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RESEARCH ARTICLE

A new dynamic water quality model for stormwater basins as a tool for urban runoff management: Concept and validation

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In the context of real-time control of a stormwater basin's outlet gate to improve the river's water quality, while guaranteeing population safety, it is necessary to define and test scenarios over various environmental conditions and perform long term simulations. This paper presents a new dynamic model for stormwater basins, which can reproduce the evolution of the water quality in the basin. The developed model describes the behaviour of pollution associated with particles, accounting for the distribution of particle settling velocities. After detailing the model, simulation results of an experiment representing settling under quiescent hydraulic conditions, are presented to validate the developed model's concepts. The dynamic behaviour of a pollution associated with three particle settling velocity classes is presented before concluding on the perspectives that can be offered by such a model.

Keywords: modeling; particle separation; real time control; settling velocities; stormwater

1. Introduction

Stormwater in urban areas can cause serious flooding problems due to large runoff volumes transferring quickly to rivers. At the same time it is common knowledge that stormwater contains a considerable amount of suspended solids (SS) and pollutants (metals, pathogens, etc.) associated with them (Vaze and Chiew 2004, Characklis *et al.* 2005, Tuccillo 2006). To deal with flooding problems induced by increased impervious areas, dry stormwater basins have been built to reduce the negative hydraulic effects on the river's morphology and ecology.

Some earlier studies have successfully tested the idea to equip stormwater basins with sluice gates at the outlet to control the outflow (Jacopin *et al.* 2001, Middleton and Barrett 2008) but they have been focused on the hydraulics of the basin. The present study is part of a larger project which develops a new approach to improve the eco-hydraulics of the receiving water body (Muschalla *et al.* 2009). The idea is to implement real time control (RTC) of the sluice gate to enhance the removal efficiency of fine particles by increasing the retention time of stored stormwater and to reduce the peak flow released in the receiving river at the same time. An integrated model for the river and drainage system is needed for the safe development of this eco-hydraulic driven RTC of stormwater basins. Robust control rules have to be defined and validated using long-term simulations (Pitt and Clark 2008) and considering multiple objectives e.g. flood protection and river water quality standards. In this context, the quality model of the stormwater basin is key. The computation has to be fast enough to allow performing multiple long-term simulations. At the same time multiple pollutants (particles, pathogens, heavy metals) and processes related to them (adsorption/desorption, settling, disinfection) have to be considered to characterize the water quality of the basin's effluent for different environmental conditions. Pathogens are a good example to illustrate the complexity of the processes occurring in a stormwater basin that have a strong influence on the pathogen concentration in the effluent. Pathogens are multiphase in the sense that they occur both attached to particles and free in the water phase (Characklis *et al.* 2005, Jeng *et al.* 2005, Krometis *et al.* 2007). The concentration of each fraction is depending on multiple factors like temperature, salinity or light penetration (Struck *et al.* 2008). The last factor is itself strongly dependant on the local suspended solids concentration and the water level in the basin (Vergeynst *et al.* 2012). Finally, resuspension of particles plays an important role when trying to predict the concentration of pathogens in the water column (Jamieson *et al.* 2005, Rehmann and Soupir 2009). To be able to describe well the concentration of pathogens at the effluence of the basin, it is thus necessary to describe the processes occurring in the basin with details, especially

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including the fact that a distribution of settling velocities exists.

Regarding the models available for water quality prediction, existing computational fluid dynamic (CFD) models for stormwater basins deal with the complex hydraulic conditions and try to explain where and when sediments will settle (Torres 2008). Due to their complexity and long computing time this type of model is not appropriate for the development of the planned RTC strategies. A plug flow model (Takamatsu *et al.* 2010) can be used for rectangular or simple detention basins but hypotheses are difficult to verify for more complex facilities operated under turbulent conditions. Alternatively, models based on a continuously stirred tank reactor approach (CSTR) can be applied. Ferrara and Hildick-Smith (1982) developed a model with one reactor in an open outlet configuration. This very simple model cannot reproduce local effects because the concentration is the same for the entire reactor. The next level of complexity is reached when different reactors are coupled to reproduce the dispersion effect along the length of the basin (Verstraeten and Poesen 2001). Wong *et al.* (2006) showed it was possible with such a model to represent specific structures and adapt the model to represent different hydrodynamic behaviour depending on the number of CSTR used. For the quality part, they used a simple first-order kinetic decay. However, this quality model does not take into account possible interaction between pollutants or the phenomena occurring when water is stagnant, e.g. the settling of particles.

Some models based on a simple reactor include complex processes like adsorption, advection, flocculation, settling or photolysis (Lessard and Beck 1991, Krishnappan and Marsalek 2002, Vezzaro *et al.* 2010). These models are able to describe the behaviour of multiple pollutants and Vezzaro *et al.* (2010) even considered the interaction with different compartments (air, sediments and ground water), which is important when considering multiple types of pollutant. However, in the previous models, due to the simple reactor hypothesis, it is not possible to consider processes in which a vertical SS concentration gradient plays a role, e.g. affecting light penetration. As the developed RTC control strategies focus on the water quality in the river considering different types of pollutants, the local processes that can occur into the basin are of major interest, especially for pollutants with complex behaviour like pathogens (Vergeynst *et al.* 2012).

To be able to create a concentration gradient along the water depth, in the present paper, the concept of layers as applied in wastewater settler modelling (Vitasovic 1989) is adapted to stormwater systems. In the developed model, each layer is homogenous. The superposition of these layers allows the creation of a gradient of concentrations over the basin's water depth. Reactions can easily be added in each layer to reproduce the behaviour of the different pollutants.

This paper focuses on the description of the basic model formulation and shows how this model can reproduce the behaviour of particulate pollutants in a stormwater basin. Laboratory experimental results used for the validation of the model concepts are presented. In addition the behaviour of pollutants under different hydraulic conditions is discussed. The possibilities of further model extensions to better reproduce the complex hydraulic and quality phenomena of a stormwater basin are identified.

2. Material and methods

2.1. Model description

The proposed stormwater basin model is composed of three submodels: a hydraulic model, a soluble pollutant model and a particulate pollutant model. The index 's' is related to soluble pollutants, index 'x' is related to particulate pollutants, C is the pollutant's concentration; 'i' is the index of the layer considered; 'in' is related to the influent of the layer; 'IN' is related to the influent of the basin; 'draw' is related to the outflow of the layer; 'DRAW' is related to the outflow of the basin, 'r' is the reaction rate for the pollutant considered and A is the area of the basin. Conventionally, in this type of layer models, layer one is at the top of the basin.

2.1.1 Hydraulic model

As stated before, the model is based on the concept of completely mixed layers developed by Vitasovic (1989) for wastewater treatment plant secondary clarifiers. The advantage of this concept is that it allows the modeller to create a gradient of concentrations along the height of the basin with simple equations. However the Vitasovic model is developed for a settler that has a constant volume of water. In a stormwater basin, the volume is variable. To take this phenomenon in account, the new model uses a mass balance of water, with a maximum physical volume defined by the stormwater basin's maximum volume (Vmax) and height (Hmax), at which stormwater overflow occurs ($Q_{OVERFLOW}$).

Figure 1 explains the different parts of the hydraulic model. In Figure 1a the volume of the basin is defined by Hmax. If the water reaches this height, overflow occurs. In the basin, the volume of water is defined by the integration of the balance between the water coming in and the water going out (1). Then the volume is divided in N layers.

$$dV/dt = Q_{IN} - (Q_{DRAW} + Q_{OVERFLOW}) \qquad (1)$$

Figure 1a and 1b show a representation of the evolution of the water volume between t and t + Δt during filling. It can be seen that the volume of each layer is changing with time. However, at each time, all layers have equal

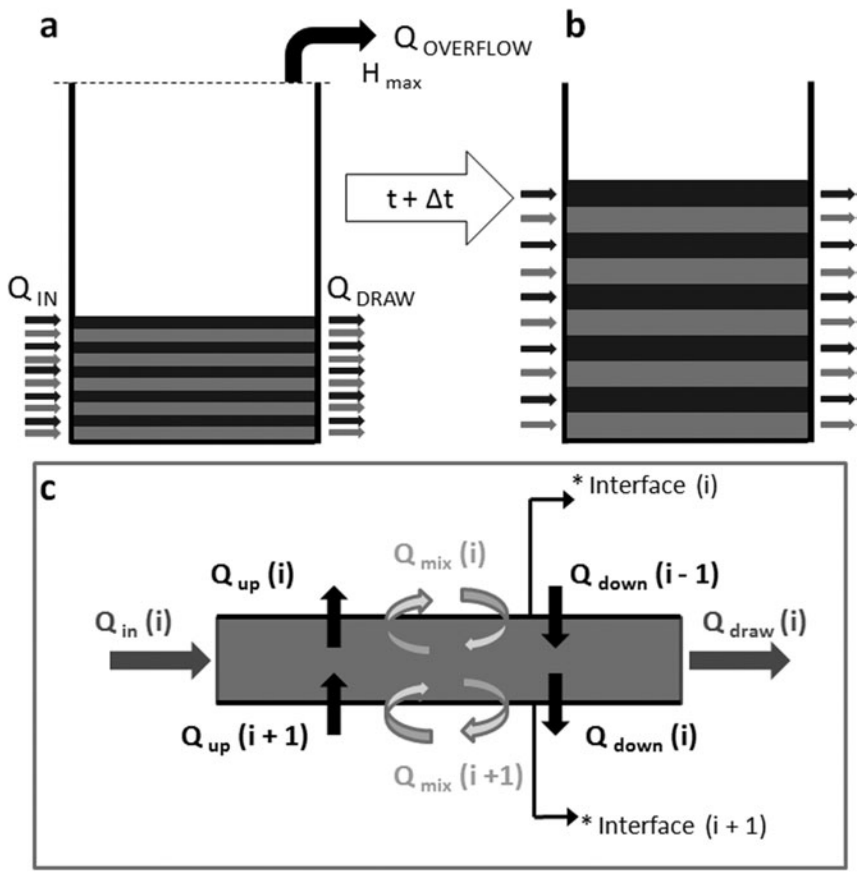

Figure 1. Hydraulic model diagram. Overview of the different variables in the hydraulic model developed. (a) and (b) present the volume change of layers in time, (c) presents the different flows accounted for in the model.

volumes. Each layer is regulated by its own inflow and outflow which allows different hydraulic conditions to be represented. For example, during a large rain event the outlet pipe can be submerged and the water is then going out from the basin through the bottom layers but not through the top layers. Turbulence created by this phenomenon needs to be represented because soluble and particulate pollutants concentrations will be affected. To take care of this phenomenon, flows between layers have also been implemented. Figure 1c shows which type of flow is taken into account between the layers, Equations (2) and (3) show the way they are calculated.

Depending on the situation (filling / drawing), there may be flows coming from the bottom to the top (Q_{up}), from the top to the bottom (Q_{down}) and there are mixing flows around the layer interface (Q_{mix}) to represent an exchange of water between two layers ($Q_{up\_net}(i)$ for the net flow of water going from layer i to the layer above, $Q_{down\_net}(i)$ for the net flow of water going from layer i to the layer below). Q_{mix} will always be included in Q_{up_net} and Q_{down_net} in addition to the part coming from Q_{in} or Q_{draw} (Equations (2) and (3)). These equations are general and are able to reproduce different flow conditions occurring around the layer i by considering the total flow that has to be transported to layers above for Q_{up} or below for Q_{down}.

$$Q_{up\_net}(i) = Q_{mix}(i) + MAX\left[\left(\sum_{j=i}^{N} Q_{in}(j) - \sum_{j=i}^{N} Q_{draw}(j)\right); 0\right] \tag{2}$$

$$Q_{down\_net}(i) = Q_{mix}(i+1) + MAX\left[\left(\sum_{j=i+1}^{N} Q_{draw}(j) - \sum_{j=i+1}^{N} Q_{in}(j)\right); 0\right] \tag{3}$$

In the present paper, for the description of the model, Q_{mix} is considered as a parameter and no equation will be related to it. For the implementation of a complete stormwater basin, the definition of Q_{mix} will vary from one site to another and will have to be specifically studied.

2.1.2 Soluble pollutant model

The variation of soluble pollutant mass (Ms) can be calculated by a mass balance for each layer.

$$\begin{aligned} dM_s(i)/dt = {} & Q_{in}(i)\cdot C_{s\,in}(i) - Q_{draw}(i)\cdot C_s(i) \\ & - Q_{up\_net}(i)\cdot C_s(i) \\ & - Q_{down\_net}(i)\cdot C_s(i) + Q_{up\_net}(i+1)\cdot C_s(i+1) \\ & + Q_{down\_net}(i-1)\cdot C_s(i-1) + r_s(i)\cdot V(i) \end{aligned} \tag{4}$$

Equation (4) holds for constant volume. In the developed hydraulic model the total volume and the position between the different layers are changing during filling and emptying of the basin. To take this phenomenon into account, the velocity of the up or down movement of the layer's interface is defined as $v_{interface}$. To complete the model in Equation (4) for varying volume it is necessary to consider the mass fluxes induced by the layer interface movements. It is then necessary to add Equation (5) to Equation (4), during filling ($v_{interface}$ positive) and Equation (6) during emptying ($v_{interface}$ negative).

$$v_{interface}(i)\cdot A\cdot C_s(i-1) - v_{interface}(i+1)\cdot A\cdot C_s(i) \tag{5}$$

$$v_{interface}(i)\cdot A\cdot C_s(i) - v_{interface}(i+1)\cdot A\cdot C_s(i+1) \tag{6}$$

The layer volumes are all the same, so the layer volume variations are the same too. Then, the layer interface velocities are calculated by adding the variation of volume divided by the surface of the basin to the interface velocity of the layer below. To initiate the process, the bottom layer interface velocity is calculated by dividing the bottom layer volume variation by the surface area of the basin.

2.1.3 Particulate pollutant model

A particulate pollutant is defined by its ability to settle. This means that the pollutant has its own settling velocity (v_x, positive when oriented from the top to the bottom of the basin) and the movement of this pollutant depends on the difference between this velocity and the upward velocity of the water. Equation (7) presents the mass of particulate pollutant (J) from the layer above and/or below which contributes to the mass variation in layer i depending on the upward velocity of the water. Max and Min functions are used to control the sign and the elements considered in terms of the relative settling velocity of particles. For layer one, there is no Q_{up_net}, it is then replaced by $Q_{overflow}$.

$$\begin{aligned} J = {} & -A\cdot C_x(i)\cdot MAX[(v_x - Q_{up_{net}}(i+1)/A);0] \\ & + A\cdot C_x(i)\cdot MIN[(v_x - Q_{up_{net}}(i)/A);0] \\ & - A\cdot C_x(i+1)\cdot MIN\left[\left(v_x - \frac{Q_{up_{net}}(i+1)}{A}\right);0\right] \\ & + A\cdot C_x(i-1)\cdot MAX[(v_x - Q_{up\_net}(i)/A);0] \end{aligned} \tag{7}$$

The variation of particulate pollutant mass (M_x) can then be calculated by a mass balance for the layer.

$$\begin{aligned} dM_x(i)/dt = {} & Q_{in}(i)\cdot C_{x\,in}(i) - Q_{draw}(i)\cdot C_x(i) \\ & - Q_{down\_net}(i)\cdot C_x(i) \\ & + Q_{down\_net}(i-1)\cdot C_s(i-1) + r(i)\cdot V(i) + J \end{aligned} \tag{8}$$

In the same way as for soluble pollutants, it is necessary to add Equation (9) during filling ($v_{interface}$ positive) and Equation (10) during emptying ($v_{interface}$ negative) to Equation (8) to consider the movement of the layer's interfaces in the mass balance.

$$\begin{aligned} J_{interface} = {} & v_{interface}(i)\cdot A\cdot C_x(i-1) \\ & - v_{interface}(i+1)\cdot A\cdot C_x(i) \end{aligned} \tag{9}$$

$$\begin{aligned} J_{interface} = {} & v_{interface}(i)\cdot A\cdot C_x(i) \\ & - v_{interface}(i+1)\cdot A\cdot C_x(i+1) \end{aligned} \tag{10}$$

One can notice that during emptying the equations result in a cumulative effect of the particle settling velocity and Q_{down_net}.

2.2. Model implementation

Usual software packages used in sewer modelling (e.g. EPA's SWMM5, (EPA (US Environmental Protection Agency) 2008)) only allow inclusion of algebraic equations to describe quality processes in stormwater management equipments. To overcome these limitations the developed model has been implemented in the WEST modelling and simulation software (Vanhooren *et al.* 2003) which is used for wastewater treatment plant modelling and integrated urban wastewater system modelling (Benedetti *et al.* 2008). WEST allows solving ordinary differential equations efficiently and it offers the possibility to easily implement process equations by Gujer matrix based description of their stoichiometry and kinetics.

2.3. Test cases

In order to demonstrate the concept and the performance of the described model, two test cases were used. The first one (ViCAs experiment) was conducted to identify the best approximation of the particle settling velocity distribution and demonstrate the use of an experimental lab test as input of the model. The second one (theoretical simulation) was conducted to verify the dynamic behaviour of the different types of pollutants (soluble, particulate) with the model.

2.3.1 Batch settling experiments

A ViCAs experiment (Chebbo and Grommaire 2009) is a particle settling test which relates a continuous particle mass distribution to its particle settling velocity distribution. It is performed under ideal settling conditions without turbulence and it is an adapted lab test that reproduces the settling conditions of a stormwater basin with a closed outlet. To evaluate the model's capacity to reproduce the settling process occurring in the basin for different settling times with a closed outlet, ViCAs experiments were simulated in terms of the cumulative settled mass. The ViCAs experiments are started by filling a settling column of around 60 cm height and 2.5 L volume with a homogenous sample. At predefined time intervals the cumulative mass settled at the bottom of the column is measured. Classes of particles with different settling velocities are determined and the mass of particles per class is calculated from the cumulative settled mass time series. Good experimental work can lead to a mass balance closing within ± 15% between the initial mass in the column and the sum of the cumulative settled mass and the final mass in the column (Chebbo and Grommaire 2009). The three ViCAs experiments taken for simulations were all in the ± 15% mass balance range.

To determine settling velocities, three ViCAs experiments have been conducted on composite samples from three different rain events. Flow-proportional composite samples of the influent of a stormwater basin in Quebec City (Muschalla *et al.* 2009) were collected by taking several 1L samples (around 25 samples for each event). Simulations were performed to validate the basic model and to verify the derived classes of sedimentation velocities. The ViCAs column in the developed model was divided into nine layers. A 10th layer was used to represent the plate that collects the sediments at the bottom of the column. The choice of 10 layers is based on the default successfully used in wastewater treatment settler models, but its value could be calibrated depending on the user needs. For the present paper, the simplicity of the configuration and the precision of the results did not ask for more or less layers but depending on the situation, this may be an issue, especially if the computation time has to be further reduced.

2.3.2 Theoretical simulation

In order to demonstrate the model's ability to describe the different behaviour of the different types of pollutants, a hypothetical situation has been simulated. Four types of pollutants have been selected; a soluble pollutant and three particulate pollutants attached to particles with a settling velocity respectively higher, equal and lower than the upward velocity of the water (respectively v_x high, v_x medium and v_x low). A basin of 3000 m^3 was set 2/3 full. A 1000 m^3/d flow of clear water was entered at the bottom layer to fill the basin, leading to an overflow after 1 day. Clear water has been chosen to clearly show the pollutant transport effect without changing the total pollutant mass in the basin; Q_{mix} has been set to 0 m^3/d. At the beginning of the simulation, pollutants that are transported by the flow (soluble and particulate pollutant with a low v_x) were located at the bottom of the basin in layer nine. The pollutant that will be settling despite the upflow (pollutant with a high v_x) was located at the top of the basin in layer 1 and the pollutant that is not supposed to move (pollutant with a medium v_x) was located in the middle of the basin in layer four. The initial masses were all the same at 5000 g.

3. Results and discussion

3.1. Simulation of the ViCAs experiments

Results of ViCAs experiments were used to define the different masses and settling velocities of particulate pollutants for the model. The ViCAs experiments give mass fraction data for n settling velocities. This means that it is possible to experimentally define n + 1 settling velocity classes. A ViCAs experiment can be decomposed in different ways into particle classes (Figure 2). The most detailed one with 11 classes closely follows the curve (Figure 2a) and considers all the experimental data. The vertical lines cross the x axis at the v_s of the class and their lengths represent the total solids fraction that has to be considered for the initial mass of the class. The lowest particle class settling velocity is set to 0 m/h but because of the logarithmic scale on the x axis, the lowest value presented is 0.01 m/h. The model fed with 11 classes of settling velocity naturally fitted the cumulative settled data very well (Figure 3).

In view of modelling the different pollutants and processes associated with the different particle classes, the decomposition into 11 classes means that it is necessary to define the pollutant characteristics for each particle class. For 11 velocity classes, it means defining the amount of metals and pathogens associated with the 11 classes of particles, in addition to the dissolved fraction. To avoid such complexity, the quality of the model is evaluated with a reduced number of velocity classes; two options are evaluated: a first one with focus on fast settling classes

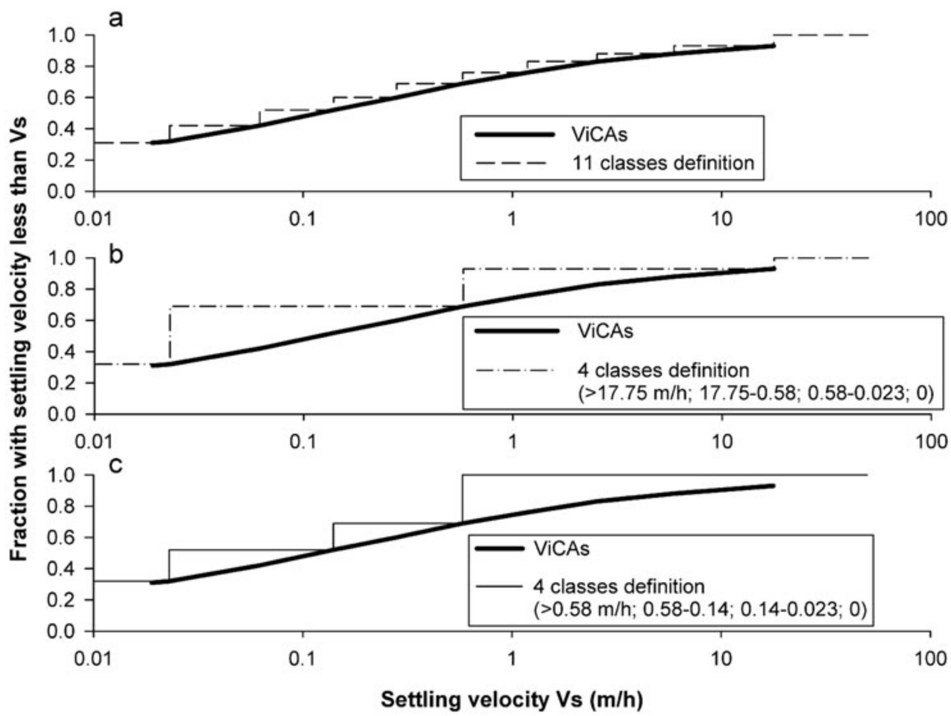

Figure 2. ViCAs experiment results and classes' decomposition. Examples of velocity classes' definition from experimental results for 11 classes (a), four classes with high settling velocities (b) and four classes with low settling velocities (c).

(Figure 2b) and the second one with focus on slow settling classes (Figure 2c).

The simulation results obtained for the different decompositions in four classes present different fits (Figure 3). The choice between fast or slow velocity classes appears very important for the modelling quality. When the velocity classes are chosen to take into account the particles with fast settling velocities (Figure 3b), the simulation results are better at the low settling times but cannot follow the data from 14 min to 1.08 d. In the context of stormwater basin modelling with closed outlet it is however more important to follow the settling over a longer time than for the first 15 min. In this case, the decomposition in four classes associated to slow settling velocities (Figure 3c) is a better choice. It gives a more accurate simulation of the solids removal efficiency over

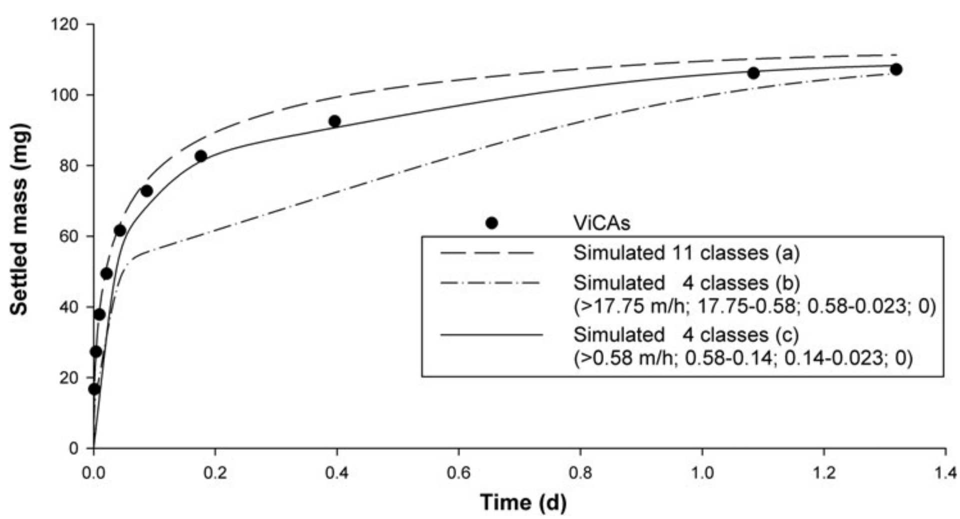

Figure 3. Results of ViCAs experiment simulations for different classes' decomposition. Cumulative mass at the bottom of a ViCAs column compared to the simulation results for different numbers (a or b, c) and types of particle classes (fast (b) or slow(c)).

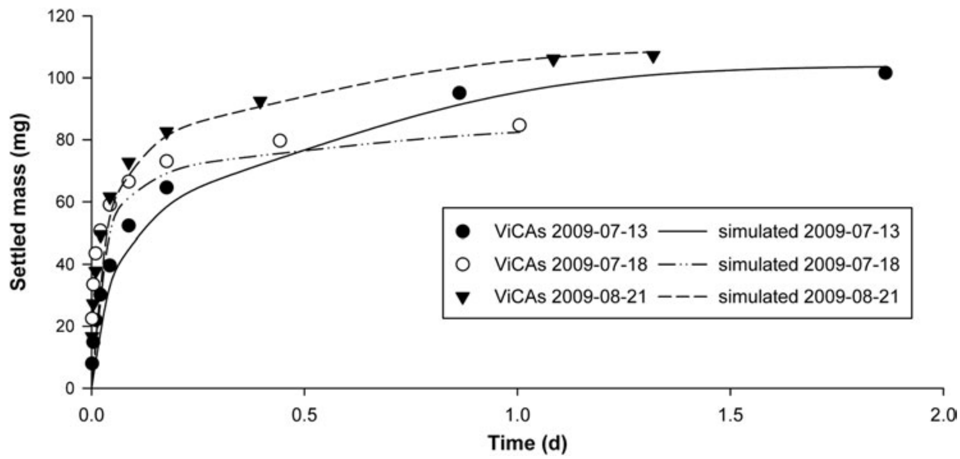

Figure 4. Results of simulations with four classes' decomposition for different ViCAs experiments. Cumulative mass observed for different ViCAs experiments compared to simulated results with the four slow classes' decomposition.

time. Thus, a better description of the water quality in the basin can be expected.

Once the four classes have been chosen, it was evaluated whether using the same definition of the four classes can give the same quality of results for other ViCAs experiments. Figure 4 presents simulations for two other ViCAs experiments. The simulations describe well the particle mass settled at the bottom of the column given the low number of classes used. It means that for long-term simulations including different kinds of rain events, the same four velocity classes could be used all along the simulation period. This will therefore not lead to excessive computation times.

3.2. Pollutant behaviour under filling

The new model has demonstrated its ability to fit experimental data for quiescent conditions. This section illustrates the behaviour of the pollutants in the stormwater basin when exposed to a filling phase with clear water entering at the bottom (layer 10). As presented in Figure 1, the inflow is increasing the volume of the layers. The stormwater basin overflows after 1 day for the simulated conditions. Figure 5 presents the dynamics of four types of pollutants by plotting the evolution of the mass of the different pollutants in each layer.

It can be seen that the soluble pollutant (Figure 5a) is pushed from layer nine to the surface with a small part going to layer 10 due the movement of the interface between layers nine and 10 (Equation (5)). For the other layers the behaviour is the same as for a soluble pollutant in a plug flow reactor with dispersion. When the pollutant reaches layer one and the basin overflows, the total mass of pollutant starts to decrease in the basin.

The particulate pollutant with low v_x (Figure 5b) has the same behaviour as the soluble pollutant. Nevertheless, the total mass remaining in the basin at the end of the simulation is higher than the mass of soluble pollutant (3500 g vs 1873 g) because the particles' settling keeps them in the basin.

The particulate pollutant with high v_x (Figure 5c) settles from layer 1 to layer 10 and all particles accumulate in the 10th layer. Finally the last type of pollutant associated with particles with medium v_x (Figure 5d) is supposed to stay in the layer in which they were initially located, given that its settling velocity equals the upward water velocity. However, it can be seen that the mass is dispersed among the layers around layer four because the layers' volumes increase and the interface moves into the depth where another layer was previously located, capturing or losing particles. For that last pollutant type, once the basin is overflowing after 1 day, the layer's interfaces no longer move. The mass of the pollutant does no longer vary in the layers where the particles were at the moment the basin started to overflow.

3.3. Further developments

The present paper has presented the basic equations of the model with examples describing the behaviour of the particulate and soluble pollutants regarding simple flow conditions. In a real case study, the complexity of the basin configuration can lead to complex hydrodynamic behaviour. With the present model, the envisaged approach is to connect different reactors to reproduce this complex behaviour as already successfully applied in different studies (Vezzaro *et al.* 2010, Wong *et al.* 2006). The connection between the basins, as well as with the inlet or outlet structure can be done by distributing the flow through all layers or just some of them. If not all layers are involved in the flow distribution, the water and pollutants will be transferred to the other layer by the Q_{up} or Q_{down}

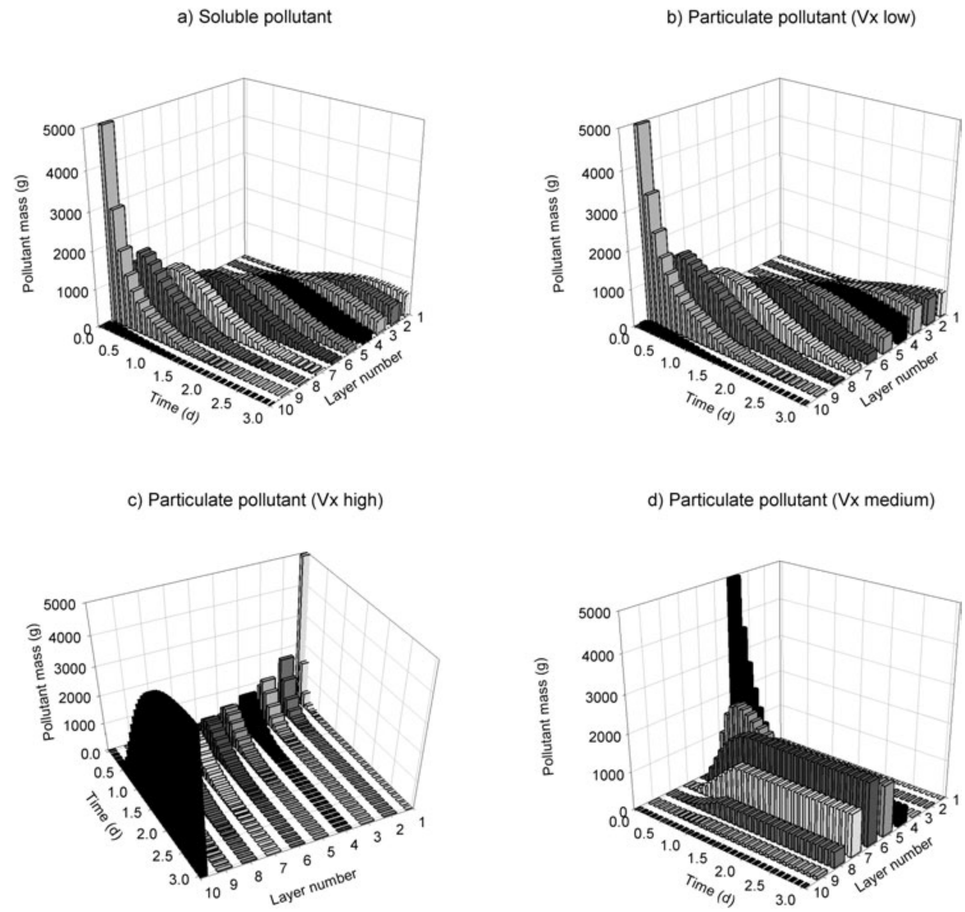

Figure 5. Dynamic pollutants' behaviour. Simulated behaviour of different types of pollutants in the developed model: Soluble pollutant (a) and particulate pollutants with low (lower than the upward water velocity) (b) high (higher than the upward water velocity) (c) and medium (equal to the upward water velocity) (d) settling velocity (v_x).

flows. In order to find the best configuration with the associated flow transfers, CFD or similar models, while not relevant in the context of the present study, can give interesting information because they are describing the major currents and the locations where particles will settle (German *et al.* 2005, Jansons *et al.* 2005, Torres 2008).

The most important feature of the developed model is that interactions between soluble and multiple particulate pollutant fractions can be added easily with a Gujer matrix editor which allows implementing reactions between different pollutants by addition of process rates and stoichiometric coefficients. A detailed example of pathogen-particle interaction is presented in Vergeynst *et al.* (2012) but the developed modelling approach allows consideration in general that each particle class can interact independently with the soluble fraction of the pollutant. For the aforementioned pathogen pollutant example, it was already discussed that multiple processes, like sorption/desorption, natural decay, UV disinfection and settling, have an influence on its concentration. Furthermore, pathogens are preferentially associated to smaller particles and are protected by them (Jeng *et al.* 2005, Oliver *et al.* 2007). In order to represent this characteristic, the process rates will be set to different values depending on the particle class considered. Moreover, because the model is able to create different concentration gradients along the water depth for different particle classes (Figure 5), the pathogen concentration can be influenced by the local conditions. For example, the disinfection due to UV exposure can be modelled as more efficient near the surface than at the bottom of the basin, where particle concentration has increased due to settling, and light penetration is inhibited increasingly.

The context of the present modelling study is to have a model with which to test RTC rules for a valve at the outlet of a dry stormwater basin. In that context, the water volume can tend to zero and, for stability reasons, a minimum volume of water should be kept in the basin. From the authors' experience, considering a water height of 5 mm of water over the area of the basin is appropriate. One should also ensure that the settled particles remain in the system between events as they could be a source of resuspended matter. With the present model, a solution can be to keep a non-variable layer at the bottom of the basin to collect the settled sediment as defined by Vezzaro *et al.* (2010). In that layer, processes can still occur even if there is nearly no water in the basin. When water is entering in the basin, the turbulent flow can resuspend the particles and associated pollutants from the sediment layer thanks to the mixing flow.

Finally, regarding the use of the model within an RTC context, the computational time is an important factor. Compared to CFD modelling which may need more than one day to simulate one event (Torres 2008), the proposed model only needs computational times around a second to generate the three days of data presented in Figure 5. Even with an increased complexity of the model by inclusion of different reactions and different connected basins the computational time will not increase dramatically. The computational efficiency allows performing long-term simulations and therefore offers the possibility of testing different RTC rules.

4. Conclusion

Reproducing the evolution of pollutant concentrations at the outlet of stormwater basins for various environmental conditions asks for water quality models for stormwater basins which include complex processes. For pollutants like pathogens, heavy metals or hydrophobic organics like oil and PCBs, the behaviour of the particles to which they are attached has to be well described.

The present paper introduces a new water quality model for stormwater basins that uses a superposition of homogeneous layers, different types of pollutants and a description of the distribution of settling velocities using a set of particle classes. This model is able to simulate the results from ViCAs experiments, reproducing settling under ideal conditions occurring in a stormwater basin with closed outlet. The model has been able to reproduce data from different ViCAs experiments with a limited number of velocity classes. A simple calibration will therefore be possible thanks to the limited number of classes that have to be characterised. The model also allows reproducing local conditions by creating a concentration gradient for each particle class along the water depth. This gradient is of major interest to describe a phenomenon like UV disinfection that depends on the UV-penetration along the depth of the water column, or different sorption/desorption coefficients depending on the particle class. By connecting different basins together, it is also possible to reproduce the spatial complexity of a stormwater basin. Finally, the computational time necessary to run the model is such that it can be used for long-term simulation and development of RTC rules.

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