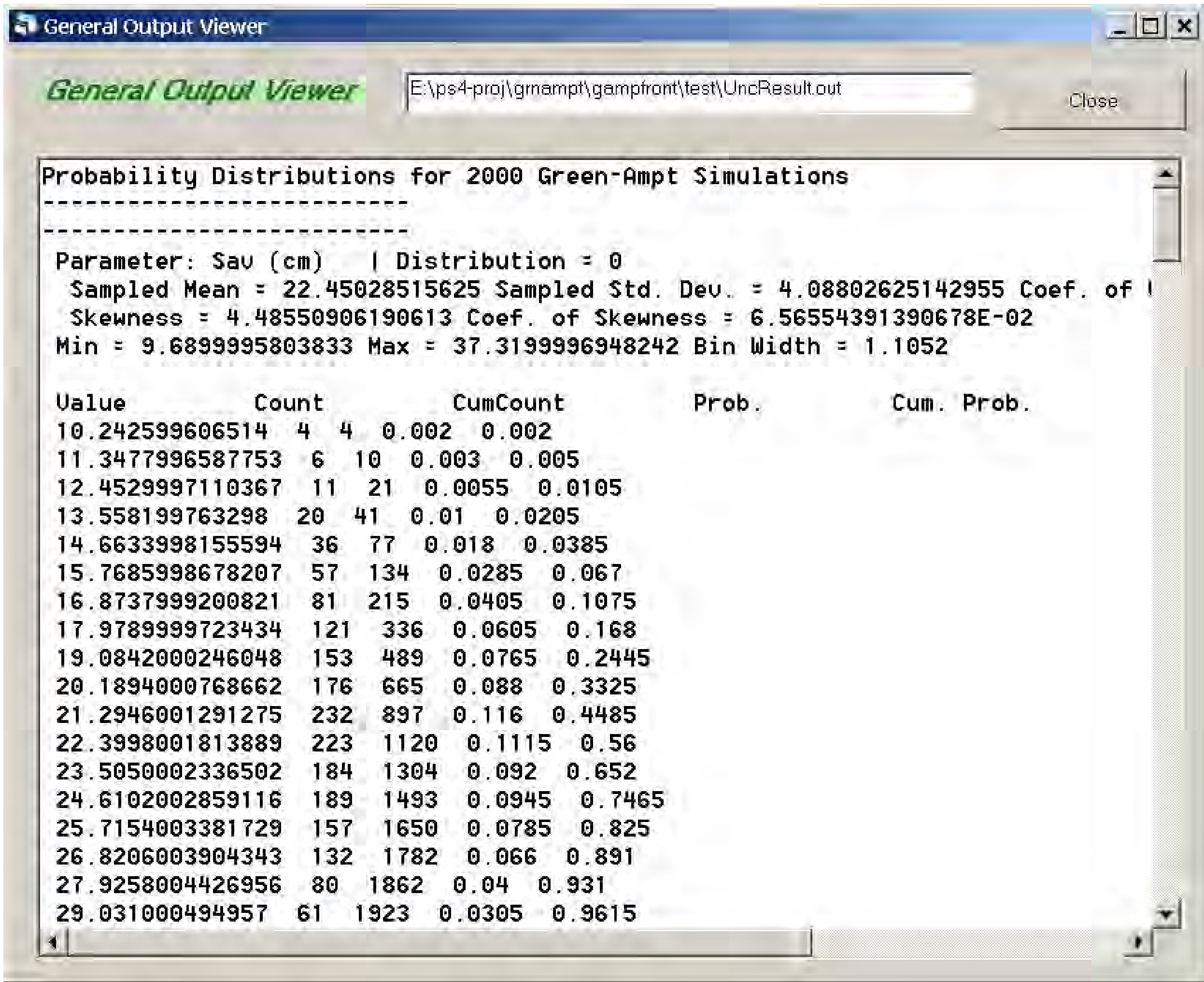


Figure 18. Output window showing the content of the output file for further analysis of the uncertainty data using external programs.

3.0 REFERENCES

Chu, S. T. 1978. Infiltration during unsteady rain. Water Resources Research. 14(3):461-466.

Green, W. H. and G. Ampt. 1911. Studies in soil physics, part I - the flow of air and water through soils. J. Agricultural Science 4:1-24.

Haan, C. T., B. Allred, D. E. Storm, G. J. Sabbagh, and S. Prabhu. 1995. Statistical Procedure for Evaluating Hydrologic/Water Quality Models. TRANS ASAE 38(3):725-733.

Haan, C. T., D. E. Storm, T. Al-Issa, S. Prabhu, G. J. Sabbagh, and D. R. Edwards. 1998. Effect of Parameter Distributions on Uncertainty Analysis of Hydrologic Models. TRANS ASAE 41(1):65-70.

Mein, R. G. and C. L. Larson. 1973. Modeling infiltration during a steady rain. Water Resources Research 9(2):384-394.

Skagg, R. W. and R. Khaleel. 1982. Chapter 4. Infiltration. In: Hydrologic Modeling of Small Watersheds, ed. C. T. Haan, H. P. Johnson, and D. L. Brakensiek. ASAE Monograph Number 5. American Society of Agricultural Engineers, 3950 Niles Road, St. Joseph, MI 49085. pp. 119-166.