Report Defining the Scheldt Use case b : linking an upstream non-tidal river model to a downstream tidal river model

1. Short description of the use case

Use case b has the intention to demonstrate the added value of the OpenMI in linking an upstream non-tidal river model with a downstream tidal river model that are set up in different modelling software. The linking will provide a downstream boundary for the non-tidal model and an upstream boundary for the tidal model.

2. Identification of the management / policy issue

The aims of both river managers are:

- The improvement of flood frequency maps
- The improvement of flood forecasting

This can be improved because:

- The tidal model lacks information about the impact of management of artificial and natural flood areas in the non-tidal river what can not be modelled with a hydrological model.
- The non-tidal model needs a downstream boundary; this is the water level that is influenced by tides and by large flood areas downstream of the boundary.

3. Solution to this management / policy issue

Linking both models would provide the necessary information to improve the results for both models.

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 of this use case is to demonstrate that two river models, that have been developed completely separately by different organisations and using different software, can be linked with each other.

- *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 concrete objective of this use case is to demonstrate that physical two-way exchanges and interactions of flows and water levels between two river systems, both in normal and in flood conditions, can be modelled by means of a runtime link between both models.

The classic approach to modelling these interactions would be as follows:

For the non-tidal model:
A downstream boundary would be a time series of the water level. In most cases there are no long term measurements of the water level, so the time series are enlarged using the short term series and the knowledge of the tides. In forecasting this information gets even less accurate. The non-tidal river model can not take into account storage areas already used by the tidal river system.

For the tidal model:
An upstream boundary would be a time series of flow when available, or a hydrological model fed by a time series of rainfall and one of evapotranspiration. A long term time series of flow is often not available and the hydrological model can not take into account important hydraulic impacts such as the management of artificial, large scale flood areas. The tidal river model can not take into account storage areas already used by the non-tidal river system.

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

The concrete 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, tend today to produce large results files and represent long simulation times. It can be expected that linking the models will increase simulation times, especially when two-way interactions cause the data exchange to iterate. Another question that needs to be answered is how the linkage of the models will affect practical aspects of the version management of models and model runs within the software.

It will be very important to assess the feasibility of remote-linking the models. In an operational use, it should be possible that both river managers can run their own models in their own offices and run the other model in the others offices simultaneously.

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

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

- Flood frequency maps, showing flood contours for different return periods
- Impact assessment analyses for new operational management and new infrastructure in the river system.
- Flood forecasting

The aim of this use case is to demonstrate how the linkage of the models will affect the current outputs and to assess whether the current outputs can still be obtained in a linked run.

4.2 Wider perspective objectives

- *Objectives about integrated water management*

This use case will demonstrate whether the link between both river models can help to work out a more integrated water management.

Linking the models will provide the opportunity to link the management of both river systems, because the models will be able to simulate the impact of the management of the other river system.

5. Defining the actions

5.1 Preconditions for linking models

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

Check if all required quantities are exchangeable (see further)

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

This is not applicable for this use case.

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

The software and the licence key are delivered, but the software still needs to be installed on the PC's. This will be done for the first tests, at the beginning of task B2.

- *The model user has input files for the model A available on his PC,*

Files to be sorted out by AWA and to be handed over to FH (iterative process during the use case)

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

The software and the licence key are delivered, but the software still needs to be installed on the PC's. This will be done for the first tests, at the beginning of task B2.

- *The model user has input files for the model B available on his PC,*

Files to be sorted out by FH and to be handed over to AWA (iterative process during the use case)

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

During the End Users training OpenMI was installed on the PC's.

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,*

In short term, both models will be installed on laptops and they will be run on a single computer. Updates of the models will be exchanged through ftp-sites, DVD or e-mail.

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?)*

The models will be linked in the area of the confluence of Dijle and Demer (see further, spatial domain). This is where the authority for the river management changes from VMM-AWA to the administration for which FH manages the river models.

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

<u>Time domain:</u>
The actual tidal model runs at a time step of 300 seconds, the actual non-tidal model runs at a 100 second time step. The time step of the models should be made exchangeable; one can be a multiple of the other. This needs to be checked, because during the End-user-training it was found out that using different time steps for the linked models ended in different results compared to using the same time step for the both models.
Another solution is to run the tidal model at 100 seconds time step, but this will lead to longer calculation times.
The save interval needs to be agreed as well.

Once the models are linked and produce correct results, the first challenge in the time domain will be to look for historical periods with different combinations of flow in the non-tidal model and of the tides in the tidal model.

Periods with the following combinations will be looked for and the historical runs of both models will be linked:

- high flow in the non-tidal model and high tide in tidal model
- high flow in the non-tidal model and low tide in tidal model
- base flow in the non-tidal model and high tide in tidal model

- base flow in the non-tidal model and low tide in tidal model

The challenge on a longer time perspective will be to link the models in a remote way. This would create the opportunity to use the Open-MI-linking in the models used for forecasting.

Spatial domain:

The upstream end of the combination of the two linked models will be the river Dijle in Korbeek-Dijle (Bertem). The most downstream end can be the river Scheldt in Terneuzen, but may be a location more upstream. The most optimal location will be searched for and chosen in function of calculation time and an appropriate downstream boundary for the tidal model.

Because the models will be linked at the confluence of Dijle and Demer, the flow of the river Demer should be taken into account. Also the Grote Laak should be considered. This is a watercourse that receives water from the river Demer and merges with river Dijle at its downstream end. Both river Demer and Grote Laak are modelled in IWRS as well. Figure 1 shows the IWRS model that includes part of river Demer and that includes the Grote Laak.

Because the IWRS-model of river Dijle contains part of river Demer and of Grote Laak, there are several possible ways to deal with those rivers in use case b. The yellow, orange and red circles in the figure show possible locations for the OpenMI link between the IWRS-model and the Mike11-model for the river Dijle.

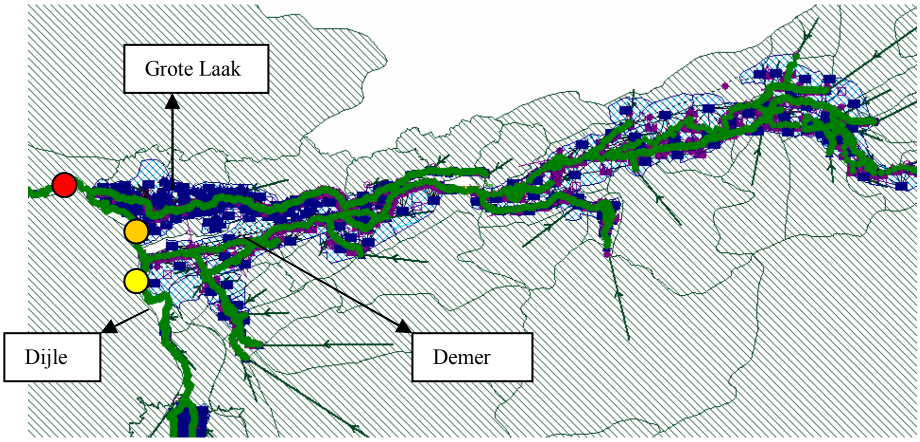


Figure 1: IWRS model at confluence of Dijle and Demer and Dijle and Grote Laak

1. The simplest way to include the effect of river Demer and Grote Laak is to replace the hydraulic model of these rivers by a simple PDM-boundary in the IWRS-model. The OpenMI link between the IWRS and the Mike11 model would be at the red circle in Figure 1 and the east-west oriented rivers you see in the figure would disappear. An alternative is to use a PDM-boundary in IWRS-model for the river Demer and a hydrological boundary in the Mike11-model for the Grote Laak (OpenMI link at the orange circle), or both river Demer and Grote Laak as hydrological boundaries in the Mike11-model (OpenMI link at the yellow circle).

The disadvantage of this way of linking is that the hydrological boundaries give far less accurate results than the hydraulic models do. The advantage is that the IWRS-model becomes at lot smaller and easier to handle for OpenMI.

2. A more accurate solution would be to link the entire Infoworks-model including part of the river Demer and including the Grote Laak, with the Mike11-model at the location of the red circle in Figure 1. Of course this is a large model and OpenMI may have problems with that.
3. Because the IWRS-model of the river Dijle including part of river Demer and Grote Laak is a rather large model, we can consider cutting it in several parts and linking these parts of the IWRS-model with another OpenMI link, one between two IWRS-models.
   These extra links can be chosen to be at different locations. We can for example cut the model in the river Dijle just upstream from the confluence of Dijle and Demer (at the yellow circle). This results in an upstream Dijle IWRS-model and a second, downstream IWRS-model that contains the Dijle between the red and the yellow circle, part of river Demer and the entire Grote Laak. The OpenMI link with the Mike11-model will then be set downstream of the confluence of Dijle and Grote Laak, at the yellow circle.
4. A last possibility is to make one IWRS-model of the river Demer and the Grote Laak, having two downstream boundaries, one at the confluence of Demer and Dijle and one at the confluence of Dijle and Grote Laak. This model can be linked to the Dijle model in several ways depending on the start of the Mike11-model. If the Mike11-model starts at the red circle, both Demer and Grote Laak can be linked to the IWRS-model of the Dijle. If the Mike11-model starts at the yellow circle the Demer and Grote Laak have to be linked to the Mike11-model.

So, there is a large set of possibilities of cutting and linking the models. Out of all these possibilities four combinations or linking schemes were selected. These are to be accomplished in the project. The first scheme is the most easy one, the last one is the most complicated but also a more preferable scheme.

- **Linking scheme 1**
  IWRS-model of river Dijle up to the confluence of Dijle and Grote Laak with the Demer and Grote Laak modelled as PDM-boundaries. There will be one OpenMI link, at the downstream end of the IWRS-model of the Dijle and the upstream end of the Mike11-model.

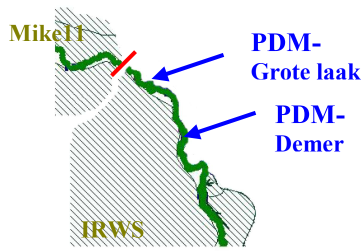
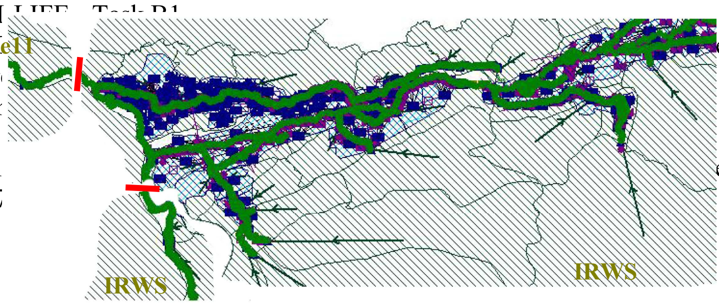


Figure 2: Linking scheme 1 (the red bar indicates the OpenMI link)

- **Linking scheme 2**
  Starting from the IWRS-model of river Dijle up to the confluence of Dijle and Grote Laak including river Demer and river Grote Laak. The IWRS-model will be cut upstream of the confluence of river Dijle and Demer. The upstream and downstream part of the IWRS-model will be linked with an OpenMI link. The downstream part of



the IWRS-model will be OpenMI-linked with the Mike11-model downstream of the confluence of river Dijle and Grote Laak.

Figure 3: Linking scheme 2 (the red bars indicate the OpenMI links)

- **Linking scheme 3**
  Again starting with the IWRS-model of river Dijle up to the confluence of Dijle and Grote Laak including river Demer and river Grote Laak. This model is cut at two places, one at the confluence of Demer and Dijle and one at the confluence of Dijle and Grote Laak. A new model having two downstream boundaries is created. This model can be linked with two OpenMI links to the IWRS model of the Dijle. The IWRS-model of river Dijle itself is OpenMI-linked with the Mike11 model downstream of the confluence of river Dijle and Grote Laak.

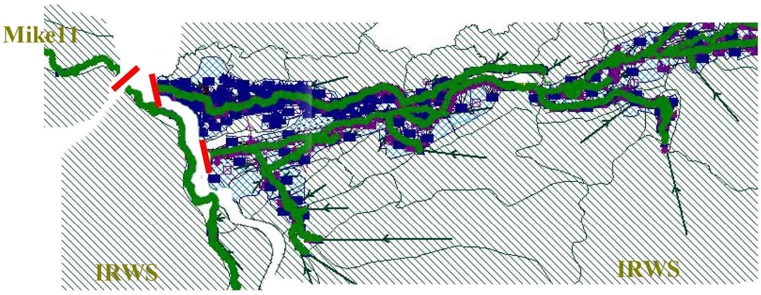


Figure 4: Linking scheme 3 (the red bars indicate the OpenMI links)

- **Linking scheme 4**
  A variant of scheme 3 could be to use a Mike11 model that starts just upstream from the confluence of river Dijle and Demer, an IWRS model from the Dijle with a downstream end at the same location and the model of river Demer and Grote Laak having two downstream boundaries. There would be then three OpenMI-links between the IWRS-models and the Mike11-model.

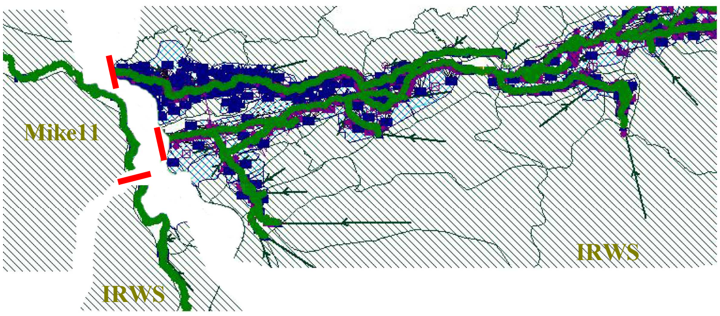


Figure 5: Linking scheme 4(the red bars indicate the OpenMI links)

- *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.)*

Before linking, some changes of the IWRS-model will be necessary in order to include the river Demer and the Grote Laak properly.

When, apart from the river, the floodplains will be linked as well, some small changes in the way the flood area is modelled may become necessary. If necessary extra nodes will be added during the iterative phase of linking.

- *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.)*

  Changes will be necessary in order to simulate the same events with both models (see further for difference about historical events and composite hydrograms).

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

<u>For runs, initiated by IWRS (AWA, non-tidal model):</u>
In the normal procedure for setting up flood frequency maps, the procedure of AWA is called "multirun" and it goes as this:

- Using all available rainfall series, the best possible rainfall series of about 100 years is created for each subcatchment of the model. So each hydrological model used as upstream boundary in the hydraulic model, has its own 100 year rainfall series.
- From these 100 years of rainfall in the model, all storms that may cause flood are selected.
- The hydraulic model runs all selected storms.
- In each node of the model, a frequency analysis is carried out.
- The results of the frequency analysis of stages in the storage areas define the contours of the floodmap for the different return periods.

For the analysis of operational management scenarios historical storms are used.
The IWRS-models are set up with PDM-boundaries that are fed by rainfall boundaries from 1/1/1901 up to 30/12/2004. So, any historical event between these dates can be run by these models.

<u>For runs, initiated by Mike11 (FH, tidal model)</u>
In the normal procedure for setting up flood frequency maps, the procedure of FH is based on fictive composite hydrograms and it goes as this:

- Using all available rainfall series, a long term simulation is created for each subcatchment of the model.
- The hydrological model runs these long term simulations
- Afterwards Peaks Over Treshold are selected and a frequency analysis is carried out and translated into composite hydrograms
- The hydraulic model runs the composite hydrograms.
- The results of the hydraulic runs define the contours of the floodmap for the different return periods.

For the analysis of operational management scenarios the model uses both composite hydrograms and historical storms.

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),*

Linking the river assuming no flood in the area of the link

At the downstream boundary of AWA-model and upstream boundary of FH-model, i.e. at one physical location:

- Flow from AWA-model to FH-model
- Stage from FH-model to AWA-model

The nodes that will exchange data in the first of the linking schemes of paragraph 5.2.2 are given in Table 1 to Table 4. Not all changes necessary for these linking schemes are already executed, so some of the node names are still provisional.

Table 1: Nodes exchanging data in linking scheme 1

	Node type	**Node name**		**Unit**
AWA	HT-boundary	130DP2140_HT (X170182;Y186494)	Sending flow, receiving stage	m³/s for flow m TAW for stage
FH	H-point	Bovendijle chainage	Sending stage	m TAW
FH	Q-point	Bovendijle chainage	Receiving flow	m³/s

Table 2: Nodes exchanging data in linking scheme 2

	Node type	**Node name**		**Unit**
AWA	HT-boundary	130DP2140_HT (X170182;Y186494)	Sending flow, receiving stage	m³/s for flow m TAW for stage
FH	H-point	Bovendijle chainage	Sending stage	m TAW
FH	Q-point	Bovendijle chainage	Receiving flow	m³/s
AWA	HT-boundary	Dijle6_HT	Sending flow, receiving stage	m³/s for flow m TAW for stage
AWA	QT-boundary	Dijle5_QT	Sending stage, receiving flow	m³/s for flow m TAW for stage

Table 3: Nodes exchanging data in linking scheme 3

	Node type	**Node name**		**Unit**
AWA	River section	130DP2140 (X170182;Y186494)	Sending flow, receiving stage	m³/s for flow m TAW for stage
FH	H-point	Bovendijle chainage	Sending stage	m TAW

FH	Q-point	Bovendijle chainage	Receiving flow	m³/s
AWA	HT-boundary	DEAW225c_HT_OMI	Sending flow, receiving stage	m³/s for flow m TAW for stage
AWA	QT-boundary	Demer_OMI	Sending stage, receiving flow	m³/s for flow m TAW for stage
AWA	HT-boundary	GroteLaak_HT_b4b	Sending flow, receiving stage	m³/s for flow m TAW for stage
AWA	QT-boundary	GroteLaak_OMI	Sending stage, receiving flow	m³/s for flow m TAW for stage

Table 4: Nodes exchanging data in linking scheme 4

	Node type	**Node name**		**Unit**
AWA	HT-boundary	Dijle0_HT (X172745;Y184319)	Sending flow, receiving stage	m³/s for flow m TAW for stage
FH	H-point	Bovendijle chainage	Sending stage	m TAW
FH	Q-point	Bovendijle chainage	Receiving flow	m³/s
AWA	HT-boundary	DEAW225c_HT_OMI	Sending flow, receiving stage	m³/s for flow m TAW for stage
FH	QT-boundary	Demer_OMI	Sending stage, receiving flow	m³/s for flow m TAW for stage
AWA	HT-boundary	GroteLaak_HT_b4b	Sending flow, receiving stage	m³/s for flow m TAW for stage
FH	QT-boundary	GroteLaak_OMI	Sending stage, receiving flow	m³/s for flow m TAW for stage

Flood conditions:
In case the area where the models are linked gets flooded, the floodplains will need to be linked as well. These are the links that will be necessary in that case:

- Flow from flood plain section from AWA-model towards flood plain section (parallel riverbranch) from FH-model.
- Stages from flood plain section from FH-model to storage area in AWA-model.

- *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,*

Each time step the flow and the stage will be exchanged as described in Table 1.

- *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.*

Transfer flows from IWRS to Mike11 at the boundary

- Providing element type : river section
- Providing quantity : flow
- Accepting element type : dfs0-file
- Accepting boundary condition :flow time series

Transfer water level from Mike11 to IWRS at the boundary

- Providing element type : H-point
- Providing quantity : stage time series
- Accepting element type : boundary node
- Accepting boundary condition :Stage-time-event

Transfer flow in flood area from IWRS to Mike11 at boundary of models:

- Providing element: floodplain section (in this case, there should be a dummy storage area downstream of the floodplain section, this is to be discussed with the software developers)
- Providing quantity: flow
- Accepting element type: floodplain section (parallel riverbranch)
- Accepting boundary condition: Flow-Time-event

Transfer of stage in flood area from Mike11 tot IWRS at boundary of models:

- Providing element: floodplain section
- Providing quantity: water level
- Accepting element type: storage area (not the dummy storage area, but the one upstream from the dummy storage area, to be discussed with software developers)
- Accepting boundary condition: no boundary condition

Vocabulary

For a good understanding between the different model users, a list of vocabulary used for modelling in the different software packages is set-up in this definition text. This should help to prevent misunderstandings and waste of time due to different vocabularies.

IWRS-vocabulary

River section:	a node representing one section of the river
Link:	links different nodes to each other and it assumes that over the entire length of the link, the upstream node of the link stays valid. A link exists between river sections and between conduit sections.

Spill:	riverbank that can flood when the stage in the river crosses the lowest level of the bank
Storage area:	part of the floodplain described as a reservoir with a stage-area table as description of the reservoir. The stage-area-table is set up using the DTM.
Flood plain section:	talus or incline separating the storage areas, receiving its data also from the DTM
Connectivity:	linking nodes without having a length
PDM-boundary:	hydrological model used as an upstream boundary of the hydraulic model

Mike11 vocabulary

Link channel:	The link channel is a short branch used to connect a flood plain to the main river branch. Link channels do not require cross sections to be specified and are consequently simpler to use than regular channels. The link is modelled as a single weir branch and will contain only three computation points.
Storage Area:	part of the floodplain described as a reservoir with a stage-area table as description. This stage area is deducted from the digital terrain model. In a storage area, the water does not flow.
Parallel Branch:	part of the floodplain described as a regular branch, which indicates that the water is able to flow on the floodplain.
NAM-boundary:	hydrological model output used as an upstream Q input for the hydrodynamic model.
Q point:	Point of the Ionescu-Abbott calculation scheme where Q is calculated.
H point:	Point of the Ionescu-Abbott calculation scheme where H is calculated.
Chainage:	Location along the branch in m.

- *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).*

Transfer flows from IWRS to Mike11 at the boundary

The river Dijle upstream of node 28050 must be removed and replaced by the 'Open-MI-boundary node'.

-Transfer water level from Mike11 to IWRS at the boundary

The river downstream from Dijle0 must be removed and replaced by the 'Open-MI-boundary node'.

Transfer flow in storage area from IWRS to Mike11 at boundary of models:

IWRS, AWA-model:

- Add a dummy storage area where the floodplain modelled by the FH-model starts

Mike11, FH-model

- Add a Q boundary

Transfer of stage in flood area from Mike11 tot IWRS at boundary of models

IWRS, AWA-model

- Add a dummy storage area where the floodplain modelled by the FH-model starts.

Mike11, FH-model

- No changes are necessary

A difference between the modelling of FH and AWA for operational management is the use of rainfall data. AWA uses historical events, FH uses composite hydrograms specific for a return period. To be able to continue working in the same way, changes due to this aspect will be necessary in the model of the two partners. It still needs to be worked out how this issue is going to be coped with.

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,*

- *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,

- The initial tests of linking will be done according to 4 linking schemes. Starting with linking scheme 1 and moving to linking scheme 4 as the project progresses.

– **Linking scheme 1**
IWRS-model of river Dijle up to the confluence of Dijle and Grote Laak with the Demer and Grote Laak modelled as PDM-boundaries. There will be one OpenMI link, at the downstream end of the IWRS-model of the Dijle and the upstream end of the Mike11-model.

– **Linking scheme 2**
Starting from the IWRS-model of river Dijle up to the confluence of Dijle and Grote Laak including river Demer and river Grote Laak. The IWRS-model will be cut upstream of the confluence of river Dijle and Demer. The upstream and downstream part of the IWRS-model will be linked with an OpenMI link. The downstream part of the IWRS-model will be OpenMI-linked with the Mike11-model downstream of the confluence of river Dijle and Grote Laak.

– **Linking scheme 3**
Again starting with the IWRS-model of river Dijle up to the confluence of Dijle and Grote Laak including river Demer and river Grote Laak. This model is cut at two places, one at the confluence of Demer and Dijle and one at the confluence of Dijle and Grote Laak. A new model having two downstream boundaries is created. This model can be linked with two OpenMI links to the IWRS model of the Dijle. The IWRS-model of river Dijle itself is OpenMI-linked with the Mike11 model downstream of the confluence of river Dijle and Grote Laak.

– **Linking scheme 4**
A variant of scheme 3 could be to use a Mike11 model that starts just upstream from the confluence of river Dijle and Demer, an IWRS model from the Dijle with a downstream end at the same location and the model of river Demer and Grote Laak having two downstream boundaries. There would be then three OpenMI-links between the IWRS-models and the Mike11-model.

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.

6. Milestones, deliverables, success scenarios

6.1 Technical

- Models are OpenMI compliant
  Is ok.

- OMI-files can be created for both models
  Is ok.

- OMI-files can be loaded into the OpenMI GUI
  Is not ok for IWRS, OpenMI doesn't always accept the omi-files.

- 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