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SPUR
Simulation of Production and Utilization of Rangelands

Documentation and User Guide

ABSTRACT

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The SPUR model is a comprehensive rangeland simulation model developed to provide information for research and management. It is composed of five basic components: (1) climate; (2) hydrology; (3) plant; (4) animal; and (5) economic. The model is driven by daily maximum and minimum air temperatures, precipitation, solar radiation, and wind run. SPUR simulates the daily growth of individual plant species or functional species groups and uses preference vectors based on forage palatability, location, and abundance to control plant utilization. Animal growth is simulated on a steer-equivalent basis, and net gain is used to calculate economic benefits. The hydrology component calculates upland surface runoff volumes, peak flow, snowmelt, streamflow, and upland and channel sediment yields. This publication contains the model documentation and a user guide with complete instructions for model operation, resource materials for determining the values of input variables and parameters, and examples of model inputs and outputs.

KEYWORDS: rangeland model, rangeland hydrology, plant model, livestock model, climate model, range management, range research, range economics

As the chapters were prepared by different individuals, there is some variation in style and units of measurement. These variations should not detract the attention of the reader. Any questions should be referred to the authors of the specific chapters.

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6. HYDROLOGY-COMPONENT PARAMETER ESTIMATION

E.P. Springer, L.J. Lane

INTRODUCTION

The hydrology submodel of SPUR is divided into three basic components: the upland, snow accumulation and melt, and channel components. Parameter estimation will be described for each of these components. The user is referred to table 3.3 in chapter 3, for the appropriate record numbers, variables, name and variable descriptions for these components.

THE UPLAND COMPONENT

The upland hydrology routines are basically the option-1 water balance routines from the CREAMS model (Knisel 1980). The condition-I curve number (CN_I), variable S1 on record 10, can be obtained from tables 6.1 and 6.2 which are curve numbers for rangeland watersheds and range sites from Hanson et al. (1980). If the SCS Hydrology Handbook is used, a condition-II CN is obtained. This can be converted to CN_I by the equation presented by Smith and Williams (1980).

The return-flow time (T_r), variable S2 on record 10, is the time required for subsurface flow from the centroid of the basin to reach the outlet. This parameter is important in snow-dominated regions where sustained baseflow occurs. Springer et al. (1984) calibrated this parameter on three experimental watersheds within the Reynolds Creek Experimental Watershed and found values that ranged from 5 to 40 days. The values vary because of the different hydrologic and geologic factors governing watershed response. Currently, we suggest that values for this parameter be determined by a hydrologist experienced with the flow characteristics of the region or through model calibration if data are available.

Four other parameters on record 10 are the Universal Soil Loss Equation (USLE) factors for the MUSLE calculations. These factors are defined and tables are given in Wischmeier and Smith (1978).

The USLE K factor (FLDK) is determined by using the nomograph in figure 6.1. Texture values required to enter the nomograph can be found in soil survey manuals or through the SCS Soils-5 database. The Soils-5 database is described in more detail below.

The USLE C factor (FLDC) can be estimated from table 6.3 (table 10, Wischmeier and Smith 1978). The USLE P factor (FLDP) is set to 1.0 for current simulations. The USLE slope-length factor (FLDLS) is critical for sediment yield calculations (Renard et al. 1983). The Grid-Contour method (Williams and Berndt 1976) is recommended for determining the slope. Average slope is calculated using a contour map and the following equations:

$$S_d = N_d \frac{H}{D_d} \tag{1}$$

$$S = \left[S_l^2 + S_w^2\right]^{\frac{1}{2}} \tag{2}$$

where:

- S_d = slope in the d grid direction,
- S = average land slope,
- N_d = total number of contour crossings from all grid lines in direction d,
- H = contour interval,
- D_d = total length of all grid lines within the field in direction d,
- S_l = slope in the length grid direction from equation 1, and
- S_w = slope in the width direction from equation 1.

The average slope length is found by the Contour-Extreme Point Method (Williams and Berndt 1976) using:

$$L = \frac{LC}{2EP} \tag{3}$$

where:

- EP = number of extreme points (channel crossings) on the contours of a topographic map,
- LC = total length of all contours within the area, and
- L = average slope length.

The variable FLDLS is computed by:

$$FLDLS = \left[\frac{L}{72.6}\right]^m [65.41 \sin^2(S) + 4.56 \sin(S) + 0.065] \tag{4}$$

where:

- S = slope of the site,
- L = slope length of the site, and
- m = an exponent proportional to slope steepness.

The exponent m varies with slope and is determined by:

$$m = 0.6\,(1 - e^{-35.835\,S}) \tag{5}$$

where S = slope.

The rooting depth, RD on record 11, is the effective depth over which plants can extract water by transpiration. Any value for RD must be less than the depth to the top of the last soil layer. Values for RD can be obtained from SCS soil surveys.

The soil evaporation parameter, CONA on record 11, has the following values suggested by Ritchie (1972): for a loam soil, 4.5, clay soil, 3.5, and 3.3 for sands (all values are in mm/day$^{1/2}$).

Table 6.1
Runoff curve numbers derived from range sites and conditions of cover for antecedent moisture condition I

Range site	Range condition		
	Poor	Fair	Good
Wetland	95	95	95
Very shallow	95	90	85
Saline subirrigated	90	90	85
Subirrigated	90	90	85
Shale	90	85	80
Dense clay	90	85	80
Alakali clay	90	85	80
Saline upland	90	85	80
Igneous	90	80	75
Shallow clayey	85	80	75
Shallow sandy	80	75	70
Shallow loamy	80	75	70
Shallow igneous	80	75	70
Steep clayey	80	75	70
Clayey	80	75	65
Gravelly loamy	80	75	65
Steep loamy	80	75	65
Overflow	80	70	60
Loamy overflow	80	70	60
Clayey overflow	80	70	60
Coarse upland	80	70	60
Limy upland	80	70	60
Shallow breaks	80	70	60
Stony	80	70	60
Steep stony	80	70	60
Lowland	80	70	60
Saline lowland	80	70	60
Loamy lowland	80	65	55
Loamy	80	65	55
Sandy lowland	75	60	50
Sandy	75	60	50
Gravelly	70	55	45
Sands	70	55	40
Choppy sands	70	55	40

Note.--As site conditions are general, the curve number should be adjusted (interpolated) for each site based upon a field investigation.

Table 6.4 was taken from Lane and Stone (1983) and provides values for CONA by soil-texture class.

Crack flow is used to simulate water movement for unsaturated soil conditions. The crack-flow factor, CF on record 12, is a decimal ranging from 0.0 to 1.0. There is little if any experience with this parameter in rangeland situations. If CF is set to 0.0, the only water movement will be by percolation when the water content of a soil layer is greater than field capacity. For most situations, this will be adequate. If there is substantial water movement by cracks or under unsaturated conditions, CF will need to be calibrated.

Records 13 to 17 are data for each soil layer. These data are essential for the primary producer (plant) routines. On rangelands, these data are often lacking so an estimation procedure is required. The advent of the SCS Soils-5 database has given users an opportunity to obtain representative values for these parameters. For access to Soils-5 data, the user should contact the local SCS office. In addition to providing soils information required on records 13 through 17, Soils-5 can be used to help estimate the USLE factors previously discussed.

Much of the following discussion uses table 6.5 which was taken from Brakensiek et al. (1984) and Rawls and Brakensiek (1985). The boldface letters over each column identify a property to be used in the following calculations.

From column A the total number of soil layers, NMSL on record 10, and the depth of each soil layer, SLDTH on record 17, can be found. The maximum number of soil layers allowed is eight. A requirement for the plant production routines is the soil-water potential at 15.0 cm (6.0 in) in the soil profile. It was discovered that by

Table 6.2
Soil Conservation Service curve numbers from selected USDA-ARS watersheds in the northern Great Plains

Watershed location	Watershed number	Area (acres)	Range type	Range condition	Hydrologic group	SCS curve No. Low	SCS curve No. Av.	SCS curve No. High
Hastings, NE	1H	3.62	Native meadow	Fair	B	40	50	88
Hastings, NE	2H	3.40	Native meadow	Fair	B	41	61	87
Hastings, NE	18H	3.74	Native pasture (heavy grazing).	Fair	B	63	80	96
Ekalaka, MT	1	2.00	Saline-upland range site.	Poor	D	86	93	99
Ekalaka, MT	2	2.00	Panspots	Poor	D	82	87	98
Ekalaka, MT	3	2.00	Panspots	Poor	D	80	89	97
Cottonwood, SD	4H	8.57	Pierre shale (heavy grazing).	Fair	D	55	71	95
Cottonwood, SD	5M	8.57	Pierre shale (medium grazing).	Fair	D	57	70	94
Cottonwood, SD	6L	8.99	Pierre shale (light grazing).	Good	D	53	67	94
Newell, SD	2	115.00	Medium-textured soils (mixed range sites).	Poor	B	52	70	89
Newell, SD	55	41.40	Medium-textured soils (mixed range sites).	Fair	B	50	61	94
Newell, SD	7	160.00	Medium-textured soils (mixed range sites).	Poor	B	55	63	93
Newell, SD	12	90.00	Fine-textured soils (mixed range sites).	Poor	D	71	89	98
Newell, SD	13	60.00	Fine-textured soils (mixed range sites).	Poor	D	57	81	96
Newell, SD	14	35.00	Fine-textured soils (mixed range sites).	Poor	D	66	77	94
Newell, SD	15	115.00	Fine-textured soils (mixed range sites).	Poor	D	66	77	93
Newell, SD	51	7.90	Sandy range sites.	Fair	B	52	61	81
Newell, SD	53	11.30	Sandy range sites.	Fair	B	42	46	86
Newell, SD	55	16.50	Sandy range sites.	Fair	B	45	50	95
Newell, SD	P5	8.00	Panspots	Fair	D	64	76	96
Newell, SD	P6	13.20	Panspots	Fair	D	63	73	90
Newell, SD	P7	7.25	Panspots	Fair	D	65	81	97
Newell, SD	P8	6.42	Panspots	Fair	D	72	82	91
Newell, SD	P9	6.96	Panspots	Fair	D	71	82	95
Aladdin, WY	1	7.70	Silty range site.	Fair	D	61	75	89
Aladdin, WY	2	8.20	Silty range site.	Fair	D	61	74	86
Aladdin, WY	3	11.60	Shallow range site.	Fair	D	71	75	95
Aladdin, WY	4	2.50	Shallow range site.	Fair	D	72	82	95
Reynolds, ID	1	205.00	Summit watershed (mixed range site).	Poor	D	74	75	86
Reynolds, ID	2	33.00	Lower Sheep (mixed range site).	Poor	D	74	75	86

Table 6.2--Continued
Soil Conservation Service curve numbers from selected USDA-ARS watersheds in the northern Great Plains

Watershed location	Watershed number	Area (acres)	Range type	Range condition	Hydrologic group	SCS curve No. Low	Av.	High
Reynolds, ID	3	306.00	Murphy (mixed range site).	Fair	C	69	70	91
Reynolds, ID	4	100.00	East Reynolds Mt. (mixed range site).	Fair	C	79	82	88
Guthrie, OK	W-I	2.50	Virgin native grass.	Good	B	33	68	95
Guthrie, OK	W-II	5.09	Virgin native grass.	Good	B	32	61	85
Guthrie, OK	W-III	9.09	Formerly cultivated; eroded.	Fair	B	56	78	98
Guthrie, OK	W-IV	13.40	Formerly cultivated; eroded.	Fair	B	53	78	98
Guthrie, OK	W-V	15.70	Formerly cultivated; eroded.	Fair	B	55	81	96
Guthrie, OK	PL, L	5.62	Native woodland	Fair	B	30	59	95
Guthrie, OK	PL, J	5.28	Severely eroded	Poor	B	53	78	93
Guthrie, OK	PL, 15A	3.13	Formerly cultivated; terraced.	Good	B	55	81	96
Guthrie, OK	PL, 13	3.21	Gullied: reformed	Good	B	58	81	98
Chickasha, OK	R-2	24.08	Sandy range site	Fair	B	45	68	86
Chickasha, OK	R-5	23.72	Virgin rangeland site.	Good	D	41	76	98
Chickasha, OK	R-7	19.19	Formerly cultivated; treated.	Poor	D	52	83	98

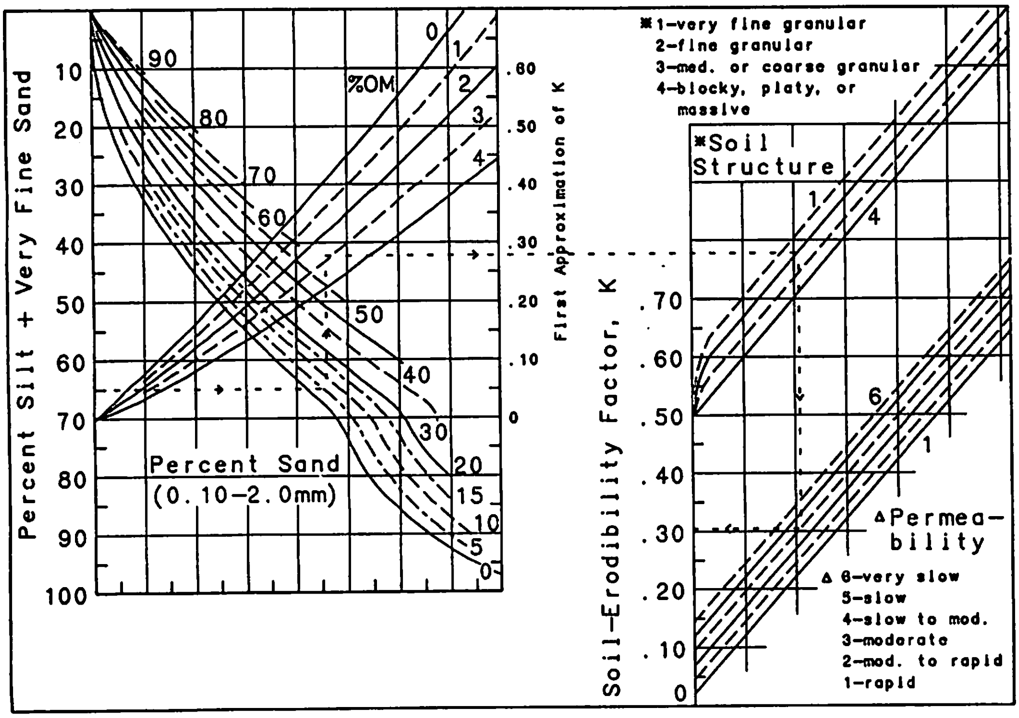

Figure 6.1
The soil-erodibility nomograph.

Table 6.3
Factor C for permanent pasture, range, and idle land[1/]

Vegetative canopy		Cover that contacts the soil surface (percent ground cover)						
Type and height[2/]	Percent cover[3/]	Type[4/]	0	20	40	60	80	95+
No appreciable canopy.		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	.45	.24	.15	.091	.043	.011
Tall weeds or short brush with average drop fall height of 20 in.	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.076	.039	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes with average drop fall height of 6 1/2 ft.	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.011
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.011
Trees, but no appreciable low brush. Average drop fall height of 13 ft.	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.084	.041	.011

1/ The listed C values assume that the vegetation and mulch are randomly distributed over the entire area.

2/ Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height and is negligible if fall height exceeds 33 ft.

3/ Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).

4/ G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 in deep. W: Cover at surface is mostly broadleaf, herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residues or both.

making the top layer 15.0 cm thick, the soil water tensions fluctuated rapidly from day to day causing unrealistic responses in the plant component. To remove the impact of moisture inputs of relatively small magnitude, the soil between 0 and 15.0 cm should be divided into two layers. The preferred thickness for each layer is 7.5 cm (3.0 in). This provides a smoother response of the soil-water tension and a more appropriate response of the plant component.

Porosity, SMO on record 13, can be determined by using the bulk density in column N of table 6.5, assuming a particle density of 2.65 g/cm^3, and by using the following equation:

$$SMO = 1.0 - \frac{BD}{2.65} \qquad (6)$$

where:

SMO = porosity,
BD = bulk density (g/cm^3), and
2.65 = assumed particle density (g/cm^3).

Soils-5 presents a range of values for many of the properties including bulk density, and at this time we cannot provide any rules as to how best to choose a value for simulation. Once a value has been chosen, that is, the upper limit, lower limit, or a mid-range value, the user should be

Table 6.4
Selected soil properties based on soil texture class

Soil texture class	Representative composition			Saturated-soil hydraulic conductivity (cm/hr)			Bare-soil evaporation parameter (c) (mm/day $^{1/2}$)		
	Clay	Silt	Sand	Avg	Low	High	Avg	Low	High
Sand	3	7	90	23.0	11.7	43.2	3.3	3.05	3.32
Loamy sand	5	15	80	6.1	3.6	11.7	3.3	3.05	3.32
Sandy loam	10	20	70	2.2	1.7	3.6	3.5	3.10	4.06
Loam	20	40	40	1.3	0.91	1.7	4.5	3.20	4.57
Silt loam	15	65	20	0.69	0.46	0.91	4.5	3.20	4.57
Silt	5	87	8	0.51	0.30	0.61	4.0	3.15	4.40
Sandy clay loam	30	10	60	0.30	0.25	0.46	3.8	3.15	4.32
Clay loam	35	35	30	0.20	0.19	0.25	3.8	3.15	4.32
Silty clay loam	35	55	10	0.18	0.15	0.19	3.8	3.15	4.32
Sandy clay	45	5	50	0.13	0.11	0.15	3.4	3.10	3.56
Silty clay	45	50	5	0.10	0.09	0.11	3.5	3.10	3.81
Clay	65	20	15	0.08	0.06	0.09	3.4	3.10	3.56

Source.--Lane and Stone (1983).

consistent for all other properties. Lane and Stone (1983) present values for porosity by texture classes (table 6.6).

There are two possible ways to obtain values for saturated hydraulic conductivity, SLSC on record 16, using Soils-5 output. Column O in table 6.5 is the range of permeability of the soil and this can be used. Another technique was presented by Brakensiek et al. (1984) and Rawls and Brakensiek (1985) which uses the relationship between soil texture and saturated hydraulic conductivity. The equations are:

$$\begin{aligned} \ln K_s = {} & 19.52348\ SMO - 8.96847\ PC + \\ & 0.00018107\ PS^2 - 0.0094125\ PC^2 - \\ & 8.295215\ SMO^2 + 0.077718\ PS\ SMO - \\ & 0.00298\ PS^2 SMO^2 - \\ & 20.019492\ PC^2 SMO^2 + \\ & 0.0000173\ PS^2 PC + \\ & 0.02733\ PC^2 SMO + 30.001434\ PS^2 - \\ & 0.0000035\ PC^2 PS \end{aligned} \qquad (7)$$

$$SLSC = 2.54\ e^{\ln K_s} \qquad (8)$$

where:

SMO = porosity from equation 6,
PC = percent clay,
PS = percent sand,
$\ln K_s$ = natural log of saturated soil-hydraulic conductivity, and
K_s = saturated hydraulic conductivity.

From table 6.5, the percentage of clay is available in column M, and SMO can be calculated from equation 6. Percentage of sand is not available in the Soils-5 output, but it can be calculated from relationships derived by R.B. Grossman of the SCS National Soil Survey Laboratory, Lincoln, Nebraska, for the Soils-5 database. Grossman's equation for percent sand is:

$$PS = 100 - \frac{100\,I}{G} \qquad (9)$$

where:

PS = percent sand,
I = value from column I of table 6.5, and
G = value from column G of table 6.5.

Once PS is determined, equations 7 and 8 can be solved to provide the saturated soil-hydraulic conductivity.

If a texture classification is used, table 6.4 from Lane and Stone (1983) can be used to determine a value for SLSC. Values should be converted to inch per hour for input to SPUR.

The volumetric water contents at 1/3-bar (SM3) and 15-bar (SM15) tensions, records 14 and 15 in chapter 3, table 3.3, can also be determined using relationships presented by Grossman for Soils-5 data or from Brakensiek et al. (1984). Brakensiek et al. (1984) proposed the following equations based on soil texture:

$$\begin{aligned} SM3 = {} & 0.1535 - 0.0018\ PS + 0.0039\ PC + \\ & 0.1943\ SMO \end{aligned} \qquad (10)$$

and:

$$\begin{aligned} SM15 = {} & 0.0370 - 0.0004\ PS + 0.0044\ PC + \\ & 0.0482\ SMO \end{aligned} \qquad (11)$$

where:

SM3 = 1/3-bar volumetric soil water content (decimal fraction),
SM15 = 15-bar volumetric soil water content (decimal fraction),
PS = percent sand,
PC = percent clay, and
SMO = porosity.

Table 6.5
SOILS-5 file for Searla soil series

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SEARLA (ID0929)COOL

MLRA(S): 25
REV. TH,GHL , 12-82
CALCIC ARGIXEROLLS, LOAMY-SKELETAL, MIXED, FRIGID

THE SEARLA SERIES CONSISTS OF VERY DEEP WELL DRAINED SOILS THAT FORMED IN COLLUVIUM FROM SEDIMENTARY ROCKS ON MOUNTAINS. ELEVATION IS 5500 TO 6900 FEET. AAP IS 14 TO 16 INCHES. MAST IS 42 TO 45 F. FFS IS 50 TO 70 DAYS. VEGETATION IS MOUNTAIN BIG SAGEBRUSH AND BLUEBUNCH WHEATGRASS. TYPICALLY THE SURFACE LAYER IS BROWN GRAVELLY LOAM 15 INCHES THICK. THE SUBSOIL IS YELLOWISH BROWN VERY GRAVELLY CLAY LOAM TO 32 INCHES. THE SUBSTRATUM IS WHITE VERY GRAVELLY LOAM AND VERY PALE BROWN VERY GRAVELLY SANDY LOAM TO 60 INCHES. SLOPES ARE 30 TO 60 PERCENT.

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SEARLA (ID0929)COOL

A	B	C	D	E	F	G	H	I
DEPTH (IN.)	TEXTURE	UNIFIED	AASHTO	FRACT > 3IN (PCT)	PERCENT OF MATERIAL LESS THAN 3 IN PASSING SIEVE NO. 4	10	40	200
0-15	GR-L	SM-SC,GM-GC	A-4	5-10	65-85	60-80	45-60	35-50
15-32	GRV-CL	GC	A-2	5-15	45-60	35-50	25-40	20-35
32-60	GRV-L,GRV-SL	GM-GC	A-1,A-2	0-15	35-60	25-50	15-35	10-30

J	K	M	N	O	P	Q	R
LIQUID LIMIT	PLAST'Y INDEX	CLAY %<2MM	MOIST BULK DENSITY (G/CM3)	PERMEA-BILITY (IN/HR)	AVAILABLE WATER (IN/IN)	SOIL REACTION (PH)	SALINITY MMHOS/CM
25-30	5-10	12-20	1.40-1.50	0.6-2.0	0.13-0.16	6.6-7.3	-
30-40	10-15	27-35	1.40-1.50	0.2-0.6	0.10-0.13	6.6-7.3	-
25-30	5-10	10-22	1.50-1.60	0.6-2.0	0.05-0.09	7.4-8.4	< 2

S	T	U	V	W
SHRINK-SWELL	EROSION FACTORS K	T	WIND EROD. GROUP	ORGANIC MATTER (PCT)
LOW	.15	2	6	2-4
LOW	.10			
LOW	.05			

Table 6.6
Porosity (percent) and water holding capacity (water content in percent by volume) based on soil texture class

Soil texture class	Total porosity			-1/3-bar Water holding capacity			-15-bar Water holding capacity		
	Avg	Low	High	Avg	Low	High	Avg	Low	High
Sand	41	39	43	9	7	15	3	2	6
Loamy sand	43	39	45	12	10	20	6	4	8
Sandy loam	45	39	52	20	14	29	9	5	12
Loam	47	45	52	26	20	36	12	9	18
Silt loam	50	49	55	31	20	36	13	7	20
Silt	51	49	55	28	26	30	9	6	12
Sandy clay loam	42	38	45	27	17	34	17	11	21
Clay loam	47	40	51	34	29	38	20	16	34
Silty clay loam	47	46	51	36	33	40	21	18	24
Sandy clay	42	40	44	31	27	40	21	18	30
Silty clay	48	46	49	40	35	46	27	23	32
Clay	49	44	52	42	34	49	29	23	38

Source.--Lane and Stone (1983).

Again, Soils-5 can be used to provide the necessary information.

Grossman uses the relationship between 15-bar water content by weight and percent clay:

$$SM15 = \frac{.04\ M\ N}{100} \qquad (12)$$

where:

SM15 = 15-bar volumetric water content,
M = percent clay (PC) from column M of table 6.5, and
N = bulk density from column N of table 6.5.

The ratio of 0.4 of percent clay to 15-bar water content by weight is discussed by NSSL (1983) and this guide should be consulted for situations in which this ratio does not apply. The field capacity or 1/3-bar water content is found by using the following relationships:

$$SM3 = \frac{P}{1 - \frac{Z2}{100}} + SM15 \qquad (13)$$

where:

SM3 = 1/3-bar volumetric soil water content,
P = available water from column P of table 6.5,
Z2 = volume > 2 mm, see equation 14, and
SM15 = 15-bar volumetric soil water content.

A value for Z2 is computed as:

$$Z2 = \frac{Z1}{D_p>2}\left[\frac{100}{\frac{Z1}{D_p>2}\ \frac{100 - Z1}{N}}\right] \qquad (14)$$

where:

Z2 = volume > 2 mm,
Z1 = weight percentage > 2 mm,
D_p>2 = particle density for particles > 2mm (g/cm^3), and
N = bulk density for column N of table 6.5.

The equation to calculate Z1 is:

$$Z1 = E + (1 - \frac{E}{100})\,(100 - G) \qquad (15)$$

where:

Z1 = weight percentage > 2 mm,
E = fraction > 75 mm from column E of table 6.5, and
G = value from column G of table 6.5.

The particle density for particles greater than 2 mm is 2.65 g/cm^3 unless the organic matter content is greater than 5 percent. If this limit is exceeded, D_p>2 can be determined by the following formula:

$$D_p>2 = 2.65\left[\frac{100 - W\,(1 - \frac{Z1}{100})}{100}\right] + \frac{1.4\ W}{100}\,(1 - \frac{Z1}{100}) \qquad (16)$$

where:

D_p>2 = particle density for > 2 mm fraction (g/cm^3),
W = organic matter percentage column W in table 6.5, and
Z1 = weight percentage > 2 mm; see equation 15.

Another method to derive 1/3-bar water content uses data from table 6.5 and ratios presented in table 6.7. Table 6.7, obtained from NSSL (1983), expresses the ratio between percent silt and available water. Available water is in column P in table 6.5 and percent silt can be calculated by subtracting the sum of percent clay and sand from 100.0. The 1/3-bar water content is determined as:

$$SM3 = (PSI\ RA\ N) + SM15 \qquad (17)$$

where:

SM3 = 1/3-bar volumetric soil water content,
PSI = percent silt,
RA = ratio value from table 3.8,
N = bulk density (g/cm^3), and
SM15 = 15-bar volumetric soil water content.

For texture classes, table 6.6 from Lane and Stone (1983) has values listed for both 1/3-bar and 15-bar water contents. These relationships will help the user when field data cannot be obtained. The previous formulas do not and should not be used to remove the necessity of data collection which will provide the best results for any particular site in question.

THE SNOW ACCUMULATION AND MELT COMPONENT

The HYDRO-17 model used to calculate snow accumulation and melt for SPUR is applied to each field in the basin-scale version of the model. The model was developed by Anderson (1973) and is part of the National Weather Service River Forecast Model. The following material was taken primarily from Anderson (1973).

Anderson defines six major and six minor parameters for HYDRO-17. These parameters are input to SPUR on records 19 and 20. Record 21 is the initial snow water equivalent present on a field at the start of a simulation. The major parameters are SCF, MFMAX, MFMIN, UADJ, SI, and an areal depletion curve. The minor parameters are NMF, TIPM, PXTEMP, MBASE, PLWHC, and DAYGM.

The snow-catch correction factor (SCF) is used to adjust precipitation gauge-catch amount for deficiencies in snowfall catch. The value is dependent on wind speed and the exposure of a site. Also, Anderson noted that SCF could be used to implicitly account for gains and losses in the snow water equivalent that are not included in the model, for example, vapor transfer, drifting, and interception. He suggested two methods for determining SCF from data. The first uses wind data and the exposure of each site, and the second uses a dual-gauge site with one shielded and another unshielded precipitation gauge at a site.

When information was not available, Anderson recommended a value of 1.2 for SCF. This represented a protected site with moderate winds during a snow event. More-protected sites would approach a value of 1.0, and less-protected sites would be considerably above the 1.2 value.

Table 6.7
Guides for estimating available water capacity (prepared by STSC)

Soil texture class	Western States[1]	Nebraska[2] data	Tennessee[3] West	Tennessee[3] East	Oklahoma[4] guides	Louisiana[5] mean values	Suggested values[6]
Coarse sand & gravel	0.05-0.07	0.03-0.05			0.02-0.06		0.02-0.05
Sands		0.02-0.08				0.05	0.02-0.06
Fine sand	0.05-0.07				0.04-0.06		0.05-0.08
Loamy sand	0.06-0.08	0.07-0.12	0.05-0.09		0.06-0.09		0.06-0.10
Loamy fine sand	0.08-0.11				0.06-0.09	0.08	0.07-0.11
Sandy loam	0.11-0.13	0.12-0.15		0.10-0.16	0.09-0.13	0.12	0.10-0.14
Fine sandy loam	0.13-0.15	0.15-0.18		0.17-0.24	0.09-0.13	0.14	0.11-0.15
Very fine sandy loam	0.15-0.17				0.12-0.16	0.22	0.13-0.20
Loam	0.16-0.18	0.19-0.23		0.19-0.03	0.12-0.16	0.18	0.15-0.20
Silt loam (not loess)	0.19-0.21			0.20-0.03	0.14-0.18	0.23	0.16-0.24
Silt loam (loess), silt		0.23-0.26	0.27-0.05				0.22-0.28
Sandy clay loam	0.14-0.16				0.12-0.16	0.15	0.12-0.17
Clay loam	0.19-0.21	0.21-0.22		0.17-0.03	0.15-0.19	0.17	0.15-0.20
Silty clay loam	0.19-0.21	0.22-0.26	0.25-0.04	0.18-0.04	0.15-0.19	0.21	0.18-0.22
Sandy clay	0.15-0.17				0.14-0.18	0.17	0.14-0.18
Silty clay	0.15-0.17	0.15-0.17		0.19-0.04	0.14-0.18	0.18	0.14-0.18
Clay	0.14-0.16	0.13-0.15		0.15-0.03	0.14-0.18	0.19	0.12-0.18

1/ Guides developed in Western States.
2/ Jordan, R.H., Available water capacity for Nebraska soils, (unpublished).
3/ Longwell, T.J., W.L. Parken, and M.E. Springer, 1963, Moisture characterization of Tennessee soils, Agricultural Experiment Station Bulletin 367.
4/ Guides developed from Oklahoma data.
5/ Guides developed from many sources currently in Louisiana.
6/ Guides based on the data in this table plus other data from States in the Southern Region.

Rangelands are often windswept and open areas and should probably fall in the latter category.

The maximum- and minimum-melt factors (MFMAX and MFMIN) are used to calculate snowmelt for nonrain periods. In HYDRO-17, the computational interval is 6 hours so temporal variations in temperature and precipitation can be accommodated. The SPUR model uses daily values. The extrapolation from 6.0-hour parameter values to 24.0-hour values is not known at this time. Table 6.8 is from Anderson and provides values for both MFMAX and MFMIN for different cover conditions for 6-hour intervals.

The wind function UADJ on record 19 can be computed from wind speeds during rain-on-snow events and the following equation:

$$UADJ = 0.0002\ WIND \tag{18}$$

where:

UADJ = the average wind function using measurements taken 1.0 meter above the snow surface (mm/mb), and

WIND = daily wind movement at 1.0 meter (km).

Anderson (1973) indicated that values for UADJ should range from 0.03 to 0.19 mm/mb with the lower values in forested areas and higher values in open areas.

The variable SI is the maximum accumulation above which there is 100 percent snow cover. Determining this value requires knowledge of snow water equivalent and areal snow cover relationships for several years, and these data are not generally available. Currently, SI is set to a very high value. This allows the annual accumulated maximum snow water equivalent to control the areal depletion curve. Users should be cautioned in setting the value for SI too low since this affects the areal depletion curve and snowpack processes.

A single parameter, ADPT on record 19, parameterizes the areal depletion curve. The five general shapes of areal depletion curves can be seen in figure 6.2. Each number on figure 6.2 corresponds to a value for ADPT. This variable, ADPT, can also be fractional which results in the interpolation between primary ADPT curves. An ADPT value of 3.5 will produce an essentially straight line. If ADPT exceeds 5, the curve for 5 will be used. If ADPT is less than 1, the curve for 1 will be used. The shape of an areal depletion curve is dependent on topography, prevailing wind direction, and snowfall amount, and there are almost no rules for its selection. The user will need to be qualitatively familiar with snow accumulation and melt characteristics for the site to select the proper shape.

The negative melt factor (NMF) and antecedent-temperature parameter (TIPM), both on record 19, control energy exchange during snowmelt periods. The variable, TIPM, weights previous air temperatures for calculation of current snowpack temperature. A low value of TIPM gives more weight to temperatures from previous computational periods. Anderson (1973) suggested a value of 0.5 for TIPM. The variable NMF controls the heat flow into the snowpack and has a recommended value of 0.15 mm/ °C/6-h.

Table 6.8
Typical values of melt factors as related to forest cover for areas with distinct accumulation and melt seasons (units are mm $°C^{-1}$ 6 hr^{-1}).

Forest cover	MFMAX	MFMIN
Coniferous forest - quite dense	0.5 - 0.8	0.2 - 0.3
Mixed forest - coniferous plus open and/or deciduous	0.8 - 1.0	0.25 - 0.4
Predominantly deciduous forest	1.0 - 1.3	0.35 - 0.5
Open areas	1.3 - 2.0	0.5 - 0.9

Source.--Anderson (1973).

The base temperature above which snowmelt will occur during nonrain periods is MBASE and is on record 20. A value of 0.0 °C has been found to be adequate. The variable PXTEMP on record 20 differentiates rain from snow and can range from 0.0 to 2.0 °C (Anderson 1973). At higher elevations snow occurs at temperatures of 3.0 to 5.0 °C.

The percent liquid-water holding capacity for ripe snow, PLWHC on record 20, is generally between 0.02 to 0.05 (Anderson 1973).

The daily groundmelt, DAYGM on record 20, is a constant which represents average daily melt during an average winter. For regions with frozen soils, the value should be close to zero and for areas with relatively mild winters and deep snow cover, for example, the Sierra Nevadas, a value of 0.3 mm is suggested (Anderson 1973).

Table 6.9 lists snow accumulation and melt parameters used by SPUR. Initial values or suggested ranges from Anderson (1973) are included.

THE CHANNEL COMPONENT

The channel component routes water and sediment through the channel system. Limitations of the routing techniques can be found in Part I on the channel component by Lane.

On record 4, the basin-wide hydrograph parameters,

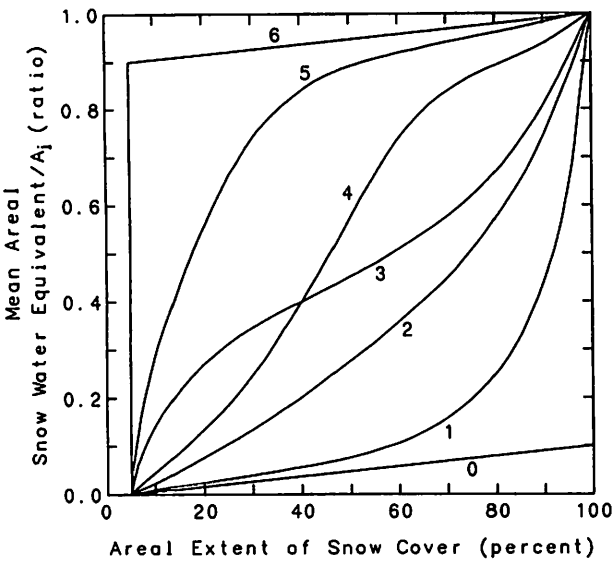

Figure 6.2
Snow cover areal-depletion-curve types corresponding to ADPT values of 0, 1, 2, 3, 4, 5, and 6 (modified from Anderson 1973).

Table 6.9
List of parameters and suggested value or range for HYDRO-17 snow accumulation and melt routines used in SPUR

Parameter	Value
SCF	1.0 - ? (1.2)[1/]
MFMAX	See table 6.8
MFMIN	See table 6.8
UADJ	0.03 - 0.19 mm/mb
SI	
ADPT	
NMF	0.15 mm/°C/6-h
TIPM	0.1 < TIPM < 1.0 (0.5)
MBASE	0.0 °C
PXTEMP	0.0 - 2.0 °C
PLWHC	0.02 - 0.05
DAYGM	0.0 - 0.3 mm

[1/] Value in parentheses is suggested.

Source.--Anderson (1973).

C1 through C5, are entered which predict peak flow response. Parameters C1 and C2 relate drainage area to mean event flow duration, and parameters C3 and C4 are for the watershed area to event runoff-volume equation. Parameter C5 is the hydrograph-shape parameter. The relationships and parameter values listed in table 6.10 were derived from an analysis of small watershed data in Arizona. Streamflow from these basins was ephemeral or intermittent so these relationships should not be applied to perennial streams. For watersheds with a significant baseflow component, a steady state procedure is used to determine daily flow rate. When a rainfall event occurs, the routing routines using the double-triangle approximation are used, thus the baseflow is neglected in this case.

Values for hydrograph parameters for the Arizona watersheds from Murphey et al. (1977) are given in table 6.10. The preferred method of deriving parameter values is using data from a gauged watershed in the region of interest and obtaining parameters using the established equations. Extrapolation of the derived parameters to the simulation watershed should take into account relationships such as area, elevation, length, and soils to the watershed from which the parameters were derived.

The coefficient, C1, in the runoff-duration/watershed-area relationship was between 2.0 and 5.5, inclusive (table 6.10).

The exponent in the runoff-duration/watershed-area relationship, C2 on record 4, ranges between 0.2 and 0.5, inclusive (Table 6.10). If hydrograph analyses cannot be conducted, the recommended value for C2 is in the range of 0.2 to 0.3.

The parameter C3 on record 4 is the coefficient in the runoff volume/watershed-area relationship, and values for C3 are listed in table 6.10.

The exponent in the runoff-volume/watershed-area equation, C4 on record 4, lies between 0.0 and 0.2, but a value in the interval 0.1 to 0.2 is suggested after C3 has been selected.

The hydrograph-shape parameter, C5 on record 4, can be found by relating the mean peak flow rate to the mean runoff volume divided by the mean storm duration. Estimates are found in table 6.10.

The channel hydraulic conductivity is used to calculate channel transmission losses. Table 6.11 is a list of effective hydraulic conductivity values for different types of material and can be used as a guide for streams where it is known that channel transmission losses are important.

The hydraulic properties of the channel are calculated with the Manning equation. Channels are assumed to be rectangular in cross section. On record 6, Manning's "n" values are required for both total (XN) and wall (XNW) roughness. Table 6.12 lists values for total roughness for various types of open channels. The relationship between XN and XNW can be seen in table 6.13. The reader is referred to the channel component documentation by Lane (Part I, Chapter 5) for a more complete description of the relationship between total and wall roughness.

The sediment transport routines estimate both suspended load and bed load. All material is assumed to be present in the bed and only transport capacity limits sediment yield.

Table 6.10
Parameters in the transmission loss, streamflow routing procedures

Parameter or variable	Range in values	Source of estimate and comments
Watershed area A	---	Topographic map. Drainage area contributing to the channel segment.
Channel Length x Width w	---	Topographic map and field observations.
Hydraulic conductivity K	0.001 - 5.0	Table 6.2 or runoff data. Function of channel alluvium, antecedent moisture, and so forth.
Hydrograph parameters		
C1	2.0 - 5.5	Murphey et al. (1977) or hydrograph analysis.
C2	0.2 semiarid to 0.5 subhumid.	Murphey et al. (1977) or hydrograph analysis.
C3	0.03 - 0.07 semiarid.	Murphey et al. (1977) or hydrograph analysis.
C4	-0.2 semiarid to 0.0 subhumid.	Murphey et al. (1977) or hydrograph analysis.
C5	2.8 - 6.0	Murphey et al. (1977), SCS (1972) or hydrograph analysis.
D	> 0.0	D = C1 A C2, mean duration of flow (h)
V	> 0.0	V = C3 A C4, mean runoff volume (in), must convert to acre-ft.

Particles less than 0.062 mm in diameter compose the silt-clay fraction and are transported as suspended load. The decimal value of the bed material in this category is the fraction of silt and clay (FSC) on record 6. Table 6.14 shows an upper limit of 0.10 for FSC. The sediment transport routines have not been tested for values greater than this, as these larger values may represent a channel with more cohesive material. The suspended sediment transport parameter, CAS on record 6, is also listed in table 6.14 with suggested values.

The bed-load calculations require a distribution of particle sizes for the material greater than 0.062 mm in diameter and the number of particle-size classes (NPC) is entered on record 6. The maximum allowed number of classes is 10. The median particle diameter for a class (DI) and the fraction of material represented by that diameter (FI) are entered on records 7 and 8, respectively. The sum of the FI values must equal 1.0 minus FSC (table 6.14). The median particle diameter of the bed material, d_{50} on record 6, must be within the range given in table 6.14.

Ponds are simulated as part of the channel system. A channel ends at a pond, or its outflow is inflow to a pond, and outflow from a pond is into another channel segment (figure 3.2). The inputs for ponds are on record 9 and they are self-explanatory. Most of them will require a field survey. The hydraulic conductivity for seepage out of the pond bottom can be obtained from Table 6.11.

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Table 6.11
Effective hydraulic conductivity for transmission losses in channel alluvium[1]

Bed material group	Bed material characteristics	Effective hydraulic conductivity[2] (in/h)
Very high loss rate	Very clean gravel and large sand $d_{50} > 2$ mm.	> 5.0
High loss rate	Clean sand and gravel under field conditions. $d_{50} > 2$ mm.	2.0 - 5.0
Moderately high loss rate	Sand and gravel mixture with less than a few percent silt-clay.	1.0 - 3.0
Moderate loss rate	Mixture of sand and gravel with significant amounts of silt-clay.	0.25 - 1.0
Very low loss rate	Consolidated bed material with high silt-clay content.	0.001 - 0.1

1/ Based on analysis of data from 14 channel reaches in Arizona, Texas, Kansas, and Nebraska, data from 14 other channel reaches in Arizona, and canal seepage rates in unlined canals.

2/ Values of effective hydraulic conductivity reflect the flashy, sediment-laden character of many ephemeral streams, and thus, do not represent clear-water infiltration rates at steady state.

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Table 6.12
Approximate hydraulic roughness coefficients for open-channel flow. Values are for the total roughness coefficient, n_T

Total Manning's n value n_T	Description of channel
(0.02 - 0.10)	Excavated or dredged channels[1/]
0.022	Earth, straight, uniform, and clean.
0.027	Same, but with some short grass or weeds.
0.025	Earth, winding, and sluggish with no vegetation.
0.030	Same, but with some grass or weeds.
0.080	Channels not maintained; weeds and some brush.
(0.03 - 0.10)	Natural streams[1/]
0.030	Clean and straight; no rifts or deep pools.
0.040	Clean and winding; some pools and shoals.
0.048	Clean and winding; some weeds, stones, and pools.
0.070	Sluggish reaches with weeds and deep pools.
(0.012 - 0.040)	Wide alluvial channels[2/]
0.018 - 0.030	Ripples bed form, sediments finer than 0.6 mm, Froude Nos. < 0.37.
0.020 - 0.040	Dunes bed form, Froude Nos. 0.28 to 0.65.
0.014 - 0.030	Transitional bed form, Froude Nos. 0.55 to 0.92.
0.012 - 0.030	Antidunes bed form, Froude Nos. > 1.0.

1/ Source.--Chow 1959.

2/ Source.-- ASCE 1969 and Simons and Richardson 1971.

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Table 6.13
Approximate hydraulic roughness coefficients for total and bank or wall roughness in natural, alluvial channels

Description of channel	Total n_T	Wall n_w
Upland streams		
Sand and gravel bed; bare, exposed banks	0.030 - 0.040	0.030 - 0.045
Sand and gravel bed; exposed banks with vegetation; grass and weeds.	0.035 - 0.045	0.035 - 0.050
Sand and gravel bed, vegetated banks; grass and weeds, with some brush.	0.040 - 0.048	0.045 - 0.060
Wide, alluvial channels		
Sand bed; bare, exposed banks	0.025 - 0.035	0.030 - 0.040
Sand bed, vegetated banks	0.030 - 0.040	0.035 - 0.050
Gravel bed, vegetated banks	0.030 - 0.040	0.035 - 0.050

Note.--See table 3.12 for values of n_T. In natural alluvial channels, n_w is usually greater than n_T.

Table 6.14
Parameters in the sediment transport, sediment yield procedure

Parameter or variable	Range in values	Source of estimate and comments
Channel		
Width w	> 0.0	Cross-section data. This width is not the mean reach width as used in the transmission loss equations; it is the actual width at the cross section of interest.
Slope s	> 0.0	Topographic map; field observations.
Sediment		
Particle-sized distribution (f_i, d_i)	$f_i = 1 - f_{sc}$	Bed material samples. Distribution of bed sediments larger than 0.062 mm. Up to 10 size fractions.
d_{50}	$0.062 < d_{50} < 2.0$ mm	Bed material samples. Median particle size.
f_{sc}	$0.0 < f_{sc} < 0.10$	Bed material samples. Proportion of bed material finer than 0.062 mm. Values of $f_{sc} > 0.10$ may indicate cohesive material.
Hydraulics		
Total roughness n_T	0.012 - 0.048	Tables 3.12 and 3.13; field observations.
Wall roughness R_w	$0.030 - 0.060^{+}$	Table 3.13; field observations.
Transport parameters		
$B_s(d_i)$	> 0.0	Equation 55 of chapter 5, Part I.
$B_c(d_i)$	> 0.0028	Equation 56 of chapter 5, Part I.
CAS	1.0 - 10.0	Suspended-transport parameter. Complex function of particle dynamics. Estimate from calibration using observed data. Default value, corresponding to medium-sized silt, of CAS = 5.0 is recommended in the absence of better estimates.