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Hydrologic Simulation on Solid Waste Disposal Sites

HYDROLOGIC SIMULATION ON SOLID WASTE DISPOSAL SITES (HSSWDS)

by

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Permit Writers Guidance Manual/Technical Resource Document

Preface

The land disposal of hazardous waste is subject to the requirements of Subtitle C of the Resource Conservation and Recovery Act of 1976. This Act requires that the treatment, storage, or disposal of hazardous wastes after November 19, 1980, be carried out in accordance with a permit. The one exception to this rule is that facilities in existence as of November 19, 1980 may continue operations until final administrative dispostion is made of the permit application (providing that the facility complies with the Interim Status Standards for disposers of hazardous waste in 40 CFR Part 265). Owners or operators of new facilities must apply for and receive a permit before beginning operation of such a facility.

The Interim Status Standards (40 CFR Part 265) and some of the administrative portions of the Permit Standards (40 CFR Part 264) were published by EPA in the Federal Register on May 19, 1980. EPA will soon publish technical permit standards in Part 264 for hazardous waste disposal facilities. These regulations will ensure the protection of human health and the environment by requiring evaluations of hazardous waste management facilities in terms of both site-specific factors and the nature of the waste that the facility will manage.

The permit official must review and evaluate permit applications to determine whether the proposed objectives, design, and operation of a land disposal facility will be in compliance with all applicable provisions of the regulations (40 CFR 264).

EPA is preparing two types of documents for permit officials responsible for hazardous waste landfills, surface impoundments, and land treatment facilities: Permit Writers Guidance Manuals and Technical Resource Documents. The Permit Writers Guidance Manuals provide guidance for conducting the review and evaluation of a permit application for site-specific control objectives and designs. The Technical Resource Documents support the Permit Writers Guidance Manuals in certain areas (i.e. liners, leachate management, closure, covers, water balance) by describing current technologies and methods for evaluating the performance of the applicant's design. The information and guidance presented in these manuals constitute a suggested approach for review and evaluation based on best engineering judgments. There may be alternative and equivalent methods for conducting the review and evaluation. However, if the results of these methods differ from those of the EPA method, their validity may have to be validated by the applicant.

In reviewing and evaluating the permit application, the permit official must make all decisions in a well defined and well documented manner. Once an initial decision is made to issue or deny the permit, the Subtitle C regulations (40 CFR 124.6, 124.7 and 124.8) require preparation of either a statement of basis or a fact sheet that discusses the reasons behind the decision. The statement of basis or fact sheet then becomes part of the permit review process specified in 40 CRF 124.6-124.20.

These manuals are intended to assist the permit official in arriving at a logical, well-defined, and well-documented decision. Checklists and logic flow diagrams are provided throughout the manuals to ensure that necessary factors are considered in the decision process. Technical data are presented to enable the permit official to identify proposed designs that may require more detailed analysis because of a deviation from suggested practices. The technical data are not meant to provide rigid guidelines for arriving at a decision. References are cited throughout the manuals to provide further guidance for the permit official when necessary.

ABSTRACT

The purpose of this research project was to provide an interactive computer program for simulating the hydrologic characteristics of a solid and hazardous waste disposal site operation. A large number of stations (cities) within the United States for which 5 years of climatic records exist have been put on tape for easy access and can be used in lieu of on-site measurements. In addition, to expedite model usage, the model stores many default values of parameter estimates which can be used when measured and existing data files are not available. The user must supply the geographic location, site area and hydrologic length, the characteristics of the final soil and vegetative cover, and default overrides where deemed necessary. From minimal input data, the model will simulate daily, monthly, and annual runoff, deep percolation, temperature, soil-water, and evapotranspiration.

The model, which is a modification of the SCS curve number runoff method and the hydrologic portion of the USDA-SEA hydrologic model (CREAMS), has been modified to conform to the design characteristics of solid and hazardous waste disposal sites. The model takes hydrologic parameter input data and operates sequentially as precipitation information is read. The user can request a final cover soil with a vegetative and a barrier layer or with a uniform final cover soil. The user can select an "impermeable liner" separating the final cover soil material from the solid waste cells and select the life expectancy of the liner. The model is designed for use in a conversational manner, that is, the user interacts directly with the program and receives output immediately. No prior experience with computer programming is required for model usage. All necessary commands to use the model are presented in the user's manual.

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FIGURES

FIGURES (continued)

FIGURES (continued)

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ACKNOWLEDGEMENTS

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SECTION 1

INTRODUCTION

Percolation and runoff of precipitation is of particular concern on solid waste disposal sites as a potential for contamination of ground and surface waters by leachate. The proper landfill site design and operational approach is to minimize or eliminate percolation through the solid waste. The purpose of this report is to provide a communication-type computer package to aid in the evaluation of disposal facilities by stimulating hydrologic characteristics of sanitary landfill operations. The HSSWDS model permits rapid evaluation of design, final soil cover materials, and operational methodologies by estimating leachate generation on solid waste management systems.

The design of municipal solid waste facilities and sanitary landfills has been discussed in detail by Brunner and Keller (1), Pavoni et al. (2), Geswin (3), Beck (4), and Bartos (5). Most solid waste is ultimately disposed on land in a landfill where solid waste is covered with soil at the end of each day's operation. A general description of a sanitary landfill operation follows the process where solid waste is spread on the ground and compacted to the maximum density practical. At the end of each working day, all solid waste delivered to the site during the day is covered with compacted soil. This constitutes a solid waste cell. A sanitary landfill consists of one or more lifts of solid waste cells. If two or more lifts are placed, each lift is covered by an intermediate cover. All completed sanitary landfills are covered with a thick final layer of a cover soil.

Although a large variety of types and designs of solid waste sites does occur, this report deals only with the hydrology of the final cover material (see Lutton et al. (6)). The simulation model assumes that the moisture content of the solid waste material is at field capacity. That is, drainage due to gravitational forces has ceased. Therefore, the volume of water entering the solid waste by percolation through the final cover material will immediately be lost into leachate drainage at the bottom of the cell.

The hydrologic simulation models considered were deterministic, that is, the behavior of a hydrologic variable is assumed known and its characteristics can be predicted without uncertainty. These models are termed "lumped systems." That is, the dynamic equations governing their behavior are not involved with space coordinates. In models of this type (Perrier et al. (7), Fenn et al.(8)), position is not important, and all components may be regarded as being located at a single vertical line in space. These models are described by ordinary differential equations and assume uniform slope and uniform final soil and vegetative cover materials.

SECTION 2

GENERAL DESCRIPTION OF HSSWDS PROGRAM

The HSSWDS program was developed to evaluate permit applications. The program may also assist engineers and planners in producing a feasible plan for the design and implementation of a solid waste disposal site. The program is a set of computer-based modules which perform water balance calculations on various cover materials and operational methodologies to develop the planning level design. The program has been written for the user who may not have any background in computer programming. The only equipment required to run the program is a small computer terminal and a telephone. The input and output is interactive so the user can have instant results.

The hydrologic portion of the USDA-SEA model entitled Chemicals Runoff and Erosion from Agricultural Management Systems (CREAMS) (9) has been modified to conform to the general design characteristics of solid waste disposal sites (for a detailed description see Appendix A). The flowchart for the hydrology simulation model is shown in Figure 1 for daily time steps. From minimal input data, the model will simulate daily, monthly, and annual values of runoff, cover and waste drainage, temperature, soil-water, and evapotranspiration. To expedite model usage, the model stores many default values of parameter estimates to be used when measured and existing data are not available, for example, soil-water characteristics, precipitation, mean monthly temperatures, mean monthly solar radiation, and vegetative characteristics. In addition, a large number of stations within the United States which contain 5 years of climatic records are on tape for easy access to be used in lieu of onsite measurements. The user must supply the title, geographical location, the site area, length and slope, and the characteristics of the landfill material, soil, and vegetative cover. A sensitivity study for the model is given in Appendix C.

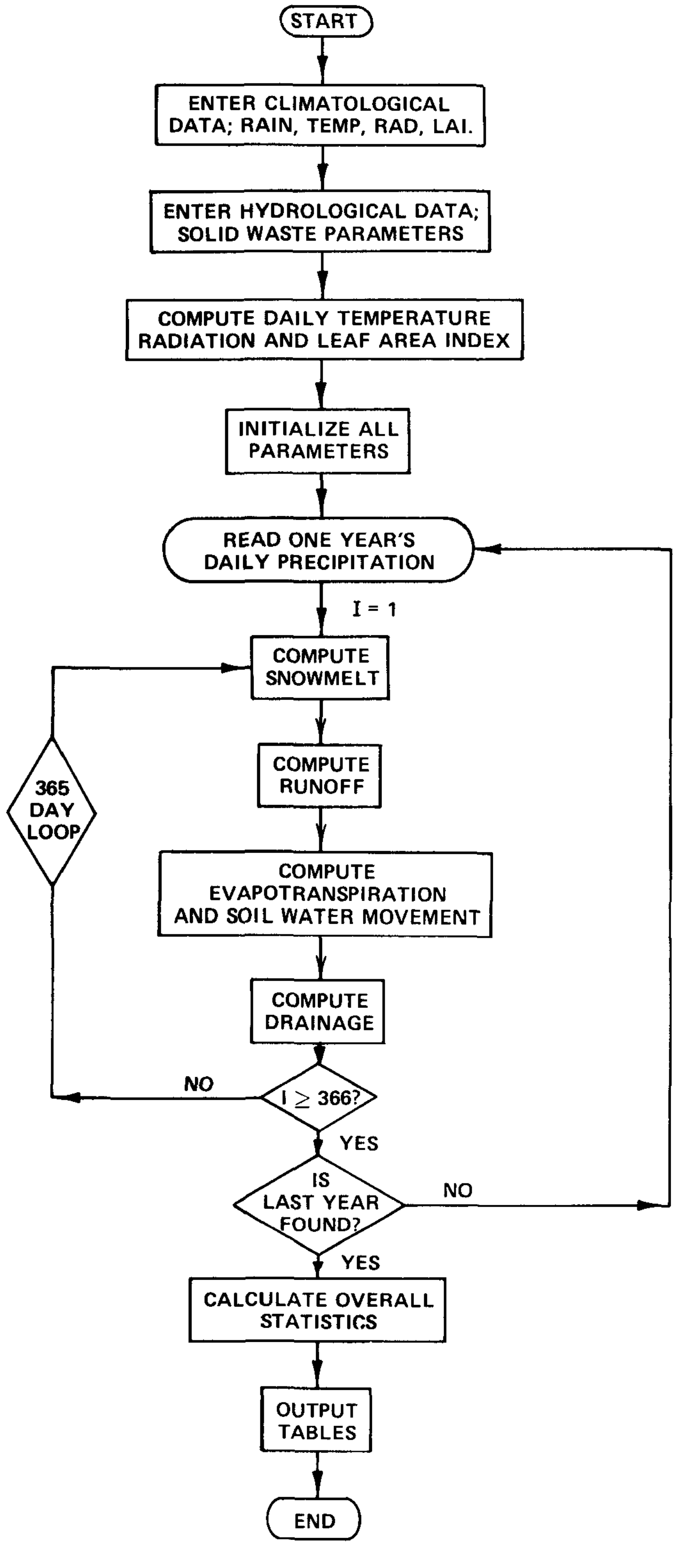

Figure 1. Generalized flowchart for the hydrologic simulation Model HSSWDS.

SECTION 3

HSSWDS USER'S MANUAL

All major hydrologic processes which occur during a rainstorm, such as rainfall, infiltration, soil-water, deep drainage and surface water flow, can be simulated in various levels of detail. This model scales the field hydrologic response during and between storm events. It is a continuous simulation model which uses a day as the time step for evapotranspiration, soil-water movement, and deep percolation. This section is presented as an aid to the planner and technician to develop climatological input and site parameter information and, if necessary, to set up data files for running the model.

The hydrologic processes that the model addresses are shown in Figure 2 for a solid waste disposal site. A portion of the precipitation in the form of rain or melted snow which infiltrates the soil cover at the surface percolates to the interface of the soil cover and solid waste. The model limits the user to only two layers in the final cover soil, a vegetative soil and a barrier soil. At the interface of the final cover soil and the solid waste, the user may specify an impermeable liner usually of a polymeric material. The model will evaluate the life of the liner using the age equations (power law). The solid waste material is assumed to be at field capacity and, therefore, any water percolating across the interface will eventually drain either out of the site or into the soil layers beneath the solid waste storage. The model permits an examination of the soil cover/impermeable liner type scenario to better design these parameters under existing climatic conditions.

A conceptual understanding of soil-water contents and movement is shown in Figure 3. Individual soils have values different from these shown; however, the general relation of soil-water to soil texture is presented. The terminology (11) used is defined as follows:

Field capacity is the water content that a soil retains after drainage ceases (due to the forces of gravity).
Wilting point is the water content a soil retains after plants cannot extract any more soil-water and they remain wilted.
Available water capacity is the difference between the soil-water at field capacity and the wilting point.
Hydraulic conductivity is the rate of soil-water movement (due to the forces of gravity) between the soil-water contents at saturation and field capacity.

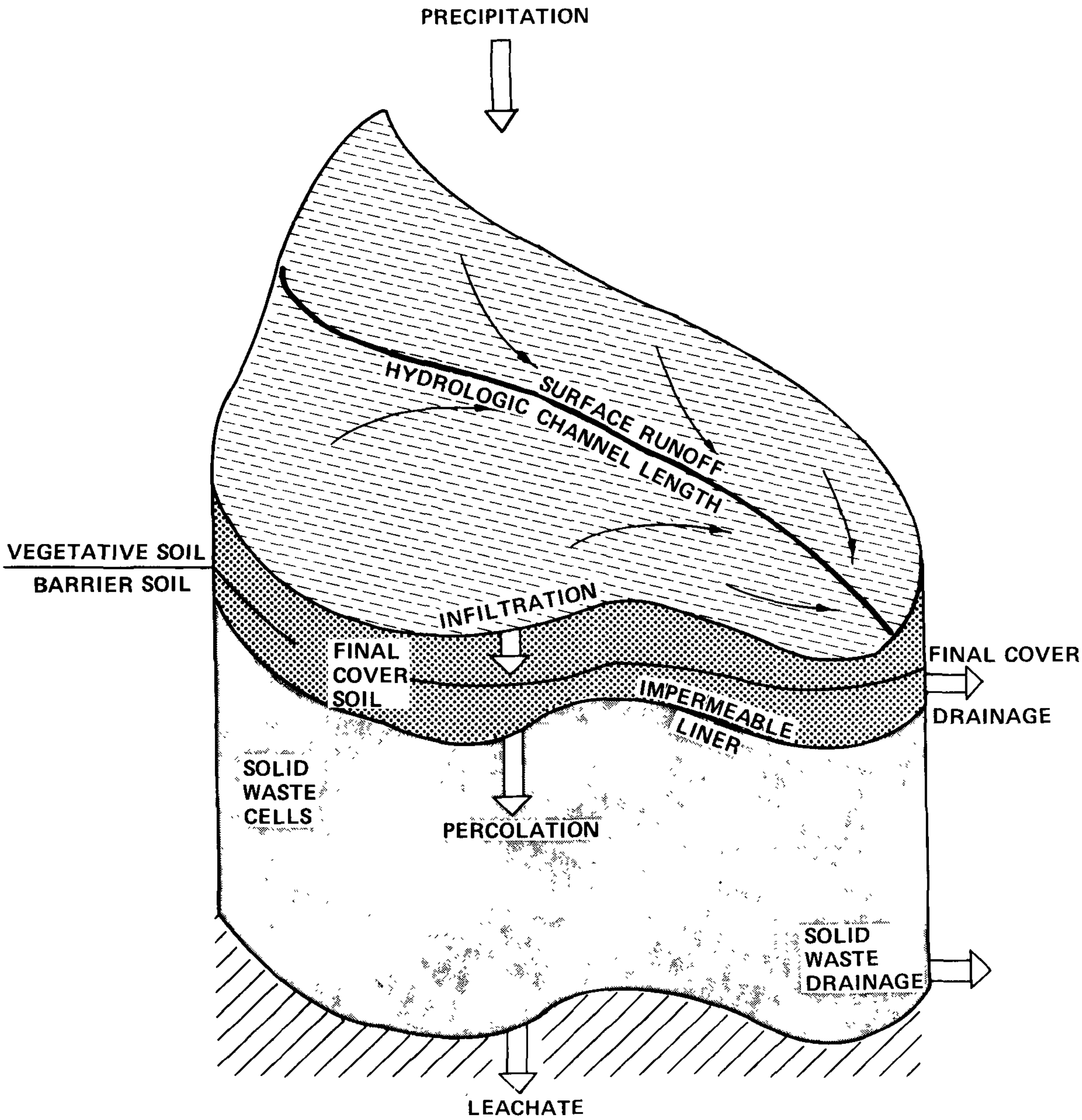

Figure 2. Schematic diagram of the hydrologic cycle on a solid waste disposal site.

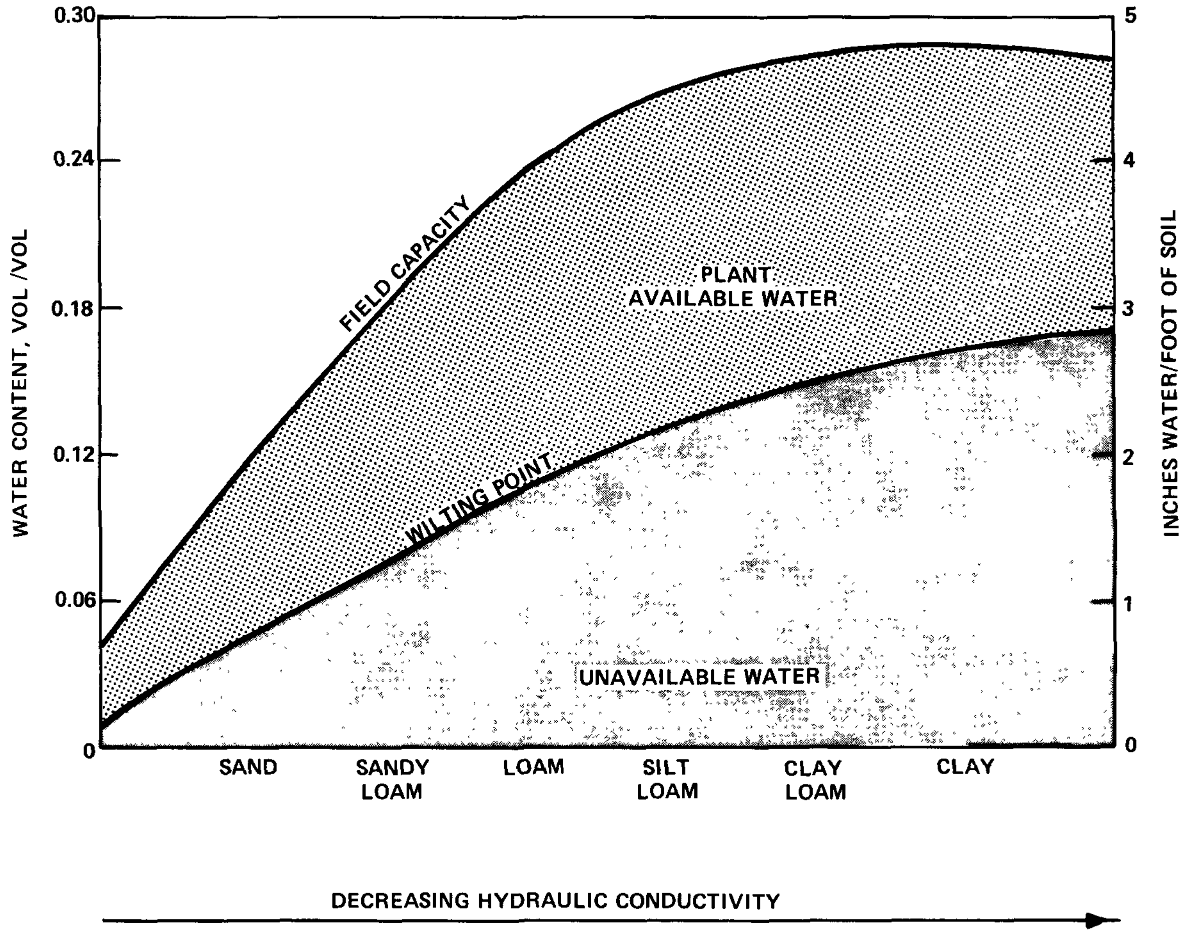

Figure 3. General relation between soil-water, soil texture, and hydraulic conductivity (10).

MODEL OPERATION USING DEFAULT DATA

To expedite model usage, one portion of the model inputs evapotranspiration, evaporation, and soil-water characteristics as defaults. A portion of these values is shown in Table 1. Figure 4 is provided to assist the user in the soil classification system of the USDA. In addition, several stations within the United States which contain 5 years of climatic records are on tape for easy access to the geographical location of interest. The locations available for using default data are presented in Table 2. The steps to log on/off the Boeing Computer System (BCS)* are shown in Figure 5, which presents the 9 steps to log on the computer and 1 step to log off.†

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* To obtain information on using BCS for an account number and password (ID, PASSWORD), call 1-800-426-7676 and ask for EKS customer service. (See Appendix B.)

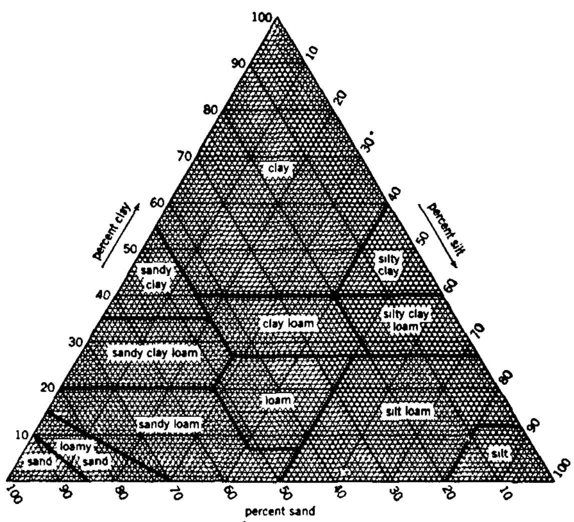
† See Appendix D for log on/off information for the EPA COMNET system.

TABLE 1. SOLID WASTE COVER SOIL CHARACTERISTICS* (DEFAULT)

	Texture class		MIR	Porosity	Ksat	AWC	Evap
	USDA	USCS	in./hr	vol/vol	in./hr	vol/vol	coef.
1	CoS	GW	0.50	0.351	11.950	0.067	3.3
2	CoSL	GP	0.45	0.376	7.090	0.087	3.3
3	S	SW	0.40	0.389	6.620	0.133	3.3
4	FS	SM	0.39	0.371	5.400	0.122	3.3
5	LS	SM	0.38	0.330	2.780	0.101	3.4
6	LFS	SM	0.34	0.401	1.000	0.540	3.3
7	LVFS	SM	0.32	0.390	0.910	0.086	3.4
8	SL	SM	0.30	0.442	0.670	0.123	3.8
9	FSL	SM	0.25	0.458	0.550	0.131	4.5
10	VFSL	MH	0.25	0.511	0.330	0.117	5.0
11	L	ML	0.20	0.521	0.210	0.156	4.5
12	SIL	ML	0.17	0.535	0.110	0.199	5.0
13	SCL	SC	0.11	0.453	0.084	0.119	4.7
14	CL	CL	0.09	0.582	0.065	0.127	3.9
15	SICL	CL	0.07	0.588	0.041	0.149	4.2
16	SC	CH	0.06	0.572	0.065	0.078	3.6
17	SIC	CH	0.02	0.592	0.033	0.123	3.8
18	C	CH	0.01	0.680	0.022	0.115	3.5
Solid waste				0.526	0.030	0.156	4.5

* USDA = USDA Soil Classification System, Co = coarse, C = clay,
SI = silt, S = sand, L = loam, F = fine, V = very;
USCS = Unified Soil Classification System, S = sand, M = silt,
L = low liquid limit, H = high liquid limit, W = well graded;
MIR = Minimum Infiltration Rate;
Ksat = Hydraulic Conductivity; and
AWC = Available Water Capacity.

SAND–2.0 to 0.05 mm DIAMETER
SILT–0.05 to 0.002 mm DIAMETER
CLAY–SMALLER THAN 0.002 mm DIAMETER



U S DEPARTMENT OF AGRICULTURE TEXTURAL CLASSIFICATION CHART

PERCENTAGE OF SAND SIZES IN SUBCLASSES OF SAND, LOAMY SAND, AND SANDY LOAM BASIC TEXTURAL CLASSES AS DEFINED BY THE U S DEPARTMENT OF AGRICULTURE

Basic soil class	Subclass	Soil separates				
		Very coarse sand, 2.0 - 1.0 mm	Coarse sand, 1.0 - 0.5 mm	Medium sand, 0.5 - 0.25 mm	Fine sand, 0.25 - 0.1 mm	Very fine sand, 0.1 - 0.05 mm
Sands	Coarse sand	25% or more		Less than 50%	Less than 50%	Less than 50%
	Sand	25% or more			Less than 50%	Less than 50%
	Fine sand	Less than 25%		-or-	50% or more	Less than 50%
	Very fine sand					50% or more
Loamy sands	Loamy coarse sand	25% or more		Less than 50%	Less than 50%	Less than 50%
	Loamy sand	25% or more			Less than 50%	Less than 50%
	Loamy fine sand	Less than 25%		-or-	50% or more	Less than 50%
	Loamy very fine sand					50% or more
Sandy loams	Coarse sandy loam	25% or more		Less than 50%	Less than 50%	Less than 50%
	Sandy loam	30% or more Less than 25%			-and- Less than 30%	Less than 30%
	Fine sandy loam	-or- Between 15 and 30%			30% or more	Less than 30%
	Very fine sandy loam	Less than 15%		-or-	More than 40%*	30% or more

*Half of fine sand and very fine sand must be very fine sand.

Figure 4. USDA classification system (12).

TABLE 2. MEAN DAILY SOLAR RADIATION (LANGLEYS) (9)

States and cities	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alaska												
Annette	63	115	236	364	437	438	438	341	258	122	59	41
Bethel	38	108	282	444	457	454	376	252	202	115	44	22
Fairbanks	16	71	213	376	461	504	434	317	180	82	26	6
Arizona												
Flagstaff	300	382	526	618	695	707	680	596	516	402	310	243
Phoenix	301	409	526	638	724	739	658	613	566	449	344	281
Tucson	315	391	540	655	729	699	626	588	570	442	356	305
Arkansas												
Little Rock	188	260	353	446	523	559	556	518	439	343	244	187
California												
Sacramento	174	257	390	528	625	694	682	612	493	347	222	148
Fresno	184	289	427	552	647	702	682	621	510	376	250	161
Inyokern (China Lake)	306	412	562	683	772	819	772	729	635	467	363	300
San Diego	244	302	397	457	506	487	497	464	389	320	277	221
Los Angeles WBAS	248	331	470	515	572	596	641	581	503	373	289	241
Santa Maria	263	346	482	552	635	694	680	613	524	419	313	252
Colorado												
Denver	201	268	401	460	460	525	520	439	412	310	222	182
Grand Junction	227	324	434	546	615	708	676	595	514	373	260	212
Florida												
Tallahassee	298	367	441	535	603	578	529	511	456	413	332	262
W. Palm Beach	297	330	412	463	483	464	488	461	400	366	313	291
Jacksonville	267	343	427	517	579	521	488	483	418	347	300	233
Miami Airport	249	415	489	540	553	532	532	505	440	384	353	316
Tampa	327	391	474	539	596	574	534	494	452	400	356	300
Orlando	307	370	470	550	607	591	548	511	456	396	360	292

(continued)

TABLE 2 (continued)

States and cities	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Georgia												
Atlanta	218	290	380	488	533	562	532	508	416	344	268	211
Watkinsville	236	292	375	464	535	568	555	500	417	328	257	224
Hawaii												
Honolulu	363	422	516	559	617	615	615	612	573	507	426	371
Idaho												
Boise	138	236	342	485	585	636	670	576	460	301	182	124
Pocatello	163	240	355	462	552	592	602	540	432	286	176	131
Lewiston	121	205	304	462	558	653	699	562	410	245	146	96
Illinois												
Chicago	96	147	227	331	424	458	473	403	313	207	120	76
East St. Louis	170	242	340	402	506	553	540	498	398	275	165	138
Indiana												
Indianapolis	144	213	316	396	488	543	541	490	405	293	177	132
Iowa												
Des Moines	174	253	326	403	480	541	436	460	367	274	187	143
Kansas												
Dodge City	255	316	418	528	568	650	642	592	493	380	285	234
Topeka	192	264	345	433	527	551	531	526	410	492	227	156
Kentucky												
Lexington	172	263	357	480	581	628	617	563	494	357	245	174
Louisiana												
Lake Charles	245	306	397	481	555	591	526	511	449	402	300	250
New Orleans	214	259	335	412	449	443	417	416	383	357	278	198
Shreveport	232	292	384	446	558	557	578	528	414	354	254	205
Maine												
Caribou	133	231	364	400	476	470	508	448	336	212	111	107
Portland	152	235	352	409	514	539	561	488	383	278	157	137

(continued)

TABLE 2 (continued)

States and cities	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Massachusetts												
Boston	129	194	290	350	445	483	486	411	334	235	136	115
Michigan												
East Lansing	121	210	309	359	483	547	540	466	373	255	136	108
Sault Ste. Marie	130	225	356	416	523	557	573	472	322	216	105	96
Minnesota												
St. Cloud	168	260	368	426	496	535	557	486	366	237	146	124
Missouri												
Columbia	173	251	340	434	530	574	574	522	453	322	225	158
Montana												
Glasgow	154	258	385	466	568	605	645	531	410	267	154	116
Great Falls	140	232	366	434	528	583	639	532	407	264	154	112
Nebraska												
Grand Island	188	259	350	416	494	544	568	484	396	296	199	159
North Omaha	193	299	365	463	516	546	568	519	410	298	204	170
Nevada												
Ely	236	339	468	563	625	712	647	618	518	394	289	218
Las Vegas	277	384	519	621	702	748	675	627	551	429	318	258
New Jersey												
Seabrook	157	227	318	403	482	527	509	455	385	278	192	140
Edison	150	232	339	403	482	527	509	455	385	278	182	140
New Mexico												
Albuquerque	303	386	511	618	686	726	683	626	554	438	334	276
New York												
Syracuse	116	194	272	334	440	501	515	453	346	231	120	96
Central Park	130	199	290	369	432	470	459	389	331	242	147	115
Ithaca	160	249	335	415	494	565	543	462	385	289	186	142
Schenectady	130	200	273	338	413	448	441	397	299	218	128	104
New York City (JFK)	155	232	339	428	502	573	543	475	391	293	182	146

(continued)

TABLE 2 (continued)

States and cities	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Carolina												
Greensboro	200	276	354	469	531	564	544	485	406	322	243	197
Jacksonville	238	317	426	569	635	652	625	562	471	358	282	214
North Dakota												
Bismarck	157	250	356	447	550	590	617	516	390	272	161	124
Ohio												
Cleveland	125	183	303	286	502	562	562	494	278	289	141	115
Columbus	128	200	297	391	471	562	542	477	422	286	176	129
Put-in-Bay	126	204	302	386	468	544	561	487	382	275	144	109
Cincinnati	128	200	297	391	471	562	542	477	422	286	176	129
Oklahoma												
Oklahoma City	251	319	409	494	536	615	610	593	487	377	291	240
Tulsa	205	289	390	454	504	600	596	545	455	354	269	209
Oregon												
Portland	89	160	287	406	517	570	676	558	397	235	144	80
Medford	116	215	336	482	592	652	698	605	447	279	149	93
Astoria	90	162	270	375	492	469	539	461	354	209	111	79
Pennsylvania												
Pittsburgh	94	169	216	317	429	491	497	409	339	207	118	77
Philadelphia	157	227	318	403	482	527	509	455	385	278	192	140
Rhode Island												
Providence	155	232	334	405	477	527	513	455	377	271	176	139
South Carolina												
Charleston	252	314	388	512	551	564	520	501	404	338	286	225
South Dakota												
Rapid City	183	277	400	482	532	585	590	541	435	315	204	158
Tennessee												
Nashville	149	228	322	432	503	551	530	473	403	308	208	150
Knoxville	161	239	331	450	518	551	526	478	416	318	213	163

(continued)

TABLE 2 (concluded)

States and cities	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Texas												
Brownsville	297	341	402	456	564	610	627	568	475	411	296	263
El Paso	333	430	547	654	714	729	666	640	576	460	372	313
Dallas	250	320	427	488	562	651	613	593	503	403	306	245
Midland	283	358	476	550	611	617	608	574	522	396	325	275
San Antonio	279	347	417	445	541	612	639	585	493	398	295	256
Utah												
Cedar City	238	298	443	522	565	650	599	538	425	352	262	215
Salt Lake City	163	256	354	479	570	621	620	551	446	316	204	146
Virginia												
Lynchburg	172	274	338	414	508	525	510	430	375	281	202	168
Norfolk	87	157	274	418	514	578	586	507	351	194	102	75
Washington												
Yakima	117	222	351	521	616	680	707	604	458	274	136	100
Pullman	121	205	304	462	558	653	699	562	410	245	146	96
Seattle-Tacoma	75	139	265	403	503	511	566	452	324	188	104	64
Wisconsin												
Madison	148	220	313	394	466	514	531	452	348	241	145	115
Wyoming												
Lander	226	324	452	548	587	678	651	586	472	354	239	196
Cheyenne	216	295	424	508	554	643	606	536	438	324	229	186
Puerto Rico												
San Juan	404	481	580	622	519	536	639	549	531	460	411	411

STEP	OPERATION
1	Turn on data terminal.
2	Dial 1-800-426-7676 (if a local number is available, it is less expensive).
3	Ask operator for: EKS1, 30 CPS data line. (Company)
4	Put telephone handle in the handset muff.
5	Wait for green light to come on (on line), then press RETURN key.
6	The computer system types: USER NUMBER: You type: ID,PASSWORD (press RETURN key).
7	The computer system types: RECOVER/USER ID: You type: (your last name) (press RETURN key).
First Run:	
8a	The computer system types: C> You type: -HYDBAT (press RETURN key), (-minus sign).
Second Run:	
8b	The computer system types: C> You type: -HYDGO (press RETURN key).
9	At this point, the program prints a heading (see page 15) and begins to ask questions (see page 16) for entry of site and program operation.
10	When program is finished, the computer system types: C> You type: BYE (press RETURN key) or repeat step 8b for reruns.

Figure 5. Steps to log on and off BCS.

A worksheet is presented in Figure 6 for the entry of site and soil characteristics data necessary to run the model. Most computer input requests are self explanatory. The computer terminal that the user is operating should be set to enter information using all CAPITAL LETTERS. Initially, the program prints a heading as shown below which details the title, name and address of the authors, and the telephone numbers to call for information about the program and to clarify problems if and when they arise.

STATE: ____________________

CITY: ____________________

STUDY TITLE: ____________________

AREA LOCATION: ____________________

YEARS OF INTEREST: ____________________

Surface area of solid waste site . . . . ________ acres

Depth of soil cover . . . . ________ inches

Depth of vegetative cover . . . . ________ inches
Depth of barrier cover . . . . ________ inches

Depth of solid waste . . . . ________ inches

Solid waste site slope . . . . ________ ft/ft

Hydrologic channel length . . . . ________ ft

Figure 6. Default data worksheet.

```
**********************************************************************
**********************************************************************
*                                                                    *
*        HYDROLOGIC SIMULATION ON SOLID WASTE DISPOSAL SITES         *
*                                                                    *
*                            WRITTEN BY                              *
*              EUGENE R. PERRIER AND ANTHONY C. GIBSON               *
*                                                                    *
*                              OF THE                                *
*               WATER RESOURCES ENGINEERING GROUP                    *
*                    ENVIRONMENTAL LABORATORY                        *
*               USAE, WATERWAYS EXPERIMENT STATION                   *
*                          P.O. BOX 631                              *
*                       VICKSBURG, MS 39180                          *
*                                                                    *
**********************************************************************
*                                                                    *
*                USER'S MANUAL AVAILABLE UPON REQUEST                *
*               FOR CONSULTATION CONTACT AUTHORS AT                  *
*                          (601) 634-3710                            *
*                                                                    *
**********************************************************************
**********************************************************************
```

Example. The following example illustrates the interaction that occurs between the program and the user to obtain 5 years of default data for Los Angeles, California. To use default data, it must be a city given in Table 2. After the heading, the computer will ask:

```
DO YOU WANT TO USE DEFAULT CLIMATOLOGIC AND HYDROLOGIC DATA?
   ENTER YES OR NO


I>YES
```

The computer will type a table of the cities and states from which the climatological default data is available.

```
ENTER NAME OF STATE OF INTEREST


I>CALIFORNIA

ENTER NAME OF CITY OF INTEREST


I>LOS ANGELES
```

CLIMATOLOGICAL DATA WILL BE ENTERED

TYPE BYE AND WAIT AT LEAST 30 MINUTES

Note: the user must enter a word or value for each input prompt I> and after the word or value has been entered the user must press the RETURN key.* In the event an error was committed when typing CAILFORNIA, press and hold the CONTROL (CTRL) key, and press the H key 8 times (8 backspaces).† Then type LIFORNIA to correct the spelling, and press the RETURN key as shown.

ENTER NAME OF STATE OF INTEREST

I>CALIFORNIA

To correct an entire line error, the user may press the BREAK key and the computer will type *DEL*. Then the user should type in the correct message as shown.

ENTER NAME OF CITY OF INTEREST

I>LOO ANGELES *DEL*
LOS ANGELES

The first run of the computer program (using 8a) calls the tape from which the cities and states climatological data is stored. This step

---

* COMNET does not use input prompts.

† Some computer terminals use a different backspace command.

requires a waiting period of at least 30 minutes for operators to mount the climatological tape on a tape drive and for the computer to execute the initial program.

After the 30-minute waiting period, the second run requires the user to repeat steps 1 through 7 in Figure 5; however, step 8a is not repeated; instead step 8b is performed. With this process, default climatological data have been put on a permanent file for the specific city/state requested by the user. Thus, countless runs can be made by using steps 1-7 and step 8b without recalling step 8a.

After the program retrieves the climatological data on precipitation, solar radiation, and leaf area index (LAI) for the city requested, the program reprints the heading (page 16) and asks the following questions.

```
ARE YOU USING DEFAULT CLIMATOLOGICAL DATA?
ENTER YES OR NO
I>YES

CLIMATOLOGICAL DATA FROM LOS ANGELES   CALIFORNIA   ARE ON FILE.
```

Because the climatological data are already on file, when the prompt I> is printed for the second question, the user types a 2 for the hydrological input.

```
    DO YOU WANT CLIMATOLOGY, HYDROLOGY OR OUTPUT?

   ENTER 1 FOR CLIMATOLOGICAL INPUT,
         2 FOR HYDROLOGICAL INPUT,
         3 FOR OUTPUT OR
         4 TO STOP PROGRAM.


   I>2
```

The program queries the following for the user's information only and this information is printed twice in the output for the user's interest only. The study title could include site and vegetation information.

```
  ENTER TITLE ON LINE 1,
        LOCATION OF SOLID WASTE SITE ON LINE 2
        AND TODAY'S DATE ON LINE 3.


  I>HYDROLOGY OF A SOLID WASTE DISPOSAL SITE (EXAMPLE 1)
  I>LOS ANGELES, CALIFORNIA -- 10 MILES NORTH OF DOWNTOWN
  I> 12 JUNE   1980
```

At this point, the user has the option of designing the final cover soil with a vegetative and a barrier layer or with a uniform cover soil. If the user desires a two-layered system, the following commands are answered.

```
DO YOU HAVE A LAYERED SOIL COVER?
(ONLY 2 LAYERS PERMITTED VEGETATIVE PLUS BARRIER)
        ENTER YES OR NO


I>YES

ENTER TOTAL DEPTH OF SOIL COVER (INCHES)
 (VEGETATIVE PLUS BARRIER)



I>36
```

Now the user must select the general texture class of vegetative soil cover. This enables the user to select one of the values that are shown in Table 1. The vegetative soil cover is assumed to be spread as uniformly as possible by depth and surface roughness. If a vegetative cover of a grass or row crop is assumed, then the appropriate cultivation and seedbed preparation is also accomplished.

```
ENTER SOIL TEXTURE OF VEGETATIVE SOIL COVER

SELECT THE TEXTURE CLASS OR GROUP SYMBOL OF SOIL MATERIAL


ENTER NUMBER (1)             COARSE SAND        GW
             (2)       COARSE SANDY LOAM        GM
             (3)                    SAND        SW
             (4)               FINE SAND        SM
             (5)              LOAMY SAND        SM
             (6)         LOAMY FINE SAND        SM
             (7)    LOAMY VERY FINE SAND        SM
             (8)              SANDY LOAM        SM
             (9)         FINE SANDY LOAM        SM
            (10)    VERY FINE SANDY LOAM        MH
            (11)                    LOAM        ML
            (12)               SILT LOAM        ML
            (13)         SANDY CLAY LOAM        SC
            (14)               CLAY LOAM        CL
            (15)         SILTY CLAY LOAM        CL
            (16)              SANDY CLAY        CH
            (17)              SILTY CLAY        CH
            (18)                    CLAY        CH


I>9
```

The user must enter the depth of the barrier soil (inches), the texture of the soil material, and answer as to whether or not the barrier soil was compacted. If the barrier soil was compacted, the values of hydraulic conductivity are reduced by a factor of 20, and the values of available water capacity and porosity are halved.

```
ENTER DEPTH OF BARRIER SOIL (INCHES)


I>12

ENTER SOIL TEXTURE OF BARRIER SOIL COVER

SELECT THE TEXTURE CLASS OR GROUP SYMBOL OF SOIL MATERIAL


ENTER NUMBER (1)          COARSE SAND       GW
             (2)    COARSE SANDY LOAM       GM
             (3)                 SAND       SW
             (4)            FINE SAND       SM
             (5)           LOAMY SAND       SM
             (6)      LOAMY FINE SAND       SM
             (7) LOAMY VERY FINE SAND       SM
             (8)           SANDY LOAM       SM
             (9)      FINE SANDY LOAM       SM
            (10) VERY FINE SANDY LOAM       MH
            (11)                 LOAM       ML
            (12)            SILT LOAM       ML
            (13)      SANDY CLAY LOAM       SC
            (14)            CLAY LOAM       CL
            (15)      SILTY CLAY LOAM       CL
            (16)           SANDY CLAY       CH
            (17)           SILTY CLAY       CH
            (18)                 CLAY       CH


I>14

DID YOU COMPACT THE BARRIER SOIL?
           ENTER YES OR NO


I>YES
```

If the user does not request a layered final cover soil, the user must select the soil texture and enter the depth of the soil cover (inches). The computer now responds with:

```
SELECT THE TYPE OF VEGETATIVE COVER


ENTER NUMBER (1) BAREGROUND
             (2) GRASS (EXCELLENT)
             (3) GRASS (GOOD)
             (4) GRASS (FAIR)
             (5) GRASS (POOR)
             (6) ROW CROP (GOOD)
             (7) ROW CROP (FAIR)


I>4
```

An explanation of some of the terms may be in order (for further explanation see Appendix C). For example grass (excellent) implies that the soil cover will be planted with a grass which has excellent production. This assumes that the vegetative cover is well managed; that is, fertilizer, weed control, and harvest (no grazing) are maintained to maximum production. Obviously, this is the best type of vegetative cover available but, realistically, is difficult to achieve. Row crop assumes some type of cultivation will be maintained throughout the season, and it is assumed the crop will produce well. It should be remembered that loam is the ideal soil texture to maximize vegetative production and that soil textures either side of loam will lower production. Of course, good management may circumvent some of the production loss, but a clay or sand cannot maintain even a fair grass cover without management difficulties.

The user now enters 2 values of characteristics of the solid waste site at each input prompt, I>. It must be remembered that the program uses only English units such as acres, feet, and inches.

```
ENTER 2 VALUES, SURFACE AREA OF SOLID WASTE SITE(ACRES)
                AND DEPTH OF SOLID WASTE (INCHES).


I>6
I>180
```

As shown in Figure 2, some solid waste sites may be designed with some type of an "impermeable liner" separating the final cover soil material from the waste cells (6). However, as most "impermeable liners" age and eventually deteriorate, due to known and unknown causes, the power law was used for functional age relations as shown in Figure 7. The indefinite life of a liner was limited to 100 years. The computer asks the following questions:

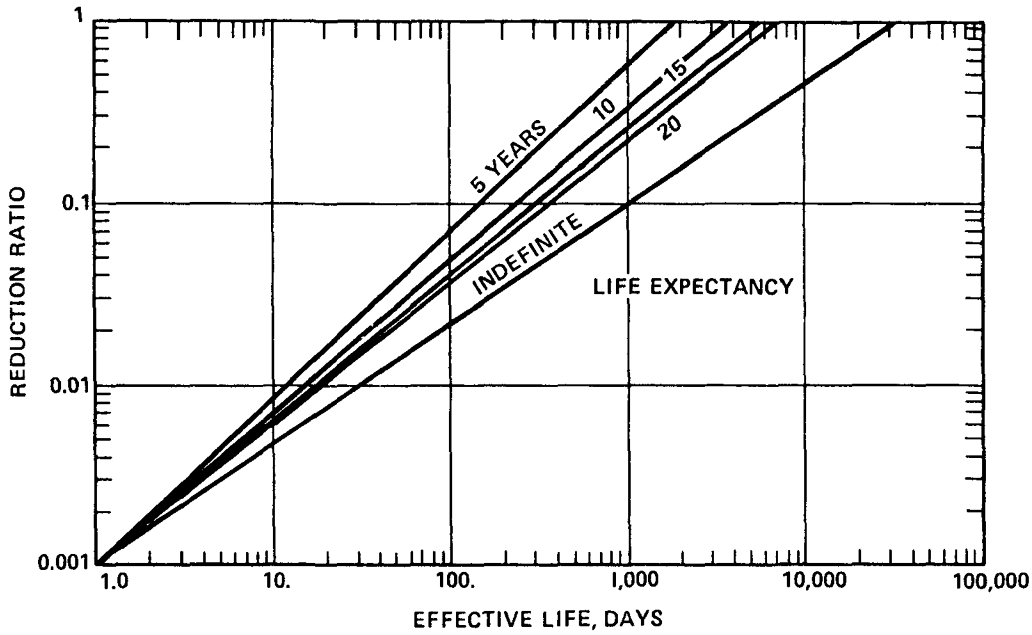


Figure 7. Power law relations used to estimate the effective aging of an impermeable liner.

```
IS THERE AN IMPERMEABLE LINER AT THE INTERFACE?
        ENTER YES OR NO


I>YES

WHAT IS THE EXPECTED LIFE OF THE LINER?

ENTER Ø FOR FIVE YEARS,
      1 FOR TEN  YEARS,
      2 FOR FIFTEEN YEARS,
      3 FOR TWENTY YEARS OR
      4 FOR INDEFINITE LIFE.

I>Ø
```

With the above answers to the prompt commands, initially, the flow of water through the "impermeable liner" is totally impeded. But, as a function of time, the volume of water percolating through the soil cover increases and in five years the "impermeable liner" has no effect on the volume of water percolating into and through the solid waste. However, with proper management, some of the problem may be alleviated; that is, the vegetative cover may have established an excellent grass cover and the amount of deep percolation would be controlled by the increased evapotranspiration demand.

At this point, and if there was no "impermeable liner," the user enters the site slope (ft/ft) and the site channel length (ft). The site slope (ft/ft) is the length of slope divided by the relative relief (difference between high and low elevations along the slope). The decimal fraction should be entered in the program. For example, a slope 3000 ft long with a 30 ft change in elevation would give a site slope ratio of 0.010 to be entered in the program. The hydrologic or site channel length is determined from the overland flow outlet along the main flow path to the most distant point on the upper site boundary (see Figure 1).

```
ENTER 2 VALUES, SITE SLOPE (FT/FT),
                AND SITE CHANNEL LENGTH(FT)


I>.Ø22
I>541
```

The hydrologic or site channel length and the area (acres) of the solid waste site are used to determine the rectangular shape of the site. Thus, for simulation purposes the surface geometry of the site is in the simplistic form of a rectangle whose length is the site channel length.

Now all of the necessary data inputs have been entered for climatology and hydrology when using the default mode and the user is ready for output. However, the user still must specify the number of years of output and whether or not daily or annual summaries are required. As output for both the default and input options are the same, the discussion of output will follow the section on input data files.

INPUT DATA FILES

When default data are not used, the worksheets for input data, as shown in Figure 8, are required. At this time, there is no method available to use only part of the default data and then override specific default parameters with better input data; however, at some future date this option will be available. The most difficult part of this aspect of the model operation is to input the precipitation data. Daily precipitation data are available from local libraries or from the National Weather Service* climatological data

* Director, National Climatic Center, NOAA, Federal Building, Asheville, N.C. 28801

records. When the precipitation data are to be input, if the entire field of ten (10) values is zero (0), only <u>one</u> zero needs to be entered before the RETURN is pressed (right justified). If you have a line partially filled with precipitation data and the remainder is to be filled with zeros, after typing the precipitation data only a RETURN is required. Each year requires 10 values per line and 37 lines of input. The model, as written, will only accept a minimum of 2 years and a maximum of 5 years of precipitation data. For best results, at least 5 years of precipitation data should be used.

When the user enters the program, the following commands are given to input the data files.

```
ARE YOU USING DEFAULT CLIMATOLOGICAL DATA?
ENTER YES OR NO
I>NO


 DO YOU WANT CLIMATOLOGY, HYDROLOGY OR OUTPUT?

ENTER 1 FOR CLIMATOLOGICAL INPUT,
      2 FOR HYDROLOGICAL INPUT,
      3 FOR OUTPUT OR
      4 TO STOP PROGRAM.


I>1

************************************************************************
          USE ONLY ENGLISH UNITS OF ACRES,INCHES, AND DAYS
                     UNLESS OTHERWISE INDICATED

#################################ENTER ALL ZEROS########################
************************************************************************
          A VALUE **MUST** BE ENTERED FOR EACH COMMAND
************************************************************************



DO YOU WANT TO ENTER PRECIPITATION DATA?
    ANSWER YES OR NO


I>YES


############################ NOTICE ############################

   PRECIPITATION INPUT WILL ACCEPT ONLY **FIVE** (5) YEARS MAXIMUM
            AND ONLY **TWO** (2) YEARS MINIMUM
```

The climatological module input data includes the precipitation, mean monthly temperature and solar radiation, and the growth characteristics of the vegetative cover in terms of the LAI. The hydrologic module input data include site, soil-water, and evaporation characteristics. The output module prints tables of the input and simulated data.

Mean monthly air temperature and mean monthly solar radiation (insolation) data are required inputs (12 values each) which are used to compute the daily evapotranspiration. Temperature data are regularly published by the National Weather Service. Solar radiation data in Langleys/day can be obtained from the Climatic Atlas of the United States* or from Table 2 for specific locations. For each year of input, the following commands are printed, and for this example the year of the data to be input is 74.

```
ENTER DAILY RAINFALL .
ENTER YEAR OF RAINFALL (EXAMPLE  76)
OR ZERO (Ø) TO END RAINFALL INPUT.

I>74

**********************************************************************
**********************************************************************

         WHEN PRECIPITATION DATA ARE TO BE INPUT,
         IF THE ENTIRE FIELD OF TEN (1Ø) VALUES
         ARE ZERO (Ø) ONLY ONE NEED BE ENTERED
         BEFORE CARRIAGE RETURN (RIGHT JUSTIFIED)

         IF YOU HAVE A LINE PARTIALLY FILLED WITH
         PRECIPITATION DATA AND THE REMAINDER IS TO
         BE FILLED WITH ZEROS *ONLY* A CARRIAGE
         RETURN IS REQUIRED

**********************************************************************
**********************************************************************
```

* U. S. Dept. of Commerce, 1968, "Climatic Atlas of the United States," U. S. Govt. Printing Office, Washington, D. C.

CLIMATOLOGIC INPUT

DAILY PRECIPITATION (INCHES)

1 YEAR (10 VALUES/LINE, 37 LINES)

YEAR:__________

1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										
31										
32										
33										
34										
35										
36										
37										

(continued)

Figure 8. Data input requirements (no defaults).

Figure 8. (continued)

YEAR: __________

1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									
32									
33									
34									
35									
36									
37									

(continued)

Figure 8. (continued)

Month	Mean Monthly Temperature (°F)	Mean Monthly Insolation (Langleys/Day)
January		
February		
March		
April		
May		
June		
July		
August		
September		
October		
November		
December		

Leaf Area Index Values

Day	Area
1	
366	

(continued)

Figure 8. (concluded)

Hydrological Input

Study Title: ______________________________

Area Location: ______________________________

Today's Date: ______________________________

Date of first storm event (Julian date) ______________________________
(example = 73038, 1973 and 38 Julian day)

Surface area of solid waste site . . . . __________ acres

Hydraulic conductivity of vegetative soil . . . . __________ in./hr

Hydraulic conductivity of barrier soil . . . . __________ in./hr

Depth of soil cover . . . . __________ inches

Depth of vegetative layer . . . . __________ inches

Depth of barrier layer . . . . __________ inches

Depth of solid waste . . . . __________ inches

Soil porosity of vegetative soil . . . . __________ vol/vol

Soil porosity of barrier soil . . . . __________ vol/vol

SCS curve number . . . . __________

Channel slope . . . . __________ ft/ft

Hydrologic channel length . . . . __________ ft

Available water capacity of vegetative soil . . . . __________ vol/vol

Available water capacity of barrier soil . . . . __________ vol/vol

Winter cover factor . . . . __________

Evaporation coefficient of vegetative soil . . . . __________

Evaporation coefficient of barrier soil . . . . __________

At this point, 37 lines of data, with 10 values per line, are entered in the following manner:

```
ENTER RAINFALL DATA OF 10 VALUES PER LINE
WITH 37 LINES PER YEAR.

ENTER LINE  1

I>.04 0 .25 1.7 .47 1.07 1.67 .06 .02
ENTER LINE  2

I>0 0 0 0 0 .11 .1 0 0 .11
ENTER LINE  3

I>0
ENTER LINE  4

I>0 0 0 .05
ENTER LINE  5

I>0 .04 0 0 0 .85 .26
ENTER LINE  6

I>1.0 .04 0 0 0 .85 .06
ENTER LINE  7

I>0
ENTER LINE  8

I>0 0 0 0 .01 .26 0 0 .02
ENTER LINE  9

I>.12 .02 0 .01
ENTER LINE 10

I>0
```

After each year's entry, the heading is printed; however, when all the precipitation data have been entered (2 year minimum and 5 year maximum), a zero is entered at the prompt I> and all input data previously entered are printed so that the user can detect and change any input errors.

```
ENTER LINE 35

I>Ø Ø Ø Ø Ø .1
ENTER LINE 36

I>Ø
ENTER LINE 37

I>.99 .99 .99 .99 .99

ENTER DAILY RAINFALL .
ENTER YEAR OF RAINFALL (EXAMPLE  76)
OR ZERO (Ø) TO END RAINFALL INPUT.


I>Ø
```

If an error has been made, as in the example (year 74 and on line 37) where five 0.99's were incorrectly entered, the following questions would have to be answered and the corrected precipitation values entered:

```
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          2Ø
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          21
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          22
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          23
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          24
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          25
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          26
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          27
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          28
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          29
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          3Ø
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          31
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          32
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          33
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          34
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ  .1Ø Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          35
74 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          36
74  .99  .99  .99  .99  .99 Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ Ø.ØØ          37
```

```
                ARE THESE VALUES CORRECT?
                      DO YOU WANT TO USE THEM?
                      ANSWER YES OR NO


I>NO

ENTER YEAR OF INTEREST

I>74

ENTER LINE OF INTEREST


I>37

 ENTER 10 CORRECTED PRECIPITATION VALUES

I>0 0 0 0 .01

 ARE THERE ANY MORE ERRORS?
  ANSWER YES OR NO
I>NO
```

The precipitation tables are reprinted and the question as to their correctness is asked before proceeding to the entry of mean monthly temperature data.

After the entry of data files for daily precipitation, mean monthly temperature, mean monthly solar radiation, and LAI (see Figure 8), the program reprints the input data and asks, "Do you want to change them?". The user has the option of changing any of the data entered before advancing to the next data entry. The following commands are used to enter mean monthly temperature data:

```
DO YOU WANT TO ENTER TEMPERATURE DATA?
     ANSWER YES OR NO


I>YES


ENTER 6 TEMPERATURE VALUES
      JAN.-JUNE (DEGREES F.)


I>62.7
I>61
I>68.7
I>59.6
I>69.1
I>7Ø.7


ENTER 6 TEMPERATURE VALUES
      JULY-DEC. (DEGREES F.)


I>66.9
I>7Ø.Ø
I>78.5
I>71.4
I>57.5
I>52.6

THESE ARE THE INPUT TEMPERATURES VALUES
         JAN.-JUNE        JULY-DEC.

             62.7             66.9
             61.Ø             7Ø.Ø
             68.7             78.5
             59.6             71.4
             69.1             57.5
             7Ø.7             52.6



DO YOU WANT TO CHANGE THEM?
      ENTER YES OR NO


I>NO
```

To enter solar radiation (13) data, the following commands are used (the city of Los Angeles, California, is the example):

```
DO YOU WANT TO ENTER SOLAR RADIATION DATA?
     ANSWER YES OR NO


I>YES


ENTER 6 SOLAR RADIATION VALUES
      JAN.-JUNE (LANGLEYS/DAY)


I>248
I>331
I>397
I>457
I>506
I>486


ENTER 6 SOLAR RADIATION VALUES
      JULY-DEC. (LANGLEYS/DAY)


I>497
I>464
I>389
I>320
I>277
I>221

THESE ARE THE INPUT RADIATION VALUES
         JAN.-JUNE        JULY-DEC.

            248.0          497.0
            331.0          464.0
            397.0          389.0
            457.0          320.0
            506.0          277.0
            486.0          221.0



DO YOU WANT TO CHANGE THEM?
       ENTER YES OR NO


I>NO
```

The LAI is used to estimate the amount of vegetative ground cover of a particular crop and is an effective partition of the plant transpiration to soil evaporation ratio which is used in both model options. For example, a conceptual understanding of LAI is made by considering a one square foot area of a soil surface with no vegetation (bare ground) on the 5th of January. However, 100 days later on the 15th of April, vegetation has grown on the example area. When viewing this area from above, the veget ition now covers 50 percent of the surface area which gives an LAI value of 1.50. Table 3 gives some leaf area index distributions for normalized times through a growing season for several crops. These values must be apportioned between actual local planting and harvesting dates.* Points for day = 1 and day = 366 are necessary for model operation. There must be exactly 13 LAI values entered for a specific vegetative ground cover. The program interpolates between the LAI values for daily estimates.

TABLE 3. TYPICAL LEAF AREA INDEX DISTRIBUTIONS FOR VARIOUS VEGETATIVE COVERS (9)

Portion of growing season	LAI**				
	Corn	Oats	Wheat	Grass†	Soybeans
0.0	0.00	0.00	0.00	0.00	0.00
0.1	0.09	0.42	0.47	1.84	0.15
0.2	0.19	0.84	0.90	3.00	0.40
0.3	0.23	0.90	0.90	3.00	2.18
0.4	0.49	0.90	0.90	3.00	2.97
0.5	1.16	0.98	0.90	3.00	3.00
0.6	2.97	2.62	1.62	3.00	2.96
0.7	3.00	3.00	3.00	2.70	2.92
0.8	2.72	3.00	3.00	1.96	2.30
0.9	1.83	3.00	0.96	0.96	1.15
1.0	0.00	0.00	0.00	0.50	0.50

** Good production assumed for all crops. LAI should be lowered for poor production.

† No grazing assumed. LAI must be lowered if grazed or not managed.

* USDA, 1941, "Climate and Man, Yearbook of Agriculture," U. S. Govt. Printing Office, Washington, D. C.

To enter the data in the model, the following approach is required:

```
DOES THE SOIL SURFACE HAVE VEGETATION?
ENTER YES OR NO


I>YES


DO YOU WANT TO ENTER LEAF AREA INDEX DATA?
     ANSWER YES OR NO


I>YES
```

The condition for bare ground is entered automatically if no vegetation is to be required. Some of the input and inspection of the input follows.

```
ENTER TWO VALUES,
      ONE FOR DAY OF MEASUREMENT(JULIAN DAY)
      AND ONE FOR LEAF AREA INDEX.
     (EXAMPLE, 100  1.65)
```

```
I>1  Ø
ENTER ANOTHER SET OF VALUES

I>41  Ø
ENTER ANOTHER SET OF VALUES

I>59  .61
ENTER ANOTHER SET OF VALUES

I>77  1
ENTER ANOTHER SET OF VALUES

I>95  1
ENTER ANOTHER SET OF VALUES

I>113  1
ENTER ANOTHER SET OF VALUES

I>131  1
ENTER ANOTHER SET OF VALUES

I>149  1
ENTER ANOTHER SET OF VALUES

I>167  .9
ENTER ANOTHER SET OF VALUES

I>185  .71
ENTER ANOTHER SET OF VALUES

I>203  .65
ENTER ANOTHER SET OF VALUES

I>221  Ø
ENTER ANOTHER SET OF VALUES

I>366  Ø
```

```
THESE ARE THE DAYS AND LAI VALUES INPUT
                DAYS          LAI


                   1          0.00
                  41          0.00
                  59           .61
                  77          1.00
                  95          1.00
                 113          1.00
                 131          1.00
                 149          1.00
                 167           .90
                 185           .71
                 203           .65
                 221          0.00
                 366          0.00

DO YOU WANT TO CHANGE THEM?
        ENTER YES OR NO

I>NO

******************************************************************************
                CLIMATOLOGICAL INPUT IS COMPLETE
******************************************************************************
```

At this point, the user can make appropriate corrections to the data set if so required. It should be remembered that 13 LAI values must be entered, no more--no less.

This completes the entry of data into the climatological module and data are now to be input into the hydrological module as requested.

```
 DO YOU WANT CLIMATOLOGY, HYDROLOGY OR OUTPUT?

ENTER 1 FOR CLIMATOLOGICAL INPUT,
      2 FOR HYDROLOGICAL INPUT,
      3 FOR OUTPUT OR
      4 TO STOP PROGRAM.


I>2
```

The program user now enters the study title, site location, and today's date. This information is used for table headings in the output only and is not used in the model operations.

```
ENTER TITLE ON LINE 1,
      LOCATION OF SOLID WASTE SITE ON LINE 2
      AND TODAY'S DATE ON LINE 3.


I>HYDROLOGY OF A SOLID WASTE DISPOSAL SITE (EXAMPLE 1)
I>LOS ANGELES, CALIFORNIA -- 10 MILES NORTH OF DOWN TOWN
I>18 APRIL  1980
```

The user must now enter the year and Julian date of the day before the first storm event. Thus, if the first year's data are only a partial data set with, say, the first 138 days set to zero for 1973 data, this entry would follow as 73138. But, for the Los Angeles data set, it rained on 1 January 1974, and the entry appears as:

```
ENTER YEAR AND DATE OF FIRST STORM EVENT (JULIAN DATE)
(EXAMPLE= 73138, 1973 AND 138 JULIAN DAY)

I>74000
```

If the soil cover has a vegetative layer plus a barrier layer, then this information is entered here:

```
DO YOU HAVE A LAYERED SOIL COVER?
(ONLY 2 LAYERS PERMITTED VEGETATIVE PLUS BARRIER)
        ENTER YES OR NO


I>YES

ENTER TOTAL DEPTH OF SOIL COVER (INCHES)
 (VEGETATIVE PLUS BARRIER)


I>36
```

```
ENTER VALUES FOR VEGETATIVE SOIL COVER

ENTER 4 VALUES, HYDRAULIC CONDUCTIVITY, (IN/HR)
                 SOIL POROSITY, (VOL/VOL)
                 EVAPORATION COEFFICIENT AND
                 AVAILABLE WATER CAPACITY (VOL/VOL)


I>.51
I>.41
I>4.5
I>.13

ENTER DEPTH OF BARRIER SOIL (INCHES)


I>12

ENTER VALUES FOR BARRIER SOIL COVER

ENTER 4 VALUES, HYDRAULIC CONDUCTIVITY, (IN/HR)
                 SOIL POROSITY, (VOL/VOL)
                 EVAPORATION COEFFICIENT AND
                 AVAILABLE WATER CAPACITY (VOL/VOL)


I>.ØØ4
I>.29
I>3.1
I>.Ø64
```

The effective hydraulic conductivity (14,15) of the vegetative and barrier soil must be entered at this point. Experiments and theory suggest that approximations of the variation of this parameter can also be related to soil conditions (9). Thus, the relative value entered for the effective hydraulic conductivity should reflect the conditions of the cover materials. If compaction of the barrier soil is requested, then its effect on the hydraulic conductivity should be estimated. The actual value of the hydraulic conductivity to reproduce the same runoff as predicted by the SCS curve number method (16) depends to a large extent on the storm depth and duration. Thus, for daily values, the hydraulic conductivity is moderately sensitive and the quality of the input is generally only fair to good. Should measured values from laboratory or field data be available, they can be used to develop better parameter estimates.

The soil porosity is usually half water and half air. When a soil is totally saturated, the volume of water to volume of solid material (mineral plus organic matter) is the porosity. The total pore space for soils is between 0.50 to 0.60, being somewhat less for sandy soils and somewhat greater for loamy soils with high contents of organic matter.

The SCS curve number technique is the method used for predicting runoff from daily rainfall. Figure 9 shows a graphical example of estimating the curve number from the minimum infiltration rate (MIR) if not known from other sources. The evaporation coefficient (9) is a cover soil evaporation parameter dependent on soil water transmission characteristics and is used to fraction the evapotranspiration (ranges from about 3.3 to 5.5 $mm/d^{1/2}$). It is suggested that a value of 4.5 be used for loamy soils, 3.5 for clays, and 3.3 for sands; however, it cannot be less than 3.0. The available water capacity, AWC, was previously discussed in conjunction with Figure 3.

The surface area of the solid waste site, channel slope, and hydrologic channel length should be measured from a map or design plan, when available. The hydrologic channel length is determined by measuring the distance from the solid waste site surface outlet along the main flow path to the most distant point on the solid waste site boundary.

```
ENTER 2 VALUES, SURFACE AREA OF SOLID WASTE SITE (ACRES),
                AND DEPTH OF SOLID WASTE (INCHES).


I>6
I>18Ø
```

The next question the program asks is whether or not an "impermeable liner" was used. The discussion of the usage of an "impermeable liner" was presented under the default data option and will not be repeated at this point.

```
IS THERE AN IMPERMEABLE LINER AT THE INTERFACE?
       ENTER YES OR NO


I>NO


ENTER 3 VALUES, SCS CURVE NUMBER,
                 CHANNEL SLOPE AND
                 HYDROLOGIC SLOPE LENGTH (FT).


I>79.3
I>.Ø22
I>541
```

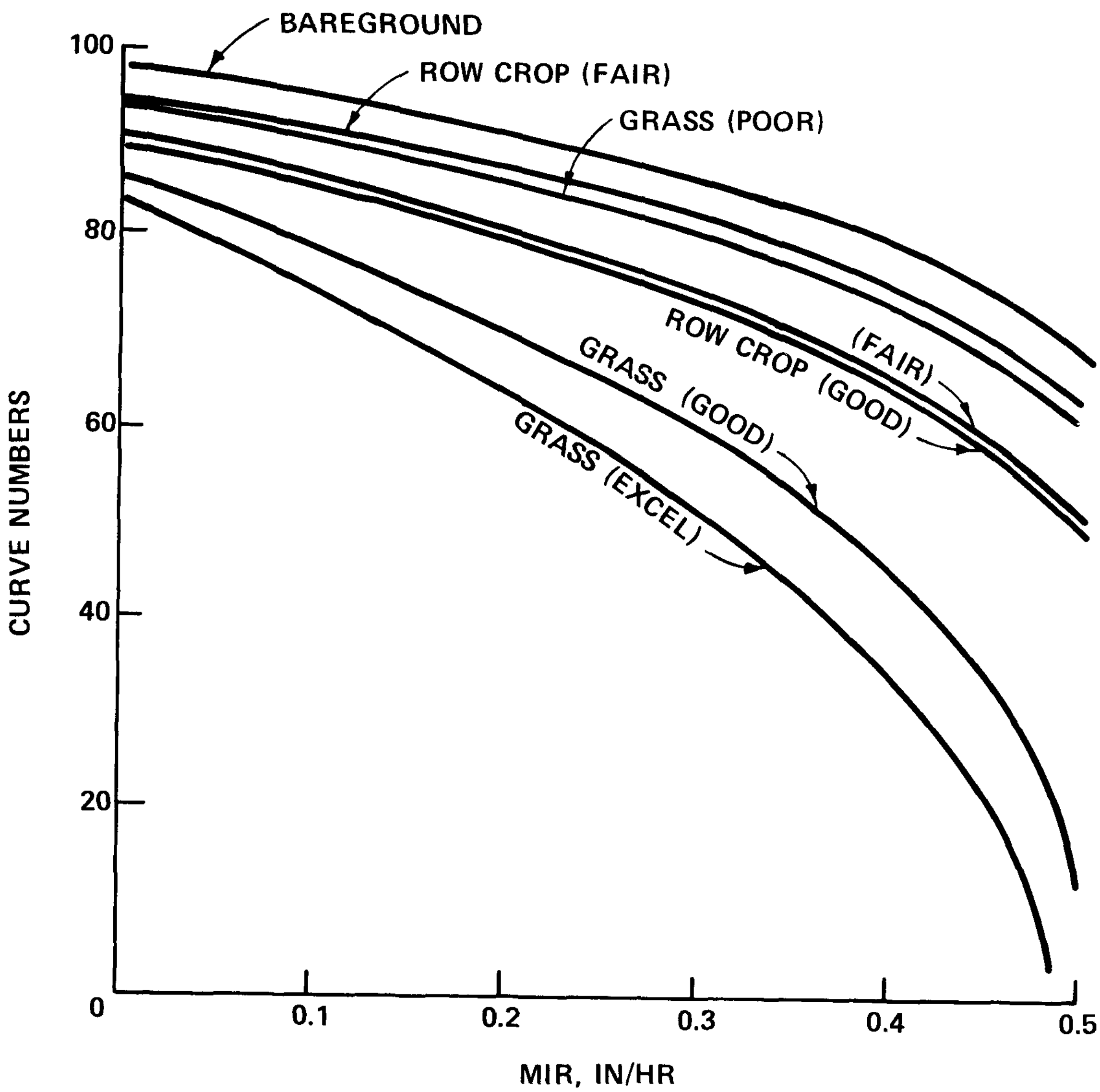


Figure 9. SCS curve number for several vegetative covers in relation to the minimum infiltration rate (MIR)

Lutton et al. (6) have presented an excellent review of the SCS curve number technique with graphs and tables for estimating runoff curve numbers for a wide variety of soil and moisture conditions.

The winter cover factor is used to reduce soil evaporation as a result of ground cover, for example, dormant grass or a heavy crop residue (mulch). The value of the winter cover factor usually varies from 0.5 for an excellent grass cover to 1.0 for bare ground or harvested row crop (9). The value must be estimated for each type of vegetative cover.

```
ENTER WINTER COVER FACTOR

I>.6
```

OUTPUT

If 5 years of climatological data are input, the printing of the output starts with the first year entered. For example, if climatological data were entered for 1974, 1975, 1976, 1977, and 1978, but only 2 years of printed output were requested, the program would print only the 1974 and 1975 data sets. At this time, the consecutive output dates cannot be user specified. In addition, the user input or default data files, once entered, will remain on line indefinitely or until the user changes the files or terminates the program. The output for both the default and input data options are the same, and the questions about output follow:

```
 DO YOU WANT CLIMATOLOGY, HYDROLOGY OR OUTPUT?

ENTER 1 FOR CLIMATOLOGICAL INPUT,
      2 FOR HYDROLOGICAL INPUT,
      3 FOR OUTPUT OR
      4 TO STOP PROGRAM.


I>3

HOW MANY YEARS OF OUTPUT DO YOU WANT?

TWO (2) YEARS MINIMUM AND
FIVE (5) YEARS OF PRECIPITATION ARE MAXIMUM


I>5


DO YOU WANT DAILY PRECIPITATION OUTPUT?
(NO PRINTS THE ANNUAL SUMMARIES)
ANSWER YES OR NO


I>YES
```

Hydrologic output is composed of input information and calculated values. Daily and annual summaries of simulated output data are available for both options. Output for the simulation period includes monthly totals, means of rainfall, runoff, evapotranspiration, drainage, and average soil-water content. The data include annual totals for each component.

For the hydrologic output, first the program prints the title of the project, the location, and current date of the run. Then for reference purposes, the program prints the input values. The input of the climatological module is printed first and then the input of the hydrological module. LAI-DAYS is an indicator of the potential growth index. It is obtained by integrating the LAI versus time (days) data and is used to check the model

HYDROLOGIC OUTPUT

(DAILY PRECIPITATION VALUES)

HYDROLOGY OF A SOLID WASTE DISPOSAL SITE (EXAPLE 1)
LOS ANGELES, CALIFORNIA -- 10 MILES NORTH OF DOWNTOWN
18 APRIL 1980

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
59.33	59.71	61.71	64.78	68.10	70.79
72.12	71.74	69.74	66.67	63.35	60.66

MONTHLY MEAN RADIATION, LANGLEYS PER DAY

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
265.39	315.13	382.99	450.79	500.36	518.41
500.11	450.37	382.51	314.71	265.14	247.09

LEAF AREA INDEX TABLE

DATE	LAI
1	0.00
41	0.00
59	.61
77	1.00
95	1.00
113	1.00
131	1.00
149	1.00
167	.90
185	.71
203	.65
221	0.00
366	0.00

```
                 WINTER C FACTOR =      .60
                 LAI-DAYS           = 141.66
SOLID WASTE AREA                       =     6.00000 ACRES
EFFECTIVE HYDRAULIC COND SOIL          =      .51000 IN/HR
EFFECTIVE HYDRAULIC COND BARRIER       =      .00400 IN/HR
FIELD CAPACITY                         =      .52500 VOL/VOL
CHANNEL SLOPE                          =      .02200 FT/FT
SCS CURVE NUMBER                       =   79.30000
SITE CHANNEL LENGTH                    =  541.00000 FT
UPPER LIMIT OF STORAGE                 =     3.49200 IN
INITIAL SOIL WATER STORAGE             =     1.74600 IN
```

UPPER LIMIT OF STORAGES IN COVER (INCHES)

DEPTH	1.000	6.000	12.000	18.000	24.000	30.000	36.000
	.130	.650	.780	.780	.384	.384	.384

INITIAL SOIL WATER STORAGE IN COVER (INCHES)

DEPTH	1.000	6.000	12.000	18.000	24.000	30.000	36.000
	.065	.325	.390	.390	.192	.192	.192

An example of daily output is given which shows the amount of water that percolated through a vegetative soil cover of a fine sandy loam soil, 7, and a barrier soil of clay loam texture, 12, which had been compacted. However, no "impermeable liner" was used so that all the water that infiltrated and percolated to the interface of the final soil cover and solid waste material drained into and out of the solid waste material (waste drain).

DATE JULIAN	RAINFALL INCHES	RUNOFF INCHES	COVER DRAIN INCHES	WASTE DRAIN INCHES	AVERAGE TEMP. DEG. F.	AVERAGE SOIL W. VOL/VOL	ACCUM. ET INCHES
78004	.21	0.00	.0135	.0628	55.81	.28	.28
78005	.76	.23	.0062	.0290	55.63	.29	.35
78007	1.02	.78	.0121	.0566	55.52	.29	.50
78010	1.45	1.07	.0181	.0856	55.35	.29	.71
78011	1.09	1.02	.0053	.0252	55.23	.29	.78
78015	1.51	.90	.0225	.1087	55.08	.29	1.07
78016	.13	.06	.0052	.0253	54.94	.29	1.15
78017	1.09	.87	.0066	.0320	54.89	.29	1.22
78018	.02	0.00	.0052	.0253	54.85	.29	1.29
78020	.20	0.00	.0100	.0493	54.78	.29	1.44
78037	1.42	0.00	.0679	.3557	54.48	.27	2.46
78038	.05	0.00	.0045	.0238	54.32	.29	2.55
78039	.89	.55	.0061	.0322	54.31	.29	2.65
78040	.70	.60	.0048	.0256	54.31	.29	2.74
78041	.92	.65	.0061	.0322	54.31	.29	2.84
78042	.82	.72	.0048	.0257	54.31	.29	2.94
78044	.75	.31	.0104	.0562	54.32	.29	3.15
78045	.23	.12	.0048	.0257	54.34	.29	3.26
78058	.20	0.00	.0487	.2768	54.47	.27	4.49
78059	.07	0.00	.0028	.0158	54.69	.25	4.59
78060	1.61	.03	.0037	.0210	54.73	.29	4.73
78061	1.48	1.18	.0057	.0326	54.77	.29	4.87
78062	.42	.28	.0043	.0248	54.82	.29	5.01
78063	.19	0.00	.0042	.0244	54.86	.29	5.16
78064	2.27	1.93	.0060	.0351	54.91	.29	5.30
78065	.02	0.00	.0042	.0247	54.96	.29	5.45
78069	.13	0.00	.0157	.0937	55.10	.28	6.01
78071	.04	0.00	.0073	.0438	55.28	.27	6.32
78081	.06	0.00	.0261	.1632	55.70	.25	7.29
78082	.58	0.00	.0011	.0067	56.12	.25	7.43
78090	.28	0.00	.0024	.0158	56.51	.23	8.32
78091	.28	0.00	0.0000	0.0000	56.93	.23	8.50
78095	.23	0.00	0.0000	0.0000	57.18	.23	8.93
78097	.27	0.00	0.0000	0.0000	57.48	.23	9.17
78106	.69	0.00	0.0000	0.0000	58.08	.22	9.51
78116	.04	0.00	0.0000	0.0000	59.17	.22	10.02
78248	.03	0.00	0.0000	0.0000	66.19	.22	10.05
78249	.36	0.00	0.0000	0.0000	68.35	.23	10.22
78294	.04	0.00	0.0000	0.0000	66.51	.22	10.45
78315	.10	0.00	0.0000	0.0000	62.91	.22	10.54
78316	.26	0.00	0.0000	0.0000	61.53	.23	10.63
78318	.32	0.00	0.0000	0.0000	61.34	.23	10.73
78326	.40	0.00	0.0000	0.0000	60.72	.23	10.88
78327	.12	0.00	0.0000	0.0000	60.15	.24	10.97
78336	.01	0.00	0.0000	0.0000	59.54	.24	11.08
78351	.06	0.00	0.0000	0.0000	58.15	.24	11.26
76352	.10	0.00	0.0000	0.0000	57.29	.24	11.33
78353	.61	0.00	0.0000	0.0000	57.19	.25	11.41
78354	.05	0.00	0.0000	0.0000	57.09	.25	11.45

Daily output is printed only for days when precipitation occurred. The runoff is the predicted overland flow. The cover drainage is only that which flows out of the cover and does not percolate into the waste drainage. The average temperature is that predicted by the model and the accumulative evapotranspiration carries through the model and keeps track of the potential evapotranspiration and the available water capacity. The average soil water is the fractional water content (volume basis) of the final soil cover. This is an average of each of seven soil storages permitted by the CREAMS model for the final soil cover. The CREAMS model (9) permits the top storage depth to equal 1/36 of the final soil cover depth, 2nd storage depth to equal 5/36 of the final soil cover depth, and the other storage depths to equal 1/6 of the final soil cover depth. For example, if the final soil cover had a depth of 24 inches, then the 7 depths for computational purposes would be 0.67, 3.33, 4, 4, 4, 4, 4 inches, respectively. The program apportions these fractions which are printed in the initial input data along with the depth considered.

The annual totals for the particular year in question is then printed and the water budget balance is presented (should be about zero) which shows whether or not the parameters were properly computed and time changes correctly evaluated.

ANNUAL TOTALS FOR 1978 (INCHES)		
PRECIPITATION	=	24.58
PREDICTED RUNOFF	=	11.30
TOT SOIL DRAIN	=	.3462
TOT WASTE DRAIN	=	1.8550
TOTAL ET	=	11.58
BEGIN SOIL WATER	=	2.51
FINAL SOIL WATER	=	2.01
WATER BUDGET BAL.	=	0.00

Next, the average annual values are printed for a quick glimpse at the model output, in this case, 5-year averages.

AVERAGE ANNUAL VALUES (INCHES)		
PRECIPITATION	=	13.52
PREDICTED RUNOFF	=	3.67
TOT SOIL DRAIN	=	.4539
TOT WASTE DRAIN	=	.5641
TOTAL ET	=	8.68

For the second phase of the data output, the heading is reprinted and monthly averages for each year and for monthly annual averages are printed as shown for 1978 and 5-year annual averages.

1978

MONTH	RAIN	RUNOFF	ET	SOIL DRAIN	WASTE DRAIN	AVG SW
JAN	7.48	4.93	2.17	.1048	.4997	2.16
FEB	6.05	2.96	2.42	.1609	.8696	1.73
MAR	7.08	3.41	3.73	.0806	.4857	1.19
APR	1.51	0.00	1.71	0.0000	0.0000	.06
MAY	0.00	0.00	0.00	0.0000	0.0000	0.00
JUN	0.00	0.00	0.00	0.0000	0.0000	0.00
JUL	0.00	0.00	0.00	0.0000	0.0000	0.00
AUG	0.00	0.00	0.00	0.0000	0.0000	0.00
SEP	.39	0.00	.39	0.0000	0.0000	.06
OCT	.04	0.00	.04	0.0000	0.0000	.00
NOV	1.20	0.00	.59	0.0000	0.0000	.31
DEC	.83	0.00	.53	0.0000	0.0000	.71
TOT/AVE	24.58	11.30	11.58	.35	1.86	.52

ANNUAL AVERAGES

MONTH	RAIN	RUNOFF	ET	SOIL DRAIN	WASTE DRAIN	AVG SW
JAN	3.30	1.98	1.32	.1768	.1812	1.36
FEB	2.36	.69	1.57	.1585	.2106	1.08
MAR	2.92	.68	2.57	.0711	.1170	.65
APR	.63	0.00	.71	0.0000	0.0000	.02
MAY	.52	.00	.52	0.0000	0.0000	.06
JUN	.06	0.00	.06	0.0000	0.0000	.00
JUL	.00	0.00	.00	0.0000	0.0000	.00
AUG	.50	.02	.27	0.0000	0.0000	.13
SEP	.45	0.00	.36	0.0000	0.0000	.31
OCT	.46	.01	.32	0.0000	0.0000	.29
NOV	.42	0.00	.39	.0196	.0298	.41
DEC	1.88	.29	.55	.0279	.0255	.76
TOT/AVE	13.52	3.67	8.66	.45	.56	.42

ENTER -HYDGO TO RERUN PROGRAM OR
ENTER BYE TO LOGOFF COMPUTER SYSTEM

C>BYE

If the programming session is completed, then the logoff command BYE is typed at the next prompt. However, if the user would like to reenter the hydrologic model using the same climatological data, the user should enter -HYDGO. At this point, the program heading would be reprinted and the beginning questions asked (Figure 5). If the user would like to change the climatological input data, -HYDBAT should be entered and the user should follow the steps outlined in Figure 5 (page 14).

SECTION 4

CONCLUSIONS

Runoff is significantly affected by the type of soil and vegetative cover, as well as management practices, and they affect the routing of runoff water from the final soil cover surface. A loam soil with an excellent well-managed grass cover can reduce percolation into the solid waste to negligible amounts. Management practices during the growing season affect the hydraulic runoff through changes in the LAI. Increasing LAI causes greater water use (higher evapotranspiration), and thus soil-water storage is reduced along with a significant reduction in percolation and eventually leachate.

In addition, increasing the SCS curve number increases the amount of surface runoff. Paved and impervious water surfaces are always a curve number of 100, whereas a curve number of 1 would imply a totally porous system.

FUTURE CONSIDERATIONS

1. Sensitivity and verification analysis should be accomplished to compare model output to solid waste disposal site measurements.

2. Interaction between default data and input data usage: This would allow the user to select default data for the input data mode and permit broader model usage.

3. Program scenarios: This would permit the user to change the vegetative cover, temperature, solar radiation, soil porosity, hydraulic conductivity, etc., on a year to year basis.

4. Design a synthetic storm on a 25-, 50-, or 100-year probability of occurrence using hourly records (duration-frequency data) to design and evaluate solid waste disposal sites under intense storm conditions.

5. To estimate the amount of erosion anticipated on the final cover soil and vegetation which can be accomplished by using the output of the surface runoff.

6. A nutrient and pesticide routine can be added to evaluate the "Best Management Practices" of the vegetative cover and thus increase evapotranspiration and reduce percolation.

7. Chemical leachate algorithms can be added to estimate specific parameters that would accompany the leachate.

8. Gaseous diffusion algorithms can be added to evaluate gaseous losses through the soil cover.

9. An economic package can be added to estimate the current cost of construction and maintenance of the solid waste disposal site using various materials and management practices.

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APPENDIX A

HYDROLOGIC SIMULATION

Model development will be presented in this section for daily water movement on the surface and through the final cover soil. The following description of the principles on which the model was developed is from Knisel (9), SCS-NEH (14), and Hjelmfelt and Cassidy (16). In the model, precipitation is separated into runoff, evapotranspiration, and subsurface drainage to maintain a continuous water balance.

"Computerized rainfall-runoff models have been used extensively since the mid-50's. However, confusion and misunderstanding over their application still exist. There are those who will not accept the results of any model, no matter how well documented and verified. At the other extreme, there are those so in awe of computer technology that they accept the results of all such models without adequate scrutiny. These attitudes have promoted the feeling that hydrologic simulation models can only be properly understood by the hydrologist specializing in this seemingly esoteric computer-oriented discipline. There is, however, no merit to that conclusion which often leaves models categorized as intellectual toys."

Mathematical modeling concepts deal with deterministic and stochastic variables. A deterministic variable is one whose temporal and spatial properties are known, i.e., it is assumed that the behavior of a hydrologic variable is definite and its characteristics can be predicted without uncertainty. The HSSWDS model is deterministic in its modeling concepts. A general weakness with most research efforts employing deterministic models is that they have focused on obtaining "best" estimates of runoff and percolation parameters which are then used as the "true" values of the process.

A stochastic variable is one whose properties are governed by purely random-time events, sequential relations, as well as functional relations with other hydrologic variables. Precipitation is an excellent example of a stochastic parameter. It includes all forms of water delivered to the land surface. It may occur in the form of rain, snow, hail, sleet, or dew and the form of precipitation is an important factor in determining its flow path. On the average, precipitation occurs only 5 percent of the time throughout a year and the distribution of precipitation is seldom uniform in space and is never uniform in time.

RUNOFF

During a given rainfall, water is continually being intercepted by trees, plants, root surfaces, etc., and at the same time, transport and evapotranspiration are occurring simultaneously throughout the period. Once rain begins to fall and the initial requirements of infiltration are fulfilled, natural depressions collect the excess rain to form small puddles. In addition, minute depths of water begin to build up on permeable and impermeable surfaces within the waste disposal site. This stored water collects in small rivulets conveying the water into small channels, i.e., overland flow or surface runoff.

The SCS curve number technique (14) was selected (9) for the runoff process for the following reasons: (17)

a) a well established reliable procedure,
b) computationally efficient,
c) required inputs available, and
d) soil types, land use, and management can be estimated.

A plot of the accumulative rainfall versus the accumulative runoff can be used to develop the relation (14) between rainfall, runoff, and retention (the rainfall not converted to runoff). Although rainfall and runoff do not start at the same time (initial abstraction I_a), this relation as shown in Figure A-1 can be expressed as:

$$\frac{F}{S'} = \frac{Q}{P}$$

where

F = actual retention
S' = potential maximum retention ($S' \geq F$)
Q = actual or direct runoff
P = potential maximum runoff ($P \geq Q$)

The retention S' is a constant for a particular storm because it is the maximum that can occur under the existing conditions if the storm continues without limit. The time delay I_a between rainfall and runoff consists mainly of interception, infiltration, and surface storage, all of which occur before runoff begins. Therefore, the initial abstraction I_a is brought into the relation by subtracting it from the rainfall, thus:

$$S' = S - I_a \quad \text{or} \quad S = S' + I_a$$

$$P = P - I_a$$

which is represented by the dashed line in Figure A-1. The retention F (amount that infiltrates) varies because it is the difference between P and Q at any point along the plotted curve, e.g.

$$F = P - Q$$

and

$$F = (P - I_a) - Q$$

where

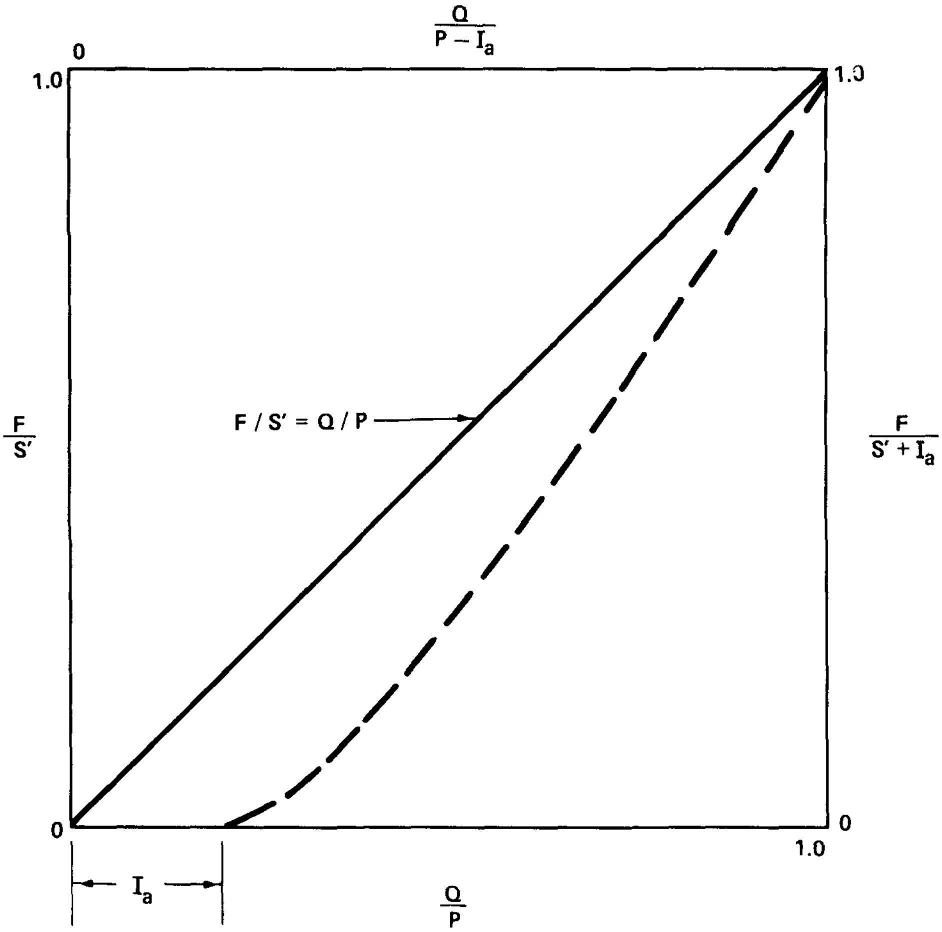

Figure A-1. Relation between the fraction of runoff and the fraction of retention.

$$F \geq S$$

$$Q \leq (P - I_a)$$

Now combining terms, it follows:

$$\frac{(P - I_a) - Q}{S} = \frac{Q}{P - I_a}$$

After algebraic manipulation this expression becomes:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Rainfall and runoff data from a large number of small watersheds showed the relation between I_a and S (which includes I_a) as:

$$I_a = 0.25$$

Thus, the runoff is predicted for daily rainfall for hazardous and solid waste disposal sites using:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (1)$$

where

Q = the daily runoff
P = the daily rainfall
S = the retention parameter

all having the dimensions of length. This equation represents a family of curves of Q on P for a range of values of S from 0 to ∞

Expanding the numerator, applying polynomial division, and dividing through by S yields (18,19):

$$\frac{Q}{S} = \frac{P}{S} - 1.2 + \left(\frac{S}{P + 0.8S}\right)$$

where the term in the brackets is the remainder from division which approaches 0 as P approaches ∞. This relation can be seen in Figure A-2 and shows that the maximum possible amount that can be stored or infiltrated is:

$$P - Q = 1.2S \qquad (2)$$

or

$$\frac{Q}{S} = \frac{P}{S} - 1.2$$

where P approaches ∞. Upon rewriting equation 1 by dividing through by S^2 and rearranging gives:

$$\frac{Q}{S} = \frac{\left(\frac{P}{S} - 0.2\right)^2}{\frac{P}{S} + 0.8}$$

for all $P/S \geq 0.2$. This relation is also shown in Figure A-2 which shows that the value of Q/S approaches P/S - 1.2 asymptotically.

A convenient method was selected to transform the site storage S into curve numbers CN which had a range of 0 to 100 (14).

$$CN = \frac{1000}{10 + S} \qquad (3)$$

As stated the system is in inches and must be converted to use metric units.

The potential site retention parameter S is related to the soil water content (9) by the expression:

$$S = S_{mx}\left(1 - \frac{SM}{UL}\right)$$

where

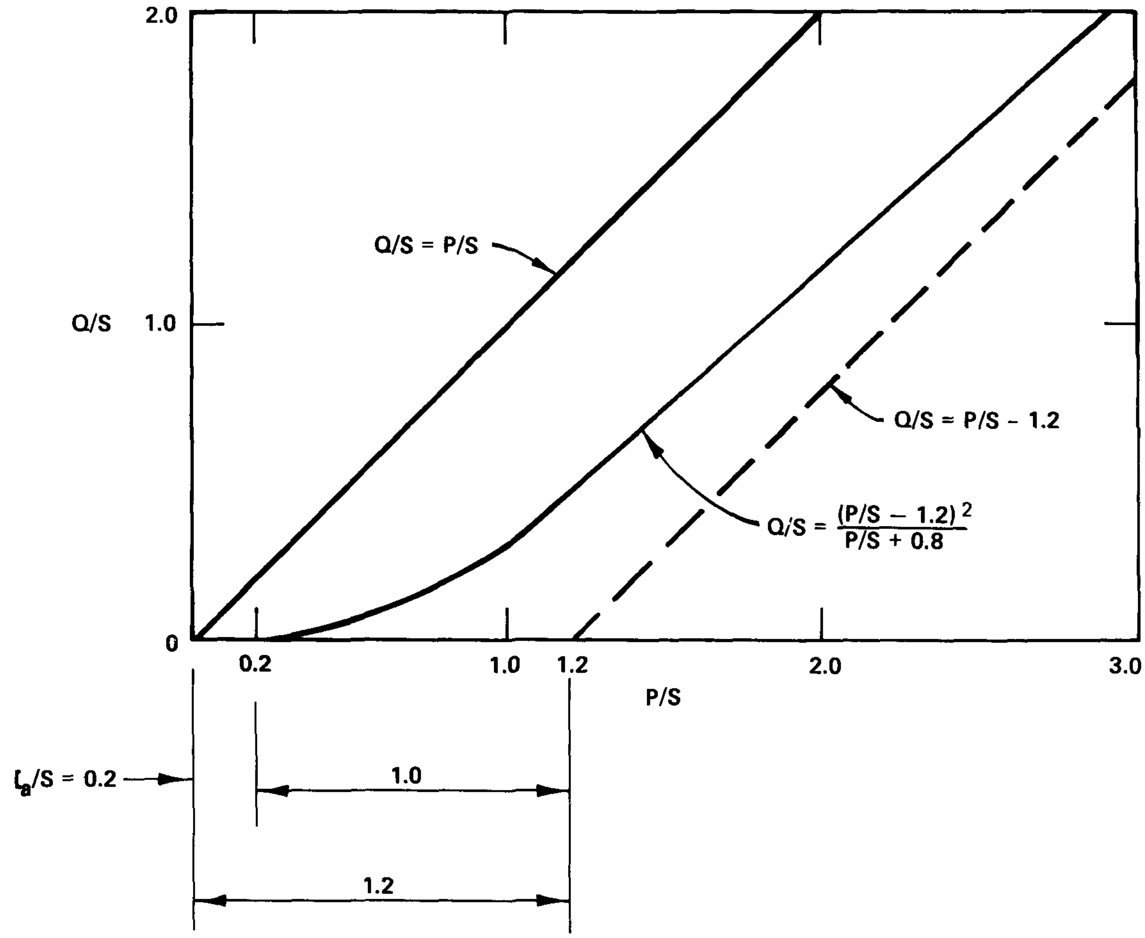

Figure A-2. SCS rainfall-runoff relation standardized on retention parameter S

SM = soil water content in the final soil cover
UL = upper limit of soil water storage
S_{mx} = maximum value of S

The maximum value of S is estimated with the initial moisture condition I for the curve number CN_I by combining equations 2 and 3 as:

$$S_{mx} = 1.2 \left(\frac{1000}{CN_I} - 10 \right)$$

In this model, the moisture condition II was related to CNI using the polynomial:

$$CN_I = -16.91 + 1.348(CN_{II}) - 0.01379(CN_{II})^2 + 0.0001177(CN_{II})^3$$

The hydrologic condition II can be estimated using Figure 8 or the detailed listings in the SCS-HEC (14) manual for the specified final soil cover complex.

To assist in uniformly distributing the soil-water in the profile, a weighting technique was developed that divided the soil profile into seven layers and weighting factors with the equation:

$$S = S_{mx}\left(1 - \sum_{i=1}^{N} W_i \frac{SM_i}{VL_i}\right)$$

where

W_i = weighting factor at depth i

The weighting factors decrease with depth according to the default values: 0.111, 0.397, 0.254, 0.127, 0.063, 0.032, and 0.016. Using this procedure, runoff is predicted for the solid waste disposal site.

Generally, each solid waste disposal site is thought to be unique; however, uniqueness suggests a lack of information as well as a limitation in data gathering capabilities. It is necessary to place in proper perspective the role that such items as rainfall intensity, storm duration, interception, site slope, shape, size, and roughness play upon the time distribution of runoff. Between storms, however, water within the soil also moves upward (capillary rise) because of the flux of water from soil to atmosphere. Also, the vaporization of rainfall or snow resting on the outer plant surfaces is gained by the atmosphere. These processes are usually called evaporation.

EVAPOTRANSPIRATION

The major portion of solar radiation is used in the process of evapotranspiration. Evapotranspiration is the amount of water lost by evaporation and transpiration from a plant surface. For example, if thermal energy is added to a body of water with a free surface, the kinetic energy of the molecules is increased to the extent that some of the water molecules at the surface can overcome their surrounding cohesive bonds and are able to escape across the air/water interface (16). As the molecule of water passes from the liquid to the vapor state, it absorbs heat energy, thus cooling the water left behind. As water enters the soil it becomes either evapotranspiration, storage, or drainage below the final soil cover. In this simulation model a daily time interval is used to evaluate the components of the water balance equation such as,

$$SM_i = SM_{i-1} + FR_i - ET_i - DR_i + M_i$$

where

SM = soil water storage on day i
FR = water entering the soil
ET = evapotranspiration
DR = drainage below the final soil cover
M = amount of snowmelt

When precipitation occurs and the temperature is below freezing, 32°F (0°C), that precipitation is stored in the form of snow. When snow storage exists and the temperature T is above freezing, snowmelt M occurs by the following equation as:

$$M_i = 0.18T$$

where i is the number of days. This relation is used unless M is greater than the amount of surface snow.

To compute the potential evaporation a modification of the Penman method that uses energy balance principles is used in the model as:

$$E_o = \frac{1.28\ \Delta H_o}{\Delta + \gamma}$$

where

E_o = potential evaporation

Δ = slope of the saturation vapor pressure curve at the mean air temperature

H_o = net solar radiation, and

γ = is the psychrometric constant

The slope Δ of the saturation vapor pressure curve for water at the mean air temperature is computed from:

$$\Delta = \frac{5304}{T^2} e^{(21.255-5304/T)}$$

where T is the daily temperature in degrees Kelvin. The net solar radiation H_o is computed from the equation:

$$H_o = \frac{(1 - \lambda)R}{58.3}$$

where

λ = albedo for solar radiation, i.e., 0.23

R = daily solar radiation

When the potential evaporation E_o is known, the potential soil evaporation E_{so} at the soil surface is predicted by:

$$E_{so} = E_o e^{0.4\ LAI}$$

where LAI is the leaf area index defined as the area of plant leaves relative to the soil surface, i.e., a ground cover component. The actual soil evaporation is computed in two stages. In the first stage, soil evaporation is limited only by the energy available at the soil surface and, therefore, is equal to the potential soil evaporation. When the accumulated soil evaporation exceeds the stage one upper limit, the stage two evaporative process begins. The stage one upper limit U is estimated by:

$$U = 9\ (\alpha - 3)^{0.42}$$

where α is a soil evaporation parameter whose values are given in Table 1 for various soil types and water transmission characteristics. Stage two daily soil evaporation is predicted by:

$$E_s = \alpha\ t^{1/2} - \left[(t - 1)^{1/2}\right]$$

where

E_s = soil evaporation for day t

t = number of days since stage two evaporation began

Plant transpiration E_p is computed by the equations:

$$E_p = \frac{E_o\ (LAI)}{3}\ ,\ 0 \le LAI \le 3$$

In general, this relation requires LAI to be on a scale of 0 to 3, where 3 is a complete ground cover, i.e., when $LAI = 3$ then $E_p = E_o$. Occasionally, LAI values found in the literature are determined on different scales but it is a simple matter to recompute them on the required 0-3 scale.

If soil moisture is limiting plant growth, plant transpiration E_{pl} is reduced by the equation:

$$E_{pl} = \frac{E_p * SM}{0.25}\ FC\ ,\ SM \le 0.25\ FC$$

where

E_p = normal plant transpiration

FC = field capacity of the soil

Evapotranspiration, the sum of plant and soil evaporation, cannot exceed the potential evaporation E_o. When the soil-water falls below the wilting point of plants, plant growth is stopped by holding the LAI constant until soil-water becomes available to the plants.

DRAINAGE

The model uses a soil storage routing technique to predict flow through the final soil cover (9). The soil cover is divided into seven layers for routing as follows:

$$Q = \sigma\left(F + \frac{ST}{\Delta t}\right),\ F + \frac{ST}{\Delta t} > FC$$

where

F = the inflow rate

ST = the storage volume

Δt = the routing interval (24 hours)
σ = the storage coefficient

If the inflow plus the storage does not exceed the field capacity FC, drainage cannot occur. The storage coefficient σ is a function of the travel time t through the storage and is expressed by the equation:

$$\sigma = \frac{2\Delta t}{2t + \Delta t}$$

The travel time t is estimated by the equation:

$$t = \frac{SM - FC}{K_{sat}}$$

where

SM = soil water storage

K_{sat} = hydraulic conductivity

Each soil storage layer is subject to evapotranspiration ET losses besides those due to deep drainage. The water use rate U as a function of final cover depth D is given by:

$$U = U_o e^{-4.16D}$$

where U_o is the water use rate at the surface and U is the water use rate by the crop at depth D. The evapotranspiration ET for any depth can be obtained by integrating the above equation:

$$ET = \frac{U_o}{4.16}\left(1 - e^{-4.16D}\right)$$

The value of U_o is determined for the depth D each day.

Drainage from the final soil cover occurs when the saturated volume of the soil exceeds the field capacity. The total soil water storage UL is equal to the porosity Φ times the final soil cover depth D as:

$$UL = \Phi D$$

APPENDIX B

COST BREAKUP OF BOEING COMPUTER SERVICES

1. There are three cost parameters associated with Boeing Computer Services (BCS); connect, storage, and central computer unit costs.

2. These costs are for the Ciber 175 computer system. This is the computer used by the Water Resources Engineering Group.

3. The connect cost occurs during the interactive mode. This cost is $8.50 per hour for the 30 characters per second printed.

4. Disc and magnetic tape are the two types of storage costs. The disc storage cost is $0.007 per day for the first 8,000 sectors; 8,001 sectors to 16,000, the cost is $0.005 per day; 16,001 sectors to 24,000, the cost is $0.0035 per day; 24,001 sectors to 50,000, the cost is $0.0025 per day; 50,001 sectors and up, the cost is $0.0015 per day. The magnetic tape cost for the first 200 sectors is $0.20 per day for Government users. The next 200 sectors are $0.15 per reel per day; over 400 sectors, the cost is $0.10 per reel per day.

5. The computer charging units (CCU) costs depend on the mode interactive or remote batch. The interactive process during prime time is $0.20 per CCU. The CCU costs for the remote batch process for one-half an hour is $0.15 per CCU; for 1 hour, $0.125 per CCU; for 4 hours, $0.10 per CCU; for 8 hours, $0.085 per CCU; for 16 hours, $0.075 per CCU; for 48 hours, $0.06 per CCU.

6. These costs presented above are given without the Government discount (30 percent).

APPENDIX C

SENSITIVITY ANALYSIS

By

R. J. Wills, Jr., E. R. Perrier, and A. C. Gibson

The Hydrologic Simulation of Solid Waste Disposal Sites (HSSWDS) is a simulation model with two input options. The default option inputs climatological and hydrological data from permanent data files stored in the computer, and the data input option permits the user to input all the necessary data from external or measured sources. However, both input options use the same output formats. To facilitate the data handling for the sensitivity analysis only the complete data input option was used.

The climatological and hydrological data were input for Cincinnati, Ohio, area and the values used are shown in Figure C-1. The climatological data consist of 5 years of daily precipitation values and the yearly means are shown in Figure C-2, as well as mean monthly temperature, mean monthly solar radiation, and the Leaf Area Index (LAI) values. In addition, Table C-1 presents the hydrological data for a fictitious solid waste site somewhere in the Cincinnati area.

Table C-1 presents the sensitivity runs to be made for each parameter with other variables being fixed as shown in Figure C-1. A total of 36 computer runs were made to demonstrate the sensitivity of the selected parameters to changes in climatological and hydrological data of the solid waste site. The discussion of each parameter will follow the organization presented in Table C-1.

IMPERMEABLE LINER

As shown in Table C-1 the life of the impermeable liner (see Figure 2 of main text) was varied for values of 5, 10, 15, and 20 years as well as an option of indefinite life. As expected, the impermeable liner is only affected by water that has percolated past a point beyond runoff and evapotranspiration. The main effect upon the liner is whether the percolated water drains from the site as soil drainage or waste drainage (see Figure 2 of main text). As shown in Figure C-3, a liner with a 5-year life accounted for only 9.6 percent of the total percolation for waste drainage the first year; whereas, waste drainage accounted for 89 percent of the total pecolation by the 5th year. By comparison, the indefinite life liner accounted for

CLIMATOLOGIC INPUT

DAILY PRECIPITATION (INCHES)

1 YEAR (10 VALUES/LINE, 37 LINES)

YEAR: 1974

1				0.41				0.16	0.10	0.64
2	0.02							0.03	0.09	0.33
3			0.62			0.42		0.32		
4			0.01				0.42			
5										0.43
6		0.37	0.07		0.21					0.46
7				0.20	0.20	0.29		0.02		1.11
8	0.38			0.57					0.15	0.34
9		0.21	0.01					0.52	0.20	
10	0.53		0.46	0.34	0.05	0.05	0.20	0.78		
11										
12		0.63								0.54
13		1.03						0.19		
14		0.09			0.22		0.73	0.31	0.80	
15		0.14	0.03					0.04	0.42	0.81
16	1.03	0.13				0.15		0.54	0.26	
17	0.18	0.05				0.30	0.03			
18	0.12	0.04	1.55	0.10		0.03			0.15	
19	0.02					0.11			0.34	
20	0.20	2.03					0.57			
21	0.41				0.03					
22				0.16	0.32			0.06		
23		0.05	0.45					0.26	0.80	0.02
24									0.41	2.09
25	0.55	0.49	0.05	0.64	0.57	0.75				
26			0.21	1.02	0.02	1.81				
27			0.03	0.06						0.16
28	0.45	0.09								
29							0.61	0.60	0.05	
30		0.03								
31		0.02	0.01		0.19	0.58	0.08	0.68		
32					0.72			0.05		
33			0.39					0.67	0.02	
34	0.30			0.63	0.14	0.17				
35	0.71	0.23	0.01		0.03	0.04	0.02		0.36	
36			0.17		0.03		0.03	0.36	0.11	
37	0.04				0.42					

(continued)

Figure C-1. Data input requirements for climatological and hydrological modules.

Figure C-1. (continued)

YEAR: 1975

1			0.21			0.03		0.42		1.04
2	0.02	0.01				0.01		0.44	0.14	
3					0.17	0.03		0.07	0.33	0.13
4	0.46	0.07			0.17	0.23	0.04			0.09
5		0.02	0.19				0.13	0.15		
6			0.32	2.32		0.07				
7		0.01				0.22			0.28	0.04
8	0.96	0.01	0.54		0.05		0.44	0.08		
9	0.38	0.98	0.60			0.35	0.69	0.70	0.01	
10		0.27								
11				0.22			0.04		0.55	
12			0.32	1.56	0.53		0.04			0.18
13	0.50		0.13			0.33				
14		0.10			0.01		0.03			
15				0.01	0.02	0.09			0.44	0.13
16	1.12	0.20			1.52	0.02				
17	0.05	0.82	0.08		0.21	0.02		1.41	0.02	
18	0.25						0.67			
19					0.43	0.88			0.41	
20		0.05		0.27	0.54					
21	0.09	0.07				0.04				
22				0.15	0.27	0.07	0.26			
23		1.38	0.14				0.78	0.12		
24	0.03					0.08				
25						0.31		0.24		
26				1.75	0.18				0.07	0.20
27	0.71		0.23			0.50	0.05		0.22	
28										
29	1.18	0.07						0.06		1.90
30	0.38	0.12	0.02					0.02		
31		0.28					0.03			
32	0.19		0.77	0.39						
33				0.04					0.06	0.51
34	0.02		0.14	0.55						0.35
35			0.08			0.05		0.01	0.90	
36				0.04	0.02				0.63	0.19
37	0.04	0.02		0.33	0.96					

(continued)

Figure C-1. (continued)

YEAR: 1976

1		0.48	0.05				0.43	0.01		
2	0.01		1.07			0.05			0.07	0.04
3	0.23				0.65	0.46				0.01
4					0.06	0.23	0.01			
5							0.18	0.05	0.73	
6		0.24	0.06							
7						0.20				
8	0.05	0.36	0.03			0.06				0.78
9						0.20	0.12		0.19	0.05
10	0.15				0.14					
11		0.69								
12		0.97			0.21	0.19	0.01			
13		0.01	0.04				0.10			
14		0.01				0.12	0.15	0.59		
15									0.12	
16	0.33	0.67	0.48		0.04					
17								0.92		0.60
18	0.51	0.09		0.01	0.01	0.74	0.41			
19	0.20	0.16							0.95	
20	0.16							0.18	0.18	
21				0.26			0.04			0.21
22			0.01						2.40	
23						1.04	1.00	0.41		
24								0.72	0.22	
25					0.16			0.10		
26			0.53							0.09
27				0.05						0.41
28	0.46		0.09	0.33						0.49
29			0.16							
30			0.02	0.70				0.70	0.48	
31				0.76	0.18					
32										
33							0.02		0.07	
34	0.37	0.07	0.08	0.02			0.01			
35	0.15	0.02			0.05	0.03				
36					0.13					0.03
37										

(continued)

Figure C-1. (continued)

YEAR: 1977

1			0.06	0.05	0.90	0.13	0.03		0.19	0.15
2				0.45						0.04
3	0.01		0.01	0.38	0.01	0.03		0.03		
4					0.03					
5			0.02			0.01				0.29
6	0.02			0.28	0.03		0.05	0.02		0.30
7		1.12	0.10							
8	0.62					0.02	0.77		0.15	0.40
9	0.08					0.08	0.07			
10		1.84		0.40	0.20	0.22				
11										
12		0.23	0.01	0.02	0.05			0.38		
13	0.15		0.07	0.21	0.04	0.41	0.14			
14									0.15	
15			0.11						0.18	
16					0.07			0.71		
17		0.02		0.10					0.50	
18			0.51	0.01	0.02	2.34		0.34	1.05	
19	1.07								0.03	
20		0.75	0.04	0.29						
21							0.77			
22	0.36							0.01	0.07	0.12
23		0.16	0.56	0.85		0.11		0.34	0.02	
24			0.59			1.53				
25										
26		0.10				0.05	0.10	0.52	0.13	
27	0.01	0.53								
28			0.08	0.57	0.01			0.14	0.10	0.04
29	0.45							0.07		
30								1.40	0.03	
31				0.04						0.27
32	0.02		0.04	0.08					0.01	1.05
33				0.33	0.01	0.05				
34	0.10	0.03	0.15	1.18	0.27	0.02	0.18		1.07	0.38
35		0.48	0.04	0.02			0.33	0.54		
36	0.30	0.13		0.04				0.17		
37	0.01									

(continued)

Figure C-1. (continued)

YEAR: 1978

1	0.03	0.02			0.45		0.43	1.32		
2		0.08	0.06	0.02	0.02	0.35	0.31		0.04	0.18
3	0.01			0.22	0.09	0.31		0.01		
4	0.01					0.04				
5				0.13			0.03		0.03	
6	0.01	0.02	0.02						0.03	0.02
7	0.17	0.11				0.08	0.24			0.19
8	0.26	0.05	0.49		0.04				0.20	
9	0.05	0.11	0.57	0.02						
10	0.02		0.01	0.06		0.34			0.01	
11	0.26							1.03	0.04	0.08
12			0.40	0.20	0.07				0.14	0.06
13				0.46	0.02		0.07	0.68	0.26	
14	0.01	0.61	0.75	0.37	0.02	0.05				0.22
15			0.94							
16			0.01					0.61	1.08	
17			0.16						0.35	
18	0.35	0.11				1.31	0.11			0.01
19			1.41	0.66	0.02				0.15	
20		1.12			0.37					
21		0.11		0.13	1.91	0.03				
22	0.03	1.05			0.49					
23			0.60	1.02	1.32	0.66		0.02		0.02
24					0.09		0.6	0.56		
25										
26							0.6		0.12	
27										
28			0.32			0.49				
29				0.60	1.02	1.45	0.66		0.02	
30	0.02					0.09		0.06	0.56	
31						0.22				
32						0.10		0.19	0.48	0.01
33	0.62						0.19		0.51	0.16
34						0.03	1.45	0.09		
35	0.58	1.80	0.09							0.06
36			0.03	0.46				0.16		
37				0.28	0.88					

(continued)

Figure C-1. (continued)

Month	Mean Monthly Temperature (°F)	Mean Monthly Insolation (Langleys/Day)
January	11.3	128
February	18.8	200
March	25.3	297
April	54.3	391
May	59.6	471
June	72.9	562
July	73.8	542
August	72.5	477
September	74.6	422
October	58.8	286
November	50.0	176
December	40.8	129

Leaf Area Index Values

Day	Area
1	0
92	0
104	.61
116	.99
128	.99
140	.99
152	.99
164	.99
176	.89
188	.71
200	.65
213	.61
366	0

(continued)

Figure C-1. (concluded)

Hydrological Input

Study Title: Sensitivity Study

Area Location: Cincinnati, Ohio

Today's Date: 18 July 1980

Date of first storm event (Julian date) 74003
(example = 73038, 1973 and 38 Julian day)

Surface area of solid waste site	24	acres
Hydraulic conductivity of vegetative soil	.33	in./hr
Hydraulic conductivity of barrier soil	.0011	in./hr
Depth of soil cover	24	inches
Depth of vegetative layer	18	inches
Depth of barrier layer	6	inches
Depth of solid waste	180	inches
Soil porosity of vegetative soil	.621	vol/vol
Soil porosity of barrier soil	.226	vol/vol
SCS curve number	90	
Channel slope	.1	ft/ft
Hydrologic channel length	1446	ft
Available water capacity of vegetative soil	.156	vol/vol
Available water capacity of barrier soil	.038	vol/vol
Winter cover factor	.8	
Evaporation coefficient of vegetative soil	4.5	
Evaporation coefficient of barrier soil	3.1	

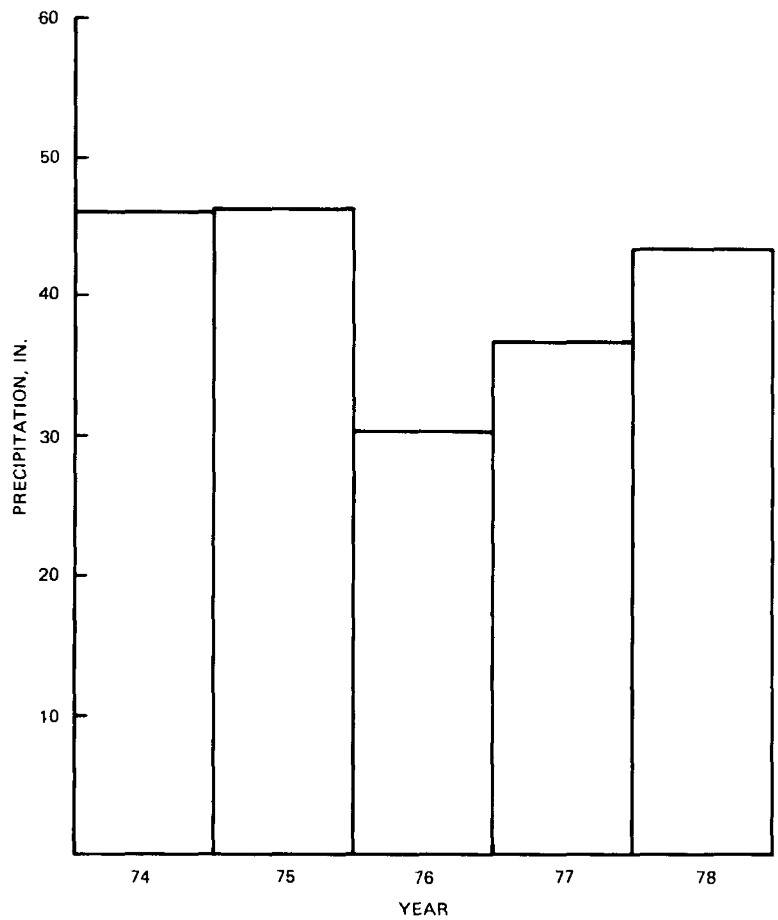

Figure C-2. Annual Cincinnati, Ohio, precipitation from 1974 to 1978.

TABLE C-1. PARAMETERS VARIED FOR SENSITIVITY ANALYSIS

Number of runs	Parameters	Parameter variation
5	Impermeable liner	5, 10, 15, 20, Ind. (years)
3	SCS curve number	81, 90, 99
3	Winter cover factor	0.5, 0.8, 1.0
3	Depth of barrier soil	6, 12, 18 (inches)
3	Depth of vegetative soil	12, 24, 36 (inches)
5	Leaf area index	Ex, Gd, Fr, Pr, Brgnd*
2	Barrier soil compaction	Compacted, not compacted
12	Soil texture†	
	Vegetative soil	Barrier soil
	S	S, SL, L, SCL, C
	SL	L, SCL, C
	L	SCL, C
	SCL	C
	SCL	C (compacted)

* Excellent, Good, Fair, Poor, Bare ground.

† S = sand, L = loam, C = clay.

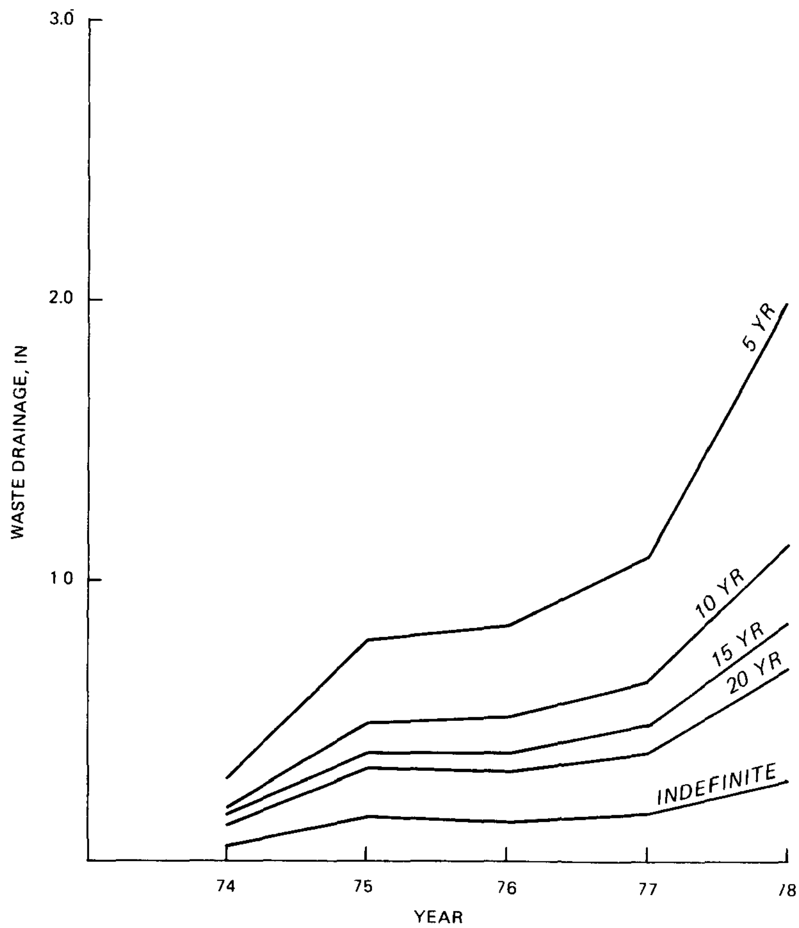

Figure C-3. Annual waste drainage as related to the impermeable liner.

2.5 percent of total percolation for waste drainage the first year which increased to 13 percent of total percolation for waste drainage by the 5th year. The final percentages of percolation accounted for by waste drainage for the 10-, 15-, and 20-year options were 31, 38, and 50 percent, respectively.

Figures C-3 and C-4 show that the 10-, 15-, and 20-year life options correlated with the indefinite life liner. Based upon the 5-year data set, waste drainage increased by 585 percent with the 5-year liner life as compared to 285 percent with the indefinite liner life.

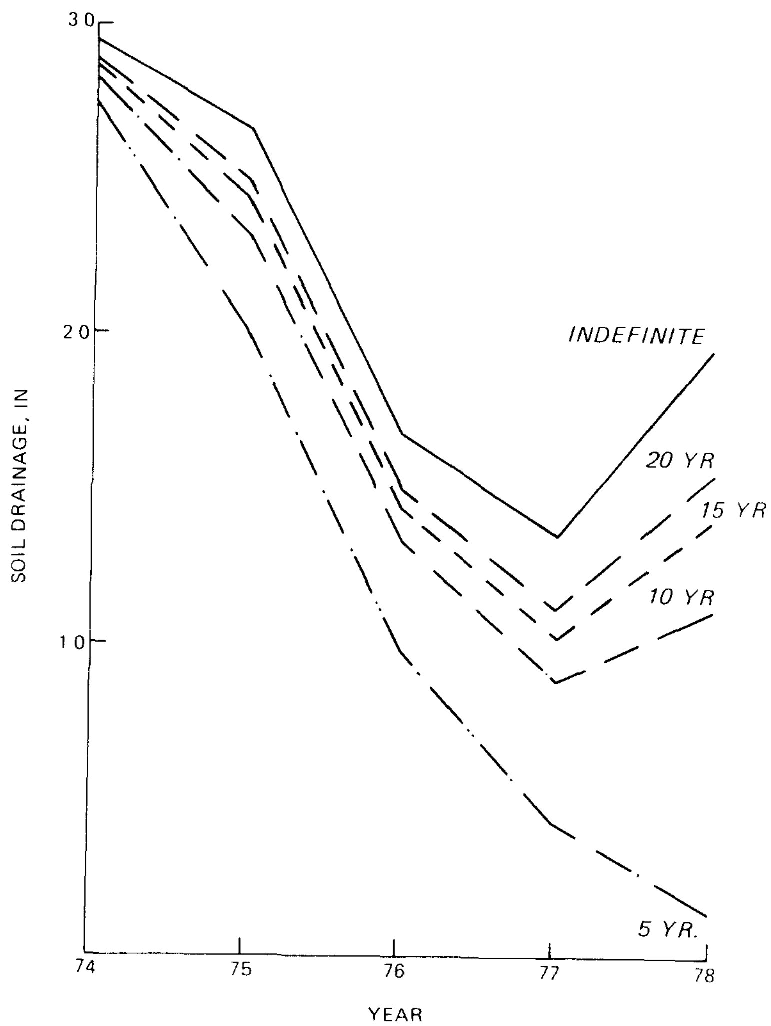

Figure C-4. Annual soil drainage as related to the impermeable liner.

SCS CURVE NUMBER

The results for the SCS curve number are interpreted for the yearly totals because the curve number is not a time dependent variable. As expected, this variable is a primary factor for surface runoff (Figure C-5) and a secondary factor for evapotranspiration (Figure C-6) and waste drainage. As presented in Table C-2, the average annual totals for a curve number of 81 shows that surface runoff was 17 percent of the total precipitation; whereas, for a curve number of 99, the surface runoff increased to 52.2 percent or an increase of 35 percentage points. Evapotranspiration decreased by 26 percentage points from 73.8 percent for a curve number of 81 to 47.5 percent for a curve number of 99. These differences in evapotranspiration accounted for most of the increase in surface runoff with the remainder (about 9 percentage points) being accounted for by decreases in waste drainage and soil water.

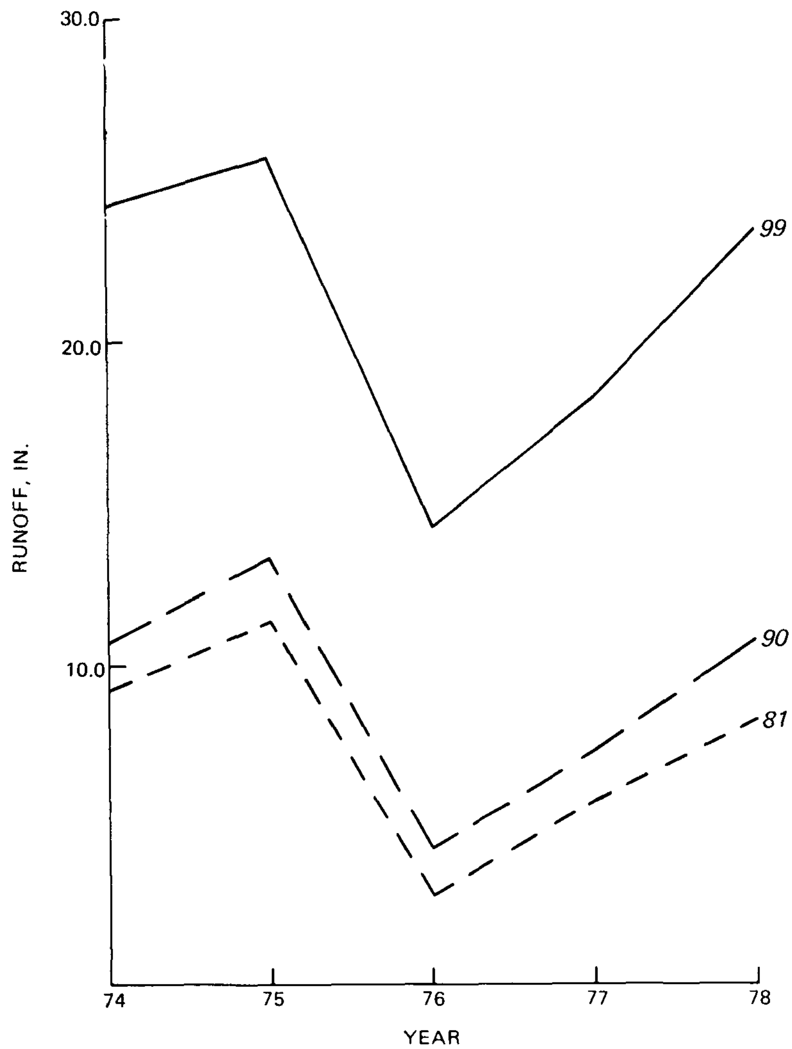

Figure C-5. Annual runoff as related to the SCS curve number.

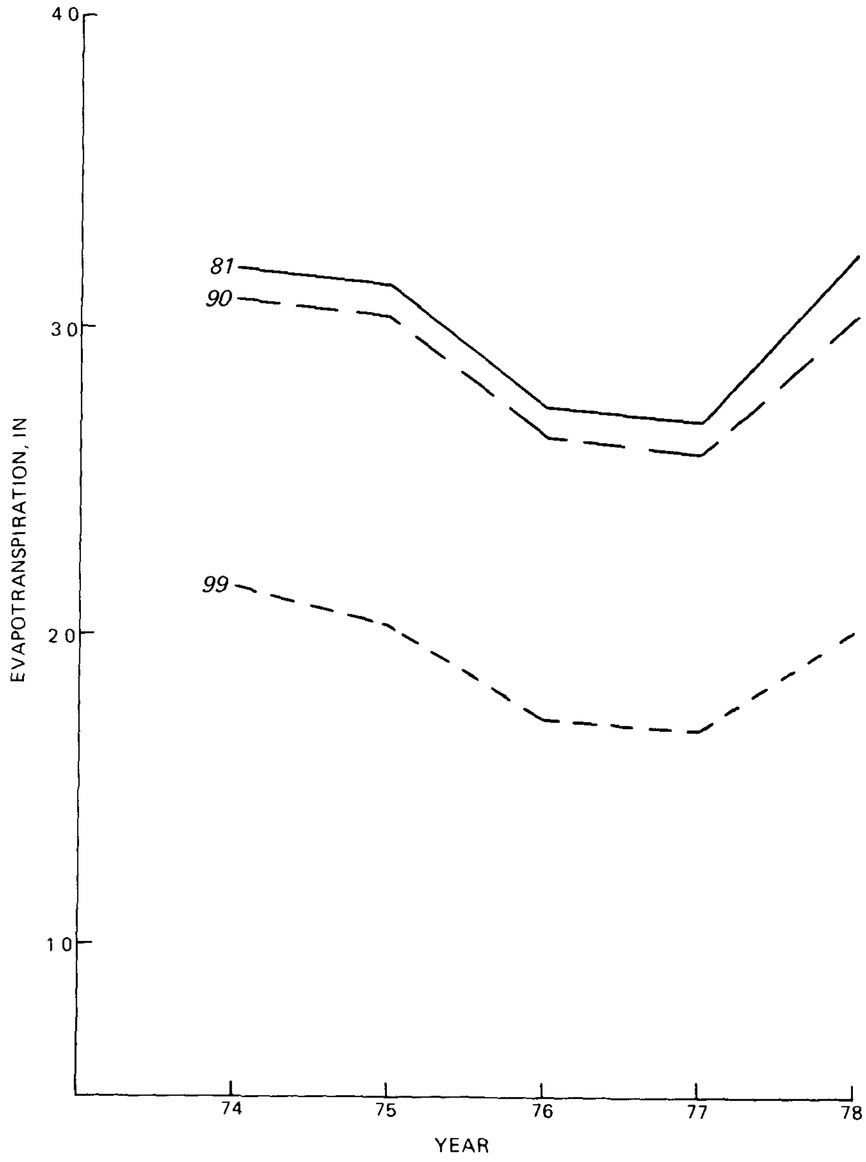

Figure C-6. Annual evapotranspiration as related to SCS curve number.

TABLE C-2. PERCENTAGES OF THE SURFACE RUNOFF, WASTE DRAINAGE, AND EVAPOTRANSPIRATION TO THE AVERAGE ANNUAL PRECIPITATION* FOR THE SCS CURVE NUMBER

Parameter	SCS curve number		
	81	90	99
Surface runoff, percent	17.0	21.6	52.2
Waste drainage, percent	7.1	5.6	0.1
Evapotranspiration, percent	73.8	70.8	47.5

* Average annual precipitation = 40.6 inches.

Table C-2 shows that the percentages for the curve numbers of 81 and 90 were more comparable than the percentages for the 99 curve number.

Figure C-7 shows that waste drainage changed from an average of 2.87 in./year for a curve number of 81 down to nearly zero (0.0549 in./year) for a curve number of 99.

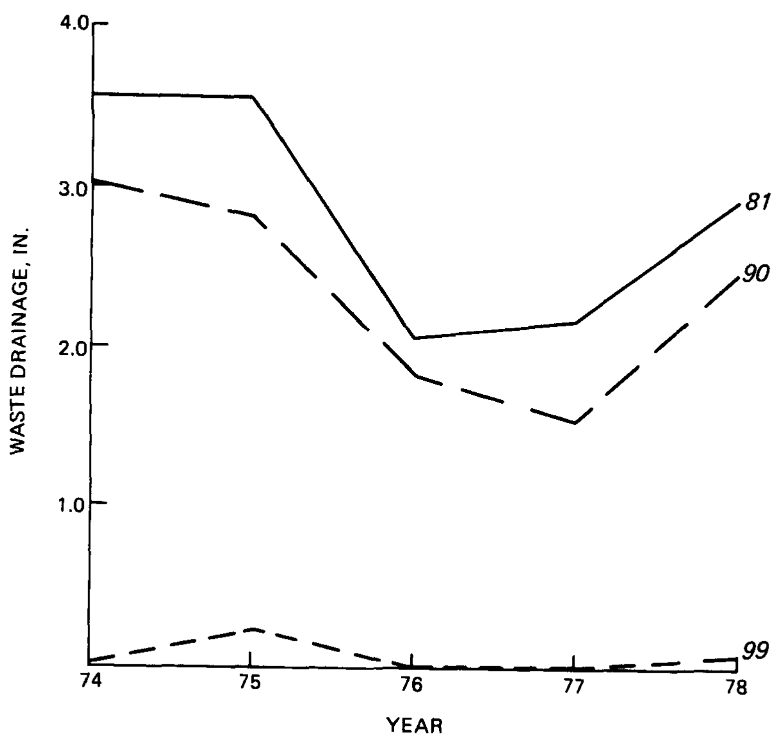

Figure C-7. Annual waste drainage as related to the SCS curve number.

WINTER COVER FACTOR

The winter cover factor is seasonally dependent and directly effects the process of evapotranspiration. Figures C-8, C-9, and C-10 demonstrate that the winter cover factor affects the results from September through April until the growing season starts April 1st and declines after July 31st. Since the winter cover factor is seasonally dependent monthly evaluation is preferable.

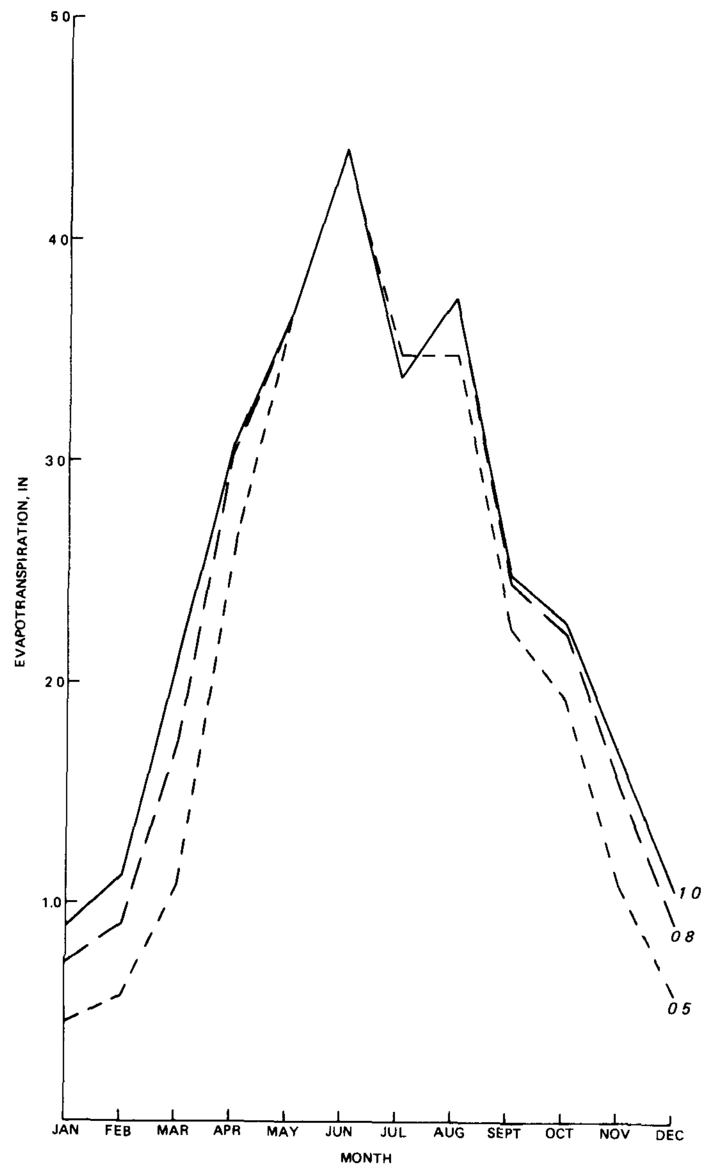

Figure C-8. Average monthly evapotranspiration as winter cover factor.

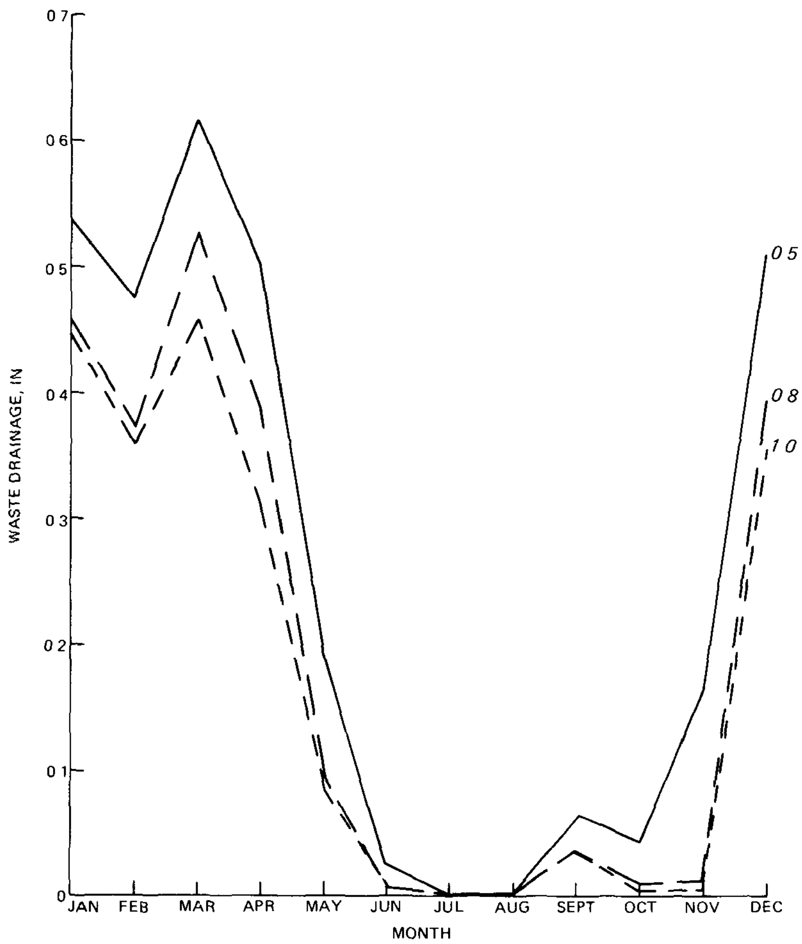

Figure C-9. Average monthly waste drainage as related to the winter cover factor.

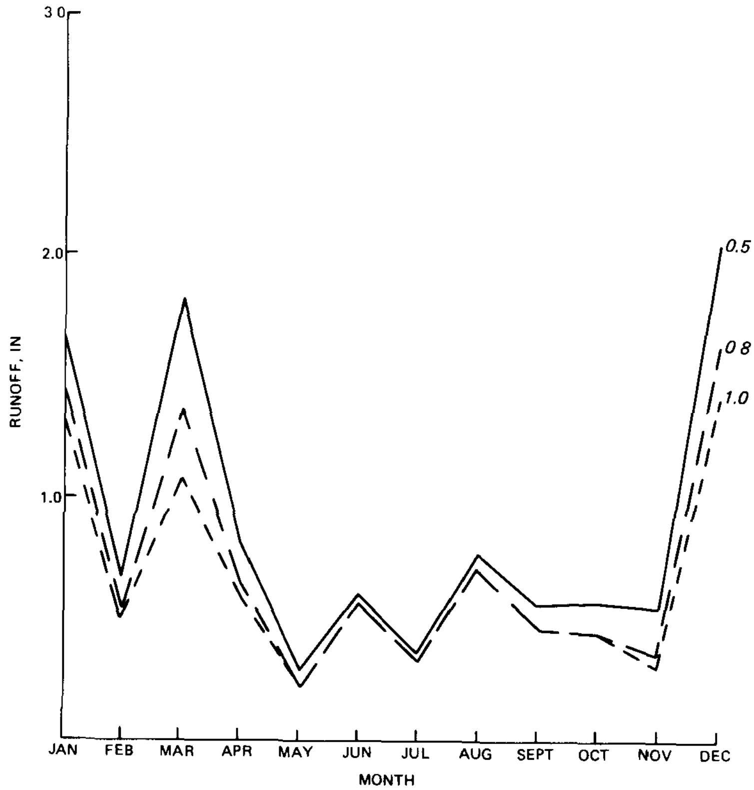

Figure C-10. Average monthly runoff as related to the winter cover factor.

When comparing each parameter as a percentage of average annual precipitation, evapotranspiration was shown to increase by 10.3 percentage points as the winter cover factor went from 0.5 to 1.0. Over the same range of winter cover factors, surface runoff and waste drainage decreased by 6.9 and 2.6 percentage points, respectively. The winter cover factor of 0.5 implies an excellent grass cover while the winter cover factor of 1.0 implies the bare ground condition; however, in this study these values were linked with the LAI for a grass in fair condition. While this contradiction is necessary to protect the integrity of the study, it should be noted that these extreme conditions would rarely be found in a field situation. If the user chooses the default option, the winter cover factor that corresponds to the selected LAI is automatically assigned.

DEPTH OF BARRIER SOIL

To evaluate the effect of varying barrier soil depth the total soil depth was set at 24 inches and the barrier soil was assigned depths of 6, 12, and 18 inches. Therefore, the depth of vegetative soil computed by the model varied accordingly.

Figures C-11 and C-12 show the yearly significance of the barrier soil

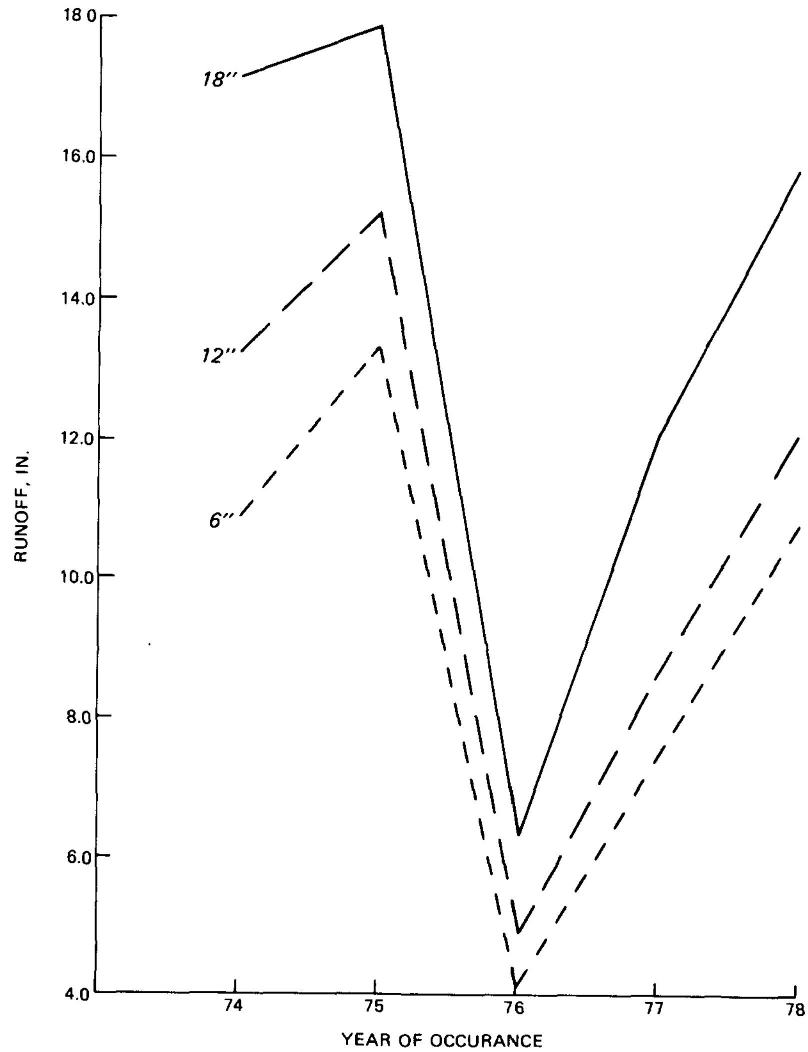

Figure C-11. Annual surface runoff as related to depth of barrier soil.

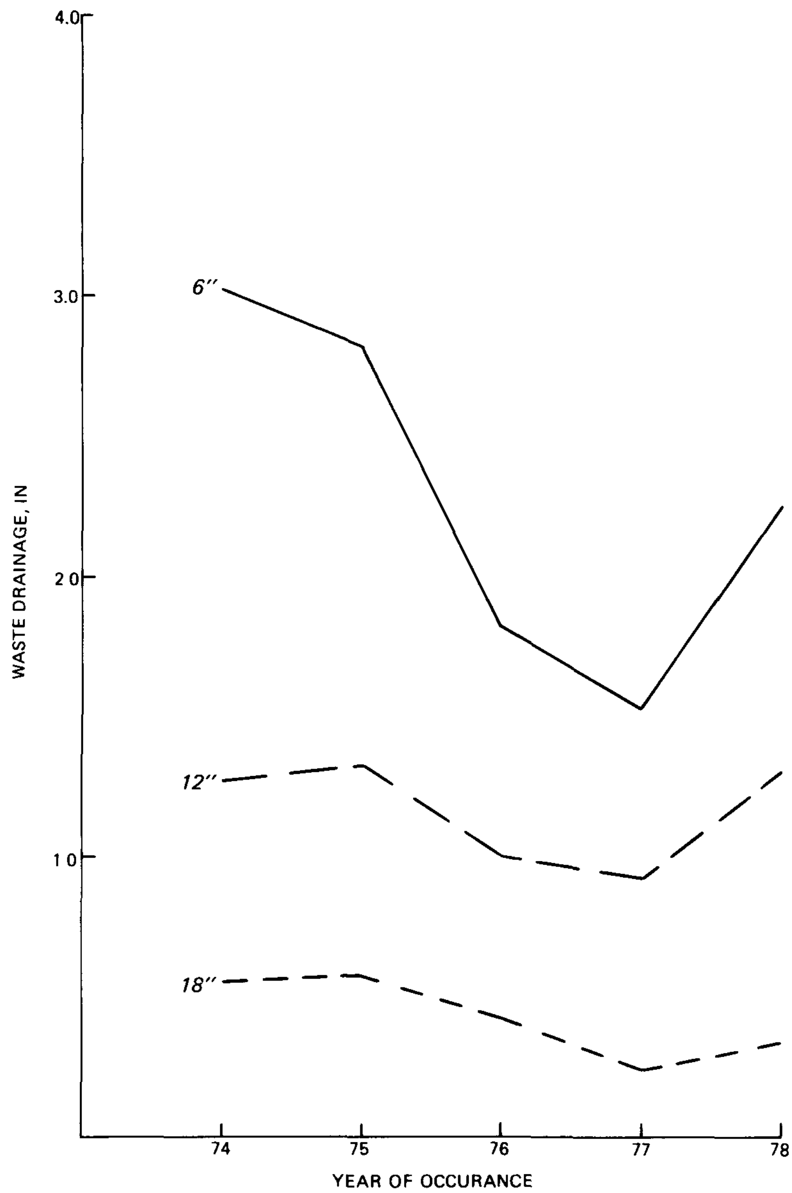

Figure C-12. Total waste drainage versus year of occurrence as related to depth of barrier soil.

depths on the waste drainage and surface runoff. All three depths are equally sensitive to surface runoff; however, for waste drainage the 6-inch barrier soil depth is more sensitive to precipitation than is the 18-inch depth. When the barrier soil depth increases, the lag time for waste drainage also increases. Therefore, with late fall precipitation a significant percentage of waste drainage will percolate through the 6-inch barrier layer depth; however, at the 12- or 18- inch barrier soil depth this waste drainage will continue into the next year.

Figures C-13 and C-14 show the seasonal dependence of the depth of barrier soil to the surface runoff and waste drainage. The seasonal cycles of

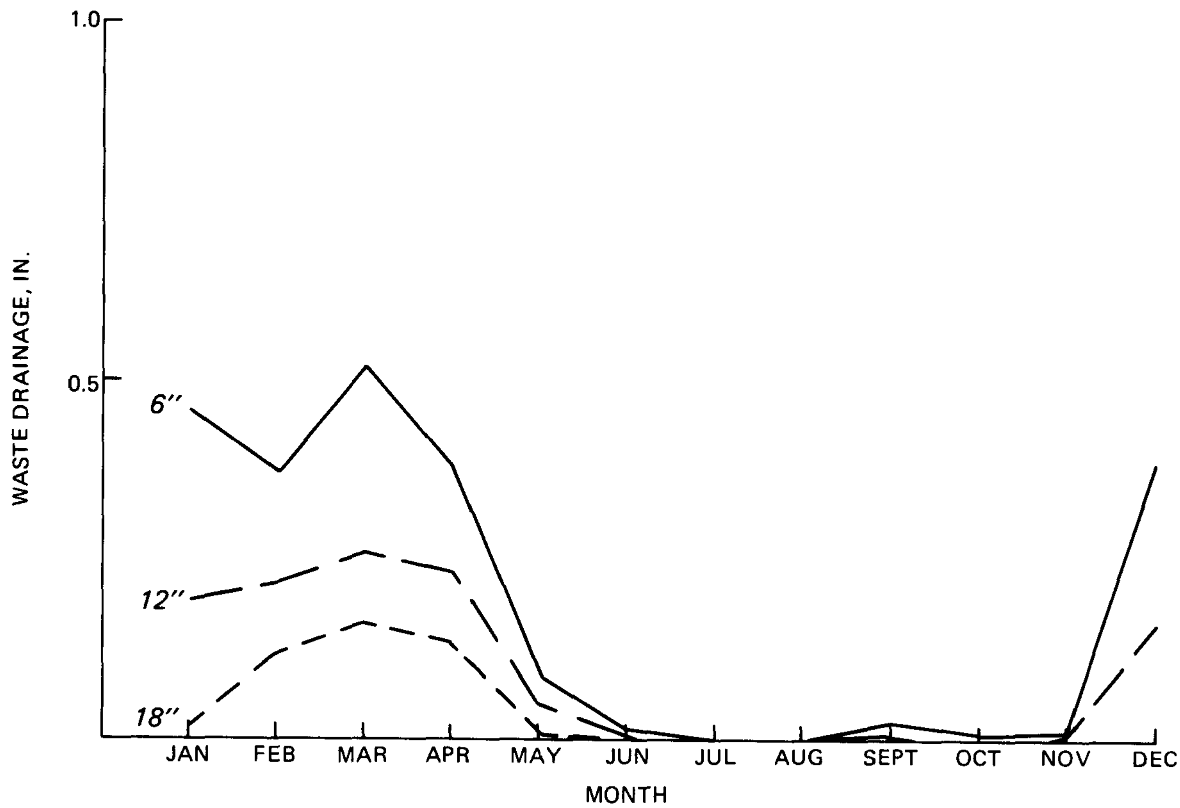

Figure C-13. Average monthly surface runoff as related to depth of barrier soil.

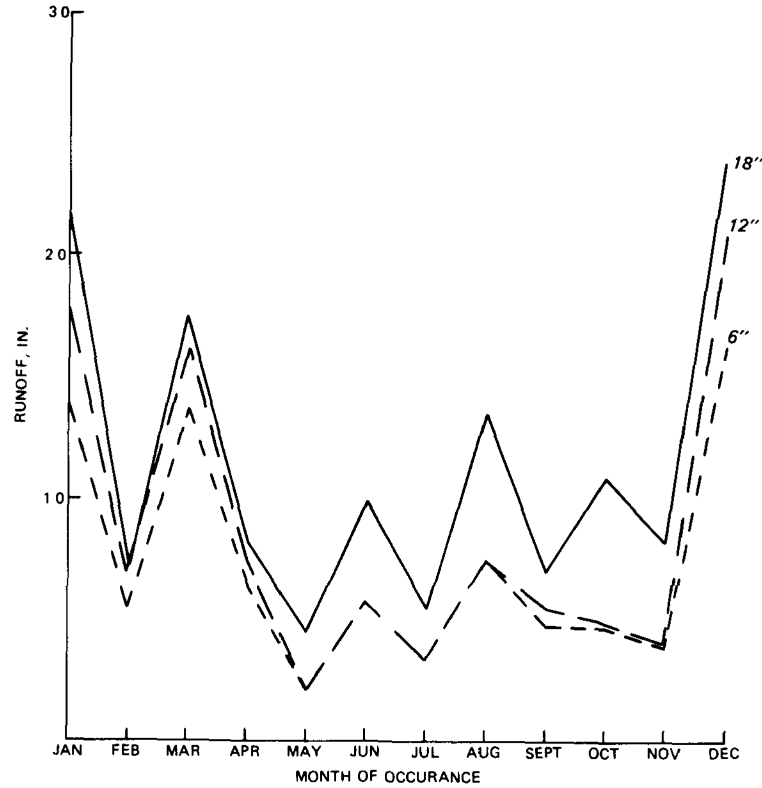

Figure C-14. Average monthly waste drainage as related to depth of barrier soil.

rainfall, solar radiation, temperature, and LAI suggest that the barrier soil depth should be considered time dependent.

Comparison of each parameter as a percentage of the average annual precipitation showed that the surface runoff increased by 12.5 percentage points from the 6- to the 18-inch barrier soil depth. However, waste drainage and evapotranspiration decreased by 4.6 and 6.7 percentage points, respectively. It should be noted that the selection of the 18-inch depth of barrier soil was for test purposes only. In most instances, a 6-inch vegetative soil layer would not support an adequate plant growth and is not recommended for field applications.

DEPTH OF VEGETATIVE SOIL

For this part of the study, the depth of the vegetative soil layer varied 12, 24, and 36 inches and no barrier soil was used. Table C-3 compares the percentages of the surface runoff, waste drainage, and evapotranspiration to the average annual precipitation for each depth of vegetative soil. Surface runoff showed the least change as soil depth was varied. The greatest difference was only 0.3 percentage points and was not considered significant.

TABLE C-3. PERCENTAGES OF THE SURFACE RUNOFF, WASTE DRAINAGE, AND EVAPOTRANSPIRATION TO THE AVERAGE ANNUAL PRECIPITATION* FOR DEPTH OF VEGETATIVE SOIL

Parameter	Vegetative soil depth, inches		
	12	24	36
Surface runoff, percent	15.1	15.2	14.9
Waste drainage, percent	16.7	12.1	8.7
Evapotranspiration, percent	67.9	72.2	75.7

* Average annual precipitation = 40.6 inches.

The largest differences of the vegetative soil depth affected the amount of the initial soil water storage and the upper limit of the soil water storage resulting from the increased soil depth. For a vegetative soil depth of 12 inches the initial soil water was 0.936 inches and the upper storage limit was 1.87 inches; however, for the 36-inch vegetative soil depth the initial soil water increased to 2.81 inches and the upper limit of storage increased to 5.62 inches. As the soil depth increased, larger volumes of water were available to the plants which resulted in an increased evapotranspiration. Table C-3 shows that evapotranspiration increased by 7.8 percentage points and waste drainage decreased by 8.0 percentage points as the vegetative soil depth increased.

Figure C-15 shows the relation of the annual waste drainage to year of occurrence with the vegetative soil depth as the parameter. It shows that waste drainage is not uniform with time, a condition caused by the initial soil water storage and the upper limit of soil water storage that result in soil water storage difference for each vegetative soil depth. This stored soil water is sensitive to replenishment by precipitation and to depletion by evapotranspiration and waste drainage. A distortion in the waste drainage is noticeable for the years of 1976 and 1977.

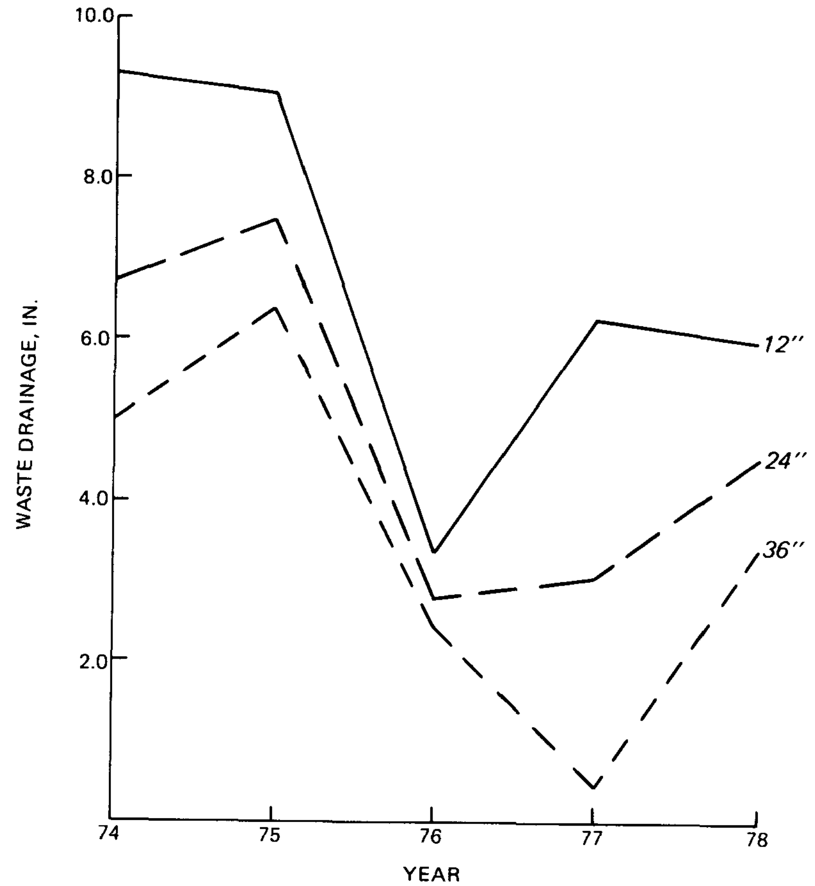

Figure C-15. Annual waste drainage as related to the depth of vegetative soil.

Figure C-16 for average monthly values for the 5-year data set and the 1976 data set is an expansion of Figure C-17 for the average annual soil water with vegetative soil depth as the parameter for both figures. It was shown in Figure C-1 that 1976 was the driest year in the 5-year study period with only 30.07 inches of precipitation during the year. The lack of precipitation affected the 12-inch soil depth waste drainage immediately (see Figure C-15) since percolation for waste drainage was reduced. However, at the 36-inch soil depth the volume of water was greater for percolation resulting in less waste drainage. The lack of precipitation becomes more acute since the drier months occurred in the last quarter of the calendar year when evapotranspiration decreased thus allowing higher waste drainage than would occur normally. The situation is reversed for the first half of 1977 as the seasonal precipitation refills the soil profile to the 36-inch depth while at the 12-inch depth percolation to waste drainage occurs at an earlier time. This relation of soil water storage with time effects the evapotranspiration; however, evapotranspiration is not as effective during October through February, the critical time period under observation.

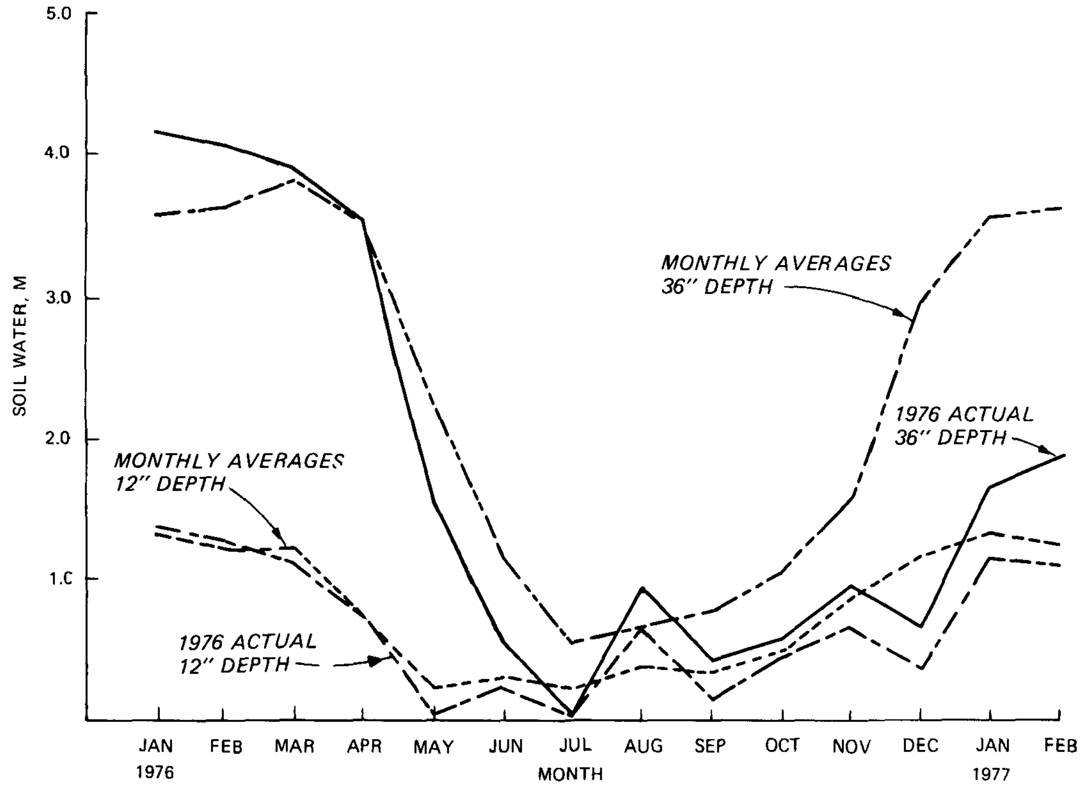

Figure C-16. Average monthly soil water for the 5-year data set and the 1976 data set for January 1976 through February 1977 with vegetative soil depth as the parameter.

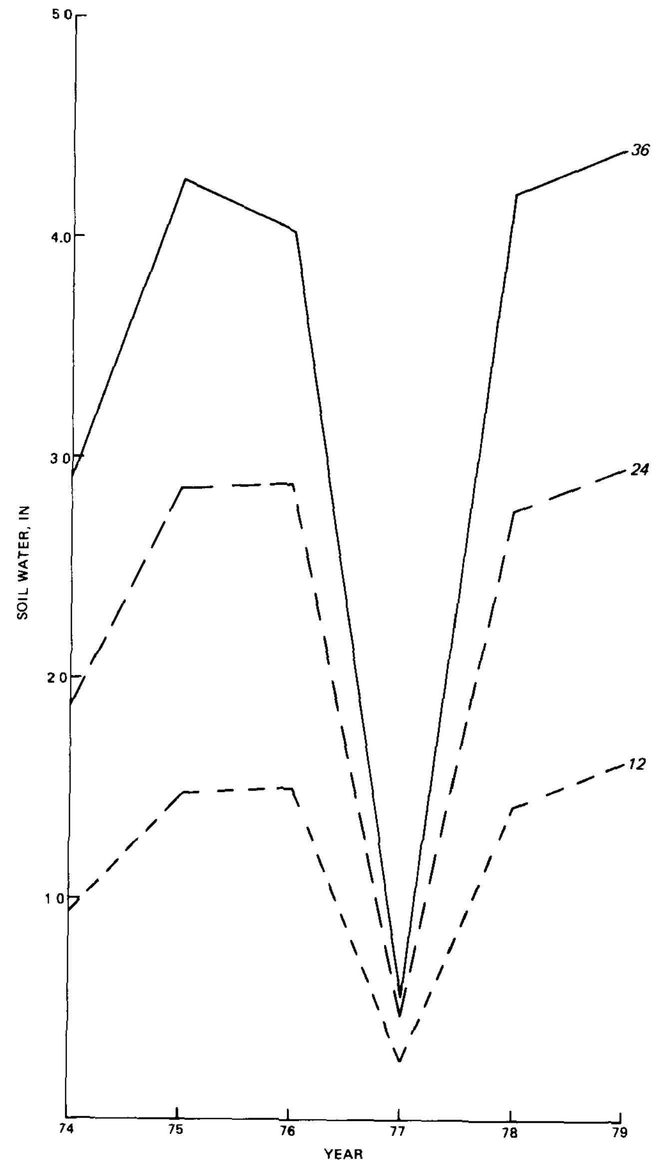

Figure C-17. Average annual soil water as related to the vegetative soil depth.

LEAF AREA INDEX (LAI)

The LAI is a measurable scale of the amount of vegetative ground cover that exists as a function of time and is an effective partition of the plant transpiration to soil evaporation ratio. This part of the sensitivity study was designed to investigate changes resulting from using five different LAI distributions as inputs. Bare ground conditions, as the name indicates, has a 0.0 LAI for the entire year. An excellent crop condition is regraded as the best possible condition and an occurrence of good, fair, and poor cropping conditions are designated as 66.6 percent, 33.3 percent, and 16.7 percent of an excellent crop value, respectively. For the Cincinnati, Ohio, climatic condition, the growing season starts on day 92 (April 1st) and continues until day 213 (July 31st).

As expected, the parameter most sensitive to changes in LAI was evapotranspiration. The percentages in relation to average annual precipitation, as presented in Table C-4, show that evapotranspiration decreased by 14.5 percentage points between the extreme values for an excellent crop and bare ground. Surface runoff increased by 7.6 percentage points, while waste drainage increased by 6.1 percentage points. However, the greater portion of the variation occurred between the values of poor crops and bare ground. From excellent to poor crop conditions, the increases for surface runoff and waste drainage were 3.1 and 1.2 percentage points, whereas evapotranspiration increased by 4.5 percentage points.

TABLE C-4. PERCENTAGES OF THE SURFACE RUNOFF, WASTE DRAINAGE, AND EVAPOTRANSPIRATION TO THE AVERAGE ANNUAL PRECIPITATION* FOR THE LEAF AREA INDEX, LAI

Parameter	Leaf Area Index				
	Excellent	Good	Fair	Poor	Bare ground
Surface runoff	19.9	20.4	21.5	23.0	27.5
Waste drainage	5.1	5.2	5.6	6.2	11.1
Evapotranspiration	73.1	72.5	70.8	68.6	58.6

* Average annual precipitation = 40.6 inches.

Figures C-18, C-19, and C-20 show the large variation that occurred between the values for a poor crop condition and a bare ground condition. As expected, Figures C-18 and C-20 demonstrate that LAI is seasonally dependent and for parameters such as evapotranspiration and surface runoff the LAI changes do not affect the results before the growing season begins. After the growing season starts, differences between the parameters affected by the LAI accumulate until the peak of the growing season; then, there is a sharp decline until the end of the growing season.

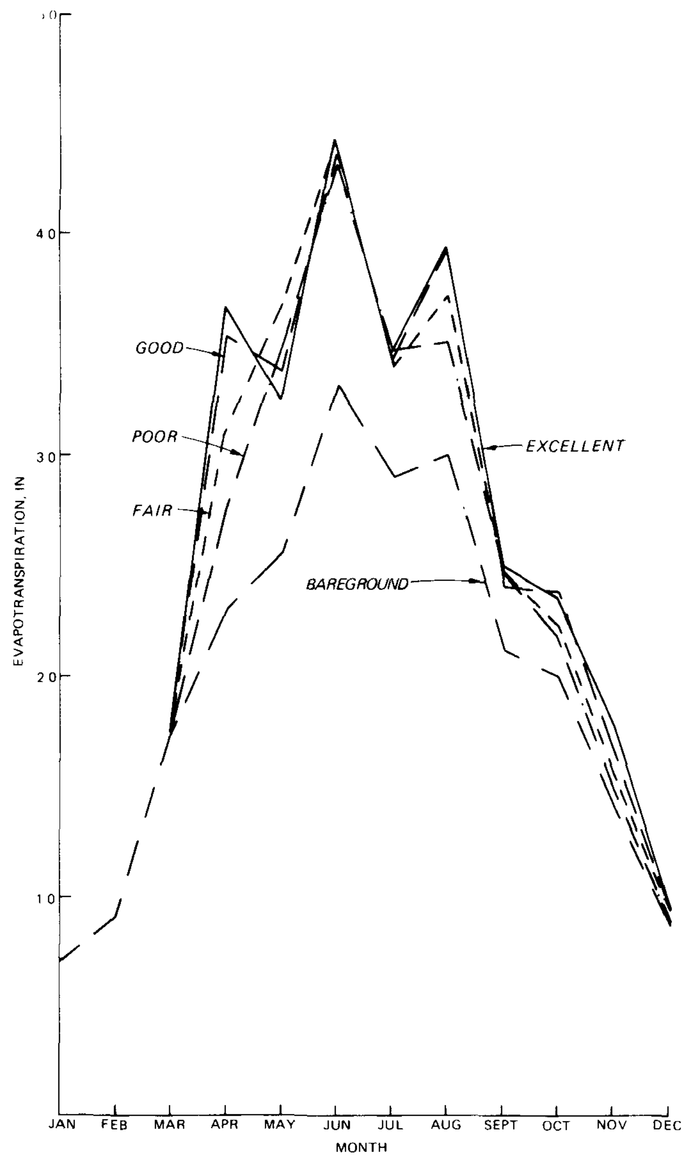

Figure C-18. Average monthly evapotranspiration as related to the LAI.

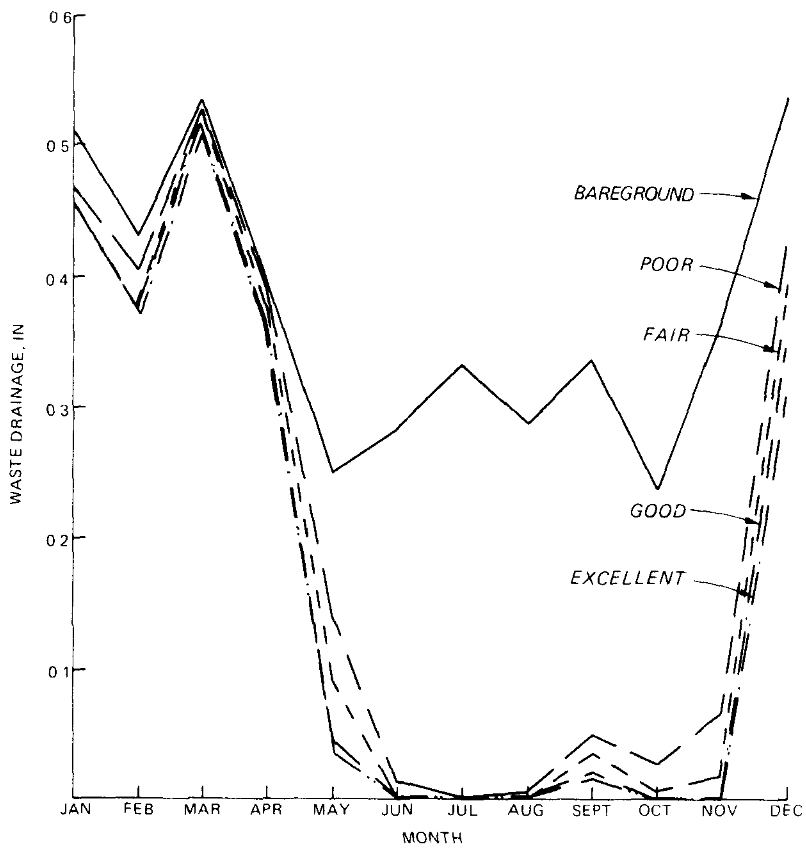

Figure C-19. Average monthly waste drainage as related to the LAI.

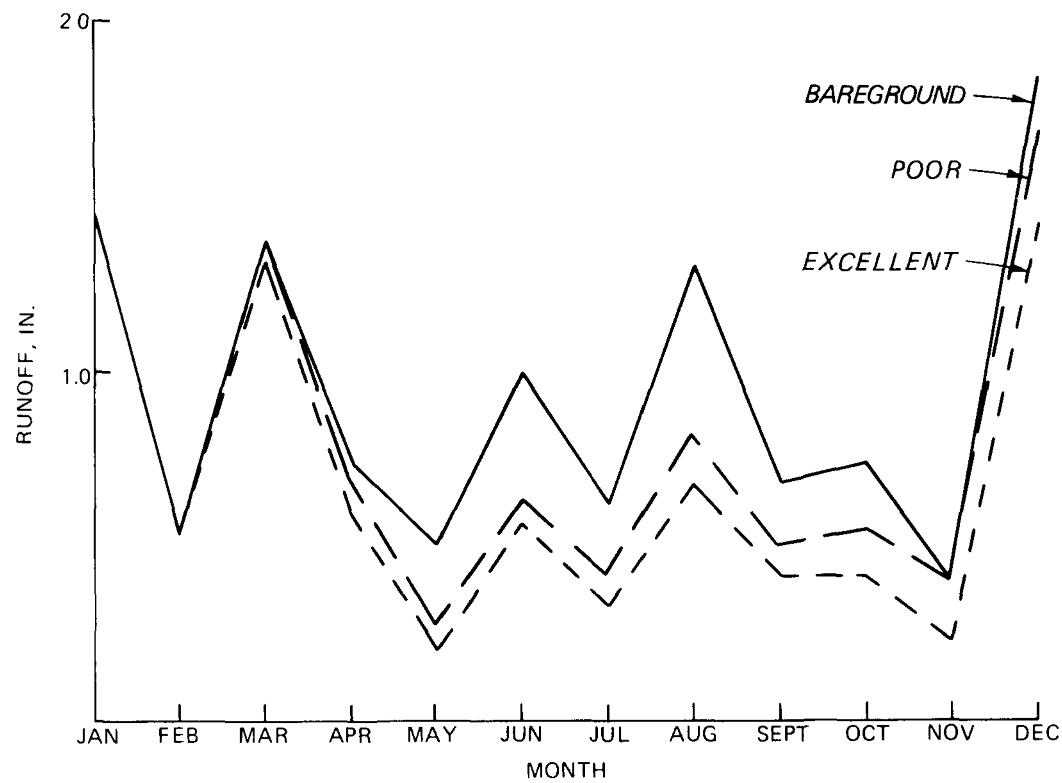

Figure C-20. Average monthly surface runoff as related to the LAI.

Figure C-19 shows that the waste drainage parameter differences in LAI values are evident early in the year caused by accumulated differentials in the soil water parameter. The effect of the soil water condition is also shown in Figure C-21. When comparing the various LAI options of a vegetative cover to that of bare ground, the significant beneficial effect of the vegetative cover is to provide additional control to waste drainage. This effect is also noted in Figure C-19 showing that any LAI value increase from a poor to an excellent crop condition decreases waste drainage during the growing season to nearly zero.

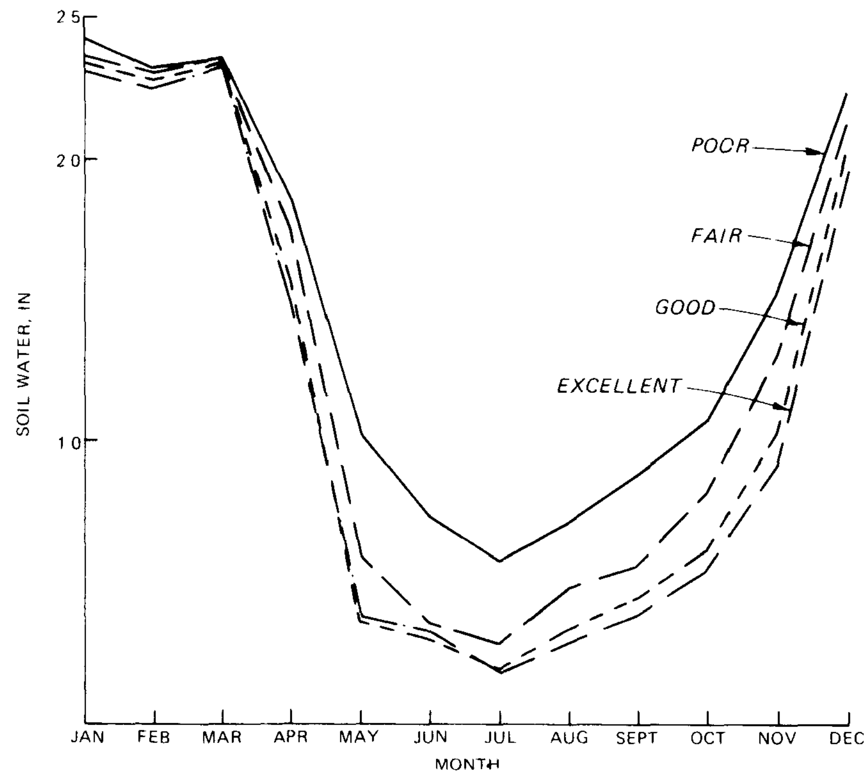

Figure C-21. Average monthly soil water as related to the LAI.

An unusual result of this LAI computation is shown in Figure C-18 when evapotranspiration is related to time. For the month of April, the order of the cropping options from the highest to the lowest evapotranspiration was excellent, good, fair, poor, and bare ground. However, for the month of May, the cropping order was changed to fair, poor, good, excellent, and bare ground. Figure C-21 explains this apparent inconsistency by displaying the average soil water results. The higher LAI values for the good and excellent cropping options resulted in increased evapotranspiration that lowered the soil water in April to a level where further evapotranspiration in May was limited. The increase in evapotranspiration of the poor and fair cropping options was not large enough to affect the soil water. The difference between the extreme cropping options, excellent and fair, was about 0.4 inches during May.

BARRIER SOIL COMPACTION

For this section of the sensitivity study the concern was whether the barrier soil had been left as placed or compacted by some means. In the model, compaction reduces the values for hydraulic conductivity, porosity, and available water. When using the model default option, the hydraulic conductivity is reduced by a factor of 20 and the values of a.ailable water content and porosity are reduced by a factor of 2. The input values for these parameters in the sensitivity analysis are shown in Table C-5. These values resulted in an upper limit for soil water storage of 2.8 inches for the compacted barrier soil as opposed to 3.1 inches for the noncompacted barrier soil.

TABLE C-5. HYDRAULIC CONDUCTIVITY, AVAILABLE WATER CONTENT, AND POROSITY VALUES USED TO EVALUATE BARRIER SOIL COMPACTION

Parameter	Noncompacted	Compacted
Hydraulic conductivity (in/hr)	0.022	0.0011
Available water content (vol/vol)	0.076	0.038
Porosity (vol/vol)	0.452	0.226

The most sensitive parameters to the degree of compaction for the barrier soil were surface runoff and waste drainage. Over the 5-year study period, the waste drainage averaged 13.2 percent of precipitation in the noncompacted barrier soil (Table C-6), and was 5.6 percent for the compacted barrier soil showing a decrease of 7.6 percentage points. The surface runoff showed a decrease of 6.6 percentage points between the compacted and noncompacted barrier soil. The effect of barrier soil compaction on evapotranspiration was negligible.

TABLE C-6. PERCENTAGES OF THE SURFACE RUNOFF, WASTE DRAINAGE, AND EVAPOTRANSPIRATION TO THE AVERAGE ANNUAL PRECIPITATION* FOR BARRIER SOIL COMPACTION

Parameter	Compacted	Noncompacted
Surface runoff, percent	21.5	15.0
Waste drainage, percent	5.6	13.2
Evapotranspiration, percent	70.8	71.0

* Average annual precipitation = 40.6 inches.

The relationship of barrier soil compaction to surface runoff and waste drainage need not be limited to analysis on a yearly basis, but can affect the parameters monthly and seasonally. Figures C-22 and C-23 show that surface

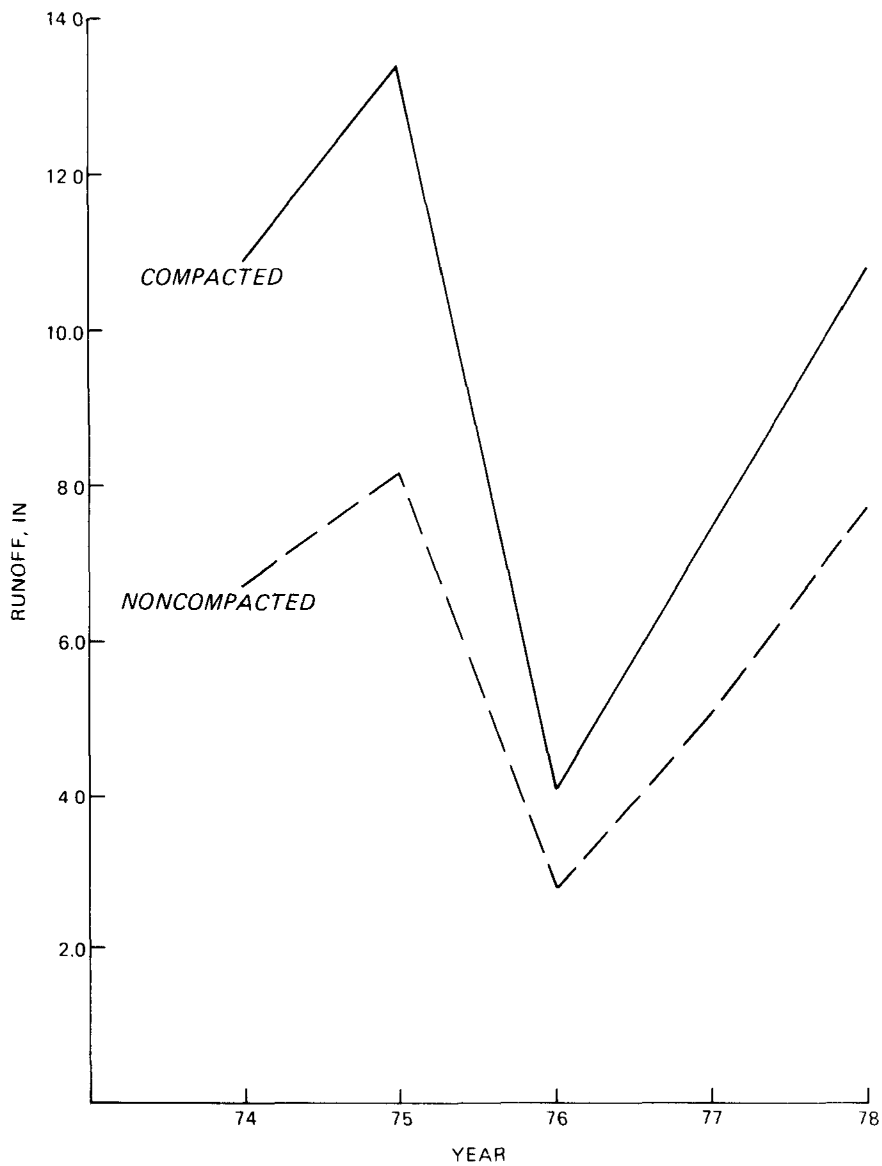

Figure C-22. Annual surface runoff as related to the barrier soil compaction.

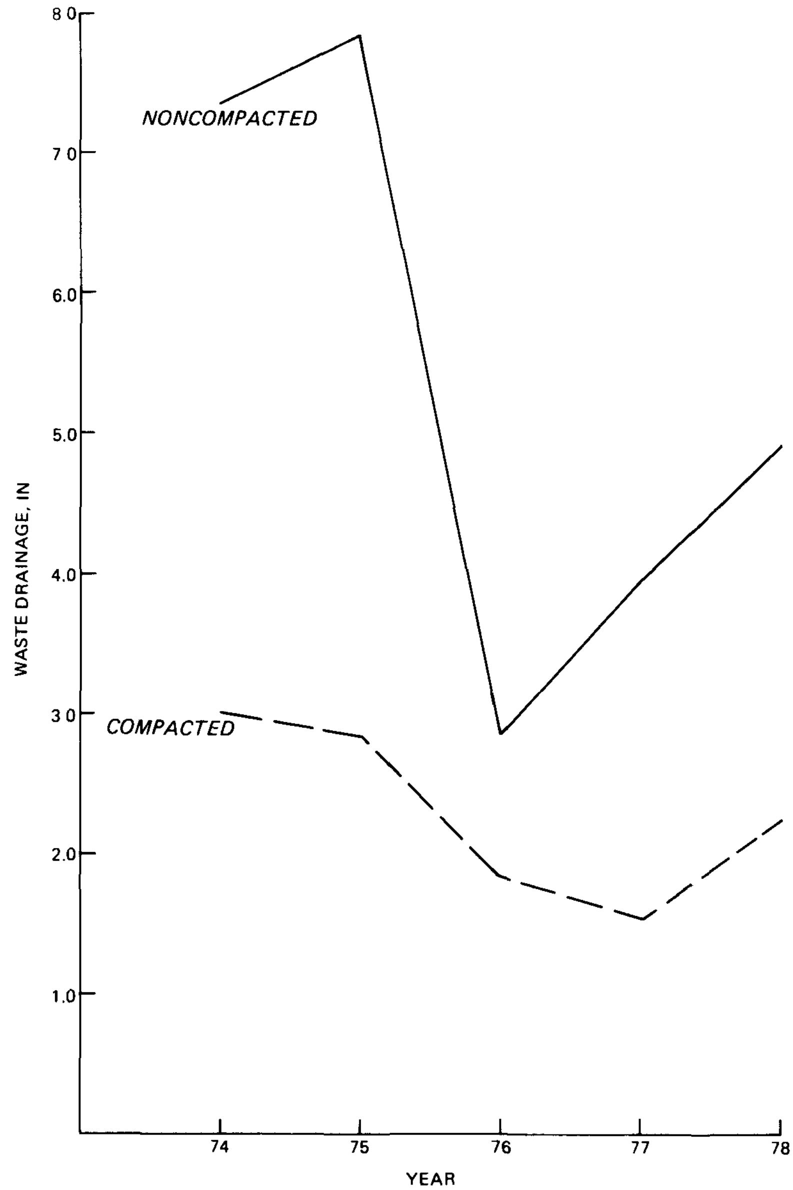

Figure C-23. Annual waste drainage as related to the barrier soil compaction.

runoff is not as sensitive to compaction as is waste drainage. Figure C-23 shows that the waste drainage parameter during 1976 and 1977 has a delay or time lag associated with the lower hydraulic conductivity of the compacted barrier soil. Also, the waste drainage parameter is very sensitive to the delay in the downward water movement process. The primary times of the year when waste drainage is significant are the early spring (January-May) and the late fall (October-December).

As noted earlier, the Cincinnati, Ohio, growing season runs from April 1st to July 31st. For the majority of this season, the increased evapotranspiration which resulted from increased LAI, decreased the soil water to a level where waste drainage was zero. Later in the season the precipitation restored the soil water and the waste drainage continued to cycle through the winter and into early spring. Since the precipitation cycle typically starts in the last quarter of the year and continues to the first quarter of the next, yearly totals can be deceptive, especially when the results of abnormal rainfall are affected by time dependency.

When considering Figure C-23, for instance, the waste drainage for the 1976 noncompacted soil showed a much larger drop in waste drainage than the compacted barrier soil. However, in 1977 the waste drainage from the noncompacted soil increased while the waste drainage from the compacted soils continued to drop. This apparent inconsistency is explained by the increased time lag associated with the compacted barrier soil.

Figure C-24 shows that the total precipitation for 1976 is significantly less than the average (30.37 inches as compared to 40.64 inches), the largest deficits occurring from March to May and late in the year from November through December. The precipitation during the middle of the year (see Table C-1) was not too much below average but since it occurred during the time of year when evapotranspiration was at a peak, waste drainage was negligible.

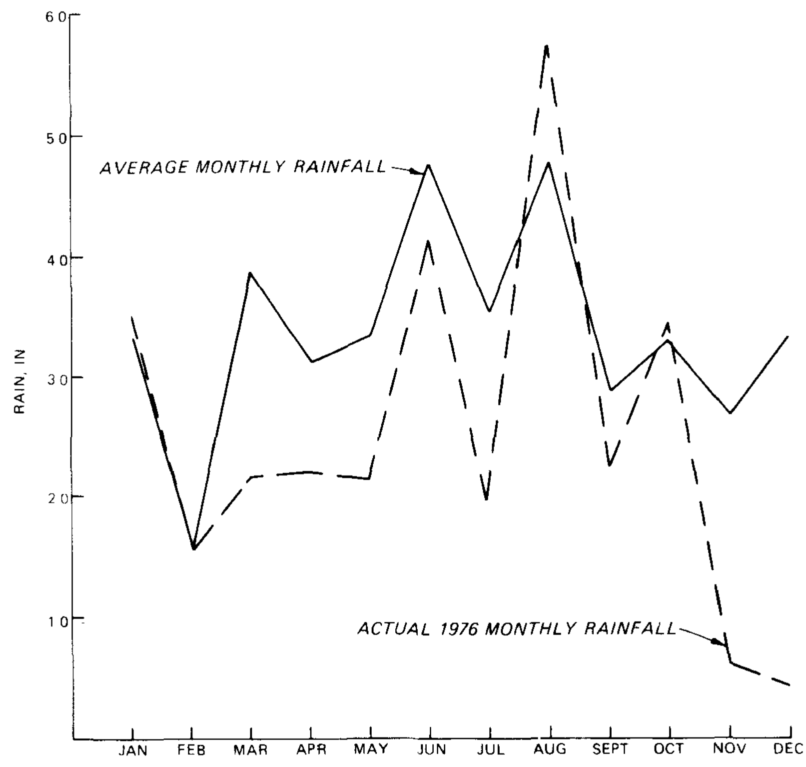

Figure C-24. Comparison of average monthly precipitation to 1976 precipitation.

Later in 1976, when precipitation could have had a more direct effect on waste drainage, the lack of rainfall meant that soil water remained depleted and waste drainage was lowered. Had the precipitation reached normal levels during this time period, the soil water would have been replenished and some waste drainage would have occurred. When the barrier soil is noncompacted, normal precipitation increases waste drainage during November and December, but the compacted barrier soil permits less water to percolate and therefore some waste drainage occurs in December, January, and February of 1977. With normal late year precipitation, the waste drainage from noncompacted soil occurs soon after the rainfall but for compacted barrier soils some of the waste drainage occurs during the next year.

Figure C-25 shows a comparison of the monthly waste drainage to the corresponding precipitation for 1978. Once again the effect of the time lag is shown as the precipitation during February was extremely low. The immediate effect was to reduce waste drainage for the noncompacted soil while the compacted barrier soil shows the time lag of the waste drainage for December 1977 and January 1978. Also, the waste drainage decreases to zero from May through September as precipitation increased which is the effect of increased evapotranspiration. It isn't until later in the year when soil water increases and evapotranspiration decreases that waste drainage again occurs.

SOIL TEXTURE

The purpose of this section was to evaluate the sensitivity of the hydrologic modeling processes to changes in the soil texture of the vegetative and barrier soil. Varying the soil texture changes many of the other input parameters such as the hydraulic conductivity, soil porosity, evaporation coefficient, and available water capacity. Parameter values which were used with the various soil textures are presented in Table C-7.

Changing the hydraulic conductivity, soil porosity, evaporation coefficient, and available water capacity for the vegetative and barrier soil resulted in small changes in the upper storage limit and the initial water storage. Since these variables are used in computations such as surface runoff, evapotranspiration, and waste drainage, it would be expected that these processes reflect these changes. However, these processes do not show a uniform change with respect to a single variable when evaluated on a yearly basis. Table C-8 presents each process for each parameter computed as a percentage of the average annual precipitation. Waste drainage changed by 9.8 percentage points from one soil texture extreme to the other while evapotranspiration and surface runoff changed by 3.5 and 8.5 percentage points, respectively. However, most of the variation is attributable to case No. 12 sandy clay loam/clay (compacted). Disregarding the results of this soil texture, waste drainage only changes by 2.3 percentage points while evapotranspiration changes by 3.5 percentage points and surface runoff by 2.1 percentage points. The variations resulting from changing the soil texture are small in comparison to variations found with other parameters. Most of the changes caused by soil texture are a result of the previously mentioned variations in soil-water relationships which are compounded by conditions in the late fall and winter. These conditions involve the replenishment of the

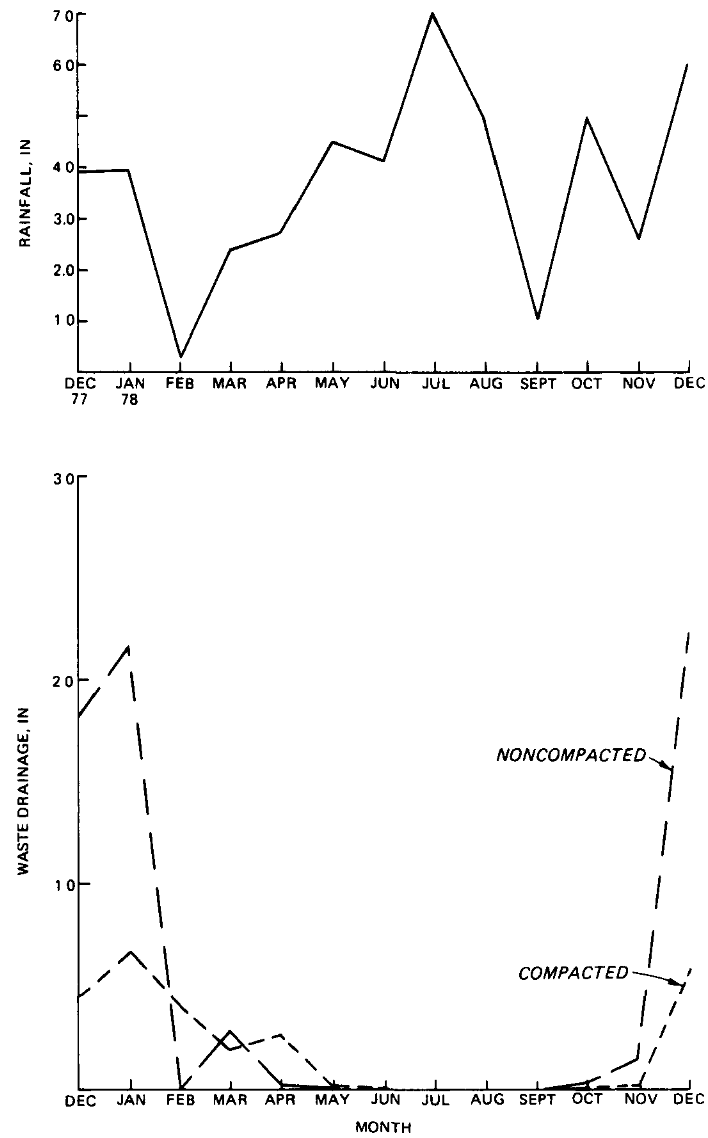

Figure C-25. Waste drainage and precipitation during the month of occurrence for 1978.

TABLE C-7. SOIL PARAMETER VALUES USED IN THE SENSITIVITY STUDY

Soil texture	Hydraulic conductivity (in./hr)	Soil porosity (vol/vol)	Evaporation coefficient	Available water content (vol/vol)
Sand	5.4	0.389	3.3	0.133
Sandy loam	0.67	0.442	3.8	0.123
Loam	0.21	0.521	4.5	0.156
Sandy clay loam	0.084	0.453	4.7	0.199
Clay (noncompacted)	0.022	0.680	3.5	0.115
Clay (compacted)	0.0011	0.226	3.1	0.038

In all, 12 different combinations of vegetative and barrier soils were run as follows:

No.	Vegetative soil	Barrier soil
1	Sand	Sand
2	Sand	Sandy loam
3	Sand	Loam
4	Sand	Sandy clay loam
5	Sand	Clay
6	Sandy loam	Loam
7	Sandy loam	Sandy clay loam
8	Sandy loam	Clay
9	Loam	Sandy clay loam
10	Loam	Clay
11	Sandy clay loam	Clay (noncompacted)
12	Sandy clay loam	Clay (compacted)

TABLE C-8. PERCENTAGES OF THE SURFACE RUNOFF, WASTE DRAINAGE, AND EVAPOTRANSPIRATION TO THE AVERAGE ANNUAL PRECIPITATION FOR VARIOUS SOIL TEXTURES

No.	Soil textures	Surface runoff percent	Waste drainage percent	Evapotranspiration percent
1	Sand/sand	16.7	14.7	68.1
2	Sand/sandy loam	16.7	14.8	68.0
3	Sand/loam	16.7	14.4	68.4
4	Sand/sandy clay loam	16.7	14.9	68.0
5	Sand/clay	16.1	14.8	67.9
6	Sandy loam/loam	15.8	13.8	69.9
7	Sandy loam/sandy clay loam	15.8	14.4	69.4
8	Sandy loam/clay	15.2	14.2	69.3
9	Loam/sandy clay loam	15.3	12.6	71.6
10	Loam/clay	14.6	12.5	71.6
11	Sandy clay loam/clay (non)	14.5	13.7	70.6
12	Sandy clay loam/clay	23.1	5.1	69.8

soil water to levels approaching the storage limit by the precipitation later in the year. Waste drainage, which is dependent on the level of soil water, is sensitive to the precipitation rate as well as the effect of soil texture on percolation.

To illustrate relationships on a daily basis as well as to evaluate the time lag of waste drainage for the different soil textures, the first 4 months of 1978 were selected for detailed analysis. Table C-9 shows the waste drainage as a function of time and displays precipitation data for the first 114 days of 1978. Waste drainage was zero after 114 days (continuing through summer and early fall) for all cases except the sandy clay loam - vegetative soil and the clay (compacted) - barrier soil. This occurred because of the increased evapotranspiration following the start of the growing season on day 92.

The waste drainage output will be evaluated first, for those conditions without a barrier soil of clay and second, for those conditions with a

TABLE C-9. AMOUNT OF WASTE DRAINAGE AND PRECIPITATION AS A FUNCTION OF TIME AND SOIL TEXTURE (VS = vegetative soil, BS = barrier soil, comp = compacted)

Day	Precipitation	VS-S BS-S	VS-S BS-SL	VS-S BS-L	VS-S BS-SCL	VS-S BS-C	VS-SL BS-L	VS-SL BS-SCL	VS-SL BS-C	VS-L BS-SCL	VS-L BS-C	VS-SCL BS-C	VS-SCI BS-C-Comp
1	0.03												0 0631
2	0.02												0 0115
5	0.45	0.1854	0 1854	0.1853	0.1853	0.1013	0 1851	0 1851	0.1012	0 1763	0.0965	0 1019	0 0394
7	0.43	0.3103	0.3103	0.3103	0 3103	0.2426	0.3114	0.3114	0.2431	0.3085	0.2380	0 2439	0 0390
8	1 32	0.5476	0.5476	0.5476	0.5476	0 3814	0 5476	0.5476	0.3816	0.5476	0 3805	0.3818	0 0187
12	0.08					0 3052			0.3503		0 3047	0 3054	0 0698
13	0.06	0 0264	0.0264	0 0264	0.0264	0.0172	0.0264	0 0264	0 0173	0 0264	0.0173	0 0173	0 0170
14	0.02					0.0086			0 0086		0.0086	0.0086	0 0166
15	0 02					0 0034			0.0034		0.0034	0 0034	0 0162
16	0.35	0.2733	0 2733	0.2733	0.2733	0.1466	0.2735	0 2735	0 1467	0 2729	0.1464	0 1467	0 0211
17	0.31	0.2519	0.2519	0.2519	0.2519	0.2119	0.2519	0 2519	0.2120	0.2519	0.2118	0.2120	0 0187
19	0.04					0.1448			0 1448		0.1447	0 1448	0 0360
20	0 18	0.1480	0.1480	0.1480	0.1480	0 0931	0.1480	0.1480	0.0932	0.1479	0 0931	0 0932	0 0200
21	0.01					0.0474			0.0475		0.0475	0 0475	0 0187
24	0 22	0.1326	0.1326	0.1326	0.1326	0.0984	0 1329	0.1329	0.0986	0.1320	0.0980	0 0986	0 0561
25	0.09	0.0656	0.0656	0 0656	0 0656	0 0738	0.0656	0.0656	0 0739	0.0656	0 0736	0 0739	0 0187
26	0.31	0.2504	0.2504	0 2504	0.2504	0 1673	0 2504	0.2504	0.1674	0 2504	0 1673	0.1674	0 0207
28	0.01					0.1191			0.1191		0 1190	0 1191	0 0369
31	0.01					0 0175			0.0175		0 0175	0 0175	0 0516
36	0.04					0 0006			0 0006		0 0006	0.0006	0 0766
44	0.13												0 1036
47	0.03												0 0337
49	0.03												0 0211
51	0.01												0 0200
52	0.02												0 0096
53	0.02												0 0094

(Continued)

Day	Precipitation	VS-S BS-S	VS-S BS-SL	VS-S BS-L	VS-S BS-SCL	VS-S BS-C	VS-SL BS-L	VS-SL BS-SCL	VS-SL BS-C	VS-L BS-SCL	VS-L BS-C	VS-SCL BS-C	VS-SCL BS-C-Comp
59	0.03												0.0516
60	0.02												0.0078
61	0.17												0.0076
62	0.11												0.0074
66	0.08												0.0274
67	0.24												0.0059
70	0.19												0.0150
71	0.06												0.0041
72	0.05												0.0037
73	0.49	0.1565	0.1565	0.1565	0.1565	0.0832	0.0377	0.0377	0.0201	0.0258	0.0137	0.0111	0.0045
75	0.04					0.0634			0.0153		0.0105	0.0085	0.0102
79	0.20					0.0098			0 0024		0.0016	0.0013	0.0198
81	0.05					0.001							0.0082
82	0.11												0.0036
83	0.57	0.2845	0.2845	0.2845	0.2845	0.1513	0 2798	0.2798	0.1488	0.2689	0.1430	0.1496	0.0104
84	0.02					0.0819			0.0806		0.0774	0.0801	0.0127
91	0.02					0.0513			0.0506		0.0484	0.0507	0.0803
93	0.01	1st day of growing season											0.0204
94	0.06												0.0098
96	0.34												0.0189
99	0.01												0.0266
101	0.26												0.0166
108	1.03	0.0268	0.0268	0.0268	0.0268	0.0143							0.0516
109	0.04					0.0077							0.0063
110	0.08					0.0031							0.0058
113	0.40					0.0016							0.0147
114	0.20												0.0040

barrier soil of clay. The waste drainage characteristics of the barrier soils without clay demonstrate that leachate production occurs on a day of heavy precipitation. As these soil textures have relatively high hydraulic conductivities, water percolates within the 24-hour period and rapidly appears as waste drainage. Even though some of the hydraulic conductivities are 60 times as large as others (sand equals 5.4 in./hr and sandy clay loam 0.084 in./hr) all waste drainage is completed within the 24-hour time interval. During the early part of the season, waste drainage is essentially the same for cases without a clay barrier soil. Some differences begin to show after the 72nd day resulting from increased evapotranspiration as solar radiation and temperature increases. After the growing season starts on the 92nd day, increased evapotranspiration causes the waste drainage to go to zero except for the sand vegetative soil layers where the available water capacity has reduced to a level unavailable to plants.

Secondly, to be considered is the output from those cases with a barrier soil of clay. The low hydraulic conductivity (0.022 in./hr) results in percolation that exceeds the 24 hour model time period. From days 5 through 36, waste drainage occurred continually for all clay barrier soils. In comparison, nonclay barrier soils had five events during the 31-day time period when no waste drainage occurred. Also, the peak values of waste drainage for clay barrier soils was not as high as nonclay barrier soils.

The waste drainage is virtually identical for clay barrier soils which was a similar relation noted for nonclay barrier soils. When the clay barrier soil was compacted and the hydraulic conductivity was lowered to 0.0011 in./hr, the percolation continued through the first 125 days although at a greatly reduced rate and magnitude (1.2452 inches of leachate in 117 days for the compacted clay barrier soil and 2.5909 inches of leachate in 117 days for the noncompacted clay barrier soil). The time lag on percolation was great enough to provide leachate through the dry period, from day 36 through 72.

Figure C-26 shows the time lag for the three extreme soil texture combinations. While some correlation of peak waste drainage is shown, the reduced magnitude and time lag effect is readily apparent.

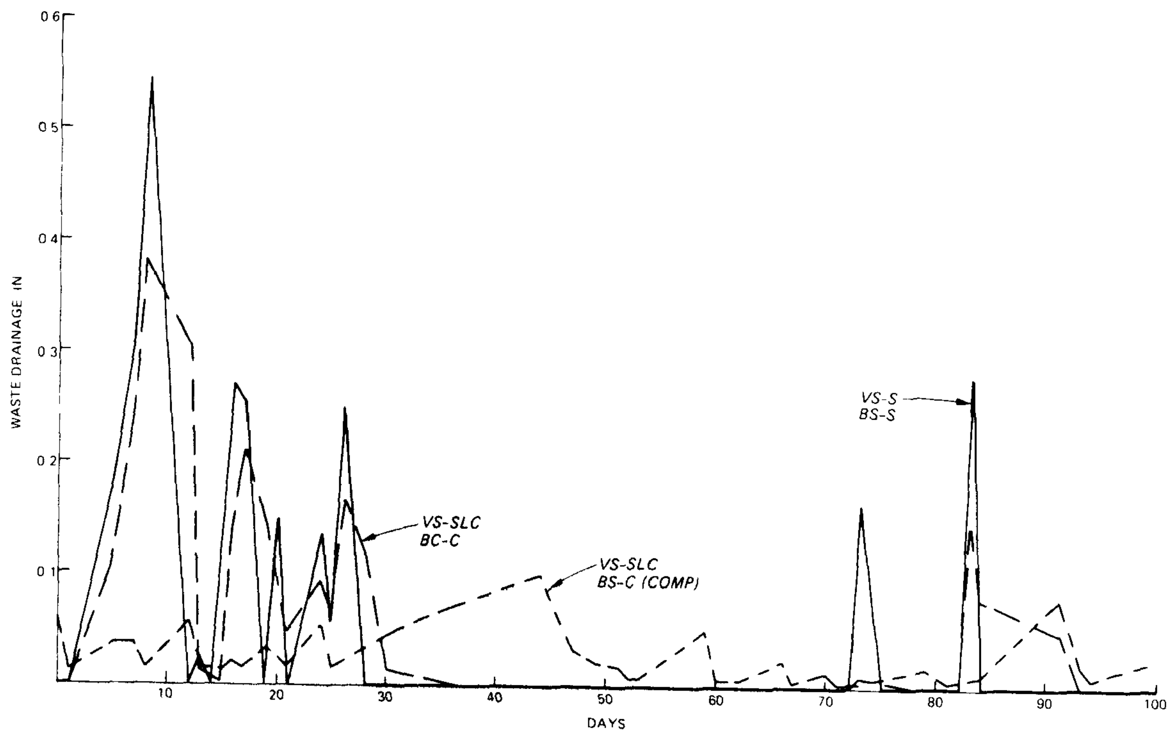

Figure C-26. Waste drainage as related to time in days for various soil textures (V = vegetative soil, BS = barrier soil, comp = compacted).

SUMMARY OF SENSITIVITY STUDY

In summarizing the sensitivity study performed, Table C-10 was constructed from the results. It demonstrates the relative effect of the changes in the selected parameters on the more salient features of the simulation. However, it should be noted that the study was for a particular area in or near Cincinnati, Ohio. The responses shown may change somewhat for hazardous and solid waste sites with radically different climatological and hydrological data sets.

The general summarization of the sensitivity study conclusions are presented as follows:

1. Waste drainage and evapotranspiration are significantly affected by changes in the soil-water storage and the available water capacity.

2. The winter cover factor is seasonally dependent and directly affects sensitivity of the evapotranspiration.

3. The SCS curve number primarily affects the surface runoff and secondarily affects both the evapotranspiration and the waste drainage.

4. The impermeable liner only affects water that has percolated past where there is control by evapotranspiration and surface runoff.

5. The surface runoff was the most sensitive parameter when varying the barrier soil depth.

6. The effects of the LAI are seasonally dependent and the parameters most sensitive to changes in LAI were evapotranspiration and waste drainage.

7. The primary parameters affected by the barrier soil compaction were waste drainage and surface runoff.

8. Changes in soil texture are highly time dependent and produce conditions where other parameters are very sensitive.

TABLE C-10. SUMMARY OF SENSITIVITY STUDY RESULTS

Parameter	Change		Surface Runoff			Evapotranspiration			Waste Drainage			Soil Drainage			Type of Variable
	From	To	Sensitivity	Direction	Rank*	Sensitivity	Direction	Rank	Sensitivity	Direction	Rank	Sensitivity	Direction	Rank	
Impermeable liner	5 yr	Ind.	NA**	NA	NA	NA	NA	NA	†	↑	1	†	↑	1	Computed
SCS curve number	81	99	††	↑	1	††	↓	2	‡	↓	3	NA	NA	NA	Constant
Winter cover factor	0.5	1.0	‡	↓	2	‡‡	↑	1	†	↓	3	NA	NA	NA	Seasonal
Depth of barrier soil	6 in.	18 in.	‡‡	↑	1	‡	↓	2	†	↓	3	NA	NA	NA	Constant
Depth of vegetative soil	12 in.	36 in.	†	V**↓	3	§	↑	2	§	↓	1	NA	NA	NA	Constant
Leaf area index	Excell	Brgd	§	↑	2	‡‡	↓	1	‡	↑	3	NA	NA	NA	Seasonal
Barrier soil compaction	NCP	CP	‡	↑	2	†	↓	3	§	↓	1	NA	NA	NA	Constant
Soil Texture															
Vegetative layer-S	S	C	†	V↓	1	†	V↓	2	†	V↑	3	NA	NA	NA	Constant
Vegetative layer-SL	L	C	†	↓	1	†	↓	2	†	V↑	3	NA	NA	NA	
Vegetative layer-L	SLC	C	†	↓	1	†	↓	3	†	↓	2	NA	NA	NA	
Vegetative layer-SLC	NCP	CPD	§	↑	1	†	↓	3	§	↓	1	NA	NA	NA	

NOTE: Arrow indicates direction of changes, (↑ increase and ↓ decrease).

* Rank means the percentage change when the parameter is related to the average annual precipitation (1 = largest, 3 = lowest change).

** NA - Not Affected, and V - Variable (Arrow indicates general tendancy)

† - Slightly

‡ - Moderately

§ - Significantly

‡‡ - Highly

†† - Extremely

APPENDIX D

OPERATION OF COMNET COMPUTER SYSTEM*

1. Turn on data terminal.

2. Dial appropriate telephone number given in Table D-1.

3. Put telephone handle in handset muff (or depress telephone line button).

4. Wait for green light to come on (on line), then press RETURN key.

5. You type: WCCTSO (press RETURN key).†

6. The computer system types:

   TSO SYSTEM AT COMNET - ENTER LOGON -

   You type on the same line

   LOGON (identification number)/Password (press RETURN key)

7. The computer system types:

   READY

   You type:

   RUNHYDRO (press RETURN key)

8. At this point, the program prints a heading and begins to ask questions.‡

9. When program is finished, you type:

   LOGOFF (press RETURN key) or repeat step 7 for reruns.

---

* Computer Network Corporation (COMNET).
† To correct typing error use the BACKSPACE key.
‡ There are no input prompts.

TABLE D-1. TELEPHONE NUMBERS NEEDED TO LOG ON THE COMNET COMPUTER SYSTEM

State	City*	Telephone
Alabama	Montgomery	(205) 277-9390
California	San Francisco	(415) 546-1395
Colorado	Denver	(303) 837-0843
Connecticut	Wethersfield	(203) 529-3378
Dist. of Col.	Washington	(202) 966-9510
Georgia	Athens	(404) 549-3882
	Atlanta	(404) 873-6431
Illinois	Chicago	(312) 663-1640
Louisiana	New Orleans	(504) 566-0041
Massachusetts	Boston	(617) 742-0420
Michigan	Grosse Ile	(313) 675-8936
Missouri	Kansas City	(816) 474-3540
Nevada	Las Vegas	(702) 736-1988
New York	New York	(212) 962-7943
Ohio	Cincinnati	(513) 751-5800
Pennsylvania	Philadelphia	(215) 925-4407
North Carolina	Raleigh/Durham	(919) 541-2000
South Carolina	Columbia	(803) 256-1018
Tennessee	Nashville	(615) 244-8020
Texas	Dallas	(214) 651-1723
Washington	Seattle	(206) 682-6456

* Other cities (800) 424-3690.

COST BREAKUP FOR THE COMNET-TSO SYSTEM

1. There are two cost parameters associated with the Computer Network Corporation Time Sharing Operation (COMNET/TSO). These are storage charges and central computer processing costs. There is no connect cost with the COMNET/TSO system.

2. There are three types of data storage on COMNET/TSO. The public online disk storage charge is $.00666 per track per day. Private online disk cost is $1000.00 per pack per month and private mountable disk cost is $50.00 per pack per month. There is no charge for private disk pack mounts.

3. COMNET time sharing charges are computed by the TSO Utilization Unit (TUU) algorithm. The TUU costs are $0.56 per TUU.

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