Cairo University

SCS METHOD RELIABILITY ANALYSIS IN ESTIMATING RUNOFF DISCHARGES AND VOLUMES IN ARID REGIONS

By

Mohamed Ahmed Abdel Fatah El Sayed Wahdan

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Irrigation and Hydraulics Engineering

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Title of Thesis:

SCS method reliability analysis in estimating runoff discharges and volumes in arid regions.

Key Words:
SCS method ; arid regions; reliability analysis; runoff;

Summary:

Reliability analysis was applied to evaluate the uncertainty of SCS method in estimation of peak discharge and runoff volume at various return periods if the SCS input parameters (CN and T_{lag}) were considered as random variables in arid regions. The study main conclusions are: 1) The SCS method should be used with caution when the rainfall coefficient of variation is smaller than 0.5. 2) Design of water structures should consider the peak discharge and runoff volume in arid regions. 3) Application of SCS method in arid regions is more reliable when the return period is small.

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Nomenclature

3D	Three dimension
A	Catchment area
AMC	Antecedent moisture condition
API	Antecedent rainfall
ARC	Antecedent moisture runoff condition
CN	Curve number
F	Actual losses
FERUM	Finite element Reliability Using MATLAB
FORM	First Order Reliability Method
hr	Hour
Ia	Initial abstraction
MCS	Monte Carlo simulation
MFOSM	Mean-value First Order Second Moment
min	Minute
mm	Millimeter
NEH-4	National Engineering Handbook
NRCS	National Resources Conservation Service
P	Mean value of the maximum annual 24-hr rainfall
Pcov	Rainfall coefficient of variation
PD	Peak Discharge
Pf	Probabilities of failure
S	Maximum potential retention
SCS	Soil Conservation Services
SMI	Soil moisture index
SORM	Second Order Reliability Method
STD	Standard deviation
Tc	Time of concentration
T_{lag}	Lag time
Tp	Time to peak
UH	Unit Hydrograph
USDA	US Department of Agriculture
V	Volume

Abstract

When runoff measurements are not available, runoff can be estimated using the relationship between rainfall and runoff. One of the most widely used methods is the SCS method with its inputs: the curve number (CN), the design rainfall, the lag time (T_{lag}) and the catchment area. Usually in the SCS method the rainfall is considered as the only random variable, however the variation of CN and T_{lag} are neglected and a single (mean) value is assigned for each parameter. This assumption considers only the uncertainty of the rainfall and neglects the uncertainty associated with the CN and T_{lag} parameters and the corresponding risk in the calculated runoff peak discharge and runoff volume.

Recently, special interest was given to multivariate design variables / parameters (e.g. peak discharge and runoff volume). This is of particular interest for retention / detention ponds or flood protection dams. This research aims to study the resulting probabilities of failure *Pf* for peak discharge and runoff volume if the SCS input parameters (CN and T_{lag}) were considered as variables in arid regions. It answers the following questions: What is the risk of failure for the resulting peak discharge and the runoff volume if the CN and T_{lag} are random variables and not constants? Consequently, what would be the acceptable range of application of the SCS method at different return periods (10, 50 and 100 years) to remain within the vicinity of the targeted design probability of failure? This research focuses on arid regions, where the rainfall variability is high and the mean rainfall value is usually small. It is directed to study the scenarios when the *Pf* for runoff volume dominates the failure and those when the *Pf* for peak discharge prevails.

A reliability approach using First Order Reliability Method (FORM) is used to evaluate the impact of the uncertainty of SCS parameters on the estimated probability of failure due to exceedance of the design peak discharge and/or runoff volume. A wide spectrum of the variability of the SCS parameters is tested to cover both arid and non-arid regions and compare between them.

The study concluded that the estimated runoff peak discharge using the SCS method is critical in arid regions even for a runoff depth more than 0.5 inch under the condition of small rainfall coefficient of variation (*Pcov* less than 0.5). Application of the SCS method in arid regions should be avoided when the rainfall coefficient of variation *Pcov* is smaller than 0.5. The study confirmed that design of water structures should consider the design peak discharge and the volume as in arid regions where the mean rainfall is low the runoff volume is more critical than the peak discharge. The estimated runoff using the SCS in arid regions is more reliable when the return period is small.

Chapter 1 : Introduction

1.1. Background

Estimation of the runoff volume and the peak discharge is necessary to design flood control structures. Moreover, understanding the infiltration process is important for hydrologists in water resources management studies. There are common methods to estimate the peak discharge such as the rational method, the Soil Conservation Services (SCS) Curve Number (CN) method, Horton's model for infiltration capacity and the Green Ampt infiltration model (Thomas, 2001). The choice of either method depends on the available data, catchment size, the method assumptions, limitations and suitability for the required application. The rational and the Curve Number methods depend on rainfall-runoff relationship that requires rainfall data to estimate the runoff (Kabiri atl., 2013).

The Rational method is the simplest and widely used method to estimate peak discharge for small urban catchments from available rainfall data. Horton's model is a simple method used to estimate total runoff depth from infiltration; however the application of this method requires field measurements (Thomas, 2015). Green and Ampt method is based on a physically based model that basically assumes that water infiltrates in dry soil as a sharp water front and applied to estimate the total runoff depth from infiltration. This method is accurate in infiltration calculation; however it is complex and requires field measurements for input data needed in the model (Thomas, 2015). The CN method was developed by the Soil Conservation Services (SCS) (lately named the National Resources Conservation Service (NRCS)) to estimate the runoff from rainfall using an empirical parameter the Curve Number (CN) (SCS, 1993).

The SCS method is one of the most popular runoff estimation methods when the peak discharge measurement data are not available. Uncertainty associated with the SCS runoff estimation parameters has a significant impact on the calculated runoff peak discharge and runoff volume. The main parameters used in the SCS method are the catchment area (A), the Curve Number (CN), the lag time (T_{lag}), the mean rainfall value P and the design rainfall depth. The lag time (T_{lag}) is defined as the time interval from the center of rainfall excess to the peak discharge. For simplicity these parameters can be classified as watershed properties parameters and rainfall characteristics parameters. The SCS method reliability in practical application depends on the uncertainty of the used parameters.

In practical design, engineers usually consider rainfall as the only uncertain random variable in the SCS method (i.e. associated with a certain probability), while the CN and the (T_{lag}) are constants. This assumption considers only the uncertainty of the rainfall variability and neglects the uncertainties associated with the CN and T_{lag} parameters and the corresponding risk in the calculated runoff peak discharge and runoff volume. A recent reliability analysis study has been carried out to figure out the impact of the uncertainty of the CN and Tc in arid regions on the calculated runoff peak discharge for the 100-year return period. The study concluded that it is important to study the impact of the variability of the CN and T_{lag} in arid regions on the design and presented the safe range where the SCS method can be applied with reliable estimated design peak discharge (Saad, 2013).

The current study aims to evaluate the uncertainty of the SCS method application if the CN and *Tc* parameters are also considered as random variables to determine the risk associated with the design runoff peak discharge as well as the runoff volume in arid regions where the rainfall design value is usually small. The reliability analysis considers the uncertainty associated with input parameters and consequently the reliability of the resulting output. The uncertainty analysis method adopted in this research is the First Order Reliability Method (FORM). FORM is one of the most reliable sampling methodologies widely used in reliability analysis.

1.2. Problem Definition

Arid regions are characterized by special hydrological characteristics (e.g. rainfall) that are different from humid regions characteristics. Considering a single fixed value for each parameter (i.e. CN and T_{lag}) to estimate the runoff in deterministic models is not accurate and subject to high uncertainties in arid regions.

The point of interest in this research is the uncertainty of the peak discharge and runoff volume estimated using the SCS method for various return periods (i.e. 100, 50 and 10 year). The study has a special focus on the arid regions that are characterized with high variability in rainfall and small design rainfall values. The SCS parameters considered in uncertainty analysis are the Curve Number, the lag time, the mean value of the maximum annual 24-hr rainfall and its rainfall coefficient of variation *Pcov*.

In this work, a reliability approach using First Order Reliability Method FORM is used to evaluate the impact of the uncertainty of the CN and the time of concentration *Tc* in the SCS method for various return periods in arid regions to compare with previously studied uncertainties for the 100-year return period (Saad, 2013). Moreover, this work extends the previously mentioned study to assess the uncertainty of CN and *Tc* on the probability of failure either by exceeding the design volume or the design peak discharge in the SCS runoff model. This is of particular interest for retention ponds or flood protection dams where failure of the structure may be due to exceeding the design capacity and/or exceeding the design peak discharge of the overflow or the evacuation works.

1.3. Study Objectives

The research aims to study the probability of failure *Pf* for exceeding the design peak discharge and/or design runoff volume if the SCS input parameters (CN and Tc) were considered as random variables in arid regions. This study answers the following question: What is the risk of failure for the resulting peak discharge and the runoff volume if the CN and *Tc* are random variables and not constants? And consequently what is the acceptable range of application of the SCS method at various return periods (10, 50 and 100 years)? This research aims to study also the critical scenarios to determine where the probability of failure *Pf* for runoff volume exceeds the *Pf* for peak discharge.