

Modelling bidirectional interactions between sewer and river systems using OpenMI - a case study in the Scheldt River Basin (Belgium)

Modélisation des interactions bidirectionnelles entre réseaux d'égouts et rivières à l'aide de OpenMI – étude pilote dans le bassin versant de l'Escaut (Belgique)

Johan Van Assel*, Gunther Waterschoot*, Neel Devroede**, Yves Ronse**, Susan Anderson***, Rob Millington***

* Aquafin nv, Dijkstraat 8, 2630 Aartselaar, Belgium
(johan.vanassel@aquafin.be)

** Vlaamse Milieumaatschappij, A. Van de Maelestraat 96, 9320 Erembodegem, Belgium

*** MWH Soft, Howbery Park, Wallingford, Oxfordshire OX10 8BA, UK

RÉSUMÉ

Le développement de la nouvelle technologie OpenMI (Open Modelling Interface) a créé des opportunités pour l'échange de données en temps réel entre des modèles de nature et origine différentes. Ce document expose une étude pilote dans laquelle les interactions entre des réseaux d'égouts et de rivières ont été simulées à l'échelle réelle dans la partie Belge (Flamande) du bassin hydrographique international de l'Escaut. Elle est une de sept études dans le cadre du projet Européen subventionné OpenMI-Life.

Le couplage des modèles comprend l'échange simultané et bidirectionnel de débits et niveaux d'eau dans plus de deux cent points. Des scénarios différents ont été étudiés afin d'évaluer les différences entre la modélisation séparée et intégrée, et afin d'évaluer quel est l'impact des changements effectués dans un système sur l'état d'un autre système.

Bien qu'il reste des questions techniques prioritaires à résoudre et améliorer, il est clair que l'OpenMI offre un potentiel important pour l'étude et la gestion intégrée des systèmes aquatiques dont les interactions n'ont pas pu être étudiées auparavant.

ABSTRACT

The development of the Open Modelling Interface (OpenMI) has made it possible to exchange data at runtime between models of different nature and origin. In this paper a case study is described in which interactions between sewer and river systems have been simulated on full scale operational models in the Belgian (Flemish) part of the international Scheldt River Basin. It is one of seven case studies in the framework of the European funded OpenMI-Life project.

The linkage involves the simultaneous bidirectional exchange of flows and levels at more than two hundred locations. Various scenarios have been looked at to evaluate the differences between stand alone and linked modelling, and to evaluate the impact of changes in one system on the other.

While inevitably a number of technical issues remain to be improved, it is clear that the OpenMI provides an important potential for studying and managing interacting water systems in a way that was not possible before.

KEYWORDS

Integrated modelling, OpenMI, river modelling, urban drainage.

1 INTRODUCTION

Watercourses in highly urbanised areas often interact in a complex manner with the urban drainage system, especially when the latter is a combined sewer system that contains multiple combined sewer overflows (CSOs). Discharges from one or more CSOs may indeed affect the behaviour of the watercourse to an extent that the increased water levels form a significant obstacle for other – neighbouring- CSOs to discharge freely. The only way to model such interactions –apart from a real integration of both models in a common conceptual framework (e.g. Kandori and Willems (2008))- was until recently through the exchange of results files. Because of the bidirectional nature of the interactions this exchange process would have to be iterated several times, which is very laborious and in most cases not practical. Since the release of the Open Modelling Interface (OpenMI) (Gregersen *et al.* (2007)), new opportunities have arisen to solve this type of problem. Without having to modify the original models significantly, OpenMI offers the possibility to exchange data between various types of models at runtime and simultaneously in both directions.

2 DESCRIPTION OF THE CASE STUDY

The case study described below was set up as part of the OpenMI-Life project (funded under the Life Programme of DG Environment of the European Commission – contract n° LIFE06 ENV/UK/000409). In this project, authorities and institutions involved in the management of the Scheldt (Belgium, Netherlands) and Pinios (Greece) River Basins tried out various aspects of full scale operational model linking. An overview of all four Scheldt case studies was given in Devroede *et al.* (2008).

Organisations involved in this case study are Aquafin (Flanders' wastewater operator, responsible for the building and operation of sewage treatment plants (STPs) and trunk sewers) and the Division of Operational Water Management of the Flemish Environmental Agency (Vlaamse Milieumaatschappij, VMM), responsible for the flood management of the primary non-navigable watercourses. Technical assistance was given by MWH Soft (UK) (formerly Wallingford Software), who are also involved in the further development of the OpenMI Standard.

The study area comprises the larger drainage area of the town of Leuven (situated approximately 20 km east of Brussels). The central STP of Leuven has a capacity of about 120000 population equivalents. In this area there is a very strong interaction between the sewer system and the watercourses, mainly as a result of the complex branching of the local river Dijle on its passage through the town centre of Leuven. In an area of about 75 km² no less than 180 sewer discharge points were identified along 50 km of watercourses. The majority of the sewer system is still combined, with a high number of combined sewer overflows (CSOs), although in some areas quite a number of separate (storm) sewers have been constructed during the last five to ten years.

3 APPROACH

The OpenMI-Life project was the first real opportunity to demonstrate the applicability of the OpenMI technology at a real operational scale, and it was clear that this would involve different challenges and practical problems from those encountered during the period of research and technological development (Tindall (2005)).

Therefore the case studies were split up in three technical phases, followed by a general evaluation (Ronse and Safiolea (in prep.)) :

- definition phase : during this phase the existing models were screened and the properties and characteristics of the links to be achieved were technically described and analysed;
- test phase : during this phase the various issues and potential problems, described during the definition phase, were tested and corrections and improvements to the implementation of the OpenMI were made;
- demonstration phase : the goal of this phase was to use the finally linked models in the closest possible approximation to current operational modelling practice;

3.1 Definition Phase

The models to be linked were :

- a 10000 nodes sewer model of the larger drainage area of Leuven, built in InfoWorks CS by Aquafin;
- a 4000 link river model of the river Dijle and its tributaries in an area coinciding with that of the sewer model, built in InfoWorks RS by VMM.

Although both models use the InfoWorks product suite (MWH Soft, UK), the differences in concept and approach of the CS and RS modules make the linking of these models not as straight forward as it might seem.

The main issues that arose from the definition phase were the following :

- While the obvious exchanges between sewer and river systems are flows and water levels at the various discharge points, it was required that flood volumes could be exchanged as well (see Figure 1). Due to the different response times, river and sewer systems generally do not flood at the same moment in time, but flooding of one system may affect the behaviour of the other. This exchange had to be described conceptually and a practical approach for both models had to be defined.
- The type of simulations used by Aquafin and VMM differs substantially. While VMM typically simulates (discontinuous) episodes of events, selected from a long rainfall time series (Cauwenberghs (2007)), Aquafin either uses fully continuous time series or synthetic rainfall (Van Assel and Dirckx (2007)). Both approaches had to be combined or reconciled.
- Sewer models need rainfall data with a higher temporal resolution than river models (typically 2-10 minutes for sewers compared to 1 hour for rivers). This is necessary to generate correct peak discharges e.g. at CSOs. Acquiring such high resolution historic rainfall data for the same period and with the same spatial distribution as what is currently used by VMM would be very expensive. This puts a practical (non technical) limitation to the extent of the simulations that can be run.
- RS contains a semi-black box hydrological model (PDM) which has been calibrated by VMM on the basis of historic rain and flow gauge data. Because these flow gauge data intrinsically include flows from upstream sewer discharges, there will be a double counting of some flows when sewer models are linked to river models without adapting the calibration of the hydrological model.

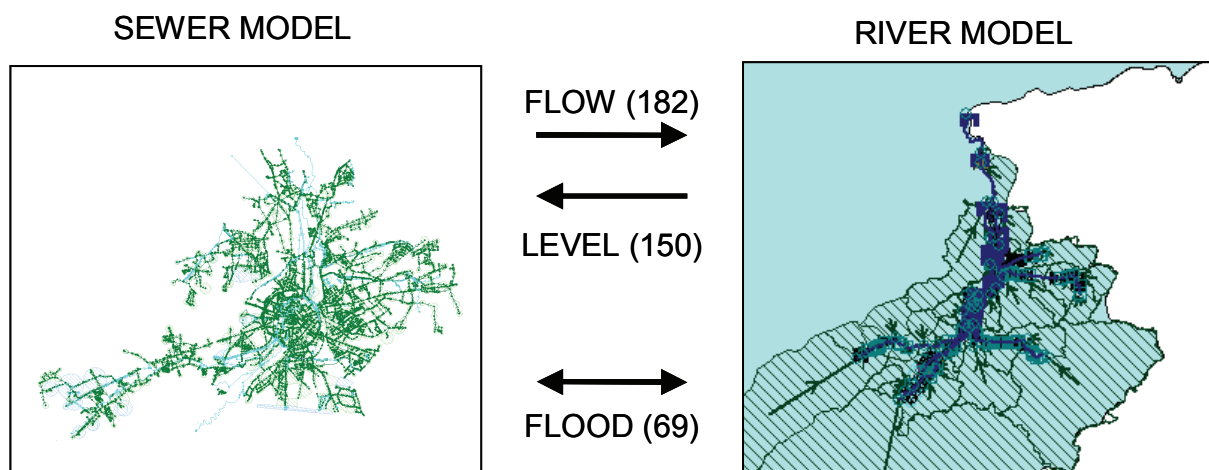


Figure 1 : Type and number of interactions between sewer and river system

3.2 Test Phase

The major initial finding of the test phase was that the original implementation of OpenMI in InfoWorks could not deal with the size of the existing models with respect to performance and memory usage. As a result of this a re-engineering of the OpenMI implementation had to be carried out by MWH Soft before any further testing could be performed.

During the test phase different versions of InfoWorks were tried out (varying from version 8.0x until version 9.5x including non-commercially released patches) following successive improvements and developments.

As part of the UK OpenWeb project (<https://openweb.uk.net>) MWH Soft also developed the Pipistrelle configuration tool that provides more functionality and flexibility than the standard OpenMI Configuration Editor which is provided by the OpenMI Association Technical Committee. Different versions of Pipistrelle were tried out during the test and demonstration phase.

As a response to the issues defined during the definition phase, the following solutions or workarounds became available :

- A concept of flood volume exchange was proposed, according to which flood links could be created without major implications for the current models. It is expected that the concept and definition of flood links will be further simplified in future versions of InfoWorks.
- The standard RS event selection procedure was modified to incorporate additional events that are critical to sewer systems (typically short and high intensity events). While VMM just used the extended list of events, Aquafin alternated them with standalone runs in CS so as to maintain a fully continuous simulation period. The automated scheduling of multiple linked simulations was made possible through Pipistrelle.
- For practical reasons described in par. 3.1 above, the use of the historic rainfall series of Ukkel (Brussels) was limited to 36 years (1967-2002), being the period for which Aquafin had the data available in sufficiently high resolution. The normal period to be considered for VMM would be from 1898 to present date.
- A proper recalibration of the hydrologic model was not feasible in the framework of the case study. Comparison of standalone and linked model results has to indicate to which extent this puts a restriction to the conclusions that can be drawn from the case study.

Problems with numerical stability (oscillations in bidirectionally exchanged values) did occur in specific circumstances (typically at the short and very high rainfall intensities, which are critical to sewers only). A satisfactory workaround was found by duplicating in both models some of the nodes or links involved in those exchanges. Given the smooth exchanges at the vast majority of the other events, it cannot be stated that the bidirectional exchange mechanism of the OpenMI standard would be intrinsically unstable.

3.3 Demonstration Phase

The first objective of the demonstration phase was to compare or evaluate the linked simulations with the normal operational stand alone simulations.

In addition, two other scenarios were run with a view to evaluating :

- the effectiveness of storm water buffering in the sewer system with respect to the prevention of floods in the river;
- the impact of the construction of new trunk sewers to the river system.

3.3.1 Comparison linked vs. stand alone

Figure 2 illustrates the importance of bidirectional linking. It shows an example of a reverse flow from a watercourse into a storm sewer outlet. The water level that causes this reverse flow is in itself determined by the discharges of various neighbouring CSOs, and hence it would not be possible to impose it as a predefined boundary condition to a standalone sewer model.

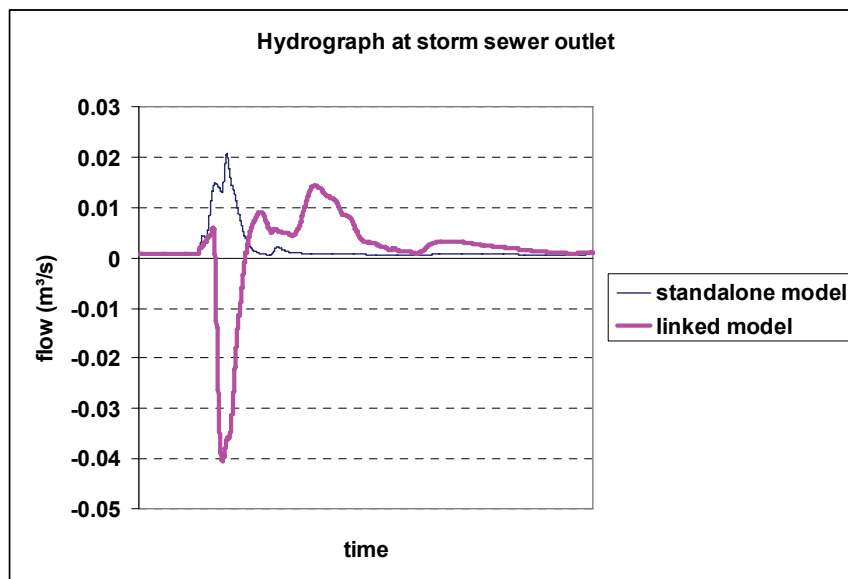


Figure 2 : Example of reverse flow from river into sewer system

Figure 3 shows a comparison of standalone and linked model results of the flow and water level in a downstream river section. The additional peak in the hydrograph of the linked model is caused by the inflow of multiple CSO discharges from the sewer model. The remaining deviation between the two hydrographs is due to the continuous contributions from storm sewers, which are already accounted for in the hydrology of the standalone model. This illustrates the need for recalibration of the river hydrologic model when used in combination with the sewer model.

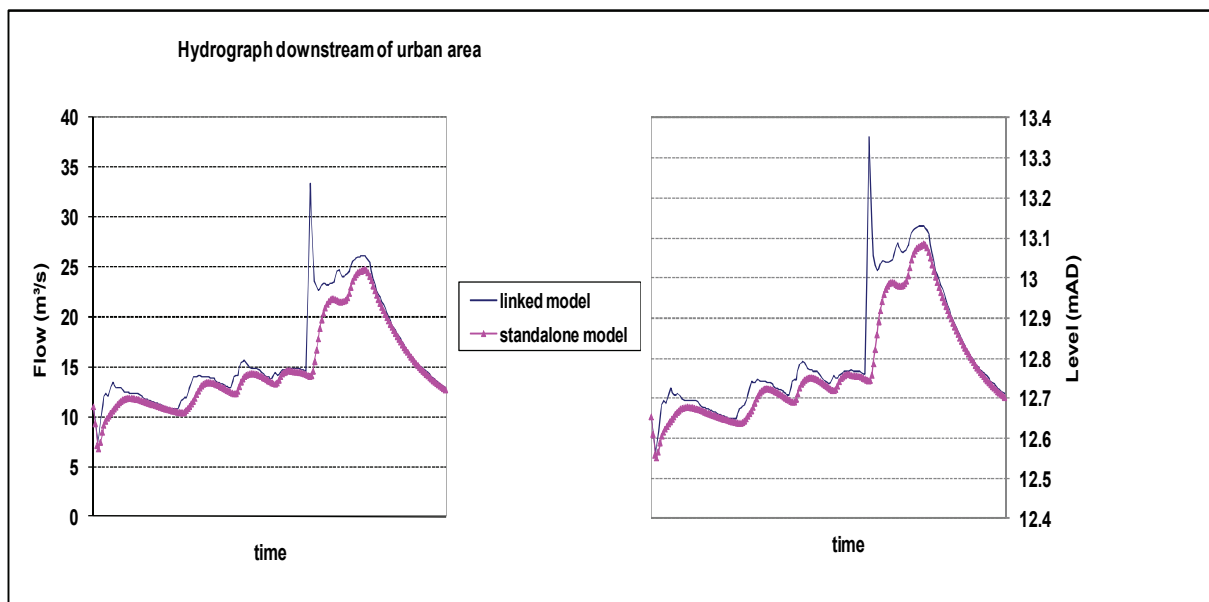


Figure 3 : Impact of sewer peak discharges on river flow and level

Whereas in the example of Figure3 the differences in water level are still relatively limited (0.25 m level rise for 10 m³/s increase in flow), this is not the case for the smaller tributaries. In these upstream areas differences in water level between 0.5 m and 1 m occur at various CSO spill events.

From the total sewer system's point of view, the yearly averaged cumulative CSO spill volume is less

than 1% lower in the linked model than in the standalone model, but the results at individual CSOs show much larger differences (50-100% at various locations). The overall duration of the spills is about 18% lower in linked mode.

The difference between the standalone and the linked model also depends on the boundary conditions that are used in the standalone model. The percentage differences mentioned above apply to a partly hybrid sewer model, i.e. the model contains simplified river sections, but no proper hydrological input. This means that the water level in the simplified river sections rises due to CSO spills and may therefore create a certain downstream condition for some other CSOs, but in general it is expected that these water levels are underestimated because of the lack of hydrological input.

A genuine standalone sewer model (i.e. without any river sections) was run using synthetic rainfall and fixed maximum boundary conditions. This is the typical configuration that would be used in sewer modelling practice to analyse extreme behaviour, because it is often impossible to obtain sufficient details on the frequency and duration of high river levels. Using a range of design storms with return periods varying from 1/20 yr. to 100 yr., a good approximation of the average yearly spilled volume can be derived by integrating the results of the different storms over the frequency. This then allows comparison with the results from time series simulations. As can be expected, it appears that some of the high river levels cause a permanent inflow to the sewer system and this in turn causes some other CSOs to spill permanently. The calculated yearly averaged spill volume is 20-25 times higher than what is calculated with the linked model.

In a third version of the standalone model the boundary conditions for the various design storms have been derived on the basis of statistical processing of the results of the linked simulations (level-duration-frequency curves). The results of this approach are much better (only 1% higher average spill volume compared to the linked model). Although this may seem to be a good compromise between the fast (and less accurate) standalone model with design storms and the time consuming (but more accurate) linked model setup, its practical use may be questionable. Apart from the fact that the linked model always has to be run first to derive the boundary conditions, it cannot be guaranteed that these remain valid when changes are made to either of the two models.

3.3.2 Effectiveness of stormwater buffering

Current regulations in Flanders impose that peak discharges from sewer systems (both CSO spills and discharges from separate stormwater systems) be minimised by means of retention tanks. The volume and throughflow of these tanks are determined by the amount of impermeable area that is connected to the respective outfalls (e.g. 250 m³/ha imp. and 20 l/s/ha imp.). In the case of very vulnerable watercourses more stringent permits may be imposed by the river manager. However, no real criteria exist to take into account the hydraulic capacity and regime of the receiving watercourse nor to account for the combined impact of multiple retention tanks distributed spatially across the main river and its tributaries.

In order to assess the impact of stormwater buffering, a hypothetical scenario was simulated in which retention tanks were added to the five most important discharge points on the southwestern tributary Voer (which had been constructed before the current regulation started to apply).

Figure 4 shows the impact on the river downstream in the Voer tributary (1) and further downstream in the main Dijle river (2). The first peak in the hydrograph is due to the CSO spills; the second one is the hydrologic response of the river. In the more downstream hydrograph locations the effect of the retention tanks becomes negligible. Likewise the significance of the CSO peak compared to the hydrologic peak response decreases.

From the sewer system's point of view, the overall yearly averaged spill duration increases by about 2% as the result of the presence of the retention tanks. The impact on the spilled volume is negligible.

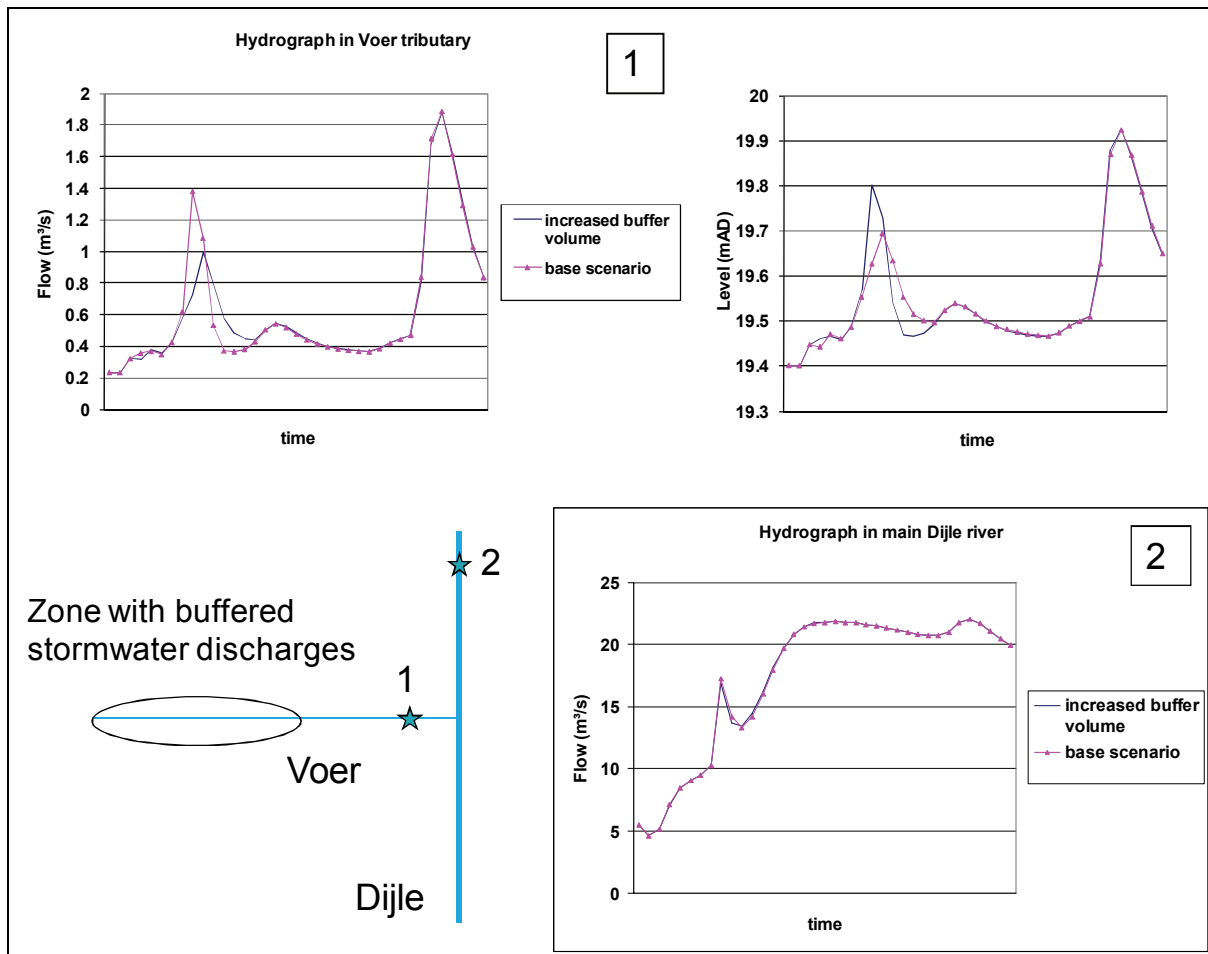


Figure 4 : Impact of stormwater buffering on Voer (local) and Dijle (further downstream)

3.3.3 Impact of newly constructed trunk sewers

The third scenario looked at the impact of recent extensions of the sewer system on the watercourse. The most significant extensions that are currently still taking place, are in the municipality of Bertem that is situated along the upper reaches of the Voer tributary. Local sewer systems are connected to the trunk sewer system, resulting in the elimination of permanent discharges from combined sewer outfalls. At the same time a new CSO has been built on the extension of the trunk sewer. Because of the connection of these local (still largely combined) systems, additional volumes of storm water runoff are carried down the trunk sewer and in extreme conditions this can affect the hydraulic behaviour of the sewer system as far as the STP.

The overall yearly average spill volume is around 1.5% higher than in the base scenario, while the overall spill duration is about 0.8% higher.

3.4 Evaluation

In general the demonstration phase learnt that it is technically possible to run full scale operational sewer and river models in linked mode. In order to approximate current modelling practice of both partners, a large number of simulations and events were run to check feasibility of linked runs in daily operational practice.

Despite the large number and complexity of the links, the (bidirectional) transfer of data generally runs smoothly. In some specific simulations numeric instabilities (oscillations and/or divergence) occurred at first and a workaround was necessary to deal with the problem. It is possible that some form of latent instability of the stand alone models contributes to the failure of some simulations. More research will have to be done to get a better idea of the exact cause of these instabilities and to find appropriate remediation for it.

From an end user point of view, it must be admitted that progress is still to be made in the field of the software implementation. Even though the Pipistrelle tool has already more functionalities and is more user friendly than the standard OpenMI Configuration Editor, the general feeling is that OpenMI is not yet as smoothly integrated in the InfoWorks suite as one might hope. Issues such as traceability, version control, error tracking etc. on the linked model compositions are not yet elaborated at a very high level.

4 CONCLUSIONS

The OpenMI has opened up new possibilities to integrate existing models that were historically developed from different viewpoints and with different objectives.

In the larger drainage area of Leuven and the river Dijle the existing sewer and river models of Aquafin and VMM were linked in the framework of the OpenMI-Life project to demonstrate the possibilities of the OpenMI at a full operational scale.

Simulations show that the complex bidirectional linking is technically and numerically feasible and the results confirm the importance of modelling the interactions that take place between both systems. However, in order to produce fully reliable results, it is important to realise that the original calibration of the models may have to be refined.

From a software point of view, more attention will have to be given to the further development of user friendly interfaces so as to bring OpenMI to a level that is comparable to working with professional standalone models.

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