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Water quality model of Alibeyköy watershed and LID implementation

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Abstract: Uncontrolled urbanization causes flood and poor water quality which results in an increase in peak flow rate and in Total Suspended Solid (TSS) concentration. Low Impact Development (LID) is a Best Management Practice (BMP) and land planning method which may be used to manage storm water runoff to reduce flooding as well as simultaneously improve water quality. Preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage, which treats storm water as a resource rather than as a waste product, are intended by implementing LID. There are several LID type of storm water BMPs such as bioretention, vegetated rooftops, rain barrels, vegetative swales and permeable pavements. In this study, the impact of LID implementation on TSS are investigated by developing a water quality model for Alibeyköy Watershed located in Istanbul, Turkey. For this purpose, the calibrated hydrologic model of Alibeyköy Watershed developed by using Environmental Protection Agency Storm Water Management Model (EPA SWMM) is employed. The water quality model is integrated into the hydrological model using EPA SWMM. Then, several LID types such as retention basins, vegetative swales and permeable pavement are incorporated into the water quality model and their impacts on TSS in Alibeyköy Watershed are observed.

Key words: Storm water treatment; Low Impact Development; Watershed Model; Total Suspended Solid (TSS) concentration

1. INTRODUCTION

High peak flow rates and huge amount of TSS yield problems such as flooding and poor water quality. These problems are observed more frequently due to high urbanization on watersheds. Implementing Low Impact Development (LID) type of storm water Best Management Practices (BMPs) has recently been recognized as a useful solution. LID BMPs is an approach of land re-development in order to manage storm water runoff and quality. LID implementation mitigates some of the negative effects of urbanized watersheds by decreasing surface peak flow rate, increasing evapotranspiration, infiltration, and ground water recharge, reducing the pollutants in surface and ground water and protecting animal habitats (Zhang and Guo 2014; Gülbaz and Kazezyılmaz-Alhan 2014; Brown and Hunt 2011; Trowsdale and Simcock 2011; Li and Davis 2009; Li et al. 2009; Davis 2008; Dietz 2007; Hunt et al. 2006; US EPA 2000). The importance of LID BMP implementation has been recognized recently in the literature (Ahiablame et. al., 2012; Fassman, 2012; Alfredo et. al., 2010; Elliott et. al., 2010; Lucas, 2010; Gilroy and McCuen, 2009; Bedan and Clausen, 2009; Gülbaz et al. 2015; Gülbaz and Kazezyılmaz-Alhan 2017). There are several LID type of storm water BMPs such as bioretention, vegetated rooftops, rain barrels, vegetative swales and permeable pavements (US EPA 2000; Davis et al. 2009; US EPA 1999).

The aim of this study is to investigate the effects of LID implementation on TSS concentration during different storm events by developing a water quality model for Alibeyköy Watershed. For this purpose, EPA SWMM is employed for watershed modelling. The water quality model is integrated into the calibrated hydrological model. Then, by using the hydrologic and water quality model, the TSS concentration in surface runoff developed over the watershed are simulated using measured rainfall data. Finally, retention basins, vegetative swales and permeable pavement types of LID BMPs are tested and their influence on reduction of TSS concentration is obtained. Consequently, the possible effects of LID BMPs on TSS in Alibeyköy Watershed are observed.

2. MATERIAL AND METHODS

2.1 EPA SWMM

EPA SWMM is a watershed hydrological and water quality model among several other software programs. In the literature, there are many studies related to water quantity and quality modeling by using EPA SWMM (Huber and Dickinson 1988). Furthermore, some LID types such as bioretention, rain garden, green roof, infiltration trench, permeable pavement, rain barrel, and vegetative swale can be modelled in EPA SWMM to simulate the effects of LID. In the literature, there are many studies related to water quantity and quality modeling by using EPA SWMM (Huber and Dickinson 1988; Rossman 2010); however, studies on LID implementation using EPA SWMM are quite rare. In order to model water quality, EPA SWMM includes buildup and wasoff functions described as follows.

Pollutant accumulation (Pollutant Buildup) in EPA SWMM is calculated as proportional to time raised to some power, until a maximum limit is achieved by using Power Function. For Exponential Function, pollutant buildup follows an exponential growth curve. Finally, for Saturation Function, pollutant buildup begins at a linear rate. Furthermore, the amount of pollutant accumulation is a function of number of preceding dry days. In this study, power function is used for pollutant buildup and is given as follows (Rossman 2010):

$$B = Min\left(C_{1p}, C_{2p}\, t^{C_{3p}}\right) \tag{1}$$

where B is the pollutant buildup (M/L^2), C_{1p} is the possible maximum buildup (M/L^2), C_{2p} is the buildup rate constant (M/TL^2), C_{3p} is the time exponent for the buildup parameter (*dimensionless*) and t is the time (T).

Pollutant washoff in EPA SWMM is calculated as proportional to the product of runoff raised to some power and to the amount of buildup remaining by using Exponential Function. For Rating Curve Function, pollutant washoff is calculated as proportional to the runoff rate raised to some power. And finally, Event Mean Concentration is a special case of Rating Curve Washoff where the Rating Curve exponent is 1. Rating Curve washoff function is used in this study and is given as follows (Rossman 2010):

$$W_{rc} = C_{3rc}\, Q^{C_{4rc}} \tag{2}$$

where W_{rc} is the amount of washoff pollutant (M/T), C_{3rc} is the washoff coefficient (M/L^3), C_{4rc} is the washoff exponent (*dimensionless*) and Q is the runoff rate (L^3/T).

2.2 Alibeyköy watershed

Alibeyköy Watershed is located on the European Continental side of Istanbul in Turkey (Figure 1). It has a drainage area of 161 km^2 and supplies an important portion of Istanbul's drinking water. There are 10 streams which gather overland flow generated over the basin. These streams are Cebeci stream, Boğazköy stream, Bolluca stream, Kocaman stream, Çıplak stream, Ayvalı stream, Elmalı stream, Gülgen stream, Malkoç stream, Çiftepınar stream. The land morphology of the great part of the watershed is in the form of sandy clay loam. The altitude of the watershed is between 30-170 m in the topographic boundaries. Alibeyköy Watershed area is composed of 23% of agricultural and pasture land, 15% of residential and industrial areas, 60% of forest and 2% of dam area. However, there is a great potential of population growth due to the new developments of infrastructures in the basin. These new infrastructures include third Bhosphorus Bridge, third airport of Istanbul and finally Canal Istanbul project. Therefore, high urbanization is expected in the next

10 years and these changes will have negative effects on the ecosystem in the future, if no action is taken. In Fig. 1, the boundary of Alibeyköy Watershed and Alibeyköy Dam are shown.

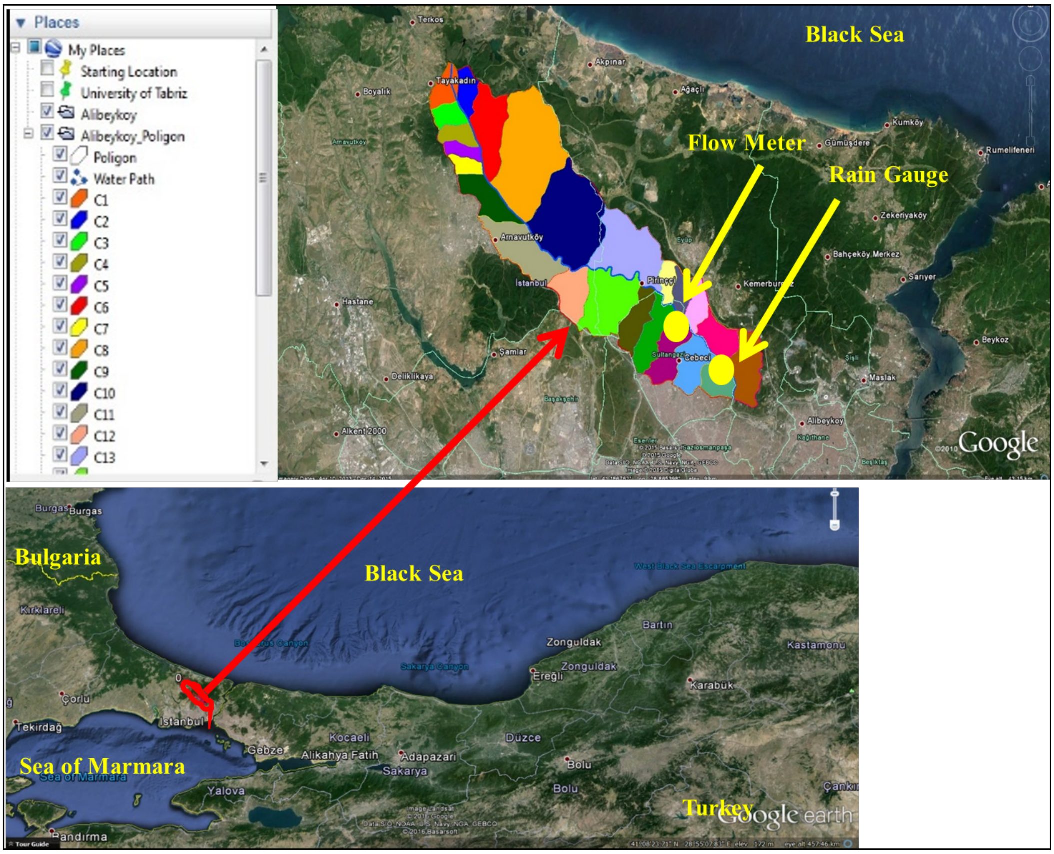

Figure 1. General view of Alibeyköy Watershed and subcatchments (Retrieved from Google Earth and Istanbul Metropolitan Municipality).

2.3 Model development

The water quality model of the watershed is based on the calibrated hydrological model. In the hydrological model, the area consists of 24 subcatchments which are defined by using slope, area, and width. Main channels, which collect the surface runoff generated over the watershed, are defined using the conduits with parameters of length, cross sectional area, roughness, and start-end points. Each link is connected with junctions which are described by invert elevation and maximum depth. The measured flow rate and rainfall data are used for calibration of the hydrological model. The water quality model is formed by defining the buildup and washoff functions of TSS. For this purpose, Power function for build-up of TSS and Rating Curve function for washoff TSS are defined on low-density residential, high-density residential, highway and commercial land use. In order to determine water quality input parameters, which belong to these functions, buildup rate constant, time exponent for the buildup parameter, washoff coefficient and washoff exponent are calculated based on the formula given by Tsihrintzis and Hamid (1998). These calculated parameters are defined into the water quality model. Then, some LID types, which are retention basins, vegetative swales, infiltration trench and permeable pavement, are introduced into the model. In order to implement these four types of LID into the model, the LID parameters are defined in the water quality model. These parameters depend on the surface, pavement, soil, and storage layers for each LID type. The values for these parameters are selected by using EPA SWMM manual (Rossman, 2010) and are given in Table 1. LID BMPs are performed about 2% of the modelled watershed. The hydrologic and water quality model of Alibeyköy Watershed is shown in Figure 2.

Table 1. Properties of surface, pavement, soil and storage layers for LID implementation (Rossman, 2010).

Layer	Parameters	Bioretention	Vegetative Swale	Infiltration Trench	Permeable Pavement
Surface Layer	Bern Height (mm)	500	500	500	500
	Storage Depth *(mm)*	NA	NA	NA	NA
	Vegetation Volume *(Fraction)*	0.2	0.2	0.2	0.2
	Surface Roughness *(Manning's N)*	0.1	0.1	0.1	0.1
	Surface Slope *(Percent)*	1.0	1.0	1.0	1.0
	Swale Side Slope *(Run/Rise)*	NA	5.0	NA	NA
Pavement Layer	Thickness *(mm)*	NA	NA	NA	150
	Void Ratio *(voids/solids)*	NA	NA	NA	0.15
	Impervious Surface Fraction	NA	NA	NA	0
	Permeability *(mm/hr)*	NA	NA	NA	100
	Clogging Factor	NA	NA	NA	0
Soil Layer	Thickness *(mm)*	1000	NA	NA	1000
	Porosity *(volume fraction)*	0.5	NA	NA	0.5
	Field Capacity *(volume fraction)*	0.2	NA	NA	0.2
	Wilting Point *(volume fraction)*	0.1	NA	NA	0.1
	Conductivity *(mm/hr)*	380	NA	NA	380
	Conductivity Slope	10	NA	NA	10
	Suction Head *(mm)*	19	NA	NA	19
Storage Layer	Thickness *(mm)*	500	NA	500	250
	Void Ratio *(voids/solids)*	0.75	NA	0.75	0.75
	Seepage Rate *(mm /hr)*	0.5	NA	0.5	0.5
	Clogging Factor	0.0	NA	0.0	0
Drain Layer	Flow Coefficient	0	NA	0	0
	Flow Exponent	0.5	NA	0.5	0.5
	Offset Height (mm)	6	NA	6	6

NA= Not Applicable

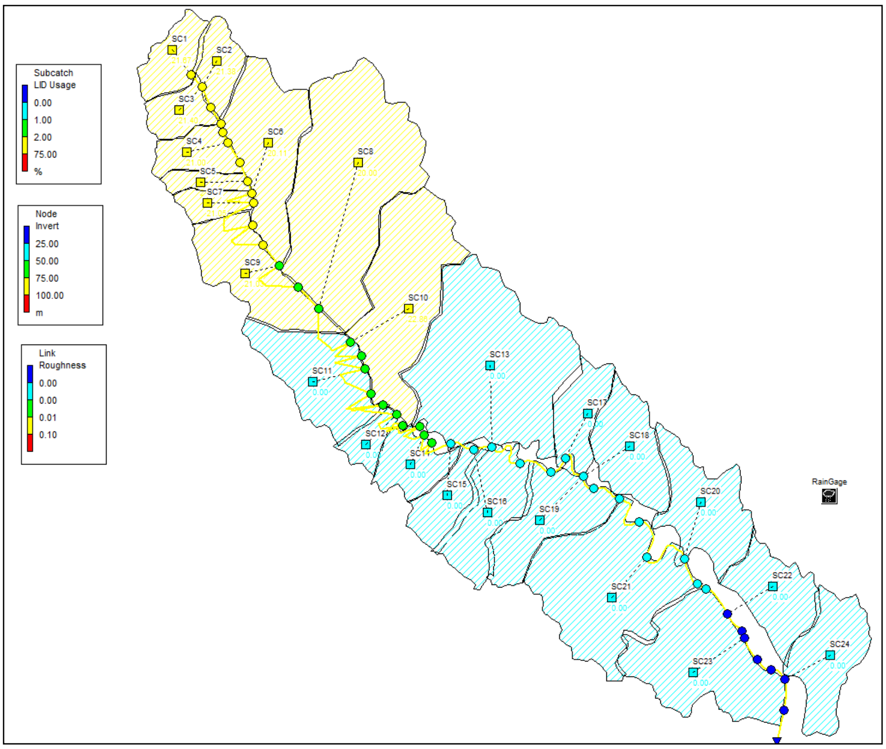

Figure 2. Hydrologic and water quality model of Alibeyköy Watershed in EPA SWMM

3. RESULTS AND DISCUSSION

The simulation results are presented for the storm events observed during March 06-09, 2010 and September 07-09, 2009 to model low and high (extreme) rainfall intensity impacts, respectively. The change in TSS concentration with and without LID BMP implementations are observed and compared. Figure 3 shows the predicted TSS concentration versus time at the outfall of the Alibeyköy Watershed with LID BMP implementation and with no LID BMP implementation. As it can be seen from this figure, for the case with LID BMPs, the peak of the pollutograph decreases from 191 mg/L to 175 mg/L. Moreover, the peaks of the polllutograph at 60^{th} and 80^{th} hours diminish as shown in Figure 3. Furthermore, the total amount of TSS washoff over the watershed decreases from 182,130 kg to 67,298 kg. The simulations are repeated for the storm event occurred on March 06-09, 2010 and the result is presented in Figure 4. As it can be seen from this figure, for the case with LID BMPs, peak of the pollutograph decreases from 64 mg/L to 61 mg/L. Furthermore, the total amount of TSS washoff over the watershed decreases from 11,382 kg to 11,094 kg. In addition, we observe that LID implementation is more effective during severe storms when the results of Figure 3 are compared with the results of Figure 4.

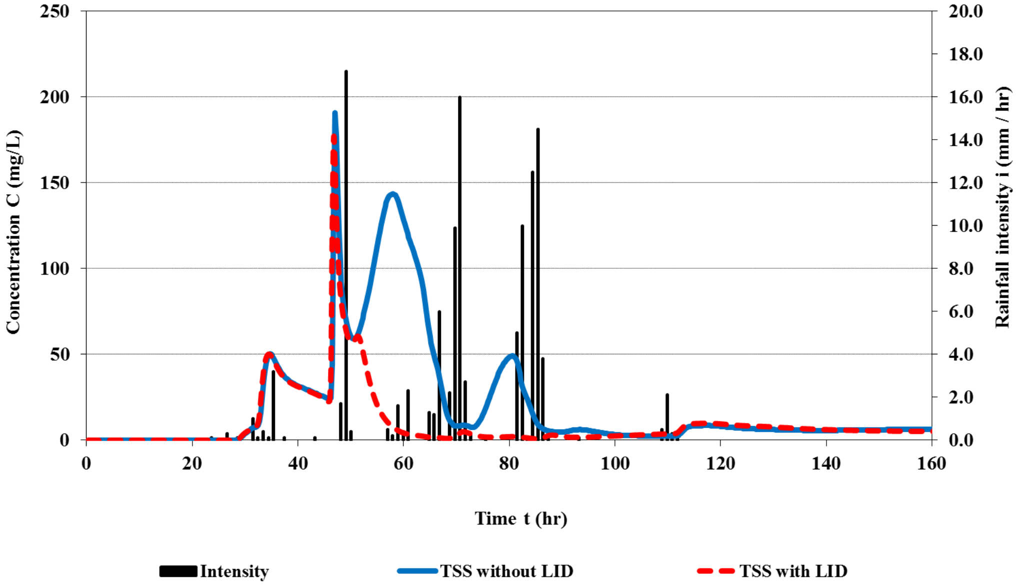

Figure 3. Predicted TSS concentration versus time at the outfall of the Alibeyköy Watershed with LID BMPs and with no LID BMPs during storm event observed between September 07-09, 2009.

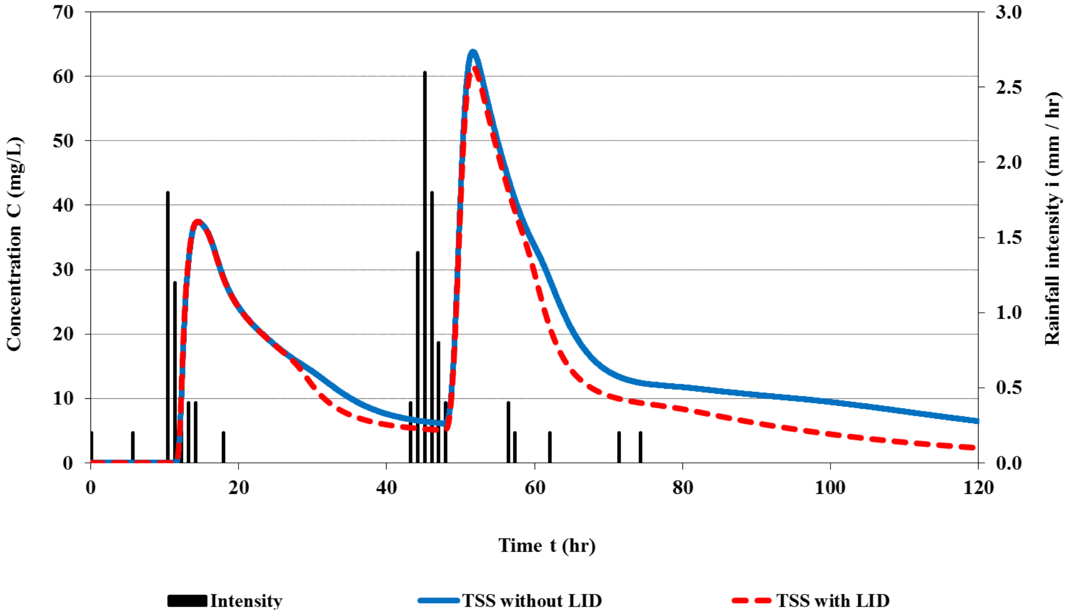

Figure 4. Predicted TSS concentration versus time at the outfall of the Alibeyköy Watershed with LID BMPs and with no LID BMPs during storm event observed between March 06-09, 2010.

4. CONCLUSIONS

The effect of LID implementation on water quality are investigated in this study. For this purpose, a water quality model is developed for Alibeyköy Watershed in Istanbul, Turkey by using EPA SWMM and integrated into the calibrated hydrological model. TSS is introduced into the model by using build up and wash off functions. Then, several types of LID are employed into the model. The TSS concentration for current urbanization with and without LID implementation are simulated under typical and extreme rainfall events using the hydrologic and water quality model. It is observed that LID implementation in the Alibeyköy Watershed results in a considerable decrease in the TSS concentration after implementing LID type of storm water BMPs.

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