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Urban Drainage Systems – Static throttle flows or real time control? A systematic approach to answer this

Systèmes d'assainissement - Régulation statique de débits ou gestion en temps réel ? Réponse par une approche systématique

M. Schütze*, M. Pabst**, U. Haas***

* ifak - Institut für Automation und Kommunikation e.V. Magdeburg, Werner-Heisenberg-Str. 1, 39106 Magdeburg, Germany, manfred.schuetze@ifak.eu
** bpi-Hannover Verworn Consultant Engineers, 30177 Hannover, Germany Email: pabst@bpi-hannover.de
*** InfraConsult GmbH, Schaiblestr. 1, 70499 Stuttgart, Germany, ulrich.haas@infraconsult.de

RÉSUMÉ

Parmi les options multiples permettant de parvenir à une gestion durable des eaux pluviales, le contrôle en temps réel (CTR) suscite une attention de plus en plus grande. Dans le cadre de la procédure d’évaluation du potentiel du contrôle en temps réel, d’autres mesures devraient être également prises en considération (par exemple le contrôle à la source, les différents réglages statiques des débits maximum dans les dispositifs à goulot). Cet article présente et démontre une méthodologie visant à inclure l’analyse des débits régulés de façon optimisée dans l’analyse du potentiel du contrôle en temps réel. Afin de réduire le lourd temps de calcul d’une application brutale de la procédure d’optimisation, une analyse de la variance est suggérée sous la forme d’une simple analyse de sensibilité comme étape préalable, dont le traitement est encore possible. La méthodologie est démontrée en utilisant comme exemple un projet de réseau d’assainissement à Astlingen, mis au point par le groupe de travail sur le contrôle intégré de la Compagnie des Eaux Allemande (DWA).

ABSTRACT

Among the manifold options to arrive at sustainable stormwater management, real time control (RTC) is receiving increased attention. As part of the procedure to assess the potential of RTC, also alternative measures should be taken into consideration (e.g. source control, different static settings of maximum flows in throttle devices). This paper outlines and demonstrates a methodology to include the analysis of optimised throttle flows in the analysis of RTC potential. In order to reduce the computational burden of a brute-force application of optimisation procedure, an Analysis of Variance is suggested as a simple form of sensitivity analysis as preceding step, which is yet computationally feasible. The methodology is demonstrated using a draft of the Astlingen drainage network set up by the working group on Integrated control of the German Water Association (DWA) as an example.

KEYWORDS

Astlingen, optimisation, real time control, static throttle flows
1 INTRODUCTION

Among the manifold options to arrive at sustainable stormwater management, real time control is receiving increased attention. Real time control is understood as taking active influence in the flow processes in the drainage system by operating, dependent on the current (and possibly past and predicted future states of the systems) control devices, such as movable gates, weirs and pumps (see, for example, Schütze et al. (2004) for a review). Whilst control proves to be beneficial for many drainage systems, it also involves additional efforts (Beeneken et al., 2013). Although the benefits of control, such as adding flexibility and resilience to the system, often outweigh such efforts, a prudent assessment of the drainage system should also consider static measures in an evaluation of potential options.

Often, the static optimisation of maximum permissible throttle flows is advocated as a solution simpler than time-varying permissible throttle flows (hereafter denoted as control). Despite significant earlier work in each of these fields – static throttles (HMULV, 2004), rule-based control, control involving online optimisation (“Model-based control”) (for example, Muschalla, 2009, Joseph et al., 2014, Regneri, 2014), real time control using generalised and easy-to-apply controllers (Alex et al., 2008) – a concise methodology considering and integrating these various schools and approaches is still missing. Thus, the practitioner often gets confused. As a small mosaic stone to structure the procedures, this contribution bridges the gap between consideration of static throttle settings and dynamic variation of throttle settings. This work is related to present work of the working group “Integrated control” of the German Water Association (DWA), which is currently preparing an application manual, illustrating to the practitioner the issues related to setting up a real time control system on an worked example.

2 IMPROVING PERFORMANCE OF A DRAINAGE SYSTEM –BUT HOW?

In order to improve the performance of a drainage system, a multitude of options (including combinations thereof) can be considered. Besides measures such as reducing runoff at source (Source control, Best Management Practices, Low-Impact Design, see Fletcher et al., 2014) or construction of additional storage volume in order to cope better with runoff, also the following represent options of potential interest, and on these the present paper is focussing:

(1) Use of the existing system “as is”, but with different static settings of maximum throttle flows

(2) Use of the existing system in a dynamic way, i.e. by real time control (time-varying settings of maximum flows)

In order to assess the potential of (2), various methods and procedures have been suggested (DWA, 2005, and others). The M180 procedure includes, in its Step 2, an analysis of the potential of alternative approaches. Here, also a systematic analysis should be carried out as to how far one can get with Option (1) for the given drainage system. For this, the following procedure is suggested and demonstrated for the Astlingen system.

3 AN EXAMPLE DRAINAGE SYSTEM - ASTLINGEN

Whilst this example is still under development by the respective working group of DWA, a draft version of this example, as presented and described by Schütze et al. (2015) is used here to illustrate the procedure. The system consists of 13 subcatchments, most of which are combined subsystems. Overall, domestic and industrial dry-weather flow amounts to 47.4 l/s, to which 17.5 l/s of infiltration inflow are added, resulting in a total dry weather flow of 64.9 l/s. The catchment area is 620 ha. Total storage volume amounts to 7800 m³.

As “base” case, it is assumed that the Astlingen drainage system is operated in a static way, i.e. the throttles in the system allow as maximum flows those designated as “nominal flows” in Table 1. These values have been found, for this example, by conventional sewer system design according to the DWA guidelines. Many real-life drainage systems, however, have been modified and extended significantly after its design. Therefore, the static throttle settings obtained long time ago might not be valid anymore. For optimisation of the throttles, a decision has to be made, which throttles are to be considered and which ranges might be permissible. In some cases, for certain throttle structures, a modification of their settings might not be feasible. A brute-force method would now involve to consider all remaining ones in the optimisation process. For these, also their feasible ranges have to be defined. Some guidance results from general considerations (minimum throttle flow larger than...
peak dry-weather flow; maximum throttle flow not exceeding downstream hydraulic limitations; see also HMULV, 2004). Following such considerations, the minimum and maximum throttle flows for the devices of the Astlingen draft system as shown in Table 1 have been defined.

Table 1: Storage tanks and overflow devices in the [draft] Astlingen system (taken from Schütze et al., 2015)

<table>
<thead>
<tr>
<th>location to WWTP</th>
<th>type</th>
<th>volume [m³]</th>
<th>specific volume [m³/ha A_wet]</th>
<th>throttle flow [l/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>tank 1</td>
<td>stormwater overflow</td>
<td>1.70</td>
<td>33.1</td>
<td>270.4</td>
</tr>
<tr>
<td>tank 2</td>
<td>stormwater overflow</td>
<td>0.87</td>
<td>29.7</td>
<td></td>
</tr>
<tr>
<td>tank 3</td>
<td>storage tank</td>
<td>3.30</td>
<td>46.2</td>
<td></td>
</tr>
<tr>
<td>tank 4</td>
<td>stormwater overflow</td>
<td>0.43</td>
<td>25.3</td>
<td></td>
</tr>
<tr>
<td>tank 5</td>
<td>stormwater overflow</td>
<td>0.30</td>
<td>22.0</td>
<td></td>
</tr>
<tr>
<td>tank 6</td>
<td>stormwater overflow</td>
<td>0.12</td>
<td>23.0</td>
<td></td>
</tr>
<tr>
<td>CSO 8</td>
<td>stormwater overflow</td>
<td>0.00</td>
<td>0.0</td>
<td>94.0</td>
</tr>
<tr>
<td>CSO 9</td>
<td>stormwater overflow</td>
<td>0.00</td>
<td>0.0</td>
<td>510.4</td>
</tr>
<tr>
<td>CSO 10</td>
<td>stormwater overflow</td>
<td>0.00</td>
<td>0.0</td>
<td>151.6</td>
</tr>
<tr>
<td>CSO 11</td>
<td>stormwater overflow</td>
<td>0.00</td>
<td>0.0</td>
<td>158.0</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>7.80</td>
<td>33.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Analysis of Variance of influence of static throttle settings

<table>
<thead>
<tr>
<th>Location in parameter space:</th>
<th>Parameter A: T2</th>
<th>Variation from 15.600000 to 39.300000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter B: T3</td>
<td>Variation from 28.900000 to 163.200000</td>
<td></td>
</tr>
<tr>
<td>Parameter C: T4</td>
<td>Variation from 15.600000 to 35.800000</td>
<td></td>
</tr>
<tr>
<td>Parameter D: T5</td>
<td>Variation from 16.700000 to 45.100000</td>
<td></td>
</tr>
<tr>
<td>Parameter E: T7</td>
<td>Variation from 34.200000 to 92.400000</td>
<td></td>
</tr>
</tbody>
</table>

Results of Analysis of Variance: F value: Comment:
- Const 94360658278.1952 1029848.2515 significant at the 0.1 % level
- B 5629478732.9212 61439.8939 significant at the 0.1 % level
- A 44037332.2758 480.6216 significant at the 0.1 % level

To optimise their static settings, would involve the constrained optimisation of a function of five variables (static throttle settings for Tanks 2, 3, 4, 5 and 7; with their respective minimum and maximum values as constraints). Optimisation is understood here as “minimisation of the total overflow volume”, whilst often several concomitant objectives will have to be met (addressed by multi-objective optimisation which has been reported vastly in the literature). Function evaluation consists in carrying out a simulation run with such settings for a predefined input time series of rainfall (which, therefore, should be – in some sense “representative”). Obviously, whilst a range of methods and add-on tools to simulators have been developed (e.g. Schütze, 2007, Henrichs et al. 2014 and others), these are not yet integrated with the analyses outlined above under (2).

As function evaluation in this context usually is computationally demanding (unless significant system simplifications are carried out), care has to be taken in the selection and application of the optimisation approach. Instead of “just” applying brute-force optimisation of all throttle devices, it is suggested to do a simple global sensitivity analysis first, in order to establish which throttle exert significant influence. A wide range of sensitivity analysis methods is available (often themselves characterised by huge computational demand); for the present purpose of practical application, a full factorial experiment, varying each of the n parameters (throttle settings) between its minimum and maximum values, results in a feasible compromise between computational demand (2ⁿ function evaluations, which might still be computationally feasible) and resulting system information about importance of parameters (derived by a formal Analysis of Variance). Application of this method is illustrated in the next paragraph.

It is assumed that, in the example drainage system, outlined above, the static throttle settings for Tanks 2, 3, 4, 5, and 7 are subjected to this analysis. Carrying out the 2⁵ full factorial experiment and analysing the variance by F tests applying various degrees of freedom (Box and Draper, 1987), gives the results shown in Table 2.
These results clearly indicate that the setting of Throttle 5 does not have much influence on the overall overflow volume in this simulation experiment. Therefore, it is discarded from the application of a formal optimisation routine in the next step. Now, the remaining four static maximum throttle flow settings are optimised (for a given rain input time series), i.e. their constant settings within their feasible ranges are optimised, applying the Shuffled Complex Evolution algorithm (Duan et al., 1992) is applied as an example of a derivative-free evolutionary algorithm for constrained optimisation. If it can be ascertained that the objective function is of well-behaved nature without the potential problem of getting stuck in local minima, also a more efficient search should be applied in this step. The optimisation yielded the following optimum settings: T2: 31.6 l/s, T3: 145.4 l/s, T4: 21.3 l/s, T7: 65.1 l/s.

In order to compare the performance of the drainage system with these constant throttle flows against the base case (nominal settings of the flows) and against performance of real time control algorithms, a different rainfall input time series should be used than the one used for optimising the static throttle flows (similar to a sound calibration-validation exercise where also different data should be used for each of these two steps).

Therefore, the drainage system is now simulated for a different historic rainfall time series (of one year duration), this time also employing non-uniform distribution of rainfall. Here, several scenarios are simulated; Simulation of these various scenarios is done using the state-of-the-art simulator Simba# (Ogurek et al., 2015), which allows also the convenient setup and analysis of control systems; its features with regard to systems analysis techniques (including optimisation) are constantly extended. The results of the simulation are summarised in Table 3.

<table>
<thead>
<tr>
<th>Control scenario</th>
<th>Total overflow volume [m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case (static throttle flows equal to nominal flows)</td>
<td>908219</td>
</tr>
<tr>
<td>Static throttle flows with optimised values as given above</td>
<td>905540</td>
</tr>
<tr>
<td>Generalised controller (as in Alex et al., 2008)</td>
<td>877239</td>
</tr>
<tr>
<td>Theoretical optimum</td>
<td>835330</td>
</tr>
</tbody>
</table>

These results indicate that, even though for the rain series for which static throttle flows were optimised they yielded good performance (far better than the base case), these do necessarily give low overflow values also for another time series, here being only marginally better than the base case. Therefore, in this example (as in many others), static throttle settings do not increase as much to the flexibility of a system as does real time control. At the same time, for example, a generalised control algorithm, set up with very little effort and without optimisation, leads to improvement of the system.

4 CONCLUSIONS

This paper outlined a small, yet important step to the methodology of assessment of real time control as a potential means to improve a drainage system’s performance by comparing the results of optimisation of static (constant) settings of maximum throttle flows against results of real time control. A method, involving an analysis of variance prior to the optimisation procedure, has been proposed and illustrated for the draft version of the Astlingen example system.

5 ACKNOWLEDGEMENTS

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LIST OF REFERENCES


