Report Defining the Scheldt Use case c : Linking river flow models to a river quality model

1. Short description of the use case

This use case concerns the linking of two river flow models to a river quality model in the Scheldt river basin. The Scheldt river basin is international. The river Scheldt takes mainly its sources in France and flows through Belgium (in the Flemish region and a small part of the Walloon region) to finally enters the Netherlands before ending in the North sea (see **Figure 1.** “The Scheldt river basin”). The use case c is applied mainly on the river Dijle in the Belgian Flemish region, part of the Scheldt river basin. The river Dijle and the river Nete flow to the Ruppel, which is a tributary of the Scheldt (see Figure 1. “The Scheldt river basin”).

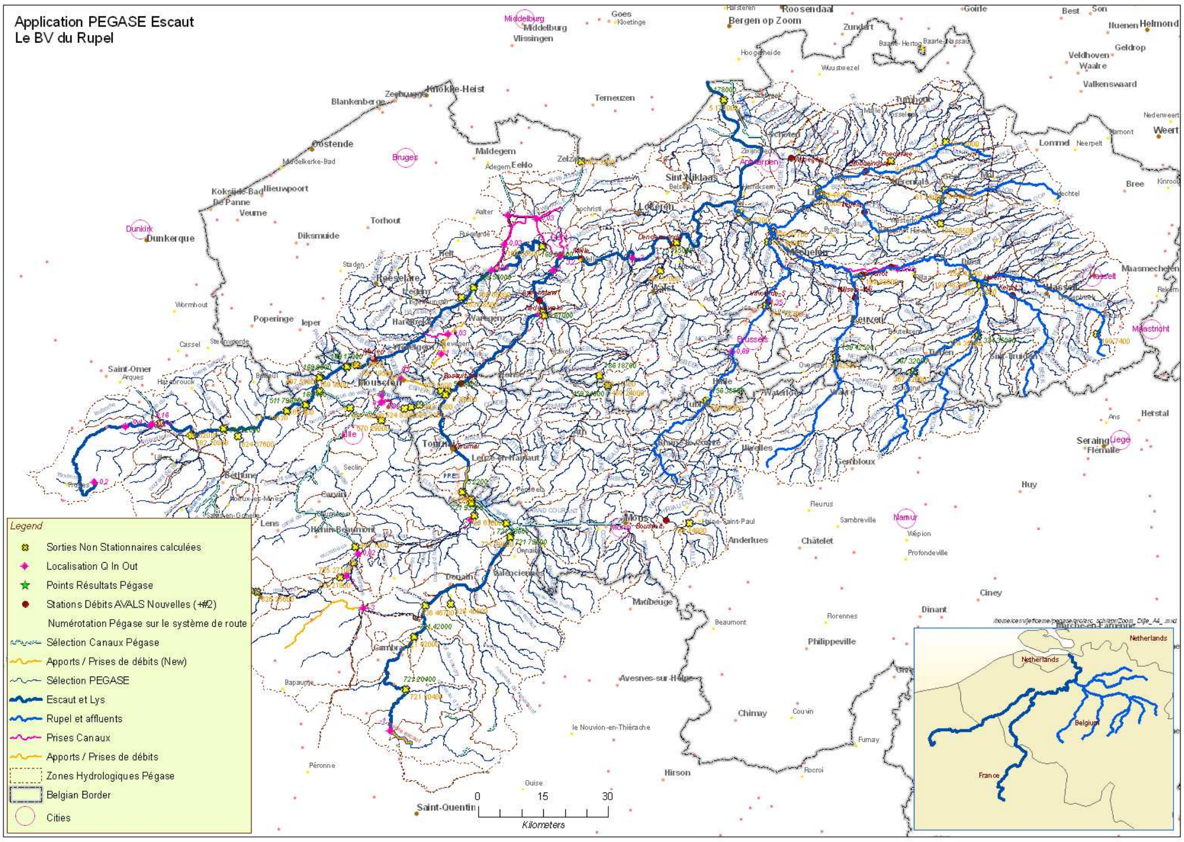

Figure 1. : “The Scheldt river basin”

This use case c will link 2 existing river flow models (also further referred as hydraulic models) for the river Dijle in the Flemish region (part of the Scheldt river basin) :

- one model for the non-tidal part of the basin;
- and one model for the tidal part of the river

to an existing river quality model applied to the whole basin.

The partners involved are :
- VMM Div. Quality Management;
- VMM Div. Water;
- Flanders Hydraulic Research,
- ULG CEME (Environment Modelling Centre).

VMM is leading this subproject.

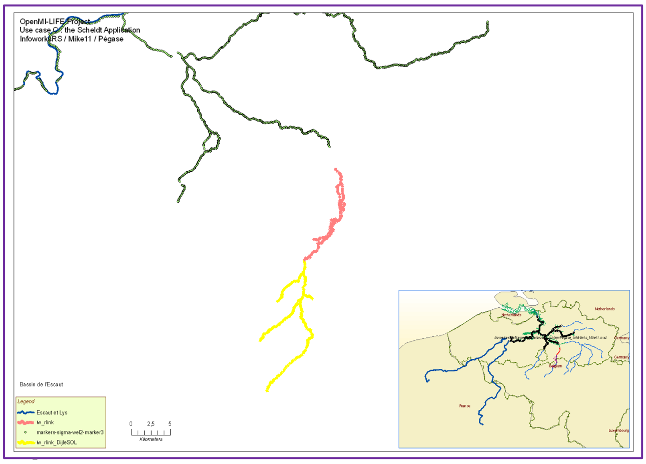

Figure 2. “The main rivers modelled by Mike11 and InfoWorks-RS in the Dijle catchment of the Scheldt river basin”

The models involved are InfoWorks-RS (the non tidal hydraulic model, VMM Div. Water), MIKE11 (the tidal hydraulic model, Flanders Hydraulic Research) and PEGASE (the river quality model, developed by ULG CEME Centre).

2. Identification of the management / policy issue

The Competent Authorities have to produce a River Basin Management Plan for the International Scheldt River Basin District by the end of the year 2009. At present, they are using different models which are all applied solely.

The Competent Authorities would like to improve the next version of the River Basin Management Plan by achieving the following objectives :

a. to develop modelling tools for Integrated Water Policy,
b. to build scenarios for Integrated Water Policy,
c. to improve the River Basin Management Plan.

To achieve these objectives, the use of a linked model system should be useful to help understanding the water system processes and the interactions between the different related water domains (hydrology, hydraulic, water quality, ecology).

In this use case we plan to focus on the interaction between the water quantity and the water quality domains. There are two major management / policy issues : the river flow regulation on the river quality and the impact of the river quality at flooding.

2.1 The river flow regulation on the river quality

The river quality model PEGASE focuses on the modelling of the river ecosystem for a refined network of hundreds of rivers. Its hydraulic module uses an efficient flow recalculation method based on the flow measured on discrete gauge stations. Whereas the hydraulic InfoWorks-RS and MIKE11 models calculate the complete water level by resolving the full hydraulic differential equations on a discrete network composed of the major rivers and a few tributaries. It means that the link of those models would allow the competent authorities to improve the flow calculation of the river quality model and then the quality calculation itself.

On another hand –as PEGASE processes all water fluxes to compute the river quality – the discharges (urban, industrial as well as sewer treatment plants discharges) from PEGASE should be helpful for the flow calculation in the hydraulic models. Indeed, those discharges may be locally very important at low flows.

2.2 The impact of the river quality at flooding

Usually, the modelling of the rivers and their floodplains are achieved with hydrologic and hydraulic models as it is not necessary to have information about the water quality. There is no impact of the water quality on these results.

When the competent authorities need to assess the impact of regulated floods in natural areas, the quality may become very important. Indeed, flooding of strongly polluted water has a much bigger impact to sensitive natural areas than the flooding of clean water has. Knowledge of the quality of the flooding water is necessary and can lead to a different issue in the management of flooded areas.

As a result, the use of a river quality model linked to a hydraulic model should be helpful to assess the impact of regulated floods in natural areas.

To achieve these aims, we have to cope and to find technical issues to the following major problems :

a. The models are applied on different domains.

- Spatially :

  - the extension of the modelled areas doesn't match. In the river quality model, the entire watershed is calculated up to the sources. For the hydraulic models, the calculated areas are associated to the selected rivers (with upstreams and lateral conditions so that some sub-basins are not calculated));

  - the selection itself of the river networks may differ from one model to the other in two ways. On one hand, the density of the selection may differ (e.g. the major rivers may be common to both models where some tributaries are not or partially represented in the hydraulic models). On another hand, the number of branches (of the same river) selected in a local area may differ from one model to the other (usually, the hydraulic model may try to represent the water heights using all local branches, e.g. in a common area around the city of Leuven, all the river Dijle branches are modelled in the hydraulic model InfoWorks-RS which is not the case in the river quality model).

- Temporally:

  the hydraulic models focus mainly on the flood events (during high flow condition)). The river quality model needs to calculate over months to represent growing processes. The most severe conditions for the water quality are met during low flow events. Are the hydraulic models able to run over an entire year (regarding CPU time, stability conditions, …) ? What is the impact of the calibration on the hydraulic models (mainly focused on high floods) at low flow ? Will they appropriately run during low flows ? So finally, when (during what kind of period) should we link the models ? Do we have to generate a run of the river quality model during one year with specific periods (of high flow) when the hydraulic models will produce some results and other periods when the river quality model uses its own flow calculation ? In that case, what about the consistencies of the flows calculated differently between the periods ?

b. The discretisations (the way the system is represented numerically : junctions, nodes, branches ...) differ from one model to another (due to internal building condition or technical constraints). Where should we link the models that contains hundreds or thousands nodes ? Do we have to use all the nodes (that are not located geographically on the same coordinates) to link the models or only a restricted list of them limited to some strategic locations. This last method will not generate CPU overcharges but will lead us to loose the full water level calculation from the hydraulic model between the nodes (even if a consistent interpolation method can fill in the gaps between nodes).

c. Ideally the models should be applied on matched data base (river widths, elevation and slopes, dam elevations, flow regulations and water abstractions, urban discharges, industrial discharges, etc.). Do we have to rebuild consistent databases or shall we transfer those data at run time. It may lead us to use hundreds of bi-directional links. Indeed, before the transferring the flows from the hydraulic model to the quality model, the hydraulic model has to receive and take into account some of these data (e.g. the flows from the urban releases) from the quality model.

d. Finally, two hydraulic models will be linked to PEGASE at run time. We have to remind that the flows calculated by both hydraulic models are not supposed to be those calculated in a linked run between each other (as scheduled in Scheldt use case b). We'll have to check the coherences between the flows calculated (separately) by InfoWorks-RS and those calculated by MIKE11.

3. Discussion and solutions to these management / policy issues

3.1 The river flow regulation on the river quality

River flow models were built up for modelling the hydraulic characteristics of the rivers in order to assure flood prevention and control. In the Flemish region, Flanders Hydraulic Research uses a MIKE11 model (in tidal parts of the Scheldt Basin) and VMM-Div. Water uses an InfoWorks-RS (in sub-catchments where there is no influence of the tides) to model the river flows.

For modelling the river quality in the Scheldt river basin, the VMM uses the PEGASE model, developed by the CEME (Environmental Modelling Centre) of the University of Liege (ULG). This model has also been built for the Walloon region and thus applied to the Walloon part of the river Scheldt. It has also been extended to the French part of the Scheldt river basin for the French Water Artois-Picardie Agency. The very little area of the Brussels Region itself has been modelled in the same time with the Flemish part of the Scheldt river basin.

The river flow models (tidal or not) were commonly built up for smaller river catchments whereas the river quality model was build for entire watersheds. At that scale, in most countries and regions, there also exist different river quantity management agencies or administrations, which make a distinction between the management of the navigable or the non-navigable parts of the rivers.

In this use case C – in order to assess the river flow regulation on the water quality and the impact of the river quality at flooding - we plan to link the two existing river flow models (tidal and non tidal models) of the river Dijle in the Flemish region with the existing river quality model applied to the entire river Scheldt basin but restricted to the common Dijle sub-catchment.

So far, some solutions to the previously mentioned technical issues (see §2. “Identification of the management / policy issue”) may be proposed.

In order to cope with the spatial differences between the models, the use case c has been limited to the Dijle catchment (see **Figure 3.** : “Zoom on the river Dijle and the river Demer and its river network modelled by Pegase”) with an area of 1.276 km2 and a population of 560,000 inhabitants. The catchment of the river Demer, the most important tributary of the river Dijle (as well as all non hydraulically calculated tributaries), shall be modelled by the PEGASE model without linking to river flow models, in order to avoid the increase in the number of linked rivers.

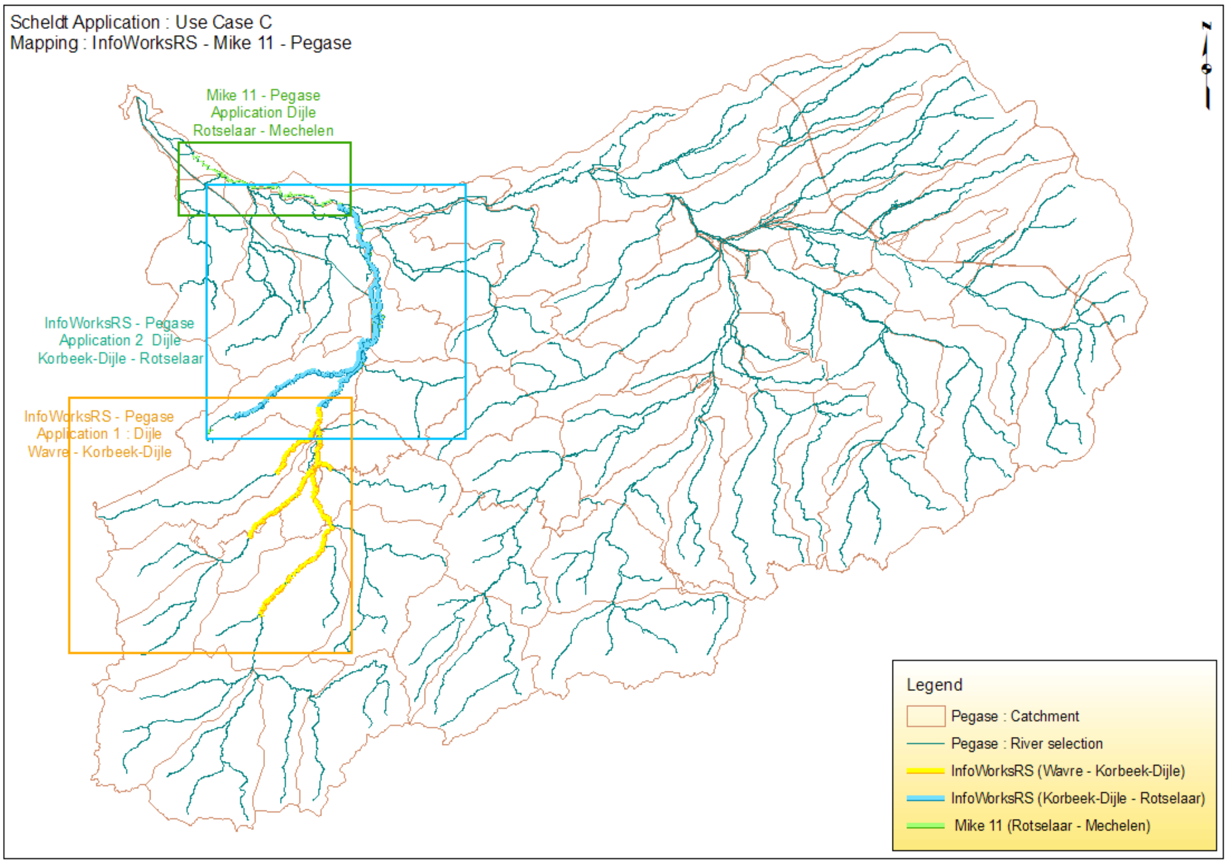

Figure 3. : “Zoom on the river Dijle and the river Demer and its river network modelled by Pegase”

The linking of the model InfoWorksRS and Pegase will occur only on the main river Dijle :

- Upstream Leuven, rivers in yellow in the orange box of **Figure 3** ;
- Around Leuven, rivers in light blue, in the blue box of the **Figure 3**.

Mike 11 will be linked to Pegase downstream Leuven in the main river Dijle (river in light green, in the green box of the **Figure 3**. The rivers modelled by InfoWorksRS and Mike11 are clearly defined in chapter 5.2.2.1. ("Defining clearly the extent of the domains, setting the limits and the boundaries, solving boundary problems and selecting the rivers in each models").

Concerning the common spatial and temporal simulation domains :

We first assume that the "exchange" time steps (when the transfer between models will occur) of each models (and which may be different from the internal numerical time steps) are totally compatible and should be fixed to one hour. But the major question remains : "When (during what kind of period) should we run and link the models ?". Some checks still have to be realised mainly concerning the consistencies of the common input data, the consistency of the hydraulic calibration during the low flow simulation periods, the weight of the CPU time, ...

We then first plan to determine the spatially common domain to the three models and to rebuild new databases, if necessary.

On an other hand, we plan to determine two monthly periods inside a common year fixed to 2000 and to make – within these periods - a few tests to the models separately.

These first tests would lead us to determine which river nodes should be used to exchange information at run time :

- o their number ? If we plan to feed all the PEGASE nodes from values calculated by the hydraulic models, we should assume that hundreds of values will be exchanged at each time step. As the coordinates do not match, we should cope with undetermined link (e.g. when a hydraulic node will correspond to several PEGASE nodes, as well as the opposite, or when a hydraulic node will be just between two PEGASE nodes located on different branches ...). The algorithms to implement to automatically cope with those situations are not foreseen. A solution should be to impose the corresponding nodes manually, for hundreds of nodes. But no solutions exist in the case of unmatched river branches between the linked models (i.e. branches that exist in the hydraulic InfoWorks-RS model and that do not exist in the PEGASE digitalisation);

- o their coordinates ? A way to solve the previously defined unsolved problem is to reduce the number of the linked nodes (e.g. only on common branches, at predefined junctions, etc). In that case the coordinates of the chosen nodes will be determined;

- the method to use to fill in the gaps if necessary;

- and as a consequence, the variables that should be exchanged at each time step. Indeed, depending on the number of the linked nodes, the method to rebuild the flow characteristics in the river quality model should differ. For a discrete number of linked nodes, a recalculation method (similar to the one implemented in PEGASE) based on the flow values (only) should be used. If all the nodes are supposed to be linkable (that may rise to several hundreds of nodes), flow, water height and velocities should be used as they are. In between, a hybrid method should be implemented. Note that in all cases, the river quality model should be adapted as it will not receive flow characteristics for all rivers that it calculates (as they are not all simulated by the hydraulic models). It means that PEGASE should be able to use values transferred by the hydraulic models when they are available and to rebuild flows everywhere else.

It will also lead us to decide the way the models will be temporally linked. As the hydraulic models and the river quality model do not focus on the same flood events, several options exist :

- run all models during common periods (e.g. one month or so). As those periods do not match, it means that some hypotheses should be decided by the end user (e.g. as the quality model should run one entire year, what is the sense of reducing the time simulation period to a few months or to avoid quality calculation during low flow events ?);
- run all models one year;
- run the river quality model during one year and the hydraulic model only during a few discrete periods of months or weeks. It means that a switch should be implemented in PEGASE so that it will be able to calculate the river flow characteristics when they will not be available by the hydraulic computing. Moreover, it rises the problem of the starting state of the hydraulic models : when do they have to start to run “a priori” and from what state, with what flows ? Normally the flows from the previous time step calculation of PEGASE to insure the continuity of the flow calculation. When ? If the periods are pre-determined, the possibility of creating some hydraulic scenarios decreases.

The choice of an option will be based on the first results obtained and more precisely, will depend on the consistence of the validation of the hydraulic models at low flows, the coherence between the calculation of both hydraulic models locally on common node and will also depend on the technical constrains that we will have to work with (CPU time, available RAM in single threaded run, the weight of swapping, the possibilities of compilation optimisations as well as structured optimisations on the codes themselves, total wall clock for linked run).

It also appears that the input databases of the models should be consistent regarding many important data:

- the river width, slopes, elevation;
- the singularities (their physical characteristics and the human management) in the river network as the dams, the canals, the flow regulations, the water abstractions (or in loads), ..
- the releases (urban, industrial, ...).

Some of these data are fixed and can be settled in the own database of each involved models (river or flow characteristics). Some other data may change during the simulations themselves (releases). Finally some data may differ from one simulation to the other (localisation of waste water treatment plants outputs, anthropogenic managements, scenarios on the releases ...). For the last two categories, the best way to share these data is to exchange them at run time. As these data are handled by PEGASE (especially the discharges), it means that before any hydraulic calculation, the river quality model must provide values to the hydraulic model. Indeed, discharges may change river inflows (that can be very important during low flow events). That kind of exchange is bidirectional. Obviously, due to the characteristics of the scenarios that we plan to test, the nodes where quality to hydraulic messages must be transferred are not necessary the same as those chosen for the reversed transfers. That may also imply that all nodes should be used for exchanging information at each time steps.

Among the numerous issues previously defined, we should also care about the way we will finally link the models. Indeed, we should link PEGASE with two hydraulic models : InfoWorks-RS and MIKE11. These two models are also planned to be linked in the Scheldt use case b. Do we have to reproduce that link with an additional link to the river quality model or shall we consider that PEGASE will be linked with InfoWorks-RS in one hand and with MIKE11 on another hand, independently? In the case where the three models are linked simultaneously, a real link can be implemented between the two hydraulic models (as in use case b). If it is not the case, how shall we insure the coherence between the flows calculated upstream by InfoWorks-RS and downstream by MIKE11?

Once more, the answer to this last issue will depend on factors that we do not know at the present time. A lot of issues will be encountered during the project progress.

In any case, the new Open MI technology is an answer to link these different models together, under the condition that the conceptual differences between the models are taken into account at a physical point of view (scales, processes, consistencies, databases, periods of calculation ...) and informatically (e.g. the river quality model PEGASE has been developed under Aix 5.2 for RISC 6000 Workstations, thus some migrations have to be implemented before linking). These last technical issues (informatics level) may also be very important regarding the weight of the executables. Depending on the RAM needed by all participating modules (the models, OpenMI, databases ...) and the CPU time required, some developments may emerge. Other implementations may also lead us to choose different ways especially the bi-directional link real capabilities (and its impact on the simulation wall-clock time), the multi-threading or multi-processors availability as well as the efficiency of the system itself in this real use case environment.

3.2 The impact of the river quality at flooding

The issues presented in the previous paragraph 3.1 “The river flow regulation on the river quality” remain to calculate the impact of the river quality at flooding.

During severe flood events, the water gets out of the river beds and flows through the major bed, largely out of the edges of the minor river bed. The full description of that kind of flooding and the processes associated to them are not taken into account in the river quality model. But in order to have a view on the quality of the water flowing in the flood plains, it’s agreed to assess the moment before flooding and to make river quality calculations just before flooding. This river quality will be taken into account in the flood plain management plans.

4. Setting the objectives

We should finally choose between all the options described in the previous chapter, in order to set an answer to the following six most important questions:

1. Do we try to link PEGASE with InfoWorks-RS or do we only work with PEGASE and MIKE11 ?
2. If InfoWorks-RS is also used, do we deal with one or two separate Pegase applications (see the discussion in §3.1. "The river flow regulation on the river quality") ?
3. What about the common database ? How do (can) we generate them so that they will be coherent and operational in all models ?
4. Do we link the models at all the common nodes or just a few chosen discrete number of them ?
5. Do we exchange information in one or two directions at each time step, between the nodes ?
6. What about the period of the simulations ? Do we tend to one year or less ?

In order to succeed in a proposal, let's redefine some specific use case objectives.

4.1 Specific use case objectives

In the Scheldt use case c, the following objectives may be pointed :

- demonstrate that the PEGASE model and the InfoWorks-RS model, which have been developed independently from each other, can be linked together;
- demonstrate that the PEGASE model and the MIKE11 model, which have been developed independently from each other, can be linked together;
- 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);
- assessing the practical feasibility (data handling, simulation times) of large scale models linking;
- demonstrate the gain of quality of derived products using the linked models.

4.2 Wider perspective objectives (about integrated water management)

By linking these models, the following objectives about Integrated River Basin Management can be achieved:

1. flood prevention and control;
2. improvements on wastewater management and public sewage treatment,

3. impact of agricultural practices on water quality (with help of a nutriment losses model);
4. phasing out, cessation of discharges and emissions, and losses of some hazardous substances as nutriments and heavy metals.

The first objective is met by the river flow models; the next three objectives are met by the river quality model. By linking these models, interactions between these objectives can be examined.

4.3 Setting a proposal

Keeping in mind the issues defined in the first chapters (cfr. Chapter 2 : "Identification of the management / policy issue" and chapter 3 : "Solution to these management / policy issues"), the six previously defined questions and the recalled objectives, a proposal should emerge :

- Two applications may be developed : one for the link of InfoWorks-RS and PEGASE and another one for the link between MIKE11 and PEGASE rather than one unique common application that will link the three models at the same time. This hypothesis may avoid us to cope with the issues associated with the use case b application. Obviously we will be forced to generate two domains, to double the databases, to calibrate, to analyze and to validate more models and results … But the runs would be quicker and easier to handle. The way the models will be linked (see the following scopes) in the two applications may differ due to the fact that the models and the domains differ.

- We plan to use coherent databases between models. It doesn't mean that the database shall be totally shared or be common but it means that – at – least – physical river characteristics may be the same for common calculated rivers in both linked models.

- During the first stage, we plan to run during a (two) period(s) of one or two months. Then we plan to increase the simulation period depending on the constrains associated to the water level calculation (see calibration issues) and the amount of total CPU time of the linked run. Once the first runs will be achieved and successful, this improvement should be easy to implement (just increase the length of the simulation period and – of course – the time dependant values in the databases) with the application MIKE11-PEGASE (as InfoWorks-RS is a priori not dedicated and calibrated for low flow events).

- This first stage will also be associated with the use of a limited discrete number of nodes to implement the links. The choice of these nodes will depend mainly on the local configuration (the rivers where the exchanges will occur) in order to get accurate hydraulic calculation. This number should stay improvable depending on the technical possibilities. We also plan tests with the use of all the nodes between MIKE11 and PEGASE (with InfoWorks-RS, the use of all the nodes – especially around Leuven – should be very complicate without changing the river selection).

- The last idea is to begin the application using one directional links. The bi-directional links must remain an objective more than an option but in this use case, it is still relevant to implement one directional exchange rather than bi-directional links as the hydraulic models apply only on major rivers (the most important unique one for MIKE11 is the river Dijle). Indeed, in that case, the flows calculated (even during low flow events) are quite lower than those associated with the local discharges. We can then assume to neglect them unless the discharges increase or if we plan to calculate upstream river sections (where the river flows are lower and then the discharges cannot be neglected anymore). Finally, it means that – for the chosen domain of application of the use case c – the use of bi-directional links is not relevant.

  Anyway, if the absolute necessity to use the discharges - from PEGASE to MIKE11 - emerge, we can also simply add them to the hydraulic database as additional inflows so that they will be correctly taken into account (this correction procedure will then simply be “manual”), without using bidirectional links.

  We still plan to have a look at the OpenMI improvement that may allow us to use “bi-directional" links and try to include then a test with bi-directional links between MIKE11 and PEGASE (as InfoWorks-RS should be able to use additional inflows but it is not planned in this project).

This proposal should remain open to be able to evolve depending on unpredictable technical issues we may still encounter. Note that the link between InfoWorks-RS and PEGASE is not planned to be the same as between MIKE11 and PEGASE. Tests to increase the time simulation period, to improve the number of linked nodes and to try bi-directional links are scheduled for the application MIKE11-PEGASE only.

5. Defining the actions

5.1 Preconditions for linking models

- The models (PEGASE, InfoWorks-RS and MIKE11) are OpenMI compliant (with standard interface specifications);
- The model user has a PC, equipped with the required operational system, softwares and libraries;
- The model user has the up to date OpenMI compliant version of the PEGASE model installed on his PC;
- The model user has installed the correct PEGASE database and input files for the link with InfoWorks-RS on his PC;
- The model user has installed the correct PEGASE database and input files for the link with MIKE11 on his PC;
- The model user has the correct OpenMI compliant version of the InfoWorks-RS model installed on his PC;
- The model user has installed the correct InfoWorks-RS database and input files for the link with PEGASE on his PC;
- The model user has the correct OpenMI compliant version of the MIKE11 model installed on his PC;
- The model user has installed the correct MIKE11 database and input files for the link with PEGASE on his PC;
- The end-user has installed on his PC an OpenMI configuration for user interface.

5.2 Actions for the definition phase

Regarding the discussion of the previous chapter (chapter 4 :"Setting the objectives"), we should keep in mind that for the Scheldt use case c :

1. two sub-cases may coexist (rather than linking all the models) :
    - linking InfoWorks-RS to PEGASE;
    - linking MIKE11 to PEGASE;
2. for each sub-case, the databases should be coherent;
3. we first plan to link the models during a predefined period of time (more or less one month) and increase it if possible;
4. we also first plan to use a discrete number of nodes for the link but we would like to increase it to all available nodes for the case linking MIKE11 to PEGASE;
5. as bi-directional links are not relevant for this application (see 4.3 "Setting a proposal", last item), we plan to test it in the sub-case "MIKE11-PEGASE".

5.2.1 Define the common environment to the 2 sub-cases

The hardware / platform requirements for linking the models are imposed by OpenMI itself. The PEGASE model will have to be recompiled for PC in the Windows environment.

Concerning the spatial domains, the two hydraulic models do not apply on the same spatial domain but it is planned to build one single PEGASE database. The associated PEGASE domain will be able to deal with the InfoWorks-RS – as well as the MIKE11 – sub-cases. Its outlet shall correspond to the one of MIKE11 (which is applied downstream InfoWorks-RS).

The time period of simulation may differ between the two sub-cases but it should be easier if they match.

5.2.2 Define the interactions to be modelled

5.2.2.1 Defining clearly the extent of the domains, setting the limits and the boundaries, solving boundary problems and selecting the rivers in each models.

Two applications of the InfoWorks-RS exist. One application covers the river Dijle from Wavre (in the Walloon region) to Korbeek-Dijle (in the Flemish region) and also includes partially three tributaries : the river Laan, the river Nethen and the river Ijsse. Another application covers the river Dijle from Korbeek-Dijle to Rotselaar (some metres upstream the confluence with the river Demer) and includes partially the river Voer as tributary.

The common extent of the spatial domain of InfoWorks-RS should be the river Dijle catchment between Wavre (in the Walloon region) and Rotselaar, if the VMM Div. Water links the two river Dijle models (Bovendijle and Dijle at Leuven) together.

Concerning MIKE11, a new domain should be rebuilt for this application : the river Dijle from Rotselaar (upstream the last InfoWorks-RS node) to Mechelen. It is not planned to include “explicitly” any tributaries for MIKE11 ; tributaries of the river Dijle are not calculated in the MIKE11 model.

The digitalisation of the PEGASE model will then be limited downstream to the last node of MIKE11 near Mechelen (and thus some 7 kilometres upstream the confluence with the river Zenne) so that it will cover the domains of InfoWorks-RS and MIKE11 as well.

The last downstream node will then be located at the (X,Y) Belgian Lambert coordinates (159018, 190360).

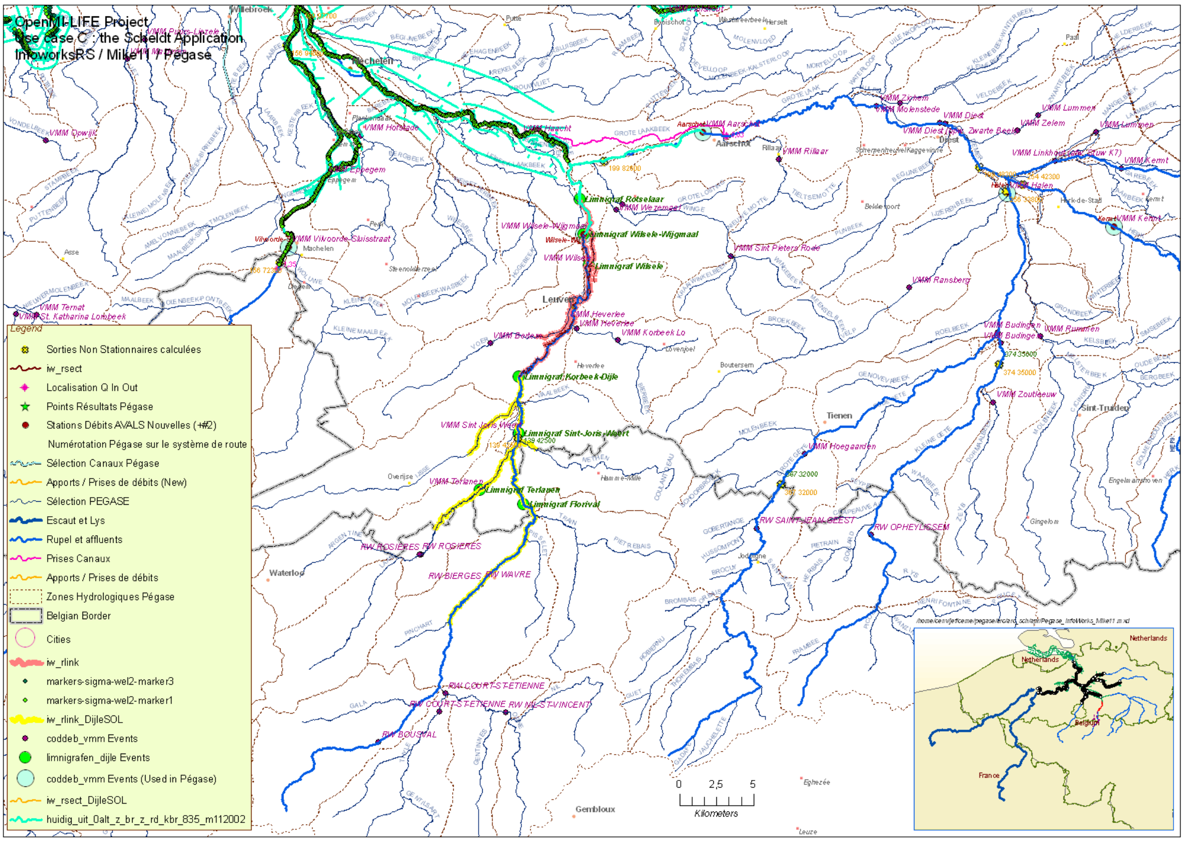

Figure 4. : “The river selection for all models”

As shown on the previous **Figure 4**, the selection – that is already fixed for all models - of the calculated rivers is not the same for each model. The MIKE11 hydraulic model will simulate the river Dijle between two points (excluding all tributaries), the InfoWorks-RS hydraulic model will simulate the river Dijle between 2 points including a few major (four) tributaries. These tributaries are not simulated up to their sources but only the last few kilometres before reaching the Dijle. The PEGASE river quality model will simulate all the river tree from their tributary to their sources excepted the smallest rivers where there are no releases).

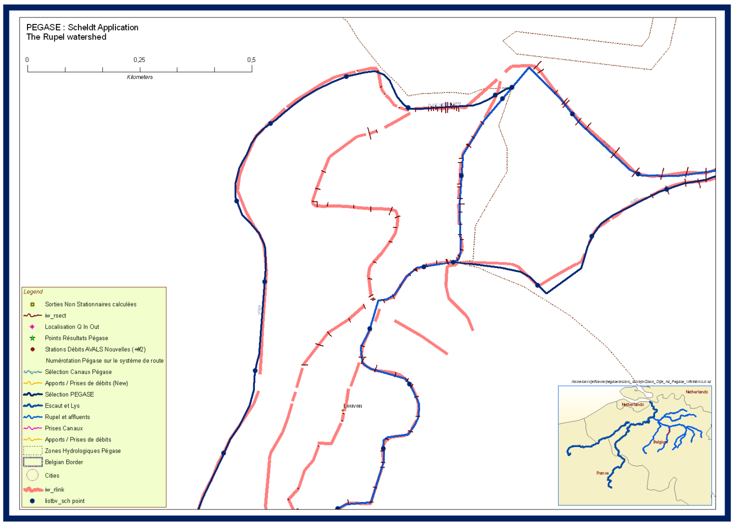

Figure 5. The river selection of InfoWorksRS and Pegase around Leuven

The differences between the river selections in InfoWorks-RS and PEGASE are critical around Leuven (see **figure 5**. beside). The number of river branches selected in InfoWorks-RS (in orange) is greater than in PEGASE (in blue).But in both models, the river flows have to be conserved. It means that we cannot interpolate hydraulic characteristics from one model to the other when several branches are used on one hand and only one branch on another hand. However, that problem can be solved if we use only a few discrete nodes to link InfoWorks-RS to PEGASE (the rebuild of the flow by the quality model is assumed to deal with the flow calculated by InfoWorks-RS as well as with the PEGASE river selection). This problem does not occur in the sub-case “MIKE11-PEGASE” and will be discussed further as it interacts with the choice of the river nodes to use for linking the models.

5.2.2.2 Define the time domains of the models

The river quality PEGASE model should run during an entire year or at least a few months. Due to the already existing and accurate databases - that were calibrated - for each model, it is planned to focus on the year 2000. The **Figure 6.** “Measured Flow at Wilsele in 2000” shows the measured flows at the gauging station of Wilsele (Station number 09310102). This station is located downstream Leuven, more or less in the middle of the studied watershed. The mean flow value for the entire year 2000 is 6.5 m³/sec.

The InfoWorks-RS is built up and calibrated for dealing with high water and flooding situations rather than for low water situations. Special investigations are needed for assessing if the river flow model InfoWorks-RS can be validated and used for dealing with low water situations. But fortunately, as we can see (see Figure 5.), there is no pertinent period that can be qualified of low flow period.

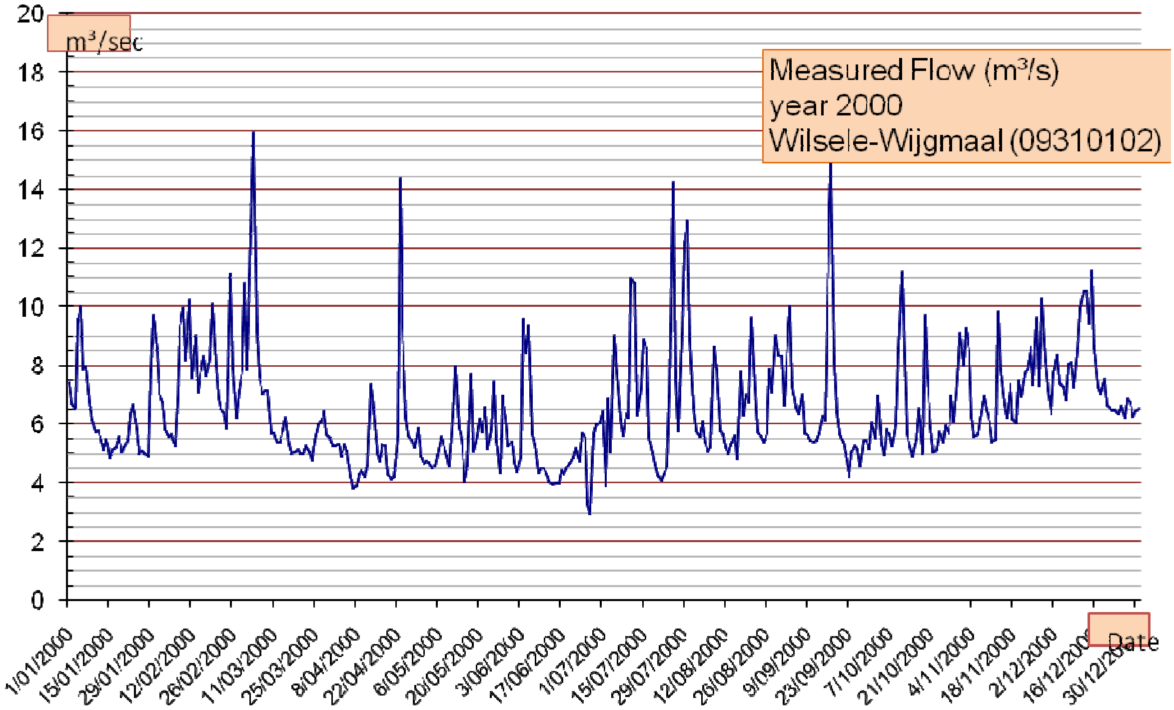

Figure 6. : Measured Flow at Wilsele in 2000

The following **Figure 7**. ("Simulation Periods in the year 2000") shows how we plan to cope with the different characteristic time periods of each model. This is a representation of the linked run i.e. the river PEGASE river quality model runs an entire year and a hydraulic model (InfoWorks-RS or MIKE11) provides it with the flow variables at each time step during several sub-periods of approximately one month.

Obviously, an ideal representation should be obtained if all models were able to run an entire year. It might be possible for MIKE11 on the selected part of the river Dijle in the year 2000 but it is not assumed that any hydraulic model could do it whatever the river or the year.

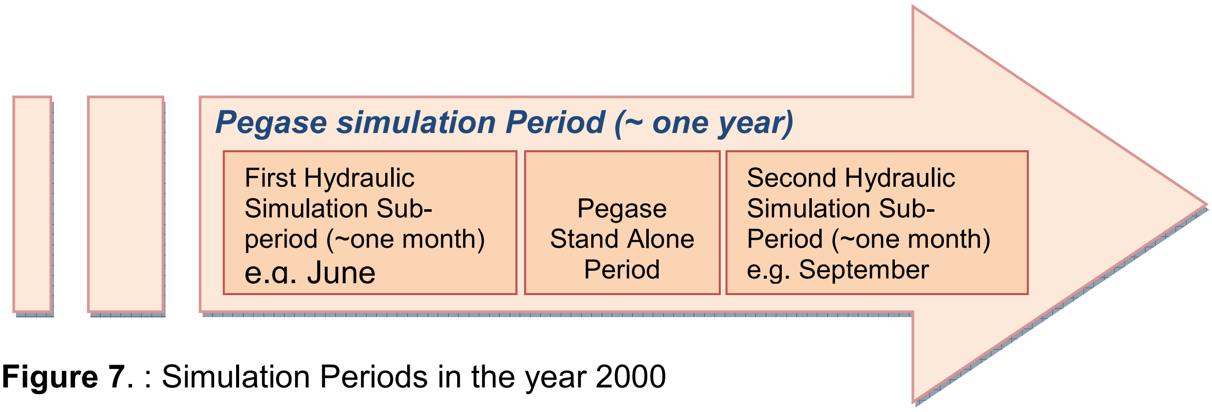

Figure 7. : Simulation Periods in the year 2000

During a common simulation period, it's agreed that the models will exchange data (flows, water stages, velocities ...) on a hourly basis.

It is assumed that we will first deal with one pre-determined period of one month (common to all models including the river quality model). It will help us to focus on the major linking problems that we will have to resolve. Another period of one month should also be tested in order to go ahead.

But as the river quality estimation needs several months of simulation, we should run PEGASE during an entire year. Depending on the hydraulic validation at low flow, we will then run PEGASE one year with :

- *one hydraulic model running during several high flow periods*. It means that PEGASE will then need to calculate the flow characteristics on its own way when the hydraulic model doesn't provide anything (as shown in figure 6). That also means that the consistencies of the different flow calculation must be checked and that the hydraulic model will be "able" to start on an hydraulic state provided by PEGASE ! This needs new adaptation in the PEGASE code and may lead to uncertain issues;

- *one hydraulic model running during the same period as the river quality model*, one year, if possible (that may be the case for MIKE11). That will also depend on the performances of the system.

5.2.3 Define the links

5.2.3.1 Define the variables and the common parameters

The common parameters should be treated in pre-processing (i.e. during the initialisation phase of the simulation or even before any processing, during the database building). Those parameters are (or must be) common to the models that are linked in order to insure the correct calculation of the river flow variables. Following are some of the variables that should be treated simultaneously and in the same way in hydraulic models as well as in quality models :

- the initial river *network digitalisation* : this geographic layer is used to generate the river networks on which each models are applied. The use of a common layer (scale, coordinate projection system, extension, ...);
- different types of *river singularities* :
  - major dams (weirs) : not applicable here;
  - aeration heights (mainly upstream) : not applicable here;
  - locks mainly around Leuven;
  - etc;

- *canals* : in the “InfoWorks-RS - PEGASE” sub-case, we should represent the “Leuven-Dijle” canal, parallel to the Dijle from Leuven. The representation may lead to collect the anthropogenic flow regulation (+ eventually the canal width, height, slope if necessary);
- river *inflows / outflows* (anthropogenic water management and “displacement” / water abstractions for water supply, industrial needs, irrigation, ...) : we still have to check if applicable;
- elevation of the river beds and associated slopes : must be common on selected rivers where exchanges will occur at run time.

Beside those pre-defined parameters, variables should be exchanged at each time step of the common simulation period. Some of them (the state variables) *must* be provided by the hydraulic model to the river quality model. These common physical variables are :

- the river flows (in m^3/sec);
- the water stage / level (in m);
- the mean cross-section water velocity (in m/sec).

Other common variables are depending on the state variables and may also be provided at each time step. This is the case of the width (in m). Indeed, the width of the river depends – of course – on the water stage and is tightly associated to the shape of the river cross-section.

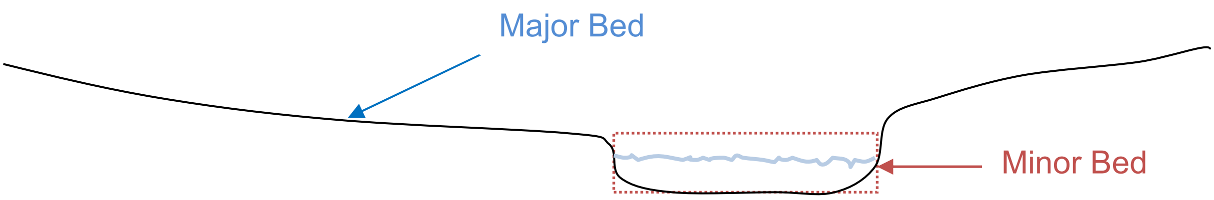

Figure 8. The Minor bed approximation

During flood events, the river gets out of its minor bed and flows through its major bed. In that case, the river width varies suddenly very much. As we do not plan to study explicitly the flooded area, we should consider the river quality before flooding, and then still located in its minor bed. Even if it is not strictly exact, the hypothesis of associating the river cross section width to a mean value of the real cross section shape is really relevant (see red rectangle on **Figure 8**. “The minor bed approximation”). Obviously, we consider that the mean cross section width vary downstream the river.

These hypotheses allow us to consider the river width as parameter that can be handled in the pre-processed databases (but common to each models).

The previous variables (state variables or not) are assumed to be provided by the hydraulic models to the river quality model. But it also exists other time-dependant variables that may be provided by the river quality model to the hydraulic model, before its flow calculation : the discharges variables. They are associated to urban discharges, industrial releases, waste water treatment plant releases ... As these variables depend on the scenario of the river quality model, they are handled – at run time – by PEGASE and directly derived from its own database. That's the reason why bi-directional links are planned to be considered in this Scheldt use case c.

5.2.3.2 Define the schematizations of the models

In that scope, we plan to describe all issues associated to the river schematizations which are different from one model to the other.

a. Rivers selected in the hydraulic model but not in the river quality model. This is an exception (we usually have the opposite due to the fact that rivers are nearly totally simulated in PEGASE rather than in the hydraulic models) but it is very important in the "InfoWorks-RS - PEGASE" sub-case around Leuven (see Figure 4. "The river selection of InfoWorks-RS and PEGASE around Leuven"). For the moment, three possibilities (options) are available in order to solve the problem of inconsistency of the river schematization between the river flow model InfoWorks-RS and the river quality model PEGASE :

- to force locally the two schematizations to match in both models (to have the same river selection) by increasing the number of branches of the river Dijle in the PEGASE model and/or by decreasing the number of branches of the river Dijle in the InfoWorks-RS model;

- to place an intermediate tool (an interface) between both models in order to use the outputs from the InfoWorks-RS model to generate correct inputs for the PEGASE model. The re-calculation of the PEGASE river flows is not trivial. This option is largely the most tricky and time consuming in new developments;

- to deal with a limited number of exchanging points (nodes) common to both models. Therefore the links will not occur on all nodes. Obviously, this option should lead to only consider nodes upstream or downstream the river selection mismatch so that the PEGASE model will consider the flow results from the InfoWorks-RS model to make its own river flow calculation between two exchanging points. A disadvantage is that only flow data will be exchanged, not water stages and velocities. Indeed, the conservation equation at junction where there are several river branches for one model and only one branch for the other, may lead to inconsistencies.

In order to avoid problems and a lot of work to adapt all models, the third option is chosen for the “InfoWorks-RS - PEGASE” sub-case. Concerning the other “MIKE11-PEGASE” sub-case, it is planned to begin our test with the same method but quickly try to use all the nodes of MIKE11.

This option is easier to implement with MIKE11 as only one river is common to both models The common river branch has an approximate length of 15 km and as PEGASE requires information at all 200 meters, we will have to cope with more or less 75 nodes.

b. *Rivers selected in the river quality model but not in the hydraulic model*. This is the case for most of the PEGASE river network. It means that PEGASE will not get information from the hydraulic models on all its nodes of those rivers. In this cases, the internal flow engine of PEGASE will rebuild the river flow characteristics from the last downstream node where it gets values from the hydraulic model, even for tributaries that are not simulated by the hydraulic models.

   This inverse method implemented and already applied in PEGASE works well but in the scope of linking a hydraulic model to PEGASE, we may get some inconsistencies due to the fact that PEGASE also uses measured data to calculate the flows upstream. Tests should be performed to ensure the two co-existing flow calculations when linking models together.

Another very important issue directly associated with the schematizations of the models is the choice of the linked nodes. As already explained, we may try to use information from all the available hydraulic schematization nodes in order to feed all PEGASE nodes with time-dependent variables. We explained that this option is not foreseen in the “InfoWorks-RS - PEGASE” application but is an objective of the “MIKE11 - PEGASE” application, if possible. Even if we will first test the case linking with a discrete number of nodes, the attempt of using all the nodes may allow us to really use the three state variables directly calculated in the MIKE11 model. This is the best way to get the most important benefit of linking a river quality model to MIKE11. Indeed, when using a discrete number of linkable nodes, only the flow value (e.g. the water stage cannot be interpolated between distant nodes) will be exchanged at each time step.

5.2.3.3 Define the processes to be modelled (in view of the integrated water management issues) and solving possible conceptual differences

The major conceptual differences that still remain are :

- the problem of low flow situations;
- the problem of different representation of lateral inflows;
- the different co-existing river flow calculations.

These points have already been discussed in detail previously. The way it's planned to solve them was explained.

5.2.3.4 Define the types of analysis (runs) that must be carried out

According to normal procedures, MIKE11 as well as InfoWorks-RS should simulate high flow events resting a few weeks or so. In this application, both hydraulic models are planned to be used to simulate rivers even during low flow events. Regarding this, a special care should then be accorded to the analyses of the flow calculations during long period.

The main checks must be realised on the river flow variables (mainly the flow and the heights) in comparison with measured values at gauging stations. Depending on those flow variables, checks can also be performed on quality variables in comparison with measured values and after statistical treatments.

5.2.4 Define and correct the gaps

The major gaps that still remain are :

- 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,
- 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

To ensure the consistency of the links, it is agreed that the next stepwise test procedure will be performed:

5.3.1 To perform pre-processing tasks

Migration of the river quality PEGASE model from Unix Workstations to Windows. As the CEME-ULG developed Pegase for IBM RISC6000 Workstation, under Aix 5.2, it should migrate to the PC environment under Windows.

Generation of the databases for the different models.

5.3.2 To perform runs with the models not yet linked

Run the PEGASE river quality model in stand-alone mode on its new database.

Run the river flow model (InfoWorks-RS versus MIKE11) and extraction of the model results, preparation to load these results as input data into the river quality model.

Run the PEGASE river quality model with the new input data collected from the InfoWorks-RS (versus MIKE11) run, and to evaluate the results of the model.

Evaluation of the problems encountered during the tests, and discussion on the required changes.

5.3.3 To link models and to perform tests of linked runs

Defining the (first) simulation period(s).

Defining the exchanging nodes to use in linked simulations.

Perform the initial tests of linked runs : the models will then be linked in 2 sub-cases and run together under OpenMI, on a same PC. The model results and this way of working will be evaluated.

5.3.4 To solve the problems, encountered during the tests

These first steps may be redone iteratively to correct the choice of the linkable nodes, the time simulation period, the way the link are achieved, the domain characteristics (contours, river selection, boundary conditions, ...), etc.

These steps (and tests) may also be repeated after corrections and/or changes in places.

	InfoWorks-RS - PEGASE Sub-case	MIKE11 - PEGASE Sub-case
Simulation Period	One or two times one month	One or two times one month Attempt to simulate one year
Use a few discrete number of nodes	Yes	Yes at starting point
Use all the Nodes	No	Test if possible (+/- 300)
Exchange variables from Pegase	No	Water inflow from the river quality scenario (Test if bi-directional link are useful and possible)
Exchange variables to PEGASE	Only Flow	Flow + water stage and velocities in "all nodes" mode

Figure 9. Chart of the available / chosen options

Finally, the preceding chart (**Figure 9**. "Chart of the available / chosen options") shows the available options in the two sub-cases.

5.4 Actions for the demonstration phase

The way of proceeding in the demonstration phase is as follows :

5.4.1 To carry out runs in operational mode,

There were two management / policy issues defined at chapter 2 'Identification of the management / policy issues'

1. *The impact of river flow on the river quality*

The Competent Authorities would like to achieve the following objectives :

- to build scenarios for Integrated Water Policy following the WFD,
- to make simulations of the implementation of the Integrated Water Policy measures,
- to make simulations for assessing the impact of river flow regulation on the river quality,
- to perform a Risk Analysis on the water quality of the surface water bodies after these simulations.

For assessing the impact of river flow on the river quality, following simulations can be run :

- assessing the impact of high water situations (before flooding) on the river quality,
- assessing the impact of low water situations on the river quality,
- assessing the impact of water abstractions from the river Dijle on the downstream river quality,
- assessing the impact of river flow regulation on the river Demer (main tributary of the river Dijle) on the downstream river quality.

The Risk Analysis on the water quality of the surface water bodies aims to give an answer on the question : 'Should the good status of the water quality be achieved on the surface water bodies after the implementation of the planned Integrated Water Policy measures ?'

But this exercise will be limited in this OpenMI LIFE project to assessing the impact of river flow regulation on the river quality as described here above.

2. The impact of the river quality at flooding events

The Competent Authorities would like to achieve the following objectives :

- to assess the impact of the river quality at flooding events,
- to assess the impact of regulated floods in natural areas.

For assessing the impact of the river quality at flooding events, it's agreed to assess the moment before flooding and to make river quality calculations just before flooding. This river quality will be taken into account in the flood plain management plans.

5.4.1 To evaluate the performance and stability in operational mode

5.4.2 To perform the required changes to the models and to the information environment

5.4.3 To repeat the operational runs after changes in place

5.5 Actions for the evaluation phase

The way of proceeding in the evaluation phase is as follows :

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

- Did we get a significant improvement of the quality of the river flow calculations for the river quality model ?
- Is there a significant impact of the use of these river flows by the river quality model on the river quality results ?

This evaluation can be done even during low flow situations as during high flow situations.

- Are there big differences in these results between low water situations and high water situations ?
- Have the results of these simulations been evaluated as interesting for the Competent Authorities ?

5.5.2 To evaluate the added value of integrated modelling as compared to the use of several solely models, in view of better integrated water management,

- Have the simulations for assessing the impact of river flow on the river quality been performed ?
- Did we get changes that can be interpreted in water quality of the river Dijle between the several simulations ?
- Have the results of these simulations been evaluated as interesting for the Competent Authorities ?
- Have the simulations for assessing the impact of the river quality at flooding events been performed ?
- Have the results of water quality during flooding events been evaluated as interesting for the Competent Authorities ?

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

- Did we have success with linking the river flow model InfoWorks-RS to the river quality model PEGASE ?
- Did we have success with linking the river flow model MIKE11 to the river quality model PEGASE under the use of a discrete number of nodes in one-directional link ?
- Did we have success with linking the river flow model MIKE11 to the river quality model PEGASE under the use of bidirectional links ?
- Are the simulated runs not too long ?
- Did we get stable runs while using the link between the river flow model InfoWorks-RS to the river quality model PEGASE during limited periods in a year (regarding the fact that PEGASE runs an entire year and thus InfoWorks-RS should start its calculation on PEGASE's initial flow condition) ?
- In the "InfoWorks-RS - PEGASE" sub-case, did we get a higher quality of river flow calculation using a few discrete link nodes rather than using all the available nodes ?
- In the "MIKE11 - PEGASE" sub-case, did we get a higher quality of river flow calculation using a few discrete link nodes rather than using all the available nodes?
- In the "MIKE11 - PEGASE" sub-case, did we get a higher quality of river flow calculation with bidirectional links rather than with unidirectional links ?

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

- Did we get a positive response of the OpenMI support structure to our requests ?
- Did we get a quick response of the OpenMI support structure to our requests ?
- Did we get an adapted response of the OpenMI support structure to our requests ?

6. Milestones and deliverables

6.1 Technical

Next milestones are defined :

- B1 : The models (PEGASE, InfoWorks-RS and MIKE11) are OpenMI compliant
- B2 : OMI-files can be created for all models
- B2 : OMI-files can be loaded into the OpenMI GUI
- B2 : Configuration for linked model runs is made using the OpenMI GUI
  - To browse for available linkable components
  - To create an unidirectional and georeferenced link from the Infoworks-RS model to the PEGASE model
  - To create an unidirectional and georeferenced link from the MIKE11 model to the PEGASE model
  - To create a bidirectional and georeferenced link from the MIKE11 model to the PEGASE model
  - To select input and output exchange items for the links
  - To define the common simulation periods
- B2 : Linked simulation is run
- B2 : The linked models system is ready for operational use
- B3 : The demonstration simulations are performed
- B4 : The use case evaluation is made
- B4 : The OpenMI evaluation is made

Next deliverables are defined :

- B1 : OpenMI compliant versions of the models (PEGASE, InfoWorks-RS and MIKE11)
- B1 : Use case definition report
- B2 : OMI-files
- B4 : Use case evaluation report
- B4 : OpenMI evaluation report

6.2 Use case specific

Next milestones about the demonstration and evaluation phases are more detailed :

- The added value of integrated simulations is demonstrated
  - Improved and more reliable model results
  - Assessment of interactions
  - Enhanced knowledge
- The performance, stability and flexibility under operational conditions are evaluated
- The working procedures are evaluated