The text in this file is excerpted from the ANSWERS User's Manual, second edition, 1991, which is written by

David B. Beasley, Ph.D., P.E.
Professor and Head
Biological and Agricultural Engineering
North Carolina State University
Raleigh, NC 27695-7625
Phone: (919) 515-2694
FAX: (919) 515-6772
internet: beasley@bae.ncsu.edu

and

Larry F. Huggins, Ph.D., P.E.
Professor and Head
Agricultural Engineering Department
Purdue University
West Lafayette, IN 47907-1146
Phone: (317) 494-1162
FAX: (317) 496-1115

The excerpts of the manual included here were scanned from a copy of the document and converted to text with an optical character recognition program. Thus, any errors could be from this process or from my oversight during editing.

Although including the entire manual could be helpful to the user of the ANSWERS-GRASS integration, I (Chris Rewerts) had to compromise between all-inclusiveness and time, so I selected the sections which I thought were of the greatest need. They describe how to derive the soil and landuse catagory parameter inputs needed to run ANSWERS, and this information was not included in any other place in the information within or included with the r.answers program.

The sections from the ANSWERS User's Manual included here are:

APPENDIX A - SOIL PARAMETERS

Section A.1

The parameters described in this section are concerned with the physical description of the soil condition. The parameters do have some seasonal variation: since the bulk density of a soil does vary somewhat throughout the year. The total porosity (TP) is a measure of the bulk density. The field capacity (FP) describes the upper limit of available water in the soil. It also quantifies that portion of the pore volume which can contain only gravitational water (above the moisture holding capacity of the soil). The control zone depth (DF) identifies the volume of soil (depth) that actually influences the rate of infiltration at the surface. The antecedent soil moisture (ASM) quantifies the starting point for the soil moisture-based infiltration equation. Methods for determining each of these important parameters will be presented in this section.

Total Porosity (TP).The volume of pore space within the soil is directly related to the bulk density (weight per unit volume) of the soil. The total porosity (percent pore space) of a soil is defined as:

$$TP = 100 - (BD/PD) * 100$$

where:

TP = total porosity, percent,
BD = bulk density,
PD = particle density (assumed to be 2.65).

In some cases, comprehensive soil surveys will contain information on the bulk density of the mapped soil types. However, most soil surveys, even the newer ones, do not contain this kind of data. One bit of information that is available in all soil surveys is the textural class of the individual soil types. Without specific information on the bulk density of a particular soil, the modeler can still make a reasonably good estimate of the bulk density, and thus the total porosity, by utilizing the textural class definition. Table A-1 lists bulk densities and other soil physical properties for several different soil textural classes. For those classes not listed, an interpolation can be performed. Very sandy soils or organic soils have much larger ranges of values.

Field capacity (FP). As the moisture content of the soil is increased, a point is reached when water begins to drain due to gravitational forces. Another way of describing this phenomenon is to say that the moisture holding tension within the soil becomes less than 1/3 atmosphere. The point at which this gravitational drainage begins is called field capacity (FP) and is expressed as a percentage of saturation. Saturation occurs when the total pore space within the soil is filled with water. Thus, a soil with a total porosity of 50 percent and a field capacity of 70 percent contains 35 percent water (by volume) at field capacity.

Although some soil surveys contain information about the actual field capacity of the individual soil types, most soil surveys only state what the available water capacity of the soil is. Using the information in Table A-1 and the available water capacity of the individual soils (A horizon), the modeler can easily estimate the field capacity (percent saturation) when that information is not available. By definition, the available water capacity of a soil is that water held within the pores between field capacity (tension of 1/3 atmosphere) and the wilting point (tension of 15 atmospheres). In addition, the assumption is made that approximately one half of the water in the soil is unavailable. Thus, if the available water is listed as .15 inches/inch (15 percent by volume), the field capacity of the soil is twice that amount or .30 inches/inch (30 percent by volume). Further, if the total porosity has been listed as 50 percent, that means that the field capacity of the soil is 30 percent divided by 50 percent or 60 percent of saturation.

Table A-1. Some Representative Physical Properties of Soils.

Soil Texture	Bulk Density* (g/cc)	Total Porosity* (% volume)	Field Capacity* (% saturation)	Wilting Point* (%saturation)
Sandy	1.65 (1.55-1.80)	38 (32-42)	39 (31-47)	17 (10-24)
Sandy loam	1.50 (1.40-1.60)	43 (40-47)	49 (38-57)	21 (15-26)
Loam	1.40	47	66	30

	(1.35-1.50)	(43-49)	(59-74)	(26-34)
Clay loam	1.35 (1.30-1.40)	49 (47-51)	74 (66-82)	36 (32-40)
Silty clay	1.30 (1.25-1.35)	51 (49-53)	79 (72-86)	38 (34-42)
Clay	1.25 (1.20-1.30)	53 (51-55)	83 (76-89)	40 (37-43)

*Numbers in parentheses indicate normal range.
Adapted from: (Israelsen and Hansen, 1962).

Infiltration Central Zone Depth (DF)

Of all of the parameters used in ANSWERS, this one is the least well defined and most arbitrary. Essentially, it describes the volume of soil (depth) that influences the infiltration rate at the surface of the soil. Experimental data and simulation experience have lead to the conclusion that the control zone depth (DF) varies with time. However, not enough information exists to describe a seasonal influence exactly. In general, the control zone depth is equal to or less than the depth of the A horizon. For most of the soils that have been modeled in the Midwest USA, the control depth (DF) has been assumed to be equal to .25 to .75 of the depth of the A horizon. In general, a starting value of one half of the A horizon has been used.

Antecedent Soil Moisture (ASM)

The infiltration equation in the ANSWERS model is based on the moisture content of the soil. Since the infiltration rate will be much greater when the soil is "dry" than when it is "wet", it is very crucial that the correct antecedent moisture content be used when simulating actual situations. For hypothetical or "wet weather" simulations, moisture contents at or above field capacity will generally be used.

This section details a simple moisture balance approach for determining the antecedent moisture content in each soil. The form of the moisture balance equation is:

$$ASM = ASML + RAIN - ET - RO - PERC$$

where:

ASM = antecedent soil moisture,
ASML = last known (initial) soil moisture,
RAIN = daily rainfall,
ET   = evapotranspiration,
RO   = runoff,
PERC = percolation.

In this equation, percolation refers to drainage of gravitational water (water in excess of field capacity). In order to simplify the moisture balance calculations, several assumptions are made:

1. The depth of the soil layer that influences the moisture content is equal to the control zone depth (DF),
2. The evapotranspiration rate is one half of normal on days that have rainfall in excess of 0.2 inches,
3. The soil drains down to field capacity within 1 day at the steady state infiltration rate (FC),
4. When the soil moisture content reaches the wilting point, no additional moisture is lost due to ET,

5. On days when rainfall is less than 0.3 inches, RO (runoff) is zero,
6. On days when rainfall is between 0.3 and 0.8 inches, RO 0.10*RAIN,
7. On days when rainfall is between 0.8 and 1.5 inches, RO 0.15*RAIN,
8. On days when rainfall is greater than 1.5 inches, RO 0.20*RAIN.

The rate of evapotranspiration can be calculated using any of several different equations. Each method entails certain assumptions and the user must determine which equation best serves his purposes and utilizes his data. The average monthly rates shown in the following example are representative of cropland rates in northern Indiana.

The antecedent moisture calculations should be started approximately one month prior to the time to be simulated. Field capacity or any other reasonable moisture content can be assumed as a starting point. During the period of calculation, the soil moisture is not allowed to go below the wilting point. Once enough rainfall has occurred within the calculation period to equal or exceed field capacity, the previous history is wiped out. Table A-2 shows example moisture calculations for a soil with a total porosity of 50 percent, control depth (DF) of 6 inches, field capacity of 70 percent saturation (wilting point of 35 percent saturation) and a steady state infiltration rate (see Section A.2) of 0.3 inches per hour. Using the above information and assuming that an ANSWERS simulation is to be started on June 14, the ASM value for this soil type would be 67 percent.

Section A.2

The parameters which specifically describe a soil's infiltration response as described by the modified form of Holtan's equation used in ANSWERS are defined in this section. The steady state infiltration rate (FC) indicates the rate at which the soil will absorb water when the soil is saturated. The difference between the maximum and steady state infiltration rates (A) combined with the infiltration exponent (P) helps to describe the typical exponential "drawdown" of the infiltration rate.

Infiltration Bate Descriptors (FC and A)

A simple procedure for selecting values for the steady state infiltration rate (FC) and the difference between maximum and steady state rates (A)is described here. The user is, of course, free to use any information he has concerning these values. Soil survey information is used in this procedure due to its general nature and ready availability.

Table A-2. Antecedent Soil Moisture (ASM) Calculation Example.

Day	Soil Moisture (% saturation)	Rain (in.)	ET (in.)	Runoff (in.)	Percolation (in.)
1 (5/15)	70	.01	.05	0	0
2	69	0	.05	0	0
3	67	0	.05	0	0
4	65	0	.05	0	0
5	64	0	.05	0	0
6	62	3.16	.03	.63	0
7	100	.90	.03	.14	2.26
8	94	.80	.03	.08	.73
9	93	.02	.05	0	.69
10	69	0	..05	0	0
11	67	.29	.02	0	0
12	76	0	.05	0	.18
13	68	0	.05	0	0
14	67	0	.05	0	0
15	65	.05	.05	0	0

16	65	.27	.03	0	0
17	73	.27	.03	0	.09
18 (6/1)	78	.21	.03	0	.24
19	76	.25	.03	0	.18
20	77	.35	.03	.04	.22
21	79	.39	.03	.04	.28
22	81	.53	.03	.05	.32
23	85	.03	.06	0	.45
24	69	0	.06	0	0
25	67	0	.06	0	0
26	65	0	.06	0	0
27	63	.02	.06	0	0
28	62	1.11	.03	.17	0
29	92	.04	.06	0	.66
30	69	0	.06	0	0
31 (6/14)	67				

USDA Soil Survey format) are used in the following manner:

1. The midpoint of the lower 1/3 of the range is used for FC,
2. The midpoint of the upper 2/3 of the range is assumed to be the maximum rate,
3. The value of A is equal to the maximum rate minus FC.

Assuming a permeability range of 0.2 to 1.5 inches per hour, the following example illustrates this technique:

The total range = 1.3 inches per hour
1/3 of range = 1.3/3 = .43 inches per hour

Thus, FC equals the midpoint of the lower 1/3 of range

FC = .2 + (.43/2) = .42 inches per hour

The maximum rate is the midpoint of the upper 2/3 of the range

maximum rate = ((.2 + .43) + 1.5)/2 = 1.07 inches per hour

The A value equals the maximum rate minus FC

A = 1.07 - .42 = .65 inches per hour

Using the entire range, FC would be 0.2 iph and A would be 1.3 iph. The method detailed above appears to give more realistic numbers.

Infiltration Exponent (P)

As stated in the section on component relationships, the infiltration exponent (P) relates the rate of decrease of infiltration capacity to increasing moisture content. This property varies among soil types and is most closely related to the textural class of the soil. The heavier the texture (more clay), the larger the value of P. Conversely, sandy soils show little change in infiltration rate with increasing soil moisture content and, thus, have a much smaller value of P. Table A-3 lists some starting point values for several textural classes.

Table A-3. "P" Values for Various Soil Textures.

Soil Texture	Suggested Values for "P"
Clay	.75 - .80
Silly clay	.65 - .75
Clay loam	.60 - .70
Loam	.55 - .65

Sandy loam	.50 - .60
Sand	.35 - .50

Section A.3

Two different types of information are included in this section. The USLE "K" factor or soil erodibility of each soil type is described. The general subsurface drainage characteristics of the watershed are described by the combination of the tile drainage coefficient and the groundwater release fraction. Both of these drainage terms are defined and methods of parameter value assignment are discussed.

Soil Erodibility - USLE "K" (K)

Most of the newest USDA Soil Surveys contain information on the "K" factor for each soil type mapped. Other sources of this information include statewide soil loss handbooks or brochures which are published by most state SCS offices. Wischmeier et al. (1971) have produced a nomograph technique for determining the USLE "K" factor based on textural class and other soil characteristics.

Section A.4 details a method for simplifying the soils description file presented in this Appendix. Essentially, the technique involves the grouping of soils by similarities in drainage response. When soils are grouped in this manner, the (K) parameter for the various individual soils may not be equal. If they are not, one of two methods can be used to arrive at an "effective" (K).

1. Use an area weighted average of "K" values within a drainage class, or
2. Use the value of "K" for the predominant soil(s).

Subsurface Drainage Characteristics

The two parameters which describe the rate of subsurface water movement are the tile drainage coefficient and the groundwater release fraction. The tile drainage coefficient is simply the design value for tile drainage. Interflow or groundwater release is described by putting a fraction of the water in the subsurface reservoir into the channel system at each time step. Experience has shown that the value of the fraction varies from as little as zero to approximately 0.01. Small values of the fraction may actually cause an increase in the flow rate on the recession limb of the hydrograph due to the fact that the drainage rate from the control zone is greater than the groundwater movement rate. Thus, the subsurface reservoir of water increases, and the interflow rate rises accordingly. Higher values of the fraction will cause the hydrograph to "level off" for a period of time and then decrease as the rate. of subsurface drainage becomes less than the interflow rate.

Section A.4

In order to reduce the number of soils that must be described in the "predata" file, a technique has been developed for identifying soils with similar drainage characteristics. The similar soils are then placed in a general group with drainage and erosion characteristics which describe the "average" response of the soils making up the group.

The procedure requires information about the drainage classification and hydrologic soil group of each soil type. The technique involves the following:

1. Soils are listed by their drainage classification (i.e.,

well drained, poorly drained, very poorly drained, etc.) and by hydrologic group (i.e., A, B, C or D).

2. The soils are first grouped by drainage classification. Then, those soils are examined for hydrologic group. Soils that have the same drainage classification and hydrologic group are considered to have similar responses. It is possible that within one drainage classification there may be soils with two or more hydrologic groups. The soils in each hydrologic group should be considered as a separate soil group.
3. The soil(s) that predominate the area in each soil group are chosen as representative. A more complex method would be to select the descriptive parameters based on area weighting.

APPENDIX B - LAND USE AND SURFACE PARAMETERS

Section B.1

The information presented in this section involves the extent of crop cover, the flow retardance of the surface and the relative erosiveness of the various crops or land uses. The specific land use or crop (CROP) is simply an identifier that is printed during output. The potential interception (PIT) and percent cover (PER) are used to describe the interception of rainfall. Manning's n (N) describes the surface roughness or retardance to flow. The relative erosiveness parameter (C) is actually a combination of the USLE "C" and "P" values with seasonal adjustment.

Interception Parameters (PIT and PER)

A certain amount of the precipitation during any event never reaches the soil surface. Contact with and storage on vegetation accounts for this removal and is called interception. The potential interception volume (PIT) describes the volume of moisture that could be removed if the area were completely covered by that crop or land use. The actual percentage of cover (PER) assumes the non-covered area has no interception. Table B-1 lists some example values for PIT.

Table B-1. Potential Interception Values.

Crop	PIT (mm)
Oats	.5 - 1.0
Corn	.3 - 1.3
Grass	.5 - 1.0
Pasture and Meadow	.3 - .5
Wheat, Rye and Barley	.3 - 1.0
Beans, Potatoes and Cabbage	.5 - 1.5
Woods	1.0 - 2.5

Manning's n (N)

The measure of surface roughness or flow retardance used in the flow equation in ANSWERS is Manning's n. This information, when combined with element slopes, rainfall, interception, infiltration and routing considerations, helps yield the solution to the continuity equation, which is the basis of ANSWERS. There are numerous sources for obtaining reasonable values of n for channel and overland flow situations.

Relative Erosiveness (C)

This parameter is used in determining how much soil could potentially erode due to a particular crop or land use, when compared to fallow ground under identical conditions. It is a direct combination of the USLE "C" and "P" parameters with a seasonal adjustment. Thus, conventionally tilled corn at crop stage 1 will have a higher (more erosive) C value than the same corn at crop stage 2, when there is more foliage and root structure. Agriculture Handbook No. 537 (Wischmeier and Smith, 1978) contains information for determining the USLE "C" and "P" values throughout the year for numerous crops and management systems.

Section B.2

Figure B-1 shows a profile of a section of the soil surface. The combination of the peaks and valleys yields a certain depressional storage volume. In addition, the amount of the surface that area that is inundated at any time is a direct function of the depth of water on the surface. The infiltration rate within an element is greatly affected by the amount of pondage within the area.

```
                                          _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
                                      .``.                ^
          \                          /    \       /       |
  soil      \                       /      \     /        |  HU
  surface---> \        ~\     _/        `--\/          |
               \    /  \_-/                               |
                \__/ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ v_ _ _ _ _ _ _ DATUM
```

Figure B-1. Soil Surface Profile.

Surface Storage Descriptors (HU and RC)

The ANSWERS model uses the maximum roughness height (HU) and a roughness coefficient (RC) to describe the surface storage characteristics and the ponded surface area. The roughness coefficient (RC) is, essentially, a shape factor which describes the frequency and severity of the roughness. The maximum roughness height (HU) is used to establish the upper limits of the surface roughness and is physically measurable. Table B-2 shows some typical values for both HU and RC.

Table B-2. Typical Surface Storage Coefficients.

Surface Condition	HU (mm)	RC
Plowed Ground:		
Spring- smooth	100	.53
Spring - normal	130	.48
Spring - rough	130	.59
Fall - smooth	60	.37
Fall - normal	70	.33
Fall - rough	130	.45
Disked and Harrowed:		
Very smooth	30	.42
Rather rough	60	.43
Corn Stubble	110	.59

Quick Guide for Determining Roughness Parameters for Use in the ANSWERS Model

Land Use or Cover	RC* Range	RC* Starting Value	Manning's n Range	Manning's n Starting Value	HU Range (Inches)	HU Starting Value (Inches)
Row Crop						
Turn Plowed						
Smooth	.40 - .50	.45	.070 - .100	.085	1.0 - 3.0	1.5
Cultivated	.45 - .60	.52	.090 - .120	.110	1.5 - 4.0	2.5
Chisel Plowed						
Smooth	.45 - .60	.52	.080 - .120	.100	1.0 - 4.0	2.0
Cultivated	.55 - .65	.60	.100 - .140	.120	2.0 - 5.0	3.0
No-Till						
Normal Residue	.55 - .65	.60	.100 - .150	.120	1.0 - 4.0	2.0
Heavy Residue	.60 - .70	.65	.130 - .170	.150	2.0 - 5.0	3.0
Grass or Pasture**						
Poor Cover	.35 - .45	.40	.065 - .100	.080	0.5 - 2.0	1.0
Average Cover	.40 - .50	.45	.090 - .120	.100	1.0 - 3.0	1.5
Good Cover	.45 - .55	.50	.100 - .140	.120	1.0 - 3.0	1.5
Small Grains						
Residue Removed	.40 .50	.45	.090 - .120	.100	1.0 - 3.0	1.5
Incorp'd. Residue	.50 .60	.55	.110 - .140	.120	1.5 - 4.0	2.5
Forests or Wooded Areas**						
Light Woods	.45 - .60	.55	.120 - .180	.150	1.5 - 5.0	2.5
Heavy Woods	.55 - .65	.60	.150 - .250	.200	2.0 - 6.0	3.0
Plowed Ground						
Turn Plowed						
Smooth	.25 - .35	.30	.01 - .05	.035	1.0 - 3.0	1.5
Rough	.65 - .80	.75	.25 - .50	.350	2.0 -12.0	6.0
Chisel Plowed						
Smooth	.35 - .45	.40	.03 - .08	.050	1.5 - 4.0	2.5
Rough	.60 - .70	.65	.15 - .50	.250	2.0 - 8.0	4.0
Disked						
Smooth	.30 - .40	.35	.03 - .07	.040	1.0 - 3.0	1.5
Rough	.50 - .60	.55	.10 - .40	.200	2.0 - 5.0	3.5

* The RC parameter is an exponent which describes the frequency of the surface roughness. The number varies from around .28 to .8. The larger the number, the more sinuous the surface profile (greater frequency).

**The additional cover afforded in the average or good categories also has an impact on the infiltration characteristics of the soil. This is due to prevention of crusting and to enhancement of soil surface organic matter contents.

References cited:

Israelsen, O.W. and V.E. Hansen. 1962. Irrigation principles and practices. John and Sons, Inc. NY, NY.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses - a gu
to conservation planning. Agriculture Handbook 537. science and Education Admins
U.S. Department of Agriculture. 58 p.

Wischmeier, W.H., C.B. Johnson and B.V. Cross. 1971. A soil erodibility nomograp
farmland and construction sites. Journal of Soil and Water Conservation. 26(5):