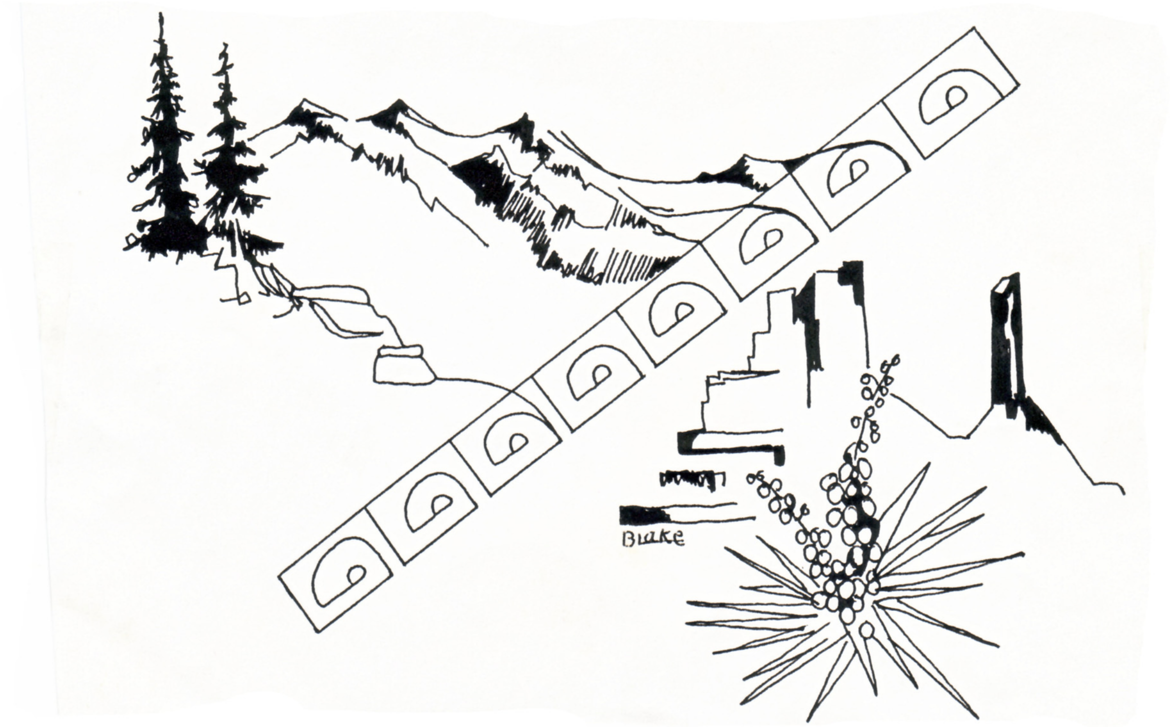
State of Colorado
Office of the State Engineer
Dam Safety Branch

HYDROLOGIC BASIN RESPONSE

PARAMETER ESTIMATION GUIDELINES



Tierra Grande International, Inc
George V. Sabol, PhD, PE

Revised May 2008

Tierra Grande International, Inc.

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23 May 2008

Mr. Garrett Jackson
Colorado Division of Water Resources
2754 Compass DR, Suite 175
Grand Junction, CO 81506

Subject: Revision to Hydrologic Basin Response – Parameter Estimation Guidelines

Dear Mr. Jackson:

The May 2007 version of the "Hydrologic Basin Response-Parameter Estimation Guidelines" manual was revised per review comments that were received. That revision was made to avoid confusion in the selection of the PSIF and DTHETA Green and Ampt equation parameters, and to address editorial comments.

Pages 1, 31, 32, 34, 45, 51 and 58 of the manual are revised and dated May 2008. An Addendum for the May 2008 revision is included. A reproducible copy plus a pdf on CD of the revised manual are enclosed.

It was my pleasure to work with you and the Dam Safety Branch staff. Please contact me if I can be of other service to the Colorado Office of the State Engineer.

Sincerely,

George V. Sabol, PhD, PE
Tierra Grande International, Inc.

Copy: Mr. Jack Byers, w/o enclosures

ADDENDUM

Hydrologic Basin Response – Parameter Estimation Guidelines

Revised May 2008

Recent use of the Hydrologic Basin Response – Parameter Estimation Guidelines, dated 16 May 2007, can result in confusion in selecting the PSIF and DTHETA Green and Ampt equation parameters. That is caused by the values for those parameters in Table 10 not always agreeing with corresponding values in Figure 4. The values in Table 10 are for "average" conditions but recognize that there is "natural variability" for each of those values. Figure 4 was developed based on the best available data and its use eliminates some data anomalies and provides greater consistency in the selection of PSIF. The intent of Table 10 was to present the basic data, but the selection of PSIF and DTHETA was to be made using Figure 4. To eliminate that confusion, the PSIF and DTHETA data in Table 10 is eliminated.

In the May 2007 version of the manual, pages 1, 31, 32, 34, 45, 51 and 58 are revised. A new title sheet dated May 2008 is provided.

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SECTION 1: INTRODUCTION

Project Description

The Hydrologic Basin Response Study was performed for the State of Colorado, Office of the State Engineer, Dam Safety Branch, Division of Water Resources, Department of Natural Resources. The project is to provide guidance and data sources for the performance of inflow design flood (IDF) hydrology studies for dam safety and dam design. Of particular interest to this study are the estimation of rainfall loss and unit hydrograph parameters that are necessary in rainfall-runoff modeling for the purpose of determining IDF hydrographs.

Project Purpose and Objectives

The purpose of this project is to investigate and document the use of data and information that are available to estimate watershed parameters for use in IDF studies. Guidelines and procedures are presented that, when used by engineers and hydrologist with appropriate training and relevant experience, will produce consistent and reasonable IDF hydrographs for dam safety studies in Colorado.

Three (3) criteria were applied in developing the guidelines; accuracy, practicality and reproducibility.

- **Accuracy** – is a measure of how well the results of the procedure reproduce the physical process being simulated. Although accuracy is highly desired, absolute accuracy is theoretically impossible to achieve in an earth science such as hydrology, and in a practical sense, accuracy is not feasible to assess except for a few situations where adequate verification data are available.

- **Practicality** – is a user's decision regarding the best and most appropriate level of technology to apply considering the information that is available, anticipated user, consequences of error, and desired or required output.

- **Reproducibility** – is a characteristic that provides reasonable confidence that consistent results will be achieved by all qualified users. Reproducibility is highly desirable for a design standard in order to eliminate – to the extent reasonable – unnecessary conflicts over the interpretation and application of the design method. Reproducibility is achieved through clear and concise procedures, user guidance, and relevant training.

It is recommended that accuracy of these procedures be assessed by performing verification studies using the recommended guidelines for gaged watersheds with a long period of high quality runoff data to statistically estimate the magnitude of the 100-year peak discharge for the watershed. The recommended procedures would then be applied to that watershed to estimate the 100-year flood and those rainfall-runoff model results compared to the statistical estimate of the flood magnitude. Verification was accomplished for two watersheds in Colorado. Due to the diversity of Colorado watershed and hydrologic conditions, additional verification studies should be performed.

The procedures meet the state-of-the-practice for IDF hydrology and make use of readily available data and information sources. The compilation data and use of current information is presented herein and is illustrated by examples to achieve the practicality test.

The guidelines have attempted to provide clear and concise instructions so that qualified users will achieve consistent and uniform results.

Previous Studies

The Hydrologic Basin Response Study is a follow-on to the Seminar on Flood Hydrology: Rainfall Losses and Unit Hydrograph Lag Equation that was conducted for the Office of the State Engineer by George V. Sabol Consulting Engineers, Inc. in December 1994. During that one day seminar, data sources for estimating rainfall losses and unit hydrograph lag were presented. A set of seminar notes was provided with data sources and relevant reference material.

In 2005, the Office of the State Engineer embarked on the Hydrologic Basin Response Study with Tierra Grande International, Inc. Two previous reports were submitted for that study: Phase I, June 2005, included an assessment of the state-of-the-practice, relevant literature, data sources and selection of study watersheds in Colorado. Phase II-A, January 2006, was a pilot program wherein two watersheds were selected and hydrologic response parameters estimated. Verification of the procedures was performed using the best available information. Those two pilot program watersheds were the La Plata River near Hesperus, Colorado and Pawnee Creek in Logan and Weld Counties.

Scope of the Current Study

Phase II-B is the preparation of guidelines for estimating rainfall loss and unit hydrograph parameters for the performance of inflow design flood (IDF) hydrologic studies for dam safety and dam design in Colorado.

Procedures for estimating rainfall loss parameters are presented for the Green and Ampt infiltration equation and the Initial loss plus Uniform Loss Rate Method.

Dimensionless unit hydrographs and S-graphs are recommended for use with natural watersheds in Colorado. The Clark unit hydrograph is recommended for use with urban and agricultural watersheds. The Clark unit hydrograph is an acceptable alternative for natural watersheds when its use results in verifiable or more reasonable results than use of dimensionless unit hydrographs or S-graphs. Procedures are provided for calculating the dimensionless unit hydrograph and S-graph lag. Recommendations are provided for estimating K_n in the lag equation. Equations and procedures are provided for calculating the Clark unit hydrograph parameters.

Applicability and Limitations of the Guidelines

1. The intent of these guidelines is to promote public safety and welfare consistent with the state-of-the-practice for the design, operation, maintenance and periodic safety inspection of dams in Colorado.

2. The guidelines are intended for use by engineers and hydrologists with proper training and experience in watershed hydrology and the modeling of the rainfall-runoff processes in digital models such as HEC-1.
3. The guidelines are recommended practices that will yield reasonable results for many watersheds in Colorado. However, they cannot address the nuances of every application in watershed type and/or hydrologic condition. These guidelines can be used in the absence of more appropriate site-specific data. These recommendations and guidelines should be modified, adjusted or replaced by more appropriate technology when that technological procedure can be demonstrated and justified as superior to the guidelines. In the absence of clearly superior data, procedures and/or information, these guidelines should be used for evaluating hydrologic adequacy of dams in Colorado.
4. It is imperative that the watershed and its characteristics that influence and dictate hydrologic basin response be adequately investigated for the purpose of dam design and dam safety studies.

SECTION 2: UNIT HYDROGRAPHS

Unit Hydrograph Selection

A unit hydrograph is defined as the time distribution of one inch of direct runoff from a storm of a specified duration for a particular watershed. Unit hydrographs reflect the physiography, topography, land-use, and other unique characteristics of the individual watershed. Different unit hydrographs are produced for the same watershed for different durations of rainfall excess. For example, a unit hydrograph for a particular watershed can be developed for a rainfall excess duration of 5 minutes, or 15 minutes, or 1 hour, or 6 hours, etc. Any duration can be selected for unit hydrograph development as long as the upper limit for duration is not exceeded for the specific unit hydrograph (discussed in the Instructions section).

Only a few watersheds in Colorado have an adequate data base (rainfall and runoff records) from which to develop a unit hydrograph for the watershed. Therefore, indirect methods are frequently used to develop unit hydrographs. Such unit hydrographs are called synthetic unit hydrographs. Several procedures are available to develop synthetic unit hydrographs, and virtually all of those procedures are empirical. The selection of a synthetic unit hydrograph procedure should be made such that the data base for the empirical development is representative of the study watershed.

The unit hydrograph itself is a lumped parameter in that it represents the composite effects of all of the watershed and storm characteristics that dictate the rate of runoff from the watershed. Although there are numerous watershed and storm characteristics that determine the shape of a unit hydrograph, only a limited number of those characteristics can be quantified and used to calculate a unit hydrograph. One or more unit hydrograph parameters (depending on the selection of synthetic unit hydrograph procedure) are needed to calculate a unit hydrograph.

The following types of synthetic unit hydrographs are recommended for estimating inflow design floods in Colorado:

- Dimensionless unit hydrographs such as those in the U.S. Bureau of Reclamation (USBR) *Flood Hydrology Manual* (Cudworth, 1989)
- S graphs such as those in the USBR *Flood Hydrology Manual* (Cudworth, 1989).
- Clark unit hydrograph

Those unit hydrographs can be applied to watersheds (or modeling subbasins) that range in size from a fraction of a square mile to several hundred square miles.

For the purposes of unit hydrograph selection in these guidelines, watersheds in Colorado are classified as:

- Rocky Mountain – The central highlands of Colorado. Watersheds and modeling sub-basins for which the Rocky Mountain unit hydrographs are to be used are those in which the watercourses are well defined in high elevations with steep topography. Overbank flow is often precluded by deeply incised watercourse banks. Two Rocky Mountain unit hydrographs are recommended; Tables 4-9 or 4-10 of Cudworth (1989) for low-intensity general storms, and Tables 4-11 or 4-12 of Cudworth (1989) for high-intensity thunderstorms.
- Great Plains – The plains of the Front Range and inter mountain valleys such as North Park, Middle Park, South Park, San Luis Valley and other isolated valleys. Watersheds and modeling sub-basins for which the Great Plains unit hydrograph is to be used are those in which the upper reach watercourses are swales, and the well defined drainage networks are limited to the lower parts of the basins. Overbank flow conditions have shallow flow and high flow resistance. The recommended Great Plains unit hydrographs are provided in Tables 4-7 or 4-8 of Cudworth (1989).
- Colorado Plateau – The high plateau region of western Colorado. Watersheds and modeling sub-basins for which the Colorado Plateau unit hydrograph is to be used are arid regions of western Colorado with sparse vegetation, fairly well defined drainage networks, and terrain varying from rolling to very rugged in the more mountainous areas. The recommended Colorado Plateau unit hydrographs are provided in Tables 4-13 and 4-14 of Cudworth (1989).
- Agricultural Fields
- Urban

The recommended types of synthetic unit hydrographs for use in estimating inflow design floods in Colorado are shown in Table 1. The Clark unit hydrograph is recommended for urban watersheds and smaller (less than 50-square mile) predominantly agricultural watersheds. Dimensionless unit hydrographs and S-graphs are recommended for Rocky Mountain, Great Plains and Colorado Plateau watersheds. The Clark unit hydrograph can be an acceptable alternative for small (less than 10-square mile) watersheds of those types and when verification studies indicate that the Clark unit hydrograph yields more reasonable results than the dimensionless or S-graphs.

Table 1

Selection of synthetic unit hydrographs for use in estimating inflow design floods in Colorado

Watershed Type	Dimensionless Unit Hydrograph or S-graph	Clark Unit Hydrograph
Rocky Mountain	Preferred	Acceptable Alternative
Great Plains	Preferred	Acceptable Alternative
Colorado Plateau	Preferred	Acceptable Alternative
Agricultural	Not Recommended except for agricultural watersheds larger than 50 square miles	Preferred
Urban	Not Recommended	Preferred

Clark Unit Hydrograph Parameter Estimation

The Clark unit hydrograph is a three parameter method; time of concentration (T_c), storage coefficient (R), and the time-area relation. Equations for estimating T_c and R were estimated from an analysis of all relevant watershed data (Sabol, 1987 and 1993), and synthetic time-area relations are available.

Time of Concentration: Time of concentration is the travel time, during the corresponding period of most intense rainfall excess, for a floodwave to travel from the hydraulically most distant point in the watershed to the point of interest (concentration point). Three time of concentration (T_c) equations are recommended depending on the type of watershed:

Rocky Mountain, Great Plains and Colorado Plateau

$$T_c = 2.4\,A^{.1}\,L^{.25}\,L_{ca}^{.25}\,S^{-.2}$$

Agricultural

$$T_c = 7.2\ A^{.1}\ L^{.25}\ L_{ca}^{.25}\ S^{-.2}$$

Urban

$$T_c = 3.2\ A^{.1}\ L^{.25}\ L_{ca}^{.25}\ S^{-.14}\ RTIMP^{-.36}$$

where T_c = time of concentration, in hours
A = area, in square miles
S = watercourse slope, in ft/mile
L = length of the watercourse to the hydraulically most distant point, in miles
L_{ca} = length measured from the concentration point along L to a point on L that is perpendicular to the watershed centroid, in miles, and
RTIMP = effective impervious area, in percent. (Note: RTIMP must be greater than 1 percent.)

In using those T_c equations, the following points should be noted and observed:

1. The area (A) is determined from the best available map. The delineation of the drainage boundary needs to be carefully performed, and special care must be taken where there is little topographic relief. In urban areas, land grading and road construction can produce drainage boundaries that separate runoff from contributing areas during small and lower intensity storms. However, larger and more intense storms, such as the design storm for an inflow design flood, can produce runoff depths that can cross those intermediate drainage boundaries resulting in a larger total contributing area. For urban watersheds, it is generally prudent to consider the largest reasonable drainage area.
2. Determination of the hydraulically most distant point will define both L and S. Often, the hydraulically most distant point is determined as the point along the watershed boundary that has the longest flow path to the watershed outlet (or subbasin concentration point). This is generally true where the topography is relatively uniform throughout the watershed. However, there are situations

where the longest flow path (L) does not define the hydraulically most distant point. Occasionally, especially in mountainous areas, a point with a shorter flow path may have an appreciably flatter slope (S) such that the shorter flow path defines the hydraulically most distant point. For watersheds with multiple choices for the hydraulically most distant point, the T_c should be calculated for each point and the largest T_c should be used.

3. Slope (S) is the average slope calculated by dividing the difference in elevation between the hydraulically most distant point and the watershed outlet by the watercourse length (L). This method will usually be used to calculate S. However, there are situations where special consideration should be given to calculating S and to dividing the watershed into subbasins. For example, if there is dramatic change in watercourse slope throughout the watershed, then the use of a multiple subbasin model should be considered with change in watercourse slope used in delineating the subbasins. There will also be situations where the watercourse contains vertical or nearly vertical drops (mountain rims, headcuts, rock outcrop, and so forth). In these situations, plotting of the watercourse profile will usually identify nearly vertical changes in the watercourse. When calculating the average slope, subtract the accumulative elevation differential that occurs in nearly vertical drops from the overall elevation differential prior to calculating S.
4. L_{ca} is measured along L to a point on L that is essentially perpendicular to the watershed centroid. This is a shape factor in the T_c equation. Occasionally, the shape of agricultural fields or urban subbasins is nearly rectangular and this may result in two different dimensions for L_{ca}. In the case of such nearly rectangular (and therefore, nearly symmetrical) watersheds or subbasins L_{ca} can usually be satisfactorily estimated as ½ L.
5. RTIMP is the effective impervious area and is used to estimate T_c for urban watersheds only. RTIMP is the same value that is used to estimate rainfall losses for the watershed. The calculation of T_c for urban watersheds is very sensitive to RTIMP as illustrated in the following;

RTIMP	% reduction in urban T_c
2	22
5	44
10	56
20	66
40	73
60	77
80	79
100	81

Therefore care must be exercised in estimating RTIMP using the best available information such as high resolution aerial photographs.

6. Ideally, the selection of the watershed or subbasin boundaries can be made so that the area represents a hydrologically uniform region that is essentially all one physiographic type and for those situations, the appropriate T_c equation is applied. However, there will be situations where the watershed or modeling subbasin is a mixture of two or more physiographic types. In those cases, the T_c equation is selected based on the watershed type that contains the greatest portion of L. The effects of a mixture of watershed physiographic types can be partially accounted for by the selection of the time-area relation.

Storage Coefficient: The storage coefficient relates the effects of direct runoff storage in the watershed to unit hydrograph shape. The equation for estimating the storage coefficient (R) is:

$$R = 0.37\ T_c^{1.11}\ L^{.80}\ A^{-.57}$$

where R is in hours and the variables are as defined for the T_c equations.

Time-Area Relation: The time-area relation is a graphical parameter that specifies the accumulated area of the watershed that contributes runoff to the outlet of the watershed at any time. Two methods can be used to develop a time-are relation: 1) by analysis of the watershed to define incremental runoff producing areas that have equal incremental travel times to the outflow location, or 2) by use of synthetic time-area relations. The development of a time-area relation by analysis of the watershed is a difficult task and well-defined and reliable procedures for that task are not available. Unless the watershed has an extremely unusual shape, or has several distinct areas of dramatically different land-use, this analysis should not be undertaken. In general, synthetic time-area relations can be used in Colorado.

The dimensionless, synthetic time-area relations that can be used in Colorado are shown in Figure 1 and the coordinate values of the curves are listed in Table 2. Curve A should be used if the watershed or subbasin physiographic type is urban or predominantly urban. Curve C should be used if the watershed or subbasin is mostly undeveloped mountains and/or plains possibly with some interspersed agricultural fields. Curve B should be used for all other situations.

Curve B is the default time-area relation in HEC-1 and will be used with the Clark unit hydrograph if a time-area relation (UA record) is not supplied. Curves A and C are dimensionless and those curves are input to HEC-1 by inserting the percent of total area values from Table 2 in the UA record.

Table 2

Values of the Dimensionless Synthetic Time-Area Relations for the Clark Unit Hydrograph

Travel Time, as a percent of T_c (1)	Contributing Area, as a Percent of Total Area[a] A (2)	B^b (3)	C (4)
0	0	0.0	0
10	5	4.5	3
20	16	12.6	5
30	30	23.2	8
40	65	35.8	12
50	77	50.0	20
60	84	64.2	43
70	90	76.8	75
80	94	87.4	90
90	97	95.5	96
100	100	100.0	100

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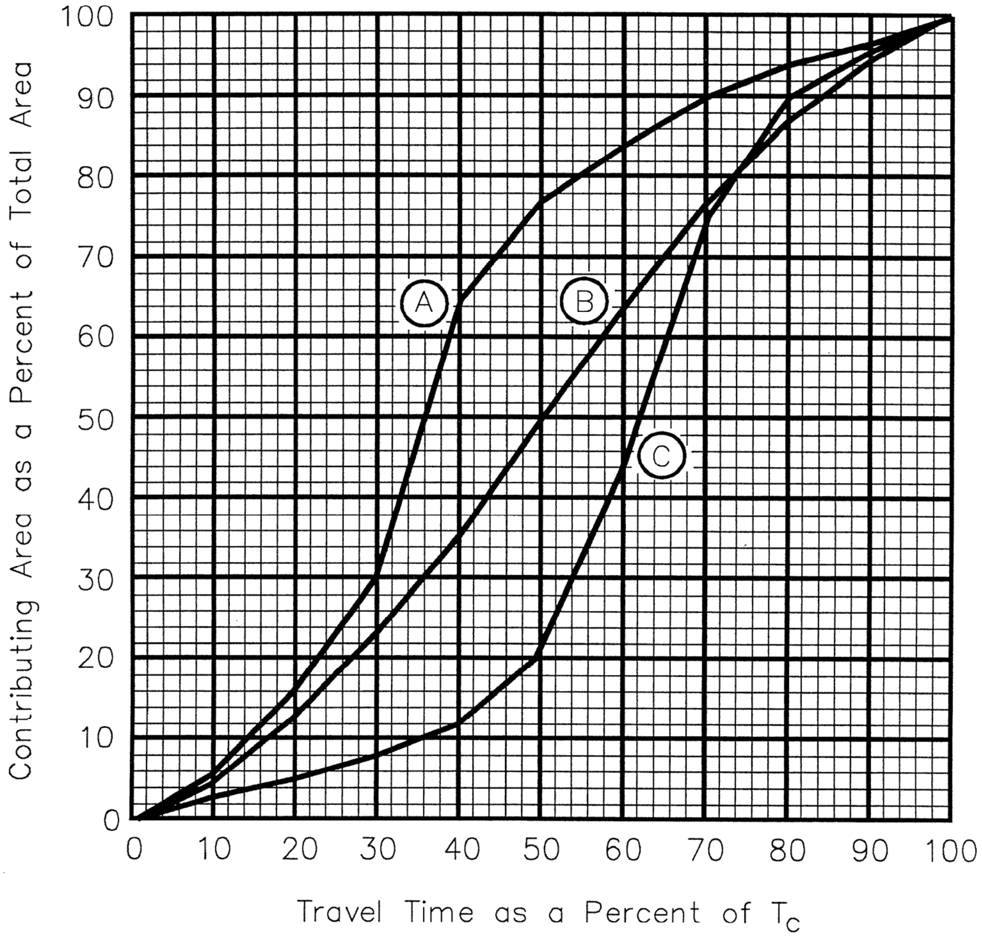
[a] - The dimensionless Synthetic Time-Area relations should be selected as follows:
A - The land-use in the watershed or subbasin is urban or predominantly urban.
B - All watersheds or subbasins other than those defined for use of curves A or C.
C - The watershed or subbasin is mostly undeveloped mountains and/or plains with some interspersed agricultural fields.

[b] - Curve B is the HEC-1 default Time-Area relation and the UA record is not needed as input to the HEC-1 model when using Curve B.

Figure 1
Synthetic Time-Area Relation



Curve A– Urban
Curve B– HEC-1 Default Relation
Curve C— Mountains/Plains

Dimensionless Unit Hydrographs and Estimation of Lag

A variety of dimensionless unit hydrographs and S-graphs (a form of dimensionless unit hydrograph) are available for use in flood hydrology studies. The U.S. Bureau of Reclamation (USBR) *Flood Hydrology Manual* (Cudworth, 1989) provides a few selected dimensionless unit hydrographs and S-graphs. Those that are recommended for use in Colorado are provided by Cudworth in Table 4-7 and Table 4-8 for the Great Plains (generally east of the Front Range); Table 4-9 and Table 4-10 for general storms in the Rocky Mountains; Table 4-11 and Table 4-12 for high intensity thunderstorms in the Rocky Mountains; Table 4-13 and Table 4-14 for the Colorado Plateau of western Colorado; and Table 4-17 and Table 4-18 for urban watersheds. A more extensive compilation of S-graphs, some of which are applicable for use in Colorado, is provided by Sabol (1987). For the USBR dimensionless unit hydrographs and S-graphs, the single parameter that defines the coordinates of the unit hydrograph is Lag.

Lag: The unit hydrograph Lag is estimated by:

$$Lag = 26\, K_n \left(\frac{L L_{ca}}{S^{0.5}} \right)^{0.33}$$

Lag = lag time, in hours

L = distance of longest watercourse, in miles

L_{ca} = distance from point of interest (basin or subbasin outlet) to a point opposite the centroid of the drainage basin (or subbasin), in miles

S = overall slope of L measured from the point of interest to the drainage basin divide, in feet per mile, and

K_n = a lumped parameter representing the resistance to overland flow from the drainage basin incorporating a weighting of the various components of flow resistance along the entire L flow path.

The definition and measurement of L, L_{ca} and S are the same as previously discussed for the Clark unit hydrograph. The value of K_n is selected by considering the hydrologic conditions of the watershed (or subbasin) of interest to watersheds of similar hydrologic conditions for which K_n values are available. Calculated values of K_n for various watersheds are presented in the literature by agencies such as the USBR and the U.S. Army Corps of Engineers.

The intent herein is to provide guidance in the selection of K_n values for use in estimating Lag when performing inflow design flood studies for dams in Colorado.

Guidance is provided for estimating K_n for use in Colorado for the following physiographic types of watersheds:

- Rocky Mountain
- Colorado Plateau
- Great Plains
- Agricultural
- Urban

K_n for Rocky Mountain, Great Plains and Colorado Plateau Watersheds: All available Lag, watershed characteristics and K_n data for Colorado watersheds are listed in Tables 3 and 4. Two of the data are for locations in New Mexico but the watersheds lie mostly in Colorado and are therefore included in the data set. Those data are obtained from Sabol (1987). Table 3 lists the data according to increasing watershed size and Table 4 lists the same data according to increasing K_n. The 20 watersheds are classified as to type; 13 in the Rocky Mountains (RM), six in the Great Plains (GP) and one in the Colorado Plateau (CP). The storm type is identified for the Rocky Mountain watersheds using information in Table 4-2 and Figure 4-7 of Cudworth (1989) as to thunderstorm (T) or general storm (G). Five of the Rocky Mountain data are for thunderstorms, five are for general storms, and three are of unknown storm type. Measured values of $LL_{ca}/S^{.0.5}$ versus Lag are plotted in Figure 2 for all 20 data points.

Table 3
Lag Data for use with Colorado Watersheds

Listed according to increasing watershed size

	River	**A**	**L**	**L_{ca}**	**S**	**$\frac{LL_{ca}}{S^{1/2}}$**	**Lag**	**K_n**	**Class[1]**	**Storm[2]**
		sq. miles	miles	miles	ft/mile		hours			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1.	N Fk Big Thompson R nr Glen Haven, CO	1.3	1.9	1.3	709.0	0.093	0.7	0.058	RM	T
2.	Dry Gulch nr Estes Park, CO	2.1	2.7	1.0	295.0	0.157	0.9	0.059	RM	T
3.	Rabbit Gulch nr Estes Park, CO	3.4	3.3	1.5	480.0	0.226	1.0	0.065	RM	T
4.	Buckhorn Ck nr Masonville, CO	6.9	6.4	3.4	312.0	1.23	1.0	0.036	GP	
5.	Willow Ck nr Lamar, CO	40.5	—	—	—	13.3	2.5	0.041	GP	
6.	Surface Ck nr Cedaredge, CO	43.0	—	—	—	11.3	11.3	0.195	RM	G
7.	Jimmy Camp Ck nr Widefield, CO	54.3	—	—	—	12.2	1.8	0.030	GP	
8.	Florida R nr Hermosa, CO	69.4	—	—	—	12.5	15.5	0.259	RM	G
9.	Dry Ck nr Lamar, CO	73.0	—	—	—	27.9	3.1	0.040	GP	
10.	Clay Ck nr Lamar, CO	213.0	—	—	—	129.0	5.2	0.040	GP	
11.	Los Pinos R nr Bayfield, CO	284.0	—	—	—	35.0	28.5	0.339	RM	G
12.	San Juan R at Pagosa Spgs, CO	298.0	23.9	10.8	254.8	16.2	4.0	0.061	RM	NA
13.	Black Squirrel Ck nr Ellicot, CO	353.0	—	—	—	92.9	3.5	0.030	GP	
14.	Plateau Ck nr Cameo, CO	604.0	49.7	20.8	131.7	90.1	7.9	0.069	CP	
15.	Purgatoire R at Trinidad, CO	742.0	44.0	20.0	159.0	69.8	8.0	0.076	RM	T
16.	Dolores R nr McPhee, CO	793.0	61.5	30.8	96.0	193.3	9.0	0.061	RM	T
17.	San Miguel R at Nuturita, CO	1,080.0	—	—	—	174	34.0	0.238	RM	G
18.	Uncompaghre R at Delta, CO	1,110.0	—	—	—	216	36.0	0.235	RM	G
19.	Animas R at Farmington, NM	1,360.0	106.3	55.2	72.4	689.6	12.9	0.057	RM	NA
20.	San Juan R at Rosa, NM	1,990.0	62.1	30.5	110.2	180.4	8.8	0.061	RM	NA

1 RM – Rocky Mountain
GP – Great Plains
CP – Colorado Plateau
2 T – Thunderstorm
G – General Storm

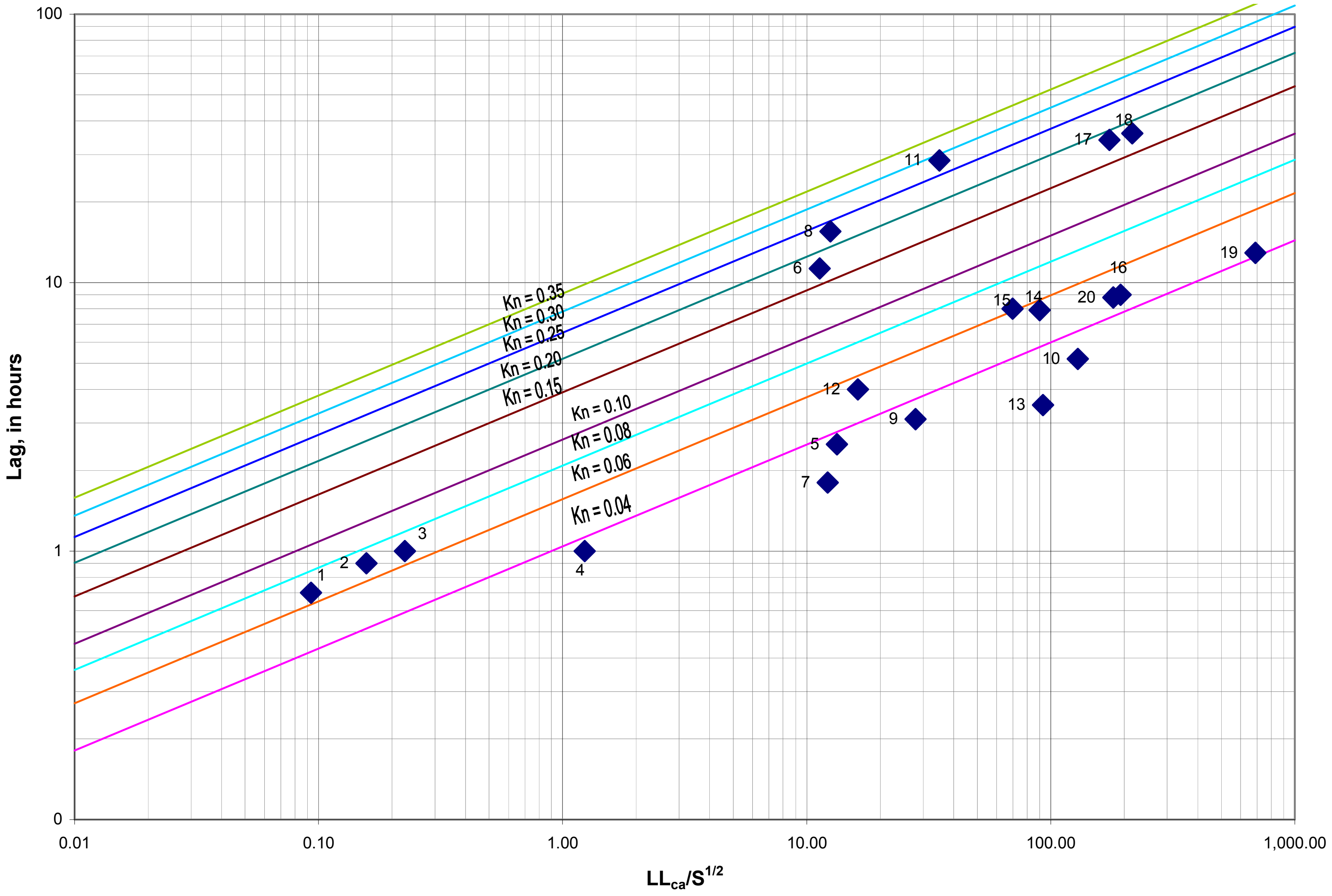
Table 4
Lag Data for use with Colorado Watersheds
Listed according to increasing K_n value

	River	A	L	L_{ca}	S	$\frac{LL_{ca}}{S^{1/2}}$	Lag	K_n	Class[1]	Storm[2]
		sq. miles	miles	miles	ft/mile		hours			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
7.	Jimmy Camp Ck nr Widefield, CO	54.3	—	—	—	12.2	1.8	0.030	GP	
13.	Black Squirrel Ck nr Ellicot, CO	353.0	—	—	—	92.9	3.5	0.030	GP	
4.	Buckhorn Ck nr Masonville, CO	6.9	6.4	3.4	312.0	1.23	1.0	0.036	GP	
9.	Dry Ck nr Lamar, CO	73.0	—	—	—	27.9	3.1	0.040	GP	
10.	Clay Ck nr Lamar, CO	213.0	—	—	—	129.0	5.2	0.040	GP	
5.	Willow Ck nr Lamar, CO	40.5	—	—	—	13.3	2.5	0.041	GP	
19.	Animas R at Farmington, NM	1,360.0	106.3	55.2	72.4	689.6	12.9	0.057	RM	NA
1.	N Fk Big Thompson R nr Glen Haven, CO	1.3	1.9	1.3	709.0	0.093	0.7	0.058	RM	T
2.	Dry Gulch nr Estes Park, CO	2.1	2.7	1.0	295.0	0.157	0.9	0.059	RM	T
12.	San Juan R at Pagosa Spgs, CO	298.0	23.9	10.8	254.8	16.2	4.0	0.061	RM	NA
16.	Dolores R nr McPhee, CO	793.0	61.5	30.8	96.0	193.3	9.0	0.061	RM	T
20.	San Juan R at Rosa, NM	1,990.0	62.1	30.5	110.2	180.4	8.8	0.061	RM	NA
3.	Rabbit Gulch nr Estes Park, CO	3.4	3.3	1.5	480.0	0.226	1.0	0.065	RM	T
14.	Plateau Ck nr Cameo, CO	604.0	49.7	20.8	131.7	90.1	7.9	0.069	CP	
15.	Purgatoire R at Trinidad, CO	742.0	44.0	20.0	159.0	69.8	8.0	0.076	RM	T
6.	Surface Ck nr Cedaredge, CO	43.0	—	—	—	11.3	11.3	0.195	RM	G
18.	Uncompaghre R at Delta, CO	1,110.0	—	—	—	216	36.0	0.235	RM	G
17.	San Miguel R at Nuturita, CO	1,080.0	—	—	—	174	34.0	0.238	RM	G
8.	Florida R nr Hermosa, CO	69.4	—	—	—	12.5	15.5	0.259	RM	G
11.	Los Pinos R nr Bayfield, CO	284.0	—	—	—	35.0	28.5	0.339	RM	G

1 RM – Rocky Mountain
GP – Great Plains
CP – Colorado Plateau
2 T – Thunderstorm
G – General Storm

Figure 2

K_n Data for Colorado Watersheds



Analysis of the data in Tables 3 and 4 and Figure 2 results in the following recommendations:

Rocky Mountain K_n

For severe thunderstorms, K_n ranges from 0.058 to 0.076. That is consistent with the range of K_n from Figure 4-7 (Cudworth, 1989) where the thunderstorm K_n ranges from 0.050 to 0.073 for all Rocky Mountain watersheds. FOR THUNDERSTORMS IN ROCKY MOUNTAIN WATERSHEDS OF COLORADO A K_n OF 0.05 to 0.08 IS A REASONABLE RANGE FOR THE PMF. Selection of K_n depends on flow retarding factors of the watershed and main watercourses. Sparse vegetation, steep slopes, hydraulically "smooth" watercourses and well defined banks with minimal overbank flow all tend to minimize K_n.

For general storms, K_n ranges from 0.195 to 0.339. That is consistent with the range of K_n from Figure 4-7 (Cudworth, 1989) where the general storm K_n ranges from 0.130 to 0.260 for all Rocky Mountain watersheds. FOR GENERAL STORMS IN ROCKY MOUNTAIN WATERSHEDS OF COLORADO, A K_n OF 0.15 to 0.30 IS A REASONABLE RANGE FOR THE PMF. Selection of K_n depends on flow retarding factors of the watershed and main watercourses. Sparse vegetation, steep slopes, hydraulically "smooth" watercourses and well defined banks with minimal overbank flow all tend to minimize K_n.

More frequent design storms (100-year) are typically assumed to occur as thunderstorm cells within a general storm and those are often modeled as the 24-hour rainfall hypothetical distribution. Under those modeling assumptions IT IS REASONABLE TO USE THE ROCKY MOUNTAIN THUNDERSTORM DIMENSIONLESS UNIT HYDROGRAPH OR S-GRAPH WITH A K_N OF 0.20 TO 0.30 as discussed above for the less intense general storm runoff conditions.

Great Plains K_n

For Great Plains watersheds in Colorado, K_n ranges from 0.030 to 0.041. That is consistent with the range of K_n from Figure 4-6 (Cudworth, 1989) where K_n ranges from 0.030 to 0.069 for all Great Plains watersheds. FOR PLAINS AND MOUNTAIN VALLEY WATERSHEDS OF COLORADO, A K_n OF 0.04 to 0.07 IS A REASONABLE RANGE FOR THE 100-YEAR FLOOD, 0.03 to 0.06 FOR THE THUNDERSTORM PMF AND 0.04 to 0.07 FOR THE GENERAL STORM PMF.

Colorado Plateau K_n

The only Colorado Plateau data that is available for a watershed in Colorado has a K_n of 0.069. The range of K_n for all Colorado Plateau, Great Basin and Southwest Desert watersheds from Figure 4-8 (Cudworth, 1989) is from 0.042 to 0.070. FOR WESTERN RANGELAND WATERSHEDS OF COLORADO, A K_n OF 0.05 to 0.07 IS A REASONABLE RANGE FOR THE 100-YEAR FLOOD, 0.04 to 0.06 FOR THE THUNDERSTORM PMF AND 0.05 to 0.07 FOR THE GENERAL STORM PMF.

It is noted that the value of K_n should be selected based on site specific data, or regional data, or an evaluation of K_n data for a similar watershed, but lacking such data, the recommended K_n values should provide reasonable results.

K_n for Agricultural Watersheds: No lag data exists for watersheds that are entirely agricultural. Data exists for three watersheds near Lamar, Colorado, that have extensive agricultural area associated with them. Those watersheds have drainage areas from 40 to more than 200 square miles and the K_n values for those three watersheds are all about 0.04. Previous research by the author (Sabol, 1993) indicates that the K_n value for small, homogeneous agricultural fields are in the range 0.06 to 0.09. A smaller value of K_n is expected for larger drainage areas where a significant portion of the flow path, L, is a defined watercourse. Recommended values of K_n for agricultural watersheds or subbasins are shown in Table 5.

Table 5

Recommended Values of K_n for Agricultural Drainage Basins

A	Large, nonhomogeneous area consisting of discrete agricultural fields connected by a defined watercourse network	$K_n = 0.04$
B	Relatively large, homogeneous agricultural field(s) with a poorly defined drainage network	$K_n = 0.06$
C	Small, homogeneous agricultural field	$K_n = 0.09$

K_n for Urban Watersheds: A listing of all known K_n data for urban watersheds is shown in Table 6. Those data were compiled (Sabol, 1987 and 1993) for urban watersheds throughout the United States, and since the hydrologic response of urban watersheds to rainfall is somewhat independent of geographic location, those data, regardless of location, are deemed useful for selecting K_n values for use in Colorado.

There are 43 sets of urban data in Table 6. The K_n values range from a minimum of 0.0113 to a maximum of 0.1029, with a mean of 0.0313 and a sample standard deviation of 0.0200. The last three data sets in Table 6 have unexpectedly high K_n values, and the exclusion of those three high data sets results in a maximum of 0.0596, mean of 0.0267 and sample standard deviation of 0.0107.

Table 6

Lag and K_n Data for Urban Watersheds

(K_n values sorted by ascending order)

Watershed	Location	A (sq. miles	L (miles)	Lca (miles)	S (ft/mi)	RTIMP (%)	L*Lca / S^.5	Lag (hrs)	kn
Concourse D	Denver, CO	0.150	0.97	0.43	a	a	b	0.24	b
Southwest Outfall	Louisville, KY	7.500	6.50	2.70	18.5	33.0	4.0803	0.50	0.0113
Alhambra Wash above Short St.	Monterey Park, CA	14.000	9.50	4.60	85.0	40.0	4.7399	0.60	0.0128
Brays Bayou	Houston, TX	88.400	23.30	10.40	4.1	40.0	119.6733	2.10	0.0131
Broadway Drain at Raymond Dike	L.A., CA	2.500	3.40	1.70	100.0	45.0	0.5780	0.30	0.0142
Southern Outfall	Louisville, KY	6.400	6.40	2.50	13.0	48.0	4.4376	0.70	0.0153
Northwest Trunk	Louisville, KY	1.900	3.00	1.10	19.0	50.0	0.7571	0.40	0.0171
Villa Del Oso	Albuquerque, NM	0.052	0.54	0.27	111.0	16.4	0.0138	0.09	0.0176
Beargrass Cr.	Louisville, KY	9.700	5.60	2.50	6.3	70.0	5.5777	0.90	0.0180
White Oak Bayou	Houston, TX	92.000	23.10	12.80	5.0	35.0	132.2321	3.10	0.0186
Taylor Ranch	Albuquerque, NM	0.136	0.55	0.23	25.0	9.6	0.0253	0.12	0.0187
Academy Acres	Albuquerque, NM	0.124	0.90	0.53	100.0	16.3	0.0477	0.16	0.0196
17th Street Sewer	Louisville, KY	0.200	0.90	0.30	48.0	93.0	0.0390	0.15	0.0198
Ballomna Cr. at Sawtelle Blvd.	L.A., CA	88.600	11.80	5.60	64.0	40.0	8.2600	1.20	0.0207
Sand Creek	Denver, CO	0.290	0.84	0.21	41.0	24.0	0.0275	0.14	0.0211
116 Ave & Claude Ct.	Denver, CO	0.260	1.16	0.49	69.0	13.3	0.0684	0.21	0.0224
Sand Creek	Denver, CO	0.290	0.84	0.21	41.0	24.0	0.0275	0.15	0.0226
High School Wash	Tucson, AZ	0.950	1.60	0.75	58.0	10.7	0.1576	0.30	0.0233
Beargrass Cr.	Louisville, KY	6.300	4.00	1.80	4.5	20.0	3.3941	1.00	0.0242
Walker Avenue Drain	Baltimore, MD	0.200	1.00	0.40	83.0	33.0	0.0439	0.20	0.0252
Villa Del Oso	Albuquerque, NM	0.052	0.54	0.27	111.0	16.4	0.0138	0.13	0.0254
Arcadia	Tuscon, AZ	2.720	3.85	2.25	42.0	13.9	1.3367	0.75	0.0258
Little Pimmit Run	Arlington, VA	2.300	2.20	1.00	77.0	20.0	0.2507	0.40	0.0260
San Jose Cr. at Workman Mill Rd	Whittier, CA	81.300	23.70	9.10	75.0	35.0	24.9034	2.40	0.0272
Arcadia, Part 2	Tucson, AZ	2.720	3.85	2.25	42.0	13.9	1.3367	0.81	0.0279
Boneyard Cr.	Austin, TX	4.500	2.80	1.30	9.5	37.0	1.1810	0.80	0.0289
Arcadia, Part 1	Tucson, AZ	2.720	3.85	2.25	42.0	13.9	1.3367	0.84	0.0289
Compton Cr. below Hooper Ave Storm Drain	L.A., CA	19.500	8.80	4.20	14.6	60.0	9.6729	1.80	0.0292
Arcadia	Tucson, AZ	2.720	3.85	2.25	42.0	13.9	1.3367	0.90	0.0310
Four Mile Run	Alexandria, VA	14.400	7.80	3.50	43.0	20.0	4.1632	1.40	0.0313
Tripps Run	Falls Church, VA	1.800	2.30	1.00	79.0	25.0	0.2588	0.50	0.0321
Villa Italia	Denver, CO	0.120	0.67	0.33	100.0	77.0	0.0221	0.20	0.0327
High School Wash	Tuscon, AZ	0.950	1.60	0.75	58.0	10.7	0.1576	0.43	0.0334
Waller Cr.	Austin, TX	4.100	5.20	1.90	48.0	27.0	1.4261	1.00	0.0336
Tripps Run	near Falls Church, VA	4.600	4.10	1.90	52.0	28.0	1.0803	0.90	0.0336
Academy Acres	Albuquerque, NM	0.124	0.90	0.53	100.0	16.3	0.0477	0.29	0.0354
Piney Branch	Vienna, VA	0.300	0.50	0.20	87.0	30.0	0.0107	0.20	0.0431
Railroad	Tucson, AZ	2.300	2.30	1.48	46.0	17.0	0.5019	0.89	0.0445
Railroad	Tucson, AZ	2.300	2.30	1.48	46.0	17.0	0.5019	1.10	0.0550
Goose Creek	Denver, CO	1.340	1.34	0.60	74.0	15.4	0.0935	0.63	0.0596
Atterbury	Tucson, AZ	4.970	6.67	3.87	26.0	3.0	5.0623	3.42	0.0710
Aqua Fria R. trib. (Sept, 1970)	Phoenix, AZ	0.130	0.77	0.39	16.0	25.0	0.0751	0.96	0.0988
Aqua Fria R. trib. (Sept, 1970)	Phoenix, AZ	0.130	0.77	0.39	16.0	25.0	0.0751	1.00	0.1029
	Maximum	92.000	23.70	12.80	111.0	93.0	132.2321	3.42	0.1029
	Minimum	0.052	0.50	0.20	4.1	3.0	0.0107	0.09	0.0113
	Mean	11.071	4.57	2.16	51.0	29.1	8.0720	0.81	0.0313
	Standard Deviation	25.179	5.88	2.75	32.3	19.1	27.0547	0.77	0.0200

The lowest value of K_n is 0.0113 which is for Concourse D of Stapleton International Airport, Denver, Colorado. That was a small (0.15 square mile, 96 acre) fully concrete covered drainage area. There are four large urban watersheds with drainage areas in excess of 80 square miles in Table 6. The K_n values for those large urban areas range from 0.0131 to 0.0272 with an average of 0.020.

In addition to L, L_{ca} and S, Table 6 lists the percent impervious area (RTIMP) for each urban watershed. Previous research (Sabol, 1993) indicates that K_n is independent of percent impervious area as well as each of the other variables listed in that table. Due to the variability of K_n for urban watersheds and lack of a means to estimate K_n for urban watersheds, the use of the USBR urban dimensionless unit hydrograph is not recommended. The Clark unit hydrograph is recommended for urban watersheds and subbasins. At best, only general conclusions, as listed below, can be reached from the urban K_n data:

A. For large, homogeneous urban areas, the use of $K_n = 0.015$ is reasonable.
B. K_n for urban areas should not exceed 0.02 unless adequately documented.
C. K_n may be as low as 0.01 for small, highly urbanized drainage areas.

Summary Of Unit Hydrograph Selection And Recommended K_n Values

The recommended unit hydrograph and K_n values to be used with selected dimensionless unit hydrographs are presented in Table 7. It is noted and cautioned that these are typical K_n values based on regional classifications. Every watershed varies according to vegetation, landform and other factors which dictate the actual value of K_n. Therefore, site specific data, watershed observations and experienced hydrologic judgment must be applied in selecting K_n for use with dimensionless unit hydrographs. The values in Table 7 are presented as reasonable values for review and as quality assurance guidelines.

TABLE 7

Summary of Unit Hydrographs and Kn Values for Colorado Watersheds

Watershed Type (1)	**Recommended Unit Hydrograph** (2)	**K_n for Dimensionless Unit Hydrograph**			
		Range (3)	**100-yr[1]** (4)	**PMF Thunderstorm** (5)	**PMF General Storm** (6)
Mountains (PMP thunderstorm)	Dimensionless Rocky Mountain Thunderstorm	0.05-0.08	NA	0.05-0.08	NA
Mountains (PMP general storm)	Dimensionless Rocky Mountain General Storm	0.15-0.30	NA	NA	0.15-0.30
Mountains (100-year)	Dimensionless Rocky Mountain Thunderstorm	0.20-0.30	0.20-0.30	NA	NA
Rangelands of western Colorado	Dimensionless Colorado Plateau	0.04-0.07	0.05-0.07	0.04-0.06	0.05-0.07
Valleys ("Parks") within mountains	Dimensionless Great Plains	0.03-0.07	0.04-0.07	0.03-0.06	0.04-0.07
Western Colorado, arid Plateau	Dimensionless Colorado Plateau	0.04-0.07	0.05-0.07	0.04-0.06	0.05-0.07
Plains of Front Range	Dimensionless Great Plains	0.03-0.07	0.04-0.07	0.03-0.06	0.04-0.07
Agricultural Fields	Clark Unit Hydrograph	NA	NA	NA	NA
Urban	Clark Unit Hydrograph	NA	NA	NA	NA

Notes:

[1] – It is assumed that for the 100-year storm the 24-hour hypothetical rainfall distribution is used. That rainfall distribution simulates high intensity thunderstorm rainfall within a long-term general storm.

Instructions

1. Delineate the watershed boundaries on an appropriate watershed base map.
2. Trace the paths of the major watercourses in the watershed on the base map.
3. If the watershed has more than one physiographic type, define the areas of the different types:
    - Rocky Mountain
    - Great Plains
    - Colorado Plateau
    - Agricultural
    - Urban
4. Determine whether the watershed can be treated as a single, hydrologically homogeneous watershed, or if it must be divided into modeling subbasins. This decision should consider the following factors:
    - topography (and watercourse)
    - land-use,
    - diversity of soil texture,
    - occurrence of rock outcrop,
    - existence of drainage and flow control structures within the watershed (detention/retention basins, elevated highway cross-drainage structures, channelized and improved watercourses, etc.), and
    - shape of watershed.

5. If the watershed is to be divided into modeling subbasins, use the information from Steps 2, 3, and 4 to delineate the subbasin boundaries.

6. For the watershed or each modeling subbasin, determine the following:

    A - area, in square miles
    L - length of the flow path to the hydraulically most distant point, in miles
    L_{ca} - length along L to a point opposite the centroid, in miles
    S - average slope of L, in ft/mile

RTIMP - effective impervious area, in percent, for urban watersheds or subbasins.

For the Clark unit hydrograph, continue with steps 7 through 10. For dimensionless unit hydrographs or S-graphs proceed to Step 11.

7. Calculate Tc depending on the type of watershed:

Rocky Mountain, Great Plains or Colorado Plateau

$$T_c = 2.4\ A^{.1}\ L^{.25}\ L_{ca}^{.25}\ S^{-.2}$$

Agricultural

$$T_c = 7.2\ A^{.1}\ L^{.25}\ L_{ca}^{.25}\ S^{-.2}$$

Urban

$$T_c = 3.2\ A^{.1}\ L^{.25}\ L_{ca}^{.25}\ S^{-.14}\ RTIMP^{-.36}$$

8. Calculate R:

$$R = 0.37\ T_c^{1.11}\ L^{.80}\ A^{-.57}$$

9. Enter the values of T_c and R in the UC record for the watershed or each subbasin.
10. Determine whether the time-area relation will be developed from an analysis of the watershed or whether a dimensionless synthetic time-area relation will be used.
    a. If the time-area relation is to be determined by analytic means, proceed with the analysis and input the incremental areas (or percentages of total area) in the UA record.
    b. If the dimensionless synthetic time-area relations are to be used (Figure 1 and Table 2),
        i. use the values for Curve A in the UA record if the watershed or subbasin is urban or predominantly urban,
        ii. use the values for Curve C in the UA record if the watershed or subbasin is undeveloped Rocky Mountains or Great Plains or Colorado Plateau possibly with some interspersed agricultural fields, and
        iii. use Curve B for all other applications (Curve B is the HEC 1 default relation and the UA record is not needed).

11. Use Table 7 to select the appropriate dimensionless unit hydrograph and for guidance in selecting K_n.

12. Calculate $Lag = 26\ K_n \left(\frac{LL_{ca}}{S^{0.5}} \right)^{0.33}$.

<u>Duration:</u> The duration of the unit hydrograph (or <u>all</u> unit hydrographs in a multiple subbasin model) is specified in HEC-1 in the IT record as NMIN. In general, NMIN will be selected according to the following criteria:

1. NMIN equal to or less than 0.15 T_c or 0.15 Lag provides adequate definition of the hydrograph peak with an optimum number of hydrograph coordinate calculations.
2. NMIN = 0.25 T_c or 0.25 Lag is the maximum value for NMIN.
3. NMIN for a multiple subbasin model should be selected based on the smallest T_c value for any of the subbasins in the model.

SECTION 3: RAINFALL LOSSES

Green & Ampt Infiltration Equation

Introduction: This model, first developed in 1911 by W.H. Green and G.A. Ampt, has since the early 1970's received increased interest for estimating rainfall infiltration losses. A sound and concise explanation of the Green and Ampt equation is provided by Bedient and Huber (1988). Use of the Green and Ampt equation as coded in HEC-1 involves the simulation of rainfall loss as a two phase process, as illustrated in Figure 3. The first phase is the simulation of the surface retention loss. This loss is called the initial loss (IA) in HEC-1. During this first phase, all rainfall is lost (zero rainfall excess generated) during the period from the start of rainfall up to the time that the accumulated rainfall equals the value of IA. It is assumed, for modeling purposes that no infiltration of rainfall occurs during the first phase. The second phase of the rainfall loss process is the infiltration of rainfall into the soil matrix. For modeling purposes, the infiltration begins immediately after the surface retention loss (IA) is completely satisfied, as illustrated in Figure 3.

Applicability: The Green and Ampt equation should be applied for the one percent storm (100-year) and more frequent storms. This method is also suitable for use with less frequent storms but the parameters IA and volumetric storage of infiltrated rainfall may not be significant for large rainfall amounts associated with storms less frequent than the one percent storm.

Method Description: The first phase of the rainfall loss process is simulated with the IA parameter. Values of IA for various land surfaces in Colorado are shown in Table 8 for natural areas and Table 9 for developed areas. The second phase of the rainfall loss estimation process is simulated with the Green and Ampt equation and an estimate of watershed impervious area (RTIMP). The three Green and Ampt equation infiltration parameters as coded in HEC-1 are:

1. hydraulic conductivity at natural saturation (XKSAT);
2. wetting front capillary suction (PSIF); and
3. volumetric soil moisture deficit at the start of rainfall (DTHETA).

Figure 3

Simplified Representation of Rainfall Losses
A Function of Surface Retention Losses Plus Infiltration

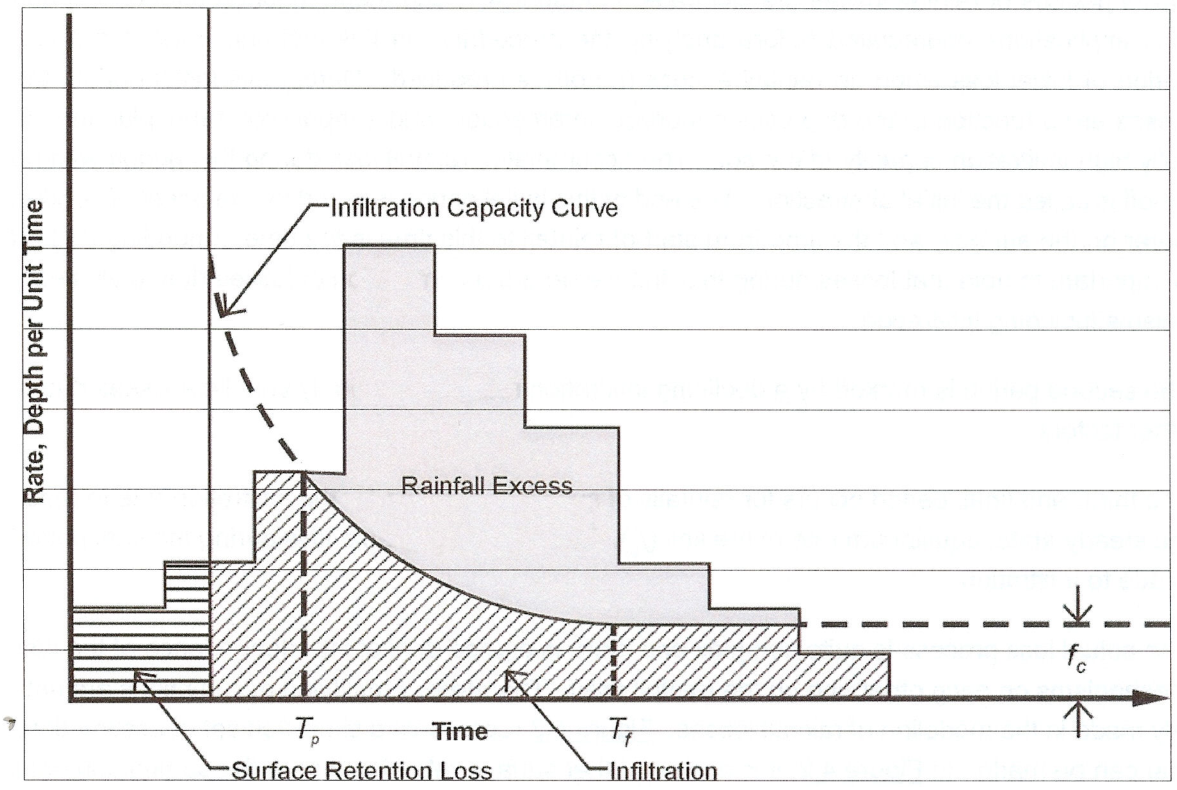


Table 8

IA as a function of vegetation cover and average land slope for natural areas

(to be used with the Green and Ampt infiltration equation for estimating rainfall losses)

Surface Retention Loss (IA), inches

Average Slope (1)	**% Vegetation Cover**			
	0-10% (2)	**10-40% (3)**	**40-80% (4)**	**80-100% (5)**
0-1%	0.4	0.6	0.8	1.0
1-5%	0.3	0.4	0.6	0.8
5-10%	0.2	0.3	0.4	0.6
>10%	0.1	0.2	0.3	0.4

Note: Not to be used in rainfall-runoff modeling with rainfalls more frequent than 100-year.

Table 9

IA and RTIMP estimates for developed areas

(to be used with the Green and Ampt infiltration equation for estimating rainfall losses)

		Surface Retention Loss (IA), inches		**Effective Impervious Area RTIMP, percent**	
Land-use		**Mean**	**Range**	**Mean**	**Range**
(1)		**(2)**	**(3)**	**(4)**	**(5)**
Developed (Residential and Commercial)					
Single Family Residential	1/4 acre	0.3	0.2-0.4	30	23-38
	1/3 acre	0.3	0.2-0.4	22	15-30
	1/2 acre	0.3	0.2-0.4	17	9-25
	1 acre	0.3	0.2-0.4	14	8-20
	2 acres	0.3	0.2-0.4	12	7-20
Multi-Family Residential		0.3	0.2-0.4	54	42-65
Commercial		0.1	0.0-0.2	85	51-98
Industrial		0.1	0.0-0.2	59	46-72
Lawn and Turf		0.3	0.2-0.5	0	0
Pavement and Roof Tops		0.1	0.0-0.2	95	95
Agricultural					
Tilled fields irrigated pasture		0.5	0.1-1.0	0	0

The three infiltration parameters are functions of soil characteristics, ground surface characteristics, and land management practices. The soil characteristics of interest are particle size distribution (soil texture), organic matter, and bulk density. The primary soil surface characteristics are vegetation canopy cover, ground cover, and soil crusting.

Values of Green and Ampt equation parameters as a function of soil characteristics alone (bare ground condition) were obtained from published reports (Rawls and others, 1983; Rawls and Brakensiek, 1983) and average values of XKSAT for each of the soil texture classes are shown in Table 10. Average values of PSIF from published data were plotted against corresponding values of bare ground XKSAT for each soil texture and a best fit line is shown in Figure 4. Values of DTHETA were derived based on soil moisture holding capacity and wilting points of typical vegetation. Three conditions are provided for DTHETA; Dry, Normal and Saturated. See page 45 for a discussion of the selection of the DTHETA condition. For Dry and Normal conditions, the value of DTHETA is selected from Figure 4 as a function of the bare ground XKSAT. For Saturated soil, DTHETA is 0.0. The values of XKSAT from Table 10 and corresponding values for PSIF and DTHETA from Figure 4 are used if the best available information is limited to a general soil texture classification of the drainage area.

Table 10

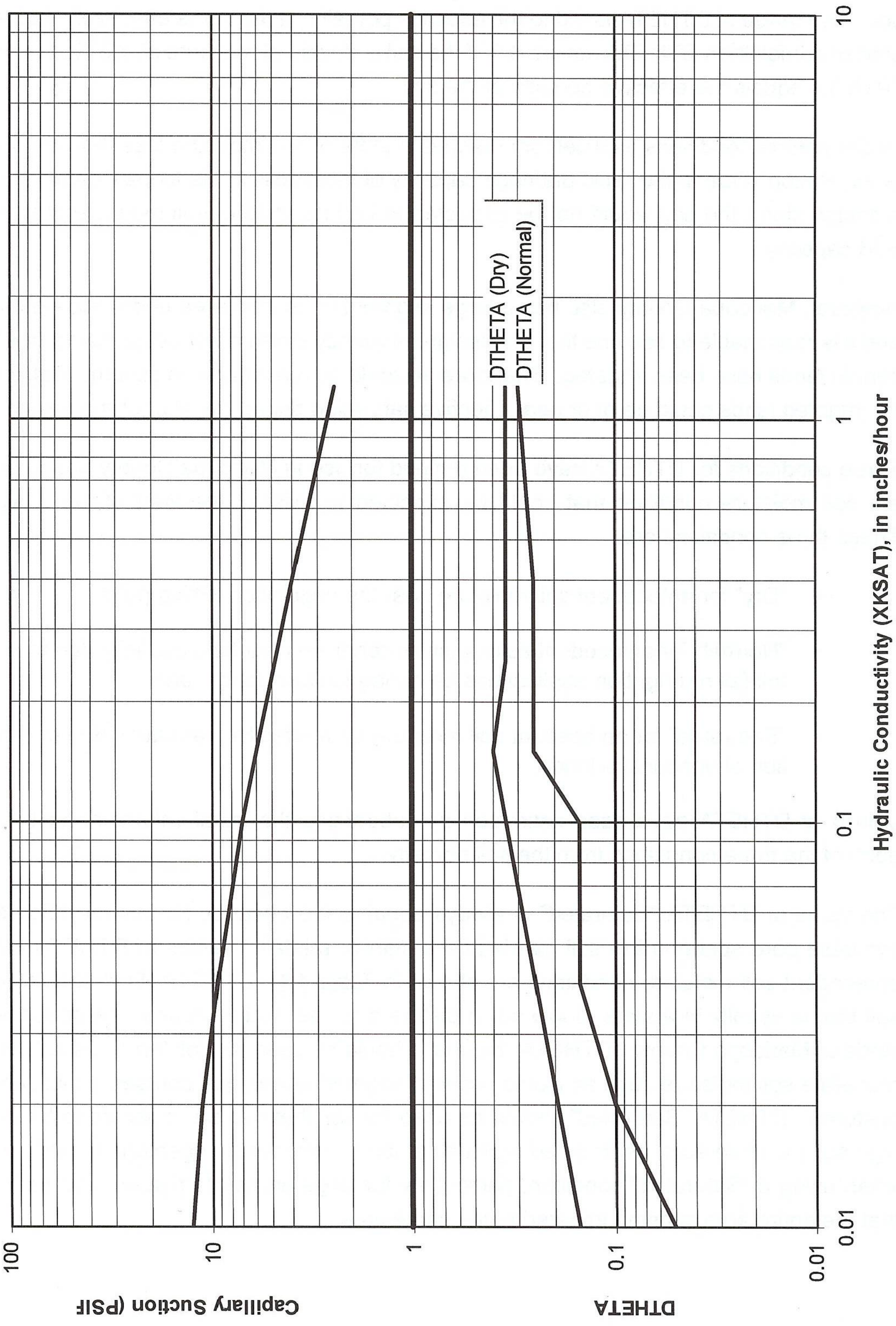
Hydraulic conductivity (XKSAT) based on bare ground soil texture

Soil Texture Classification (1)	**XKSAT inches/hour (2)**
loamy sand & sand	1.20
sandy loam	0.40
loam	0.25
silty loam	0.15
silt	0.10
sandy clay loam	0.06
clay loam	0.04
silty clay loam	0.04
sandy clay	0.02
silty clay	0.02
clay	0.01

Figure 4

Composite values of PSIF and DTHETA as a function of XKSAT

(To be used for Area-Weighted Averaging of Green and Ampt Parameters



In Table 10, loamy sand and sand are combined. The parameter values that are shown in the table are for loamy sand. XKSAT for sand is often used as 4.6 inches/hour, and PSIF is often used as 1.9 inches. Using those parameters values for drainage areas can result in the generation of no rainfall excess which may or may not be correct. Incorrect results could cause serious consequences for flood control planning and design. Therefore, it is recommended that for watersheds consisting of relatively small sub-areas of sand, the Green and Ampt parameter values for loamy sand be used for the sand portion of the watershed. If the area contains a large portion of sand, either the Green and Ampt method should be used with the parameter values for loamy sand or the Initial Loss and Uniform Loss Rate method should be used with the appropriately determined values for the parameters. New research relating soil texture with XKSAT has recently been published (Saxton and Rawls, 2004). This information has not been evaluated and tested to determine its application for hydrologic modeling, but may be of value in the future.

These guidelines are based on the following presumptions, but the user should note that the guidelines herein can also be accomplished following the same basic procedures using hand computations or CADD software.

1. ESRI ArcMap GIS software will be used to facilitate the computations. The guidelines presented herein provide an outline level of guidance that can be implemented at various levels of detail using GIS. These guidelines can be applied using standard GIS software, but there are third-party software programs such as WMS, DDMSW and various CADD software packages that will also perform many of the computation steps documented herein, except for determining a controlling soil texture for each soil map unit present in a given study area.
2. The user has a base map in GIS format or a hard-copy map for the study area of interest with the drainage area delineated into sub-basins.

3. A geospatial projection, coordinate system, and units have been selected for the study.
4. The user has a working knowledge of the Green and Ampt infiltration equation.
5. The user has access to the Internet, an understanding of how GIS systems work, and a working knowledge of GIS file types and structure.

Surface Retention Loss, IA: Surface retention loss, as used herein, is the summation of all rainfall losses other than infiltration. The major component of the surface retention loss is depression storage; relatively minor components of surface retention loss are due to interception by vegetation and evaporation. Depression storage is considered to occur in two forms. First, in-place depression storage occurs at, and in the near vicinity of, the raindrop impact. The mechanism for this depression storage is the microrelief of the soil and soil cover. The second form of depression storage is the retention of surface runoff that occurs away from the point of the raindrop impact in surface depressions such as puddles, roadway gutters and swales, roofs, irrigation bordered fields and lawns, and so forth. A relatively minor contribution by vegetation interception is also considered as a part of the total surface retention loss.

Estimates of surface retention loss are difficult to obtain and are a function of the physiography and land-use of the area. The surface retention loss on an impervious surface has been estimated to be in the range 0.0625 inch to 0.125 inches by Tholin and Keefer (1960), 0.11 inches for 1 percent slopes to 0.06 inches for 2.5 percent slopes by Viessman (1967), and 0.04 inches based on rainfall-runoff data for an urban watershed in Albuquerque by Sabol (1983). Hicks (1944) provides estimates of surface retention losses during intense storms as 0.20 inches for sand, 0.15 inches for loam, and 0.10 inches for clay. Tholin and Keefer (1960) estimated the surface retention loss for turf to be between 0.25 and 0.50 inches. Based on rainfall simulator studies on undeveloped alluvial plains in the Albuquerque area, the surface retention loss was estimated as 0.1 to 0.2 inches (Sabol and others, 1982a). Rainfall simulator studies in New Mexico result in estimates of 0.39 inches for eastern plains rangelands and 0.09 inches for pinon-juniper hillslopes (Sabol and others, 1982b). Chow (1964) quotes Horton (1935) as stating that initial detention (IA) "commonly ranges from 1/8 to 3/4 inch for flat areas and 1/2 to 1.5 inches for cultivated fields and for natural grass lands or forests." Further research for estimating values of IA for various land-uses and land surfaces is needed. All known reference sources for values of IA for use with the Green and Ampt equation are listed above and have been used in developing the data listed in Tables 8 and 9.

The selection of IA should be done using the best available data such as soils and vegetation surveys, topographic maps, aerial photographs, and site reconnaissance. Table 8 provides general guidance for natural watershed areas as a function of average land slope and vegetation cover. However, other watershed factors must be considered in selecting IA. For example, a densely forested area can have extensive forest duff which can retain several inches of rainfall resulting in IA greater than that shown in Table 8. Alternatively, seasonal factors for the design storm must be considered that would reduce the values in Table 8. For example, if the design storm occurs in late spring to early summer the watershed surface may be near saturation due to snowmelt and the effective IA could be very small or even 0.0.

For developed watersheds (residential, commercial and industrial) the IA values are typically small; however, local land development regulations may require on-site retention of some of the surface runoff thus increasing the effective IA. Alternatively, for dam safety purposes it may be prudent to consider that on-site retention capacity is depleted due to antecedent storms or snowmelt thus reducing the effective IA. For developed watersheds, runoff is generally insensitive to IA due to the overwhelming influence of RTIMP, and RTIMP must be carefully evaluated for urban watersheds. The IA and RTIMP values in Table 9 should be verified for reasonableness by use of aerial photographs, land zoning maps and site reconnaissance.

Effective Impervious Area, RTIMP: Impervious area (or nearly impervious area) is composed of rock outcrop, paved roads, parking lots, roof tops, and so forth. When performing watershed modeling with the HEC-1 program, the impervious area is to be the effective (directly connected) impervious area. For urbanized areas, the effective impervious area should be estimated from aerial photographs with guidance as provided in

Table 9. For areas that are presently undeveloped but for which flood estimates are desired for future urbanized conditions, estimates of effective impervious area should be obtained based on regional planning and land-use zoning as determined by the local jurisdiction. Estimates of the effective impervious area for urbanizing areas should be selected from local guidance, if available, along with the general guidance that is provided in Table 9. For undeveloped areas, the effective impervious area is often 0 percent. However, in some watersheds there could be extensive rock outcrop or areas of water such as reservoirs that would increase the imperviousness of the watershed. Care must be exercised when estimating effective impervious area for rock outcrop. Often the rock outcrop is relatively small (in terms of the total drainage area) and is of isolated units surrounded by soils of relatively high infiltration capacities. Relatively small, isolated rock outcrop may not be effective impervious area because runoff must pass over pervious surfaces before reaching the point of discharge concentration. However, impervious areas that are not hydraulically directly connected may still be included in the estimate of sub-basin RTIMP if the intended result includes a conservative estimate of rainfall-runoff volume. Often, the RTIMP value for such areas is reduced by a factor determined using engineering judgment.

For watersheds that have significant, contiguous rock outcrop, it may be necessary to establish those areas as separate sub-basins so that the direct runoff can be estimated and then routed (with channel transmission losses, if appropriate) to the point of interest. Paved roads through undeveloped watersheds will not normally contribute to effective impervious area unless the road serves as a conveyance to the watershed outlet. The maximum reasonable surface area of lakes and reservoirs should be included in the RTIMP estimate.

Green and Ampt Parameters – XKSAT, PSIF, DTHETA:

Obtaining Soils Information: In order to estimate the parameter XKSAT, detailed soils information is needed. Soils information for Colorado is generally available from two sources:

1. Natural Resources Conservation Service (NRCS) for general or detailed soil surveys.

2. US Forest Service (USFS) Terrestrial Ecosystem Surveys.

USFS data is generally not as readily available as the NRCS data. The NRCS and the USFS are working to make USFS data available through the NRCS Soil Data Mart, which is discussed below. This seems to be particularly true in Colorado, where selected USFS studies have been added to the Soil Data Mart. Generally, the USFS soil scientist for the forest in question will have to be contacted to obtain this data if it is not available on the NRCS Soil Data Mart web site. The following subsections describe where to look on the Internet to find NRCS soils information for a particular study area, and what information is needed.

Soils Survey Index for Colorado: The first step is to identify which soil surveys are available for a particular study watershed. The NRCS maintains two programs for obtaining soils information. The Soil Survey Geographic Database (SSURGO) program provides detailed soils information. Soils information from SSURGO is available for a large portion, but not all, of Colorado. SSURGO data for Colorado is expected to be completed in 2008. The U.S. General Soil Map (STATSGO) program provides generalized soils information for the United States. There is full coverage for the State of Colorado in this program. The STATSGO data can be used when the more detailed SSURGO or USFS data is not available.

The main NRCS web site for Colorado soil surveys is: http://www.co.nrcs.usda.gov/technical/soil/sps.htm. The NRCS maintains an index of soil surveys available on the Internet. A map showing the status of soil surveys within Colorado can be seen at: http://www.co.nrcs.usda.gov/technical/soil/soil_sur_stat.pdf and is shown in Figure 5. A more detailed soil survey index and status for SSURGO is available at: http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/status-maps.html. A link to the GIS coverage for the SSURGO soil survey boundaries and their status is found on that page.

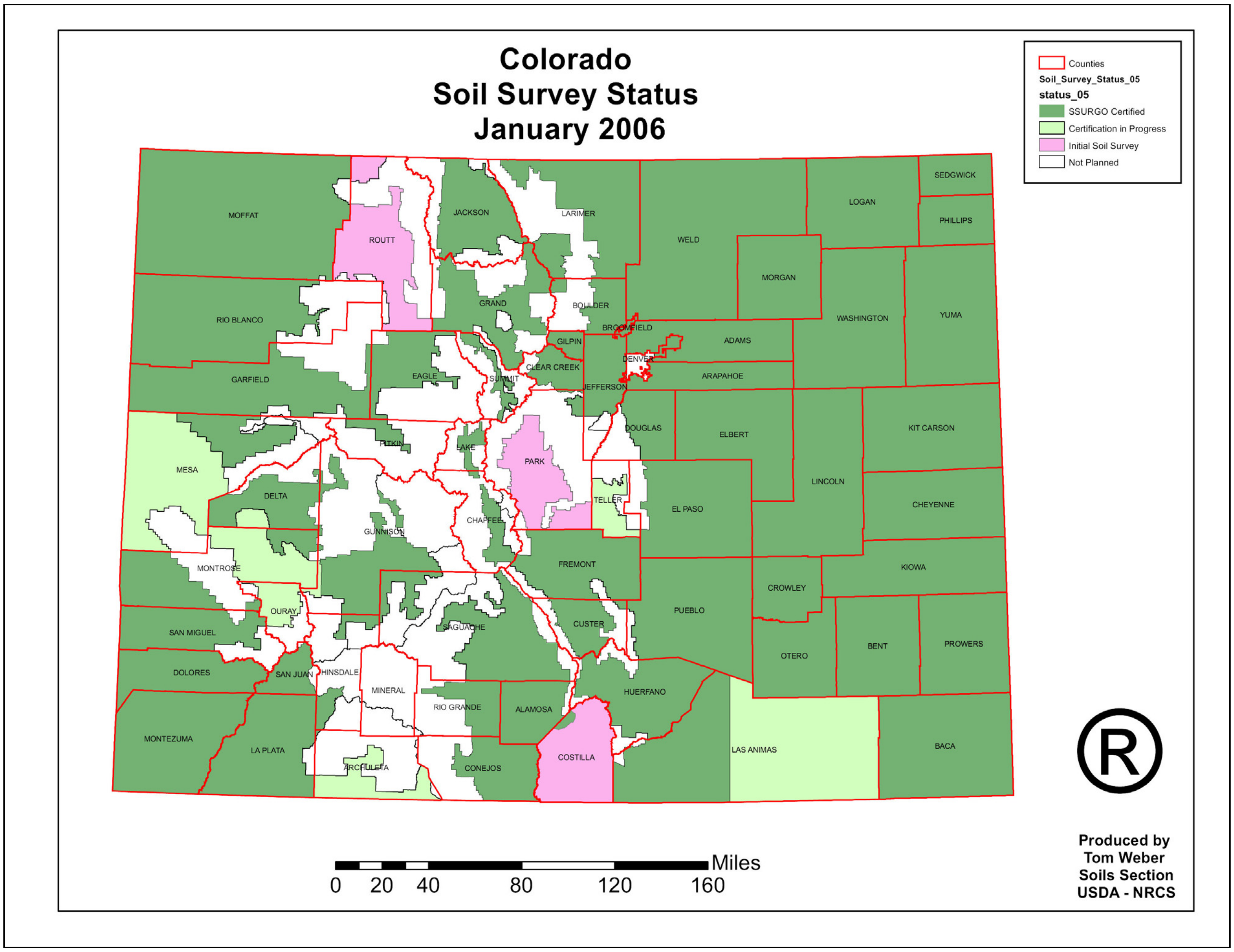
Detailed Soil Surveys (SSURGO): Once the soil survey(s) covering the study area in question are identified, the data associated with those studies can be obtained from the NRCS Soil Data Mart web site at: http://soildatamart.nrcs.usda.gov. Two types of data are needed:

1. Soil Map Unit GIS Spatial Data. The spatial data is available in ESRI ArcView shape file, ArcInfo Coverage file, or ArcInfo Exchange file formats. The spatial data consists of GIS polygon coverages of each Soil Map Unit (SMU) within an NRCS soil survey study area. The database table contains key fields needed to associate the spatial location with the corresponding information contained within the tabular data files, including the SMU identifier.

2. Soil Map Unit GIS Tabular Data. The tabular data is stored in Microsoft Access .mdb files. These databases contain the information that one would find in the published versions of an NRCS Soil Survey, plus much more. To use this information, the user must also download a template database that contains very complex macros that will load all of the tabular data and allow the user to create reports. The user may also generate specific reports through the NRCS Soil Data Mart web site "Generate Reports" option. Another option is to use the NRCS Web Soil Survey web site at http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx to generate needed reports in Adobe PDF format.

Figure 5

NRCS Soil Survey Status Map for Colorado



General Soil Survey (STATSGO): The Colorado General Soil Survey spatial data and tabular data may also be obtained from the NRCS Soil Data Mart web site by clicking on the "US General Soil Map" tab and following a similar process to that used to obtain SSURGO data.

Preparation of the Soil Survey Data: The user must download the spatial data in a projection and coordinate system matching that being used to define the watershed sub-basins. The GIS data may need to be reprojected in GIS to match the study projection and if the data is needed in International or US Survey feet.

Estimating Bare Ground XKSAT for Each Soil Map Unit: The Green and Ampt parameter that is obtained from the soils survey data is an estimate of bare ground XKSAT. The estimate is made by relating soil texture to a corresponding XKSAT value. Refer to Table 10 for a list of soil textures and the corresponding XKSAT value. Each SMU contains one or more component soils and minor soils. The soil survey provides a soil horizon for each component soil. The soil horizon defines the vertical layers of soil below the ground surface and each layer has a laboratory assigned soil texture. Refer to Figure 6 for a typical NRCS Engineering Properties table, which shows the soil horizon and component soil textures for a SMU in Logan County, Colorado. Refer to Figure 7 for a typical NRCS component legend, which shows the percent of map unit for each component soil.

The controlling layer for each component soil is determined by examining the top 6 inches of the soil horizon and selecting the layer with the most restrictive soil texture (lowest XKSAT value). A composite value of XKSAT for the SMU is then computed by area-weighting the logarithm of XKSAT of the component soils. Refer to the Instructions section for more detail.

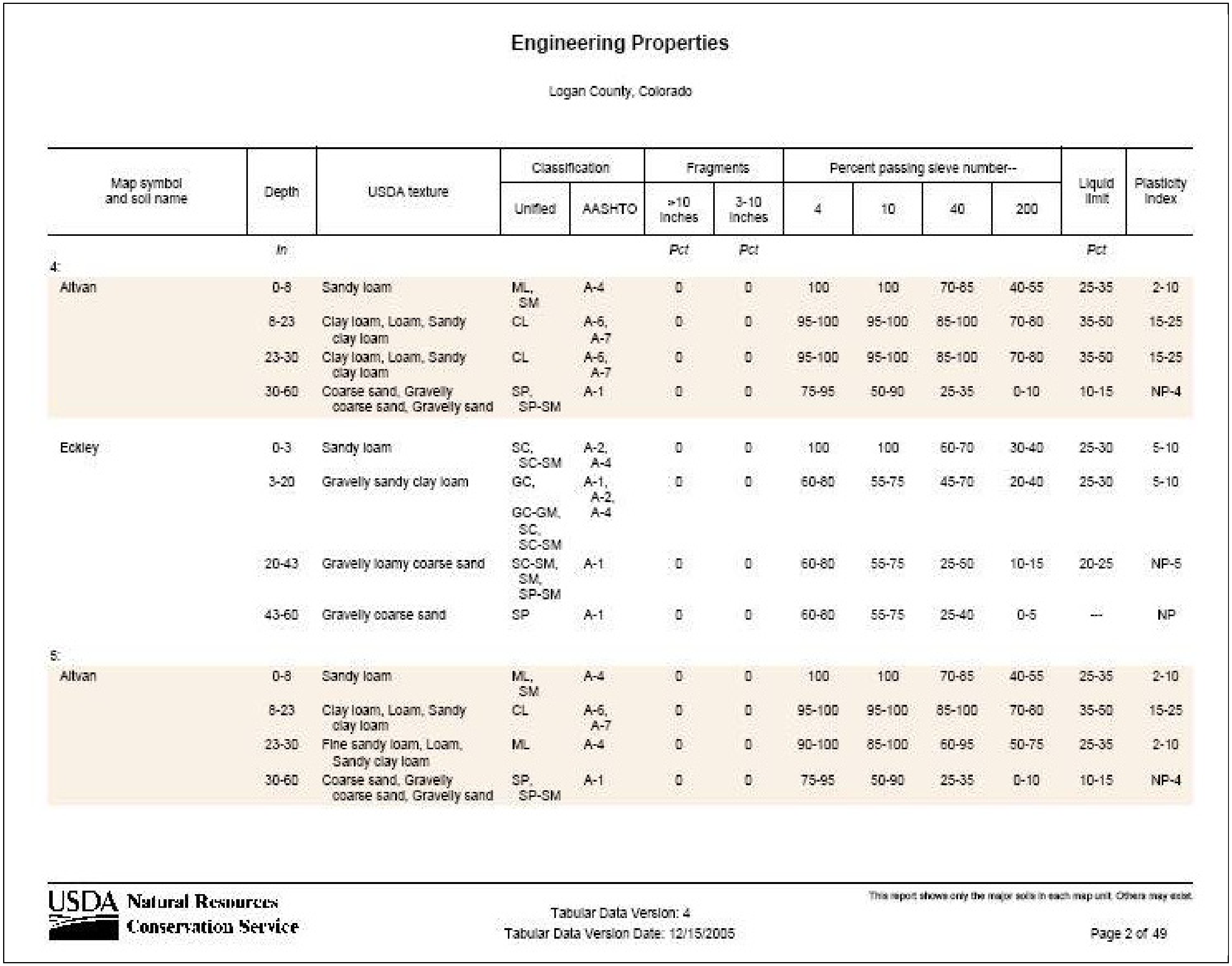
Estimating a Composite Bare Ground XKSAT for Each Sub-basin: Most drainage sub-basins will be composed of several sub-areas containing soils of different texture. Therefore, there may be need to determine composite values for the Green and Ampt parameters to be applied to the sub-basin. The process for estimating an area-weighted bare ground XKSAT value for each sub-basin in the watershed is similar to that followed for computing a composite value of XKSAT for each SMU.

Estimating PSIF and DTHETA for Each Sub-basin: The wetting front capillary suction (PSIF) is a physical parameter that directly relates to the bare ground value of XKSAT. PSIF requires no adjustment for other physical influences.

The soil moisture deficit (DTHETA) is a volumetric measure of the soil moisture storage capacity that is available at the start of the rainfall. DTHETA is a function of the effective porosity of the soil. The range of DTHETA is 0.0 to the effective porosity. If the soil is effectively saturated at the start of rainfall then DTHETA equals 0.0; if the soil is devoid of moisture at the start of rainfall then DTHETA equals the effective porosity of the soil.

Figure 6

Example of an NRCS Engineering Properties Table



Engineering Properties

Logan County, Colorado

Map symbol and soil name	Depth	USDA texture	Classification		Fragments		Percent passing sieve number--				Liquid limit	Plasticity index
			Unified	AASHTO	>10 inches	3-10 inches	4	10	40	200		
	In				*Pct*	*Pct*					*Pct*	
4:												
Altvan	0-8	Sandy loam	ML, SM	A-4	0	0	100	100	70-85	40-55	25-35	2-10
	8-23	Clay loam, Loam, Sandy clay loam	CL	A-6, A-7	0	0	95-100	95-100	85-100	70-80	35-50	15-25
	23-30	Clay loam, Loam, Sandy clay loam	CL	A-6, A-7	0	0	95-100	95-100	85-100	70-80	35-50	15-25
	30-60	Coarse sand, Gravelly coarse sand, Gravelly sand	SP, SP-SM	A-1	0	0	75-95	50-90	25-35	0-10	10-15	NP-4
Eckley	0-3	Sandy loam	SC, SC-SM	A-2, A-4	0	0	100	100	60-70	30-40	25-30	5-10
	3-20	Gravelly sandy clay loam	GC, GC-GM, SC, SC-SM	A-1, A-2, A-4	0	0	60-80	55-75	45-70	20-40	25-30	5-10
	20-43	Gravelly loamy coarse sand	SC-SM, SM, SP-SM	A-1	0	0	60-80	55-75	25-50	10-15	20-25	NP-5
	43-60	Gravelly coarse sand	SP	A-1	0	0	60-80	55-75	25-40	0-5	---	NP
5:												
Altvan	0-8	Sandy loam	ML, SM	A-4	0	0	100	100	70-85	40-55	25-35	2-10
	8-23	Clay loam, Loam, Sandy clay loam	CL	A-6, A-7	0	0	95-100	95-100	85-100	70-80	35-50	15-25
	23-30	Fine sandy loam, Loam, Sandy clay loam	ML	A-4	0	0	90-100	85-100	60-95	50-75	25-35	2-10
	30-60	Coarse sand, Gravelly coarse sand, Gravelly sand	SP, SP-SM	A-1	0	0	75-95	50-90	25-35	0-10	10-15	NP-4

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Tabular Data Version: 4
Tabular Data Version Date: 12/15/2005

This report shows only the major soils in each map unit. Others may exist.

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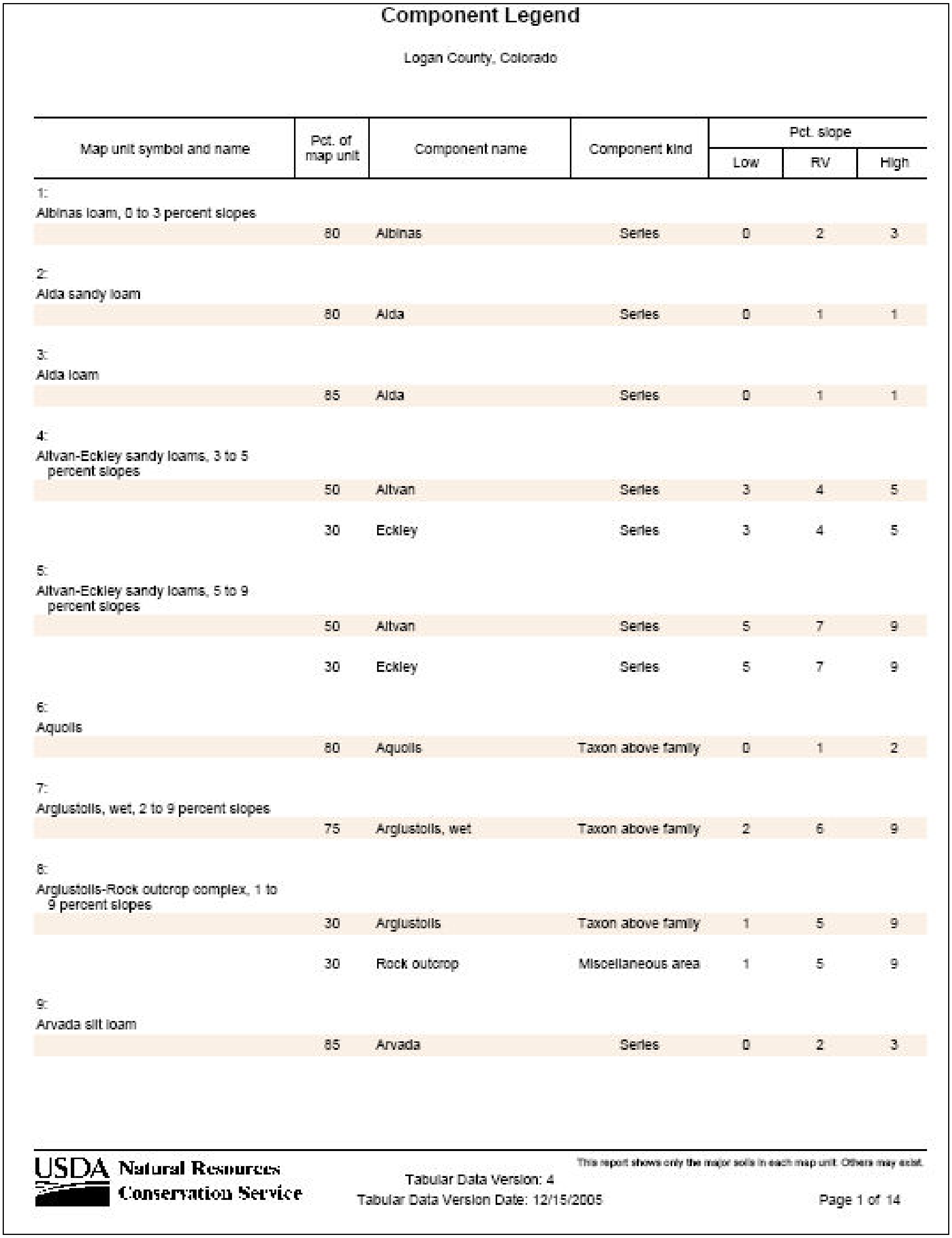
Figure 7
Example of NRCS Component Legend Table



Component Legend

Logan County, Colorado

Map unit symbol and name	Pct. of map unit	Component name	Component kind	Pct. slope		
				Low	RV	High
1: Albinas loam, 0 to 3 percent slopes						
	80	Albinas	Series	0	2	3
2: Alda sandy loam						
	80	Alda	Series	0	1	1
3: Alda loam						
	85	Alda	Series	0	1	1
4: Altvan-Eckley sandy loams, 3 to 5 percent slopes						
	50	Altvan	Series	3	4	5
	30	Eckley	Series	3	4	5
5: Altvan-Eckley sandy loams, 5 to 9 percent slopes						
	50	Altvan	Series	5	7	9
	30	Eckley	Series	5	7	9
6: Aquolls						
	80	Aquolls	Taxon above family	0	1	2
7: Argiustolls, wet, 2 to 9 percent slopes						
	75	Argiustolls, wet	Taxon above family	2	6	9
8: Argiustolls-Rock outcrop complex, 1 to 9 percent slopes						
	30	Argiustolls	Taxon above family	1	5	9
	30	Rock outcrop	Miscellaneous area	1	5	9
9: Arvada silt loam						
	85	Arvada	Series	0	2	3

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This report shows only the major soils in each map unit. Others may exist.

Tabular Data Version: 4
Tabular Data Version Date: 12/15/2005

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Under natural conditions, soil seldom reaches a state of soil moisture less than the wilting point of vegetation. However, Colorado also has a large segment of its land area under irrigated agriculture, and it is reasonable to assume that the design frequency storm could occur during or shortly after certain lands have been irrigated. Therefore, it would be reasonable to assume that soil moisture for irrigated lands could be at or near effective saturation during the start of the design rainfall.

Three conditions for DTHETA have been defined for use in Colorado based on the antecedent soil moisture condition that could be expected to exist at the start of the design rainfall. These three conditions are:

1. "Dry" for antecedent soil moisture near the vegetation wilting point,
2. "Normal" for antecedent soil moisture condition near field capacity due to previous rainfall or irrigation applications on nonagricultural lands; and
3. "Saturated" for antecedent soil moisture near effective saturation due to recent irrigation of agricultural lands, or watersheds that could reasonably be expected to have high seasonal water content due to snowmelt.

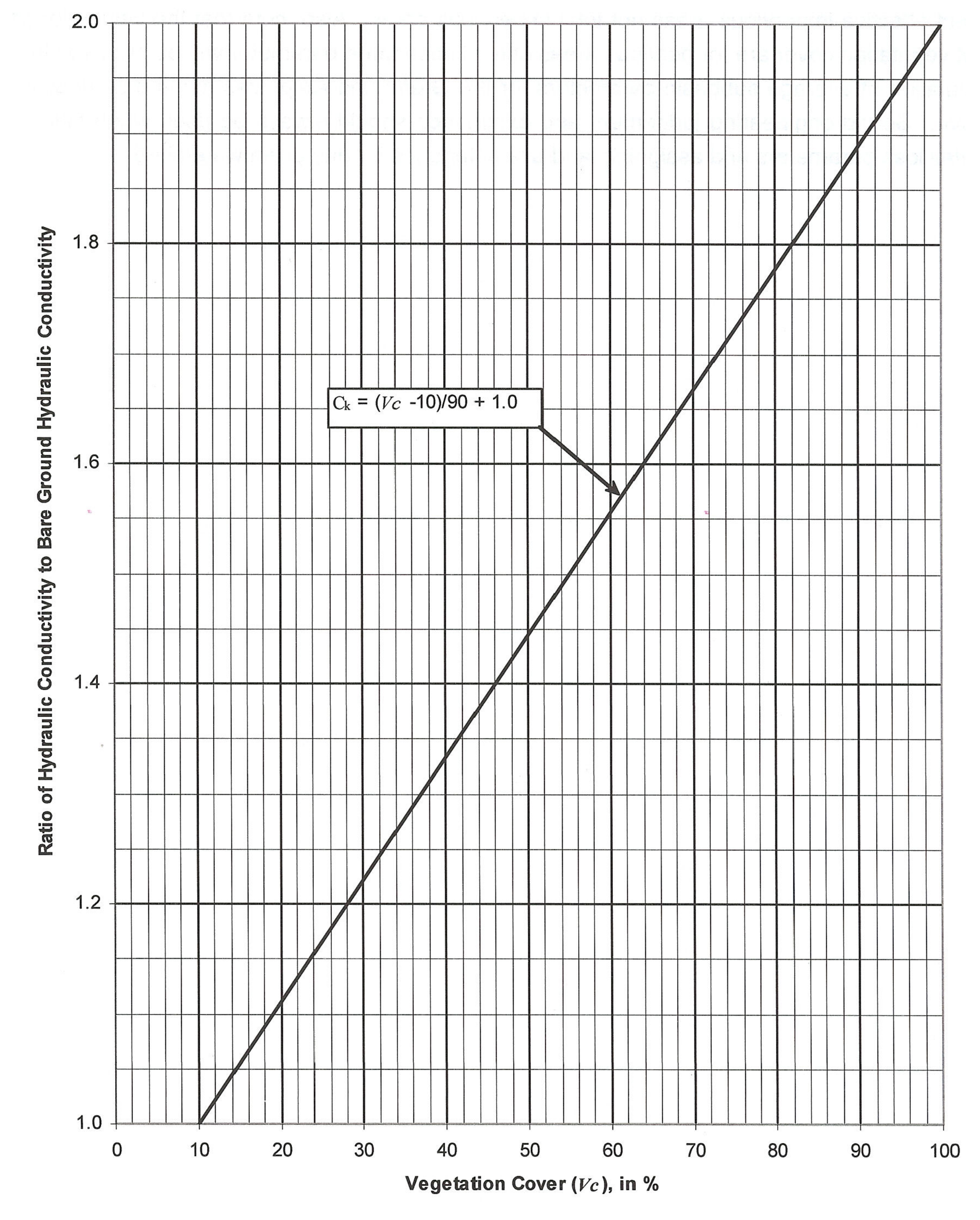
Values of DTHETA have been estimated by subtracting the initial volumetric soil moisture for each of the three conditions from the soil porosity.

The value of DTHETA "Saturated" is always equal to 0.0 because for this condition there is no available pore space in the soil matrix at the start of rainfall. DTHETA "Dry" should be used for soil that is usually in a state of low soil moisture during the period when the design storm normally occurs. However, if the design storm can occur in late spring to early summer the watershed can be in a state of high soil moisture due to snowmelt and for that condition DTHETA "Saturated" should be used. DTHETA "Normal" should be used for soil that is usually in a state of moderate soil moisture such as would occur in irrigated lawns, golf courses, parks, and irrigated pastures, and areas when the soil moisture is moderate to high during the period when the design storm normally occurs, such as high mountain areas where the snow pack may have recently melted just before or during the summer monsoon season. DTHETA "Saturated" should be used for soil that can be expected to be in a state of high soil moisture such as irrigated agricultural land. However, judgment should be exercised when using a "Saturated" condition, particularly for large areas of irrigated land as it is unlikely that the entire area is being irrigated at the same time. The effective DTHETA decreases with increasing rainfall depth. For the PMP, the selection of DTHETA results in little change in runoff volume and no change in peak discharge. Selection of DTHETA is more sensitive for the 100-year storm. Composite values for PSIF and DTHETA are determined from the composite value of bare ground XKSAT using Figure 4.

<u>Adjusting XKSAT for Vegetation Cover for Each Sub-basin:</u> the bare ground value of XKSAT can be affected by several factors besides soil texture. For example, hydraulic conductivity is reduced by soil crusting, increased by tillage, and increased by the influence of ground cover and canopy cover. The values of XKSAT that are presented for bare ground as a function of soil texture alone should be adjusted under certain soil cover conditions. Ground cover, such as grass, litter, and gravel, will generally increase the infiltration rate over that of bare ground conditions. Similarly, canopy cover such as from trees, brush, and tall grasses can also increase the bare ground infiltration rate. The procedures and data that are presented are for estimating the Green and Ampt parameters based solely on soil texture and would be applicable for bare ground conditions. Past research has shown that PSIF is relatively insensitive in comparison with XKSAT; therefore only the hydraulic conductivity parameter is adjusted for the influences of cover over bare ground.

Procedures have been developed (Rawls and others, 1989) for incorporating the effects of soil crusting, ground cover, and canopy cover into the estimation of hydraulic conductivity for the Green and Ampt equation; however, those procedures are not recommended for use in Colorado at this time. A simplified procedure to adjust the bare ground hydraulic conductivity for vegetation cover is shown in Figure 8. This figure is based on the documented increase in hydraulic conductivity due to various soil covers as reported by investigators using rainfall simulators on native western rangelands (Kincaid and others, 1964; Sabol and others, 1982a; Sabol and others, 1982b; Bach, 1984; Ward, 1986; Lane and others, 1987; Ward and Bolin, 1989). This correction factor can be used based on an estimate of vegetation cover as used by the NRCS in soil surveys; that is, vegetation cover is evaluated on basal area for grass and forbs, and is evaluated on canopy cover for trees and shrubs. Note that this correction can be applied only to soils other than sand and loamy sand.

Figure 8
Effect of Vegetation Cover on Hydraulic Conductivity
For All Soil Textures Other Than Sand and Loamy Sand



The influence of tillage results in a change in total porosity and therefore a need to modify the three Green and Ampt equation infiltration parameters. The effect of tillage systems on soil porosity and the corresponding changes to hydraulic conductivity, wetting front capillary suction, and water retention is available (Rawls and Brakensiek, 1983). Although this information is available, it is not presented in these guidelines, nor is it recommended that these adjustments be made to the infiltration parameters for design purposes use in Colorado. For most flood estimation purposes it cannot be assumed that the soil will be in any particular state of tillage at the time of storm occurrence and therefore the base condition infiltration parameters, as presented, should be used for flood estimation purposes. However, appropriate adjustment to the infiltration parameters can be made, as necessary, for special flood studies such as reconstitution of storm events.

Correction of XKSAT for vegetation cover using Figure 8 is made after the composite value of bare ground XKSAT is estimated. This process can be automated using GIS.

The rainfall loss estimation process also includes the parameter "effective impervious area." In HEC-1, this parameter is coded as the variable RTIMP. An estimate of RTIMP is provided for each sub-basin. HEC-1 computes no rainfall losses for the percentage of sub-basin area input for RTIMP.

Sensitivity of Green and Ampt Equation Parameters: It is important for the modeler to be aware of the sensitivity of the rainfall loss method to the various input parameters. More time and effort is warranted for the sensitive parameters than for the less sensitive parameters. The possible effects of each of the parameters discussed above on computation of rainfall excess and peak discharge is shown in Table 11 relative to the one percent chance storm.

Table 11

Sensitivity of Rainfall-runoff Computations to Green and Ampt Parameters

Parameter	Storm Frequency		
	More Frequent	One Percent Storm	Less Frequent
IA	Moderate	Low-Moderate	Low
Bare Ground XKSAT	High-Very High	Moderate-High	Low-Moderate
XKSAT Adjustment for Vegetation	High-Very High	Moderate-High	Low-Moderate
PSIF	Directly related to XKSAT		
DTHETA	Low-Moderate	Low	Very Low
RTIMP	High-Very High	High	Moderate-High

Instructions For Computing Green And Ampt Parameters:

General: In general the following steps are used to compute rainfall loss parameters for the Green and Ampt method. The sets of instructions following these general steps are specific to computing parameter values for each sub-basin. The descriptions below use GIS procedures to describe the process. Whether or not GIS is used to perform the data sorting and computations, the basic processes are the same for hand computations and use of CADD or other software applications. The GIS process was selected for these descriptions because the NRCS detailed soil data are mostly available in only a GIS or PDF format and the NRCS is only publishing new studies in these formats. To perform the computations by hand or using other software, the GIS data must first be converted to a scaled paper plot or converted to another digital format more convenient to the user. Additional descriptions are provided where the hand computation process differs from the GIS procedure.

1. Sub-basin Delineation. Prepare a base map of the drainage area and delineate modeling basins for the concentration points of interest. Delineate sub-basins from each basin so that the sub-basins are reasonably homogeneous in terms of area and/or time of concentration characteristics, and surface characteristics and/or soil type. Delineate large impervious areas as separate sub-basins. Create GIS polygon coverages for each basin and sub-basin and calculate the area of each basin and sub-basin.

2. <u>Sub-Area Delineation.</u> Delineate sub-areas for each sub-basin for the purpose of assigning IA and RTIMP estimates. The polygons from NRCS soil surveys delineating SMUs also are sub-areas, and often are used as sub-areas for estimation of IA and RTIMP. Create GIS polygon coverages for each sub-area and calculate the area of each sub-area within each sub-basin.
3. <u>Sub-Area Parameters.</u> Assign estimates of IA and RTIMP for each sub-area.
4. Estimate Composite IA for each Sub-basin.
5. Estimate Composite RTIMP for each Sub-basin.
6. Estimate Bare Ground XKSAT for each SMU (sub-area).
7. Estimate Composite Bare Ground XKSAT for each Sub-basin.
8. Estimate PSIF and DTHETA for each Sub-basin based on Composite Bare Ground XKSAT
9. Estimate Adjusted Composite XKSAT for each Sub-basin.
10. <u>HEC-1 Loss Rate Record.</u> Enter the composite values of IA, DTHETA, PSIF, adjusted XKSAT, and RTIMP for the drainage area or each sub-basin on the LG record of the HEC-1 input file.

<u>Instructions for Sub-basin Composite IA:</u>

1. <u>Assign an IA Estimate to Sub-basin Sub-areas:</u> Sub-basins may have to be divided into sub-areas based on land-use and/or surface characteristics. The NRCS SMUs may also be used. An estimate of IA can be made for each SMU, entered into the GIS table for each SMU, and then area averaged as described in step 2. NRCS SMUs are further described under the Saturated Hydraulic Conductivity, XKSAT section.
2. <u>Compute a Composite Value of IA:</u> If there are multiple sub-areas within a sub-basin, calculate an area-weighted value of IA using equation 1.

$$\overline{IA} = \left(\frac{\sum A_i IA_i}{A_T} \right) \quad \text{Eqn 1}$$

where:

$\overline{IA}$ = composite value of IA, inches

IA_i = IA of each sub-area, inches

A_i = size of IA sub-area

A_T = size of the watershed or sub-basin

Instructions for Soil Map Unit Bare Ground XKSAT:

1. The Determine Controlling Soil Horizon Layer: The first step in estimating XKSAT for each SMU is to determine the controlling soil layer in the horizon of each component soil type. Surface soils that are more than 6 inches thick are generally adequate to contain infiltrated rainfall for inflow design floods in Colorado without deeper soil horizons restricting the infiltration rate. This is because most common soils have porosities that range from about 25 to 35 percent, and therefore 6 inches of soil with a porosity of 30 percent can absorb about 1.8 inches (6 inches times 30 percent) of rainfall infiltration. Accordingly, in estimating the Green and Ampt infiltration parameters in Colorado, for up to and including the 100-year rainfall, the top 6 inches of soil should be considered. If the top 6 inch horizon is uniform soil or nearly uniform, then select the Green and Ampt parameters for that soil texture. If the top 6 inch horizon is layered with different soil textures, then select the horizon with the soil texture that has the lowest corresponding XKSAT value. For less frequent floods including the PMF, examine the soil to a greater depth, at least 12 inches but no more than 18 inches, and use engineering judgment in selecting the controlling horizon. From a practical consideration, since the soil in the horizon beneath the upper most horizon generally extends to depths ranging from 8 to 18 inches or more, the same soil controlling horizon will usually exist for all floods including the PMF. It is not generally warranted to use different controlling soil horizons for different design events unless unusual soil horizons or shallow soil over an impermeable layer exists for large areal extents.

To illustrate this process, refer to Figure 6 and Figure 7. Figure 6 is an excerpt from a PDF of the Engineering Properties table created using the NRCS Web Soil Survey web site. Figure 7 is an excerpt from the Component Legend table. Both are from the Soil Survey for Logan County, Colorado. Examining the data supplied for SMU 4, it can be seen that there are two component soils for SMU 4. From Figure 7, Altvan makes up 50% of the SMU, and Eckley 30%. The remaining 20% of the SMU is made up of minor soils, which are ignored for the purposes of estimating an XKSAT value for an SMU.

The Altvan component has a horizon identified for the first 60 inches of the soil profile, which is typical of most NRCS soil surveys. The first layer is 8 inches thick and consists of a soil with a sandy loam texture. Sandy loam is therefore assumed to be the controlling texture, and has a corresponding XKSAT value of 0.4 inches per hour.

The Eckley component has multiple layers within the first 6 inches. The first 3 inches have a sandy loam texture. The next 17 inches have a gravelly sandy clay loam texture. Ignoring the gravelly adjective for now, the corresponding XKSAT value for a sandy clay loam is 0.06 inches per hour. The controlling horizon layer is the sandy clay loam.

2. Estimate the XKSAT Value for the SMU: The estimated XKSAT value for the SMU is derived by area-weighting the XKSAT values for the SMU component soils. The engineer may do this by applying engineering judgment or by mathematically computing a weighted value. The mathematical computation should be done using equation 2. Equation 2 is also used for computing an area-weighted value of bare ground XKSAT for watershed sub-basins.

$$\overline{XKSAT} = a\log\left(\frac{\sum A_i \log XKSAT_i}{A_T}\right) \qquad \text{Eqn 2}$$

where:

$\overline{XKSAT}$ = composite bare ground hydraulic conductivity for the SMU (or watershed sub-basin), inches/hour

$XKSAT_i$ = bare ground hydraulic conductivity of the SMU component soil (or SMU within a sub-basin), inches/hour

A_i = component area in % of SMU (or size of SMU sub-area within a sub-basin)

A_T = % of SMU components (or size of the watershed or sub-basin)

When the SMU component percentages do not total 100%, the percentages should be normalized to total 100%. For this example, the area-weighted bare ground XKSAT value for SMU 4 is:

$$SMU\ 4\ \overline{XKSAT} = a\log\left(\frac{\left(\frac{50}{80}\right)\log(0.40) + \left(\frac{30}{80}\right)\log(0.06)}{80/80}\right) = 0.20\ inches/hour$$

3. <u>Update GIS Table:</u> Add a bare ground XKSAT field to the GIS soils polygon coverage and populate it with the computed values for each SMU.

4. <u>Additional Considerations:</u> Many SMUs will have soil textures described with adjectives such as gravelly, very gravelly, fine, cobbly, very cobbly, etc. There is virtually no guidance in the literature regarding how to address these conditions, and where guidance is found, it is conflicting. Until further conclusive research is performed, these adjectives should be ignored when assigning XKSAT values, unless the hydrologist has scientific evidence to support adjustments to the general soil texture.

   Rainfall-runoff parameter values for design should be based on reasonable estimates of watershed conditions that would minimize rainfall losses. The hydrologist should keep this in mind when assigning XKSAT values to SMUs. Using engineering judgment when assigning a weighted XKSAT value for SMUs that have more than one component soil may provide just as valid an estimate as computing the estimate.

Minor soils may be ignored when estimating an XKSAT value for a SMU.

When an SMU has a component consisting of rock outcrop, that component should not be used in estimating a weighted value of XKSAT.

Instructions for PSIF and DTHETA:

1. Read Values of PSIF and DTHETA from Figure 4: Enter the x-axis of Figure 4 with the composite bare ground value of XKSAT for each sub-basin. Read the corresponding value of PSIF, and DTHETA dry or normal, on the y-axis.

Instructions for Sub-Basin Composite XKSAT:

1. Clip the GIS Soils Coverage: Use the ArcMap clip tool to divide the SMU polygon coverage so that the SMU polygon boundaries are divided by the watershed sub-basin boundaries. This is done by using the SMU polygon coverage as the input feature and the watershed sub-basin GIS coverage as the clip feature. The results are SMU polygons completely contained within each sub-basin polygon.
2. Simplify the GIS Soils Coverage: Use the ArcMap dissolve tool to simplify the SMU polygons within each watershed sub-basin, based on the SMU identifier field. When completed, there will only be one polygon for each SMU within each sub-basin polygon. When performing this step by hand, identify all polygons that have the same XKSAT value and then color code the XKSAT polygons.
3. Compute a Composite Bare Ground XKSAT Value for Each Sub-basin: Use ArcMap to compute the area of each SMU within each sub-basin. Then either use ArcMap to apply equation 2, or export the SMU number, XKSAT value and area information for each sub-basin into a Microsoft Excel spreadsheet and apply equation 2 within the spreadsheet. When performing these computations by hand, planimeter each color-shaded polygon to obtain the total area of each XKSAT value within the sub-basin. Then apply equation 2 by hand or within a spreadsheet.

Instructions for Adjusting XKSAT for Vegetation Canopy Cover:

1. Estimate Vegetation Cover Density for Each Sub-basin: Determine an estimate of average vegetation cover density (canopy cover) using aerial photographs supplemented by field verifications. Use the NRCS Rangeland Productivity and Plant Composition table from the NRCS Soil Survey tabular data as a guide to the types of vegetation normally present within the various SMUs, and their percent coverage. Field transects should be made at strategic locations determined from the aerial photographs to verify estimates made using the photographs. This is typically done by laying out a 100-foot surveyor chain and measuring the width of vegetation canopy and grass basal area intersected by the chain.
2. Obtain the Bare Ground XKSAT Adjustment Factor from Figure 8: Enter Figure 8 on the x-axis with the estimated vegetation cover density for each sub-basin. Read the ratio of Adjusted XKSAT to bare ground XKSAT on the y-axis.
3. Compute Adjusted XKSAT: Multiply the sub-basin bare ground XKSAT estimate by the factor from the y-axis of Figure 8 to obtain the adjusted XKSAT value.

Instructions for Sub-basin Composite Effective Impervious Area RTIMP:

1. Assign an RTIMP Estimate to Sub-basin Sub-areas: Sub-basins may have to be divided into sub-areas based on land-use and/or surface characteristics. RTIMP consists of any impervious surface that is hydraulically connected to the watershed outlet, including large areas of natural rock, large bodies of pooled water, asphalt and concrete pavement, rooftops, etc. Aerial photographs can be used to aid in the process of defining sub-areas, particularly for developed watersheds. Planning and zoning maps may also be used for developed or developing areas. The NRCS SMUs may be used to aid in estimating RTIMP for natural areas. An estimate of RTIMP can be made for each SMU, entered into the GIS table for each SMU, and then area averaged as described in step 2. NRCS SMUs are further described under the Saturated Hydraulic Conductivity, XKSAT section.

   The maximum reasonable surface area of lakes and reservoirs within sub-basins should be included in the RTIMP estimate.

2. Compute a Composite Value of RTIMP: If there are multiple sub-areas within a sub-basin, calculate an area-weighted value of RTIMP using equation 3.

$$\overline{RTIMP} = \left(\frac{\sum A_i RTIMP_i}{A_T} \right) \qquad \text{Eqn 3}$$

where:

$\overline{RTIMP}$ = composite value of RTIMP, inches

$RTIMP_i$ = RTIMP of each sub-area, inches

A_i = size of RTIMP sub-area

A_T = size of the watershed or sub-basin

Initial Loss And Uniform Loss Rate:

Introduction: This is a simplified rainfall loss estimation method that is often used, and generally accepted, for flood hydrology. It is assumed that the rainfall loss process can be simulated as a two-step procedure, as illustrated in Figure 9. The two steps are:

Step 1: All rainfall is lost to runoff until the accumulated rainfall is equal to the initial loss (STRTL).

Step 2: After the initial loss is satisfied, a portion of all future rainfall is lost at a uniform rate (CNSTL). All of the rainfall is lost (runoff does not occur) if the rainfall intensity is less than the uniform loss rate.

The HEC-1 implementation of this method requires input of the three parameters, STRTL, CNSTL, and RTIMP. These guidelines are based on the same presumptions listed in the method description for the Green and Ampt parameters section.

Applicability: This method is acceptable for use when modeling very infrequent storms with high amounts of precipitation. It is also an acceptable method for more frequent storms when the dominate soils in the watershed are sand and/or loamy sand. This method should not generally be used for the one percent and more frequent storms.

STRTL: The initial loss, STRTL, can be assumed to consist of two components, the surface retention loss, IA from the Green and Ampt method, and the initial infiltration, II. After the

IA is satisfied, II includes all other losses that occur until the soil profile is saturated and a stabilized, uniform infiltration condition occurs. Therefore, STRTL is the sum of IA and II. IA can be estimated using Table 8. II can be estimated using Table 12.

CNSTL: The uniform loss rate parameter, CNSTL, is equivalent to the Green and Ampt method bare ground XKSAT parameter adjusted for vegetation cover and can be estimated using the procedures for adjusted XKSAT.

RTIMP: RTIMP for the Initial Loss and Uniform Loss Rate method is identical to the parameter used with the Green and Ampt method. The procedures defined for estimating RTIMP for the Green and Ampt method should be used for the Initial Loss and Uniform Loss Rate method.

Figure 9
Representation of Rainfall Loss According to the Initial Loss Plus Uniform Loss Rate Method (IL + ULR)

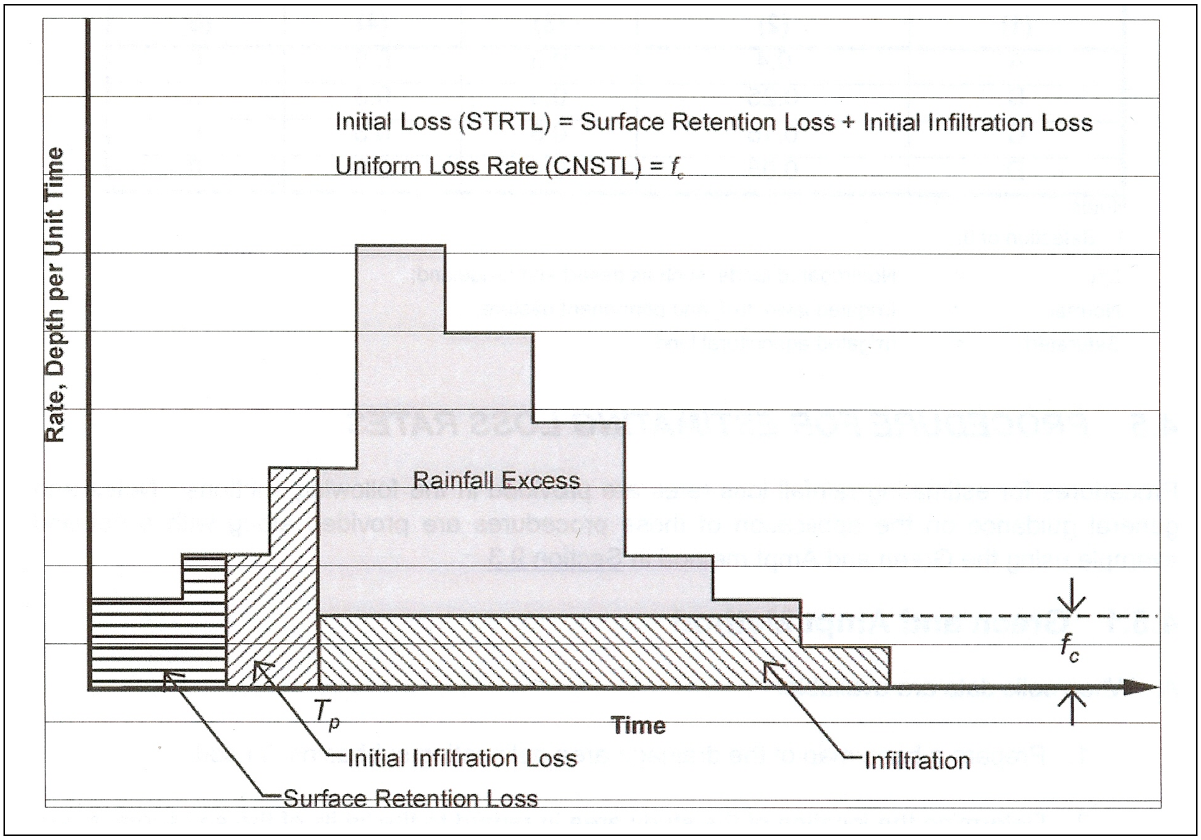


Table 12
Initial Loss Plus Uniform Loss Rate Parameter Values for Bare Ground

Uniform Loss Rate, inches/hour	**Initial Infiltration, inches II[1]**		
(1)	**Dry (2)**	**Normal (3)**	**Saturated (4)**
0.30 – 1.20	0.6	0.5	0
0.15 – 0.30	0.5	0.3	0
0.05 – 0.15	0.5	0.3	0
0.00 – 0.05	0.4	0.2	0

Note:

1. Selection of II:
   Dry = Non-irrigated lands, such as mountain, hillslope and rangeland.
   Normal = Irrigated lawn, turf, and permanent pasture.
   Saturated = Irrigated agricultural land, or land that can be assumed to have high soil moisture content due to snowmelt.

Instructions For Computing Initial And Uniform Loss Parameters:

General: In general the following steps are used to compute rainfall loss parameters for the Initial Loss and Uniform Loss Rate method. The sets of instructions following these general steps are specific to computing parameter values for each sub-basin.

1. Sub-basin Delineation. Prepare a base map of the drainage area and delineate modeling basins for the concentration points of interest. Delineate sub-basins from each basin so that the sub-basins are as homogeneous as possible in terms of area and/or time of concentration characteristics, and surface characteristics and/or soil type. Delineate large areas of impervious area as separate sub-basins. Create GIS polygon coverages for each basin and sub-basin and calculate the area of each basin and sub-basin.

2. Sub-Area Delineation. Delineate sub-areas for each sub-basin for the purpose of assigning IA and RTIMP estimates. The polygons from NRCS soil surveys delineating SMUs also are sub-areas, and often are used as sub-areas for estimation of IA and RTIMP. Create GIS polygon coverages for each sub-area and calculate the area of each sub-area.

3. Sub-Area Parameters. Assign estimates of IA, II and RTIMP for each sub-area.
4. Estimate Bare Ground XKSAT for each SMU (sub-area).
5. Estimate CNSTL for Each Sub-basin. Compute composite bare ground XKSAT for each sub-basin, adjust for vegetation cover, and assign as CNSTL.
6. Estimate STRTL for Each Sub-Basin. Compute STRTL by summing composite IA and an estimate of II.
7. Estimate Composite RTIMP for each Sub-basin.
8. HEC-1 Loss Rate Record. Enter the composite values of STRTL, CNSTL, and RTIMP for the drainage area or each sub-basin on the LU record of the HEC-1 input file.

STRTL:

1. Compute a Composite Value of IA: Use the procedures defined for the Green and Ampt method to compute a composite value of IA for each sub-basin.
2. Compute a Composite Value of II: Use the sub-basin composite estimate of CNSTL (see below) to estimate a value of II from Table 12.
3. Compute an Estimate of STRTL for each Sub-Basin: Add IA and II to obtain an estimate of STRTL.

CNSTL:

1. Compute a Composite Value of CNSTL: Use the procedures defined for the Green and Ampt method to compute a composite value of XKSAT adjusted for vegetation cover for each sub-basin, and use those values for CNSTL.

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