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Application of Stormwater Runoff Estimation Methods in the Case of Faculty of Agriculture Main Campus

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Abstract: Stormwater management is the practice to reduce the volume and velocity of runoff generated from development sites. Measuring and quantifying volume of runoff associated with land use characteristics is important for sustained practice. This study aims to fill the gap of applying a stormwater management model to quantify runoff volumes in a university campus for flood mitigation. To evaluate the effects of stormwater management practices in a small scale urban setting, we performed modeling using the Stormwater Management Model (SWMM) to make projections for reducing overall stormwater flow and flooding during the long-term storm events. Modeling results show that 23% of surface runoff (6,027 m^3) was infiltrated. More than 19.000 m^3 of water could be stored for irrigation purposes and almost 73.600 US Dollars could be saved annually by these techniques. Results indicate that SWMM holds promise for use at smaller scales in urban settings.

Keywords: Stormwater management, SWMM, rainfall, surface runoff, campus design, Ankara

Introduction

Urban sprawl with deteriorated open and green spaces with impervious surfaces leads to alteration of hydrological regimes and changes to local system discharge [1]. Current sewage treatment systems regularly overflow and malfunction with inadequate capacity to hold and direct surface runoff from site. Rather than volume, chemicals and nutrients are hazardous materials carried by runoff to streams and wetlands [2]. Additionally, due to global warming, intensity and duration of rainfall is ever changing, which causes urban floods [3]. It is therefore crucial to design sustainable stormwater retention systems in cities for the health and benefit of its occupants. These systems should intend to slow down the runoff and prevent volumes of water contaminating natural water resources [4]. Since the conventional strategy of using pipes to collect surface water has lost its effectiveness, the aim of this rational stormwater management approach is to reduce high runoff and harvesting of rainwater as an alternative water supply source.

Stormwater management, which aims to rapidly collect and deliver surface runoff from developed lands to streams, lakes and rivers [5, 6, 7, 8], is an ecological approach to mitigate the effects of excess runoff. Stormwater handling and treatment methods include managing and treating urban stormwater runoff on site as opposed to conventional solutions [9, 10, 11, 12]. Low Impact Development (LID) [13, 14, 15], Water Sensitive Urban Design (WSUD) [16, 17, 18], and Sustainable Urban Drainage Systems (SUDS) [9, 19, 20] aim to control urban runoff at source by retention and detention recharge to either groundwater or surface waters. These approaches create opportunities for sustainable site design techniques such as rain gardens, green roofs, reforestation, and pervious pavements [21, 22].

Accurate modeling of surface runoff under extreme rainfall loads and urban flooding is possible with existing software. These are based on equations that can simulate the process of converting rainfall to runoff and predict runoff volumes and rates [23, 24, 25] and can be used to visualize runoff flow directions [26]. These methods rely on a hypothetical rain event known as a design storm for their rainfall input. There are only few models in the market for stormwater runoff calculation that can benefit landscape design. The most advanced tool is EPA's Storm Water Management Model (SWMM) [27]. It is a dynamic rainfall-runoff and hydraulic simulation engine that was designed to predict the resultant runoff in urban areas from each modeled

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subcatchment in response to precipitation input [28, 29, 30, 31].

Research conducted on estimating surface runoff volumes in major cities of Turkey has commonly concluded that tight resource management aiming to use alternative water resources such as rainwater are required for better environment, health and economy [32, 33, 34, 35, 36, 37, 38]. However, more research is needed to model surface runoff volumes in developing countries where rapid and unplanned urbanization is a major concern.

This study seeks to apply the SWMM in the context of a small urban setting. It is aimed to propose a more viable solution to design local and small-scale system to specify drainage patterns on predeveloped sites based on the locations of subcatchments, intersections, flows and outlets. The model outputs were used to identify potential impacts of built space on water management with proposals for better design of outdoor space.

MATERIALS AND METHODS

The setting for this study is the Faculty of Agriculture Main Campus with an area of 80.726 m^2 located in the central district of Ankara (Figure 1). It is the oldest university campus in the city established in 1933. The campus stormwater is being managed in the traditional way by providing stormwater drains and directing runoff through manholes and sewage. The site is now in transition to build a sustainable and an ecological campus with rational stormwater management practices, which aim to reduce runoff volumes and rates, and collect surface water for irrigation purposes.

Figure 1. Map of project area

The computer model chosen to simulate the hydrology of the campus is the Stormwater Management Model (SWMM), which was developed by the United States Environmental Protection Agency. The SWMM was chosen specifically for this research due to its ability to model continuous or single-event precipitation simulations. Model includes calculation of the hydrological losses such as infiltration, evaporation and surface detention, and computation of surface runoff which can be processed by analyzing the catchment's surface morphology. The process is based on the assumption that the calculated runoff be routed through an imaginary pond or collector. The output from the SWMM model consists of flow hydrographs and volumes at the inlet to each major discharge locations, total volume of runoff, peak rate of runoff, infiltration, evaporation and surface storage volumes.

The preliminary phase of the study included the identification of meteorological data such as annual and instant rainfall, temperature, humidity and wind. Long term regional data on temperature and precipitation was obtained from the nearest stations of the Turkish State Meteorological Service (MGM). Local data was estimated by the Krigging method using the interpolation of collected meteorological data. GIS techniques with the Simple Kriging Prediction Map allowed estimating climate values for a 12-month period [40].

The amount of runoff that will be obtained on campus was computed based on the catchment characteristics. The items of current manholes and combined sewers were incorporated into an AutoCAD drawing of the campus. The campus's landuse are grouped under three main categories namely buildings, impervious (roads, pavement and parking lots) and pervious (open and green spaces) (Figure 2).

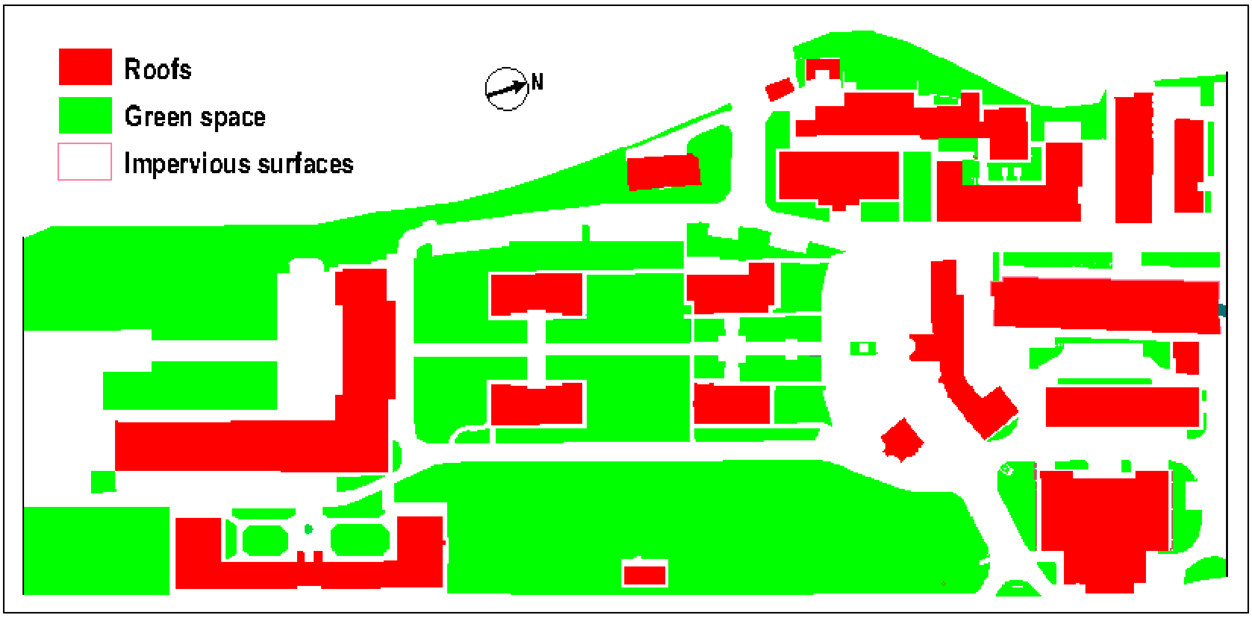

Figure 2. Current land use of project area

Using the surface morphology maps, drainage patterns were defined. According to the suspected movement of surface runoff into the drainage system towards the existing discharge outlets, 35 sub-catchments were drawn. Subcatchment areas were then delineated based on surface morphology and land use. Each subcatchment is parameterized by percent pervious/impervious, average slope, storage, soil characteristics and infiltration. While runoff is calculated using Manning's equation, infiltration is calculated by the Green-Ampt infiltration equation, which provides a modeling concept for the infiltration process, praised for its relative simplicity and is gaining popularity. The hypothetical system is designed for a 10-year storm with a scenario of runoff flowing through circular pipes to outlets where current manholes are located.

RESULTS

Normal temperatures of Ankara range from 30.3°C during summer to as low as -3°C during winter with annual average precipitation of 383 mm, according to the 81-year rainfall data [39]. The long-year monthly average amounts of rainfall from 18 stations show that the highest rainfall was in May 2014. Model input parameter of peak rainfall intensity for flood measurement is 52 mm/hr and occurs 6 hours into the rainstorm. Reliability of the precipitation data was controlled on site by using a Rainwise tipping bucket, which has been collecting 15 and 5 minute time step readings between October and May.

It is found that the hydrologic soil groups within the catchment are the combination of Group A and C and Group B [41]. The soil is mostly loamy clay with infiltration rate of 6,35 mm/hr. Land cover and land use are important factors influencing the model outputs. The cover may vary from pervious surfaces such as vegetation, lawns and groundcovers to impervious surfaces such as pavements, roofs, roads and parking lots. Based on the AutoCAD drawings, the study area was defined according to land use and land cover percentages, as follows: (1) total roof area = 17.478 m^2, (2) total ground impervious area = 31.494 m^2 and (3) total pervious area (green space) = 31.754 m^2 (Figure 1). With the Rational Method [42], a total of 47.960 m^3 of rainwater on roofs flows through gutters without any control.

The current site consists of mostly impervious surfaces. The average %IC for the campus is 60,7 % but varies significantly by location of the subcatchment within the site from a low of 0% IC to a maximum of 100% IC. Generally, impervious area within the campus consists of transportation infrastructure (parking lots, driveways, roadways) and roofs.

Surface elevations show that site has some steep terrains as well as flat surfaces around buildings. Point elevations range from 892,61 on the south corner to 900,06 meters to site's center. Eastern part of the campus has an open space with almost natural greenery. This is one of the lowest sections of the site where bioretention and rain gardens can be located. The south corner could accommodate a stormwater detention facility such as a bioswale or wetland. There is potential to direct roof drainage from the department buildings. Paved plaza in front of the clock tower could receive stormwater drainage from 7 adjacent buildings. Depression storage could be created by re-contouring the lawn in east section. The water storage capability of this area would need to be examined further, as would the identification of an outlet to offsite drainage area.

Subcatchment slopes range from 0.5 to 32 and the average slope is 2.88. Total precipitation is calculated as 26.128,8 m^3 with a 23,07% of infiltration loss (6.026,8 m^3). According to the input parameters in the system, maximum water depth in each pipe is found to be 26 cm, average velocity and flow is 1,518 m/sec and 0,184 m^3/sec respectively.
With the average slope of 2,26 % and total length of 940 meters of pipe system, all surface water can be directed to desired outlets with an average velocity of 1,52 m/sec. As a result of modeling, 19741,9 m^3 of surface runoff can be collected for reuse such as irrigation of vegetated areas with an estimated of 73.581 USD of savings on water bills. It is expected that the implementation of the project will cost less than 105.000 USD and in the second year, the project costs will be compensated (Figure 3).

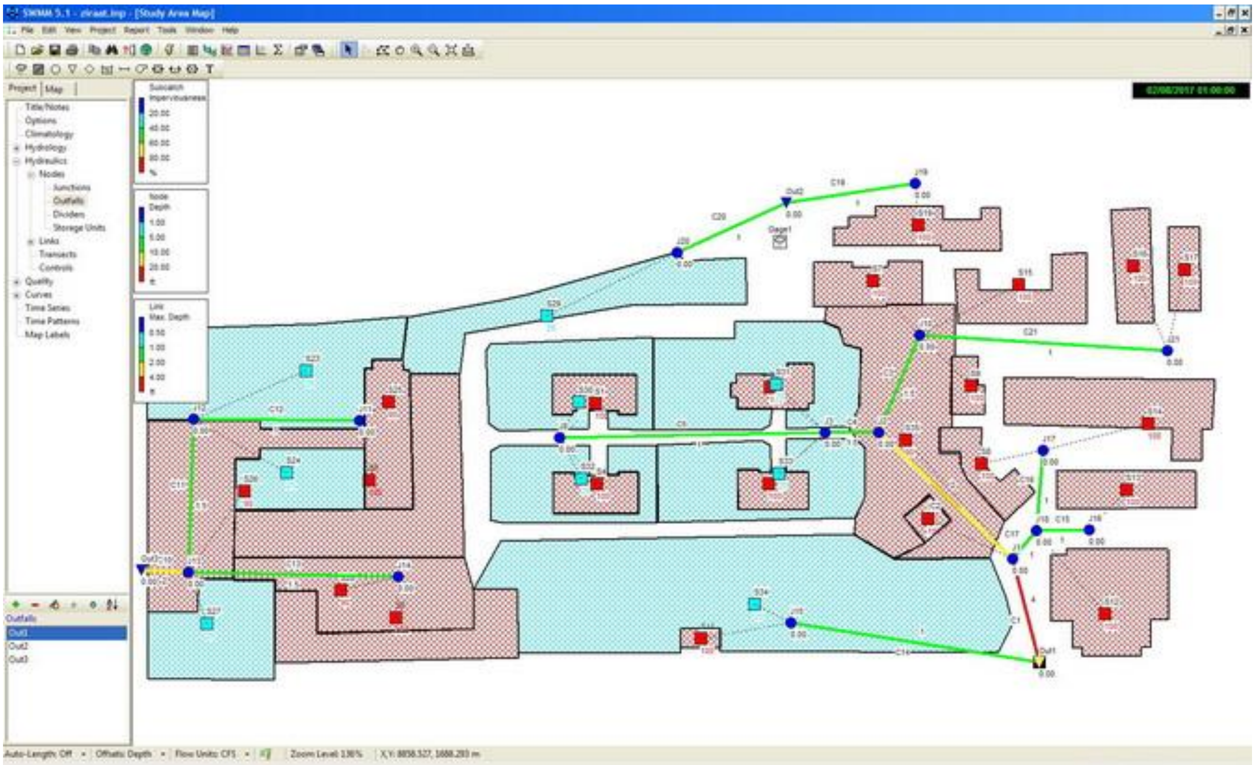

Figure 3. Screenshot of the SWMM of the subctachments

CONCLUSION

It is argued that human health and comfort is affected by the condition of the physical environment and this study proposes that we become mindful of the many roles that stormwater management, which is a key to reduce health related effects of extreme weather, can play in adapting the urban environment to climate change.

Developing countries are prone to rapid growth of population and water scarcity, which result in major environmental problems and economic crisis [43]. In a developing country like Turkey, large scale urban developments with wider roads and parking lots require proper stormwater drainage systems. Turkey, however, has limited interest in stormwater management practices, as a means of reducing urban runoff and associated pollutant loads to receiving waters. Although we see LID developments in most of the US and European cities, in accordance with stormwater management practices, Turkey cities face the challenge of limited natural lands and increased construction sites.

Conservation in urban environments is a prerequisite since usable and drinking water is also limited. Within the context of environmental problems, the city should integrate a sustainable water management and the practice should be based on proper modeling. Conservation and management practices will lead to both water and soil conservation in an ecological oriented urban environment; most of the contaminants from surface runoff will be prevented before reaching to natural streams and wetlands.

With the application of mathematical models, this study emphasizes the methodology of integrating information technology to support ecosystem-based management. Results suggest that stormwater management practices in an urban setting impact the magnitude of flood response. By simple and inexpensive methods and applications, surface runoff can be controlled and the water can be stored for reuse such as irrigation and gray water. For further developments, architects and designers will have guidelines for locating buildings and structures on spaces where stormwater can be collected, routed and infiltrated. As a result of best management practices and ecological sensitive designs, excess surface water will be controlled with less frequent flood incidents on urban streets. Results indicate that SWMM holds promise for use at smaller scales in urban settings. Results have important implications for stormwater management strategies, especially those aimed at reducing the effective impervious surface coverage of urban development sites.

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