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HYDROLOGIC SIMULATION ON SOLID WASTE DISPOSAL SITES

by

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DISCLAIMER

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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 disposition 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 the Environmental Protection Agency in the Federal Register on May 19, 1980. The Environmental Protection Agency published interim final rules in Part 264 for hazardous waste disposal facilities on July 26, 1982. These regulations consist primarily of two sets of performance standards. One is a set of design and operating standards separately tailored to each of the four types of facilities covered by the regulations. The other (Subpart F) is a single set of ground-water monitoring and response requirements applicable to each of these facilities. The permit official must review and evaluate permit applications to determine whether the proposed objectives, design, and operation of a land disposal facility will comply with all applicable provisions of the regulations (40 CFR 264).

The Environmental Protection Agency is preparing two types of documents for permit officials responsible for hazardous waste landfills, surface impoundments, land treatment facilities and piles: Draft RCRA Guidance Documents and Technical Resource Documents. The draft RCRA guidance documents present design and operating specifications which the Agency believes comply with the requirements of Part 264, for the Design and Operating Requirements and the Closure and Post-Closure Requirements contained in these regulations. The Technical Resource Documents support the RCRA Guidance Documents 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 good engineering practices. 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 Environmental Protection Agency method, they 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 CFR 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. The references are cited throughout the manuals to provide further guidance for the permit officials when necessary.

There was a previous version of this document dated September 1980. The new version supercedes the September 1980 version.

FOREWORD

The Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is the first necessary step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and the solid and hazardous waste pollutant discharges from municipal and community sources; to preserve and treat public drinking water supplies; and to minimize the adverse economic, social, health and aesthetic effects of pollution. This publications is one of the products of that research--a vital communications link between the researcher and the user community.

The Hydrologic Simulation Model on Solid Waste Disposal Sites was developed to help landfill designers and permit officials estimate the amount of moisture percolation through different types of landfill covers.

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Municipal Environmental Research
Laboratory

ABSTRACT

The Hydrologic Simulation Model on Solid Waste Disposal Sites was developed to help landfill designers and evaluators estimate the amount of moisture percolation through different types of landfill covers. This one-dimensional deterministic, computer-based, water budget model was developed and adapted from the U. S. Department of Agriculture CREAMS hydrologic model and uses the Soil Conservation Service curve method for calculating runoff. The model takes engineering, hydrologic, and climatologic input data in the form of rainfall, average temperatures, solar radiation, and leaf area indices, and characteristics of cover material and performs a sequential analysis to derive a water budget including the runoff, percolation, and evapotranspiration.

The user can specify up to three soil layers and may also specify a membrane liner at the base of the cover. The decreasing effectiveness of the liner is simulated. Five years of climatological default data are on files accessible to the program user. If no climatic data are available for a specific site, data from the nearest site where weather records are available can be substituted. The model also stores logical hydrological default values for the minimum infiltration rate, the porosity, the hydraulic conductivity, the available water capacity, and the evaporation coefficient where measurements or estimates are not available.

The model is ordinarily used in the conversational mode, which enables the user to interact directly with the program and receive output through the terminal immediately. No prior experience with computer programming is required. The model can also be run in the batch mode, which requires more computer programming experience.

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FIGURES

FIGURES (continued)

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TABLES (continued)

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of several individuals. Dr. Arlin D. Nicks of the U. S. Department of Agriculture provided a copy of the CREAMS model and made helpful criticisms and suggestions. Mr. James H. Terry III of the Waterways Experiment Station (WES), Environmental Laboratory (EL), developed the city/state climatological tape. Mr. Robert J. Wills, Jr., made constructive suggestions and prepared Appendix D of this report. Mr. Paul R. Schroeder of EL also made significant contributions. Ms. Jane Harris, S.E. Huey Co., Monroe, La., assisted throughout the project. Dr. Richard Lutton, of the WES Geotechnical Laboratory, was principal investigator for the study entitled "Cover for Solid and Hazardous Wastes." Dr. Lutton and Dr. Philip G. Malone, of EL, updated sections of the manual. Mr. James Jefferson, of the WES Computer Systems Division, contributed to the batch mode development.

The model development was conducted under the general supervision of Dr. John Harrison, Chief, EL, and Mr. Andrew J. Green, Chief, Environmental Engineering Division (EED). Direct supervision was provided by Mr. Michael R. Palermo, Chief, Water Resources Engineering Group (EED). Mr. Douglas Ammon, Mr. Robert E. Landreth, Mr. Dirk Brunner, Dr. Mike Roulier, and Mr. Bryan Young, Solid and Hazardous Waste Research Division, EPA, Cincinnati, Ohio, followed progress in the interest of the sponsor.

SECTION 1

INTRODUCTION

BACKGROUND

Current requirements for landfill design call for minimizing the discharge of contaminated percolating water (leachate) associated with landfills. Landfill leachate control begins with proper siting of a landfill and continues with the design of liners, covers, and collection and treatment systems. In a completed landfill that has been graded to eliminate or minimize runon of surface water, the major source of moisture that produces leachate is the percolation of precipitation through cover materials. In a modern, lined landfill, the percolation rate will determine when and in what volumes leachate will be produced for treatment and discharge. Predicting percolation rates in cover materials is vital to evaluating a cover design and also to establishing design criteria for collection and/or treatment systems. A recent report on the subjects of design and construction of cover identified several useful quantitative methods for estimating percolation through cover for the purpose of checking cover designs (1).

PURPOSE

This report describes the use of a computer-based model for simulating the percolation of precipitation through cover material at a solid waste disposal site. The model, referred to as the HSSWDS model (for hydrologic simulation at solid waste disposal sites) is a modification and adaptation of a soil percolation model developed by the U. S. Department of Agriculture (USDA).* The HSSWDS can be employed in the evaluation of present cover materials at a landfill or in the design of new or improved landfill covers. Of course, covers do more than limit moisture movement; they are also important in the control of disease vectors and landfill gases and in fire protection. Since cover design involves much more than estimating percolation, the evaluator should also review the companion technical resource document (2), which summarizes steps in evaluating cover designs, plans, construction, and maintenance.

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* The USDA model is entitled "Chemical Runoff and Erosion from Agricultural Management Systems" and is also identified as the CREAMS model (3).

SCOPE

The HSSWDS model is presented as a communication-type computer package that permits rapid evaluation of landfill, cover designs, and soil materials. This format makes the relatively sophisticated computer analysis available even to evaluators with little computer experience. Any mathematical model that is used in engineering design should be used with careful consideration of the assumptions that go into the calculation of design parameters and the nature of the input data.

ASSUMPTIONS AND LIMITATIONS

The HSSWDS model, in its present configuration, is a deterministic, one-dimensional model that develops a long-term water balance based on historical or simulated daily rainfall records. Infiltration of moisture through the soil surface is calculated using the SCS curve number technique. The SCS curve number technique relates runoff to soil type, land use, and management practices and uses daily rainfall records. The actual rainfall intensity, duration, and distribution are not considered.

Factors such as slope and surface roughness, which would be important if individual rainfall events (storms) were input, are considered in the context of the land use/land management factors used in the selection of the SCS curve number. Average daily temperatures, average daily solar radiations, and average leaf area indices are used to estimate water loss by evaporation or transpiration. The model is no more complex than a manual tabulation of moisture balance (4), but HSSWDS makes available a more complete data base and a state-of-the-art system for obtaining an accurate water budget over a wide variety of climatic, soil, and vegetative conditions.

SECTION 2

GENERAL DESCRIPTION OF PROGRAM

The HSSWDS program consists of a set of computer-based modules that perform daily water balance calculations on the input cover design. The water balance method can be used to estimate percolation through cover by computer analysis and by manual tabulation as well.(1,4) The HSSWDS program has been written for users who may have no 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 obtains results quickly. To reduce costs, a batch session of the program is available, but it requires additional computer programming knowledge.

The hydrologic portion of the CREAMS model (3) has been modified to conform to the configuration of cover over solid waste. Those important parts of the CREAMS model that are basic to the HSSWDS model are reviewed in Appendix A. The flow chart for HSSWDS is shown in Figure 1 for daily time steps. From minimal input data, the model will simulate daily, monthly, and annual values for runoff, percolation,* temperature, soil-water, and evapotranspiration.

To expedite its use, the model stores many default values for various parameters. These values are to be used when measured and existing data are not available--for example, soil-water characterization, precipitation, mean monthly temperatures, mean monthly solar radiation, and vegetative characteristics. Five years' worth of climatic records from many weather stations within the United States are on tape for use in lieu of onsite measurements. From 2 to 20 years' worth of climatic data can be input if the user wishes to do so manually. The user must supply the title and geographical location and the characteristics of the soil and vegeative cover. A sensitivity study of the model is given in Appendix D.

* Percolation quantities may be interpreted directly as leachate quantities only by making the major simplying assumption that water content of solid waste below the cover is at field capacity so that percolation moves instantaneously through the waste cell.

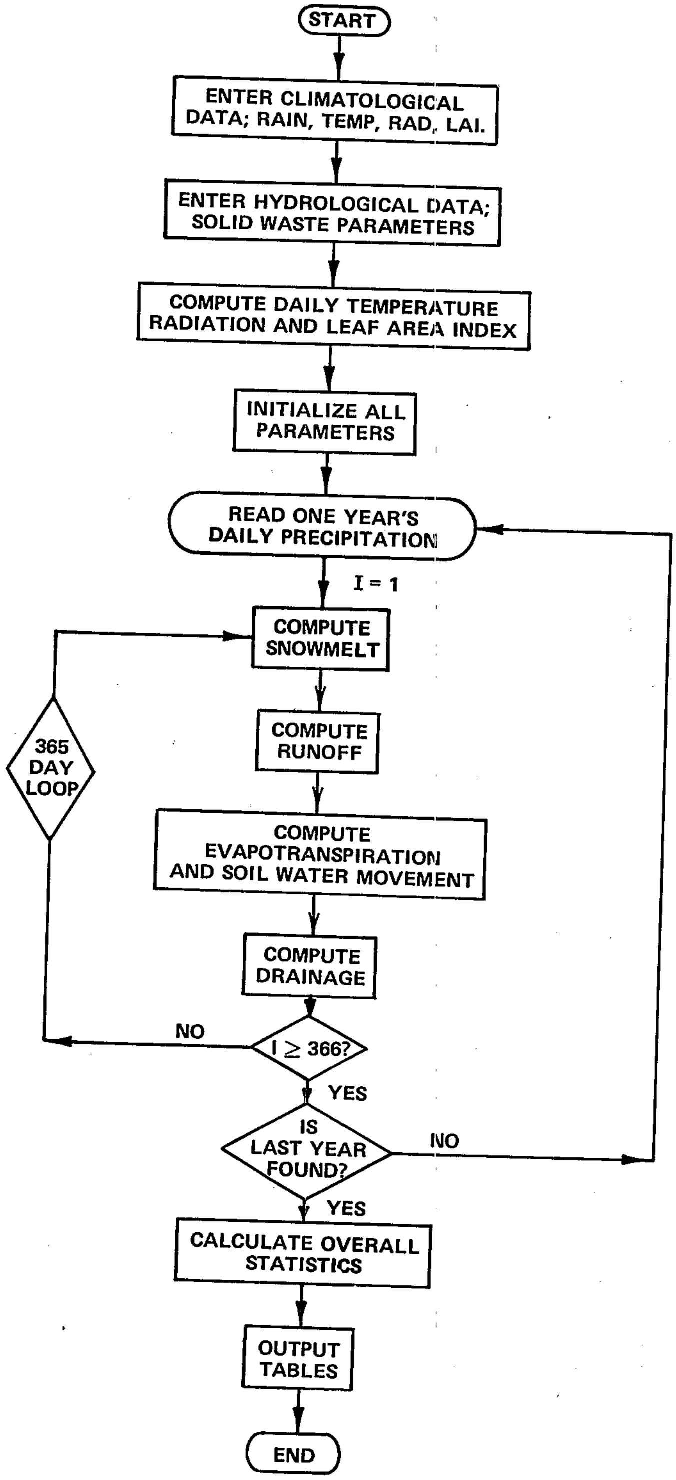

Figure 1. Generalized flowchart for the hydrologic simulation Model HSSWDS.

SECTION 3

HSSWDS USER'S MANUAL

All major hydrologic processes that occur during a rainstorm (rainfall, infiltration, soil-water movement, deep drainage, and surface water flow, for example) can be simulated at various levels of detail. HSSWDS is a continuous model that uses 1 day as the time step for evapotranspiration, soil-water movement, and percolation. This section is presented to help 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 that infiltrates the soil cover percolates across the interface of the soil cover and solid waste. The model limits the user to three layers in the final cover soil--a vegetative soil, a soil layer 2, and a soil layer 3. At the interface of the cover soil and the solid waste, the user may specify an impermeable liner, usually of a polymeric material. The model will evaluate the effect of the finite life of the liner using the age equations (power law). The model permits an examination of the soil cover system to produce a better design under specified climatic conditions.

A conceptual understanding of soil water contents and movement is necessary to model operation (Figure 3). The terminology (5) used in the model is defined as follows:

a) <u>Field capacity</u> is the water content that a soil retains after drainage ceases (due to the forces of gravity).

b) <u>Wilting point</u> is the water content a soil retains after plants cannot extract any more soil water and remain wilted.

c) <u>Available water capacity</u> is the difference between the soil water at field capacity and the wilting point.

d) <u>Hydraulic conductivity</u> is the rate of soil-water movement (because of the forces of gravity) between the soil-water contents at saturation and field capacity.

MODEL OPERATION USING DEFAULT DATA

To expedite model usage, the default option provides for input of specific default values of evapotranspiration, evaporation, and soil/water

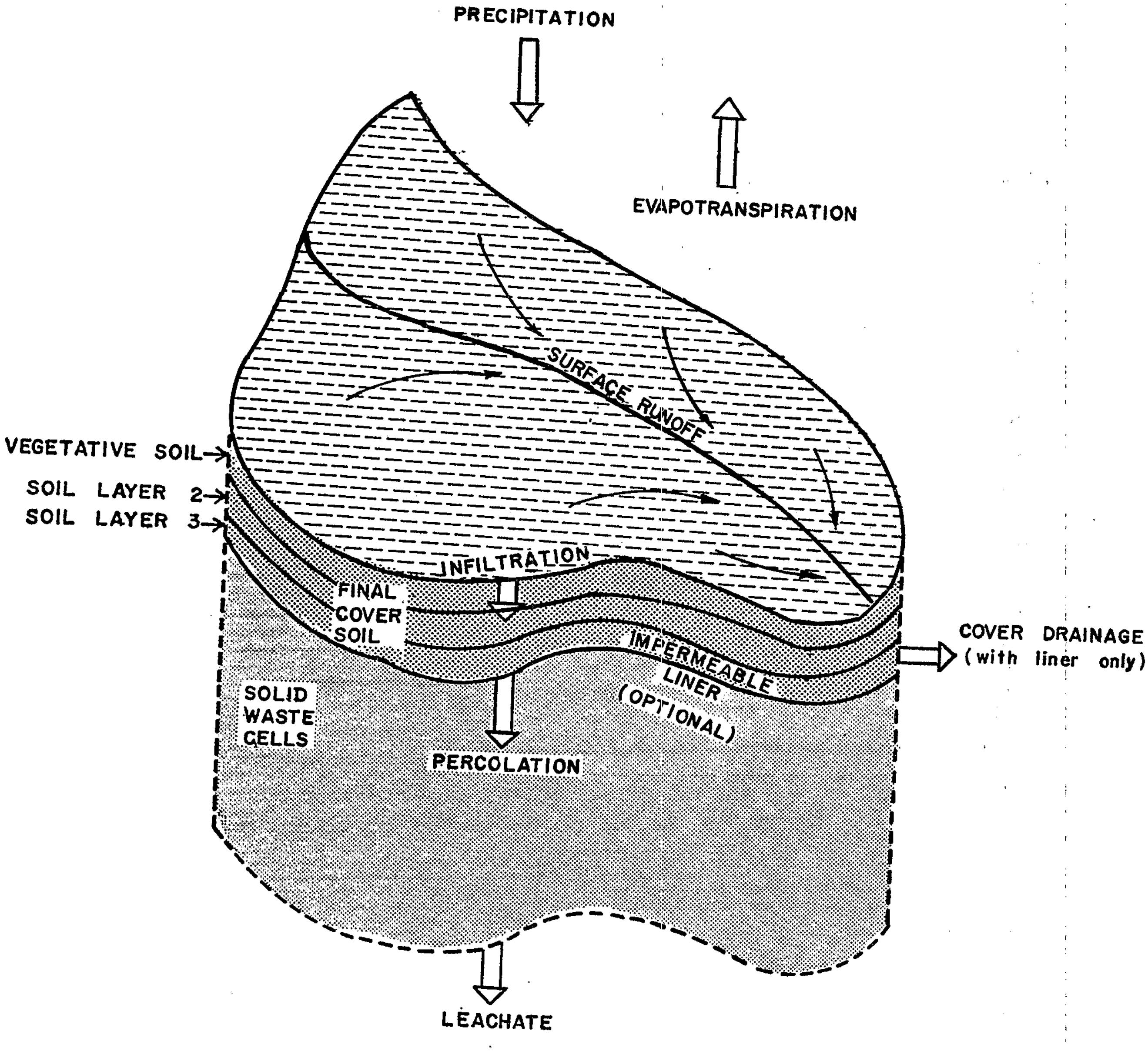

Figure 2. Schematic diagram of the hydrologic cycle on a solid waste disposal site.

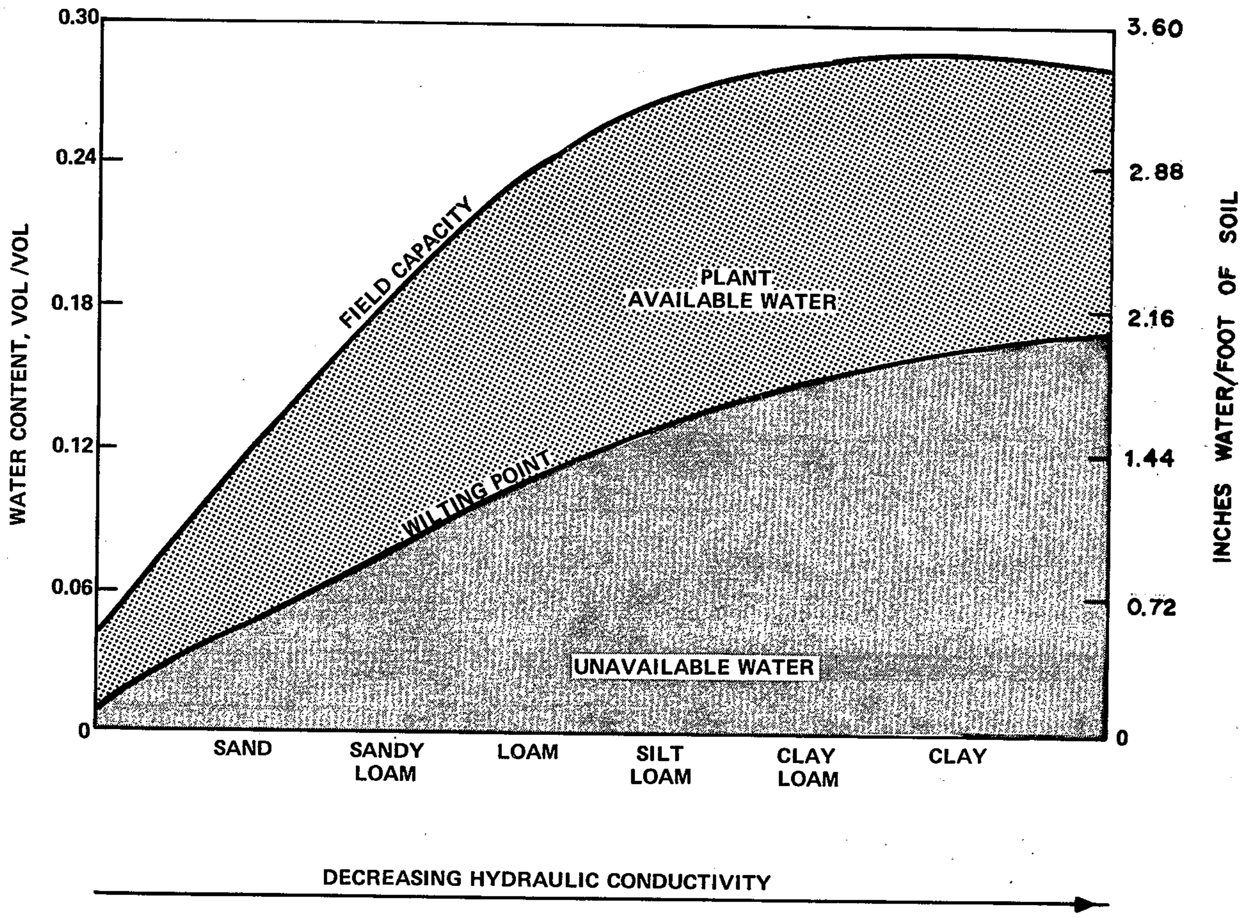

Figure 3. General relation between soil water, soil texture, and hydraulic conductivity.

characteristics. Examples of these values are shown in Table 1. References 1 and 2 describe and compare the USDA and USCS soil classes that are used in the table. In addition, numerous stations within the United States that contain 5 years' worth of climatic records are on disk for easy access to the geographical location of interest. The locations available for using default data are presented in Table 2.

STEPS TO LOG ON AND OFF NCC

The 10 steps required to log on and the one step required to log off the National Computer Center (NCC)* IBM Computer System are given as follows:

1. Turn on data terminal.

2. Dial appropriate telephone number given in Appendix C.

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

4. The computer system types:
   PLEASE TYPE YOUR TERMINAL IDENTIFIER (see Appendix C).
   You type† on the same line:
   A

5. The computer system types:
   -131Ø-Ø46-
   PLEASE LOG IN:
   You type on the same line:
   IBMEPA1;NCC
   Press RETURN key

6. The computer system types:
   IBM3 IS ON LINE
   You type:
   TSO
   Press RETURN key

7. The computer system types:
   ENTER LOGON
   You type:
   LOGON
   Press RETURN key

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* To obtain cost information for the NCC Computer System, see Appendix B.

† To correct typing errors, use the BACKSPACE key.

TABLE 1. COVER SOIL CHARACTERISTICS USED AS DEFAULT VALUES*†

Code	Soil class USDA	Soil class USCS	MIR (in./hr)	Porosity (vol/vol)	Ksat (in./hr)	AWC (vol/vol)	Evaporation coefficient
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	0.054	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

* 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.

† When soil layer 2 or 3 is compacted, the values for porosity, Ksat, and AWC are changed to account for compaction. The Ksat values are also changed in the vegetative part of the soil cover as a function of vegetation type. The AWC values listed in the table are used to compute the field capacity and wilting point.

TABLE 2. MEAN DAILY SOLAR RADIATION (LANGLEYS)*

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)

* Source: Reference 3.

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

8. The computer system types:
IKJ56700A ENTER USERID -
You type:
Identification number/password
Press RETURN key

9. The computer system types:
ENTER ACCUID
You type:
(account-VID-M)*
Press RETURN key

10. The computer system types:
READY
You type:
RUNHYDRO
Press RETURN key

11. When the program is finished, you type:
LOGOFF
Press RETURN key or repeat step 10 for reruns.

WORKSHEETS FOR DEFAULT DATA

A worksheet is presented in Figure 4 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.

ENTRY OF DEFAULT DATA

Initially, the program prints a heading (Figure 5) that details the title, name, and address of the authors, and the telephone number to call for information about the program and for clarification of problems if and when they arise.

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

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

YES
```

---

* Enter the account, the utilization identifer, and the letter P with no separators or blanks.

STATE: ______________________________

CITY: ______________________________

STUDY TITLE: ______________________________

AREA LOCATION: ______________________________

YEARS OF INTEREST: ______________________________

Thickness of soil cover . . . . ____________ inches

Thickness of vegetative layer . . . . ____________ inches

Thickness of soil layer 2 . . . . ____________ inches

Thickness of soil layer 3 . . . . ____________ inches

Figure 4. 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                           *
*                                                                 *
*******************************************************************
*******************************************************************
```

Figure 5. Example of initial program heading.

If the user enters NO, the program assumes that the method of input will be manual. (See manual input option).

```
DO YOU WANT TO USE CLIMATOLOGIC DATA
FROM THE PREVIOUS RUN?
ENTER YES OR NO


NO
```

The computer will type a table of the cities and states from which the climatological default data is available. If YES is entered, the model will print the name of the city in which the climatologic data are stored, and the user should enter the number 2 for hydrologic input.

```
ENTER NAME OF STATE OF INTEREST


CALIFORNIA

ENTER NAME OF CITY OF INTEREST


LOS ANGELES
```

Note: The user must enter a word or value for each input, and after the word or value has been entered, the user must press the RETURN key.

In the event that a typing error is committed, use the following procedures. If, for example, CAILFORNIA was typed, 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


CAILFORNIALIFORNIA
```

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


LOO ANGELES *DEL* LOS ANGELES
```

* Some computer terminals use a different backspacing method.

For the city requested, the program retrieves the climatological data on precipitation, temperatures, solar radiation, and two types of leaf area index (LAI) values (one for the row crop and the other for grass). Once this has been done, the user should enter a 2 for the input of hydrologic characteristics.

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

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


2


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

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

The program requests the following for the user's information only, and this information is printed twice in the output to label the job output. 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.


HYDROLOGY OF A SOLID WASTE DISPOSAL SITE
TEN MILES SOUTH OF TOWN
 1 FEBUARY 1982
```

At this point, the user has the option of designing the final cover soil with a vegetative layer, a soil layer 2, and/or a soil layer 3, or with a uniform cover soil. Three layers are the most permitted. If the user desires a two- or three-layer system, the following commands are answered.

ENTER NUMBER OF LAYERS IN SOIL COVER

3

The user should also enter the total thickness of the soil cover when queried.

ENTER TOTAL THICKNESS OF SOIL COVER (INCHES)
36

Now the user must select the general texture class of vegetative soil from the classes shown in Table 1. For example, the user inputs the number nine in the example problem, which is the code for fine sandy loam. The vegetative soil cover is assumed to be spread uniformly. Any grass or row crop is assumed to have had appropriate cultivation and seedbed preparation.

ENTER SOIL TEXTURE OF VEGETATIVE SOIL

ENTER A NUMBER (1 THROUGH 18) FOR TEXTURE CLASS OF SOIL MATERIAL.

CHECK USER MANUAL FOR NUMBER CORRESPONDING TO SOIL TYPE

9

The user must enter the thickness of soil layer 2 along with its texture code and must answer whether or not soil layer 2 was compacted. If soil layer 2 was compacted, the value of hydraulic conductivity is reduced by a factor of 20, and the values of available water capacity and porosity are multiplied by a factor of 0.75.

ENTER THICKNESS OF SOIL LAYER 2 (INCHES)

12

ENTER SOIL TEXTURE OF SOIL LAYER 2

ENTER A NUMBER (1 THROUGH 18) FOR TEXTURE CLASS OF SOIL MATERIAL.

CHECK USER MANUAL FOR NUMBER CORRESPONDING TO SOIL TYPE

14

The user must also enter the thickness of soil layer 3 along with its texture and must answer whether or not soil layer 3 was compacted. The compaction effects are the same as those applied to soil layer 2.

```
ENTER THICKNESS OF SOIL LAYER 3

10

ENTER SOIL TEXTURE OF SOIL LAYER 3

ENTER A NUMBER (1 THROUGH 18) FOR TEXTURE CLASS OF SOIL MATERIAL.

    **CHECK USER MANUAL FOR NUMBER CORRESPONDING TO SOIL TYPE**

2

DID YOU COMPACT SOIL LAYER 2?
           ENTER YES OR NO

YES

DID YOU COMPACT SOIL LAYER 3?
           ENTER YES OR NO

NO
```

If the user is analyzing a unilayered cover, he selects the single soil texture and enters the total thickness of the soil in inches. The computer responds with:

```
SELECT THE TYPE OF VEGETATIVE COVER

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

4
```

An explanation of the terms relating to vegetation is given in Appendix D. The two sets of leaf area index (LAI) values are stored in the default climatologic data file--one is for excellent grass cover, and the other is for good row crops. The program uses only one of these two sets of values, which is determined by the user specifying grass or row crop. If the user specifies excellent, good, fair, or poor grass, the LAI values are multiplied by 1.0, 0.67, 0.33, or 0.17, respectively. On the other hand, if the user specifies a good or fair row crop, the LAI values are multiplied by

1.0 or 0.5. Neither LAI set is used if the user selects bare ground. Excellent grass implies that the soil cover will be planted with a grass which has excellent production. This selection assumes that the vegetative layer is well managed (that is, that fertilizer, weed control, and harvesting (not grazing) operations are performed to maintain maximum production). Obviously, such a vegetative system is the best available, but realistically, it is difficult to achieve. The designation "row crop" assumes that some type of cultivation will be maintained throughout the season, and it is assumed the crop will produce well. Loam is the ideal soil texture to maximize vegetative production, and soil textures other than loam will have 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.

Some solid waste sites (Figure 2) may be designed with an impermeable liner separating the final soil cover from the waste cells (1). Since most impermeable liners age and eventually deteriorate, a power law was used for functional age relations (see Figure 6). The maximum life of a liner is limited to 100 years. The computer asks the following questions:

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


YES


WHAT IS THE EXPECTED LIFE OF THE LINER (YEARS)?
(100 YEARS IS MAXIMUM LIFE)


5
```

For an answer of 5 years, the initial flow of water is totally impeded. As a function of time, the volume of water percolating through the cover increases, and in 5 years, the impermeable liner has no effect on the volume of water percolating into the solid waste cells.

At this point, all necessary input data have been entered for climatology and hydrology when using the default mode, and the user is ready for output. The user must still specify the number of years of output and whether or not daily, monthly, or annual summaries are required. Since outputs for both the default and manual input options have the same form, the discussion of output follows later.

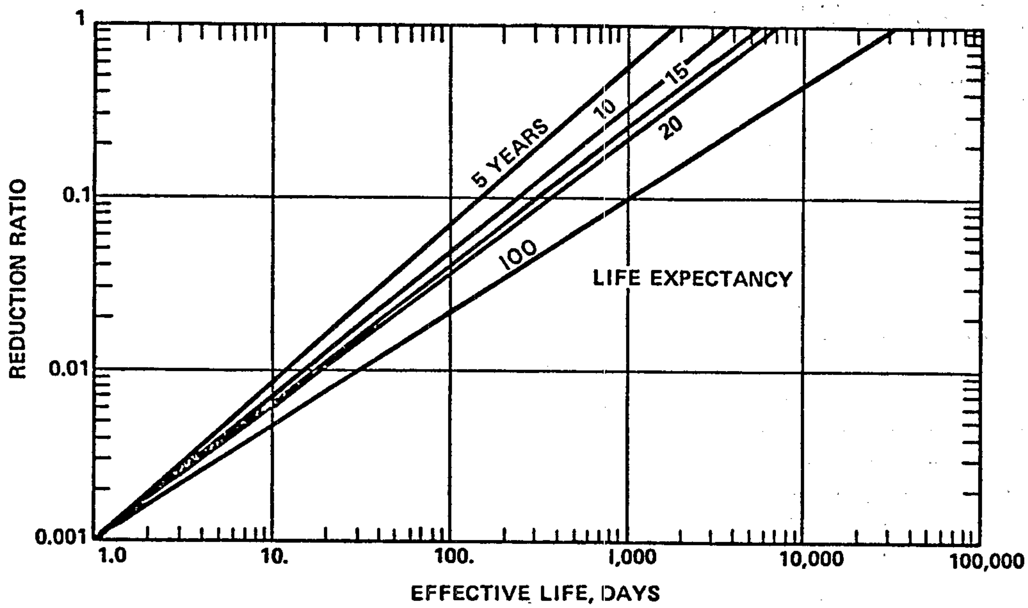

Figure 6. Examples of the power law relations used to estimate the effective aging of an impermeable liner.

MODEL OPERATION USING MANUAL INPUT DATA FILES

When default data are not used, the worksheets for manual input data (Figure 7) are required. The most difficult part of manual input is entering the precipitation data. Daily precipitation data are available from local libraries or from the National Weather Service* climatological data records. When the precipitation data are to be entered, if the entire field of ten values is zero, only one zero needs to be entered before the RETURN key is pressed (right justified). If a line is partially filled with precipitation data and the remainder is to be filled with zeros, only a RETURN is entered after typing the precipitation data. Each year requires 10 values per line and 37 lines of input. The model, as written, accepts a record ranging from a minimum of 2 to a maximum of 20 years' worth of data. For best results, at least 5 years' worth of precipitation data should be used.

MANUAL DATA ENTRY FOR THE CLIMATOLOGICAL MODULE

When the user enters the Program, the following commands are given for entry of data files.

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

MANUAL 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 7. Work sheets for manual data input (no defaults).

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 7. (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 7. (continued).

Manual hydrological input

Study title:____________________

Area location:____________________

Today's date:____________________

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

Hydraulic conductivity of vegetative soil	__________	in./hr
Hydraulic conductivity of soil layer 2	__________	in./hr
Hydraulic conductivity of soil layer 3	__________	in./hr
Thickness of soil cover	__________	inches
Thickness of vegetative layer	__________	inches
Thickness of soil layer 2	__________	inches
Thickness of soil layer 3	__________	inches
Soil porosity of vegetative soil	__________	vol/vol
Soil porosity of soil layer 2	__________	vol/vol
Soil porosity of soil layer 3	__________	vol/vol
SCS curve number	__________	
Field capacity of vegetative soil	__________	vol/vol
Field capacity of soil layer 2	__________	vol/vol
Field capacity of soil layer 3	__________	vol/vol
Winter cover factor*	__________	
Evaporation coefficient of vegetative soil	__________	
Evaporation coefficient of soil layer 2	__________	
Evaporation coefficient of soil layer 3	__________	
Wilting point of vegetative soil	__________	vol/vol

* Winter cover factor is entered with manual climatologic data when yearly temperatures, solar radiation, and LAI values are used.

Figure 7. (concluded).

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

```
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.
```

```
1
```

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

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

```
YES
```

```
 ############################## NOTICE ##############################

    PRECIPITATION INPUT WILL ACCEPT **TWENTY** (20) YEARS MAXIMUM
               AND ONLY **TWO** (2) YEARS MINIMUM


 DO YOU WANT TO ADD TO EXISTING PRECIPITATION DATA?
 ENTER YES OR NO
```

```
NO
```

The user has the option of continuing the input of precipitation data by typing YES or beginning a new precipitation data file by typing NO.

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  LAST 2 DIGIT ONLY)
OR ZERO (Ø) TO END RAINFALL INPUT.

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

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

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

```
ENTER RAINFALL DATA OF 1Ø VALUES PER LINE
WITH 37 LINES PER YEAR.

ENTER LINE  1

.24 Ø .25 1.7 .47 1.Ø7 1.67 .Ø6 .Ø2
ENTER LINE  2

Ø Ø Ø Ø Ø .11 .1 Ø Ø .11
ENTER LINE  3

Ø
ENTER LINE  4

Ø Ø Ø .Ø5
ENTER LINE  5

Ø .Ø4 Ø Ø Ø .85 .26
ENTER LINE  6

1.Ø .Ø4 Ø Ø Ø .85 .26
ENTER LINE  7

1.Ø .Ø4 Ø Ø Ø .85 .Ø6
```

ENTER LINE 31

Ø
ENTER LINE 32

Ø
ENTER LINE 33

Ø
ENTER LINE 34

Ø
ENTER LINE 35

Ø
ENTER LINE 36

Ø Ø Ø Ø Ø .1
ENTER LINE 37

.99 .99 .99 .99 .99

After each year's entry, the heading is printed; however, when all the precipitation data have been entered (2-year minimum and 20-year maximum), a zero is entered and the model asks whether precipitation values should be checked. Each time this question is asked, the user should input the year to be checked.

ENTER DAILY RAINFALL .
ENTER YEAR OF RAINFALL (EXAMPLE 76 LAST 2 DIGIT ONLY)
OR ZERO (Ø) TO END RAINFALL INPUT.

Ø

DO YOU WANT TO CHECK PRECIPITATION VALUES ENTERED?
ENTER YES OR NO

YES

ENTER YEAR

74

74	Ø.24	Ø.Ø	Ø.25	1.7Ø	Ø.47	1.Ø7	1.67	Ø.Ø6	Ø.Ø2	Ø.Ø	1
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.11	Ø.1Ø	Ø.Ø	Ø.Ø	Ø.11	2
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	3
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø5	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	4
74	Ø.Ø	Ø.Ø4	Ø.Ø	Ø.Ø	Ø.Ø	Ø.85	Ø.26	Ø.Ø	Ø.Ø	Ø.Ø	5
74	1.ØØ	Ø.Ø4	Ø.Ø	Ø.Ø	Ø.Ø	Ø.85	Ø.26	Ø.Ø	Ø.Ø	Ø.Ø	6
74	1.ØØ	Ø.Ø4	Ø.Ø	Ø.Ø	Ø.Ø	Ø.85	Ø.Ø6	Ø.Ø	Ø.Ø	Ø.Ø	7
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	8

74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	19
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	2Ø
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	21
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	22
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	23
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	24
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	25
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	26
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	27
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	28
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	29
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	3Ø
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	31
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	32
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	33
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	34
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.1Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	35
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	36
74	Ø.99	Ø.99	Ø.99	Ø.99	Ø.99	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	37

If an error has been made, as in the following 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:

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

NO
  ENTER YEAR OF INTEREST

74

 ENTER LINE OF INTEREST

37

  ENTER 1Ø CORRECTED PRECIPITATION VALUES

Ø Ø Ø Ø .Ø1
```

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

```
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 7), the program reprints the input data and asks whether changes are required. 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
```

```
YES
```

If NO is entered, the program will print a set of default temperature values and ask if you want to use them. The program will perform the same operation for solar radiation and LAI values.

```
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XX                                                        XX
XX   DO YOU WANT TO ENTER FOR EACH YEAR OF PRECIPITATION  XX
XX   A DIFFERENT SET OF MONTHLY TEMPERATURES, SOLAR       XX
XX   RADIATION, WINTER COVER FACTORS AND LEAF AREA INDEX  XX
XX   VALUES?                                              XX
XX                                                        XX
XX   ENTER YES OR NO                                      XX
XX                                                        XX
XX   (IF NO IS ENTERED THE PROGRAM WILL USE THE SAME SET  XX
XX   OF MONTHLY TEMPETATURES, SOLAR RADIATION AND LEAF    XX
XX   AREA INDEX VALUES (WINTER COVER FACTOR IS NOT        XX
XX   REQUESTED) OVER THE ENTIRE YEARS OF PRECIPITATION    XX
XX   SIMULATED.)                                          XX
XX                                                        XX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
YES
```

If NO is entered, the program will request 12 mean monthly temperatures, 12 mean monthly solar radiation values, and 13 LAI values if there is vegetation on the soil cover. Otherwise, bare ground is assumed, and LAI values are omitted. Again, if NO is entered, the temperature, solar radiation, and LAI values are constant over all the years for which precipitation data are supplied.

Mean monthly air temperature and mean monthly solar radiation (insolation) data are required inputs (12 values each) that 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.

If YES is entered for the above question asked by the program, mean monthly temperature, solar radiation, winter factor, and LAI values are requested for each year of precipitation data that is available.

```
ENTER TEMPERATURE VALUES FOR THE YEAR 1974


ARE THEY THE SAME AS PREVIOUS YEAR?
ENTER YES OR NO


NO
```

The above question is not printed if the user entered NO to the question in the X-bounded block.

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


62.7
61
68.7
59.6
69.6
70.7
```

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

66.9
70
78.5
71.4
57.5
52.6

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

             62.7             66.9
             61.0             70.0
             68.7             78.5
             59.6             71.4
             69.6             57.5
             70.7             52.6

DO YOU WANT TO CHANGE THEM?
    ENTER YES OR NO

NO
```

To enter solar radiation (6) data, the following commands are used (the city of Los Angeles, California, is the example):

```
ENTER SOLAR RADIATION VALUES FOR THE YEAR 1974

ARE THEY THE SAME AS PREVIOUS YEAR?
ENTER YES OR NO

NO
```

The above question is not requested if the user entered NO to the question in the X-bounded block.

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


248
331
397
457
5Ø6
486


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


497
464
389
32Ø
277
221
THESE ARE THE INPUT RADIATION VALUES
        JAN.-JUNE          JULY-DEC.

           248,Ø             497.Ø
           331.Ø             464.Ø
           397.Ø             389.Ø
           457.Ø             32Ø.Ø
           5Ø6.Ø             277.Ø
           486.Ø             221.Ø

DO YOU WANT TO CHANGE THEM?
    ENTER YES OR NO

NO
```

Omit the following questions and answers concerning winter cover factor if the user has entered NO for the answer to the question in the X-bounded block.

```
ENTER WINTER COVER FACTOR FOR THE YEAR 1974


IS IT THE SAME AS PREVIOUS YEAR?
ENTER YES OR NO


NO

ENTER WINTER COVER FACTOR FOR THE YEAR 1974


.6

THE WINTER COVER FACTOR ENTERED IS0.60
DO YOU WANT TO CHANGE IT?
ENTER YES OR NO


NO
```

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 (3). The value must be estimated for each type of vegetative cover. The winter cover factor is maximum when the surface area is bare ground.

The LAI is used to estimate the amount of vegetative ground cover of a particular crop and is an effective partition of the rates of plant transpiration to soil evaporation that is used in both model options. For example, a conceptual understanding of LAI is made by considering a 1-ft^2 area of a soil surface with no vegetation (bare ground) on the 5th of January. But 100 days later on the 15th of April, vegetation has grown on the example area. Viewed from above, the vegetation now appears to cover 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. Exactly 13 LAI values must be entered for a specific vegetative ground cover. The program interpolates between the LAI values for daily estimates.

---

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

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

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.

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

```
DOES THE SOIL SURFACE HAVE VEGETATION FOR THE YEAR 1974
ENTER YES OR NO

YES

ENTER LEAF AREA INDEX VALUES FOR THE YEAR 1974

ARE THEY THE SAME AS PREVIOUS YEAR?
ENTER YES OR NO

NO
```

The above question is not requested if the user entered NO to the question in the X-bounded block.

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

```
YOU MUST ENTER EXACTLY 13 VALUES FOR LAI
** REMEMBER TO START AT DAY 1 AND END AT DAY 366.**

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

1  0
ENTER ANOTHER SET OF VALUES

41 0
ENTER ANOTHER SET OF VALUES

59 .61
ENTER ANOTHER SET OF VALUES

77 1
ENTER ANOTHER SET OF VALUES

95 1
ENTER ANOTHER SET OF VALUES

113 1
ENTER ANOTHER SET OF VALUES

131 1
ENTER ANOTHER SET OF VALUES

149 1
ENTER ANOTHER SET OF VALUES

167 .9
ENTER ANOTHER SET OF VALUES

185 .71
ENTER ANOTHER SET OF VALUES

203 .65
ENTER ANOTHER SET OF VALUES

221 0
ENTER ANOTHER SET OF VALUES

366 0
```

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

               1             Ø.Ø
              41             Ø.Ø
              59             Ø.61
              77             1.ØØ
              95             1.ØØ
             113             1.ØØ
             131             1.ØØ
             149             1.ØØ
             167             1.ØØ
             185             Ø.71
             2Ø3             Ø.65
             221             Ø.Ø
             366             Ø.Ø

DO YOU WANT TO CHANGE THEM?
    ENTER YES OR NO

NO
```

At this point, the user can make appropriate corrections to the data set if so required.

If the user had entered NO to the question in the X-bounded block, at this point the program would type END OF CLIMATOLOGICAL INPUT. Since YES was input, the program will increase the year by 1 and follow the same procedure until all years of precipitation data entered have associated years of mean monthly temperature, solar radiation, winter cover factors, and LAI values. Then the program will type END OF CLIMATOLOGICAL INPUT.

DATA ENTRY FOR THE HYDROLOGICAL MODULE

Data should now be entered in the manual hydrological module as requested:

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

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

2
```

The program user now enters the study title, site location, and the day'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.
```

```
HYDROLOGY OF A SOLID WASTE DISPOSAL SITE
TEN MILES SOUTH OF TOWN
1 FEB. 1982
```

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 set with, for example, 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 DAYS)
```

```
74000
```

If the soil cover has a vegetative layer plus soil layers 2 and 3, this information is entered here:

```
ENTER NUMBER OF LAYERS IN SOIL COVER (INCHES)
```

```
3
```

```
ENTER TOTAL THICKNESS OF SOIL COVER (INCHES)
```

```
36
```

```
ENTER VALUES FOR VEGETATIVE SOIL

ENTER 5 VALUES, HYDRAULIC CONDUCTIVITY,(IN/HR)
                SOIL POROSITY, (VOL/VOL)
                EVAPORATION COEFFICIENT,
                EVAPORATION COEFFICIENT, AND
                FIELD WILTING POINT (VOL/VOL)
```

```
.51
.41
4.5
.29
.16


ENTER THICKNESS OF SOIL LAYER 2 (INCHES)


12


ENTER VALUES FOR SOIL LAYER 2

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


.ØØ4
.29
3.1
.14


ENTER THICKNESS OF SOIL LAYER 3 (INCHES)


1Ø


ENTER VALUES FOR SOIL LAYER 3

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


.52
.41
4.5
.29
```

The effective hydraulic conductivity (7,8) of the vegetative layer, soil layer 2, and soil layer 3 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 (3). Thus the relative value entered for the effective hydraulic conductivity should reflect the conditions of the cover materials. If compaction of soil layer 2 and/or soil layer 3 is requested, its effect on the hydraulic conductivity should be estimated. The actual value of the hydraulic conductivity to estimate the runoff that would be predicted by the Soil Conservation Service (SCS) curve number method (9) depends largely 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 SCS curve number technique is the method used for predicting runoff from daily rainfall. Figure 8 shows a graphic example of estimating the curve number from the minimum infiltration rate (MIR) if it is not known from other sources. Table 4 gives examples of SCS curve numbers for a different soil cover condition. The evaporation coefficient (3) is a cover soil evaporation parameter dependent on soil water transmission characteristics and is used to fraction the evapotranspiration rate (ranges from about 3.3 to 5.5 $mm/d^{1/2}$). A value of 4.5 is suggested for loamy soils, 3.5 for clays, and 3.3 for sands; however, it cannot be less than 3.0.

The next question the program asks is whether or not an impermeable liner was used. A discussion of the use of an impermeable liner was presented under the default data option.

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


NO


ENTER SCS CURVE NUMBER.


79.3
```

At this point the program asks the following question if the winter factor has not been entered with climatologic data:

```
ENTER WINTER COVER FACTOR


.6

****************************************************************
                  HYDROLOGICAL INPUT IS COMPLETE
****************************************************************
```

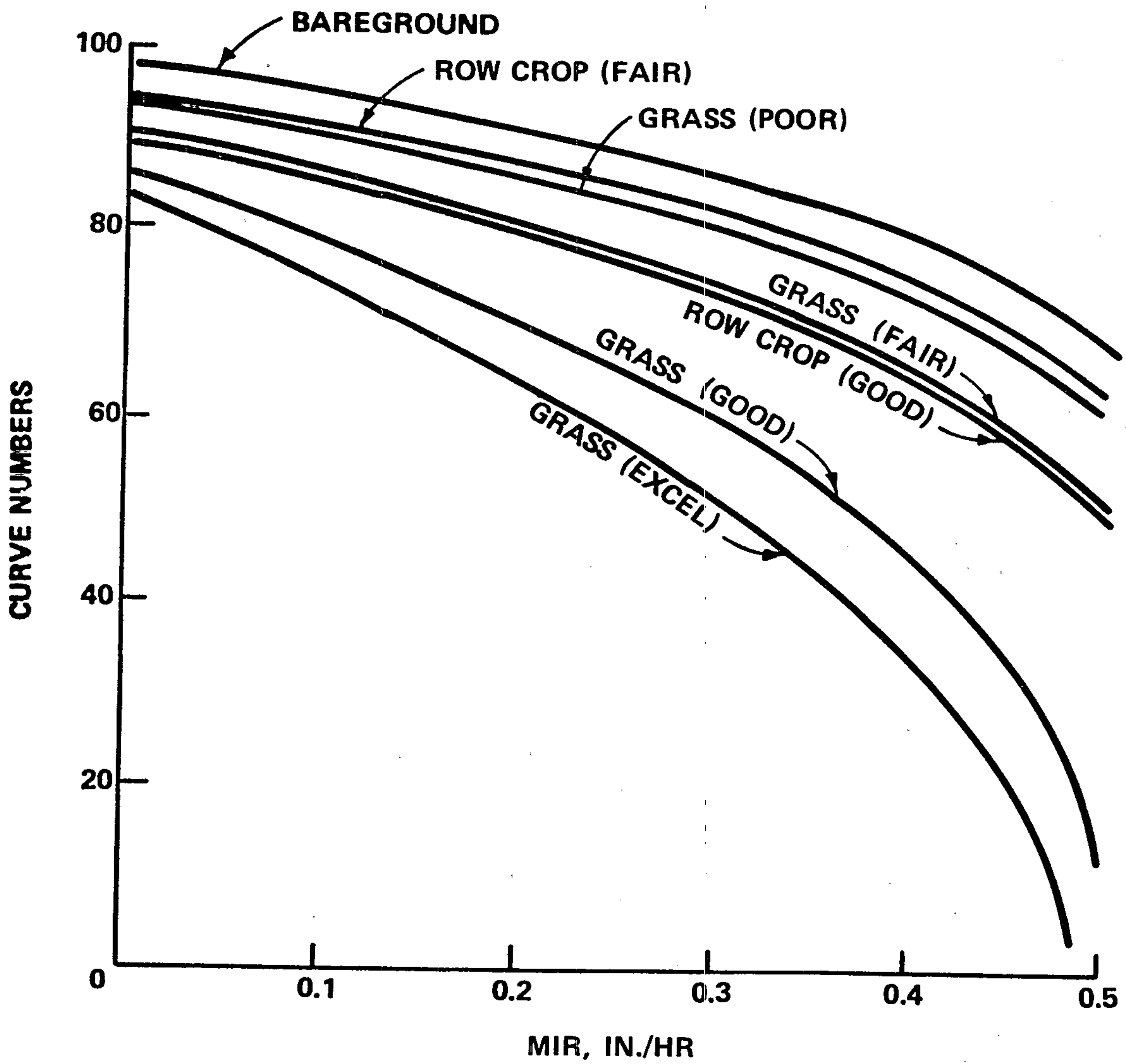

Figure 8. SCS curve number for several vegetative covers in relation to the minimum infiltration rate (MIR).

TABLE 4. SCS CURVE NUMBERS FOR NON-ERODED SOIL-COVER COMPLEXES*

Land Use	Cover Treatment or Practice	SCS Curve Number for Hydrologic Soil Groups† A	B	C	D
Fallow	Straight row	77	86	91	94
Planted in row crops	Straight row	67	87	85	89
	Contoured	65	75	82	86
	Contoured and terraced	62	71	78	81
Planted by grasses and grain	Straight row	63	75	83	87
	Contoured	61	73	81	84
	Contoured and terraced	59	70	78	81

* After Table 9.1, Ref. 7. Assumes antecedent moisture condition II (AMCII).

† Hydrologic soil groups are:

Group A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well drained to excessively drained sands or gravels. These soils have a high rate of water transmission.

Group B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

Group D. (High runoff potential). Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a slow rate of water transmission.

This step signals the end of the manual hydrological input option. The section on output is to be entered after hydrologic input is completed.

INTERACT BETWEEN THE DEFAULT AND MANUAL INPUT OPTIONS

Occasionally the user wants to use the default input option for one set of data and the manual input option for another set. This mixing of options can be done by following the example given below. Here the user wants to use default climatological data and manual input of hydrological data.

The computer system types:

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

The user types:

YES

The program types:

DO YOU WANT TO USE CLIMATOLOGIC DATA FROM THE PREVIOUS RUN?
ENTER YES OR NO

The user types:

NO

The system then types the listing of available cities and the user should enter one. For example:

CALIFORNIA

LOS ANGELES

The program types:

DO YOU WANT CLIMATOLOGY, HYDROLOGY, OR OUTPUT?

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

The user types:

1

The system types:

CLIMATOLOGICAL DATA ARE CURRENTLY ON FILE

DO YOU WANT MANUAL HYDROLOGICAL INPUT OPTION? ENTER YES OR NO

YES

At this point the user should begin to enter values for the manual hydrological input option.

OUTPUT FOR PROGRAM

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, any manually input or default data files that have been entered will remain on line indefinitely or until the user changes the files. The output for both the default and manual input data options are the same, and 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.


3

 HOW MANY YEARS OF OUTPUT DO YOU WANT?

 TWO (2) YEARS MINIMUM AND
 TWENTY (20) YEARS OF PRECIPITATION ARE MAXIMUM

 **ONLY FIVE (5) YEAR MAXIMUM FOR DEFAULT OPTION**


5


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


YES
```

HYDROLOGIC OUTPUT

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 and means of rainfall, runoff, evapotranspiration, cover, drainage percolation, and average soil-water content. The data include annual totals for each component.

For the hydrologic output, the program first prints the title of the project, the location, and the current date of the run. Then for reference purposes, the program prints the input values. The input of the climatological module is printed first, followed by the input of the hydrological module. LAI-DAYS is an indicator of the potential growth index. This figure 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
TEN MILES SOUTH OF TOWN
1 FEB. 1982

MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
54.98	54.34	55.67	58.61	62.37	65.95
68.38	69.02	67.70	64.76	61.00	57.42

MONTHLY MEAN RADIATION, LANGLEYS PER DAY

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
267.51	325.76	416.41	515.17	595.57	636.07
625.82	567.57	476.92	378.16	297.76	257.26

LEAF AREA INDEX TABLE

DATE	LAI
1	0.0
30	0.0
50	0.61
70	1.00
90	1.00
110	1.00
130	1.00
150	1.00
170	0.90
190	0.65
210	0.32
230	0.17
366	0.0

WINTER C FACTOR = 0.70
LAI-DAYS = 162.86

Next is an input summary of the hydrologic characteristics.

VEGETATIVE SOIL

EFFECTIVE HYDRAULIC CONDUCTIVITY	=	0.41250 IN/HR
POROSITY	=	0.34350 VOL/VOL
EVAPORATION COEFFICIENT	=	4.50000
AVAILABLE WATER CAPACITY	=	0.13100 VOL/VOL

SOIL LAYER 2

EFFECTIVE HYDRAULIC CONDUCTIVITY	=	0.00325 IN/HR
POROSITY	=	0.19400 VOL/VOL
EVAPORATION COEFFICIENT	=	3.10000
AVAILABLE WATER CAPACITY	=	0.04230 VOL/VOL

SOIL LAYER 3

EFFECTIVE HYDRAULIC CONDUCTIVITY	=	7.08700 IN/HR
POROSITY	=	0.37600 VOL/VOL
EVAPORATION COEFFICIENT	=	3.30000
AVAILABLE WATER CAPACITY	=	0.08700 VOL/VOL

FAIR GRASS

SCS CURVE NUMBER	=	76.20940
UPPER LIMIT OF STORAGE	=	3.81800 IN
INITIAL SOIL WATER STORAGE	=	1.90900 IN

SOIL COVER THICKNESS	(IN)
TOTAL	36.0
VEGETATIVE	14.0
SOIL LAYER 2	12.0
SOIL LAYER 3	10.0

SOIL LAYER 2 COMPACTED

DESIGN LINER LIFE 5.0 YEARS

UPPER LIMIT OF STORAGES IN COVER (INCHES)

THICKNESS	0.875	3.500	7.000	10.500	14.000	26.000	36.000
	0.086	0.258	0.344	0.344	0.344	1.572	0.870

INITIAL SOIL WATER STORAGE IN COVER (INCHES)

THICKNESS	0.875	3.500	7.000	10.500	14.000	26.000	36.000
	0.043	0.129	0.172	0.172	0.172	0.786	0.435

Daily output is printed only for days when precipitation occurred or on a day when the temperature was above freezing and runoff occurred. The cover drainage is only that liquid which flows out of the cover and does not percolate into the solid waste cells. The average temperature is that predicted by the model. The accumulative evapotranspiration is carried through the model in relation to the potential evapotranspiration and the available water capacity. The average soil water is the depth-weighted fractional water content (volume basis) of the final soil cover--an average of each of seven soil storages permitted by the CREAMS model for the final soil cover. The CREAMS model (3) permits the top storage depth to equal 1/36 of the final soil cover depth, the second 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 in. (60 cm), then the 7 depths for computational purposes would be 0.67, 3.33, 4, 4, 4, 4, 4 in. (1.68, 8.33, 10, 10, 10, 10, 10 cm), respectively. The program apportions these fractions, which are printed in the initial input data along with the depth considered.

DATE JULIAN	RAINFALL INCHES	RUNOFF INCHES	COVER DRAIN INCHES	PERCOL. INCHES	AVERAGE TEMP. DEG. F.	AVERAGE SOIL W. VOL/VOL	ACCUM. ET INCHES
78004	0.21	0.0	0.0	0.0	55.81	0.27	0.28
78005	0.76	0.20	0.0	0.0	55.63	0.28	0.35
78007	1.02	0.78	0.0	0.0	55.52	0.29	0.50
78010	1.45	1.09	0.0	0.0	55.35	0.29	0.71
78011	1.09	1.02	0.0	0.0	55.23	0.29	0.78
78015	1.51	0.94	0.0033	0.0155	55.08	0.29	1.07
78016	0.13	0.06	0.0061	0.0285	54.94	0.29	1.15
78017	1.09	0.85	0.0108	0.0504	54.89	0.30	1.22
78018	0.22	0.0	0.0061	0.0286	54.85	0.29	1.29
78020	0.20	0.0	0.0112	0.0531	54.78	0.29	1.44
78037	1.42	0.0	0.0616	0.3094	54.48	0.27	2.46
78038	0.05	0.0	0.0052	0.0264	54.32	0.29	2.55
78039	0.89	0.58	0.0097	0.0490	54.31	0.30	2.65
78040	0.70	0.60	0.0057	0.0289	54.31	0.29	2.74
78041	0.92	0.63	0.0097	0.0493	54.31	0.30	2.84
78042	0.82	0.72	0.0057	0.0290	54.31	0.29	2.94
78044	0.75	0.29	0.0139	0.0715	54.32	0.29	3.15
78045	0.23	0.12	0.0056	0.0290	54.34	0.29	3.26
78058	0.20	0.0	0.0450	0.2447	54.47	0.27	4.49
78059	0.07	0.0	0.0018	0.0097	54.69	0.25	4.59
78060	1.61	0.0	0.0052	0.0287	54.73	0.29	4.73
78061	1.48	1.21	0.0087	0.0479	54.77	0.30	4.87
78062	0.42	0.28	0.0048	0.0267	54.82	0.29	5.01
78063	0.19	0.0	0.0046	0.0254	54.86	0.29	5.16
78064	2.27	1.89	0.0114	0.0635	54.91	0.30	5.30
78065	0.02	0.0	0.0048	0.0267	54.96	0.29	5.45
78069	0.13	0.0	0.0167	0.0948	55.10	0.28	6.01
78071	0.24	0.0	0.0071	0.0407	55.28	0.27	6.32
78081	0.06	0.0	0.0135	0.0806	55.70	0.25	7.29
78082	0.58	0.0	0.0	0.0	56.12	0.25	7.43
78090	0.28	0.0	0.0	0.0	56.51	0.24	8.44
78091	0.28	0.0	0.0	0.0	56.93	0.23	8.63
78095	0.23	0.0	0.0	0.0	57.18	0.23	9.20
78097	0.27	0.0	0.0	0.0	57.48	0.22	9.52
78106	0.69	0.0	0.0	0.0	58.08	0.21	10.49
78116	0.04	0.0	0.0	0.0	59.17	0.20	11.21
78248	0.03	0.0	0.0	0.0	66.19	0.20	11.24
78249	0.36	0.0	0.0	0.0	68.35	0.20	11.41
78294	0.04	0.0	0.0	0.0	66.51	0.20	11.64
78315	0.10	0.0	0.0	0.0	62.91	0.20	11.73
78316	0.26	0.0	0.0	0.0	61.53	0.20	11.82
78318	0.32	0.0	0.0	0.0	61.34	0.20	11.92
78326	0.40	0.0	0.0	0.0	60.71	0.21	12.07
78327	0.12	0.0	0.0	0.0	60.15	0.22	12.15
78336	0.01	0.0	0.0	0.0	59.54	0.21	12.26
78351	0.06	0.0	0.0	0.0	58.15	0.21	12.44
78352	0.10	0.0	0.0	0.0	57.29	0.21	12.51
78353	0.61	0.0	0.0	0.0	57.19	0.23	12.59
78354	0.05	0.0	0.0	0.0	57.09	0.23	12.63

The annual totals for the particular year in question are then printed, and the water budget balance is presented. The latter shows whether or not the parameters were properly computed and the time changes correctly evaluated. If the parameter for unmelted snow is not equal to zero, this amount is carried over into the next year and is added to runoff and infiltration when the temperature is above freezing. The water budget balance should be off by the amount of unmelted snow. Otherwise, the water budget balance is about zero.

```
ANNUAL TOTALS FOR 1978 (INCHES)
  PRECIPITATION      =   24.58
  PREDICTED RUNOFF   =   11.24
  TOT COVER DRAIN    =    Ø.2783
  TOT PERCOLATION    =    1.458Ø
  TOTAL ET           =   12.76
  UNMELTED SNOW      =    Ø.Ø
  BEGIN SOIL WATER   =    3.Ø6
  FINAL SOIL WATER   =    1.9Ø
  WATER BUDGET BAL.  =    Ø.Ø
```

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   =    3.45
TOT COVER DRAIN    =    Ø.2159
TOT PERCOLATION    =    Ø.3213
TOTAL ET           =    9.53
```

Again, cover drainage refers to lateral transfer of moisture above a liner (synthetic membrane) in the cover. Cover drainage appears only if a liner is specified.

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

DO YOU WANT MONTHLY HYDROLOGY SUMMARY?
ENTER YES OR NO

YES

1978

MONTH	RAIN	RUNOFF	ET	COVER DRAIN	PERCOL.	AVG SW
JAN	7.48	4.93	2.17	0.0376	0.1761	3.09
FEB	6.05	2.93	2.42	0.1639	0.8469	2.82
MAR	7.08	3.38	3.85	0.0768	0.4349	2.30
APR	1.51	0.0	2.77	0.0	0.0	0.45
MAY	0.0	0.0	0.0	0.0	0.0	0.0
JUN	0.0	0.0	0.0	0.0	0.0	0.0
JUL	0.0	0.0	0.0	0.0	0.0	0.0
AUG	0.0	0.0	0.0	0.0	0.0	0.0
SEP	0.39	0.0	0.39	0.0	0.0	0.07
OCT	0.04	0.0	0.04	0.0	0.0	0.00
NOV	1.20	0.0	0.58	0.0	0.0	0.31
DEC	0.83	0.0	0.53	0.0	0.0	0.72
TOT/AVE	24.58	11.24	12.76	0.28	1.46	0.81

ANNUAL AVERAGES

MONTH	RAIN	RUNOFF	ET	COVER DRAIN	PERCOL.	AVG SW
JAN	3.30	1.87	1.32	0.0673	0.0360	2.04
FEB	2.36	0.68	1.64	0.0931	0.1839	1.92
MAR	2.92	0.68	2.93	0.0555	0.1014	1.32
APR	0.63	0.0	1.19	0.0	0.0	0.16
MAY	0.52	0.01	0.51	0.0	0.0	0.06
JUN	0.06	0.0	0.06	0.0	0.0	0.00
JUL	0.00	0.0	0.00	0.0	0.0	0.00
AUG	0.50	0.03	0.28	0.0	0.0	0.12
SEP	0.45	0.0	0.37	0.0	0.0	0.28
OCT	0.46	0.00	0.28	0.0	0.0	0.27
NOV	0.42	0.0	0.39	0.0	0.0	0.47
DEC	1.88	0.18	0.54	0.0	0.0	0.85
TOT/AVE	13.52	3.45	9.51	0.22	0.32	0.62

ENTER RUNHYDRO TO RERUN PROGRAM OR
ENTER LOGOFF TO LOGOFF COMPUTER SYSTEM

The programming session is completed. The logoff command (LOGOFF) is typed at the next READY prompt. But if the user would like to reenter the hydrologic model, he should enter RUNHYDRO. At this point, the program heading would be reprinted, and the initial questions asked.

LOADING PRECIPITATION DATA FROM OFF-LINE MEDIA

The user has the option of using manual input for 2 to 20 years of climatic data, which consist of daily precipitation, mean monthly temperatures, solar radiation, and LAI values. But this process can be very costly and time consuming when more than 5 years' worth of precipitation data are used. Thus, the user should consider input of daily precipitation values from an off-line medium. The off-line medium can be a deck of cards, magnetic tape, floppy disk, etc. Whatever off-line medium the user prefers, the user should build a file with 37 records per year and each record should consist of a field of 12 variables. The first variable has the format I10 and should contain the last 2 digits of the year. The next 10 variables have the format F5.2 which contains the daily precipitation values. The last variable has the format I10 which contains the number of the record. Moreover, the first line or record of the off-line medium must consist of the year, the daily precipitation values for January 1 to January 10, and the number 1 to indicate the first record. The following is an example of how the first record should look.

The second record should consist of the year, daily precipitation values from January 11 to January 20, and the number 2 to indicate the second record. This procedure should continue as shown below.

74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.11	Ø.1Ø	Ø.Ø	Ø.Ø	Ø.11	2
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	3
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø5	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	4
74	Ø.Ø	Ø.Ø4	Ø.Ø	Ø.Ø	Ø.Ø	Ø.85	Ø.26	Ø.Ø	Ø.Ø	Ø.Ø	5
74	1.ØØ	Ø.Ø4	Ø.Ø	Ø.Ø	Ø.Ø	Ø.85	Ø.26	Ø.Ø	Ø.Ø	Ø.Ø	6
74	1.ØØ	Ø.Ø4	Ø.Ø	Ø.Ø	Ø.Ø	Ø.85	Ø.Ø6	Ø.Ø	Ø.Ø	Ø.Ø	7
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	8
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø1	Ø.26	Ø.Ø	Ø.Ø	Ø.Ø2	Ø.Ø	9
74	Ø.12	Ø.Ø2	Ø.Ø	Ø.Ø1	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	1Ø
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	11
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	12
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	13
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	14
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	15
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	16
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	17
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	18
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	19
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	2Ø
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	21
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	22
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	23
74	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	Ø.Ø	24

74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35
74	0.0	0.0	0.0	0.0	0.0	0.10	0.0	0.0	0.0	0.0	36
74	0.00	0.00	0.00	0.00	0.01	0.0	0.0	0.0	0.0	0.0	37

Note that on line 37, the daily precipitation values are input for December 27 to December 31, and the last 5 values are zeros. If 74 were a leap year the last 4 values would be zero. However, the user must start the next year with a value of 75 for the year, 10 daily precipitation values, and the number 1 to indicate the first record.

Once the user has built the off-line precipitation data file according to the format given, the user should log on the NCC's computer system, read the off-line precipitation data file on the computer system, and save the data under the file name of PRECIP.

The user must run the HSSWDS model for manual input of mean monthly temperatures, solar radiation, and LAI values. Once the command RUNHYDRO is issued, the computer system will ask the following question and the user should enter the following commands. The computer system types:

ARE YOU USING DEFAULT CLIMATOLOGICAL INPUT

The user enters:

NO

Next, the user should respond by entering the number 1 to enter manual climatological input. The computer system types:

DO YOU WANT TO INPUT PRECIPITATION DATA

The user enters:

NO

The computer system requests the input of temperature, solar radiation, and LAI values. At this point, the model functions according to the information given in the section for manual input of climatologic data.

SAVING PRECIPITATION DATA FILES

The HSSWDS model is constructed so that the precipitation data are stored permanently. Once the user enters a new precipitation data file, the old file is replaced in permanent storage by the new one. If the user wants to save a precipitation data file, he must save it under another file name. If the user wants to retain a precipitation data file that is stored on the user's account, he should replace the old file with the file name PRECIP. The file name for all precipitation data files created and run by the HSSWDS model is PRECIP. So the user can conclude that the model will run only the precipitation data that are stored under the file name of PRECIP.

For example, assume that the user has manually input 20 years of precipitation data for Vicksburg, Mississippi. Also assume that the rest of the climatologic and hydrologic data have been input and that the output has been printed. At this point, the user should save the precipitation data stored on the file PRECIP under another name by using the EDIT, the SAVE, and the END commands as follows:

```
EDIT  PRECIP
SAVE  VICKS
END
```

The 20 years of precipitation for Vicksburg, Mississippi, is now stored on the permanent file named VICKS. The user can now run the model with another set of precipitation data, without losing the precipitation data for Vicksburg, Mississippi. To retrieve the precipitation data file for Vicksburg, Mississippi, that is stored under the file name of VICKS, the user must enter the following commands:

```
EDIT  VICKS
SAVE  PRECIP
END
```

The precipitation data for Vicksburg, Mississippi, has replaced the old precipitation data, and the model will run using the Vicksburg precipitation data.

BATCH OPERATIONS

The HSSWDS model can be run in the batch environment to reduce computer costs. The batch procedures are for running the HSSWDS model on NCC's IBM 360/370 computer system. Instructions consist of punched cards of two forms--control cards and sequential input cards. An example of the two forms of instructions are given as follows. Note that the control card instructions are separated into two steps.

The control card instructions of Step 1 that need to be changed or explained are as follows:

Explanation of Parameters		Example
USERID	= user identification	EPAWRC
ACCOUID	= the user's account plus utilization identifier plus the letter P	MAWCHSSWP
RMTXXX	= the remote number of output routing	RMT129
MASTID	= contact authors for master USERID	EPARAC
ACCOUNT	= the user's account	TERL
MASTACC	= contact authors for master account	EARL
PRTY	= priority of job where 1 = overnight turnaround time 2 = 4 hours turnaround time 3 = 2 hours turnaround time 4 = 1/2 hour turnaround time	
TIME	= time in minutes where 4 minutes are maximum amount needed	

All other control cards for Steps 1 and 2 should be punched as shown below. Be sure to insert your user identification and account. The job control card instructions are the same for every run. Once the job control cards are punched, they can be used continuously.

The sequential input cards are the answers to the interactive questions prompted by the HSSWDS model. The user must refer to the interactive question to build the sequential card deck or to use examples 1 and 2 which follow.

Control Cards Step 1

```
//USERID JOB (ACCOUID), 'LAST NAME', PRTY=1, TIME=4
/*ROUTE PRINT RMTXXX
//STEP1 EXEC PGM=IEBGENER
//SYSIN DD DUMMY
//SYSPRINT DD SYSOUT=A
//SYSUT2 DD DSN=CN.USERID.ACCOUNT.AFILE,
// DISP=(NEW,PASS,DELETE),SPACE=(TRK,(5,5)),
// DCB=(LRECL=8Ø,RECFM=FB,BLKSIZE=312Ø),
// UNIT=DISK
//SYSUT1 DD *
```

Sequential Input Cards

```
YES
NO
CALIFORNIA
LOS ANGELES
2
TEST
TEST
TEST
1
24
1Ø
7
NO
3
4
NO
YES
```

Control Cards Step 2

```
/*
//STEP2 EXEC PGM=HYDRO2
//STEPLIB DD DSN=CN.MASTID.MASTACC.HYDRO.LOAD,DISP=SHR
//FT1ØFØØ1 DD DSN=CN.USERID.ACCOUNT.AFILE,UNIT=DISK,
// DISP=(OLD,DELETE,DELETE),
// SPACE=(CYL,(5,2)),DCB=(RECFM=FB,LRECL=80,BLKSIZE=312Ø)
//FTØ6FØØ1 DD SYSOUT=A
//FTØ4FØØ1 DD DSN=CN.USERID.ACCOUNT.PRECIP,DISP=SHR
//FTØ5FØØ1 DD DSN=CN.USERID.ACCOUNT.INPUT1,DISP=SHR
//FTØ7FØØ1 DD DSN=CN.USERID.ACCOUNT.WEATHR,DISP=SHR
//FTØ8FØØ1 DD DSN=CN.MASTID.MASTACC.CITIES,DISP=SHR
//FTØ9FØØ1 DD DSN=CN.MASTID.MASTACC.PRE3,DISP=SHR
//FT11FØØ1 DD DSN=CN.USERID.ACCOUNT.HSTATE,DISP=SHR
//FT12FØØ1 DD DSN=CN.MASTID.MASTACC.DEDATA,DISP=SHR
//FT14FØØ1 DD DSN=CN.USERID.ACCOUNT.WTHYR,DISP=SHR
```

Example 1 (Batch Default Input Option)

Card No.	Example Entry	Interactive Question	Explanation
(1)	YES	DO YOU WANT TO USE DEFAULT CLIMATOLOGIC DATA? (ENTER YES OR NO.)	If YES is entered, the default input option is initiated. If NO is entered, go to example 2 for manual input option instructions.
(2)	NO	DO YOU WANT TO USE CLI-MATOLOGIC DATA FROM THE PREVIOUS RUN? (ENTER YES OR NO.)	If NO is entered, continue to the next card. If YES is entered, skip to card number (5).
(3)	CALIFORNIA	ENTER NAME OF STATE.	Enter a state located in Table 5.
(4)	LOS ANGELES	ENTER NAME OF CITY.	Enter a city located in Table 5.
(5)	2	ENTER 1 FOR CLIMATOLOGICAL INPUT, 2 FOR HYDROLOGICAL INPUT, 3 FOR OUTPUT OR 4 TO STOP PROGRAM.	Enter the number 2 for the default hydrological input section.
(6)	TEST	ENTER TITLE.	Enter the name of the site.
(7)	FOUR MILES FROM TOWN	ENTER LOCATION.	Enter the location of the site.
(8)	22 JANUARY 1982	ENTER TODAY'S DATE.	Enter the date of the computer run.
(9)	3	ENTER NUMBER OF LAYERS IN SOIL COVER.	If 1 is entered, skip all cards referring to soil layers 2 and 3. If 2 is entered, skip all cards referring to soil layer 3.
(10)	36	ENTER TOTAL THICKNESS OF COVER SOIL.	The units for the cover thickness are inches.
(11)	9	ENTER A NUMBER (1 THROUGH 18) FOR TEXTURE CLASS OF VEGETATIVE SOIL TYPE.	See Table 1 for correct soil texture that refers to associated number.
(12)	24	ENTER THICKNESS OF SOIL LAYER 2.	The units for the thickness of soil layer 2 are in inches.
(13)	16	ENTER A NUMBER (1 THROUGH 18) FOR TEXTURE CLASS OF SOIL LAYER 2.	See Table 1 for correct soil texture that refers to associated number.

Example 1 (Continued)

Card No.	Example Entry	Interactive Question	Explanation
(14)	6	ENTER THICKNESS OF SOIL LAYER 3.	The units for the thickness of soil layer 3 are in inches.
(15)	13	ENTER A NUMBER (1 THROUGH 18) FOR TEXTURE CLASS OF SOIL LAYER 3.	See Table 1 for correct texture class that refers to associated number.
(16)	YES	DID YOU COMPACT THE SOIL LAYER 2? (ENTER YES OR NO.)	If YES is entered, the hydraulic conductivity is reduced by a factor of 20, the available water capacity and porosity are reduced by a factor of 3.
(17)	NO	DID YOU COMPACT THE SOIL LAYER 3? (ENTER YES OR NO.)	If YES is entered, the hydraulic conductivity is reduced by a factor of 20, the available water capacity and porosity are reduced by a factor of 3.
(18)	1	SELECT THE TYPE OF VEGETATIVE COVER BY ENTERING A NUMBER (1 THROUGH 7) WHERE 1 = BAREGROUND 2 = GRASS (EXCELLENT) 3 = GRASS (GOOD) 4 = GRASS (FAIR) 5 = GRASS (POOR) 6 = ROW CROP (GOOD) 7 = ROW CROP (FAIR)	If grass excellent, good, fair, or poor is selected the stored surface area of the leaf area indices (LAI) are multiplied by 1.0, 0.66, 0.33, or 0.17, respectively. If row crop good or fair is selected the stored surface area of the LAI is multiplied by 1.0 or 0.50, respectively. If bare ground is selected the surface area of the LAI is multiplied by 0.0.
(19)	YES	IS THERE AN IMPERMEABLE LINER AT THE INTERFACE? (ENTER YES OR NO.)	If NO is entered, skip to card number (21).
(20)	50	WHAT IS THE EXPECTED LIFE OF THE LINER (YEARS)?	The years range from 1 to 100.

Example 1 (Concluded)

Card No.	Example Entry	Interactive Question	Explanation
(21)	3	ENTER 1 FOR CLIMATOLOGICAL INPUT, 2 FOR HYDROLOGICAL INPUT, 3 FOR OUTPUT OR 4 TO STOP PROGRAM.	Enter the number 3 for output.
(22)	5	HOW MANY YEARS OF OUTPUT DO YOU WANT?	You must enter a number from 2 to 5.
(23)	YES	DO YOU WANT A DAILY SUMMARY? (ENTER YES OR NO.)	If NO is entered, only the yearly summaries are printed.
(24)	YES	DO YOU WANT MONTHLY SUMMARIES? (ENTER YES OR NO)	If NO is entered, the monthly summaries are not printed.

Example 2 (Batch Manual Input Option)

Card No.	Example Entry	Interactive Question	Explanation
(1)	NO	DO YOU WANT TO USE DEFAULT CLIMATOLOGIC DATA? (ENTER YES OR NO.)	If NO is entered the manual input option is initated. In YES is entered, go to example 1 for default input option instructions.
(2)	1	ENTER 1 FOR CLIMATOLOGICAL INPUT, 2 FOR HYDROLOGICAL INPUT, 3 FOR OUTPUT OR 4 TO STOP PROGRAM.	Enter 1 for climatological input.
(3)	YES	DO YOU WANT TO ENTER PRECIPITATION DATA? (ENTER YES OR NO.)	If NO is entered, precipitation data are used from the previous run; skip to the card number (47). If YES is entered, continue.
(4)	NO	DO YOU WANT TO ADD TO EXISTING PRECIPITATION DATA? (ENTER YES OR NO.)	If YES is entered, the program will attach the existing precipitation data to the precipitation data to be entered.

Example 2 (Continued)

Card No.	Example Entry	Interactive Question	Explanation
(5)	74	ENTER YEAR OF PRECIPITATION.	Enter last two digits of the year only. If precipitation data entry is completed do not enter a year and skip to card number (43).
(6)	(10 values)	ENTER 10 VALUES OF DAILY PRECIPITATION DATA.	These 10 values represent the amount of precipitation (IN/HR) for January 1 through January 10. Separate each value with a blank.
(7)	(10 values)	ENTER 10 VALUES OF DAILY PRECIPITATION DATA.	These 10 values represent the amount of precipitation (IN/HR) for January 11 through January 20.
(8)	(10 values)	ENTER 10 VALUES OF DAILY PRECIPITATION DATA.	These 10 values represent the amount of precipitation (IN/HR) for January 21 through January 30.
(·)	(10 values)		The program will request that 10 values of daily precipitation be entered until 37 cards are punched. This is enough space for 365 or 366 (leap year) days of the year and the last 5 or 4 values are left blank.
(·)	(10 values)		
(·)	(10 values)		
(42)	(5 or 6 values)		
(43)	0	ENTER YEAR OF PRECIPITATION.	Last 2 digits only; if a year is entered, repeat cards 6 through 42. Enter zero when all years of precipitation data are entered.
(44)	YES	DO YOU WANT A LISTING OF PRECIPITATION VALUES? (ENTER YES OR NO.)	If NO is entered, skip to card number (47).
(45)	74	ENTER YEAR YOU WANT LISTED.	The program print precipitation data of the given year.

Example 2 (Continued)

Card No.	Example Entry	Interactive Question	Explanation
(46)	YES	DO YOU WANT TO USE THEM (ENTER YES ONLY).	Repeat card numbers 44 through 46 until all years of precipitation data are listed.
(47)	YES	DO YOU WANT TO ENTER TEMPERATURE DATA? (ENTER YES OR NO.)	If NO is entered, the program assumes temperature data are to be used from previous run.
(48)	NO	DO YOU WANT TO ENTER YEARLY CLIMATOLOGICAL DATA? (ENTER YES OR NO.)	If NO is entered, temperatures, solar radiation, and LAI values are to be constant over entire years of precipitation. Insert only cards with the label a. If YES is entered, yearly associated temperatures, solar radiation, winter cover factors, and LAI values for each year of precipitation must be entered. Insert only card numbers with the label b and skip to card number 49b.
(49a)	40.1 50.8 60.2 70.3 80.1 85.0 90.2 94.4 93.4 60.3 40.0 31.0	ENTER 12 MONTHLY TEMPERATURE VALUES.	Enter 12 values with one value per card.
(50a)	NO	DO YOU WANT TO CHANGE THE TEMPERATURE LISTED? (ENTER NO ONLY.)	The user should enter NO only.
(51a)	YES	DO YOU WANT TO ENTER SOLAR RADIATION DATA? (ENTER YES OR NO.)	If NO is entered, the program assumes solar radiation data are to be used from previous run.

Card No.	Example Entry	Interactive Question	Explanation
(52a)	230 260 290 310 320 350 370 400 355 325 250 225	ENTER 12 MONTHLY SOLAR RADIATION VALUES.	Enter 12 values with one value per card.
(53a)	YES	DOES THE SOIL SURFACE HAVE VEGETATION? (ENTER YES OR NO.)	If NO is entered skip to card number 62.
(54a)	YES	DO YOU WANT TO ENTER THE LEAF AREA INDEX? (ENTER YES OR NO.)	If NO is entered the program assumes the leaf area index data are to be used from the previous run.
(55a)	1 0.0 90 0.0 144 0.9 160 1.0 190 2.0 200 3.0 215 3.0 230 3.0 280 3.0 300 2.9 315 2.4 325 1.0 366 0.0	ENTER LAI ON 13 CARDS WITH 2 VALUES PER CARD.	The first value on the card is the day of measurement (Julian Day) and the second value is the surface area of the leaf area index.
(56a)	NO	DO YOU WANT TO CHANGE THEM? (ENTER NO ONLY.)	Enter NO only and skip to card number (62).
(49b)	NO	ARE THE TEMPERATURES THE SAME AS THE PREVIOUS YEAR? (ENTER YES OR NO.)	If NO is entered continue. If YES is entered, skip to card number 52b.
(50b)	30.1 40.2 50.0 55.0 65.4	ENTER 12 MONTHLY TEMPERATURES FOR THE YEAR 1974.	Enter 12 values on separate cards for the first year of precipitation data entered. If this is the second,

Example 2 (Continued)

Card No.	Example Entry	Interactive Question	Explanation
(50b)	73.3 79.1 75.5 62.4 61.2 31.1 29.0		third, fourth ., ., ., or twentieth time through this loop the year (1974) is increment by 1, 2, 3, ., ., ., or nineteen, respectively.
(51b)	NO	DO YOU WANT TO CHANGE THEM? (ENTER NO ONLY.)	Enter NO only and continue.
(52b)	NO	ARE THE SOLAR RADIATION VALUES THE SAME AS THE PREVIOUS YEAR? (ENTER YES OR NO.)	NO is entered for the first time through the loop. If YES is entered, skip to card number 55b.
(53b)	203 244 264 284 300 315 318 350 348 300 255 225	ENTER 12 MONTHLY SOLAR RADIATION VALUES.	Enter 12 values on separate cards.
(54b)	NO	DO YOU WANT TO CHANGE THEM? (ENTER NO ONLY.)	Enter NO only and continue.
(55b)	NO	IS THE WINTER COVER FACTOR THE SAME AS THE PREVIOUS YEAR? (ENTER YES OR NO.)	NO is entered the first time through the loop. If YES is entered, skip to card number 58b.
(56b)	0.9	ENTER WINTER COVER FACTOR.	The number range from 0.5 to 1.0, where 1.0 is for bare ground.
(57b)	NO	DO YOU WANT TO CHANGE IT? (ENTER NO ONLY.)	Enter NO only and continue.
(58b)	YES	DOES THE SOIL SURFACE HAVE VEGETATION? (ENTER YES OR NO.)	If NO is entered and it is not the last year in which precipitation data were entered, go to card number 49b; but

Example 2 (Continued)

Card No.	Example Entry	Interactive Question	Explanation
(58b)	(Continued)		if it is the last year, skip to card number 62. The program will insert the LAI value if the soil surface does not have vegetation.
(59b)	NO	ARE LAI's THE SAME AS THE PREVIOUS YEAR? (ENTER YES OR NO.)	Enter NO only if it is the first time through the loop. If YES is entered skip to card number 49b. If NO is entered and the surface does not have vegetation, the program will automatically insert the LAI values and skip to card number 49b. If this is the last year entered, skip to card number 62.
(60b)	1 0.0 90 0.0 144 0.9 160 1.0 190 2.0 200 3.0 215 3.0 230 3.0 280 3.0 300 2.9 315 2.4 325 1.0 366 0.0	ENTER LAI ON 13 CARDS WITH 2 VALUES PER CARD.	The first value on the card is the day of measurement (Julian Day) and the second value is the surface area of the leaf area index.
(61b)	NO	DO YOU WANT TO CHANGE THEM? (ENTER NO ONLY.)	Enter NO only. If this is the last year of precipitation data entered, go to the next cards; otherwise go to card 49b.
(62)	2	ENTER 1 FOR CLIMATOLOGICAL INPUT, 2 FOR HYDROLOGICAL INPUT, 3 FOR OUTPUT OR 4 TO STOP PROGRAM.	Enter 2 only for input of hydrological data.

Example 2 (Continued)

Card No.	Example Entry	Interactive Question	Explanation
(63)	TEST	ENTER TITLE.	Enter the name of the site.
(64)	FOUR MILES FROM TOWN	ENTER LOCATION OF SOLID WASTE SITE.	Enter the location of the site.
(65)	22 JANUARY 1982	ENTER TODAY's DATE.	Enter the date of the computer run.
(66)	74003	ENTER YEAR AND DATE OF FIRST STORM EVENT (JULIAN DATE).	The first rain storm occurred on January 3, 1974.
(67)	3	ENTER NUMBER OF LAYERS IN SOIL COVER.	If layer is 1, skip all cards referring to layers 2 and 3, if layer is 2, skip all cards referring to layer 3.
(68)	36	ENTER TOTAL THICKNESS OF SOIL COVER.	The units for the cover thickness are in inches.
(69)	0.550	ENTER HYDROLOGIC CONDUCTIVITY OF VEGETATIVE SOIL.	The units for the hydrologic conductivity are in inches per hour.
(70)	0.458	ENTER SOIL POROSITY OF VEGETATIVE SOIL.	The units for the porosity are in volume per volume.
(71)	4.5	ENTER EVAPORATION COEFFICIENT OF VEGETATIVE SOIL.	This value has no units.
(72)	0.287	ENTER FIELD CAPACITY OF VEGETATIVE SOIL.	The field capacity has the units of volume per volume.
(73)	0.156	ENTER WILTING POINT OF VEGETATIVE SOIL.	The wilting point has units of volume per volume.
(74)	24	ENTER THICKNESS OF SOIL LAYER 2 (in.).	
(75)	0.022	ENTER HYDRAULIC CONDUCTIVITY OF SOIL LAYER 2 (in./hr).	
(76)	0.680	ENTER SOIL POROSITY OF SOIL LAYER 2 (vol/vol).	
(77)	3.5	ENTER EVAPORATION COEFFICIENT OF SOIL LAYER 2 (vol/vol).	

Example 2 (Concluded)

Card No.	Example Entry	Interactive Question	Explanation
(78)	0.252	ENTER FIELD CAPACITY OF SOIL LAYER 2 (vol/vol).	
(79)	6	ENTER THICKNESS OF SOIL LAYER 3 (in.).	
(80)	6.620	ENTER HYDRAULIC CONDUCTIVITY OF SOIL LAYER 3 (in./hr).	
(81)	0.389	ENTER SOIL POROSITY OF SOIL LAYER 3 (vol/vol).	
(82)	3.3	ENTER EVAPORATION COEFFICIENT OF SOIL LAYER 3 (vol/vol).	
(83)	0.248	ENTER FIELD CAPACITY OF SOIL LAYER 3 (vol/vol).	
(84)	YES	IS THERE AN IMPERMEABLE LINER AT THE INTERFACE? (ENTER YES OR NO).	If NO is entered, skip to card number (85).
(85)	50	WHAT IS THE EXPECTED LIFE OF THE LINER (YEARS)?	The years range from 1 to 100.
(86)	79	ENTER SCS CURVE NUMBER.	
(87)	0.9	ENTER WINTER COVER FACTOR ONLY IF THE SAME SET OF MONTHLY TEMPERATURES, SOLAR RADIATION, AND LAI VALUES ARE USED FOR THE ENTIRE YEARS OF PRECIPITATION.	
(88)	3	ENTER 1 FOR CLIMATOLOGICAL INPUT, 2 FOR HYDROLOGICAL INPUT, 3 FOR OUTPUT OR 4 TO STOP PROGRAM.	Enter 3 only for instruction on how to control the output.
(89)	20	HOW MANY YEARS OF OUTPUT DO YOU WANT?	Do not input a number greater than the maximum number of precipitation years entered.
(90)	YES	DO YOU WANT A DAILY SUMMARY? (ENTER YES OR NO.)	If NO is entered, only the yearly summaries are printed.
(91)	YES	DO YOU WANT MONTHLY SUMMARIES? (ENTER YES OR NO.)	If NO is entered, the monthly summaries are not printed.

TABLE 5. LISTING OF CITIES AND STATES

- Alaska
  - Annette
  - Bethel
  - Fairbanks
- Arizona
  - Flagstaff
  - Phoenix
  - Tucson
- Arkansas
  - Little Rock
- California
  - Sacramento
  - Fresno
  - San Diego
  - Los Angeles
  - Santa Maria
- Colorado
  - Denver
  - Grand Junction
- Florida
  - Tallahassee
  - W. Palm Beach
  - Jacksonville
  - Miami Airport
  - Tampa
  - Orlando
- Georgia
  - Atlanta
  - Watkinsville
- Hawaii
  - Honolulu
- Idaho
  - Boise
  - Pocatello
- Illinois
  - Chicago
  - E. St. Louis
- Indiana
  - Indianapolis
- Iowa
  - Des Moines
- Kansas
  - Dodge City
  - Topeka
- Kentucky
  - Lexington
- Louisiana
  - Lake Charles
  - New Orleans
  - Shreveport
- Maine
  - Caribou
  - Portland
- Massachusetts
  - Boston
- Michigan
  - E. Lansing
  - Sault Ste. Marie
- Minnesota
  - St. Cloud
- Missouri
  - Columbia
- Montana
  - Glasgow
  - Great Falls
- Nebraska
  - Grand Island
  - North Omaha
- Nevada
  - Ely
  - Las Vegas
- New Jersey
  - Edison
- Seabrook
- New Mexico
  - Albuquerque
- New York
  - Syracuse
  - Central Park
  - Ithaca
  - Schenectady
  - New York City
- North Carolina
  - Greensboro
- North Dakota
  - Bismark
- Ohio
  - Cleveland
  - Columbus
  - Cincinnati
  - Put-in-Bay
- Oklahoma
  - Oklahoma City
  - Tulsa
- Oregon
  - Portland
  - Medford
  - Astoria
- Pennsylvania
  - Pittsburgh
  - Philadelphia
- Rhode Island
- Providence
- South Carolina
  - Charleston
- South Dakota
  - Rapid City
- Tennessee
  - Nashville
  - Knoxville
- Texas
  - Brownsville
  - El Paso
  - Dallas
  - Midland
  - San Antonio
- Utah
  - Cedar City
  - Salt Lake City
- Virginia
  - Lynchburg
  - Norfolk
- Washington
  - Yakima
  - Pullman
  - Seattle
- Wisconsin
  - Madison
- Wyoming
  - Lander
  - Cheyenne
- Puerto Rico
  - San Juan

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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 (3), SCS-NEH (7), and Hjelmfelt and Cassidy (9). In the model, precipitation is separated into runoff, evapotranspiration, and subsurface drainage to maintain a continuous water balance.

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). A stochastic variable is one whose properties are governed by purely random-time events, sequential relations, and functional relations with other hydrologic variables. The HSSWDS model is deterministic in its modeling concepts. A general weakness with most research efforts employing deterministic models is that they focus on obtaining "best" estimates of runoff and percolation parameters, which are then used as the "true" values of the process.

RUNOFF

During a given rainfall, water is continually being intercepted by trees, plants, root surfaces, etc. Transport and evapotranspiration are also 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 (7) was selected (3) for the runoff process (10) because the method:

a) Is a well established, reliable procedure,
b) is computationally efficient,
c) requires inputs that are available, and
d) permit the use of estimated data for soil types, land use, and management.

A plot of the accumulative rainfall versus the accumulative runoff can be used to develop the relation (7) between rainfall, runoff, and retention (the rainfall not converted to runoff). Although rainfall and runoff do not start at the same time (because of 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, exclusive of I_a ($S \geq F$)

Q = actual or direct runoff

P' = potential maximum runoff ($P' \geq Q$)

I_a = initial abstraction

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 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:

$$P' = P - I_a$$

where P = the daily rainfall

The retention F varies because it is the difference between P' and Q at any point along the plotted curve. Thus:

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

where

$$F \leq S$$

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

Now combining terms, it follows:

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

After algebraic manipulation this expression becomes:

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

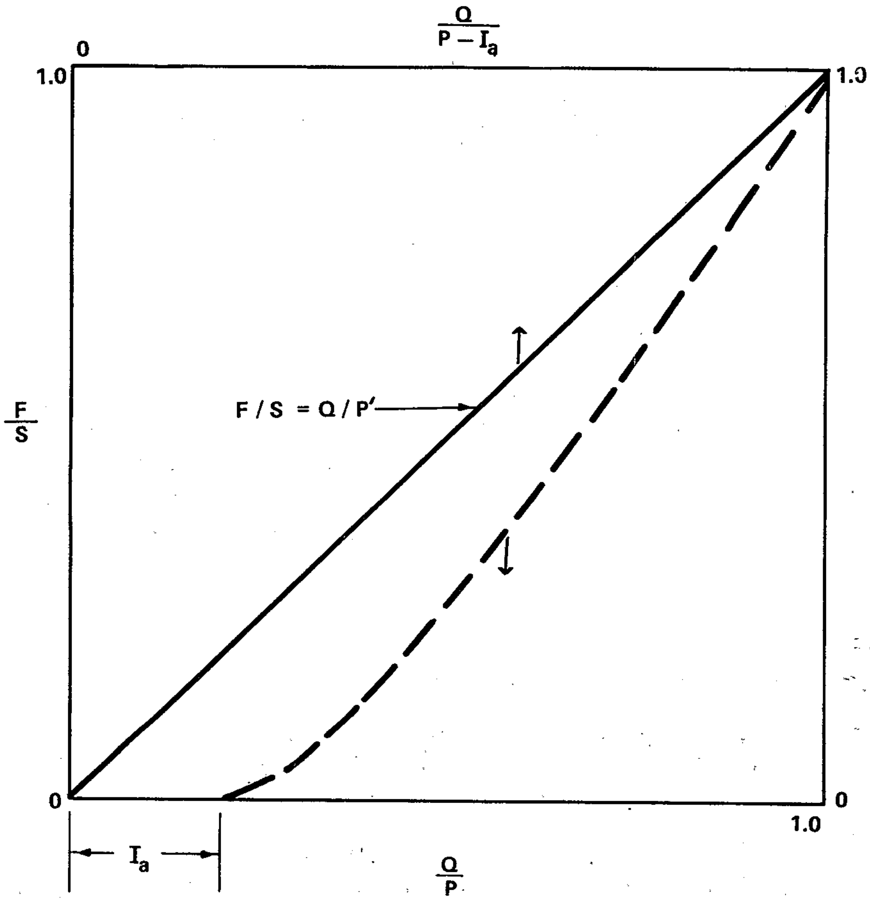

Figure A-1. Relation between the fraction of runoff and the fraction of retention.

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

$$I_a = 0.2S$$

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 zero to ∞ .

Expanding the numerator, applying polynomial division, and dividing through by S yields (11,12):

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

where the term in the brackets is the remainder from division that approaches zero 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:

$$P - Q = 1.2S \tag{2}$$

or

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

where P approaches ∞ . 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 illustrated 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 that had a range of 0 to 100 (7).

$$CN = \frac{1000}{10 + S} \tag{3}$$

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 (3) by the expression:

$$S = S_{mx}\left(1 - \frac{SM}{UL}\right) \tag{4}$$

where Smx = maximum value of S

SM = soil-water content in the final soil cover

UL = upper limit of soil-water storage

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

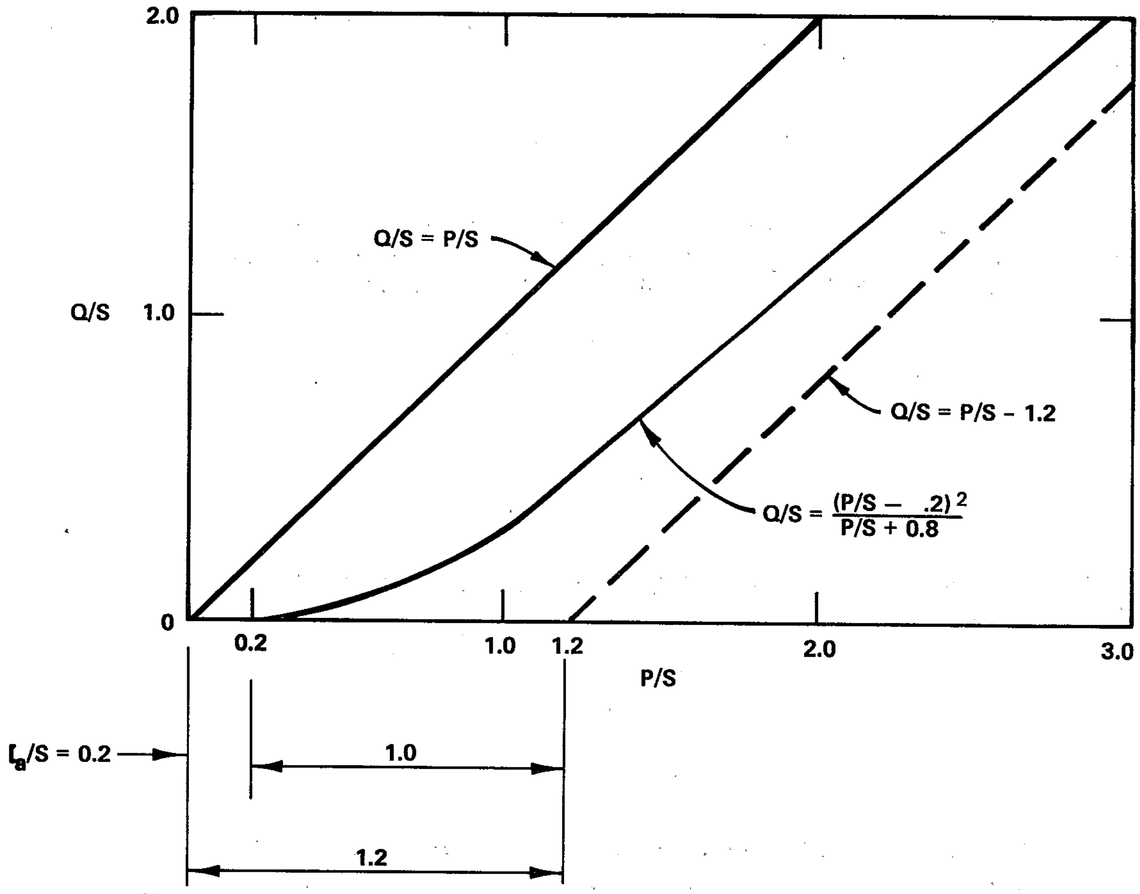

Figure A-2. SCS rainfall-runoff relation standardized on retention parameter S

$$S_{mx} = 1.2 \left(\frac{1000}{CN_I} - 10 \right) \tag{5}$$

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

$$CN_I = -16.91 + 1.348(CN_{II}) - 0.01379(CN_{II})^2 + 0.0001177(CN_{II})^3 \tag{6}$$

Hydrologic condition II can be estimated using text Figure 6 or the detailed listings in the SCS-HEC (7) 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:

$$S = S_{mx}\left[1 - \sum_{i=1}^{N} W_i\left(\frac{SM_i}{UL_i}\right)\right] \qquad (7)$$

where W_i = weighting factor at depth i .

The weighting factors decrease with depth according to the default values: 0.115, 0.405, 0.266, 0.139, 0.075, 0.000, and 0.000. With this procedure, runoff is predicted for the solid waste disposal site.

Generally, each solid waste disposal site is thought to be unique; but uniqueness suggests a lack of information as well as a limitation in data-gathering capabilities. Proper perspective must be given to the role that such items as rainfall intensity, storm duration, interception, site slope, shape, size, and roughness play on 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. The vaporization of rainfall or snow resting on the outer plant surfaces is also gained by the atmosphere. These processes are usually called evaporation.

EVAPOTRANSPIRATION

The major portion of solar radiation is used in the process of evapotranspiration, or the amount of water lost by evaporation from the soil 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 (9). 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,

$$SM_i = SM_{i-1} + FR_i - ET_i - DR_i + M_i \qquad (8)$$

where SM_i = soil water storage on day i

FR_i = water entering the soil on day i

ET_i = evapotranspiration on day i

DR_i = drainage below the final soil cover on day i

M_i = amount of snowmelt on day i

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

$$M_i = 0.10T \tag{9}$$

This relation is used unless M_i 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:

$$E_o = \frac{1.28\Delta H_o}{\Delta + \gamma} \tag{10}$$

where E_o = potential evaporation

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

H_o = net solar radiation

γ = the psychrometric constant, i.e., 0.68

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

$$\Delta = \frac{5304}{T^2} e^{(21.255-5304/T)} \tag{11}$$

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

$$H_o = \frac{(1 - \lambda)R}{58.3} \tag{12}$$

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:

$$E_{so} = E_o e^{-0.4\ LAI} \tag{13}$$

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:

$$U = 9\ (\alpha - 3)^{0.42} \tag{14}$$

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:

$$E_s = \alpha \left[t^{1/2} - (t - 1)^{1/2} \right] \tag{15}$$

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:

$$E_p = \frac{E_o \text{ (LAI)}}{3} \text{ , } 0 \leq \text{LAI} \leq 3 \tag{16}$$

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 calculated by the equation:

$$E_{pl} = \frac{E_p \text{ SM}}{0.25 \text{ FC}} \text{ , SM} \leq 0.25 \text{ FC} \tag{17}$$

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.

PERCOLATION

The model uses a soil storage routing technique to predict flow through the final soil cover (3). The soil cover is divided into seven layers for routing as follows:

$$Q = \sigma \left(F + \frac{ST}{\Delta t} \right) \text{ , } \left(F + \frac{ST}{\Delta t} \right) > \text{FC} \tag{18}$$

where σ = the storage coefficient

F = the inflow rate

ST = the storage volume

Δt = the routing interval (24 hours)

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 in addition to 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.

Percolation 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 ANALYSIS FOR THE NATIONAL COMPUTER CENTER TIME-SHARING OPERATION

1. Three cost parameters are associated with the National Computer System (NCC) time-sharing operation (TSO). These are storage charges, central computer processing costs and connection costs.

2. Three types of data storage exist on NCC/TSO. The public online disk storage charge is $.035 per track per week. Private online disk cost is $4250.00 per pack per month, and private mountable disk cost is $125.00 per pack per month. No charge is made for private disk pack mounts.

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

4. The connection cost is $6.00 per hour.

APPENDIX C

NCC ACCESS NUMBERS AND TERMINAL IDENTIFIERS

The following list contains current NCC access numbers for 300 and 1200 band rates.* These numbers are to be used to access the TSO computer in Research Triangle Park, NC. A user should locate his city of interest on the list and dial the appropriate number for access to TSO. Users who fail to find their city of interest on the list should dial the WATS number 800-334-8581 for the 300 or 1200 BAUD rate.

TABLE C-1. ACCESS TELEPHONE NUMBERS

CITIES	STATES	LOCAL NUMBERS	BAUD RATES
BIRMINGHAM	ALABAMA	205/942-4141	(300)
BIRMINGHAM	ALABAMA	205/942-1015	(1200)
HUNTSVILLE	ALABAMA	205/533-5137	(300)
MOBILE	ALABAMA	205/432-3382	(1200)
MONTGOMERY	ALABAMA	205/834-3410	(300)
PHOENIX	ARIZONA	602/249-3862	(1200)
PHOENIX	ARIZONA	602/249-9261	(300)
TUCSON	ARIZONA	602/747-4097	(1200)
TUCSON	ARIZONA	602/790-0764	(300)
FT. SMITH	ARKANSAS	501/782-3210	(1200)
JONESBORO	ARKANSAS	501/932-6886	(1200)
LITTLE ROCK	ARKANSAS	501/376-3768	(1200)
LITTLE ROCK	ARKANSAS	501/372-5780	(300)
SPRINGDALE	ARKANSAS	501/756-2201	(1200)
ALHAMBRA	CALIFORNIA	213/572-0999	(300)
ANTIOCH	CALIFORNIA	415/757-6855	(300)
ARCADIA	CALIFORNIA	213/574-7636	(300)
BURLINGAME	CALIFORNIA	415/348-4992	(300)
EL SEGUNDO	CALIFORNIA	213/640-1281	(1200)
EL SEGUNDO	CALIFORNIA	213/640-1570	(300)
FRESNO	CALIFORNIA	209/445-0911	(300)
HAYWARD	CALIFORNIA	415/785-3431	(300)
LONG BEACH	CALIFORNIA	213/435-7088	(1200)
LOS ANGELES	CALIFORNIA	213/683-0451	(300)
LOS ANGELES	CALIFORNIA	213/626-0365	(1200)
LOS ANGELES	CALIFORNIA	213/629-1561	(300)
LOS ANGELES	CALIFORNIA	213/629-3451	(300)

* The band rate is the speed that the terminal prints output.

TABLE C-1. (CONTINUED)

CITIES	STATES	LOCAL NUMBERS	BAUD RATES
LOS ANGELES	CALIFORNIA	213/623-8500	(1200)
MARINA DEL REY	CALIFORNIA	213/821-2257	(300)
MISSION HILLS	CALIFORNIA	213/365-2013	(300)
MODESTO	CALIFORNIA	209/578-4236	(300)
MOUNTAIN VIEW	CALIFORNIA	415/961-7971	(300)
MOUNTAIN VIEW	CALIFORNIA	415/941-8450	(300)
MOUNTAIN VIEW	CALIFORNIA	415/949-0330	(1200)
NEWPORT BEACH	CALIFORNIA	714/540-0951	(1200)
NEWPORT BEACH	CALIFORNIA	714/540-9560	(300)
NORTHRIDGE	CALIFORNIA	213/865-2066	(1200)
NORWALK	CALIFORNIA	213/865-2066	(1200)
OAKLAND	CALIFORNIA	415/836-8900	(1200)
OAKLAND	CALIFORNIA	415/836-8700	(300)
PALO ALTO	CALIFORNIA	415/856-9080	(300)
PASADENA	CALIFORNIA	213/577-8722	(1200)
RIVERSIDE/COLTON	CALIFRONIA	714/825-9372	(300)
RIVERSIDE/COLTON	CALIFORNIA	714/824-8170	(1200)
SACRAMENTO	CALIFORNIA	916/448-8151	(1200)
SACRAMENTO	CALIFORNIA	916/441-6550	(300)
SALINAS	CALIFORNIA	408/443-4333	(300)
SAN CLEMENTE	CALIFORNIA	714/498-3130	(300)
SAN DIEGO	CALIFORNIA	714/291-8700	(300)
SAN DIEGO	CALIFORNIA	714/293-3590	(1200)
SAN FRANCISCO	CALIFORNIA	415/986-8200	(300)
SAN FRANCISCO	CALIFORNIA	415/397-4300	(1200)
SAN FRANCISCO	CALIFORNIA	415/788-7955	(1200)
SAN JOSE/CUPERTINO	CALIFORNIA	408/446-7001	(1200)
SAN JOSE/CUPERTINO	CALIFORNIA	408/446-7309	(1200)
SAN JOSE/CUPERTINO	CALIFORNIA	408/446-1470	(300)
SAN PEDRO	CALIFORNIA	213/830-0775	(300)
SANTA BARBARA	CALIFORNIA	805/687-6119	(300)
SANTA CRUZ	CALIFORNIA	408/429-9572	(1200)
SANTA ROSA	CALIFORNIA	707/546-6776	(1200)
SANTA ROSA	CALIFORNIA	707/546-1050	(300)
VAN NUYS	CALIFORNIA	213/986-9503	(300)
VENTURA/OXNARD	CALIFORNIA	805/486-4536	(1200)
VENTURA/OXNARD	CALIFORNIA	805/487-0482	(300)
VISTA	CALIFORNIA	714/727-6011	(300)
WEST COVINA	CALIFORNIA	213/331-3954	(300)
COLORADO SPRINGS	COLORADO	303/633-9599	(1200)
COLORADO SPRINGS	COLORADO	303/475-2121	(300)
DENVER	COLORADO	303/572-1107	(1200)
DENVER	COLORADO	303/825-0635	(1200)
DENVER	COLORADO	303/573-0177	(300)
DENVER	COLORADO	303/573-9981	(300)
BRIDGEPORT	CONNECTICUT	203/579-7820	(300)
DANBURY	CONNECTICUT	203/743-1340	(300)
DANBURY	CONNECTICUT	203/743-1650	(1200)
DARIEN	CONNECTICUT	203/655-7951	(1200)

TABLE C-1. (CONTINUED)

CITIES	STATES	LOCAL NUMBERS	BAUD RATES
DARIEN	CONNECTICUT	203/655-8931	(300)
FAIRFIELD/BRIDGEPORT	CONNECTICUT	203/333-4926	(1200)
HARTFORD	CONNECTICUT	203/568-2610	(300)
HARTFORD	CONNECTICUT	203/569-3643	(1200)
NEW HAVEN	CONNECTICUT	203/787-1702	(1200)
NEW HAVEN	CONNECTICUT	203/789-0579	(300)
WATERBURY	CONNECTICUT	203/755-1153	(300)
WASHINGTON	DC	703/841-9330	(1200)
WASHINGTON	DC	703/841-0200	(300)
WASHINGTON	DC	703/841-9560	(300)
WASHINGTON	DC	703/734-8370	(1200)
WILMINGTON	DELAWARE	302/658-5261	(300)
WILMINGTON	DELAWARE	302/658-8611	(1200)
DAYTONA BEACH	FLORIDA	904/252-4481	(300)
FT LAUDERDALE	FLORIDA	305/467-7550	(300)
FT LAUDERDALE	FLORIDA	305/467-3807	(1200)
JACKSONVILLE	FLORIDA	904/721-8100	(300)
MIAMI	FLORIDA	305/374-7120	(300)
MIAMI	FLORIDA	305/358-7271	(1200)
ORLANDO	FLORIDA	305/859-7670	(1200)
ORLANDO	FLORIDA	305/851-3530	(300)
PENSACOLA	FLORIDA	904/434-0134	(300)
SARASOTA	FLORIDA	813/365-3526	(1200)
ST PETERSBURG	FLORIDA	813/535-6441	(300)
TAMPA	FLORIDA	813/977-8032	(300)
TAMPA	FLORIDA	813/977-3891	(1200)
W. PALM BEACH	FLORIDA	305/622-2871	(300)
ATLANTA	GEORGIA	404/659-6670	(300)
ATLANTA	GEORGIA	404/581-0619	(1200)
ATLANTA	GEORGIA	404/659-2910	(300)
SAVANNAH	GEORGIA	912/352-7259	(300)
BOISE	IDAHO	208/344-4311	(1200)
BOISE	IDAHO	208/343-4851	(300)
CHICAGO	ILLINOIS	312/368-4700	(300)
CHICAGO	ILLINOIS	312/641-1630	(1200)
CHICAGO	ILLINOIS	312/372-0391	(1200)
CHICAGO	ILLINOIS	312/368-4607	(300)
CHICAGO	ILLINOIS	312/346-4961	(300)
FREEPORT	ILLINOIS	815/233-5585	(300)
JOLIET	ILLINOIS	815/723-9854	(1200)
PEORIA	ILLINOIS	309/673-2156	(300)
ROCKFORD	ILLINOIS	815/398-6090	(300)
SPRINGFIELD	ILLINOIS	217/753-7900	(1200)
SPRINGFIELD	ILLINOIS	217/753-7905	(300)
EVANSVILLE	INDIANA	812/423-6885	(300)
FT WAYNE	INDIANA	219/424-5162	(300)
HIGHLAND	INDIANA	219/836-5452	(300)
INDIANAPOLIS	INDIANA	317/926-1253	(1200)
INDIANAPOLIS	INDIANA	317/257-3461	(300)

TABLE C-1. (CONTINUED)

CITIES	STATES	LOCAL NUMBERS	BAUD RATES
MARION	INDIANA	317/662-0091	(300)
MERRILLVILLE	INDIANA	219/769-7254	(300)
SOUTH BEND	INDIANA	219/233-4163	(300)
CEDAR RAPIDS	IOWA	319/363-2482	(300)
DES MOINES	IOWA	515/288-6640	(300)
IOWA CITY	IOWA	319/354-7371	(300)
WATERLOO	IOWA	319/233-0227	(1200)
SHAWNEE MISSION	KANSAS	913/677-2833	(300)
SHAWNEE MISSION	KANSAS	913/677-0707	(1200)
TOPEKA	KANSAS	913/233-0690	(300)
WICHITA	KANSAS	316/265-1241	(300)
WICHITA	KANSAS	316/264-7386	(1200)
LEXINGTON	KENTUCKY	606/253-3463	(300)
LEXINGTON	KENTUCKY	606/253-3498	(1200)
LOUISVILLE	KENTUCKY	502/361-2645	(1200)
LOUISVILLE	KENTUCKY	502/361-3881	(300)
BATON ROUGE	LOUISIANA	504/292-4050	(300)
BATON ROUGE	LOUISIANA	504/292-2650	(1200)
LAFAYETTE	LOUISIANA	318/235-3501	(300)
NEW ORLEANS	LOUISIANA	504/586-1071	(300)
NEW ORLEANS	LOUISIANA	504/524-4371	(1200)
SHREVEPORT	LOUISIANA	318/688-4666	(1200)
BALTIMORE	MARYLAND	301/547-8100	(300)
BALTIMORE	MARYLAND	301/244-8959	(1200)
BOSTON	MASSACHUSETTS	617/482-1854	(1200)
BOSTON	MASSACHUSETTS	617/482-5622	(300)
BOSTON	MASSACHUSETTS	617/482-4677	(300)
BOSTON	MASSACHUSETTS	617/482-3386	(1200)
SPRINGFIELD	MASSACHUSETTS	413/781-6830	(300)
SPRINGFIELD	MASSACHUSETTS	413/781-0145	(1200)
WORCESTER	MASSACHUSETTS	617/755-5601	(1200)
WORCESTER	MASSACHUSETTS	617/754-9451	(300)
ANN ARBOR	MICHIGAN	313/662-8282	(1200)
ANN ARBOR	MICHIGAN	313/665-2627	(300)
DETROIT	MICHIGAN	313/963-3388	(300)
DETROIT	MICHIGAN	313/963-8880	(1200)
DETROIT	MICHIGAN	313/963-2353	(1200)
FLINT	MICHIGAN	313/732-7303	(1200)
GRAND RAPIDS	MICHIGAN	616/456-9092	(1200)
GRAND RAPIDS	MICHIGAN	616/459-5069	(300)
JACKSON	MICHIGAN	517/787-9461	(300)
KALAMAZOO	MICHIGAN	616/385-3150	(300)
LANSING	MICHIGAN	517/487-2040	(300)
MANISTEE	MICHIGAN	616/723-8760	(300)
PLYMOUTH	MICHIGAN	313/459-8100	(1200)
PLYMOUTH	MICHIGAN	313/459-8900	(300)
SOUTHFIELD	MICHIGAN	313/569-8350	(300)
ST JOSEPH	MICHIGAN	616/429-2568	(300)
TRAVERSE CITY	MICHIGAN	616/946-0002	(300)

TABLE C-1. (CONTINUED)

CITIES	STATES	LOCAL NUMBERS	BAUD RATES
MANKATO	MINNESOTA	507/625-1684	(1200)
WHITE PLAINS	NEW YORK	914/694-8960	(1200)
WHITE PLAINS	NEW YORK	914/694-9361	(300)
ASHEVILLE	NORTH CAROLINA	704/255-0021	(1200)
CHARLOTTE	NORTH CAROLINA	704/376-2544	(1200)
CHARLOTTE	NORTH CAROLINA	704/376-2545	(300)
DURHAM	NORTH CAROLINA	919/549-8910	(1200)
DURHAM	NORTH CAROLINA	919/549-0441	(300)
GREENSBORO	NORTH CAROLINA	919/275-8231	(1200)
GREENSBORO	NORTH CAROLINA	919/379-0034	(300)
RALEIGH	NORTH CAROLINA	919/832-6592	(1200)
RESEARCH TRIANGLE PARK	NORTH CAROLINA	919/549-9100	(300)
RESEARCH TRIANGLE PARK	NORTH CAROLINA	919/549-9100	(1200)
RESEARCH TRIANGLE PARK	NORTH CAROLINA	919/549-9100	(1200)
WINSTON-SALEM	NORTH CAROLINA	919/725-1414	(300)
WINSTON-SALEM	NORTH CAROLINA	919/725-9252	(1200)
AKRON	OHIO	216/535-1861	(300)
CINCINNATI	OHIO	513/791-5311	(1200)
CINCINNATI	OHIO	513/891-7211	(300)
CLEVELAND	OHIO	216/781-7050	(300)
CLEVELAND	OHIO	216/861-5383	(1200)
COLUMBUS	OHIO	614/421-1650	(1200)
COLUMBUS	OHIO	614/421-7270	(300)
DAYTON	OHIO	513/223-3847	(300)
DAYTON	OHIO	513/461-6400	(1200)
MARYSVILLE	OHIO	513/642-2015	(1200)
TOLEDO	OHIO	419/255-2946	(1200)
TOLEDO	OHIO	419/243-3144	(300)
YOUNGSTOWN	OHIO	216/744-5326	(1200)
OKLAHOMA CITY	OKLAHOMA	405/847-0561	(300)
OKLAHOMA CITY	OKLAHOMA	405/949-0125	(1200)
TULSA	OKLAHOMA	918/663-2220	(300)
TULSA	OKLAHOMA	918/665-2750	(1200)
PORTLAND	OREGON	503/231-4050	(300)
PORTLAND	OREGON	503/231-4077	(1200)
ALLENTOWN	PENNSYLVANIA	215/433-6131	(300)
ALLENTOWN	PENNSYLVANIA	215/432-5926	(1200)
ALTOONA	PENNSYLVANIA	814/946-8888	(1200)
ERIE	PENNSYLVANIA	814/453-7161	(300)
HARRISBURG	PENNSYLVANIA	717/236-1190	(300)
PHILADELPHIA	PENNSYLVANIA	215/567-1381	(1200)
PHILADELPHIA	PENNSYLVANIA	215/561-6120	(300)
PITTSBURGH	PENNSYLVANIA	412/261-4151	(1200)
PITTSBURGH	PENNSYLVANIA	412/765-1320	(300)
VALLEY FORGE	PENNSYLVANIA	215/666-0930	(1200)
VALLEY FORGE	PENNSYLVANIA	215/666-9190	(300)
YORK	PENNSYLVANIA	717/846-3900	(300)
PROVIDENCE	RHODE ISLAND	401/274-5783	(300)
PROVIDENCE	RHODE ISLAND	401/831-5566	(1200)

TABLE C-1. (CONTINUED)

CITIES	STATES	LOCAL NUMBERS	BAUD RATES
COLUMBIA	SOUTH CAROLINA	803/252-0840	(300)
GREENVILLE	SOUTH CAROLINA	803/271-2418	(300)
CHATTANOOGA	TENNESSEE	615/756-0561	(1200)
CHATTANOOGA	TENNESSEE	615/756-5856	(300)
KNOXVILLE	TENNESSEE	615/637-3118	(300)
KNOXVILLE	TENNESSEE	615/523-7458	(1200)
MEMPHIS	TENNESSEE	901/529-0183	(1200)
MEMPHIS	TENNESSEE	901/529-0170	(300)
NASHVILLE	TENNESSEE	615/361-7566	(1200)
NASHVILLE	TENNESSEE	615/367-9382	(300)
AUSTIN	TEXAS	512/444-5800	(1200)
BAYTOWN	TEXAS	713/427-5856	(300)
BEAUMONT	TEXAS	713/832-2589	(300)
CORPUS CHRISTI	TEXAS	512/882-3641	(300)
DALLAS	TEXAS	214/638-8888	(300)
DALLAS	TEXAS	214/688-1444	(1200)
EL PASO	TEXAS	915/544-9590	(300)
EL PASO	TEXAS	915/532-1936	(1200)
FT WORTH	TEXAS	214/263-4581	(300)
FT WORTH	TEXAS	214/263-0278	(1200)
HOUSTON	TEXAS	713/977-4080	(300)
HOUSTON	TEXAS	713/785-4411	(300)
HOUSTON	TEXAS	713/780-7496	(1200)
HOUSTON	TEXAS	713/977-7671	(1200)
HOUSTON	TEXAS	713/780-7390	(300)
LONGVIEW	TEXAS	214/758-1756	(300)
LUBBOCK	TEXAS	806/762-0136	(300)
MIDLAND	TEXAS	915/683-9833	(1200)
MIDLAND	TEXAS	915/683-5645	(300)
ODESSA	TEXAS	915/563-3745	(300)
SAN ANTONIO	TEXAS	512/699-9627	(1200)
SAN ANTONIO	TEXAS	512/696-4002	(300)
SALT LAKE CITY	UTAH	801/582-8972	(300)
SALT LAKE CITY	UTAH	801/582-6060	(1200)
BURLINGTON	VERMONT	802/864-0054	(1200)
NEWPORT NEWS	VIRGINIA	804/596-5754	(300)
NORFOLK	VIRGINIA	804/625-8301	(1200)
RICHMOND	VIRGINIA	804/788-4604	(1200)
RICHMOND	VIRGINIA	804/649-3050	(300)
ENUMCLAW	WASHINGTON	206/825-6909	(300)
OLYMPIA	WASHINGTON	206/943-4190	(300)
RICHLAND	WASHINGTON	509/375-3367	(1200)
RICHLAND	WASHINGTON	509/375-1975	(300)
SEATTLE	WASHINGTON	206/625-9937	(1200)
SEATTLE	WASHINGTON	206/625-9900	(300)
SPOKANE	WASHINGTON	509/838-8226	(1200)
TACOMA	WASHINGTON	206/952-6800	(300)
CHARLESTON	WEST VIRGINIA	304/345-2908	(1200)
HUNTINGTON	WEST VIRGINIA	304/522-6261	(300)

TABLE C-1. (CONCLUDED)

CITIES	STATES	LOCAL NUMBERS	BAUD RATES
APPLETON	WISCONSIN	414/734-9940	(300)
EAU CLAIRE	WISCONSIN	715/834-7863	(300)
GREEN BAY	WISCONSIN	414/468-6808	(1200)
MADISON	WISCONSIN	608/221-0891	(1200)
MADISON	WISCONSIN	608/221-4211	(300)
MILWAUKEE	WISCONSIN	414/257-3482	(300)
MILWAUKEE	WISCONSIN	414/257-1703	(1200)
NEENAH	WISCONSIN	414/722-5580	(300)
OSHKOSH	WISCONSIN	414/235-4594	(300)

NCC TERMINAL IDENTIFIERS

The NCC terminal identifiers (Table C-2) are user-entered characters that identify terminal speeds, carriage-return delay times, and codes to NCC.

If you are in doubt as to which NCC terminal identifier to use, contact Anthony Gibson at (601) 634-3710 (FTS 542-3710).

TABLE C-2. IDENTIFIERS, BY TERMINAL MAKE AND MODEL

TERMINAL	ID*	TERMINAL	ID*
ADDS		1132, 1201, 1202, 1203	
580, 620, 680, 880, 980	A	1204, 1205, 1206	A
Anderson Jacobson	↵	Computek	
330		200, 300	A
830, 832	A	Conrac	
630	E	401, 480	A
860†	A	Control Data	
Ann Arbor Terminals		713	A
Design III, 200	A	Computer Transceiver	
Beehive Medical Electronics		Systems	
Mini Bee 1, 2, 4	A	Execuport	E
Super Bee 2, 3	A	DEC	
I-211, M-501, R-211	A	GT40, LA34, LA36, LA38,	
Bell System		LA120,† LS120,† VT05,	
Dataspeed 40/2		VT50, VT100, VT132	A
KD	A	Datamedia	
KDP	G	1500, 2000, 2100, 2500	A
Computer Devices		Datapoint	
1030	E	1100, 3000, 3300	A

* The symbol ↵ represents a carriage return.

† During log in, enter Control R immediately before typing your user name.

TABLE C-2. (CONCLUDED)

TERMINAL	ID*
Delta Data	
5000, 5100, 5200	A
Digi-Log	
33, 209, 300	A
General Electric	
Terminet	
300, 1200	G
Gen-Com	
300	A
Hazeltine	
1200, 2000	A
Hewlett-Packard	
2615, 2616, 262X Series, 263X Series, 264X Series, 7220A†	A
Hydra	
Model B	I
IBM	
2741	P ↵
Interdata	
Carousel 300	E
Incoterm	
SPD 10/20, 20/20, 900	A
Infoton	
Vistar	A
ITT	
3501 Asciscope	A
Lear Siegler	
7700, ADM-1, ADM-2, ADM-3, ADM-31	A
LogAbax Informatique	
LX180	I
LX1010†	A
MI	
2400†	I
Megadata	A
Memorex	A
1240	G
NCR	
260	E
796	A
Omron	
8525	A
Ontel	
4000	A
Perkin-Elmer	
1200, 1250	A
Research	
Teleray 3300, 3311, 3712	A
Raytheon	
PTS-100	A
Singer	
30	E
Scientific Measurement Systems	
1440	A
Tally	
1612†	A
Tec	
400 Series, 1440	A
Tektronix	
4012, 4013, 4014, 4023 4025	A
Teletype	
33, 35	D
38	B
43	A
Texas Instruments	
720, 725, 733, 735	E
743, 745, 763, 765, 771,† 820†	A
Texas Scientific	
Entelkon 10	A
Typagraph	
DP-30	C
Tymshare	
100, 110, 212, 213	E
200	D
310, 311	C
125, 126, 225, 315, 316 325, 350,† 420, 425,† 430, 440W, 444,† 470,† 550,† 1100†	A
Wang Laboratories	
220 OB	A
Westinghouse	
1600, 1620	A
Xerox	
BC100, BC200	A

* The symbol ↵ represents a carriage return.

† During log in, enter Control R immediately before typing your user name.

APPENDIX D

SENSITIVITY ANALYSIS

by

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

The default option of HSSWDS inputs climatological and hydrological data from permanent data files stored in the computer, and the data input option permits the user to enter all the necessary data from external or measured sources. Both input options use the same output formats, however. To facilitate data handling for the sensitivity analysis, only the complete data input option was used; no defaults were requested.

Climatological and hydrological data were input for the Cincinnati, Ohio, area, and the values used are shown in Tables D-1 through D-3 and Figure D-1. The climatological data consist of 5 years worth of daily precipitation values, the yearly means, and the mean monthly temperature, solar radiation, and LAI values. In addition, Table D-4 presents hydrological data for a fictitious solid waste site near Cincinnati.

Table D-5 presents the sensitivity runs made for each parameter, with the other variables being fixed as shown in Table D-4. Thirty-six computer runs were made to demonstrate the sensitivity of the selected variables to changes in climatological and hydrological data of the solid waste site. The discussion of each parameter will follow the organization presented in Table D-5. Hydrological data used for the vegetative soil and soil layer 2 are generally representative of loamy and compacted clay soils, respectively. In the interest of simplicity only two soil layers were considered. No liner was used except when the effect of the liner was being investigated.

IMPERMEABLE LINER

As shown in Table D-5 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 a maximum life of 100 years. As expected, the impermeable liner only affects water that migrated beyond runoff and evapotranspiration. The effect of the liner is to force some of the percolated water to drain from the site as lateral drainage rather than percolation (see Figure 2 of main text). As shown in Figure D-2, a liner with a 5-year life passed only 9.6 percent of the total percolation the first year, but 89 percent by the 5th year. By comparison, a 100-year-life liner passed 2.5 percent of total percolation the first year and 13 percent by the 5th year. The final percentages of

TABLE D-1. DAILY PRECIPITATION

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)

TABLE D-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)

TABLE D-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)

TABLE D-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)

TABLE D-1. (CONCLUDED)

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					

TABLE D-2. MEAN MONTHLY TEMPERATURES AND ISOLATION

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

TABLE D-3. LEAF AREA INDEX VALUES

Day of year	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

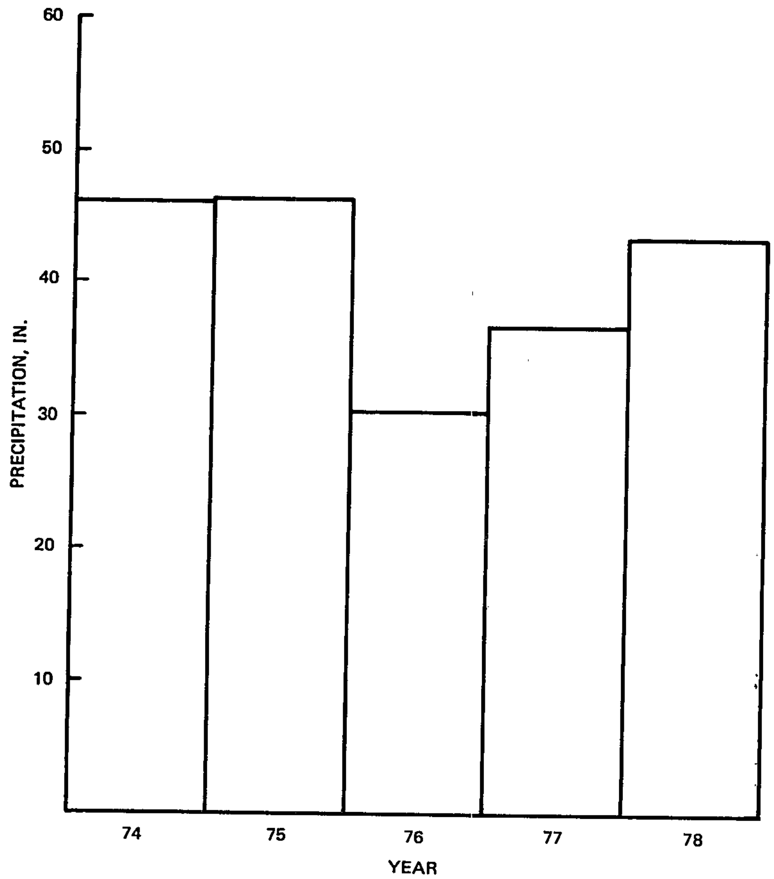

Figure D-1. Annual Cincinnati, Ohio, precipitation from 1974 to 1978.

TABLE D-4. HYDROLOGICAL INPUT FOR FICTITIOUS SOLID WASTE SITE NEAR CINCINNATI, OHIO

Item	Description
Study Title	Sensitivity study
Area Location	Cincinnati, Ohio
Today's Date	18 July 1980
Date of first storm event (Julian date) (example = 73038, 1973 and 38 Julian day)	74003
Hydraulic conductivity of vegetative soil	0.33 in./hr
Hydraulic conductivity of soil layer 2	.0011 in./hr
Total thickness of soil cover	24 inches
Thickness of vegetative layer	18 inches
Thickness of soil layer 2	6 inches
Soil porosity of vegetative soil	.621 vol/vol
Soil porosity of soil layer 2	.226 vol/vol
SCS curve number	90
Available water capacity of vegetative soil	.156 vol/vol
Available water capacity of soil layer 2	.038 vol/vol
Winter cover factor	.8
Evaporation coefficient of vegetative soil	4.5
Evaporation coefficient of soil layer 2	3.1

TABLE D-5. 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†	
	Soil layer 2	Vegetative soil
	S, SL, L, SCL, C	S
	L, SCL, C	SL
	SCL, C	L
	C	SCL
	C (compacted)	SCL

* Excellent, good, fair, poor, bare ground.

† S = sand, L = loam, C = clay.

percolation passing through for the 10-, 15-, and 20-year options were 31, 38, and 50 percent, respectively.

Figures D-2 and D-3 show that the 10-, 15-, and 20-year life options correlated with the 100-year life liner. Based on the 5-year data set, percolation increased by 585 percent with the a 5-year liner life as compared to 285 percent with a 100-year liner life.

SCS CURVE NUMBER

The results for SCS curve number are interpreted with respect to yearly totals because the curve number is not time-dependent. As expected, the curve number is a primary factor for surface runoff (Figure D-4) and a secondary factor for evapotranspiration (Figure D-5) and percolation (Figure D-6). As presented in Table D-6, the average annual totals for a curve number of 81 show that surface runoff was 17 percent of the total precipitation; whereas, for a curve number of 99, the surface runoff increased to

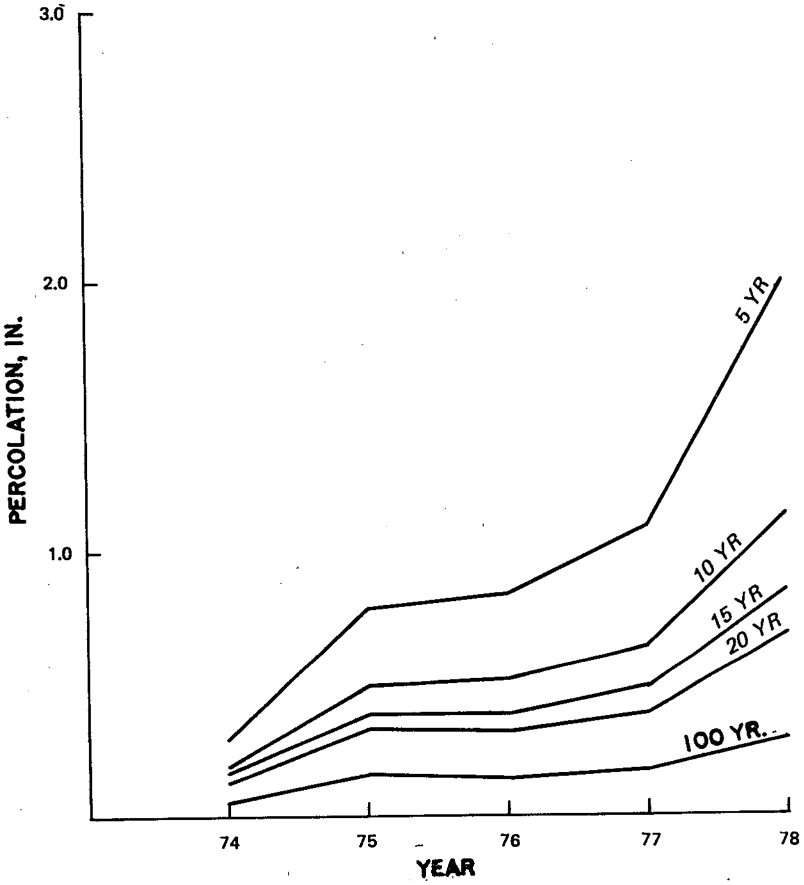

Figure D-2. Annual percolation as related to the impermeable liner.

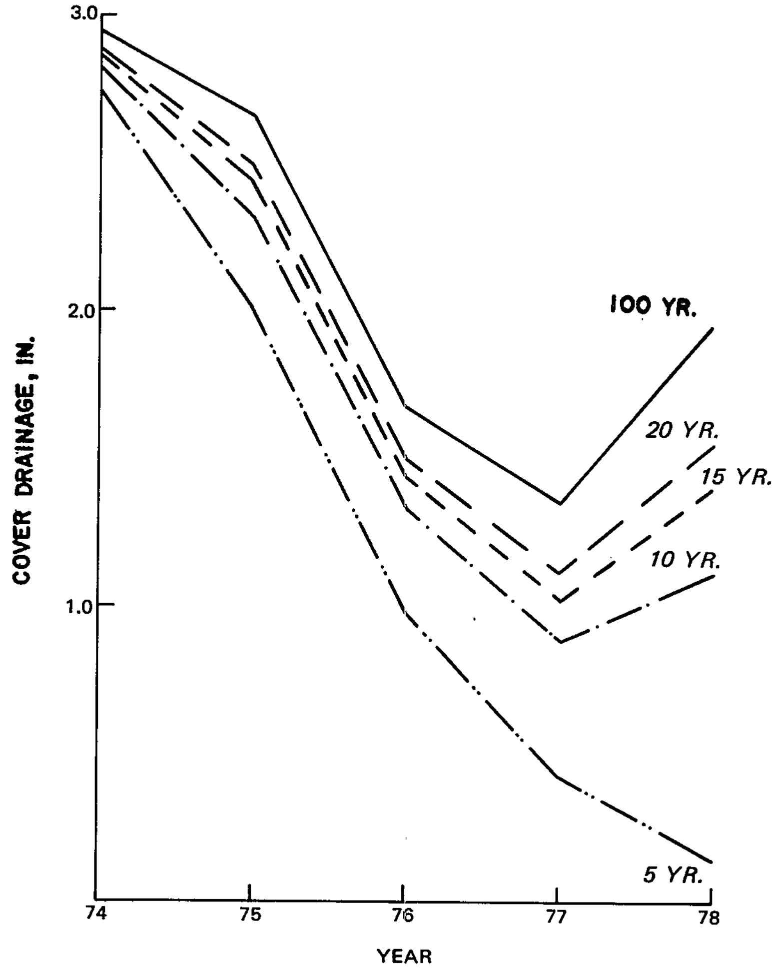

Figure D-3. Annual soil drainage* as related to the impermeable liner.

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* Soil drainage is lateral drainage.

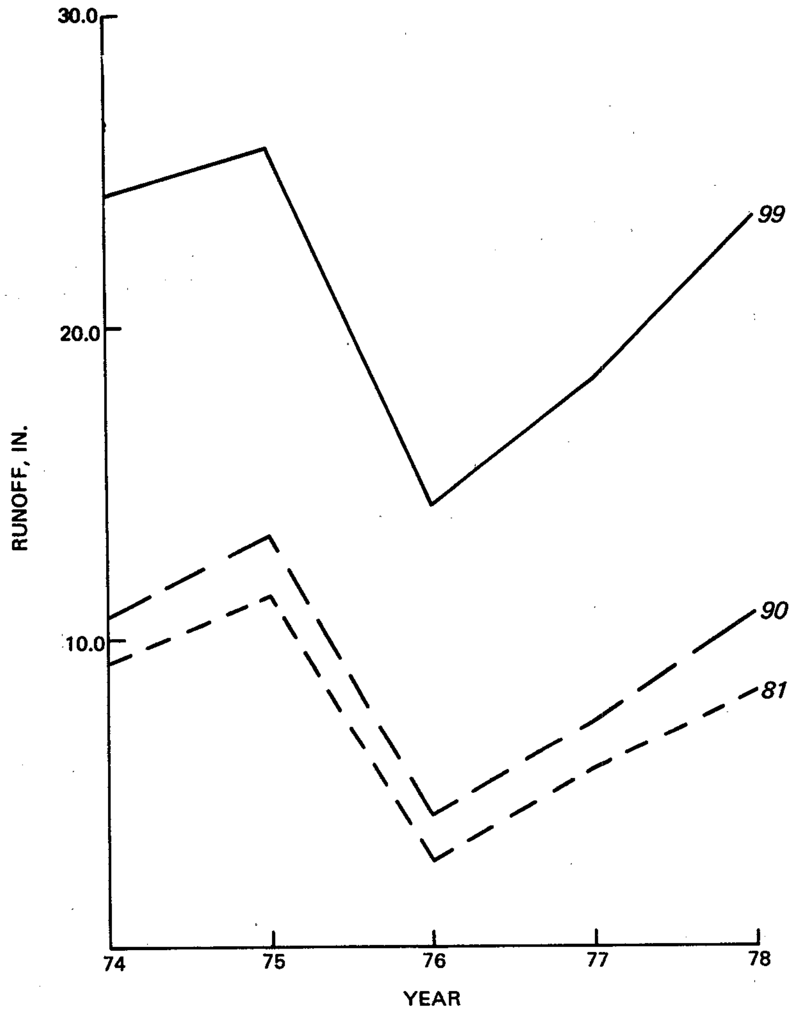

Figure D-4. Annual runoff as related to the SCS curve number.

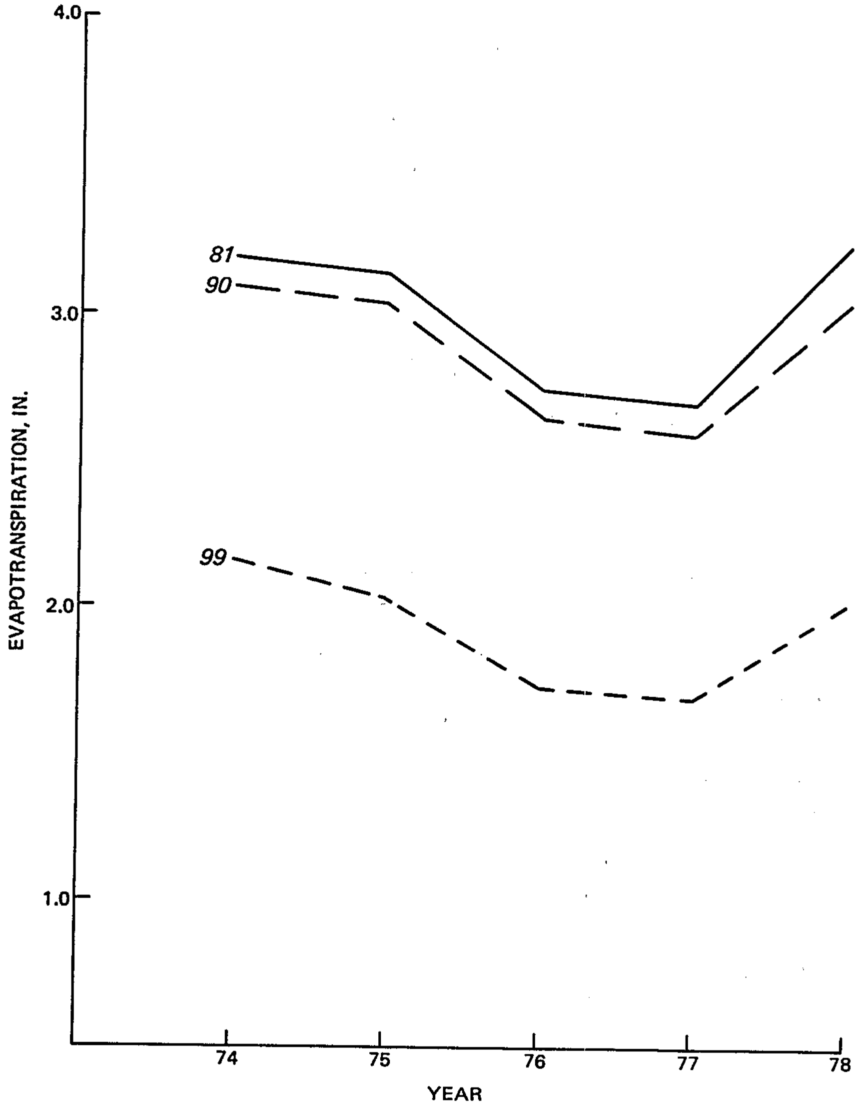

Figure D-5. Annual evapotranspiration as related to SCS curve number.

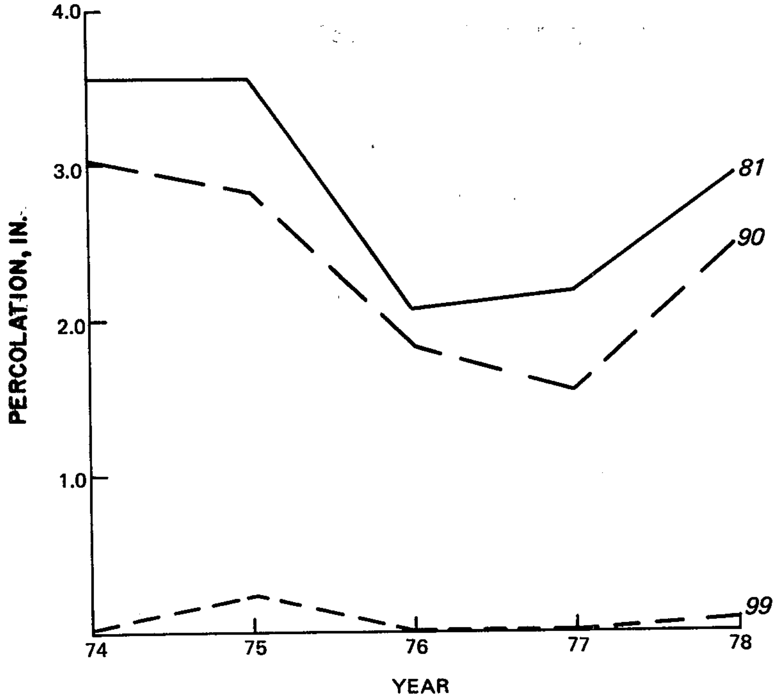

Figure D-6. Annual percolation as related to the SCS curve number.

52.2 percent, for 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 percolation and soil water.

Table D-6 shows that the percentages for the curve numbers of 81 and 90 were more comparable than the percentages for the curve number of 99.

Figure D-6 shows that percolation decreased from an average of 2.87 in./year for a curve number of 81 to nearly zero (0.0549 in./year) for a curve number of 99.

TABLE D-6. SURFACE RUNOFF, PERCOLATION, AND EVAPOTRANSPIRATION AS PERCENTAGES OF THE ANNUAL PRECIPITATION* FOR VARIOUS SCS CURVE NUMBERS

Variable	SCS curve number 81	90	99
Surface runoff	17.0	21.6	52.2
Percolation	7.1	5.6	0.1
Evapotranspiration	73.8	70.8	47.5

* Average annual precipitation = 40.6 inches.

WINTER COVER FACTOR

The winter cover factor is seasonally dependent and directly affects the process of evapotranspiration. Figures D-7 through D-9 demonstrate that the effect is greatest from September through April and declines considerably during the growing season. Since the winter cover factor is seasonably dependent, monthly evaluation is preferable.

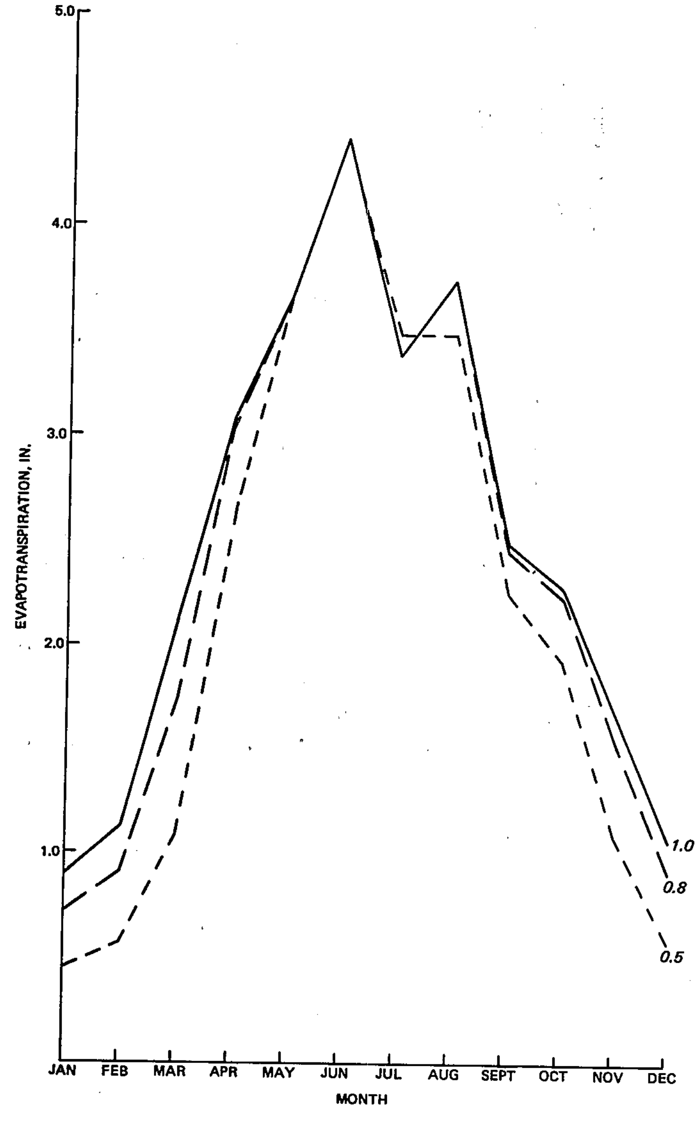

Figure D-7. Average monthly evapotranspiration as related to winter cover factor.

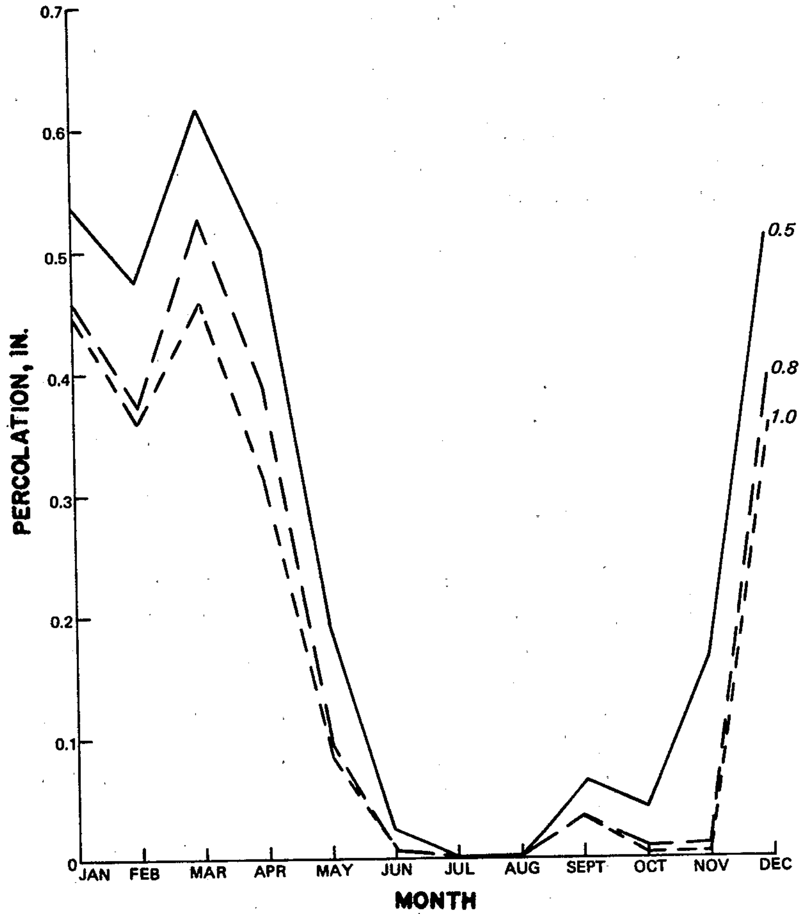

Figure D-8. Average monthly percolation as related to winter cover factor.

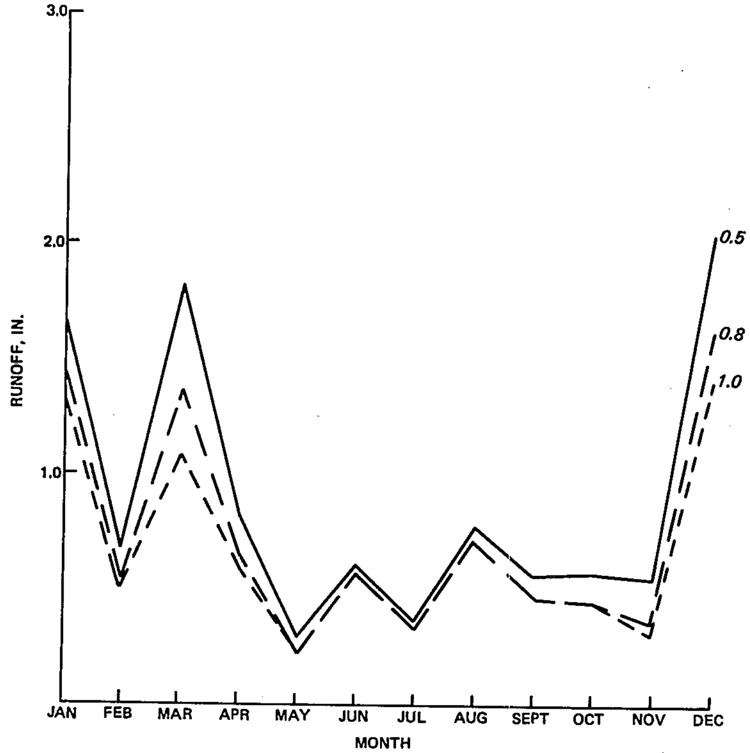

Figure D-9. Average monthly runoff as related to the winter cover factor.

When each variable was expressed 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 percolation decreased by 6.9 and 2.6 percentage points, respectively. The winter cover factor of 0.5 implies an excellent grass cover, whereas the winter cover factor of 1.0 implies the bare ground condition. In this study, however, these values were linked with the LAI for a grass in fair condition. Although this contradiction was 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.

THICKNESS OF SOIL LAYER 2

To evaluate the effect of varying the thickness of soil layer 2 the total soil thickness was set at 24 in. and soil layer 2 was assigned thicknesses of 6, 12, and 18 in. The thicknesses of vegetative soil computed by the model therefore varied accordingly. Thus, in reality, two parameters were varied simultaneously.

Figures D-10 and D-11 show the significance of soil layer 2 thicknesses

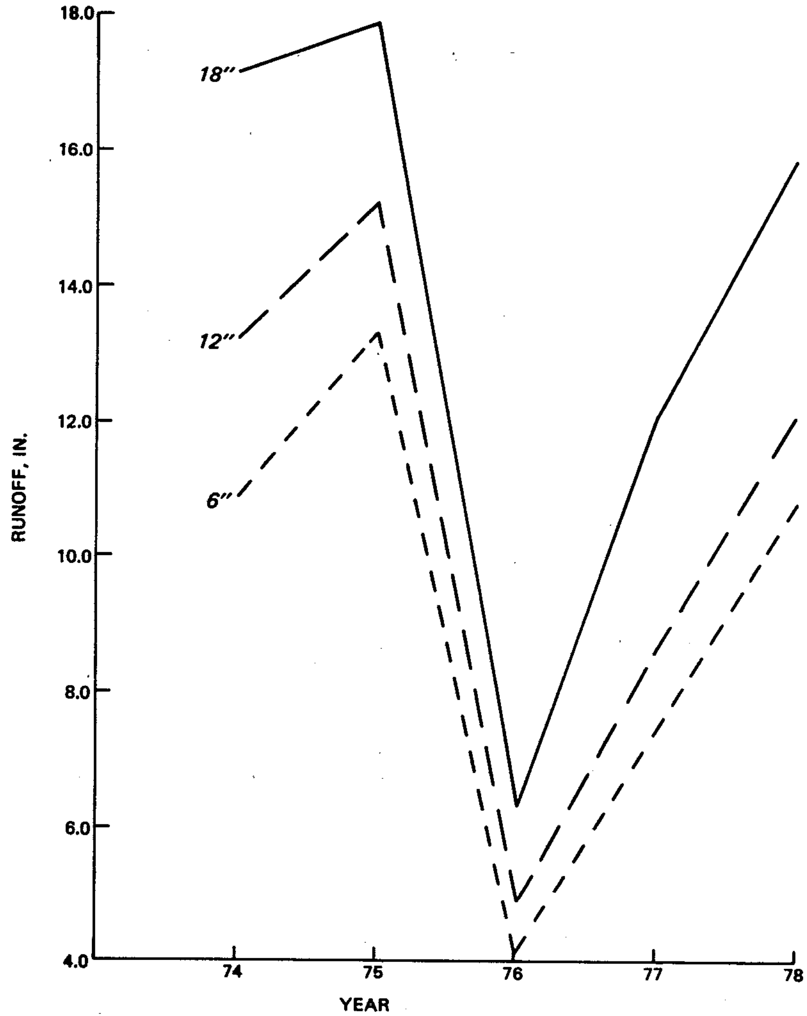

Figure D-10. Annual surface runoff as related to thickness of soil layer 2.

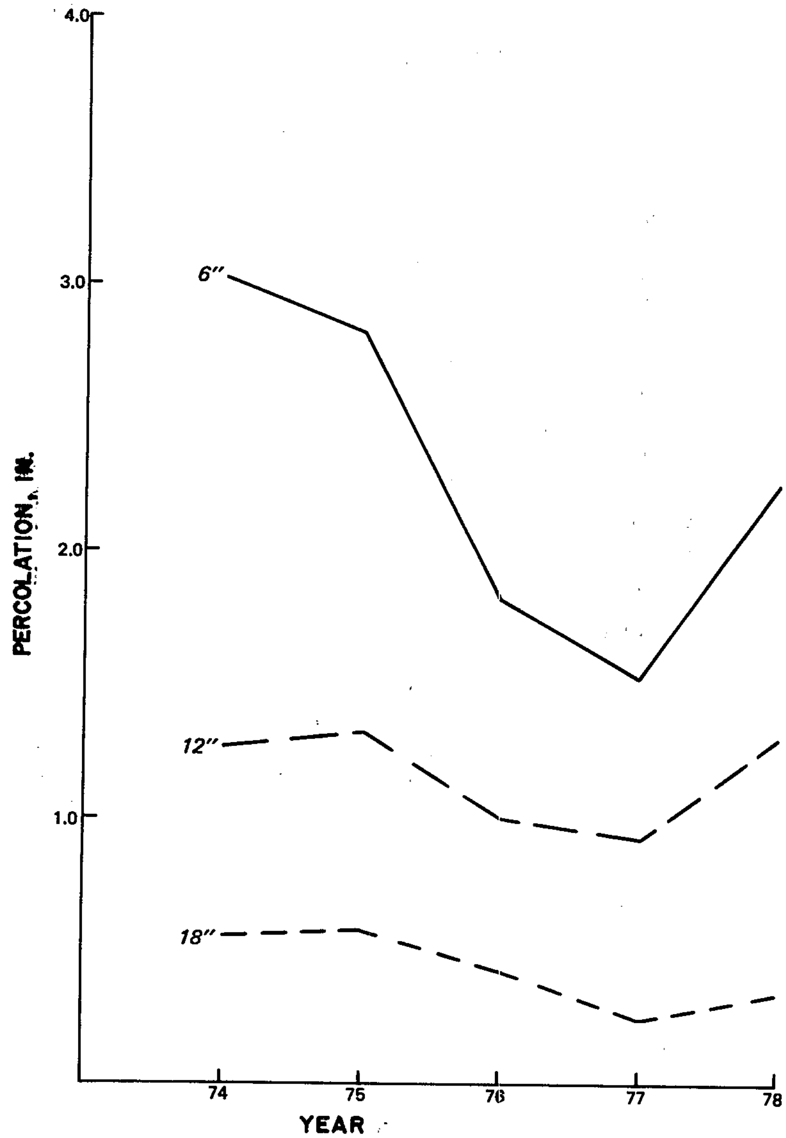

Figure D-11. Annual percolation as related to thickness of soil layer 2.

as related to annual percolation and surface runoff. As expected, runoff varied directly with the thickness of soil layer 2 while percolation varied inversely. The effect of soil layer 2 thickness on the seasonal variability of percolation and runoff is shown on Figures D-12 and D-13, respectively.

Expression of runoff, percolation, and evapotranspiration as a percentage of the average annual precipitation showed that surface runoff increased by 12.5 percentage points from the 6- to the 18-in. soil layer 2 thickness. However, percolation and evapotranspiration decreased by 4.6 and 6.7 percentage points, respectively. It should be noted that the selection of the 18-in. thickness of soil layer 2 was for test purposes only. In most instances, a

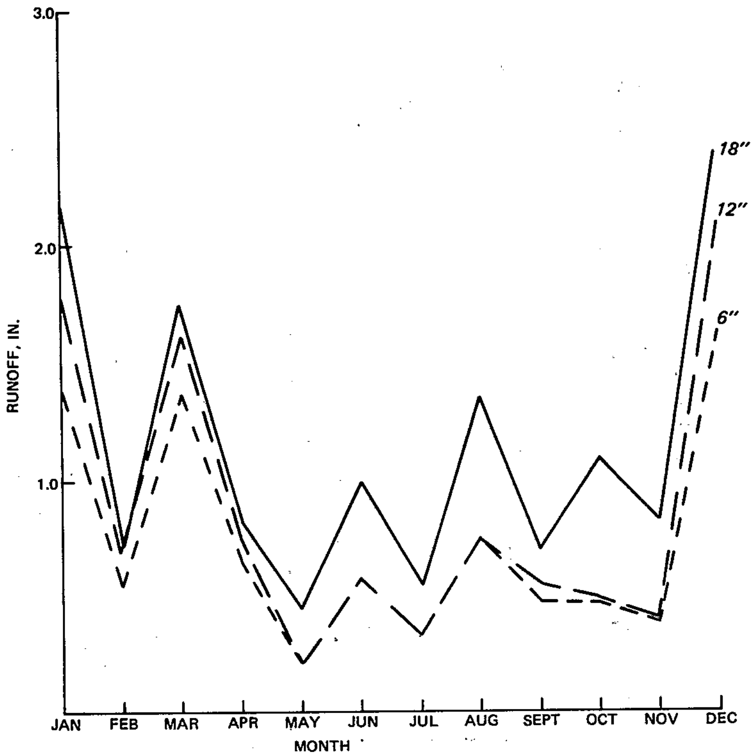

Figure D-12. Average monthly percolation as related to thickness of soil layer 2.

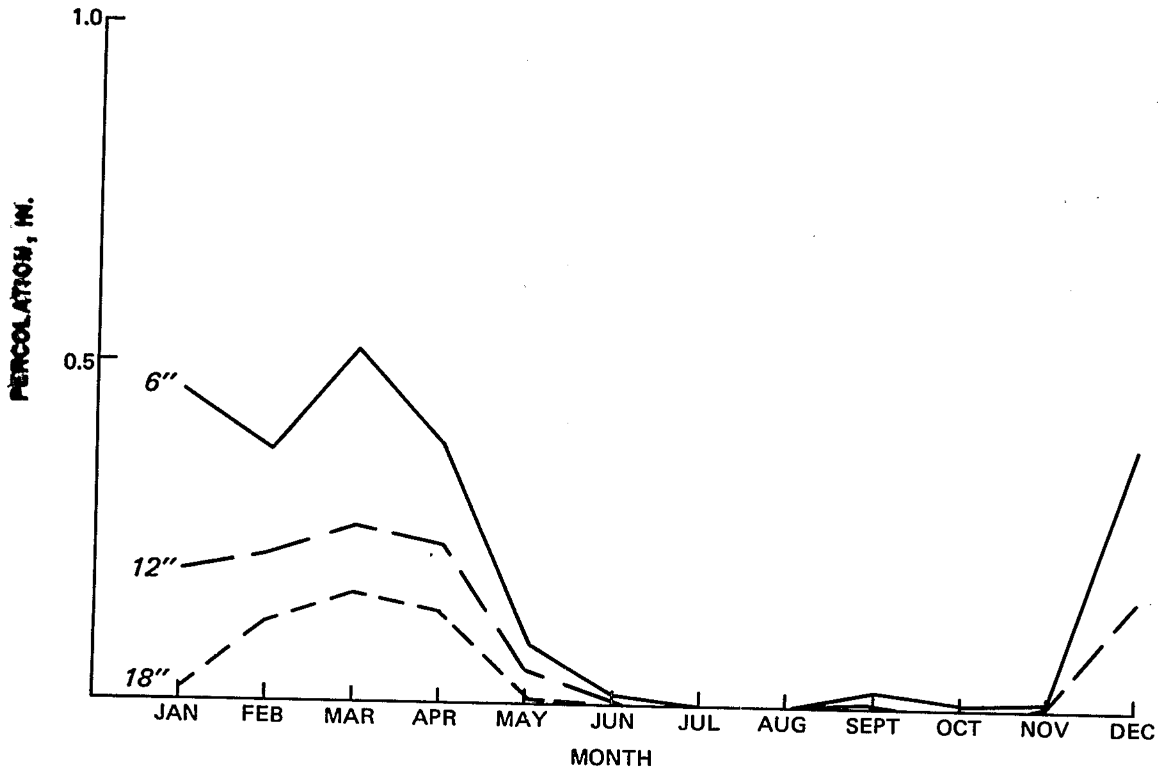

Figure D-13. Average monthly surface runoff as related to thickness of soil layer 2.

6-in. vegetative soil layer would not support an adequate plant growth, and it is not recommended for field applications.

THICKNESS OF VEGETATIVE SOIL

For this part of the study the vegetative soil layer was assigned thicknesses of the vegetative soil layer 12, 24, and 36 in. and no soil layer 2 was used. Table D-7 compares surface runoff, percolation, and evapotranspiration as percentages of the average annual precipitation for each thickness of vegetative soil. Surface runoff showed the least change as soil thickness was varied. The greatest difference was only 0.3 percentage point, and was not considered significant.

TABLE D-7. SURFACE RUNOFF, PERCOLATION, AND EVAPOTRANSPIRATION AS PERCENTAGES OF AVERAGE ANNUAL PRECIPITATION* FOR VARIOUS THICKNESSES OF VEGETATIVE SOIL

Variable	Vegetative soil thickness, in. 12	24	36
Surface runoff	15.1	15.2	14.9
Percolation	16.7	12.1	8.7
Evapotranspiration	67.9	72.2	75.7

* Average annual precipitation = 40.6 in.

The initial soil-water storage and the upper limit of the soil-water storage increased significantly with increased soil thickness. For a vegetative soil thickness of 12 in., the initial soil water was 0.936 in., and the upper storage limit was 1.87 in.; however, for the 36-in. vegetative soil thickness, the initial soil water increased to 2.81 in. and the upper limit of storage increased to 5.62 in. As the soil thickness increased, larger volumes of water were available to the plants. This, in turn, resulted in increased evapotranspiration and decreased percolation. Table D-7 shows that evapotranspiration increased by 7.8 percentage points and percolation decreased by 8.0 percentage points as the vegetative soil thickness was increased from 12 to 36 in.

Figure D-14 shows the relation of annual percolation to the year of occurrence with vegetative soil thickness as the parameter. The extreme variation in percolation for 1976-77 is caused, in part, by differences in initial soil-water storage and the upper limit thereof for the various vegetative soil thicknesses. This is not surprising since stored soil-water is subject to replenishment by precipitation and depletion by evapotranspiration and percolation.

Figure D-15 shows average monthly values for the 5-year data set. The 1976 data set is an expansion of Figure D-16 for the average annual soil water. Vegetative soil thickness is the parameter for both figures. Table D-1 shows that 1976 was the driest year in the 5-year study period, with only 30.07 in. of precipitation during the year. The lack of precipitation affected the 12-in. soil thickness percolation immediately (see the 36-in. soil thickness, where the volume of stored soil-water was greater). The effect of the lack of precipitation is dramatized since the drier months occurred in the last quarter of the calendar year, when evapotranspiration normally decreases, and thus allowed for even greater percolation than would have otherwise occurred. The situation is reversed for the first half of 1977; the seasonal precipitation required considerable time to refill the soil profile to the 36-in. depth, but percolation was possible at an earlier time for the 12-in. thickness.

LEAF AREA INDEX (LAI)

The LAI is a measurable indicator of the amount of vegetative ground

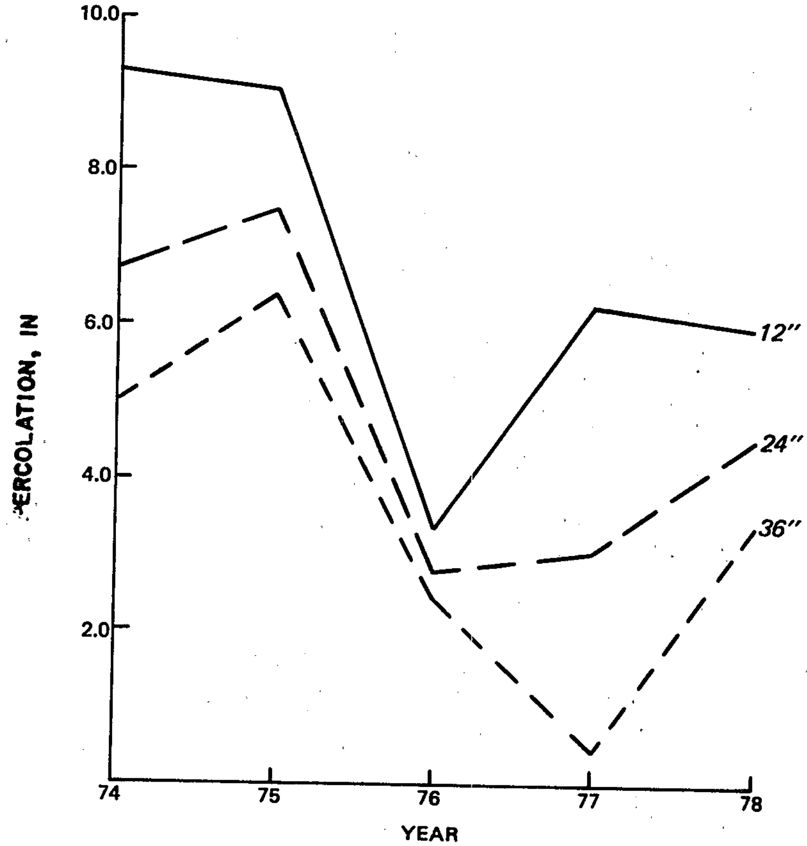

Figure D-14. Annual percolation as related to the thickness of vegetative soil.

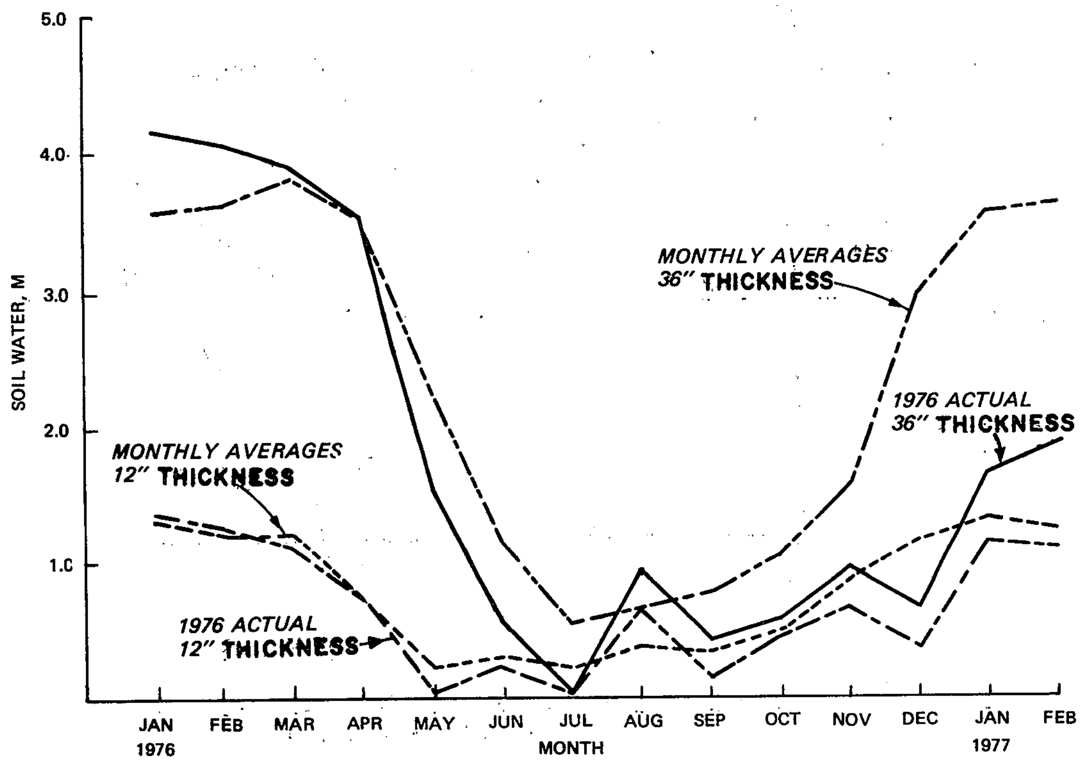

Figure D-15. Average monthly soil water for the 5-year data set and for January 1976 through February 1977 with vegetative soil thickness as the parameter.

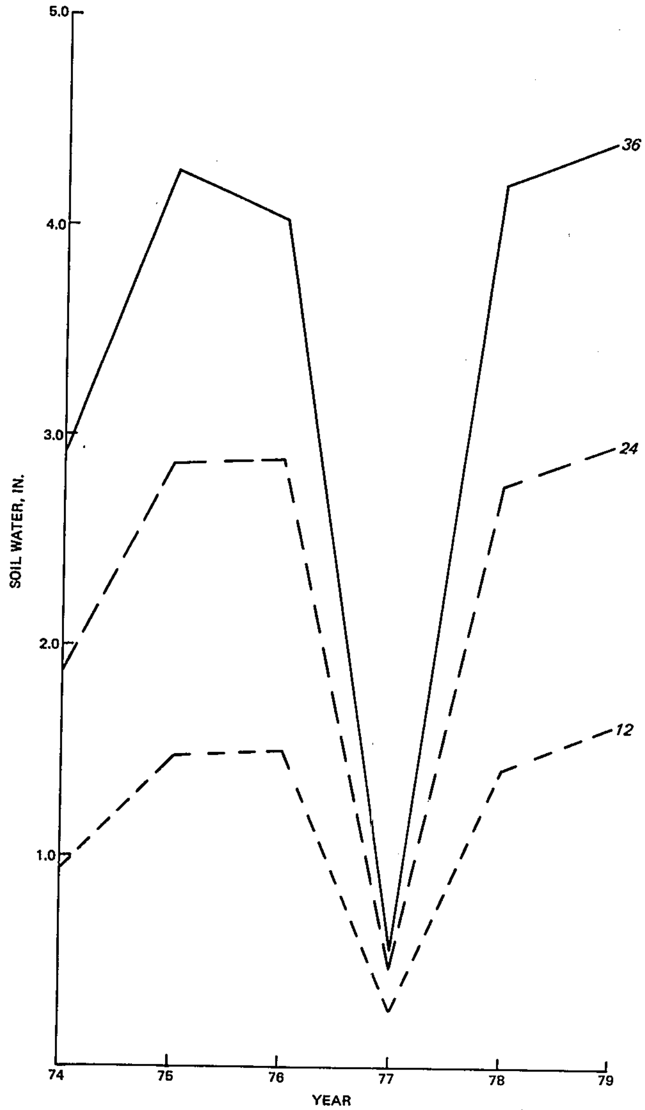

Figure D-16. Average annual soil-water as related to the vegetative soil depth.

cover that exists as a function of time, and directly affects the ratio of plant transpiration to soil evaporation. This part of the sensitivity study was designed to investigate changes resulting from the use of five different LAI distributions as inputs. Bare ground conditions, as the name indicates, have a 0.0 LAI for the entire year. An excellent crop condition is regarded 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 the 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 variable most sensitive to change in LAI was evapotranspiration. Surface runoff, percolation, and evapotranspiration are presented as percentages of average annual precipitation in Table D-8. These figures 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, and percolation increased by 6.1 percentage points. But the greater portion of the variation occurred between the values for poor crops and bare ground. From excellent to poor crop conditions, the increases for surface runoff and percolation were 3.1 and 1.2 percentage points, whereas evapotranspiration increased by 4.5 percentage points.

TABLE D-8. SURFACE RUNOFF, PERCOLATION, AND EVAPOTRANSPIRATION AS PERCENTAGES OF AVERAGE ANNUAL PRECIPITATION* FOR VARIOUS LAI

Variable	Leaf area index				
	Excellent	Good	Fair	Poor	Bare ground
Surface runoff	19.9	20.4	21.5	23.0	27.5
Percolation	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 in.

Figures D-17 through D-19 show the large variation that occurred between the values for a poor crop condition and a bare ground condition. As expected, Figures D-17 and D-19 demonstrate that the effect of LAI is seasonal and for variables such as evapotranspiration and surface runoff, LAI has little effect before the growing season begins. After the growing season starts, differences between the variables affected by the LAI increase and then subsequently decrease toward the end of the season.

Figure D-18 shows that percolation differences are evident early in the year as a result of accumulated differentials in the soil-water parameter. The effect of the soil-water condition is also shown in Figure D-19. When the various LAI options for a vegetative cover are compared with that of bare ground, the significant beneficial effect of the vegetative cover is to provide additional control of percolation. This effect is also noted in Figure D-18, which shows that even a poor crop condition decreases percolation during the growing season to nearly zero.

An unusual result is shown in Figure D-17, where 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. But for the month of May, the cropping order was changed to fair, poor, good, excellent, and bare ground. Figure D-20 explains this apparent inconsistency by displaying the average soil-water storage. 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 for the poor and fair cropping options was not large

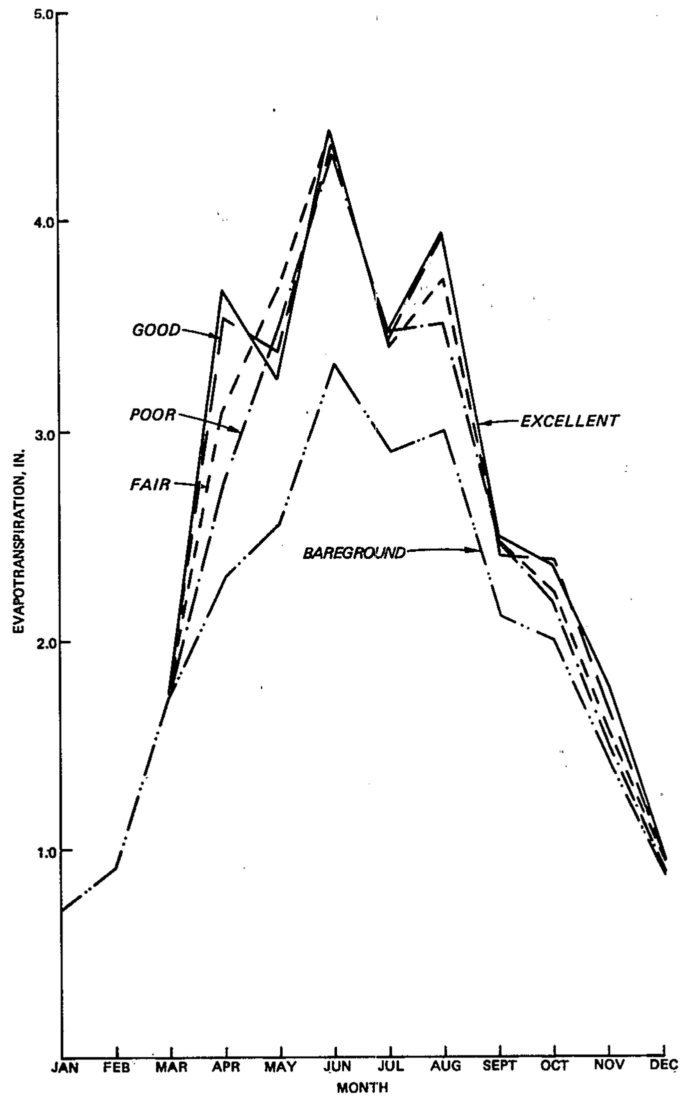

Figure D-17. Average monthly evapotranspiration as related to the LAI.

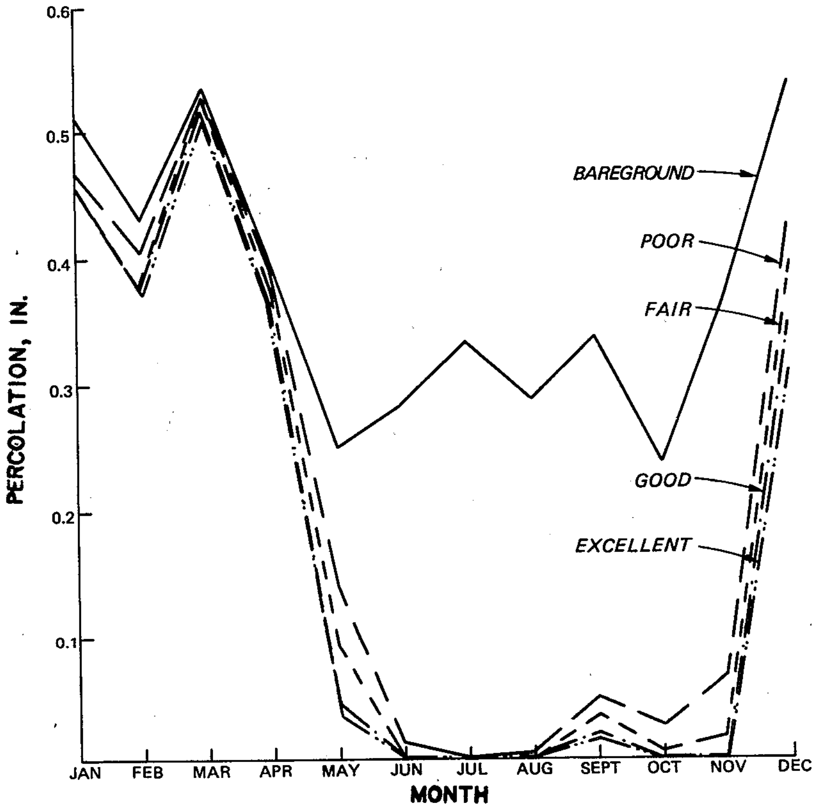

Figure D-18. Average monthly percolation as related to the LAI.

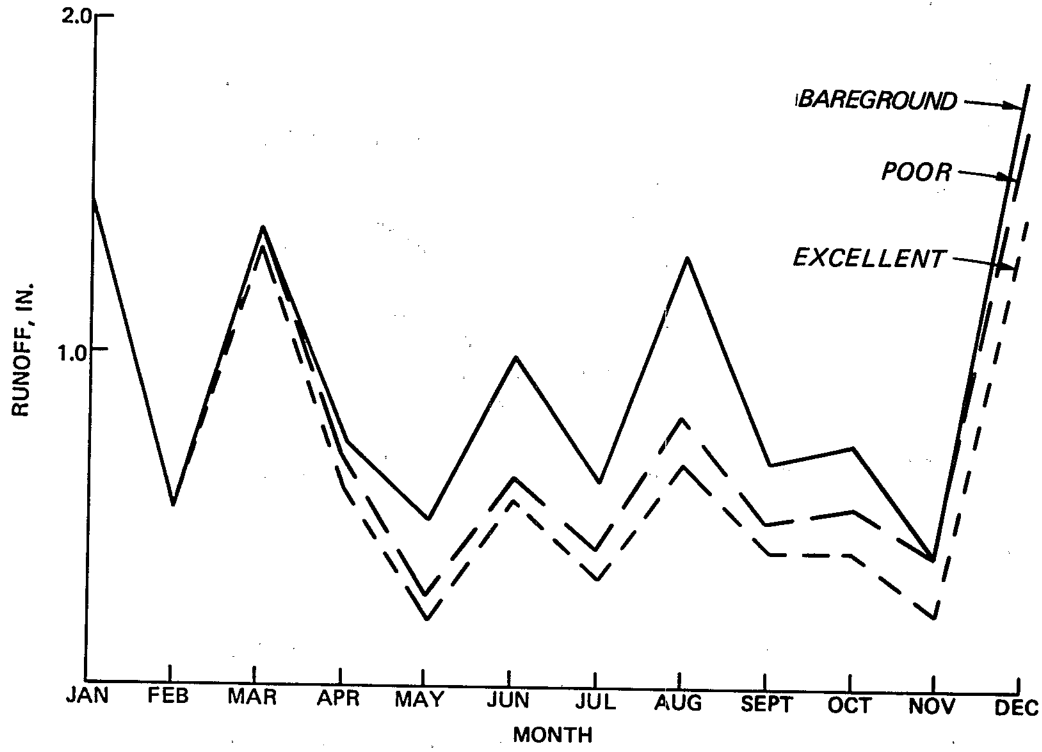

Figure D-19. Average monthly surface runoff as related to the LAI.

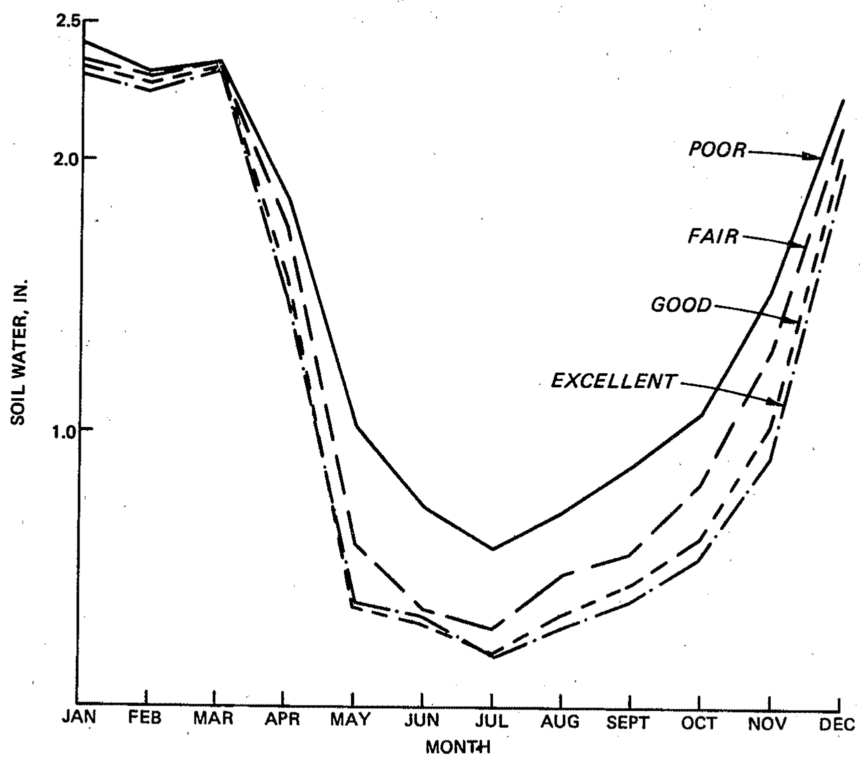

Figure D-20. Average monthly soil-water as related to the LAI.

enough to affect the soil-water. The difference between the extreme cropping options, excellent and poor, was about 0.4 in. during May.

SOIL LAYER 2 COMPACTION

For this section of the sensitivity study the concern was whether soil layer 2 was 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 available 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 D-9. These values resulted in an upper limit for soil-water storage of 2.8 in. for the compacted soil layer 2, as opposed to 3.1 in. for the noncompacted soil layer 2.

The variables most sensitive to the degree of compaction of soil layer 2 were surface runoff and percolation. Over the 5-year study period, percolation averaged 13.2 percent of precipitation for the noncompacted soil layer 2 (Table D-10), and 5.6 percent for the compacted soil layer 2--a decrease of 7.6 percentage points. The surface runoff showed a decrease of 6.6 percentage

TABLE D-9. HYDRAULIC CONDUCTIVITY, AVAILABLE WATER CONTENT, AND POROSITY VALUES USED TO EVALUATE SOIL LAYER 2 COMPACTION

Variable	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

TABLE D-10. SURFACE RUNOFF, PERCOLATION, AND EVAPOTRANSPIRATION AS PERCENTAGES OF THE AVERAGE ANNUAL PRECIPITATION* FOR SOIL LAYER 2 COMPACTION

Variable	Compacted	Noncompacted
Surface runoff	21.5	15.0
Percolation	5.6	13.2
Evapotranspiration	70.8	71.0

* Average annual precipitation = 40.6 in.

points between the compacted and noncompacted soil. The effect of soil layer 2 compaction on evapotranspiration was negligible.

The relationship of soil layer 2 compaction to surface runoff and percolation need not be limited to analysis on a yearly basis, but it can affect the parameters monthly and seasonally. Figures D-21 and D-22 show that surface runoff is not as sensitive to compaction as is percolation. Figure D-22 shows that percolation during 1976 and 1977 was affected by a delay or time lag associated with the lower hydraulic conductivity of the compacted soil layer 2. Also, it is evident that percolation is sensitive to the delay in the downward water movement process.

As noted earlier, the Cincinnati, Ohio, growing season runs from April 1st to July 31st. For most of this season, the increased evapotranspiration resulting from increased LAI decreased the soil-water to a level where percolation was zero. Later in the season, the precipitation restored the soil-water, and the percolation 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.

In Figure D-22, for instance, the 1976 percolation for the noncompacted soil decreased much more rapidly than that for the compacted soil layer 2. But in 1977, percolation from the noncompacted soil increased and the percolation from the compacted soils continued to decrease. This apparent

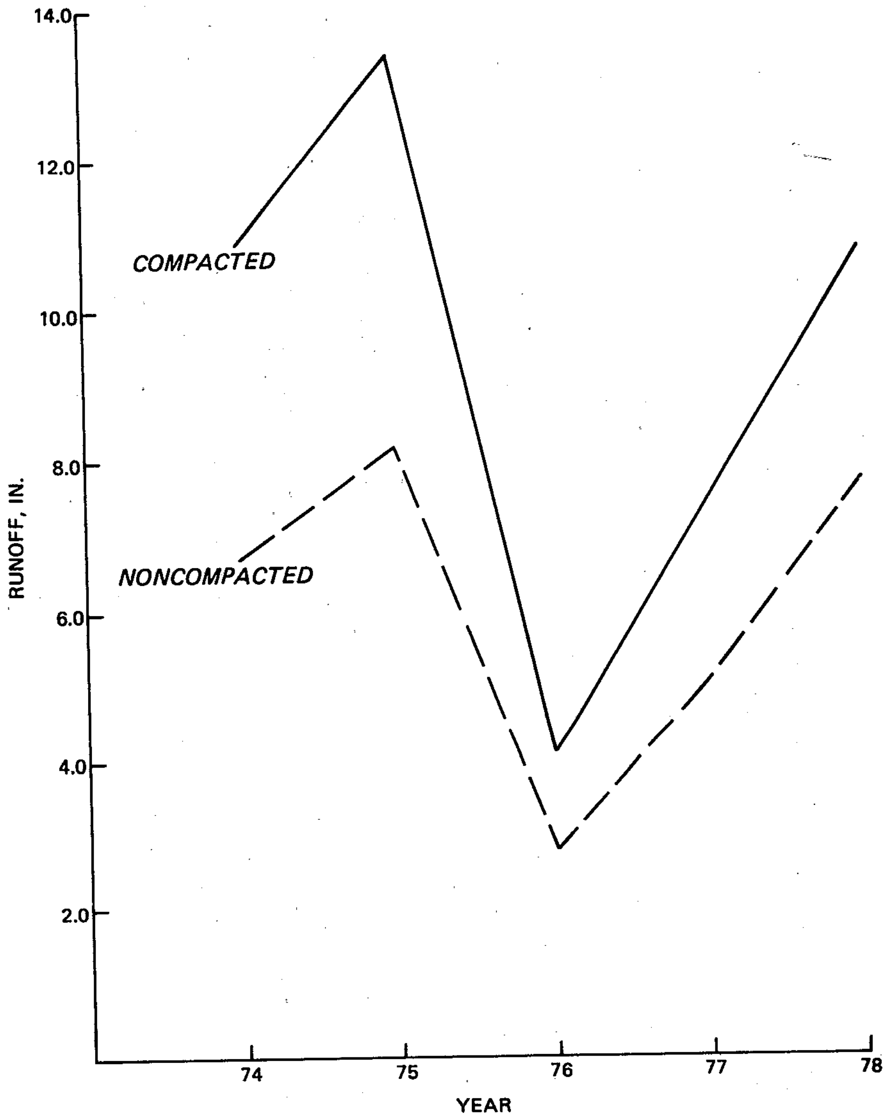

Figure D-21. Annual surface runoff as related to soil layer 2 compaction.

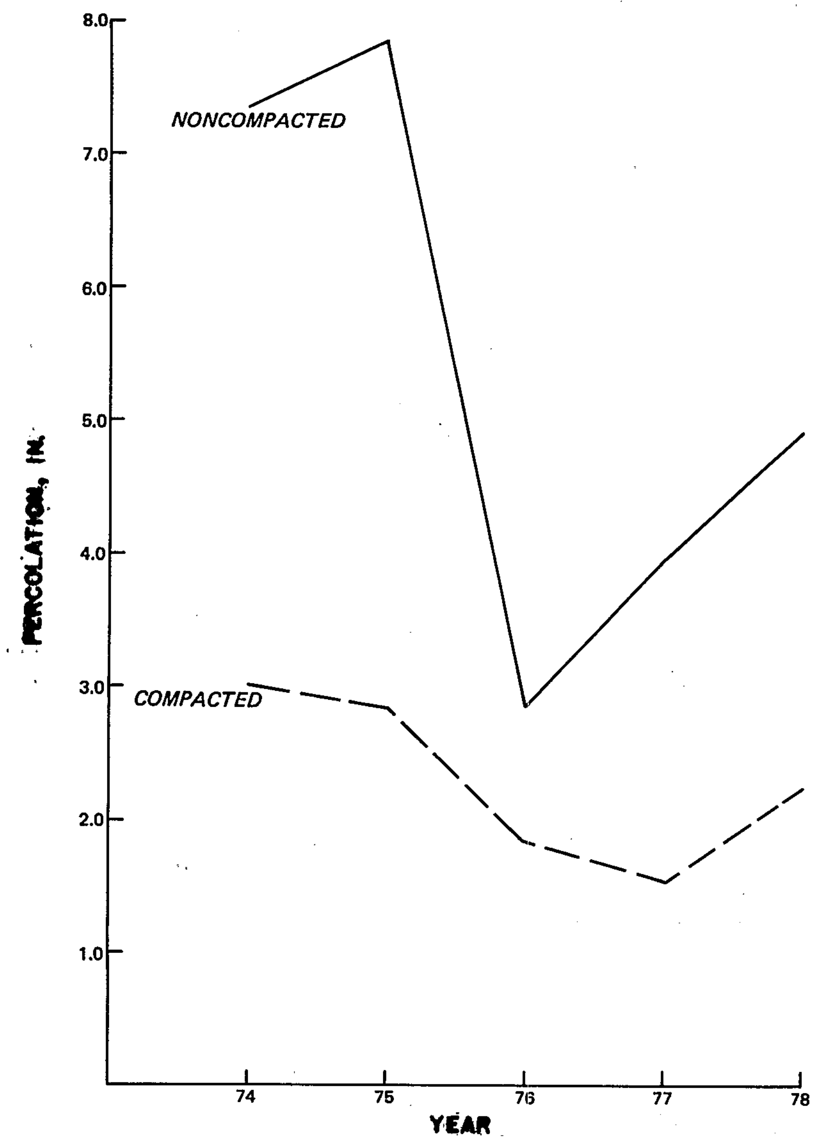

Figure D-22. Annual percolation as related to soil layer 2 compaction.

inconsistency is explained by the increased time lag associated with the compacted soil layer 2.

Figure D-23 shows that the total precipitation for 1976 is significantly less than the average (30.37 in. compared with 40.64 in.), with 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

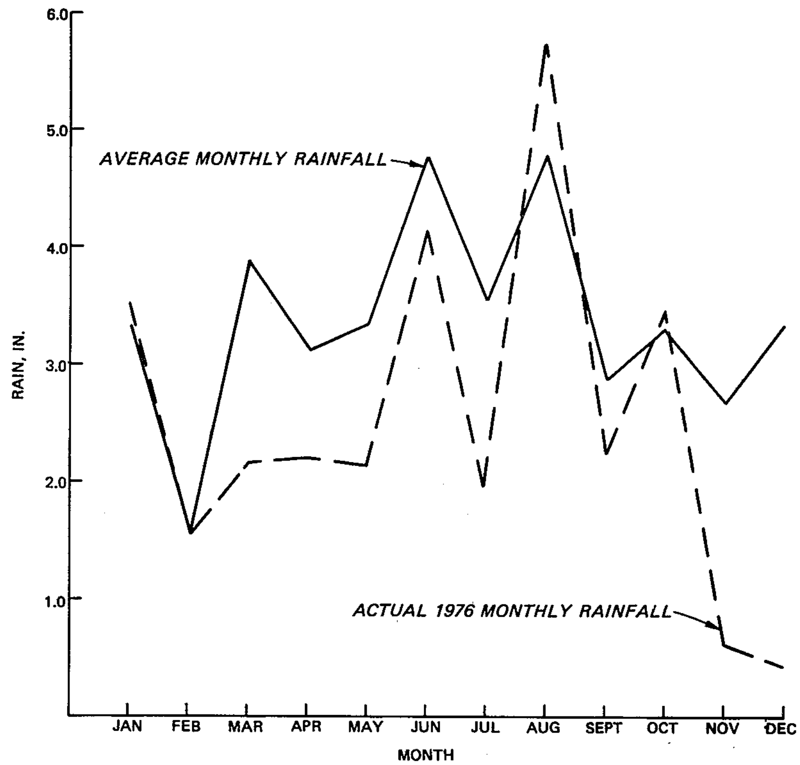

Figure D-23. Comparison of average monthly precipitation to 1976 precipitation.

Table D-5) was not much below average, but since it occurred during the time of year when evapotranspiration was at a peak, percolation was negligible. Later in 1976, when precipitation could have had a more direct effect on percolation, the lack of rainfall meant that soil-water remained depleted and percolation was lowered. Had the precipitation reached normal levels during this time period, the soil-water would have been replenished and some percolation would have occurred. When soil layer 2 is not compacted, normal precipitation increases percolation during November and December. But the compacted soil layer 2 permits less water to percolate and therefore some percolation occurs in December, January, and February of 1977. With normal late-year precipitation, the percolation from uncompacted soil occurs soon after the rainfall. But for compacted soil layer 2, some of the percolation occurs during the next year.

Figure D-24 compares the monthly percolation to the corresponding precipitation for 1978. Once again, the effect of the time lag is shown as the result of extremely low precipitation during February. The immediate effect was to reduce percolation for the uncompacted soil. The compacted soil layer 2 shows the time lag of the percolation for December 1977 and January 1978. Also, the percolation decreases to zero from May through September as precipitation increases (the effect of increased evapotranspiration). Not until later in the year, when soil-water increases and evapotranspiration decreases, does percolation occur again.

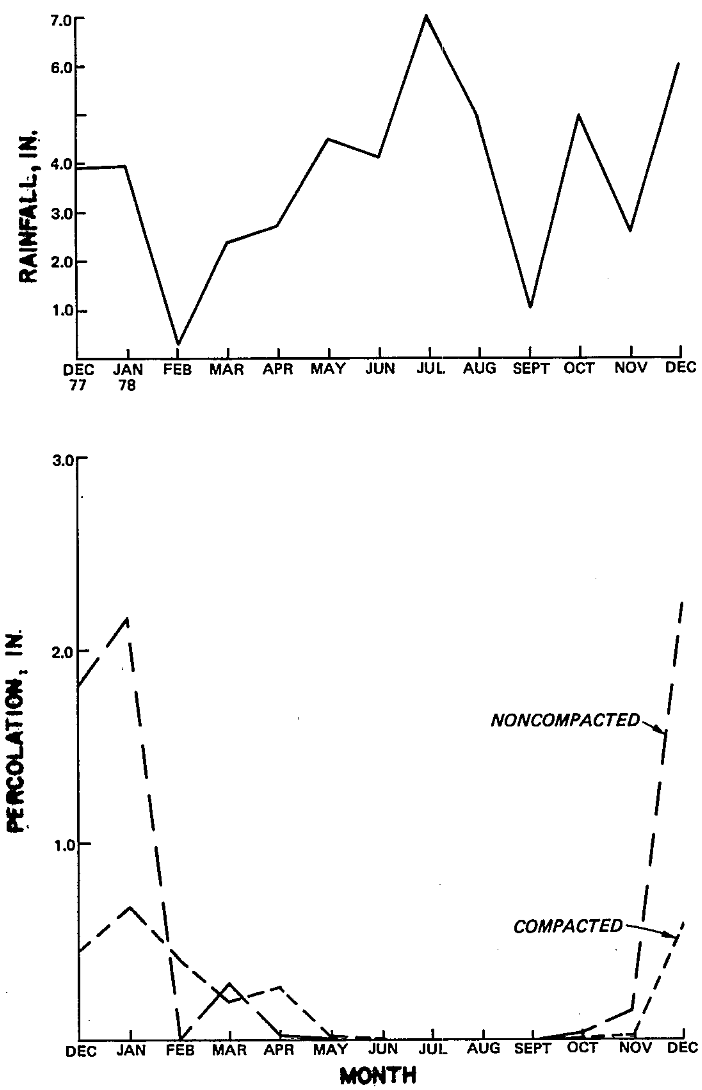

Figure D-24. Percolation and precipitation during the month of occurrence for 1978.

SOIL TEXTURE

The purpose of this section is to evaluate the sensitivity of the hydrologic modeling processes to changes in the soil texture of the two soil layers. Varying the soil texture changes many of the other input data such as hydraulic conductivity, soil porosity, evaporation coefficient, and available water capacity. Data that were used with the various soil textures are presented in Table D-11, and combinations of vegetative soil layer and soil layer 2 are shown in Table D-12.

Changing the hydraulic conductivity, soil porosity, evaporation coefficient, and available water capacity for the vegetative soil and soil layer 2 resulted in small changes in upper storage limit and initial water storage. Since these variables are used in computations of surface runoff, evapotranspiration, and percolation, these processes would be expected to reflect these changes. They do not, however, show a uniform change with respect to a single variable when evaluated on a yearly basis. Table D-13 presents each variable for each parameter computed as a percentage of the average annual precipitation. Percolation changed by 9.8 percentage points from one soil texture extreme to the other, and evapotranspiration and surface runoff changed by 3.5 and 8.5 percentage points, respectively. Most of the variation is attributable to case No. 12 (sandy clay loam/clay, compacted). If the results of this soil texture are disregarded, percolation changes by only 2.3 percentage points, evapotranspiration by 3.5 percentage points, and surface runoff by 2.1 percentage points. The variations resulting from changing the soil texture are small compared with 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 soil-water to levels approaching the storage limit by the precipitation later in the year. Percolation, which depends on the level of soil-water, is sensitive to the precipitation rate as well as the effect of soil texture on percolation.

TABLE D-11. SOIL HYDROLOGICAL DATA 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

TABLE D-12. COMBINATIONS OF VEGETATIVE AND SOIL LAYER 2 SOIL TEXTURES FOR THE SENSITIVITY STUDY

No.	Vegetative soil	Soil layer 2
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 D-13. SURFACE RUNOFF, PERCOLATION, AND EVAPOTRANSPIRATION AS PERCENTAGES OF AVERAGE ANNUAL PRECIPITATION FOR VARIOUS SOIL TEXTURES

No.	Vegetative/Soil layer 2	Surface runoff	Percolation	Evapotranspiration
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

To illustrate relationships on a daily basis as well as to evaluate the time lag of percolation for the different soil textures, the first 4 months of 1978 were selected for detailed analysis. Table D-14 shows percolation as a function of time and displays precipitation data for the first 114 days of 1978. Percolation was zero after 114 days (continuing through summer and early fall) for all cases except the sandy clay loam vegetative soil and the compacted clay soil layer 2 combination. This occurred because of increased evapotranspiration following the start of the growing season on day 92.

The percolation output will be evaluated--first, for those conditions without a soil layer 2 of clay, and second, for those conditions with a soil layer 2 of clay. The percolation characteristics of soil layer 2 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-hr period and rapidly appears as percolation. 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 percolation is completed within the 24-hr time interval. During the early part of the season, percolation is essentially the same for cases without a clay soil layer 2. Some differences begin to show after the 72nd day as a result of increased evapotranspiration as solar radiation and temperature increase. After the growing season starts on the 92nd day, increased evapotranspiration causes the percolation to go to zero, except for the sandy vegetative soil layers, where the available water capacity has been reduced to a level unavailable to plants.

Second to be considered is the output from those cases with a soil layer 2 of clay. The low hydraulic conductivity (0.022 in./hr) results in percolation that exceeds the 24 hr model time period. From days 5 through 36, percolation occurred continually for all clay soil layer 2 cases. In comparison, nonclay soils experienced five events during the 31-day time period when no percolation occurred. Also, the peak values of percolation for clay soil layer 2 were not as high as for nonclay soil layer 2.

The percolation is virtually identical for all cases involving a clay soil layer 2 (this was also true of the cases involving a nonclay soil layer 2). When the clay soil layer 2 was compacted and the hydraulic conductivity was lowered to 0.0011 in./hr, percolation continued through the first 125 days although at a greatly reduced rate and magnitude (1.2452 in. of percolation in 117 days for the compacted clay soil layer 2, and 2.5909 in. in 117 days for the noncompacted clay soil layer 2). The time lag on percolation was great enough to carry through the dry period--from day 36 through 72.

Figure D-25 shows the time lag for the three extreme soil texture combinations. Although some correlation of peak percolation is indicated, the reduced magnitude and time lag effect is readily apparent.

SUMMARY OF SENSITIVITY STUDY

A summary of the sensitivity study is shown in Table D-15, which demonstrates the relative effect of changes in the selected parameters on the more salient features of the simulation. However, it should be noted that the

TABLE D-14. AMOUNT OF PERCOLATION AND PRECIPITATION AS A FUNCTION OF TIME AND SOIL TEXTURE

VS = vegetative soil, BS = soil layer 2, 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-SCL 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)

TABLE D-14. (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

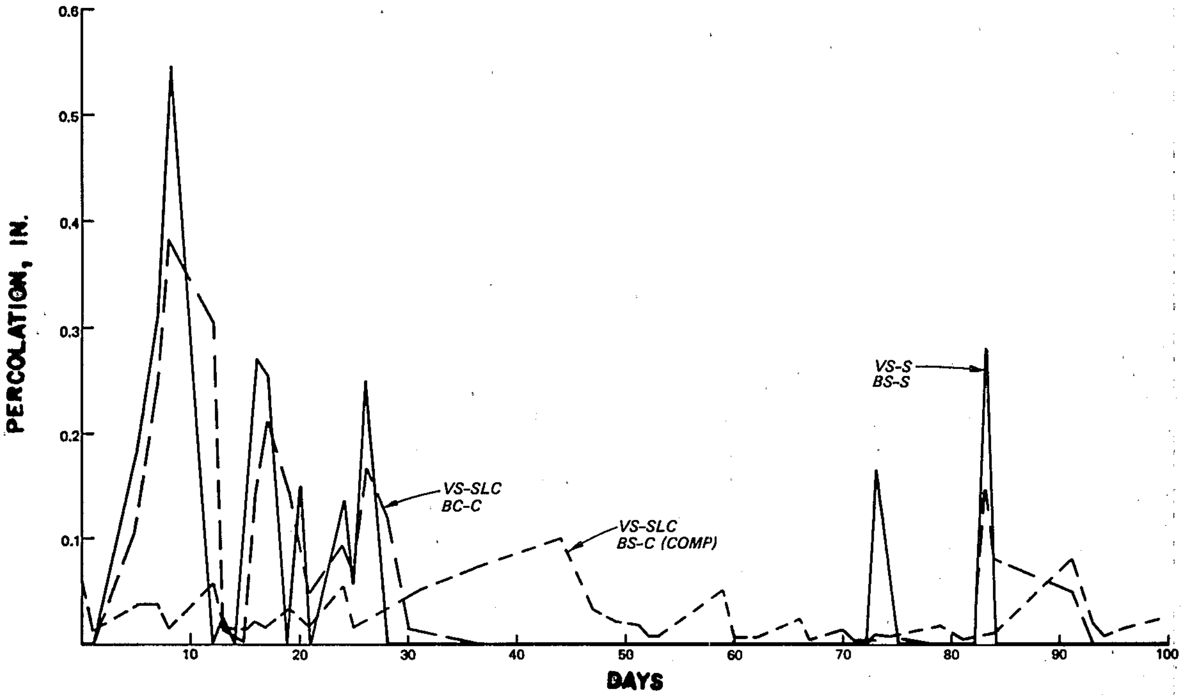

Figure D-25. Percolation as related to time in days for various soil textures (V = vegetative soil, BS = soil layer 2, COMP = compacted).

TABLE D-15. SUMMARY OF SENSITIVITY STUDY RESULTS

Parameter	Change		Surface runoff			Evapotranspiration			Percolation			Cover 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
Thickness of soil layer 2	6 in.	18 in.	‡‡	↑	1	‡	↓	2	†	↓	3	NA	NA	NA	Constant
Thickness 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
Soil layer 2 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	SCL	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 = least change).

** NA - Not affected, and V - Variable (arrow indicates general tendancy).

† Slightly.

†† Extremely.

‡ Moderately.

‡‡ Highly.

§ Significantly.

study was for a particular area in or near Cincinnati, Ohio. Therefore, responses shown may change somewhat for hazardous and solid waste sites with radically different climatological and hydrological data sets.

Conclusions drawn from the sensitivity study are as follows:

a) Percolation and evapotranspiration are significantly affected by changes in soil-water storage and available water capacity.

b) The effect of the winter cover factor is seasonal and the variable most affected is evaporation.

c) The SCS curve number primarily affects surface runoff and secondarily affects both evapotranspiration and percolation.

d) The impermeable liner only affects water that has percolated past the point at which it is controlled by evapotranspiration and surface runoff.

e) Surface runoff was the variable most affected by the thickness of soil layer 2.

f) The effects of the LAI are seasonally dependent and the variables most sensitive to changes in LAI are evapotranspiration and percolation.

g) The variables most affected by soil layer 2 compaction are percolation and surface runoff.

h) Changes in soil texture result in highly time-dependent changes in runoff and percolation and produced conditions under which other variables become more sensitive.

*U.S. GOVERNMENT PRINTING OFFICE: 1982-0-361-082/319