Urban Flood mitigation by development of Optimal detention ponds in urban areas: A case study

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ABSTRACT

Detention ponds as one of the effective best management practice (BMP) techniques enable urban stormwater drainage systems (USDSs) to significantly attenuate the flood hydrograph peak at the urban catchments outlets. This paper presents a multi-objective optimization problem for site location and determining optimal dimensions of detention ponds in a real-world USDS. The two objectives considered are to minimize the urban flood hydrograph peak and the total volume of detention ponds. The decision variables are a number of outlet parameters in detention ponds as well as the location of the ponds in the USDS. SWMM and a multi-objective genetic algorithm are used as hydraulic simulation and optimization models respectively. The application of the proposed model is demonstrated for an urban drainage system of Golestan City located in Tehran Province, Iran. To solve this problem, 17 potential locations for water storage have been recognised within the city to be selected by the optimization model. The results show that the most flood peak mitigation can be achieved when effective investment is employed with respect to the optimal solutions. In addition, the flood peak can be more attenuated as the number of detention ponds increases for a fixed total volume of storage.

Keywords: Detention ponds, multi-objective genetic algorithm, site location, SWMM, urban drainage systems.

INTRODUCTION

Flood management in urban areas is often a cause of concern for authorities due to the increased flow rates of urban areas which would increase flood intensity.

Best management practices (BMPs) are recognized as efficient techniques to improve stormwater system designs especially attenuating flow and pollutants. Detention ponds as one of the effective BMP techniques are often designed primarily for flood control. The storage used in the pond is widely employed in urban runoff quantity and quality control, providing both peak flow reduction and suspended solids removal. Facilities like this must control not only the extreme runoff events to prevent flooding, but also the more common smaller events that produce a "first flush" pollution phenomenon and thereby impact the quality of receiving water bodies. Therefore, the primary task of this type of pond in urban stormwater drainage systems (USDSs) is to attenuate the peak of a flood hydrograph at the urban catchments outlets. However, the overall performance of detention ponds as to how much they attenuate outlet hydrograph peak strongly depends on the site location, size and design parameters of the storages and outlets.

This paper addresses a multi-objective optimisation problem to find the best site locations and optimal dimensions of ponds in a real-world USDS.

METHODOLOGY

Two objectives defined here for flood mitigation purposes in an USDS are: (1) to minimise the peak of flood hydrograph at some specific urban areas; (2) minimise the total volume of detention ponds as a surrogate of the total capital cost for building the ponds in an USDS. The reason for choosing the first objective is because the devastating power of the flood is significantly seen when the hydrograph peak of urban flood occurs. Hence, any measure which can lead to lowering this peak value can greatly assist in the mitigation of an urban flood magnitude. Therefore the first objective function (f_1) can be written as

$$f_1 = Min(Hydrograph\ Peak\ at\ Outlets)$$

The second objective function reflects the total capital cost which is mainly dependent on dominant factors. Therefore, the second objective function (f_2) can be stated as

$$f_2 = Min(\sum_{i=1}^{n} A_i \times H_i)$$

Where A_i, H_i=area and height of th pond respectively; and n= number of ponds. It is assumed that the pond has a rectangular shape; hence the volume can be simply calculated by this function.

Ten decision variables are defined here for each pond. They are (1-4) dimensions of two side rectangular orifices including width (W_{or}) and height (H_{or}), (5) elevation (location) of the upper orifice (E_{or}) (it is assumed that the elevation of the lower orifice is the invert elevation of the pond), (6-7) elevation (location) (E_w) and height (H_w) of a weir in the pond, (8-9) height (H_s) and total area (A_s) of the bottom of the detention pond, and (10) location of a pond (N_S) in the USDS. The first nine decision variables can be specified in the SWMM model when a new storage unit as a detention pond is added to the model. These decision variables are repeated for each pond; hence the total number of decision variables is equal to the number of detention ponds multiplied by ten (Figure 1).

N_S^1	$W_{or_1}^1$	$H_{or_1}^1$	$E_{or_2}^1$	$W_{or_2}^1$	$H_{or_2}^1$	E_w^1	H_w^1	A_S^1	H_S^1	…	N_S^n	$W_{or_1}^n$	$H_{or_1}^n$	$E_{or_2}^n$	$W_{or_2}^n$	$H_{or_2}^n$	E_w^n	H_w^n	A_S^n	H_S^n

Figure 1. Schematic representation of decision variables (genes) for each solution (chromosome)

Some specific constrains are as follows:

$$5\ cm \le H_{or1}, W_{or1} \le 50\ cm \quad (3)$$

$$5\ cm \le H_{or2}, W_{or2} \le 70\ cm \quad (4)$$

$$H_{or1} + 5\ cm \le E_{or2} \le 250\ cm \quad (5)$$

$$H_{or2} + E_{or2} + 5\ cm \le E_w \le 400\ cm \quad (6)$$

$$5\ cm \le H_w \le 150\ cm \quad (7)$$

$$5\ m^2 \le A_s \le 1000\ m^2 \quad (8)$$

RESULTS AND DISCUSSION

The application of the proposed optimisation model is demonstrated for an USDS of Golestan City located in Tehran Province, Iran. The hydraulic SWMM model of the USDS is represented in the following Figure 2. It comprises 22 subcatchments with a total area of 1000 ha, 129 open surface rectangular channels with total length of 16.6 km and dimensions of 70 cm by 120 cm and 80 cm by 130 cm. The flood hydrograph peak of the main outlet of the USDS for a rainfall with a 50 year return period is 4.5 m^3/sec for the business as usual situation where there is no detention pond in the system.

In order to mitigate the urban flood, 17 locations within the urban areas have been recognised within the city as potential locations for building detention ponds (Figure 2).

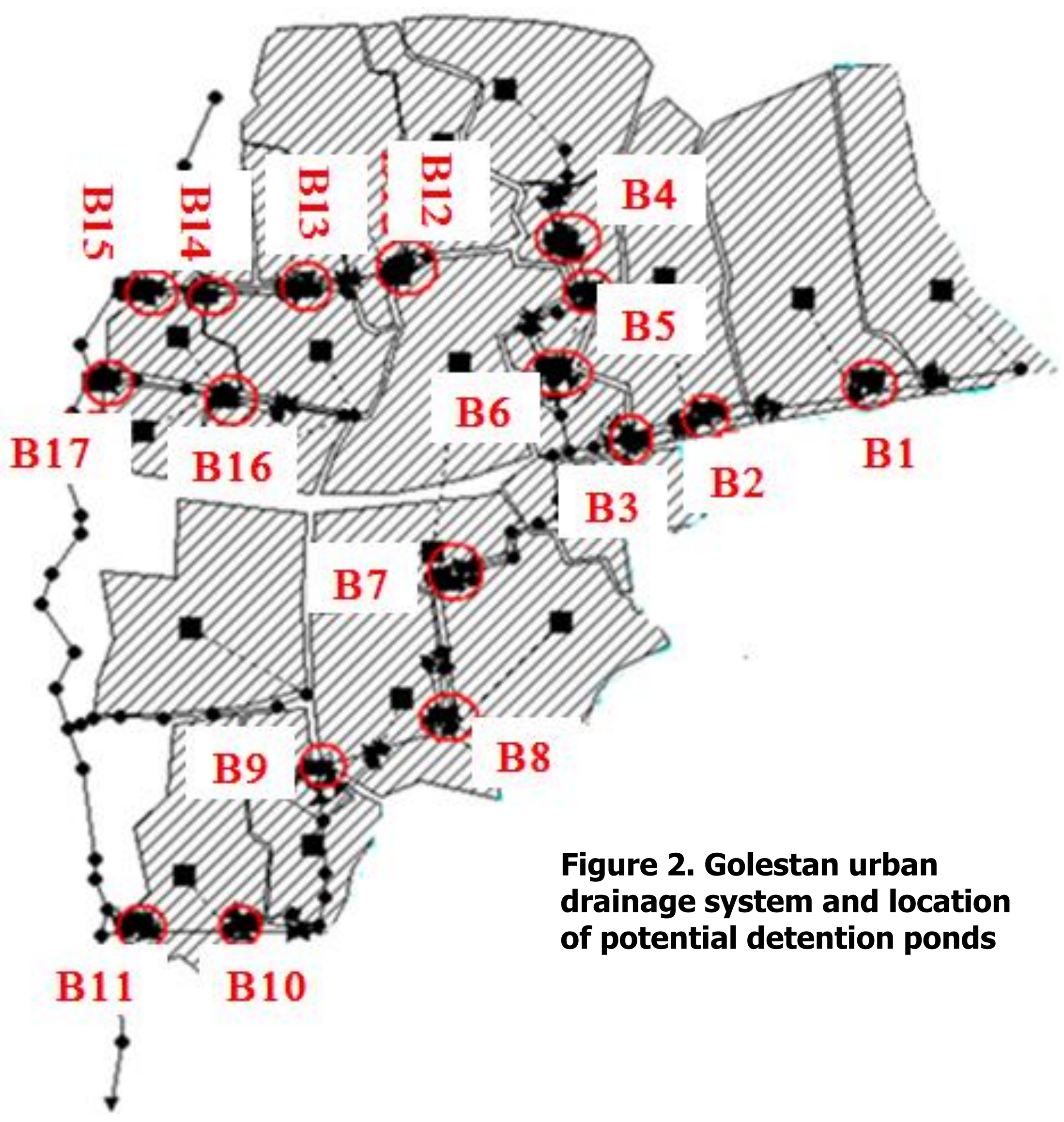

Figure 2. Golestan urban drainage system and location of potential detention ponds

The result of the Pareto-optimal fronts for different number of detention ponds is shown in Figure 3. This Figure shows a trade-off between the two objective functions (i.e. the total volume of the detention ponds and the urban flood peak) for a fixed number of detention ponds installed. The number of non-dominated solutions of the Pareto-optimal front varies from 52 to 37 solutions when the fixed number of detention ponds changes from 2 to 5 respectively.

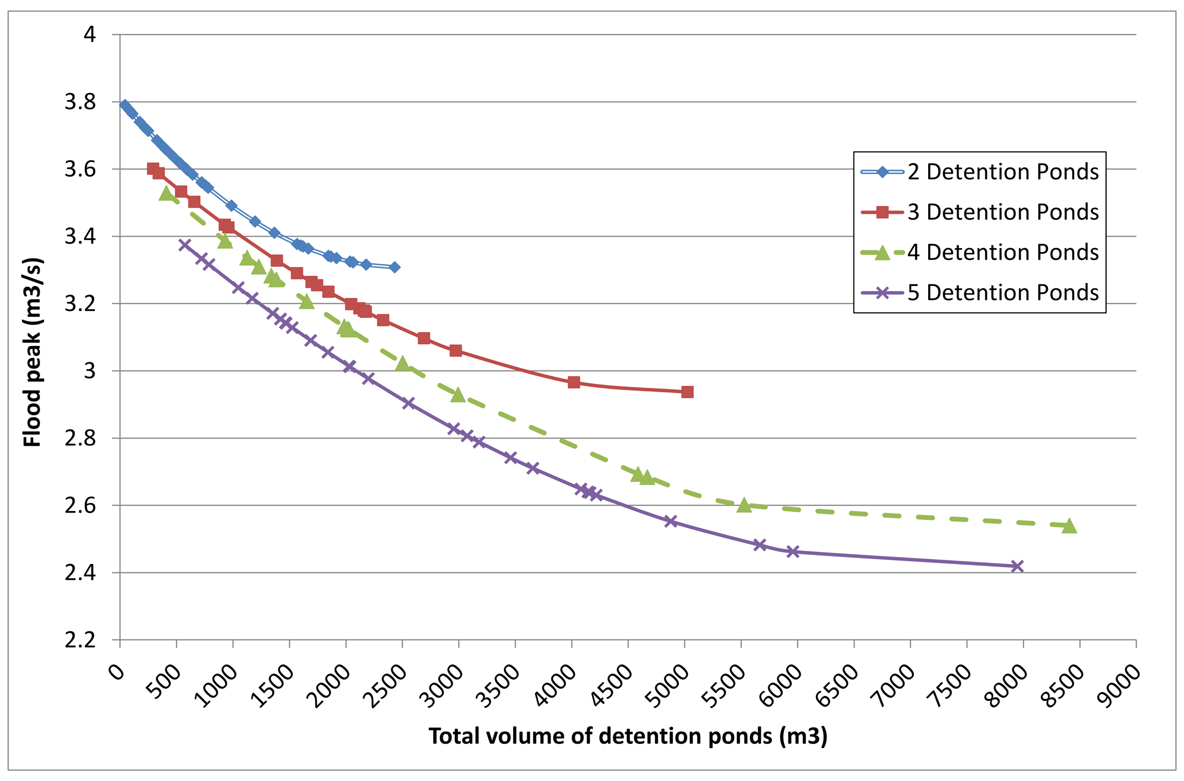

Figure 3. Pareto-optimal front between Total volume of detention ponds and flood peak

As expected, the flood peak is more attenuated when the total volume of the detention ponds increases more. The Figure also shows that considerable flood peak attenuation (from 4.5 m3/sec to 3.8 m3/sec) can be achieved if minimum budget is provided through two detention ponds with minimum volume for the USDS.

The different Pareto optimal fronts can be further analysed through comparing the flood hydrographs of outlet in the USDS resulted from the best solutions of each front. Figure 4 represents the flood hydrographs of the best solutions of different Pareto optimal fronts. This figure can be useful for selecting an appropriate plan where the ultimate benefit of the number of ponds can be seen and compared with others and especially business as usual when there is no detention pond in the USDS.

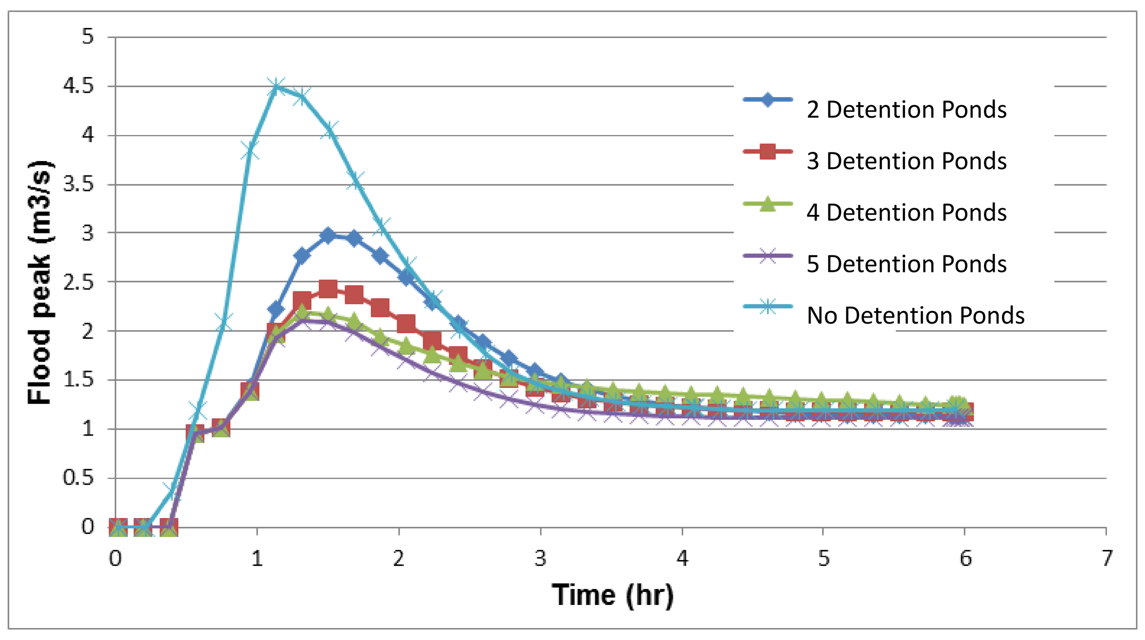

Figure 4. Comparison of the flood hydrograph of the main outlet for different number of detention ponds

CONCLUSION

The mitigation of the flood peak of the outlet hydrograph from an USDS was addressed in this paper for a real world case study in Iran. To alleviate the effect of devastating flood peak, creating detention ponds in the USDS were proposed and examined as a sustainable BMP solution. The problem was then to find optimal locations of detention ponds and the design parameters of their outlets in the USDS.

Although the results show some promising and clear solutions related to the location and size of detention ponds, they cannot be used to make any real decisions. To obtain a robust solution, a further sensitivity analysis related to the most uncertain parameters still needs to be tested and evaluated for multiple future scenarios and risk type criteria.