A New Curve Number Calculation Approach Using GIS Technology

Track: Water Resources
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Abstract

Runoff Curve Number is a key factor in determining runoff in the hydrologic modeling based on the NRCS (Natural Resources Conservation Service) runoff Curve Number (CN) method. The traditional method to calculate the composite CN is very tedious, and takes up a major portion of hydrologic modeling time. CN is a function of soil type and land use. Since GIS formatted soil and land use data are becoming increasingly available from the public domain, this paper introduces data retrieving and processing procedures using ArcGIS 9.1. After overlaying with soil survey data polygon, drainage subbasin polygon and land use polygon, a new intersection shape file can be created as a base file for the CN calculation. Techniques to convert SSURGO soil data into hydrologic group, and a method to calculate the composite CN based on polygon's land use category are also described. The CN calculation with this approach can be dramatically simplified.

Introduction

NRCS runoff curve number method is the most widely used method for estimating runoffs in water resources field. It was originally developed by Natural Resources Conservation Service (NRCS, formally called Soil Conservation Service). Most runoff calculation models such as TR-55, TR-20, HEC-1 and HEC-HMS adopt this method. The traditional method to calculate the composite CN at individual drainage basin is summarized as follows:

- Scan Soil Survey Map published by USGS
- Reference it in CAD file and digitize it
- Make each soil group as polygon and count soil group and area
- Overlay with land use map and drainage area map to further divide overlaid polygon
- Record each polygon's soil information, land use information and area
- Write program or spread sheet to calculate

One of the main disadvantages of the traditional NRCS CN method is tedious data processing. In the recent decade, Geographic Information System (GIS) has been increasingly applied to hydrologic study. Current GIS hydrologic models such as ArcHydro, GeoHMS and RiverCAD have automated many hydrologic data processing procedures such as drainage area delineation, flow path and slope calculations which have made flow time concentration calculation in watersheds much simpler in the model. However, automation of composite CN calculation has been left behind. Because of this gap, some non-commercial application and efforts have been made for trying to fill the gap [Halley, etc, 2000].

Methods

Determination of CN depends on the soil hydrologic characteristics and ground cover conditions in the watershed. The factors determining CN include the hydrologic soil group (HSG), cover type, treatment, hydrologic condition, and antecedent runoff condition (ARC). HSG reflects infiltration rates of soils, which are classified as four groups, A, B, C and D. Group A has the highest infiltration rate (lowest CN with more sands and gravels) and Group D has the lowest infiltration rate (highest CN with more silts and clays). Runoff curve numbers under the different ground cover and soil features are summarized as follows:

OBJECTID	LUCODE	CLASSIFICATION	A	B	C	D
1	11	Water	100	100	100	100
2	12	Ice, Snow	100	100	100	100
3	21	Low Intensity Resident	61	76	84	88
4	22	High Intensity Resident	81	88	91	93
5	23	Comm, Industr, Trans	91	94	95	96
6	31	Rock, Sand, Clay	77	86	91	94
7	32	surface mining	70	75	80	85
8	33	transitional	77	86	91	94
9	41	Deciduous Forest	36	60	73	79
10	42	Evergreen Forest	36	60	73	79
11	43	Mixed Forest	36	60	73	79
12	51	Shrub land	35	56	70	77
13	61	Orchard, Vineyard	43	65	76	82
14	71	Grassland	49	69	79	84
15	81	Pasture, Hay	49	69	79	84
16	82	Row Crop	69	79	86	90
17	83	Small Grain	64	75	83	87
18	84	Fallow	77	86	91	94
19	85	Urban Grass	49	69	79	84
20	91	Woody wetland	98	98	98	98
21	92	Herb wetland	98	98	98	98

Table 1 Curve Number Look Up Table

Table 1 is a simplified CN look up table based on a previous study and the author's experience. A more detailed list is published in TR-55 Manual [NRCS, 1986]. From the above table, it can be found that CN depends on the land use and HSG. Different HSG with different land use will generate a unique CN for the sub-basin. Therefore, CN in the watershed is a composite CN which can be described as:

$$CN = 98*Imp\% + \Sigma A_i CN_i * (1 - Imp\%)/\Sigma A_i \quad \textit{Eq. <1>}$$

Where A_i is the area with CN_i, Imp % is the soil's imperviousness percentage in the area A_i and 98 is assumed CN for the connected impervious area, where runoff eventually flows into the drainage system. From the above equation, it can be found that the calculation of composite CN is to count each intersection of every HSG and Land Use polygon. Equation 1 is a fundamental equation to calculate the composite CN in watershed using GIS data, which most GIS CN calculation techniques are based on. The difference among them is how to process data and how to retrieve the data into the calculation platform.

Application

With the previous-mentioned calculation basics, the detailed procedures to retrieve the data are introduced as follows:

1. Drainage Area Delineation

   Automation of drainage area delineation has been widely used. Many hydrologic programs such as ArcHydro, HEC-GeoHMS, Pre-pro2000, WMS and RiverCAD have this capability. Instead of the delineation of watershed itself, the availability of the 3-D data will become the key issue to complete this task. The current most available 3-D data is the USGS Quadrangle Topographic Map. Its shortcoming is its accuracy (10 ft vertical and 30 meter horizontal). However, for drainage area delineation purposes, it should meet the basic requirement for the square mile sized watershed.

2. Soil Data Processing

   Originally, soil data was obtained from the USDA NRCS County Soil Survey Book. Then, maps could be digitized into GIS platform. With Soil Survey Geographic (SSURGO) Database available on-line [NRCS, 2006], GIS formatted soil survey map can be directly used as base soil data.

   SSURGO data obtained from NRCS contains the following attributes (here, Brazos County in Texas is used as example, See Fig. 1 for detail; shape file name is soilmu_a_tx041.shp).

Attributes of soilmu_a_tx041

FID	Shape*	AREASYMBOL	SPATIALVER	MUSYM	MUKEY
0	Polygon	TX041	1	SpB	363233
1	Polygon	TX041	1	WzA	363253
2	Polygon	TX041	1	SpB	363233
3	Polygon	TX041	1	RsD	363221
4	Polygon	TX041	1	Gd	363196
5	Polygon	TX041	1	RaB	363215
6	Polygon	TX041	1	Ka	363203
7	Polygon	TX041	1	SpB	363233
8	Polygon	TX041	1	NvB	363212
9	Polygon	TX041	1	KuD	363206
10	Polygon	TX041	1	NvB	363212
11	Polygon	TX041	1	RtC	363222
12	Polygon	TX041	1	WzA	363253
13	Polygon	TX041	1	RsD	363221
14	Polygon	TX041	1	MrA	363211
15	Polygon	TX041	1	BuB	363181
16	Polygon	TX041	1	LuD	363200
17	Polygon	TX041	1	RsD	363221
18	Polygon	TX041	1	BeB	363176

Record: 1 Show: All Selected Records (0 out of 5521 Selected.) Options

Fig. 1 SURRGO Data Attribute List

Unfortunately, previous table does not list HSG. However, from the county soil survey map (see Fig. 2 for example), Soil name/symbol (MUSYM in SSURGO data) can be related to HSG.

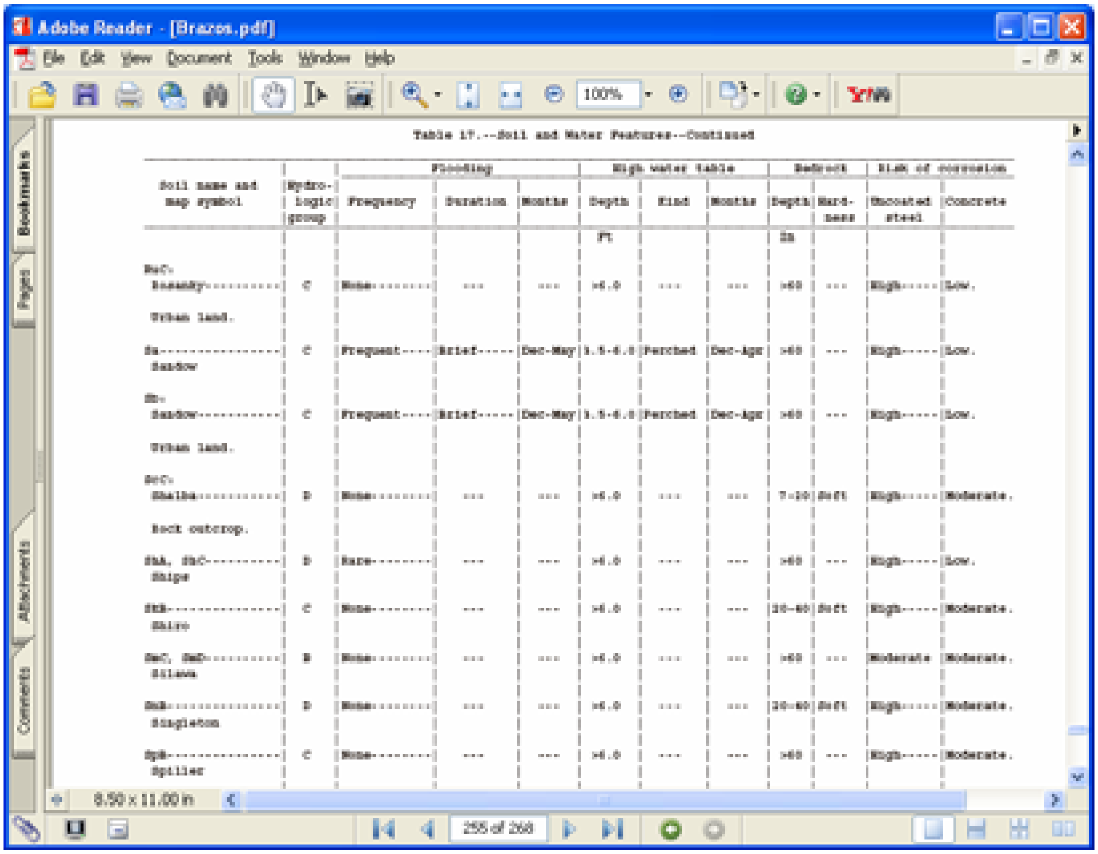
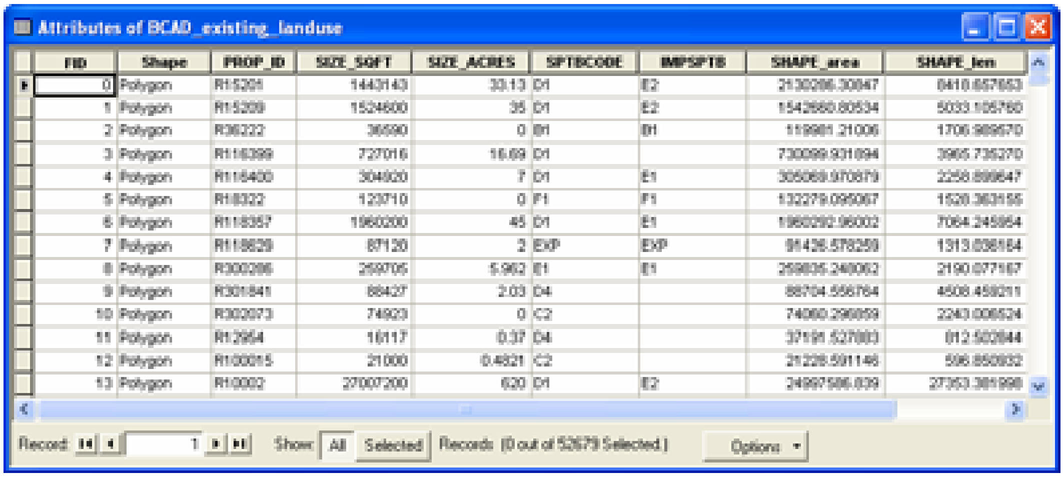


Figure 2. Soil Data Table in County Survey Map

The next step is to assign a new column as HSG using above-mentioned classifications. Then a Visual Basic code is written to sort MUSYM and generate HSG column.

3. Land Use Map Processing

The GIS formatted land use or zoning maps have been becoming more and more popular in the public domain. Most of the time, this map can be obtained from the local government agency. However, those maps may not be up to date. Therefore, maps need to be updated based on surveys or the most current aerial ortho-photograph.



Attributes of BCAD_existing_landuse

FID	Shape	PROP_ID	SIZE_SQFT	SIZE_ACRES	SPTBCODE	IMPSPTB	SHAPE_area	SHAPE_len
0	Polygon	R15201	1443143	33.13	D1	E2	2130286.30847	8410.657653
1	Polygon	R15209	1524600	35	D1	E2	1542660.80534	5033.105760
2	Polygon	R36222	36590	0	B1	B1	119981.21006	1706.989670
3	Polygon	R116399	727016	16.69	D1		730099.931894	3965.735270
4	Polygon	R116400	304920	7	D1	E1	305069.970879	2258.899647
5	Polygon	R18322	123710	0	F1	F1	132279.095067	1520.363155
6	Polygon	R118357	1960200	45	D1	E1	1960292.96002	7064.245954
7	Polygon	R118629	87120	2	EXP	EXP	91436.578259	1313.036184
8	Polygon	R300286	259705	5.962	E1	E1	259835.248062	2190.077167
9	Polygon	R301841	88427	2.03	D4		88704.556764	4508.459211
10	Polygon	R302073	74923	0	C2		74060.296859	2243.006524
11	Polygon	R12954	16117	0.37	D4		37191.527883	812.502844
12	Polygon	R100015	21000	0.4821	C2		21228.591146	596.850932
13	Polygon	R10002	27007200	620	D1	E2	24997586.839	27353.381998

Record: 1 Show: All Selected Records (0 out of 52679 Selected.) Options

Figure 3. Attribute List of Land Use Map Data

Figure 3 shows the example of land use map attribute list. The attribute, SPTBCODE (State Property Tax Board) lists each lot's land use information. Since each government entities have their own definition on land use categories, this attribute shall be re-classed to match the definition in Table 1.

4. Intersect Three Base Maps

After obtaining three fundamental maps/shape files: Drainage Basin, Land Use and Soil Data shape files, and using ArcToobox Overlay in Analysis Tool, they can be intersected as a new map/shape file which contains each individual polygon with unique HSG and Land Use features. Figure 4 shows the final intersected map.

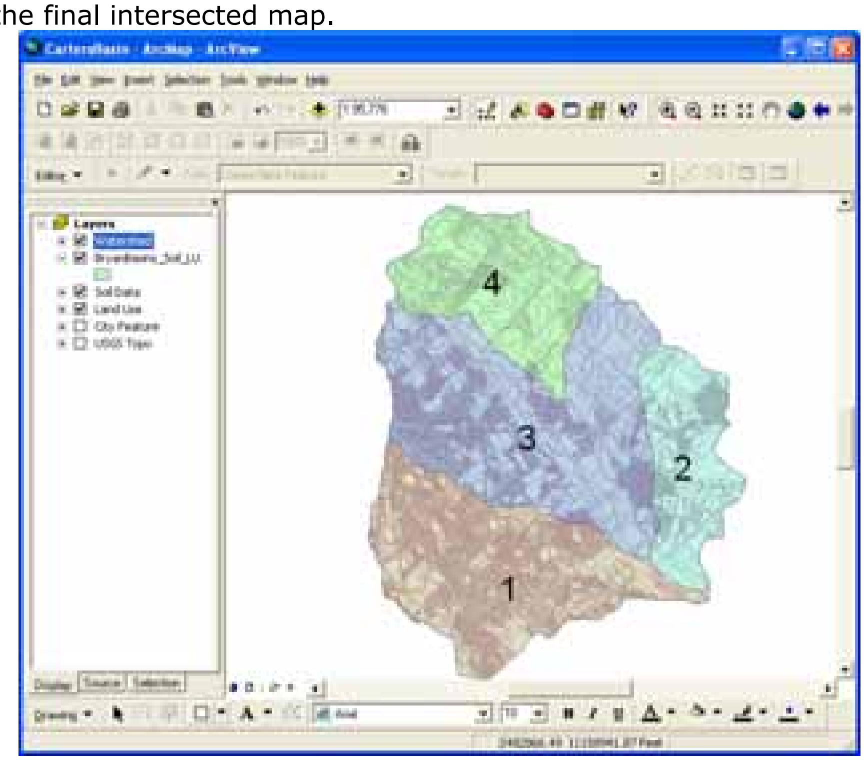
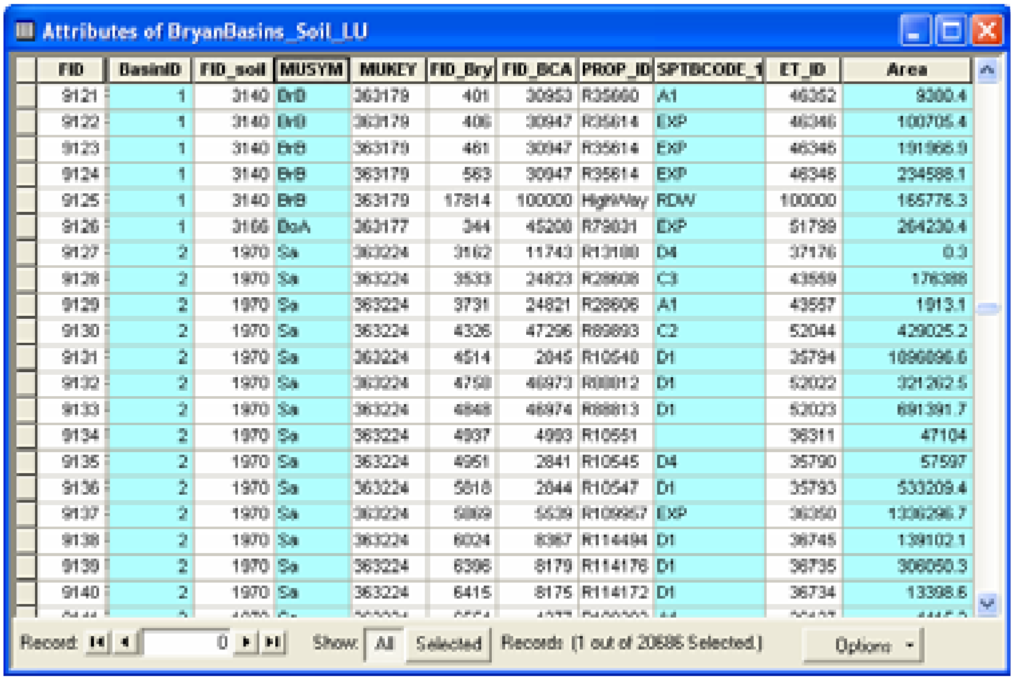


Figure 4. Intersected Basin, Soil and Land Cover Map

Figure 5 lists attributes of this intersect map where the key elements are BasinID, LUCODE(SPTBCODE), MUSYM and Area.



Attributes of BryanBasins_Soil_LU

FID	BasinID	FID_soil	MUSYM	MUKEY	FID_Bry	FID_BCA	PROP_ID	SPTBCODE_1	ET_ID	Area
9121	1	3140	DrB	363179	401	30953	R35660	A1	46352	9300.4
9122	1	3140	DrB	363179	406	30947	R35614	EXP	46346	100705.4
9123	1	3140	BrB	363179	461	30947	R35614	EXP	46346	191966.9
9124	1	3140	BrB	363179	563	30947	R35614	EXP	46346	234588.1
9125	1	3140	BrB	363179	17814	100000	HighWay	ROW	100000	165776.3
9126	1	3166	DoA	363177	344	45200	R79031	EXP	51799	264230.4
9127	2	1970	Sa	363224	3162	11743	R13100	D4	37176	0.3
9128	2	1970	Sa	363224	3533	24823	R28608	C3	43559	176388
9129	2	1970	Sa	363224	3731	24821	R28606	A1	43557	1913.1
9130	2	1970	Sa	363224	4326	47296	R89893	C2	52044	429025.2
9131	2	1970	Sa	363224	4514	2045	R10540	D1	35794	1096096.6
9132	2	1970	Sa	363224	4758	46973	R88812	D1	52022	321262.5
9133	2	1970	Sa	363224	4848	46974	R88813	D1	52023	691391.7
9134	2	1970	Sa	363224	4937	4993	R10551		36311	47104
9135	2	1970	Sa	363224	4961	2841	R10545	D4	35790	57597
9136	2	1970	Sa	363224	5818	2044	R10547	D1	35793	533209.4
9137	2	1970	Sa	363224	5869	5539	R109957	EXP	36350	1336296.7
9138	2	1970	Sa	363224	6024	8367	R114494	D1	36745	139102.1
9139	2	1970	Sa	363224	6396	8179	R114176	D1	36735	306050.3
9140	2	1970	Sa	363224	6415	8175	R114172	D1	36734	13398.6

Figure 5. List of Attributes in the Intersection Map

5. Calculation of Composite CN

Now the final step is to calculate the composite CN based on the table from Figure 5. With available data from the above table and Equation 1, data quarries can be performed on ArcGIS platform. Here in this paper, another method is introduced in which the pivot table from spreadsheet application is used. From the MS Excel Spreadsheet, starting with Pivot Table and Pivot Chart Wizard, Soil data will be assigned to attribute or column field; land use data will be assigned to feature or raw field; polygon area will be assigned to data field and each subbasin will be assigned to page field. In this way, automatic sorting can be performed in the pivot table wizard and shown in the light blue portion of Table 2. Based on Equation 1, the calculation portion can be formed in the dark blue portion.

Sum of AREA	**HSG**				
Land Use	A	B	C	D	Grand Total
21		109345.1	12876527.7	149530386	162516258.8
22	183887.3	1348300.7	15871156.6	83792136.8	101195481.4
23	15603.9	311808.6	18014949.9	210923819.3	229266181.7
71	395069.1	1719360.2	42904034.1	155084856.6	200103320
81				1704708.8	1704708.8
85	241205.3	486705.2	6686075.3	31119956.3	38533942.1
Grand Total	835765.6	3975519.8	96352743.6	632155863.8	733319892.8

Imp &	Curve No.				WT CN	WT CN
	A	B	C	D		
38%	61	76	84	88	91.6	20.3
65%	81	88	91	93	96.1	13.3
85%	91	94	95	96	97.7	30.5
5%	49	69	79	84	83.5	22.8
5%	49	69	79	84	84.7	0.2
5%	49	69	79	84	83.5	4.4
					Final CN	91.5

Table 2. Composite CN Calculation Table

Thus, the final composite CN can be resulted from Table 2.

Final Notes

The above mentioned method can speed up the composite CN calculation time from several weeks work into work that can be done within a day. It will also reduce the possibilities of the manual input error. However, it is still a preliminary non-professional application and looks complicated. The author hopes that ESRI will make this calculation become a professional application and a formal module in the near future.

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