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Estimation Curve Numbers using GIS and Hec-GeoHMS Model

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ABSTRACT

Recently, the development and application of the hydrological models based on Geographical Information System (GIS) has increased around the world. One of the most important applications of GIS is mapping the Curve Number (CN) of a catchment. In this research, three softwares, such as an ArcView GIS 9.3 with ArcInfo, Arc Hydro Tool and Geospatial Hydrologic Modeling Extension (Hec-GeoHMS) model for ArcView GIS 9.3, were used to calculate CN of (19210 ha) Salt Creek watershed (SC) which is located in Osage County, Oklahoma, USA. Multi layers were combined and examined using the Environmental Systems Research Institute (ESRI) ArcMap 2009. These layers are soil layer (Soil Survey Geographic SSURGO), 30 m x 30 m resolution of Digital Elevation Model (DEM), land use layer (LU), "Look–Up tables" and other layers resulted from running the software.

Curve Number which expresses a catchment's response to a storm event has been estimated in this study to each land parcel based on LU layer and soil layer within each parcel. The results showed that a CN of 100 (dark Blue) means surface water. The high curve numbers (100 -81) (Blue and light Blue) corresponding to urbanized areas means high runoff and low infiltration; whereas low curve numbers (77- 58) (Brown and light Brown) corresponding to the forested area means low runoff and high infiltration. Four classes of land cover have been identified; these are surface water, medium residential, forest and agriculture.

Keywords:GIS, land use, curve number (CN), watershed planning.

تقدير ارقام المنحني CN بأستخدام نظم المعلومات الجغرافية GIS و HEC-GeoHMS

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مدرس
كلية الهندسة - الجامعة المستنصرية

الخلاصة

في الآونة الاخيرة ازداد تطوير وتطبيق النماذج الهيدرولوجية على أساس نظم المعلومات الجغرافية (GIS) في جميع أنحاء العالم. واحد من اهم التطبيقات هو حساب (قيم ارقام المنحني Curve Numbers) . في هذا البحث ، تم استخدام ثلاث برامج مع بعضها لغرض حساب قيم ارقام المنحني لمستجمع مياه الجدول المالح البالغ مساحته 19210 هكتار ، ولاية اوكلاهوما والواقع في امريكا. وبتراكب عدة طبقات كطبقة التربة (مسح التربة الجغرافي SSURGO) وطبقة نظم ملف موديل الارتفاع الرقمي DEM وطبقة ملف الغطاء الأرضي (LU) مع دمج جدول Look-Up وطبقات اخرى ناتجة من عمل البرامج المستخدمة.
في هذه الدراسة، تم حساب قيم ارقام المنحني التي تعبر عن مدى استجابة المستجمع المائي الى عاصفة مطرية . اظهرت النتائج ان رقم المنحني المتمثل باللون الأزرق الغامق والمساوي الى 100 يعني مياه سطحية . ان الأرقام العالية بين (100-81) والمتمثلة

بالمناطق العمرانية (اللون الأزرق والازرق الفاتح) تعني ان الاستجابة لامتصاص الماء قليل جداً في هذه المناطق، بينما الأرقام الواطئة بين (77-58) والمتمثلة بمناطق الغابات والمناطق الزراعية (اللون البني والبني الفاتح)، تعني ان الاستجابة لامتصاص الماء كبيرة .لقد تم تصنيف أربعة انواع من الغطاء الأرضي لمنطقة الدراسة: مناطق مائية، مناطق سكنية متوسطة، مناطق غابات، ومناطق زراعية.
الكلمات الرئيسية : نظم المعلومات الجغرافية، ملف الغطاء الأرضي، الرقم المنحني، التخطيط العمراني.

1. INTRODUCTION

A curve number (CN), an index developed by the Soil Conservation Service (SCS) now called the Natural Resource Conservation Service (NRCS), is used to estimate the amount of rainfall that infiltrates into the soil and the amount of surface runoff **Chin, 2000 ; Durrans, 2003**. It is first developed for agricultural watersheds, and then it was consequently used in urban areas. This method should be used only with 24- hour rainfall duration. It is not time dependent; thus, it neglects differences resulting from varying rainfall durations and intensities **Durrans, 2003; USDA, 1986**. Modeling is increasingly used to determine Curve number. ArcView 9.3 has been developed by the Environmental Systems Research Institute (ESRI) for analyzing, modeling, manipulating, querying, and visualizing data from many different sources, **Wang and Cui, 2004**. Various types of watershed models, such as SWMM **James, et al. 2010** and SWAT **Arnold et al. 1996,** TR-55, Tr-20, HIC-!, WMS, and HIC-HMS use this method to determine runoff **Shadeed and Almasri, 2010**. Sediment and pesticide are then calculated based on the runoff. An area weighted average curve number is often used to calculate the runoff for the entire watershed by helping GIS. Implementing GIS techniques for producing spatially varied curve number can reduce the time from days, if not weeks, to hours. In addition, GIS can be used for future analysis to predict watershed response associated with change in urbanization Zhan &Huang 2004. Because curve number is a function of the soil and land use of a drainage basin, estimation of a curve number requires mapping of the soil and land use within the drainage basin boundaries, and specification of unique soil types and unique land use categories. The manual calculation of curve numbers for large areas or many drainage basins can be cumbersome and time-consuming; therefore, a Geographic Information System (GIS) is an appropriate tool to use for such an application.

Most researchers seem to agree that using GIS for estimating CN is effective and is an efficient use of time. **Gumbo, et al., 2002** described a method of assessing the effectiveness of storm drainage by combining a digital elevation model (DEM) with a rainfall-runoff model based on the Soil Conservation Service South African manual (SCS-SA). The land use, watershed and soil map of the University of Zimbabwe's (UZ) main campus was merged in Arc View and initial Curve Numbers (CN) were assigned. A composite curve number (CNc) was determined for a watershed with sub-area of different soil types and land cover by weighting the CN's for different subareas in proportion to the land area associated with each area. A combination of a DEM and rainfall-runoff model with in GIS platform proves to be useful in estimating runoff on urbanized watersheds. **Nayak, et al. 2012** calculated the curve number of Uri river watershed in Lower Narmada basin in Central India. Satellite images for two different periods (2001 and 2007) have been interpreted in ILWIS GIS platform for preparation of land use/land cover maps. The weighted average curve numbers (CN) for both years was calculated and the surface runoff volume was computed by using the SCS curve Number method. The results of runoff volume were compared with the observed volume calculated from recorded hydrograph for the selected rainfall events. The results showed that the percent increase in runoff volume in 2007 was 20-40 % compare to those in 2001for the similar rainfall events. The major advantage of employing GIS and rainfall-runoff modeling in storm drainage design is that more accurate sizing and orientation can be achieved. Furthermore the calculation can be done much faster and predictive modeling can be performed **Schulze et al., 1992**; **Gumbo, et al., 2002**.

Milhalik, et al., 2008 estimated storm water runoff and peak runoff rates by using GIS. In this study, two runoff modeling methods have been applied, the rational method and SCS_CN method. Rainfall intensities from five storms were used in the models together with the runoff coefficients and curve numbers (CN) for many lands, and then the results from the two methods were compared. The results showed that the values of peak rate estimated by SCS_CN method were more accurate than those in the Rational Method. **Zhan &Huang 2004** used the ArcCN Runoff tool, an extension of ESRI ARCGIS software, to determine curve numbers and calculate runoff for a storm event within a watershed. **Merwede, 2009** used HEC-GeoHMS to create an SCS curve number grid for Cedar Creek in northeast Indiana. Soil and land use/ land cover data were downloaded from the U.S. geological Survey (USGS) 2001 national Land Cover Dataset (USGS 2007**)** and clipped to the Cedar Creek study watershed by using GIS tools. This model saves time and effort when it was used to calculate curve number for each land use. Because of these recent advancements, the objective of this research was to apply GIS software to determine Curve Number for SC watershed as a first step for larger project to study many hydrologic models such as rainfall-runoff model to calculate runoff volume and peak discharge.

2. STUDY AREA DESCRIPTION

The watershed in Salt Creek Study Area is located in Northern Oklahoma as shown in **Fig. 1.** The drainage area for water bodies included in this study is located in Osage County. A Hec-GeoHMS model had been used to assign curve numbers (CN), which is a function of land use, soil type, and soil moisture, to Salt Creek Watershed. The model is linked to a geographic information system (GIS) for convenient generation and management of model input and output data. A CN of 100 represents a perfectly impermeable watershed. A CN of zero, on the contrary, represents a watershed abstracting all the rainfall with no runoff.

3. PROCCESSING DATA

In this study, spatial data layers (Digital Elevation Models (DEM), soil, and land use/ land cover were collected from the local USDA, NRCS United State Department of Agriculture natural resources data **USDA, 2012**. These data are usually available on the Internet. Once the data has been gathered and the software programs (ArcView GIS 9.3 with ArcInfo, Arc Hydro Tool and Hec-GeoHMS) were downloaded, then the next step is to clip these data for the study area.

The following procedure of how to incorporate GIS with soil data, land use / land cover data, and DEM to estimate CN is presented for Salt Creek watershed. Sc_dem, the raw 30 DEM for SC, Sc_lc, the land cover grid, and Sc_soil, the geodatabase with SSURGO spatial and tabular data, were all clipped using a polygon feature from the overlay layer (watershed boundary layer) as shown in **Fig.2** (a) & (b). All datasets were projected to the same coordinate system (NAD_1983_UMT_16).

The numbers in land use shown in **Fig. 3a** represent the land use class defined according to the USGS land cover institute (LCI). However, after reclassifying, the numbers which represent the land use are shown in **Fig. 3b**. The classification system used for NLCD is modified from the Anderson land-use and land-cover classification system. Many of Anderson classes especially the level III classes are best derived using aerial photography.

In the attribute table of Sc_lu, the dominant land used throughout all of the study area is grassland. The second most prevalent land use is the combination of Pasture/hey and grassland/herbaceous, and the third is the developed land and then water. Sc_lc was reclassified using **Table 1** to represent these four major classes. Sc_lc was reduced from 11 to 4 as shown in **Fig. 3a** and **3b**.

4. PREPARING SOIL DATA FOR CN GRID

To prepare soil data for CN, the author first created an empty field named Soil Code for storing soil groups because the attribute table for Sc-soil_clip has no field for storing these data. A table called “comp” in soil data, which contains the attribute hydrogroup and soil data, is linked to the map document. The polygon features in Sc_soil_clip are related to component table through mukey field **Merwade, 2009**. Usually soil surveys list soil type (e.g., Norge silt clay) by name, however, the information needed to determine a curve number is the hydrologic soil group, which indicates the amount of infiltration that occurs in each type of soil. There are four hydrologic soil groups: A, B, C and D. The definition of each is given in **Table 2.**

Four fields named PctA, PctB, PctC, and PctD were created. For Salt Creek area, only one soil group assigned to each polygon so a polygon with soil group “A” will have PctA = 100, PctB = 0, PctC = 0, and PctD = 0. Similarly for a polygon with soil group D, only PctD = 100, and the other three Pcts are zero. The attribute table below was obtained. After the calculations were done, the Soil Code will be populated with letters A, B, C, D as shown in **Fig. 4.**

5. MERGING OF SOIL AND LANDUSE DATA

By using the Union tool in ArcToolbox, Soil and land use data were merged and CNLook-Up table was created using Arc Catalogue as shown in **Fig.**

6. CREATING CN Grid

After combining land use and hydrologic soil group maps using GIS, a CN grid was created using Hec-geoHMS. Hec-geoHMS uses the merged feature class (lc_soil_union) and the lookup table (CNLookUp) to create the curve number grid. The author created a field named “LandUse” in the lc_soil_union that will have land use category information to link it to “CNLookUp”. Hec-geoHMS look for this information in Landuse field while it is stored in GRIDCODE field. The author added field named landUse and equated it to GRIDCODE as shown in **Fig.6**. By clicking on Utility → Creat parameter Grids, the author chose the lookup parameter as Curve Number, and lc_soil_Union for Curve number Polygon and left the default CNGrid name for the curve Number Grid. In a minute A CNGrid will be add to the map document as shown in **Fig.7**.

7. RESULTS AND ANALYSIS

Geographic Information System (GIS) in combination with HegGeoHMS model provide ideal tools for calculating curve numbers. Curve Numbers were successfully and easily calculated. The power of combining soil layers and land use layers which is the input of the curve number method facilitates the computations and gives an accurate CN. CN estimation without the use of GIS can be time-consuming and labor intensive. The results are summarized below:

1. GIS and Hec-GeoHMS are capable of building up most of the input data required to calculate CN. The procedure of calculating CNs, which can be applied to any watershed in Iraq such as Baghdad city, Arbil city, etc.), is depending on the availability of GIS data. The step by step method for calculating CN for any watershed is presented in **Merwade, 2009.**

2. Four hydrologic soil groups were found in the case study, soil groups A, B, C, and D. and four classes of land cover have been identified; these are surface water, medium residential, forest and agriculture. This information is very useful for Rainfall-Runoff Modeling to estimate peak discharge.

3. A CN of 100 is surface water with zero infiltration. High CNs (100-81) corresponded to the urbanized areas of the watershed (Blue and light Blue), which has the potential to generate the greatest amount of runoff in a storm event.

4. Low curve numbers (77-58) (Brown and light Brown) corresponded to the forested and agricultural areas of the watershed, which generates little runoff and high infiltration rate as shown in **Table 2**.

5. This analysis can be extended further to estimate the effect of change in land use on direct runoff and to find how curve numbers vary with season and with rainfall amount. In addition, CNs can be used with Long-Term Hydrologic Impact Assessment (L-THIA) to calculate annual runoff and nonpoint source pollution at the watershed.

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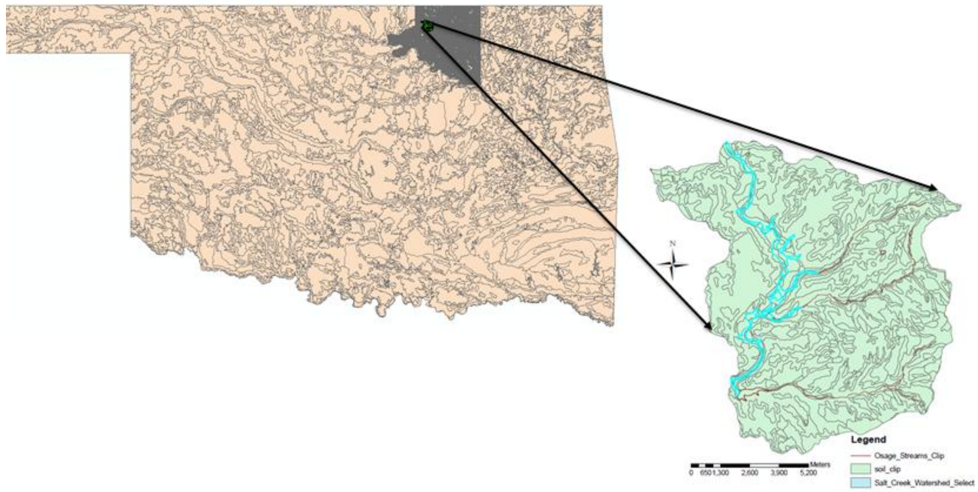


Figure 1. Location of the case study showing Osage River and streams.

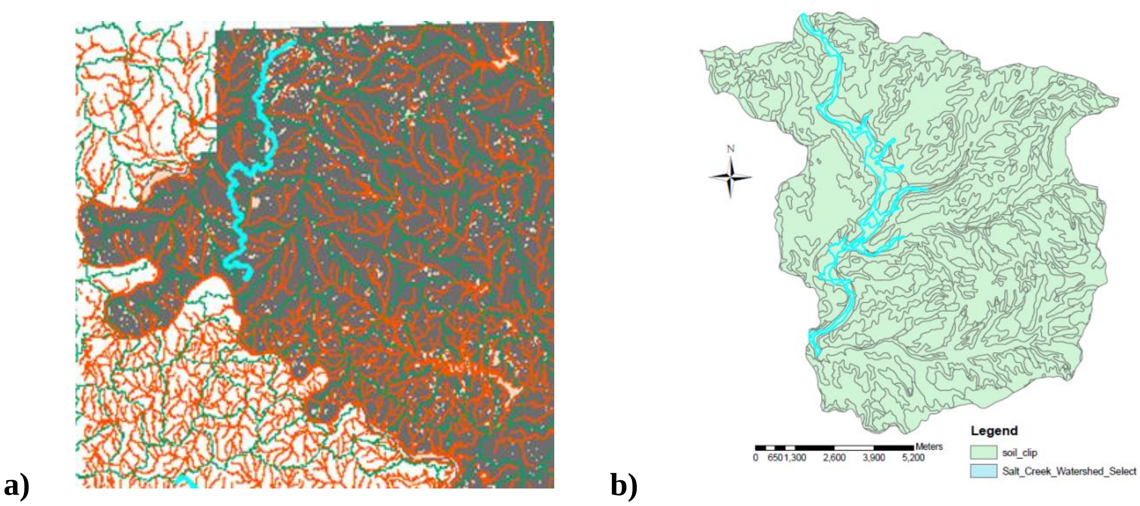


Figure 2. a) Soil data for Osage county before clipping. **b)** Soil clip map by watershed

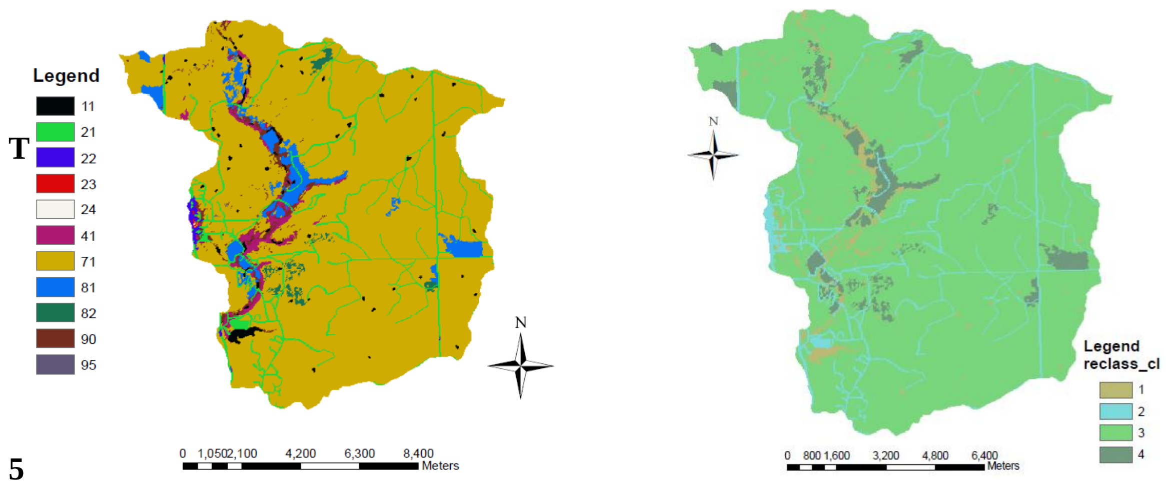


Figure 3. Prepared land use data for CN grid **a)** Land use class defined according to USGS land cover institute **b)** Land use class after reclassification which was reduced from 11 to 4 classes.

Attributes of SC_SOIL

FID	Shape *	AREASYMBOL	SPATIALVER	MUSYM	MUKEY	SoilCode	PctA	PctB	PctC	PctD
0	Polygon	OK113	2	67	623462	B	0	100	0	0
1	Polygon	OK113	2	62	623457	D	0	0	0	100
2	Polygon	OK113	2	54	623449	D	0	0	0	100
3	Polygon	OK113	2	62	623457	D	0	0	0	100
4	Polygon	OK113	2	54	623449	D	0	0	0	100
5	Polygon	OK113	2	61	623456	D	0	0	0	100
6	Polygon	OK113	2	68	623463	C	0	0	100	0
7	Polygon	OK113	2	54	623449	D	0	0	0	100
8	Polygon	OK113	2	49	623444	D	0	0	0	100
9	Polygon	OK113	2	69	623464	C	0	0	100	0
10	Polygon	OK113	2	70	623465	C	0	0	100	0

Record: 1 Show: All Selected Records (0 out of 380 Selected) Options

Figure 4. Attribute table of Sc_soil. SoilCode field populated with letters A, B, C, D.

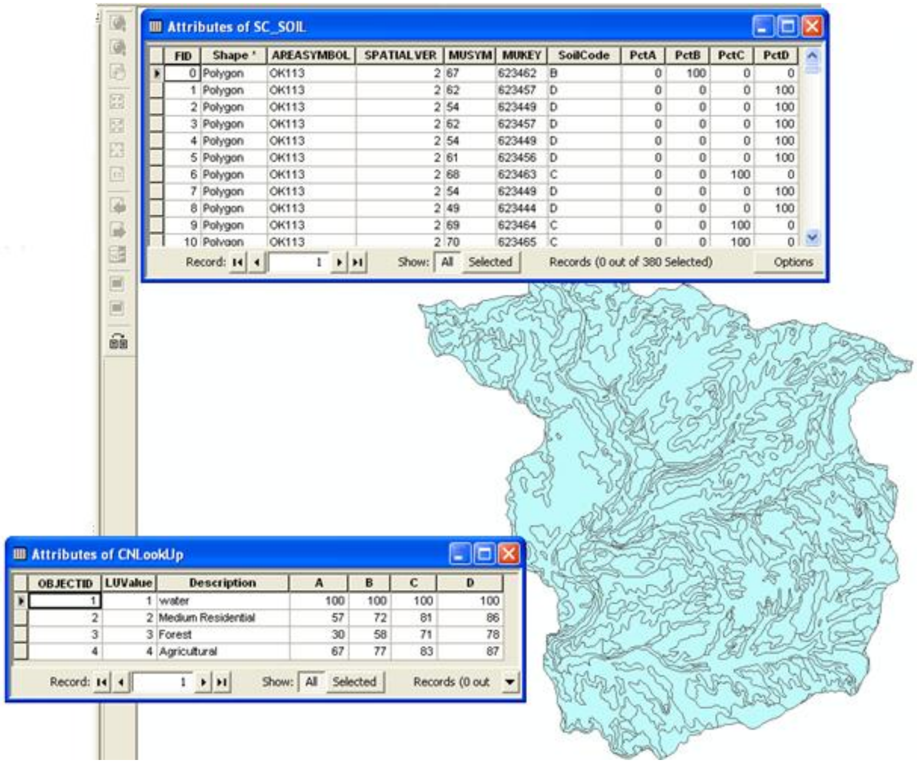
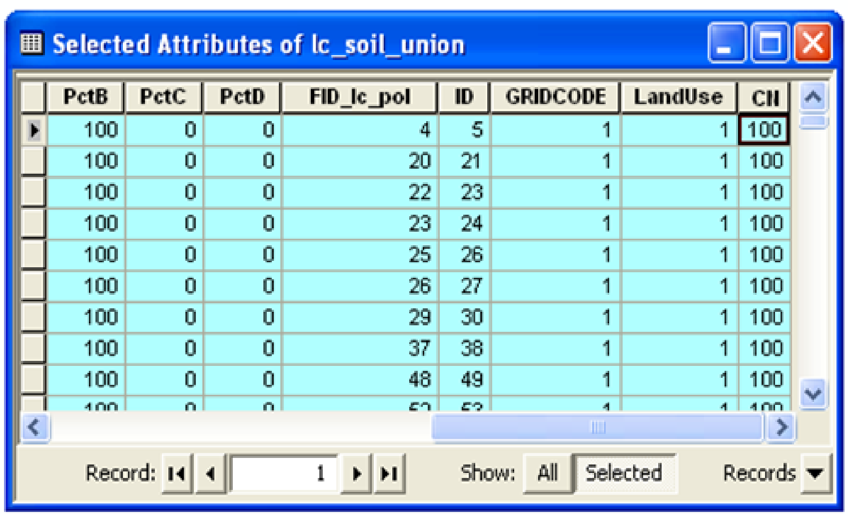


Figure 5. Creating CNLook-Up table for SC watershed



Selected Attributes of lc_soil_union

PctB	PctC	PctD	FID_lc_pol	ID	GRIDCODE	LandUse	CN
100	0	0	4	5	1	1	100
100	0	0	20	21	1	1	100
100	0	0	22	23	1	1	100
100	0	0	23	24	1	1	100
100	0	0	25	26	1	1	100
100	0	0	26	27	1	1	100
100	0	0	29	30	1	1	100
100	0	0	37	38	1	1	100
100	0	0	48	49	1	1	100

Figure 6. Creating LandUse” in the lc_soil_union attribute table

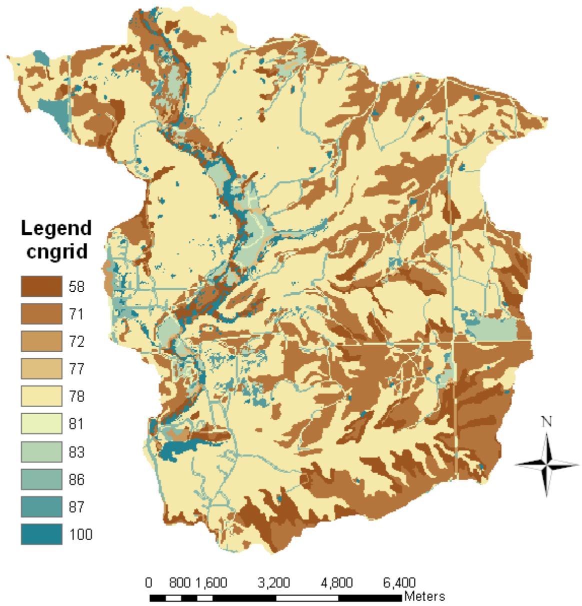


Figure 7. Curve Number (cngrid) calculations for the case study. The highest CN=100 &the lowest CN =58.

Table1. Original NLCD classification and reclassification **USGS, 2013**.

Original NLCD classification		Revised classification (re-classification)	
Number	*Description*	*Number*	*Description*
11	Open water	1	Water
90	Woody wetlands		
95	Emergent herbaceous wetlands		
21	Developed, open space	2	Medium Residential
22	Developed, low intensity		
23	Developed, medium intensity		
24	Developed, high intensity		
41	Deciduous forest	3	Forest
42	Evergreen forest		
43	Mixed forest		
31	Barren land	4	Agricultural
52	Shrub/scub		
71	Grassland/herbaceous		
81	Pasture/hay		
82	Cultivated crops		

Table 2. Description of NRCS Soil Groups **James, et al., 2010.**

Group	Description	Saturated Hydraulic Conductivity (in/hr)
A	High infiltration rates, well to excessively drained sands or gravels	≥ 0.45
B	Moderate infiltration rates , Shallow loess, sandy loam	0.30-0.15
C	Slow infiltration rates, clay loams, shallow sandy loam	0.15-0.05
D	Very slow infiltration rates, consisting chiefly of clay soil	0.05-0.00