Dynamically priced stormwater discharge fees as a way to organize distributed stormwater infrastructure

A. König, M.Eng.[1*], Prof. D. Joksimovic, Ph.D., PE[2]

[1]University of Technology Graz, Graz, Austria

[2]Ryerson University, Toronto, Canada

**Corresponding author email: albert.koenig@tugraz.at*

Highlights

- System behaviour of decentralized storages was simulated using a composite model
- Dynamically priced discharge fees prove suitable to organize individually owned and operated infrastructure toward public interest
- A market-based solution provides incentive for the construction of privately owned stormwater infrastructure

Introduction

To deal with the increasing stress on urban drainage systems due to environmental and anthropogenic factors, hopes have been put on Low Impact Development (LID) technologies. These measures aim to deal with precipitation before it enters the drainage system as stormwater runoff, through infiltration, evapotranspiration or harvesting at the source.

While traditional urban drainage infrastructure is usually publicly owned and financed, the decentralized nature of LID technologies makes private lands appealing for implementation, which could then put them into the responsibility of individual landowners. An increasing number of municipal regulations are already requiring new developments to implement stormwater retention and a minimum level of runoff reduction. However, the overall system of stormwater charges typically provides low to no reward to landowners and developers for stormwater retention on site, and no incentives for implementation of smart management of stormwater infrastructure. At the same time, Real Time Control (RTC) of sewer systems is increasingly being considered at a more granular, decentralized level (Eulogi et al., 2020; Kändler et al., 2018; Oberascher et al., 2021; Quinn et al., 2021).

However, organizing individually owned and operated infrastructure to avoid unintended adverse effects proves a challenge (Oberascher et al., 2021). As demonstrated by smart grid technology in the energy sector, market-based solutions offer a method to reward network-wide collaboration of individual agents (Kuzlu et al., 2020). A market-based system could hence be a tool for municipalities to incentivize property owners to build and manage LID technologies according to public goals. This paper aims to assess the suitability of a dynamically priced discharge fee to organize decentralized stormwater infrastructure toward reducing total runoff volume and peak flow, using a mixed land-use sample catchment in Toronto, Canada.

Methodology

Dynamically priced stormwater fees

Dynamic pricing of stormwater discharge fees is a type of service charge that varies the price of discharged flow with time, in response to the available drainage system capacity. The actual amounts of water leaving the property are billed at the prices applicable at the discharging times. The stormwater network uses monitoring data and weather forecast to predict available capacities in the drainage network and calculate the discharge fees ahead of time. In the modelled approach, discharge fees were broadcasted over a horizon of 48 hours and updated every 24 hours. A perfect weather forecast is assumed.

Modelled scenarios

Four scenarios were developed to evaluate the performance of the drainage systems with the dynamically priced discharge fee. Scenario 1 serves as a reference scenario of the as-is state. For scenario 2, scenario 1 was equipped with static storage capacities on private properties (cisterns providing 5 mm to 25 mm of storage). Scenario 3 adds the dynamically priced discharge fee and model predictive control (mpc) for each storage facility. In scenario 4 all storages have an assigned water demand profile that they include in the minimization of their cost function.

The entire catchment area amounted to 337,500 m², with 67,400 m² being routed through storages in Scenarios 2-4 (approximately 20%). 55,300 m² are covered by a storage capacity of 5 mm and the other 12,100 m² by a storage capacity of 25 mm.

Continuous and single event scenarios were simulated using the EPA SWMM5 engine. The continuous simulation used precipitation records from a nearby weather station in 5-minute intervals for April to October period in 2018, to evaluate the runoff control performance for one continuous summer period. Single design storm events with initially empty as well as partially filled storages were simulated to evaluate the impact on the system peak flow response under design loading conditions.

Simulation approach

To evaluate the different scenarios, a composite model was developed. Individual water demand profiles, which could then be partially offset by using the retained stormwater for non-potable purposes, were created for each LID-user in the model area using SIMDEUM (Blokker et al., 2010).

The dynamic discharge fee was calculated as a function of the precipitation at timestep i (Equation 1):

Equation 1

$$P_i = \min\left(\left(P_{max} * e^{k_1(V_i - V_{max})} + k_2 P_{i-1}\right); P_{max}\right)$$

With P_i being the price at timestep i and P_{max} the maximum assignable price at rain volume V_i [mm/timestep]. The weighting coefficients k_1 and k_2 are chosen as $k_1 = 0.2$ and $k_2 = 0.5$.

Storage behaviour was modelled during runtime with an mpc-algorithm. Each storage was operated to minimize the cost function for the immediate prediction horizon. The hydraulic and hydrologic model of the catchment area was simulated with EPA-SWMM5 that was augmented using the python wrapper pySWMM to accommodate the complex LID behaviour.

Results and discussion

With Scenario 1 as a reference value, the summer period simulation yielded slightly larger total outflows from the catchment outlet for scenarios 2 and 3 (2.4 % and 3.4 %). Scenario 4 resulted in an 11.9 % smaller outflow at the catchment outlet. This effect can be attributed to the non-potable water consumption. The slightly higher outflow volumes from scenarios 2 and 3 can be attributed to less water being routed through pervious surfaces and thus infiltrating before entering the drainage system.

Flow exceedance times (ETs) for the catchment outlet and a Condo unit with 25 mm storage capacity during the summer period simulation are shown in

Figure 1. At catchment level, below a flow of 2500 L/s the ETs are approximately 0.2 hours lower than that of Scenario 1; above 2500 L/s the difference diminishes to < 0.1 hours. Peak flows are slightly lower for the mpc scenarios than the static scenario, which in turn is lower than Scenario 1. On a lot leven, the differences are more distinguished. Single event analyses for individual contributors showed that the

individual LIDs operated as expected, releasing the stored water ahead of forecasted storm events and retaining it for as long as possible. Once a rain event exceeded the storage capacity, the underdrains conveyed any inflow directly to the drainage system. Storages were operated to accommodate peak inflows in favour of earlier inflows, that were drained directly.

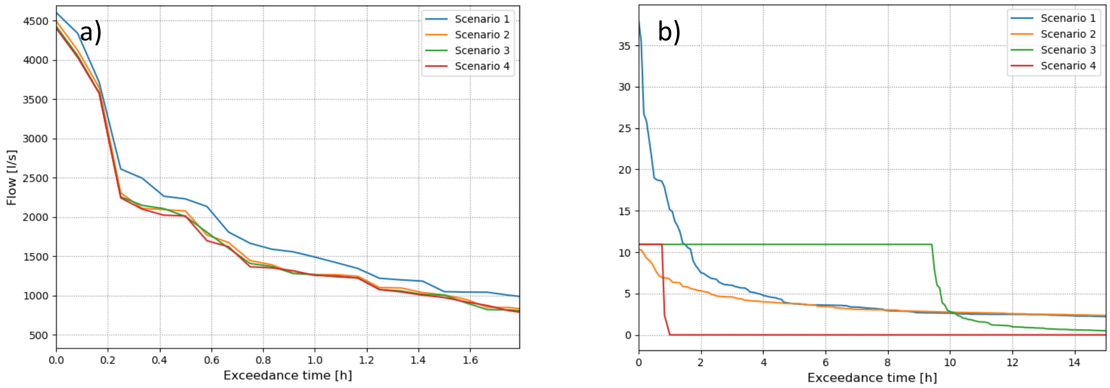

Figure 1. Flow exceedances during the summer period simulation at a) the catchment area's outlet b) a condo unit

Conclusions and future work

The largest improvements in ETs can be seen in sub-peak flow conditions. These improvements can mainly be attributed to the increased storage volume of scenarios 2 to 4 compared with Scenario 1. The generally small gains in performance can be ascribed to the small fraction of the catchment area affected by the implemented measures. With many rain events exceeding the storage capacity, surplus inflow after filling will discharge right into the stormwater network.

On a lot-level (Figure 2b)), the mpc-controlled property units have shown large potential to reduce peak flow and retain inflows during peak times. The dynamically priced discharge fee proved a feasible tool to organize distributed ownership and operation of stormwater infrastructure.

Future research is necessary to look at how the switch to a market-based system would affect property owner behaviour regarding the implementation of storage capacities and non-potable water consumption. Further improvements to the calculation of the dynamic fee that takes water dumping ahead of and after rain-events into consideration should be investigated.

References

Blokker, E. J. M., Vreeburg, J. H. G., & van Dijk, J. C. (2010). Simulating Residential Water Demand with a Stochastic End-Use Model. *Journal of Water Resources Planning and Management*, *136*(1), 19–26. https://doi.org/10.1061/(asce)wr.1943-5452.0000002

Eulogi, M., Ostojin, S., Skipworth, P., Shucksmith, J. D., & Schellart, A. (2020). Hydraulic optimisation of multiple flow control locations for the design of local real time control systems. *Urban Water Journal*, *18*(2), 91–100. https://doi.org/10.1080/1573062x.2020.1860238

Kändler, N., Annus, I., Vassiljev, A., Puust, R., & Kaur, K. (2018). Smart In-Line Storage Facilities in Urban Drainage Network. *Proceedings*, *2*(11), 631. https://doi.org/10.3390/proceedings2110631

Kuzlu, M., Sarp, S., Pipattanasomporn, M., & Cali, U. (2020). Realizing the Potential of Blockchain Technology in Smart Grid Applications. *2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*. https://doi.org/10.1109/isgt45199.2020.9087677

Oberascher, M., Kinzel, C., Kastlunger, U., Kleidorfer, M., Zingerle, C., Rauch, W., & Sitzenfrei, R. (2021). Integrated urban water management with micro storages developed as an IoT-based solution – The smart rain barrel. *Environmental Modelling & Software*, *139*(139), 105028. https://doi.org/10.1016/j.envsoft.2021.105028

Quinn, R., Rougé, C., & Stovin, V. (2021). Quantifying the performance of dual-use rainwater harvesting systems. *Water Research X*, *10*(X 10), 100081. https://doi.org/10.1016/j.wroa.2020.100081

Ray, P. P. (2018). A survey on Internet of Things architectures. *Journal of King Saud University - Computer and Information Sciences*, *30*(3), 291–319. https://doi.org/10.1016/j.jksuci.2016.10.003