Estimating Stormwater Runoff from the 3D-model of an Urban Area in Istanbul

Muhammed Ali Örnek[1], Melike Ersoy[2], Yasin Çağatay Seçkin[3]

[1]Istanbul Technical University, Istanbul/Turkey · maornek@itu.edu.tr
[2]Istanbul Technical University, Istanbul/Turkey · ersoymeli@itu.edu.tr
[3]Istanbul Technical University, Istanbul/Turkey · cseckin@itu.edu.tr

Abstract: The aim of this study is to develop a plugin, which works in conjunction with Rhinoceros software, that both estimates and reports storm water runoff. The plugin is initially developed based on the SCS Runoff Curve Number Method. The CN method is the most commonly used method for determining peak discharges from small drainage areas. The formula is traditionally used to size storm sewers, channels, and other storm water structures which handle runoff from drainage areas of less than 1 km^2. For this purpose, all data, such as land use description, hydrologic soil groups, cover type, runoff curve numbers, time of concentration in minutes, slope, drainage area, rainfall depth in 24 hours duration, unit peak discharge, rainfall intensity at time concentration, rainfall data for the different sites in Turkey, are important. Each is used as an input for the operation of the plugin which also takes sensitive design data, such as topographic, footprint, hard and soft landscape surfaces, from existing drawings and makes estimations. After obtaining all the necessary data and writing the plugin, a case study area in the form of a high density urban area in Istanbul, will be analyzed using the plugin. The accuracy of the results will be compared with the results we get from traditional calculations.

The importance of the study derives from facilitating the process of storm water runoff estimation that is one of the outstanding factors of the architectural, landscape and urban design process related to sustainability. In addition, this research presents a user-friendly decision support and even decision-making tool by employing recent computer technologies by corresponding to the lack of research in literature. With this research, it is aimed both to accelerate and ease the estimation process in terms of storm water management, and also to create an evaluation and decision support system for designers.

Keywords: Storm water runoff estimation, plugin, landscape information modelling, system thinking, Istanbul

1 Introduction

When natural landscapes are developed, it has a significant impact on the natural hydrology cycle. The hydrological cycle follows a number of steps: precipitation, condensation, evaporation, infiltration, surface runoff, groundwater flow and evapotranspiration. In naturally vegetated areas, precipitation lands on the ground, infiltrates the soil and the surface runoff response to precipitation is relatively slow. However, increased use of hard surfaces (roads, streets, parking areas and buildings covered with impermeable materials) can affect the hydrological cycle in a bad way and cause the prolongation of the process. Depending on this elongation of time, runoff volume, velocity, temperature and pollutant loads increase and affect the environment negatively. Actually, not only impervious hard surfaces, but urbanization as a whole also changes watershed behavior during rainfall events.

The purpose of this study is to develop a plugin by employing Rhinoceros and Grasshopper software to facilitate the estimation process of storm water management even in the early stage of the design. This plugin is initially developed based on the CN method, and calculates the total runoff of the selected area based on CAD drawings. The CN method is explained as

Journal of Digital Landscape Architecture, 1-2016, pp. 198-206. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-612-3, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537612023.

a method used to estimate runoff generated from a 24-hour rainfall event in the Technical Release-55 (TR-55, 1986) by the American Natural Resources Conservation Service (NRCS). In order to estimate the runoff from storm water, the CN method uses the runoff curve numbers for different hydrological soil groups. The determination of the runoff curve number depends on land use, soil type, soil infiltration capability, the depth of the seasonal high water table, and cover type. The higher the runoff curve number, the more the impervious the area is, and the more the impervious the area, the greater is the surface runoff. Therefore, all these data provide crucial information for the calculation.

According to the CN method, the total rainfall (P) is divided into three parts: initial abstraction, continuous abstraction and excess rainfall. *Initial abstraction* (I_a) describes the amount of rainfall that is used for filling surface depressions, and never leaves the watershed. The I_a value is highly variable but is generally related to soil properties and cover parameters (TR-55, 1986). After this initial abstraction is satisfied, the remaining amount of rainfall is used to satisfy the remaining soil storage as a continuous abstraction. Continuous abstraction is directly related to *potential maximum retention (S)*. The *S* variable is also related to the soil properties and cover parameters in the watershed. It can be calculated using the formula shown in Eq. 4, with the help of the runoff curve number.

Eventually, when daily rainfall *(P)* is lower than the I_a value, no runoff would be generated from the site. When *P* is higher than the I_a value, then the runoff (*Q*) created depends on the cover type and can be calculated using the formula shown in Eq. 3 (Technical Release TR_55, 1986).

Table 1: Empirical Equations for the CN Method

(Eq. 1)	$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$	Where;
(Eq. 2)	$I_a = 0{,}2 \text{ x } S$	• **Q** = runoff (mm) • **P** = rainfall (mm) (24 hours rainfall event)
(Eq. 3)	$Q = \frac{(P - 0{,}2S)^2}{P + 0{,}8S}$	• **S** = potential maximum retention after runoff begins (mm) • $\mathbf{I_a}$ = initial abstraction (mm)
(Eq. 4)	$S = \frac{2540}{C\ Number} - 25{,}4$	• **CN**= coefficient of surfaces *(all kind of surfaces has different coefficient)*

The identification of surface types and hydrological soil groups has an important role to play in the determination of the runoff curve number. According to the USDA Natural Resources Conservation Service, which was formerly called the *Soil Conservation Service* or *SCS*, there are four main soil groups in terms of their soil conditions and infiltration rates:

- **Group A:** Sand, loamy sand or sandy loam soil textures. Have water transmission rates greater than 8 mm for per hour.
- **Group B:** Silt loam, or loam soil textures. Have water transmission rates in the rage of 4 mm – 8 mm per hour.

- **Group C:** Sandy clay loam soil textures. Have water transmission rates in the range of 1 mm – 4 mm per hour.
- **Group D:** Clay loam, silty clay loam, sandy clay or clay soil textures. Have water transmission rates in range of 0.0 –1 mm per hour.

Table 2 shows the runoff curve numbers that have been determined for different land cover conditions and hydrological soil groups by the USDA Natural Resources Conservation Service (HARRIS & DINES 1998).

Table 2: Recommended runoff coefficient values of surfaces for CN Method

Condition Type	Hydrologic Soil Group			
	A	B	C	D
Commercial and Business Area	89	92	94	95
Residential Areas				
500 m^2	77	85	90	92
1000 m^2	61	75	83	87
2000 m^2	54	70	80	85
4000 m^2	51	68	79	84
Parking areas, Roofs, Driveways	56	74	82	86
Streets and Roads				
paved with curbs and storm sewers	98	98	98	98
paved with open roadside ditches	83	89	92	93
gravel	76	85	89	91
dirt	72	82	87	89
Open spaces, lawns, parks, golf courses, cemeteries, etc.				
poor < 50 % ground cover	68	79	86	89
fair, 50 to 75 % ground cover	49	69	79	84
good> 75 % ground cover	39	61	74	80

In addition to all this information, the daily rainfall data of Istanbul that is used in the case study has been gathered from the TSMS (Turkish State Meteorological Service) website. According to the website, while the minimum annual 24 hours rainfall is 43 mm, the maximum value is 71 mm (TSMS 2016).

2 Research

This research consists of four parts.

1. Literature review in order to understand the CN method and data collection to use for the plugin and the case study
2. Plugin design
3. Case study
4. Findings and the evaluation of the accuracy of the plugin.

The case study area is Levent in Istanbul. Levent is a high density urban area consisting of various surfaces and different land usages. Runoff in this area will be calculated through both the conventional method and the developed plugin to measure the accuracy of the plugin.

2.1 Methodology

The developed plugin was based on the Rhinoceros (2016) modeling software through using the Grasshopper extension (2016). Rhinoceros is a NURBS modeling software which is popular in that it is a bridge between modeling and fabrication for design disciplines. When Rhinoceros works in conjunction with Grasshopper, it becomes a parametric design tool that doesn't require any coding skills. Grasshopper presents a user-friendly interface that allows users to build program structures by both defining information and function modules and connecting the information map relating to them. In this research, the Rhinoceros and Grasshopper software were used because of their programming simplicity and their full compatibility with other CAD software.

The workflow of the plugin was outlined in four phases. In the first phase, the runoff and runoff curve number values were defined in the plugin as textual and numerical modules. Then, the data from the drawing were defined in the plugin as geometrical shapes such as curves and surfaces, to get the area values of all components. In the third phase, equations and formula modules were defined and modified in order to calculate the Q value. Finally, all essential information were collected and reported in a panel module. The workflow of the plugin was outlined as shown in Figure 1.

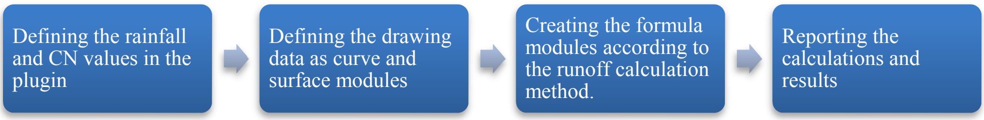

Fig. 1: The workflow of the proposed plugin

In the first phase, the essential information (rainfall data and runoff curve numbers for different cover descriptions) were defined in the plugin as variables and tables. While the rainfall data can be described only using numerical values, the description of the runoff curve numbers should contain both textual and numerical parameters. For that purpose, the rainfall data was defined as *the number slider module* to allow users to enter local rainfall values. On the other hand, the runoff curve numbers are defined as tables through *the panel modules* in order to allow users to choose the type of surface cover by using a drop-down selection list.

In the second phase, the structure of the plugin was built by defining the geometrical data of drawings through the *curve* and *surface* modules. These modules can be used to keep the analytical parameters of drawings such as coordinates, area, length, slope, etc. The curve modules were defined for each surface type, and these modules were connected to the *surface* modules to be able to obtain area values from the drawing. Then, the area module was connected to the surface module by allowing the *mass addition* module to calculate the total surface area of the assigned drawing. At last, a dropdown selection module was created to allow users to define the surface type (Figure 2).

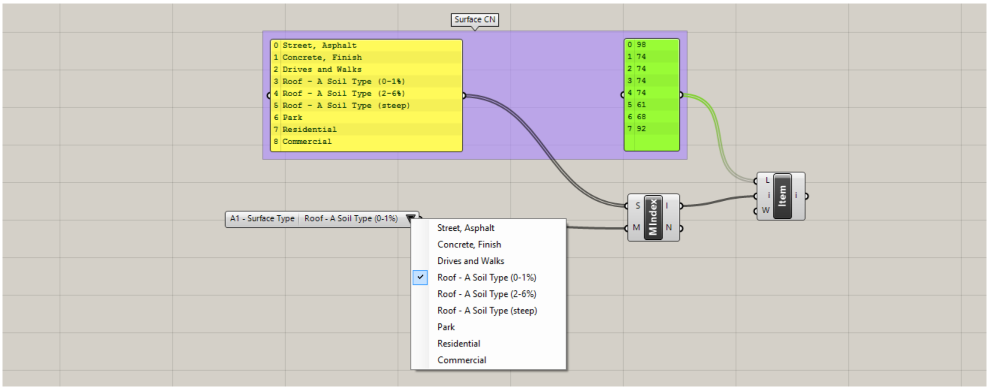

Fig. 2: Screenshot of the modules which is both gathering information from the drawing and calculating the total area

In the third phase, equation and calculation modules were created and modified according to the CN method in order to calculate the *Q* Value. For that purpose, total *CN* values and surface areas were calculated using the regular operator modules. In order to calculate the *Q* value, an *expression* module was employed to calculate multiple variables in a complex formula.

In the last phase, a reporting system was created by collecting the essential information and data in a panel module to allow users to copy the results directly from the interface. For this purpose, a reporting layout was created by using the *concentrate* modules, and all were connected to the final report in the proper order. In order to present users with a simplified interface, most of the calculations and variable modules were clustered into one module (Figure 3).

2.1 Case Study: Levent – Istanbul

Levent is one of the fully developed commercial and residential districts of the European side of Istanbul. The selected area (Figure 4) combines both high-rise commercial buildings and different kinds of residential living. The maximum annual 24-hours' rainfall for the area is 71 mm. The hydrological soil group in the area is identified as B type soil, which refers to silt loam or loam soil textures, which also has water transmission rates in the range of 4 mm – 8 mm per hour (YALÇIN 2012).

Fig. 3: Annual precipitation of Turkey – 24 hours rainfall (TSMS 2016)

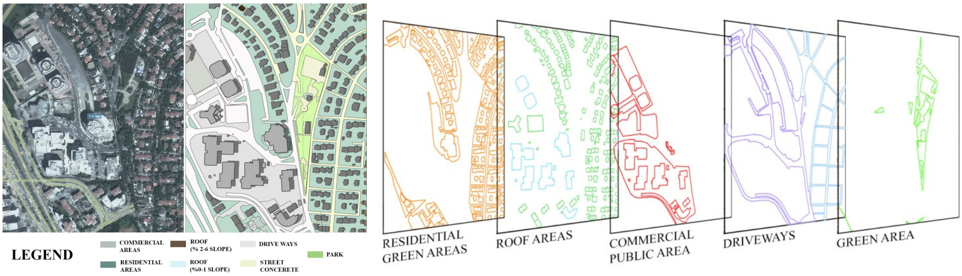

Fig. 4: Case Study Area related with land usage in city center Istanbul, Levent

3 Findings

Afterwards, the accuracy of the plugin was verified through the use of both the conventional method and the proposed plugin for storm water runoff calculation with regard to the case study area. In order to calculate the storm water runoff, the site plan drawing was imported to the plugin in different layers. Finally, the results were compared to determine the accuracy of the plugin.

The results of the calculation using the conventional method, show that:

- Average CN is 84,76
- Total Surface Area is 244.394 m^2
- *Q value* is 65,79 mm.

$$\boldsymbol{S} = (2540 / \text{CN}) - 25{,}4 \qquad \boldsymbol{I_a} = 0{,}2\ S \qquad \boldsymbol{Q} = (P - 0{,}2\ S)^2 / (P + 0{,}8\ S)$$

$$\boldsymbol{S} = (2540 / 84{,}76) - 25{,}4 \qquad \boldsymbol{I_a} = 0{,}91 \qquad \boldsymbol{Q} = (71 - 0{,}91)^2 / (71 + (0{,}8 \text{ x } 4.56))$$

$$\boldsymbol{S} = 4{,}56 \qquad \boldsymbol{Q} = \mathbf{65{,}79\ mm}$$

Table 3: The storm water runoff of the case study was calculated through the Conventional Method (The CN Method)

Land Use	Soil Group	Curve Number	Area (m²)	Area x CN
Residential Areas	B	68	63,816	4,339,488.00
Roof Areas	B	98	71,313	6,988,674.00
Commercial Areas	B	92	49,352	4,540,384.00
Driveways	B	74	27,419	2,029,006.00
Streets paved with curbs and storm sewers	B	98	22,603	2,215,094.00
Green area good > 75 % ground cover	B	61	9,891	603,351.00
TOTAL		84.76	244,394.00	20,715,997.00

The results of the calculation using the plugin, show the same results:

- Average CN is 84,76
- Total Surface Area is 244.394 m^2
- *Q value* is 65,79 mm.

$$\boldsymbol{S} = (2540 / \text{CN}) - 25{,}4 \qquad \boldsymbol{I_a} = 0{,}2\,S \qquad \boldsymbol{Q} = (P - 0{,}2\,S)^2 / (P + 0{,}8\,S)$$

$$\boldsymbol{S} = (2540 / 84{,}76) - 25{,}4 \qquad \boldsymbol{I_a} = 0{,}91 \qquad \boldsymbol{Q} = (71 - 0{,}91)^2 / (71 + (0{,}8 \text{ x } 4.56))$$

$$\boldsymbol{S} = 4{,}56 \qquad \boldsymbol{Q = 65{,}79 \text{ mm}}$$

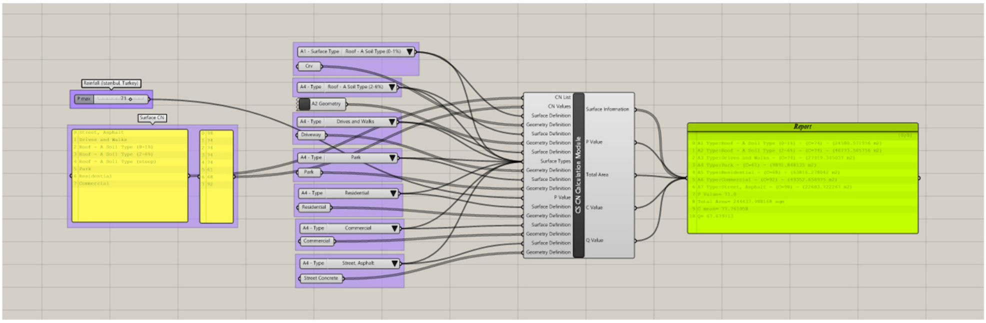

Fig. 5: Screenshot of the calculation interface of plugin

In addition, the plugin was used to compare the surface runoff of the design alternatives for the case study area. As a second design alternative, the impervious surfaces of commercial areas and roof areas have been considered as green roofs.

Table 4: The storm water runoff of the case study was calculated through the plugin for the second design alternative

Land Use	Soil Group	CN	Area (m²)	Area x CN
Residential Areas	B	68	63,816	4,339,488.00
Green Roofs	B	75	71,313	5,348,475.00
Commercial Impervious Areas as Green Roofs	B	75	49,352	3,701,400.00
Driveways	B	74	27,419	2,029,006.00
Streets paved with curbs and storm sewers	B	98	22,603	2,215,094.00
Green area good > 75 % ground cover	B	61	9,891	603,351.00
TOTAL		74.62	244,394.00	18,236,814.00

$$\boldsymbol{S} = (2540 / \text{CN}) - 25{,}4 \qquad \boldsymbol{I_a} = 0{,}2\,S \qquad \boldsymbol{Q} = (P - 0{,}2\,S)^2 / (P + 0{,}8\,S)$$

$$\boldsymbol{S} = (2540 / 74{,}62) - 25{,}4 \qquad \boldsymbol{I_a} = 1{,}72 \qquad \boldsymbol{Q} = (71 - 0{,}1.72)^2 / (71 + (0{,}8 \text{ x } 8{,}63))$$

$$\boldsymbol{S} = 8{,}63 \qquad \boldsymbol{Q = 61{,}59 \text{ mm}}$$

The new Q value is 61,59 mm. This means that if the commercial units were impervious and roof surfaces can be redesigned as green roof, the surface runoff will be reduced by 6,38 %. As is seen in the example, the conclusion is that this plugin can be used as an evaluation tool for determining the land uses of surfaces.

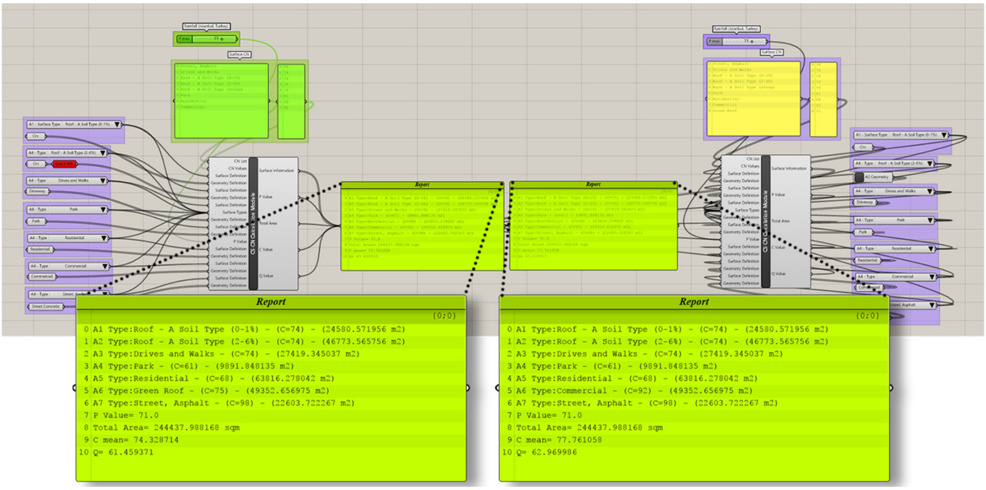

Fig. 6: Screenshot of the calculation interface of plugin

4 Conclusion

The research was aimed to present a storm water runoff calculation tool that automates the CN method. This tool allows designer and planners to calculate the storm water runoff in their design alternatives even at early design stages. This tool differs from current calculation methods since it allows users to calculate directly using the CAD drawings and choosing surface types on the user-interface. In addition, it enables users to report the results and essential information in real-time, and compare multiple projects at the same time. In this research, the accuracy was validated compared to the conventional SCS method. The plugin was then used to compare the storm water runoff values in two different design alternatives to show how this plugin can be employed as a design evaluation tool. Additional work is necessary to develop the proposed tool for creating a three-dimensional model of a given drawing, statistical diagram and figures, for its more effective use in design practice.

References

GRASSHOPPER (2016), Grasshopper Plugin: Algorithmic Modeling for Rhino. January 23, 2016. http://www.grasshopper3d.com/.

GREEN VALUES STORMWATER TOOLBOX (2016), National Green Values Calculator Methodology. March 14, 2016. http://greenvalues.cnt.org/calculator/downloads/methodology.pdf.

HARRIS, C. W. & DINES, N. T. (1998), Time Saver Standarts for Landscape Architecture. 2nd Ed. McGraw-Hill Publishing, USA.

RHINOCEROS (2016), Rhinoceros Modeling Software. January 23, 2016. https://www.rhino3d.com/.

TURKISH STATE METEOROLOGICAL SERVICE (TSMS) (2016), Maksimum Yağışlar Şiddet ve Tekerrür Analizi, January 21, 2016. http://www.mgm.gov.tr/veridegerlendirme/maksimum-yagisalar.aspx#sfU.

U.S. DEPARTMENT OF AGRICULTURE (1986), Urban Hydrology for Small Watersheds Natural Resources Conservation Service, Conservation Engineering Division, Technical Release – 55 (TR-55).

YALÇIN, M. (2012), Afet Yönetimi-Hazırlık Bileşeni İçin Konumsal Veri Altyapısı Tasarlanması, Sel Ve Taşkına Duyarlı Alanlar: İstanbul Avrupa Yakası Örneği, MSc Thesis, Yıldız Technical University, Graduate School of Natural and Applied Sciences, Istanbul.