Report Defining the Scheldt Use case a : linking hydraulic sewer and river models

1. Short description of the use case

Use case a) has the intention to demonstrate the added value of the OpenMI in linking hydraulic sewer and river models with a view to optimising investments and operational strategies of the sewerage and river managers. The use case is situated in the Dijle river basin and more specifically around the town of Leuven. The partners involved are Aquafin and Division Water of the Flemish Environment Agency (VMM-AWA). Both partners use InfoWorks (CS and RS respectively) as their modelling software, but as a result of different objectives and working procedures, the current models are not really compatible or geared to one another.

2. Identification of the management / policy issue

The overall main aim of both partners is the minimisation of flood risk (both urban and rural flooding), but the context in which this aim is to be situated is slightly different :

Aquafin is responsible for carrying out investment schemes of trunk sewers and wastewater treatment plants, assigned to them by the Flemish Environment Agency (VMM), and for operating these assets after their realisation. In order to optimise the design of these schemes and to minimise the risk of flooding after their realisation, hydrodynamic sewer models are being built and used. Specific attention is also given to minimising the risk of intermittent urban pollution (from combined sewer overflows) during wet weather conditions, which are not necessarily flood conditions.

VMM-AWA is fully responsible for the flood management of the main (so called 1st category) non-navigable water courses, and works closely together with the provinces, which are responsible for the more upstream (2nd category) reaches of these watercourses. This involves both the optimisation of statistical flood risks (calculation of flood maps) and the minimisation of flood damage in actual conditions through realtime operation and forecasting.

3. Solution to this management / policy issue

Traditional solutions to the above objectives are mostly focussed on the specific competence or management domains, and therefore may not provide a global solution.

It is clear that the objectives from both the sewer and the river managers cannot be seen as independent from each other, as sewer peak discharges during wet weather can severely affect the flood management in the rivers. Due to their short response times to heavy rainfall and the difficulty to forecast the exact locations where the highest peaks will occur, a more integrated modelling approach could contribute significantly to drawing more accurate flood maps and to a better realtime forecasting. From the point of view of the sewer manager, a more realistic calculation of high water levels in the river can also lead to a better decision making as to where excess storm water can be evacuated safely from the sewer system in order to avoid urban flooding.

The possibilities to link sewer and river models can lead to a better understanding of the two way interactions between those systems in terms of the temporal and spatial accumulations of both fast and slow hydrologic and hydraulic responses. This better understanding should lead to more optimal investments and daily operation.

Following are some examples where the linking would provide an opportunity for more optimised management:

- Opportunity to improve investment schemes:

  Conservative restrictions for discharge permits, imposed by the river manager to the sewer manager, with a view to minimising flood risks or intermittent pollution, can lead to excessive requirements for storage volumes in the sewer system.

- Opportunity to investigate the impact of national policies:

  Rigid application of policy strategies to move from combined to separate systems, with a view to minimising the risk of intermittent urban pollution and to optimising the operation of sewage treatment plants, but without fully understanding the hydrologic and hydraulic impacts to the river system, could -especially in highly urbanised areas- possibly lead to increased flood risks.

- Opportunity to integrate the operational management of river and sewer system:

  River managers need to be aware of the impact of some high water levels on the sewer system. When this knowledge becomes available through the linking of models, the control strategies for sluices and weirs can take this information into account and help to optimise the working of the sewer system.

4. Setting the objectives

4.1 Specific use case objectives

- *Demonstrate that model A and model B, which have been developed independently from each other, can be linked together,*

The concrete objective for this use case is to demonstrate that :

sewer models, which have been built independently by (or by order of) Aquafin

- with the main objective of an optimal hydraulic design of collector (trunk) sewers,
- using the InfoWorks CS package (or its predecessor HydroWorks) and
- following Aquafin's modelling procedure (Hydronaut-Procedure)

can be linked with

river models, which have been built independently by (or by order of) VMM-AWA

- with the main objective of drawing flood risk maps, improving the operational management and infrastructure, and flood forecasting,
- using the InfoWorks RS package (or its predecessor Isis) and
- following AWA's modelling procedures

- *Demonstrate how physical system interactions can be dealt with by linking the models at runtime and how this is different to the classic approach of representing these interactions explicitly in every individual model (if it's possible to do it in each stand alone model)*

The classic approach to modelling interactions between sewer systems and rivers would be to predefine boundary conditions in the form of time series of flow and level hydrographs for both models, where in the best case these time series would have been prepared on the basis of knowledge and results of each others' model, but in reality more often only represent a best guess.
Unless through a very laborious iterative process, this approach does not allow for the mutual influencing of river and sewer system, as a predefined boundary condition cannot take into account the instantaneous impact it will have on other boundary conditions.

The objective of this use case is to demonstrate that physical two way exchanges and interactions of flows and water levels between sewer and river systems, both in normal and in flood conditions, can be modelled through one single simulation using a runtime link between both models.
The objective is also to demonstrate that other types of interactions, which in a classic approach are much more difficult to be described by boundary conditions, can be modelled in the same way. Especially the transfer of flood volumes between both systems is envisaged.

- *Assessing the practical feasibility (data handling, simulation times) of large scale models linking*

The objective of this use case is to assess to which extent the model linking affects the practical aspects of large computer simulations.

Both models, when run in stand alone mode, today tend to produce already large results files and represent long simulation times (depending of course on the scope of the simulation and the complexity of the model). It can be expected that the linking of the models will not improve this.

Simulation times are expected to slow down considerably, compared to stand alone simulations, because the two way interactions will cause the data exchange at many occasions to be iterative. But the most important reason for slowing down will obviously be the fact that both engines will use memory simultaneously.

The same applies for results files : although the individual file sizes will remain the same, and the post processing of the results should not be affected by the size of the other model's files, additional disk space will have to be foreseen to store all the results files of both models.

For the above reasons, the idea of remote linking will have to be considered from the beginning of the use case as the ultimate goal for practical application of the OpenMI after the project will be finished. Even though it is likely that remote data exchange would in itself not be beneficial to reducing calculation times, the advantage of having only one engine in memory and only one set of result files to store, is thought to be considerable. But apart from that, it is also thought not be practicable if all future linked runs would always require the exchange of models on each other's computers, and to have permanent availability of licenses for each other's models, which would not be used for anything else.

Another question, specific to InfoWorks (both RS and CS), that will have to be answered, is whether or how the linkage of the models will affect practical aspects of the version management of models and model runs within the software.

- *Demonstrate the gain of quality of derived products using the linked models.*

The main products of the current stand-alone models are :

- River flood risk maps, showing flood contours for different return periods (statistical processing of output from (episodes of) long time series simulations.
- Impact assessment analyses for new operational management and new infrastructure in the river system.
- Sewer flood maps, maximum water levels and hydrographs at specific locations, according to design rainfall return periods.
- Combined sewer overflow spill statistics, based on continuous simulations.

The aim of the use case is to demonstrate how the linkage of the models will improve these current outputs, with special attention to a reconciliation of flood calculations in those parts of the sewer system that are directly affected by the river flood behaviour.
A special case is the output of the sewers , which is based on design rainfall : where the sewer model can easily be run with the same rainfall events as the river, it is neither realistic nor useful to impose the sewer design rainfall to the river system. The use case will have to demonstrate how this problem can be tackled in a practical way.

4.2 Wider perspective objectives

- *objectives about integrated water management*

The general description of the use case mentioned already the intentions to look at the sewer and river management in a more integrated way.

From the wider Water Framework Directive perspective, it is clear that the integrated hydraulic modelling of sewers and rivers are –apart from its specific objectives- also a first step to come to a global assessment of the impact of urban systems on river quality (both during normal and flood conditions) and finally to the ecological status of the river system.
This would involve the extension of the current sewer models to aspects of pollution transport and the linking with dynamic treatment plant process models and river quality models. Such wider perspective however does not form the objective of this use case in the frame of the OpenMI-LIFE project.

5. Defining the actions

5.1 Preconditions for linking models

- *The models have been migrated to/made compliant with the OpenMI standard interface specifications*

The InfoWorks software is already compliant.

- *The model user has a (multiprocessor) PC (or other hardware platform), equipped with the required operational system and software libraries,*

Both parties' laptops are equipped and should be sufficiently performant to execute the required simulations.

- *The model user has the OpenMI compliant version of both models installed on his PC,*

InfoWorks version 8.0 has been released in February 2007 and has been installed by both parties.

- *The model user has input files for both models available on his PC,*

The versions to be used at the start of the trial phase have been decided in a technical meeting dd. March 5th. As soon as these versions are prepared and available, they will be exchanged between Aquafin and VMM-AWA. At this point, rainfall data will be limited to periods that both parties have already available today.
During the trial period, new versions will have to be exchanged regularly.

- *The model user has an OpenMI configuration user interface installed on his PC.*

InfoWorks 8.0 works with OpenMI version 1.0. This has been installed by both parties.

5.2 Actions for the definition phase

5.2.1 Define the hardware environment

- *To define the hardware / platform requirements for linking the models and to decide if a stepwise test procedure is possible or not,*

During the project, trial runs will be done on laptops.
Investigations into hardware requirements or specifications for future remote linking should start early in the trial phase.

5.2.2 Define the interactions to be modelled

- *To define clearly the extent of the domain, setting the limits, the boundaries, and solving boundary problems,*
  (e.g. : not same extent of modelled area : what to do at boundaries ?)

In theory the whole drainage area of Leuven is situated within the river Dijle basin. There are however a few points of attention :

- some of the more northern parts discharge into water courses which are tributaries to the tidal part of the Dijle. As this is beyond the limits of the river model that will be used, no OpenMI links will be foreseen for these discharges (hence, they will be normal outfalls as in a stand alone model).
- In some upstream parts of the model, a number of trunk sewers have not been constructed yet, which means that there are still many small permanent discharge points close to each other. It doesn't seem very useful at this stage to provide all these discharges with open links, but rather to keep them implicit in the current pdm-boundary of the river model. The consistency of the runoff areas has to be checked, though.

The boundaries of the river model to be used have still to be decided as well. There are different possibilities as to where to take the upstream end of the model (whether or not to include the Walloon part, or the most southern of the Flemish tributaries IJse and Laan). The downstream end of the model is likely to be taken at the control point of the watermill in Rotselaar, just upstream from the confluence with the Demer river. The chosen option will decide which upstream or downstream boundary conditions are necessary.

The final decisions for the boundary conditions of the models have been listed in the minutes of the technical meeting dd. March 5th. It is foreseen that this model version will be fixed for at least half a year.

- *To define the spatial and time domains of the models,*
  (e.g. : not same time step : what to do ?)

With regard to the time steps, no real problems are expected. Sewer models typically run at a timestep of 60s, which can be automatically adapted by the engine during runtime to overcome convergence problems (up to 7 consecutive timestep halvings). When running continuous long term simulations, the opposite can be applied to speed up simulations of long dry weather periods (up to 32 times the normal timestep). The latter is at present not yet supported by the OpenMI implementation of InfoWorks. It is a feature request to Wallingford Software to enable this.

Normal river timesteps are 20 to 300 seconds, depending on the stability of the model. The more stable the higher the timestep can be. The model that will be used is developed to run at a timestep of 100 seconds. Running it at smaller timesteps is always possible, higher timesteps will cause problems of stability.

The difference in time steps between both models is thus not of an order that is expected to give problems (no extreme time interpolation or extrapolation required).

- *To define the schematization of the models, solving possible conceptual differences,*
  (e.g. : lateral flow channels of rivers not implemented; different location of river nodes etc.)

Two different problems can be identified : the inconsistency in the degree of details of the sewer and river model, and the inconsistency in the "up-to-date-ness" of the models.

Sewer models are normally much more detailed than river models, which means that a number of modelled discharge points are located on smaller watercourses (ditches or 3rd category watercourses) that are often not present in the river model.

There are different possible solutions to this :

- the links could be made from the discharge point in the sewer model to the nearest downstream modelled river location. This has the disadvantage that travel times between the two physical locations are ignored (and often in these smaller watercourses they may be important) and that several discharges may have to be grouped, where they are not in reality.
- The river model could be extended with the smaller watercourses. This is certainly not obvious given the risk for instabilities in the river model. And moreover these smaller watercourses are not under the authority of VMM-AWA nor of the provinces.
- The sewer model could be extended with some open channels to a location where they would meet a modelled river section. Apart from the availability of the data, the main problem in this case is that InfoWorks CS is not really suitable for modelling hydrology of these small watercourses.

During the technical meeting of March 5th it was decided that the number of cases where discharge points are not present in the river model, are fairly limited, and that for these cases the river model would keep its present PDM boundaries, rather than providing a direct link with the sewer model. The impervious areas for these boundaries will be checked against the sewer model, though.

A second problem is related to the regular updating of the models. So far, all sewer models have been built with the primary objective of trunk sewer design and not so much for operational management. This means that –after the hydraulic design has been completed- models are most of the time not further updated with recent changes, unless new or additional investments are defined in the same area.
This problem is even intensified by the fact that Aquafin has no responsibility for local sewers and cannot impose any updating procedures to the local authorities, despite the fact that knowledge about changes in the local sewers can be crucial for optimising the operational management.

It was agreed that both parties would try to make their models represent the situation of April 1st 2007. As this will not be possible immediately, it may require the exchange of a number of consecutive model versions in the next months to come.

- *To define the processes to be modelled in view of the integrated water management issues to be dealt with, and solving possible conceptual differences,*
  (e.g. : river flow models are not built for dealing with low flow situations; different representation of lateral inflows etc.)

Processes modelled are urban runoff, sewer hydraulics, river hydrology and river hydraulics. As already stated before, they are the fundamental processes to flood management, but they also form the basis for any water quality considerations, although this aspect will not be studied in the frame of this use case and to some extent also not in the frame of the OpenMI-LIFE project.

Conceptual difficulties relate to overlaps between sewer runoff and river hydrology and to possible complex flood behaviour in river flood plains. These problems are discussed further.

- *To define the types of analysis (runs) that must be carried out according to normal modelling procedures*

Currently the following types of runs are used :

River simulations

- river models use a selection (episode) of rainfall events, originating from a historic 100 year rainfall series. These events are determined through statistical processing (peak-over-threshold) of the full 100 year calculations of the hydrological boundaries. These selected events can vary considerably in length, and the total length of all selected events can be approximately 10-20 years.
- Outputs of the hydraulic model (water levels, flood contours, peak discharges, …) are converted into statistical return periods (frequency analysis).

For this type of simulation, there is no fundamental problem of linking expected, as the sewer model can easily be run for the same set of rainfall events. InfoWorks CS however has no possibility for episode run scheduling, which means that the different events would have to be defined as individual simulations. This will have to be discussed with Wallingford Software.

Forecasting simulations

These simulations use a different technology than the above described ones (FloodWorks instead of InfoWorks, which also relies on online input from monitoring devices). It is not (yet) decided if these simulations would form the subject of the OpenMI-LIFE project. At present, there is no FloodWorks version for the sewer model anyway.

Sewer simulations (time series rainfall)

- sewer models are sometimes run for a continuous period of time to analyse intermittent behaviour (CSOs, storage basins, …). Contrary to river model practice, no selection of events is made, because some parts of the sewer system (especially pumping stations or other flow limiting devices) can be much more sensitive to small variations in flow (typically between 1 and 6 times the dry weather flow), and because the time step can be speeded up during long dry periods. Depending on the required outputs, such simulations may be up to 27 years long (this is the reference period for the design rainfall).
- In such simulations, as in the river simulations, outputs are postprocessed statistically, although the system of postprocessing seems to be slightly different. It has to be investigated if CS and RS could use each others' postprocessing functionalities (and whether this requires a full license).

As the 27 years is in the same order of duration as the full event selection, it would be expected that this type of simulation could be run in linked mode without too many problems as well. There may however be problems of stability for the river model in long dry periods.

Sewer simulations (design rainfall)

- this type of simulations is completely different in concept to the previous ones. Design storms of different return periods are used to quickly evaluate the behaviour of the sewer system under extreme events. Although it is not entirely correct to assign the return period of the storms equally as a return period to the model output, this is a common procedure in sewer modelling.

One of the main problems in this approach is exactly to define suitable boundary conditions for the sewer model that are in line with the return period of the design rainfall. In this respect, a linked simulation would partly take away that uncertainty. Unfortunately, it is not possible in practice to define design storms for a river basin in the same way as they were made for sewer systems.

Currently, the only sort of solution for this is probably to use the linked simulations to derive more realistic boundary conditions for the stand-alone simulations with design storms.

For all simulations, there is in additional problem in the definition of which rainfall has to be used (single gauge, distributed rainfall, …) :

- River simulations use distributed rainfall, which is partly composed of actually recorded rainfall intensities and partly of daily recorded volumes with extrapolated intensities (depending on the availability of historic data). In this case the river rainfall can be imposed to the sewer network according to the same spatial distribution. There may be a problem however with the time resolution of the rainfall data. For river hydrology an hourly interval is sufficient, while for sewer systems an interval of ten to fifteen minutes is a more appropriate interval. Comparisons in the past have shown that one hour interval rain events may not cause certain overflows to spill, where the same events at ten minutes interval would cause a significant spill.

- Forecast simulations use actual recorded rainfall (gauges and radars) and predicted rainfall, which means that the resolution might be less a problem, as it can be processed online as requested.

- Sewer simulations (whether carried out with time series rainfall or design rainfall) always use the Ukkel (Brussels) rainfall data, as all design and evaluation criteria are based upon the statistics of this rainfall. This means that –if a linked simulation were to be initiated by the sewer model- the input from the river model should be based on uniform Ukkel rainfall and should be limited to the period 1967-1993. Any other rainfall would make the evaluation of the sewer system performance inconsistent with the official guidelines.

5.2.3 Define the links

- *To define the links in a conceptual descriptive way (i.e. in terms of common physical variables or processes)*

Normal conditions

In normal conditions two types of links can be identified :

- Transfer of flows from the sewer to the river at discharge points (permanent outfalls/overflows/treatment plant). Flows may occasionally revert in these cases were discharge points are not protected by a flap valve
- Impose water levels from the river to the sewer at discharge points to prevent free discharge

In flood conditions two additional types of links can be identified for sewer manholes, which are located in a river flood zone (storage area) and which are defined as floodable (i.e. no sealed or watertight covers) :

- Exchange of flood volumes between the sewer manholes and the river flood zone.
- Impose flood levels in the river flood zone to the sewer manholes to prevent free flooding

- *To translate the above described links in terms of model variables, including spatial and temporal data operations involved for the different types of runs as described above,*
    - *To define the output exchange items (which a model provides),*
    - *To define the input exchange items (which another model accepts),*
    - *Following elements are to be given :*
        - *what can be exchanged (the quantity ID),*
        - *where it can be exchanged (the element set ID),*
        - *the used unit.*

Following table gives an overview of the input and output exchange items and the possible accepting and providing element sets.

Link type	Provider		Acceptor	
	Element type	Quantity	Element type	Boundary type
Flow sewer to river (pos/neg.)	CS conduit	CS d/s flow	RS boundary node	RS Q,t boundary
Water level river to sewer	RS River section	RS Stage	CS node (outfall)	CS Level hydrograph
Flood volume sewer to river (pos/neg.)	CS node	CS Flood volume ?	RS boundary node	RS Q,t boundary
Flood level river to sewer	RS storage area	RS flood level	CS node	CS level hydrograph

For the flood exchange, it may be necessary to make a few adaptations to both CS or RS to allow all the necessary transfers. This will be discussed further with Wallingford Software.

It was agreed that not all possible links would be elaborated from the beginning, but that a stepwise procedure would be followed :
First the most important or permanent flows would be linked, then the smaller ones. Flooding will only be exchanged in a second stage.

This means that the list of element IDs will be gradually revised as more links will be established.

At first thought, there is no need for time or data operations. Compatibility of units has to be checked.

- *To define the conceptual changes, that must be made to the models in order to define the links (i.e. to replace fixed input or boundary files by open links) or to avoid overlapping input (i.e. the input, provided by the OpenMI link, must not be already incorporated in a calibrated input of the model itself).*

Following changes must be made to the models :

- remove current overlapping element sets : modelled river sections in the sewer model and urban boundaries in the river model
- check overlaps in hydrology between both models. All impermeable areas that drain to outfalls with an open link should be removed from PDM-boundaries. PDM-boundaries in areas where open links are not established should be checked against sewer subcatchment information.
- All flow and level boundaries in CS where applicable to be replaced by open links
- Include new boundaries in RS to allow links to be made .

5.2.4 Define and correct the gaps

- *To check if all the envisaged variables can be exchanged or not. If not, to define what modifications are needed to be made to the models and to the information environment*

Special attention must be given to the exchange of flood parameters, as this might not be all possible in the current version of InfoWorks.
Another possible gap is the possibility of having both open and predefined boundaries in one and the same simulation. According to Wallingford Software this should work.

- *To check if the models are ready or not to be linked,*
- *To make the required adaptations to the models and to the information environment,*

5.3 Actions for the iterative phase

5.3.1 To link models and to perform tests of linked runs

- *To perform the initial tests of linked runs*

See minutes of technical meeting of March 5th for practical details. These will be elaborated further in following technical meetings.

5.3.2 To solve the problems, encountered during the tests

- *To evaluate the problems, encountered during the tests, and to discuss the required changes,*
- *To repeat the tests after changes in place.*
- *To perform tests of linked runs in an operational environment.*

5.4 Actions for the demonstration phase

- *To carry out runs in operational mode,*
- *To evaluate the performance and stability in operational mode,*
- *To perform the required changes to the models and to the information environment,*
- *To repeat the operational runs after changes in place.*

5.5 Actions for the evaluation phase

- *To evaluate the results of integrated simulations in terms of objectives, questions answered, improved insight in process interactions,*

- *To evaluate the added value of integrated modelling as compared to single domain modelling in view of better integrated water management,*

- *To evaluate the OpenMi technological issues in view of performance and stability,*

- *To evaluate the working of the OpenMI support structure in view of flexibility, time of response etc.*

The aim of the demonstration case with respect to the OpenMI support structure is to evaluate inter alia :

- what is the average response time to deal with technical limitations in the current OpenMI (find workarounds, release updates, …)
- what will be the response time of Wallingford Software for providing updates, workarounds, … in case the problem is not to be solved in OpenMI itself but in the way InfoWorks has adopted the OpenMI ?
- what will be the consequences of having to switch to new versions of both OpenMI and InfoWorks (incompatibilities, …)
- How quick will the normal InfoWorks support desk respond to OpenMI related questions in case of its usual "busy periods" (betatest periods, user conferences, …)

6. Milestones, deliverables, succes scenarios

6.1 Technical

- *Models are OpenMI compliant*
- *OMI-files can be created for both models*
- *OMI-files can be loaded into the OpenMI GUI*
- *Configuration for linked model runs is made using the OpenMI GUI*
- *Linked simulation is run*

6.2 Use case specific

- *Demonstrate added value of integrated simulations*
    - *Improved and more reliable model results*
    - *Assessment of interactions*
    - *Enhanced knowledge*
- *Evaluate working procedures*
- *Performance under operational conditions*