Real-Time Control For Enhanced Urban Stream Function : Promising or Over-Promising ?

Contrôle en temps réel pour une meilleure gestion des cours d'eau urbains : promesses ou espoirs démesurés ?

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RÉSUMÉ

L'adaptation des infrastructures statiques de gestion des eaux pluviales par l'installation de vannes contrôlables a été étudiée comme moyen d'atténuer les effets des infrastructures surchargées. Cependant, peu d'études de cas quantifient l'impact du rejet d'eau provenant d'installations de gestion des eaux pluviales à contrôle actif sur les cours d'eau récepteurs. Pour remédier à cela, un système de quatre bassins de rétention secs à vidange lente a été équipé de vannes contrôlables à Knoxville, dans le Tennessee. La qualité de l'eau et le débit ont été surveillés dans le cours d'eau récepteur afin d'évaluer les impacts de cette intervention. Ce système physique était couplé à un modèle numérique conçu pour permettre de tester les résultats potentiels dans le cours d'eau en fonction de différentes règles de contrôle. Les quatre bassins étaient situés juste en amont du point de surveillance, dans le tiers inférieur du bassin versant expérimental. Les résultats de cette étude indiquent que les effets du contrôle en temps réel sont visibles dans le cours d'eau, avec une turbidité accrue observée lors du déversement des bassins après la décrue des eaux de crue. Cependant, une modélisation complémentaire indique que les impacts les plus importants de l'urbanisation sur le cours d'eau, tels que la contrainte de cisaillement maximale lors d'un événement donné, pourraient ne pas être atténués. Cela est probablement dû au positionnement des installations contrôlées dans la partie inférieure du bassin versant, c'est-à-dire que l'urbanisation en amont n'est pas prise en compte. Ces résultats indiquent que le positionnement des installations au sein du bassin versant a un impact significatif sur les résultats. De plus, même si la contrainte de cisaillement maximale n'est pas réduite, la durée de la contrainte de cisaillement excessive peut être réduite, ce qui constitue un résultat positif pour le fonctionnement du cours d'eau.

ABSTRACT

Retrofitting static stormwater infrastructure with controllable valves has been investigated as a means to mitigate the effects of overburdened infrastructure. However, few case studies exist which quantify the impact of water release from actively controlled stormwater assets on receiving waters. To address this, a system of four dry extended detention basins were retrofitted with controllable valves in Knoxville, TN, USA. Water quality and flow were monitored in the receiving stream to assess the impacts of this intervention. Coupled with this physical system was a computational model designed to allow testing of possible in-stream outcomes based on various control rules. The four ponds were located just upstream of the monitoring point in the bottom third of the experimental watershed. Results from this study indicate that the effects of real-time control are visible in the stream, with elevated turbidity observed during pond discharge after the storm flows have receded in the stream. However, supplemental modeling indicates that the largest impacts of urbanization in the stream, such as maximum shear stress during a given event, may not be mitigated. This is likely due to the controlled assets being positioned in the lower portion of the watershed, that is, upstream urbanization is not being mitgated. These results indicate that the positioning of the asset within the watershed has a significant impact on outcomes. Further, even if the maximum shear stress is not reduced, the duration of excess shear may still be reduced, a positive outcome for stream function.

KEYWORDS

Real-Time Control, Stormwater, Pond, Stream, Machine Learning

1 INTRODUCTION

Smart systems, including those designed for stormwater management, consist of real-time adaptive infrastructure that relies on information and communication technology (Kerkez et al 2016). Smart water networks are supported by an ensemble of models that process information on conditions such as in-stream surface flow alongside stormwater inputs and rates. Through information acquired from environmental sensors, real-time decisions can be realized through automated control points (e.g., weirs, valves) that allow for tailored management of stormwater infrastructure. Despite this understanding, there are limited case studies that show how real-time control (RTC) can influence stream conditions at the watershed scale. Such studies will help advance the implementation of RTC by identifying challenges that arise under field conditions, and testing the limits of its effectiveness.

2 METHODS

Connor Creek watershed is located west of Knoxville, TN, USA, and is actively being developed whereby pasture and forested areas are being converted into residential and commercial land uses. Approximately 2000 m from the headwaters of Connor Creek, an elementary, middle, and high school were constructed on the same contiguous parcel. To satisfy local stormwater management requirements, four dry ponds were constructed on the parcel. Each of these ponds has been retrofitted with remotely controllable valves, allowing them to be differentially controlled based on local or global objectives (Figure 1). Additionally, in-stream flow and water quality parameters were collected to measure stream response. Objective functions were quantified for this specific watershed by determining critical shear stress for the stream channel and using physical measurements to determine when pond outlets may be overtopped.

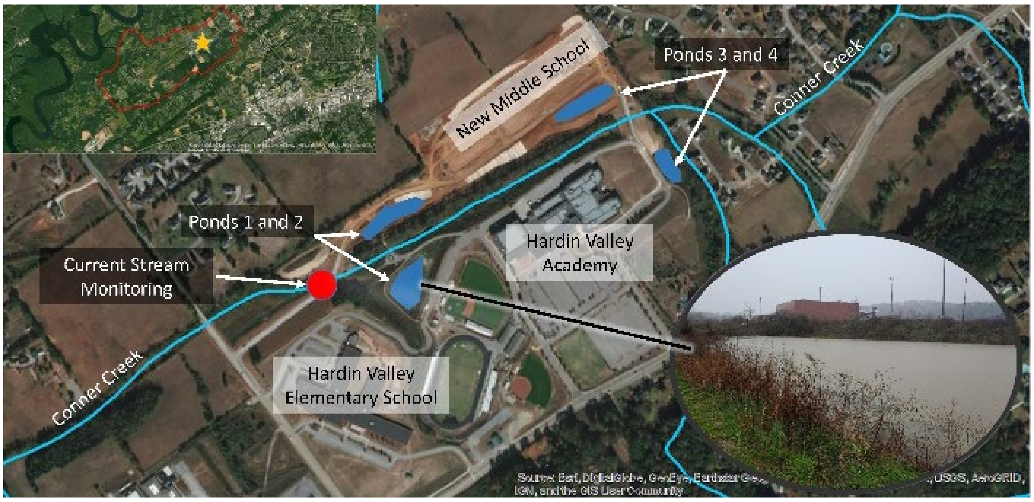

Figure 1 : Schematic of Experimental Location

To supplement this field site, a computational model was developed in SWMM to allow testing of possible in-stream outcomes. Further, a surrogate model (based on a Bidirectional Long Short-Term Memory Model) was developed to reduce the computational time associated with SWMM, with model outputs showing excellent performance in comparison to those from SWMM. A reinforcement learning model was utilized within these hydrologic modeling platforms to determine how the four ponds should be operated to meet the system objectives.

3 RESULTS

Preliminary analyses focused on the largest pond (Pond 1), which was anticipated to have the greatest in-stream impact due to the large volume it holds and discharges. A simple set of control rules were used as a starting point. As anticipated, Pond 1 had a noticible affect on in-stream conditions. As an example, Figure 2 illustrates the change in in-stream temperature when water is released from the pond (as compared to the expected temperature per a SARIMA model). Overall, the pond discharge resulted in noticeable impacts to stream level, temperature, and turbidity. As such, controlling these ponds does have an affect on in-stream conditions, necessitating refinement of the control strategies to determine how unique objectives can be achieved.

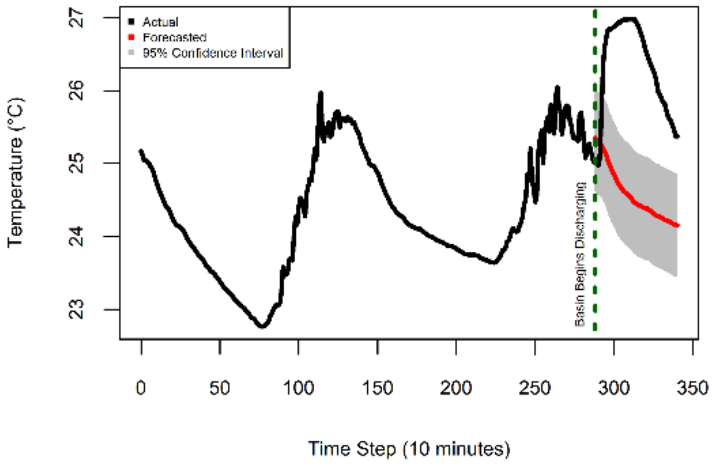

Figure 2. In-stream temperature and the estimated impact of the dry detention basin discharge

As a first step, another simple control strategy was employed in the models to better understand the system and verify it creates logical outputs : open the control valves when storage rises to 75% of the maximum. The models were combined with Surrogate-Accelerated SVERL (Shapley Value Estimation for Reinforcement Learning). This framework allows us to mathematically quantify the "Value of Information" for variables in the network. Figure 3 shows the results of this exercise, with the results having a logical conclusion that rainfall acts as the stressor for the system, and pond depth is the variable that triggers the valve opening.

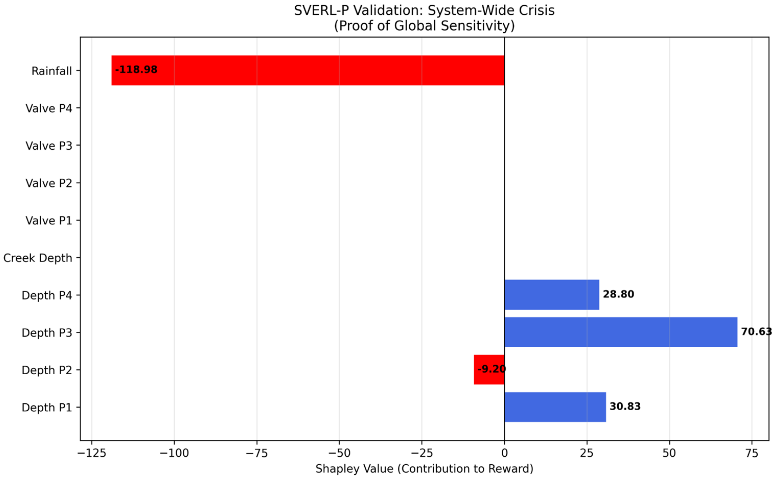

Figure 3 : Bar chart of Shapley Values for the 'Logic Agent,' confirming Pond Depth as a positive trigger and Rain as a negative stressor.

As a next step, more complex objective functions were added to the modeling framework. Namely, reducing shear stress in the downstream channel while simultaneously ensuring that the pond outfalls do not overtop. These objectives are conflicting, as water being held in the ponds to the greatest extent possible will lead to reduced shear stress in the downstream channel. However, holding this water as the rain event progresses could lead to overtopping. Initial testing showed complications in how the reinforcement learning model handles this conflict. Continued testing and manipulation of the model is ongoing and new results are expected soon. As part of this continued testing, it was observed that while the maximum shear stress experienced during a given event may not be reduced, the duration of excess shear can be lowered. This may be, in part, due to the ponds being at the bottom third of the experimental site, whereby impervious areas in the headwaters are greatly contributing to the urban hydrologic regime of Conner Creek.

4 CONCLUSION

Real-time control holds promise for optimizing stormwater infrastructure performance across an array of objectives. Conner Creek in Knoxville, TN, USA, is acting as a test bed for RTC development. Initial studies show that RTC does impact the conditions within the stream, and that full control of multiple assets holds promise for improving in-stream conditions. However, the spatial distribution of controlled assets in the watershed is critical. Stream conditions can still be degraded by portions of the watershed where stormwater is not being managed.

LIST OF REFERENCES *(only for scientific papers)*

Kerkez, B., Gruden, C., Lewis, M., Montestruque, L., Quigley, M., Wong, B., ... & Pak, C. (2016). Smarter stormwater systems. *Environmental Science & Technology 50*(14), 7267-7273.