Report Defining the Scheldt Use case d: linking a 1D-river model (Dender) to a more dimensional estuary model (of the Westerschelde)

1. Short description of the use case

Use case d has the intention to demonstrate the added value of the OpenMI in linking an upstream one-dimensional river model with a downstream two-dimensional tidal model which are set up in different modelling software. The linking will provide one or more downstream boundaries for the 1D model and one or more upstream boundaries for the 2D-tidal models. Two different 2D-models, Kustzuid and Zeekennis, and their link with a 1D- model of river Dender will be investigated in this use case.

The Kustzuid model is a Waqua-model. It covers a large part of the North Sea and the East- and Western Scheldt. Figure 1 gives an overview of the extent of the model. The most upstream boundary is Melle in Flanders.

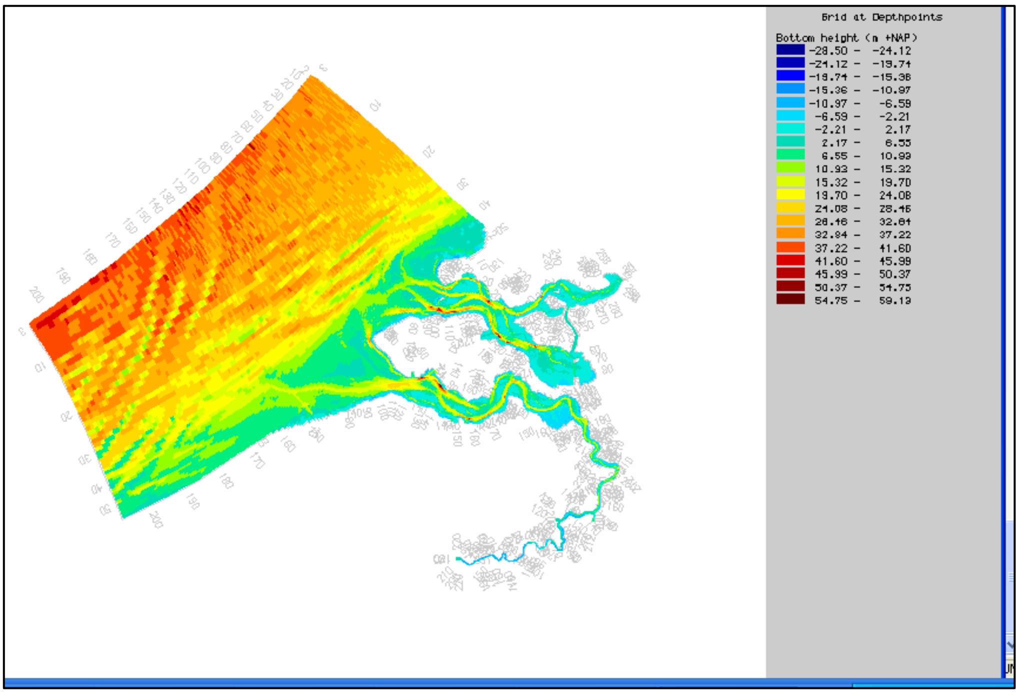

Figure 1: Extent of Kustzuid model

The Zeekennis model is a Delft3D model and covers about the same area as the Waqua model. The upstream part stops at Rupelmonde in Flanders (Figure 2).

The Dender model is built in Mike11. It covers the Flemish part of river Dender from the Walloon border up to Dendermonde, where it reaches the tidal part of river Scheldt. Figure 3 shows the extent of this model.

For this use case there will be also some calculations with the Mike11 SIGMA model in order to deliver upstream discharges for Seascheldt at Dendermonde and at Rupelmonde. The model itself will not be linked through OpenMI but time series will be produced for each calculation period.

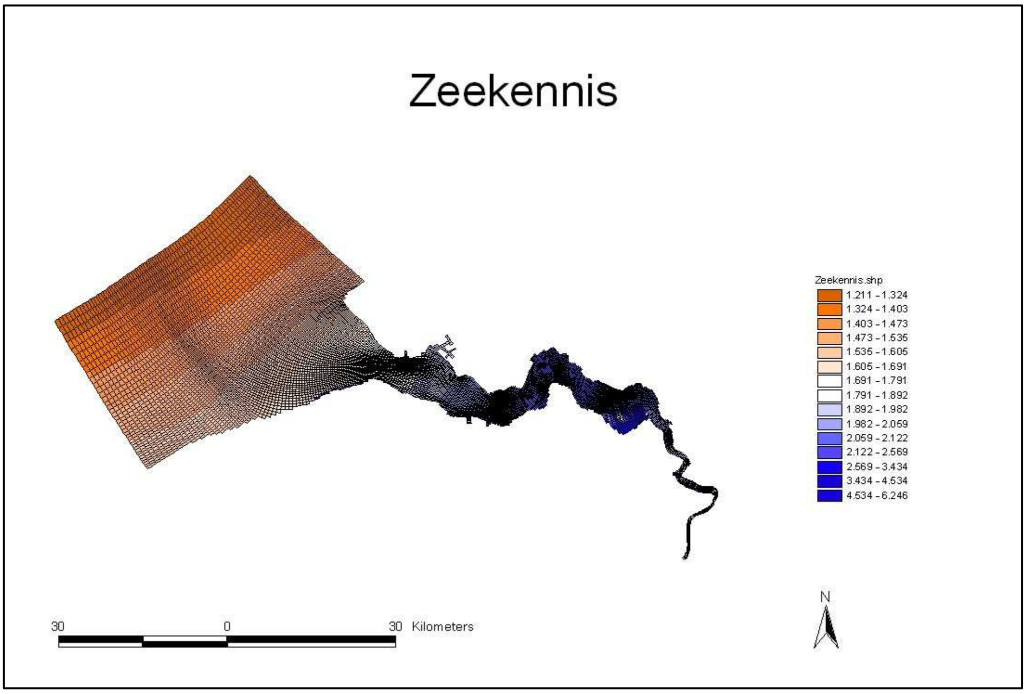

Figure 2: Extent of Zeekennis model

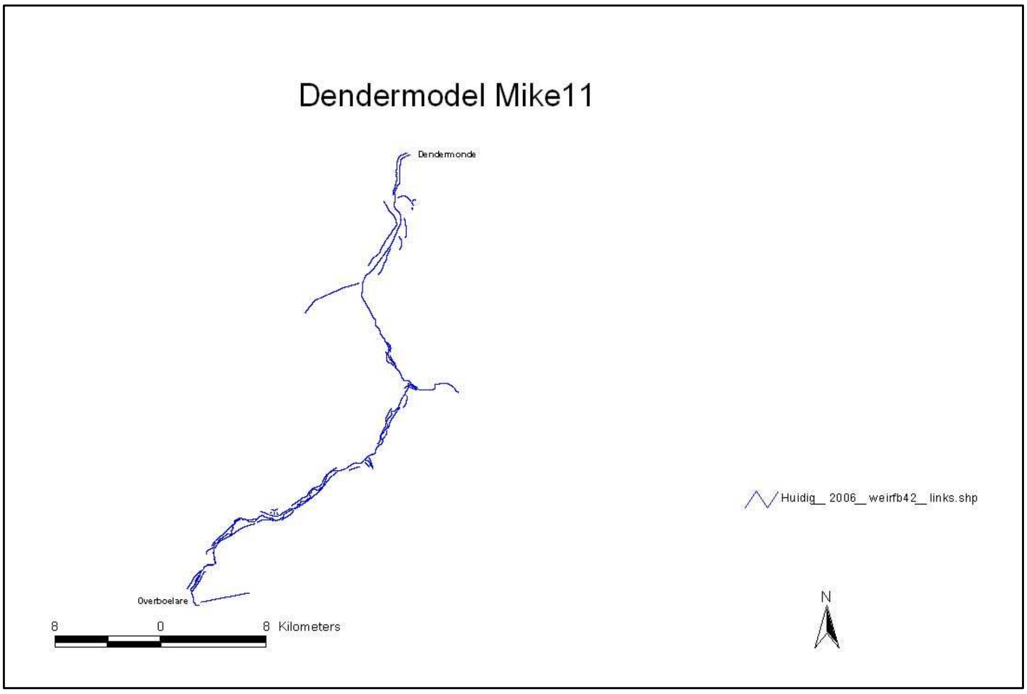

Figure 3: Extent of Dender Mike11 model

2. Identification of the management / policy issue

Different Authorities today tend to manage their own part of the River Basin, therefore using specific tools like numerical models. These models do not always have the same extent and if so, they do not have the same kind of detail in every region, especially in the abroad part, where the gathering of detailed hydrological and field data in the past wasn't always possible.

The different Authorities today also realise that within the scope of the Water Framework Directive a more integrated way of modelling will be essential in the future. The coupling of different models, each with their own extent, specific features and detail, can contribute to a better insight and understanding of different processes. Instead of extending and overlapping the existing models, the coupling of existing models can be a very efficient and effective tool for the future. The linking of models from different organisations even in different countries will also contribute to a better dialogue with the different partners.

In this use case we plan to focus on the interaction between different water quantity models. The main management and policy issues are the improvement of boundary conditions, improvement of flood forecasting and a better understanding of the accessibility of harbour areas.

- Improvement of boundary conditions within each model.

In this way overlap between models can be avoided and each model will be used in the region where it is best suited for: the 1D-model for the river and the 2D-model for the estuary and the sea.

- Improvement of flood forecasting during storm surges and/or high inland discharges.

Storm surge is nowadays forecasted by different authorities in Flanders and the Netherlands, each with their own models. In periods of high inland discharges, this forecasting can be strongly influenced, especially in the most upstream tidal part in Flanders. Because the Dutch Authority lacks much detail of the upstream tidal part, discharge inputs of the more detailed model of the Flemish Authority can contribute to a better forecast and understanding.

- Improvement of discharge and velocity distribution in Westerscheldt due to high inland discharges in the scope of an improved forecasting of the accessibility of Antwerp Harbour.

The 2D-model is used in order to evaluate the different velocities within the estuary. A much differentiated pattern and/or extreme high currents will limit a safe and smooth access to the Harbour area of Antwerp in Flanders. Again, a better estimate of high inland discharges, delivered by the 1D-river models can contribute to a better understanding of the real velocity distribution in the estuary region around Antwerp.

The reason why we expect a coupling will lead to an improved insight for both Authorities is also because on the one hand the 2D-tidal model lacks information about the impact of management of artificial and natural flood areas in the tidal river, which are in detail included in the 1D-model. Especially during storm surges these areas can have a significant impact on local water levels in the upstream tidal area. The 1D-river model on the other hand needs a downstream boundary, which is directly influenced by tides at normal periods and especially at storm surges.

3. Solution to this management / policy issue

The different Authorities involved are Flanders Hydraulics and RIKZ. Flanders Hydraulics owns the Mike11 Dender model and manages the Mike11 SIGMA model. RIKZ owns and manages the Kustzuid Waqua model. WL | Delft Hydraulics is supplier of the Delft3D modelling system. The Zeekennis model is a Delft3D model derived from the KustZuid Model.

The more dimensional tidal models of the Scheldt will receive from the 1D model of the Dender and the SIGMA-model more detailed discharge inputs. The more dimensional models lack information in the upstream part in Flanders. Therefore the more dimensional models will have their most upstream point in Dendermonde. At that point the model of Flanders Hydraulics will take over. On the one hand the SIGMA model will calculate and deliver discharge time series for the Scheldt at Dendermonde and Rupelmonde for the different calculation periods. This will happen without an OpenMI link. At Dendermonde the most upstream part of the tidal Scheldt from Ghent up to Dendermonde will be included in the discharge time series, at Rupelmonde the river Nete, Zenne, Dijle and Demer will be included in the calculated discharge time series.
On the other hand at Dendermonde, there will be an OpenMI link with the one-dimensional Dendermodel itself. At this point the model will exchange Discharge and Water level at each timestep of the calculation (simulation).

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 the more dimensional models of the tidal Scheldt and the one-dimensional river model Dender 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),* A next 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 the respective models.

The classic approach to modelling these interactions would be to

For the 1D-river model:
A downstream boundary would be a time series of water level in the Scheldt. This time series is nowadays produced by a 1D-tidal river model, which can not take into account the complex pattern of stream velocities and the exact propagation of storm surges in this area.
By enlarging the more dimensional models up to Dendermonde, this propagation will hopefully be more precise and will deliver better downstream boundary conditions for the river model Dender.

For the 2D-tidal models:
An upstream boundary would be a time series of flow. Nowadays the more dimensional model of WL | Delft Hydraulics uses estimated discharge time series for Rupelmonde. The more dimensional model of RIKZ covers the whole tidal part of the Scheldt and uses measured discharge time series at Melle and estimated discharge time series at Rupelmonde.
The models of both WL | Delft Hydraulics and RIKZ lack detailed terrain information in Flanders, for instance the management of artificial large scale flood areas in the upstream area, which strongly influences the flow.
The SIGMA model and the Dender model have detailed information about such areas, which will lead to a better understanding of discharge inputs into the Scheldt.

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

During the test of this use case, it will become clear to which extent the model linking affects the practical aspects of large computer simulations.

All 3 models, when run in stand alone mode, today tend to produce large results files and represent long simulation times. Table 1 gives an indication of the time step and the calculation time for calculating 1 month.

Table 1. Time step and calculation time for the models of Scheldt use case D.

Model	**Time step**	**Calculation time (1 month)**
Mike11 Dender	30 seconds	1 hour
Delft3D Zeekennis	1 minute	1 hour
Waqua Kustzuid	1 minute	1 hour

It can be expected that the linkage of the models will slow down simulation times, especially when two way interactions cause the data exchange to iterate.

Another question that needs to be answered in the future, is how the linkage of the models will affect the practical aspects of the version management of models and model runs within the software. The kinds of models that are used for water management are regularly updated by new information about management, terrain info, extra measurements,… It will be interesting in the future always to work with the most updated model version.

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

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

- Impact assessment analyses for new operational management and new infrastructure in the river system, for instance controlled flood areas in the upstream part.
- Flood forecasting in Scheldt basin.
- Accessibility of Antwerp Harbour.

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.
By having more detail of the upstream discharge inputs into the more dimensional model, the Accessibility of the Harbour area will hopefully be more precise. The more dimensional models hopefully produce more precise water levels, especially in case of storm surge.

4.2 Wider perspective objectives

- *Objectives about integrated water management*

This use case will demonstrate whether linking river models can help to improve integrated water management.
Linking, in the future, the more dimensional models of the Scheldt with the more upstream one-dimensional river models like Dender, Leie and Upperscheldt will provide the opportunity to manage the complete river system of the Scheldt, from its origin in France up to the Westerscheldt. These linked models will be able to simulate the impact of the management of the complete river system of the Scheldt basin. In this way modelling cost can be reduced as the overlap in the models is reduced or even omitted. Respect for each others methods and models will contribute to a better dialogue with the different partners.

- *Objectives about remote linking*

In this scope it will be very important in the future also to assess the feasibility of remote linking the model. In operational use, it should be possible that both river managers can run their own model in their own offices linked at runtime with the other model which runs on the hardware at the offices of the other river manager. In this case the problem of versioning is better managed. This also will prevent huge overlaps between different models, sometimes in areas where detailed terrain information is only available in one model.

5. Defining the actions

5.1 Preconditions for linking models

The result of this phase is the acknowledgement of the software-suppliers that Mike-11, Waqua and Delft3D are OpenMI-compliant, specifically:

- Mike-11 can accept Water levels and deliver Discharges, both at a downstream boundary (point, later in this document addressed by ID); and
- Waqua and Delft3D can deliver Water levels and accept Discharges, both at an up-stream boundary (point, later on addressed by ID).

The software-suppliers had to undertake real action. RIKZ still has to make Waqua OpenMI-compliant, both input and output. WL | Delft Hydraulics extended the OpenMI-compliancy of Delft3D to the output of (at least) water levels. For DHI there is nothing extra to do as Mike-11 is already OpenMI-compliant.

The different software's and license keys are delivered by the software suppliers and will be installed at the beginning of the trial phase on laptop pc's at each of the partners desk.

The OpenMI-editor has been installed by the different partners at their desk.

5.2 Actions for the definition phase

This phase is aimed at defining the complete set-up of the link between the one-dimensional Dender model and the more dimensional tidal Scheldt models. During this phase the aim is also running stand-alone models on dedicated PC's at each of the offices of the partners: FH and RIKZ.

5.2.1 Define the hardware environment

The models Kustzuid and Zeekennis will be installed on a laptop pc at Flanders Hydraulics at the beginning of the trial phase. The Dender model will be installed at RIKZ also on laptop pc's. All this is to be done at the start of the trial phase.

5.2.2 Define the interactions to be modelled

The models will be linked in the area of confluence of river Dender and Scheldt in Flanders, especially at Dendermonde.

Time domain

The first challenge in the time domain is the time step of the different models. From table 1 it is clear that the models run at a time step of either 30 or 60 seconds. At the end user training, it was stated that time steps could be made exchangeable, when one time step is a multiply of the other, which is the case here. From the end-user training it was clear that using different time steps for linked models gives different results compared to using the same time steps for

each of the models. In the last case the time step of the models should be a multiple of 60 seconds. The save interval needs to be agreed as well.
It would be interesting to test different set-ups in the scope of calculation time, with the time steps being equal for all the models on the one hand and some multiple of a model time step on the other. We expect the essential OpenMI communication between the different models at each time step or at a multiple of a model time step, will also be a very time-consuming process.

The second challenge is the look for historical periods with different flow regimes. In the first technical meeting in Middelburg the following periods were mentioned:

- standard/normal tidal period;
- storm period, selected from a RIKZ-list of storms (Table 2);
- december 2002- january 2003, a period with high inland discharge.

Table 2. Recent storm periods with indication of type.

Storm periods (RIKZ)	Type of storm surge
26 February - 2 March 1990	Moderate
20 December 1991	Low
29 January 1994	Moderate
1 - 2 January 1995	Low
3 - 4 December 1999	Low
29 – 30 January 2000	Low
21 – 22 December 2003	Low
8 – 9 February 2004	Low
1 November 2006	Low
18-21 January 2007	Low

The periods to calculate with the OpenMI-link will be based on the above table, with very recent storm periods still to add. The only period for which the Mike11 Dendermodel is calibrated at this moment is December 2002-January 2003.

In this use case different periods, already calculated for all models, or easy to recalculate for all models in terms of data retrieval will be evaluated. Evaluating different flow regimes will be essential for evaluating the profit of model linking. During storm periods we expect the more dimensional tidal models to produce better inland water levels as boundary condition for the river models. During periods of high and intensive inland rainfall, we expect the river models to produce better downstream discharges as input to the tidal system. The calculation of different periods will make it possible to evaluate the above statement.

The ultimate challenge on a longer time perspective will be the remote linking of the different models, in order to use the OpenMI-tool and the respective models for forecasting and storm surges. Linking over the net might not be too much time-consuming and safety rules will have to be dealt with within the different organisations

Spatial domain

The point where the models will be linked is Dendermonde. The Mike11 Dender model and the Waqua Kustzuid model comprise this location. This is not the case for the Delft3D Zeekennis model, so this has to be enlarged up to there, by using the data setup of the Waqua model.
Because the Kustzuid model runs up to Melle (Ghent) the most upstream part between Melle and Dendermonde has to be removed before linking.
The part upstream of Rupelmonde, more specific the flow from river Zenne, Nete, Dijle and Demer via Rupel, is not in the more dimensional models comprised. Therefore extra calculations for the selected calculation periods will be delivered as Delft or Waqua discharge boundary conditions by the one-dimensional model of the tidal Scheldt (SIGMA). This is also the case for the river Durme and for the discharge coming from the upstream part of the Scheldt up to Dendermonde.

An important issue in this use case is the translation of a one-dimensional discharge from the Mike11 to a more dimensional discharge in the Waqua or Delft3D grid and vice versa for the water levels.

Also the use of different water level reference systems is to be handled in this use case, namely the Belgian system mTAW (meter Tweede Algemene Waterpassing) and the Dutch system NAP (Normaal Amsterdams Peil). In general the TAW reference point is about 2.33 m lower than the NAP reference point, which means that elevations, water levels,… in Belgium have a higher numerical indication. We will implement a translation for the water levels to be exchanged between the models via the OpenMI link. From the end-user training it was clear that a translation is possible during the exchange.

Also of interest is which model will be used as a ‘trigger’ in the OpenMI environment.

At the end of this exercise there will be 3 models which will be linked through OpenMI:
- Mike11 Dender-down-to-Dendermonde;
- Waqua Kustzuid-up-to-Dendermonde;
- Delft3D Zeekennis-up-to-Dendermonde.

There will be also a fourth model, used by Flanders Hydraulics, to produce offline discharge boundaries for the more dimensional models:
- Mike11 SIGMA.

This model calculates contributory discharges for Rupel at Rupelmonde, Scheldt at Dendermonde and Durme at the mouth of Durme (around Tielrode). Figure 4 indicates these locations within the SIGMA model.

Working scheme

Before the real linking will start, we suggest to have some “stand-alone” simulations on the designated hardware. Each partner will run its own complete model in a “stand-alone” mode and will deliver these results to the different partners. In this case the exchange-data (water level and discharge at the linking-location) is treated as “normal” boundary condition, thus provided via the standard user-interface and/or boundary-files of each software.

In the next step an offline OpenMI-link will be established by each of the partners by setting up a test on the designated hardware at their office which consists of:

- OpenMI-AsciiReader (reading data form file) and providing them (as input-ExchangeItems) to:
- OpenMI-Linkable-Component *Dender* or *KustZuid* or *Zeekennis*;
- RIZA_OpenMI_DataMonitor (to check on output ExchangeItems).

The OpenMI-ASCII-reader will be provided by WL | Delft Hydraulics. A recent version of the RIZA_OpenMI_DataMonitor will be available on SourceForge shortly.

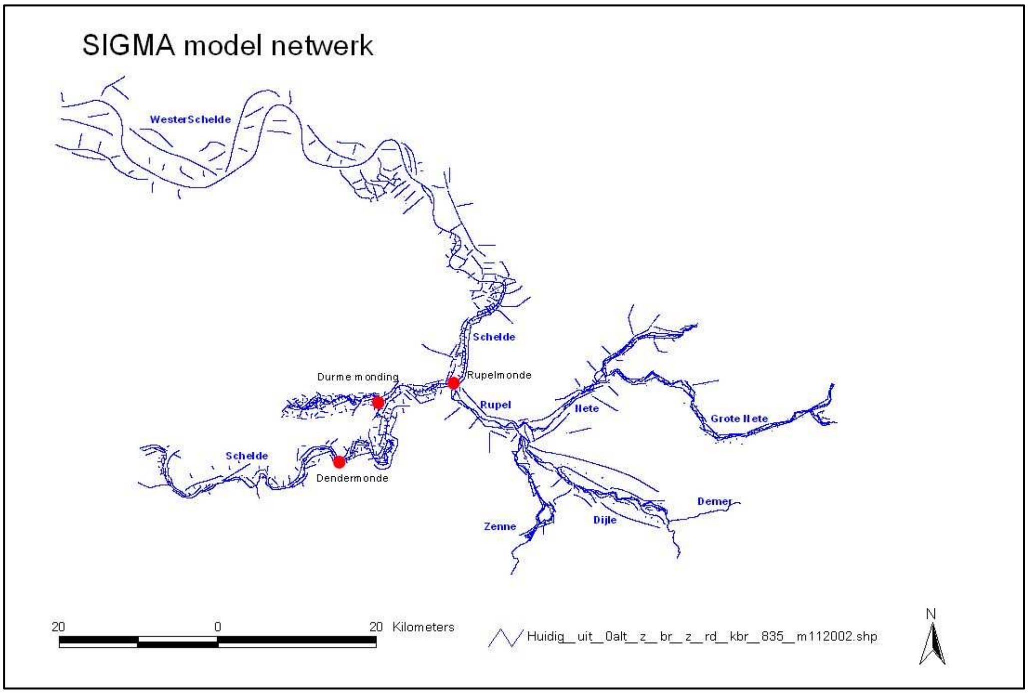

Figure 4: Extent of Mike11 SIGMA model with indication (red dots) of locations where an offline discharge boundary will be delivered for the more dimensional Waqua and Delft3D models.

The final step will be the OpenMI-Linking of the models itself. This step will finish the technical linking of the models. The result is an operational version of two OpenMI-linked models. Two combinations are foreseen: Dender-Kustzuid and Dender-Zeekennis, both linked at Dendermonde.

The exact linking location is specified in Table 3 via the model node name and position in Lambert72 geographical coordinates for the different OpenMI linked set-ups.

Table 3. Information concerning the linking location for the models of Scheldt use case D.

Model	**Node type**	**Node name**		**Unit**
Mike11 Dender	Q point	Dender chainage 49480 Control structure: stuw Dender X = 129979, Y = 192619	Sending flow from Dender	m³/s
Zeekennis			Receiving flow	m³/s

Kustzuid				m³/s
Mike11 Dender	H point	Dender chainage 49866.5 X = 130347, Y = 192734	Receiving stage	mTAW
Zeekennis			Sending stage	mNAP
Kustzuid			Sending stage	mNAP

The exact locations where an offline Q boundary will be delivered from the Mike11SIGMA model are summarized in Table 4.

Table 4. Exact locations where offline Q boundaries will be exchanged in Scheldt use case D.

Model	**Node type**	**Node name**		**Unit**
Mike11 SIGMA	Q point	Rupel chainage 399.89268 X = 145791, Y = 201418	Flow from Rupel into Scheldt	m³/s
Zeekennis			Q boundary Rupel at Rupelmonde	m³/s
Kustzuid			Q boundary Rupel at Rupelmonde	m³/s
	Q point	Zeeschelde chain. 71554.483 X = 130424, Y = 192935	Flow Scheldt upstream Dendermonde	m³/s
Zeekennis			Q boundary Scheldt at Dendermonde	m³/s
Kustzuid			Q boundary Scheldt at Dendermonde	m³/s
	Q point	Durme chain. 117.07978 X = 136351, Y = 199177	Flow from Durme into Scheldt	m³/s
Zeekennis			Q boundary Durme at Tielrode	m³/s
Kustzuid			Q boundary Durme at Tielrode	m³/s

Vocabulary

For a good understanding between the different model users and partners, a list of typical vocabulary used for modeling with the different software packages is added. This should help to prevent misunderstandings and waste of time due to different vocabularies. This list is not a static list, but new terms will be added during the remaining time of the project.

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 modeled 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

Delft3D-vocabulary and Waqua-vocabulary will be added in the next phase.

5.3 Actions for the Demonstration phase

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

- 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.

5.4 Actions for the Evaluation phase

There are several actions to be evaluated. Here is already a description and some first questions to be answered.

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

Did we get a significant realistic improvement of the flow calculation in the more dimensional models when there was a link with the one-dimensional river models?
Are there big differences in these results between storm surges, normal tides, and/or high inland discharge periods?
Are there differences in results between the 2 tested links?
Have the results of these simulations been evaluated as interesting for the Competent Authorities?

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

Did we get significant changes that can be interpreted in water levels as downstream boundary for the one-dimensional and in discharge inputs for the more dimensional models?
If there are big differences in the results between storm surges, normal tides, and/or high inland discharge periods, when is the linking most appropriate?

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

Did we have success with linking the different models via OpenMI?
Are the simulated runs not too much time consuming?
Did we get stable runs while using the link between the different models?
Is there difference in the link from Mike11 to Delft and from Mike11 to Waqua in terms of stability and performance?

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

Did we get a positive, quick and clear response of the OpenMI support structure to our requests?

6. Milestones, deliverables, success scenarios

6.1 Technical

The next milestones are defined:

- 3 Models are OpenMI compliant: This has already been done for the Delft3D Zeekennis model and for the Mike11 Dender model. The Waqua Kustzuid model will be OpenMI in the very near future.

- OMI-files can be created for all 3 models: This has already been done for the Delft3D Zeekennis model and for the Mike11 Dender model. The Waqua Kustzuid model will be OpenMI in the very near future.

- OMI-files can be loaded into the OpenMi configuration Editor (OmiEd): This is already done for the Delft3D Zeekennis model at WL | Delft Hydraulics with the OpenMI-Editor version 3. It does not work at Flanders Hydraulics for the Zeekennis and Dender model.

- Configuration for linked model runs is made using the OpenMI GUI: WL | Delft Hydraulics has already setup an OpenMI link by using the GUI with the Delft3D Zeekennis model and a dummy SOBEK model of Dender. This test is presented at the workshop of 18-19 April 2007.

- Linked simulation is run: See above for the already successful link between Delft3D and SOBEK, tested by WL | Delft Hydraulics.

6.2 Use case specific:

- Definition of the use case d: This is done (this report).

- Evaluation report of use case d: has to be prepared during the evaluation phase.

More specific milestones will be described in detail in the evaluation report of the project. Here are already some suggestions:

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