Knowledge for Climate

KKF-Model Platform Coupling
Summary report KKF01b

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1 Introduction and Guide to the reader

This report summarizes the results of the different detailed technical reports that have been made by the different partners. It serves as the final report of the project *together* with the following detailed technical reports:

1. Inventory of available and accessible data and models and design and first setup for a pilot system (Schellekens et al., 2011a).

2. Inventarisatie van socio-economische modellen voor het KKF-modellenplatform (in Dutch with English summary, Ward and Veldkamp, 2011) .

3. *Klimaatverandering en modellering van natuureffecten. Verkenning van mogelijkheden om natuur effecten te voorspellen met hydrologische modellen als uitgangspunt*(in Dutch with English summary, Barendregt et al., 2011)

4. Coupling the air quality model LOTOS-EUROS to the climate model RACMO (Manders et al., 2011)

5. *Koppelingen in het NHI* (in Dutch with English summary) (in Dutch with English summary, Veldhuizen et al., 2011)

6. Application of KKF-pilot system in case studies (Schellekens et al., 2011b)

This overview report is for convenience only, it does not contain information that is not in the technical reports and should not be relied on without consulting the technical reports.

2 Summary

The Netherlands are carrying out the Delta programme to adapt their water management system to climate change and sea level rise. Adaptation needs a number of decisions regarding the way the Netherlands will organize -- in the long -term -- their flood protection system, their water supply and the distribution of this water over the different sectors and regions.

To support these decisions quantative information is needed on the occurrence of different water levels with respect to floods, on the water supply and the occurrence of dry spells, on the water available and its quality needed for flushing polders, sectors as agriculture, drinking water, recreation etc etc. The only way to provide such information is by simulation, using combinations of hydrological and hydraulic models that are linked to sectoral models. Where all models are forced by climatic and sea level boundary conditions.

The water management system in the Netherlands, situated within the Rhine Meuse Delta, depends on the fluctuations and rise in sea level, variations and trends in river flow, rainfall and evaporation. The delta has a highly complicated system of water distribution and the design levels for flood protection are among the highest in the world. Adaptation measures are implemented on relatively small scales. Therefore the questions asked to the results of the simulation models are increasingly detailed. This all puts substantial pressure on the level of functional and technical design of these models .

It is therefore essential that these models are used in a consistent way. Even more so, many of these models cannot be run independently but should be linked to other models to solve the interactions between the different parts of the simulated (natural) system.

For the deltaprogramme, a model is currenly assembled from the numerous modelling systems that occur in the Netherlands (the Detamodel). To support the building of this Deltamodel, in this Knowledge for Climate project we explore methods for linking different existing models within the spatial domain in and around The Netherlands. We investigated the chain of hydrological and hydrodynamic models needed in the Rhine/Meuse basin and the North Sea and the groundwater, water demand and distribution model (NHI) for The Netherlands.

In addition, the necessary interaction between the hydrological models and land-use and nature models was investigated and a suitable structure for linking these has been proposed that is based on existing modelling systems that are developed and maintained at different research institutes in the Netherlands.

In parallel the coupled running of a climate and air quality model has been worked on, resulting in detailed simulations of air quality in a changing climate.

The focus is particularly on the technology, as we prepared a prototype of such a linked modelling system. It will be used later to facilitate the preparation of scenarios in the investigated areas (water, air quality, nature, land use). It will also support further research that can support the Netherlands adaptation planning

The first case studies that have been run using 30 years of ESSENCE data driving the entire modeling chain show that such diverse results as future habitat development in Lake IJssel and the coincidence of high flow in the Rhine and storm Surge in the North Sea can be obtained.

We are convinced that by formalizing the model linkages in a data and modeling platform, we increase the consistency of the different scenarios .

3 Samenvatting

Nederland bereidt zich voor op een sneller stijgende zeespiegel en een veranderend klimaat. Hiervoor is het Deltaprogramma gestart. Dit deltaprogramma voorziet een serie beslissingen die grote gevolgen zullen hebben voor het beheer van het water in Nederland. Om deze beslissingen zorgvuldig te nemen is informatie nodig over hoe het klimaat en de stijgende zeespiegel dit waterbeheer zullen beïnvloeden.

In de Rijn-Maas delta komt het water via de regen van boven, via het grondwater van beneden, via de zee door de voordeur en via de rivieren door de achterdeur. In de delta komt dit water samen. Om een goed beeld te krijgen van de consequenties moeten zowel de effecten van de trends in de vier aanvoeren afzonderlijk worden doorgerekend als combinaties ervan. Combinaties van gebeurtenissen zoals het samenvallen van niet al te extreme hoge waterstanden op zee met die op de rivieren, kunnen leiden tot extreem hoog water op de benedenrivieren. De stijgende zeespiegel zal bij lage rivierwaterstanden leiden tot het indringen van zout diep landinwaarts. Via het grondwater komt zout omhoog, dat weg wordt gespoeld met water dat uit deze rivierarmen wordt gehaald. Tijdens laagwater op de rivieren kan dat leiden tot zilter water dat minder geschikt is voor de landbouw en niet geschikt voor drinkwater.

Dergelijke gebeurtenissen hangen allen samen met de weerscondities boven dit deel van Europa, het weer op de Noordzee heeft te maken met het weer boven het Rijnstroomgebied. Daarom moet een modelplatform dat gemaakt wordt om kwantitatie informatie hierover te geven, bestaan uit simulatiemodellen die het geheel beschrijven van de Alpen tot aan de Atlantische oceaan.

Verder is Nederland een klein en dichtbevolkt land; adaptatiemaatregelen spelen veelal op kleine schaal en de gevraagde informatie is zeer gedetaileerd. Maatregelen in het ene deel van Nederland, hebben bovendien gevolgen voor het waterbeheer in het andere deel. Ook dit moet in samenhang kunnen worden beschouwd.

Dit alles stelt grote eisen aan een dergelijk modelplatform. De verantwoordelijke ministeries hebben daarom opdracht gegeven om het Deltamodel te bouwen. Dit model is erop gericht maatregelen in het water systeem in Nederland op een samenhangende wijze door te rekenen.

In dit Kennis voor Klimaat coupling-project wordt een modelplatform ontwikkeld dat op dit Deltamodel vooruitloopt. Er worden bestaanden modelsystemen gekoppeld die te samen de Nederlandse waterhuishouding beschrijven. Tevens worden de modelsystemen voor de Nederlandse waterhuishouding verbonden met systemen die dit sterk beinvloeden, via de noordzee en het

Rijngebied. Dit laatste valt buiten de scope van het deltamodel en hier ligt dan ook het innovatieve karakter van het coupling project. De ervaringen in het coupling project worden echter wel direct doorgegeven aan de ontwikkelaars van het deltamodel.

Inhoudelijk is het in een dergelijk integraal systeem belangrijk dat de consistentie voor het bepalen van de gevolgen voor het waterbeheer in verschillende delen van het gebied gewaarborgd is. De modellen die de gevolgen van klimaatverandering berekenen zullen daarom met dezelfde klimaat forcering en gekoppeld aan elkaar moeten worden gebruikt. In dit onderzoek is gekeken naar het linken van hydrologische en hydrodynamische modellen – en daaraan gekoppelde modellen die de ontwikkelingen in natuur en landgebruik modelleren -- die het gebied van de Alpen tot en met de Noordzee inclusief Nederland beschrijven.

Er is gebruikt gemaakt van bestaande modellen (zoals NHI voor Nederland) die met behulp van Delft-FEWS zijn gekoppeld. Pilots zijn uitgevoerd waarbij 30 jaar ESSENCE klimaat gegevens zijn gebruikt om de ketting van modellen aan te sturen. Daarbij zijn de resultaten gebruikt om te kijken naar de habitat ontwikkeling in het IJsselmeer en het gelijktijdige voorkomen van een hoge stormopzet aan de kust en een hoge afvoer van de grote rivieren.

Tegelijkertijd is gewerkt aan het beter koppelen van een luchtkwaliteitsmodel aan een klimaatmodel. Deze koppeling en de gedraaide testen laten zien dat het gemaakte data en modelplatform het maken van klimaatscenarios consistenter en gemakkelijker maakt. Het formaliseren van de koppeling tussen de verschillende modellen in een platform verhoogt de consistentie tussen resulteren klimaatscenarios voor de verschillende disciplines.

4 Background and Scientific Significance

The Netherlands are carring out the Delta programme for preparing their water management system to adapt to climate change and sea level rise. The preparation for these changes needs a number of decisions regarding the way the Netherlands will organize their water system. This includes the flood protection system and the water supply and the distribution of this water over the different sectors and regions. Among the decisions are the protection of the Rotterdam Harbour area against the risk of flooding, the increase of water stocks by rising the levels in lake Ijssel in summer and the distribution of the river water over the different river branches. Such measures cannot be taken independently but need to be evaluated in concert, as they may seriously affect each other.

In the Netherlands, situated in the Rhine Meuse delta the water management system is extremely complicated and executed in detail. Variations in sea level, such as spring tides, storm surges, but also in discharge from the rivers and in rainfall all play a role. Moreover the entire system is heavily regulated.

To develop and evaluate such adaptation strategies requires information of possible future development of physical boundary conditions as well as changes in socio economic development. During the past years much research has been carried out to provide this type of information at various research centres. The results are published in many reports and scientific papers. The quantitative results of this research are, however, not easy to access and to use by third parties. So far an overall model, taking all these interactions into consideration is lacking.

The water authorities in the Netherlands therefore commissioned the preparation of a delta model that should provide the information required for long term decisions on the design of the water management system.

This Knowledge for Climate project supports this imitative. Where the main goal is to develop interfaces between the climate models and climate impact models and to carry out selected pilot studies based on the combination of the different components using an integrated model platform. Wherever possible we have tried to use existing components (models) and integrated them into a flexible model and data platform.

The end product is a data and modelling platform that facilitates the supply of consistent scenarios for physical boundary conditions as well as for other boundary conditions. Initially the platform is limited to data exchange; later fully coupled models may be constructed. Such a platform allows for regular updating and guarantees that the scenarios will be based on up-to-date science and technology.

The development of a data and modelling platform has a strong technological character supporting further research into climate impacts. The modelling platform will integrate a series of numerical models describing the hydrology, hydraulics in the Rhine basin and additionally the effects for flood risk, water demand and distribution in the delta. This enables the provision of continuous simulations of the hydrological and hydraulic response on climate change. The boundary conditions of the modelling platform are formed by the Alpine region in the south (where the River Rhine starts) while the lower boundary is located at the border between the Atlantic ocean and the North sea. The innovative value of the platform is that it allows simulating the hydrological response of the water system in the Rhine-Meuse basin, the Rhine Meuse delta and the adjacent North Sea directly from the output of regional and global climate models. Thus it handles climate impact effects in a consistent way. By using poor-man ensembles (created using the outcome of multiple models) uncertainties can be taken into account. Accessibility of existing models and data will be improved. In addition, the platform is also able to include new models and run those with the same consistent data set. This makes it possible to investigate uncertainties associated with different model concepts by comparing them side by side within the same environment and learn from these new models. Figure 4.1. shows a number of available modelling systems indicating the different temporal and spatial scale they are working in.

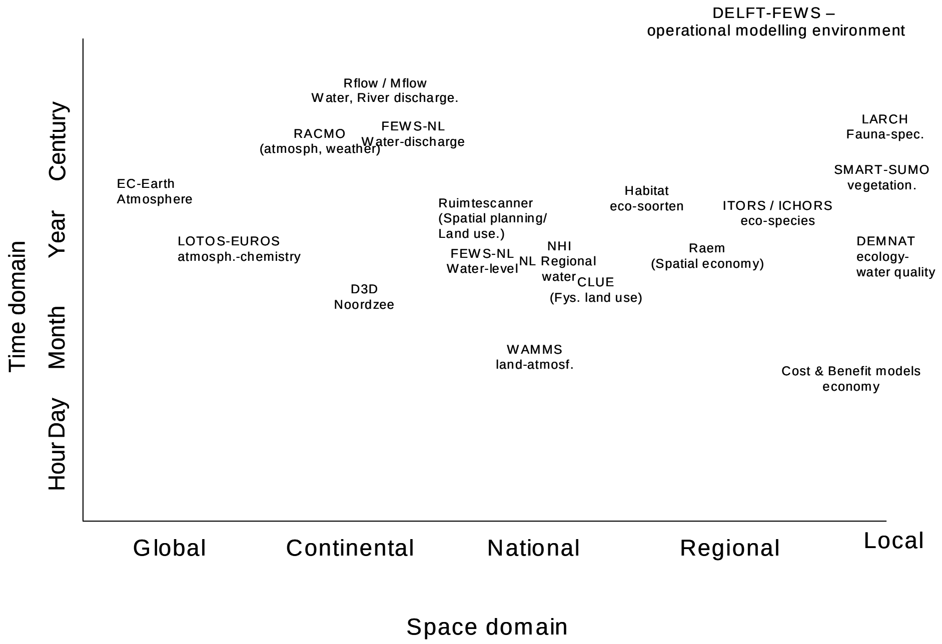

Figure 4.1 Available modelling systems to evaluate the effects of climate change in The Netherlands, plotted in time and space domain

5 Project structure and setup

Many useful climate and climate impact models are available at the different research institutes in the Netherlands. So far, however, they are not optimally coupled. Such a coupled system enables to address climate adaptation issues at the regional to local scales. As a prototype of such a system, a distributed model and data platform is set up in this Climate Knowledge Facility project. Existing state-of-the-art technology (Delft-FEWS, Werner et al., 2004) is used to build the system. Next, the feasibility of the coupled system will be tested in two main areas: climate-water and climate-air quality.

The research approach in the project used the following assumptions:

- The Model Platform should provide scientifically sound quantitative information on temporal and spatial changes in climate, effects of climate change and impacts including changes in frequency and magnitude of extreme events.

- Models are linked in series, which implies that the output of one model is input for the next model. No feedback mechanisms will be incorporated between modelling systems at this stage.

- The Model Platform makes use of existing modelling systems for different sectors, maintained and operated by the individual partners.

- In general, lower resolution models are run first, where the low resolution models supply boundary conditions for the higher resolution models.

- The climate-air quality coupling is set-up outside of the climate water model platform

The project is carried out in three phases:

Phase 1 is the Inception phase. This resulted in the functional and technical design of the coupling of the modelling platform. In this phase an inventory is made of the available data, modeling systems and simulation results. During the inventory a workshop was held with stakeholders to discuss the models to be included in the system and the proposed setup in Delft-FEWS. Minutes of the workshop can be found in the technical report (Schellekens et al., 2011a). From the findings, a functional design and a technical design was made. In particular, models for water, nature, ecology and socio-ecomomic factors were selected based on user needs, on their scientific value, their relevance for spatial planning and on their ability to be linked with the system. These include models describing the hydrological system of the Netherlands including the National Hydrological Instrumentarium (Delsman et al., 2008); and the Lotos Euros chemistry transport model.

In Phase 2 the coupling with climate scenario's (meteorology) was investigated. The sister Future Weather project delivers climate data with an emphasis on extremes and spatial and temporal characteristics of meteorological variables. In phase 2 the models identified in phase 1 are critically assessed and the input of meteorological variables analyzed. Future weather episodes are selected and data is prepared for input in the climate impact/effect models. In Phase 3, the pilot phase a series of pilot studies were executed:

- *Pilot 1*. A pilot study that couples the available data and models for the main water infrastructure in the Netherlands. This includes the main Rivers (from the Alps down to the sea) , the water demand and distribution in, supply to and drainge from the polders, Lake IJsselmeer but also the Dutch coast, Waddensea and SW delta. In later pilots other models can be added. The results will support the design of strategies for flood protection and strategies to mitigate the effects of drought periods. Use is made of existing models for the Rhine-Meuse river basins (based on FEWS-NL), hydraulic models for the river branches FEWS-NL and a 1-D (Sobek) Schematisation for the tidal river area), IJsselmeer (an existing 1D representation of Lake IJssel, the North Sea (schematisations of Delft3D) and (parts of) the Netherlands Hydrological Instrument (NHI). All models are linked through serial exchange of data series using the DELFT-FEWS interface. This is described in section 6.1 and 6.4. See also the full technical reports.

- *Pilot 2*. A pilot that explores to which extent the system LOTOS-EUROS coupled to RACMO meteorology is able to represents the present-day climate. Since both climate models and chemistry transport models contain biases, a bias correction is required when studying the impact of climate change on air quality. In this pilot an existing link between the RCM RACMO and the Chemistry Transport Model LOTUS-EUROS is used. The purpose of this pilot is to assess the impact of the biases in the meteorology of the RCM on modelled air quality parameters. Emphasis is put on ozone and particulate matter. This research is summarized in section 6.2. See also the full technical report.

Finally, a second workshop was held in which the results where presented to a group of stakeholders and scientists.

6 Results

6.1 Inventory of available and accessible data and models and design and first setup for a pilot system

The section describes the approach taken in this project to come to a design and prototype of the Model Platform that can be used to investigate the effects of different climate scenarios and forcing on the water systems of the Netherlands. The Model Platform is based on existing models and technology; the climate scenarios are delivered by the KNMI. The Model Platform reads and stores those scenarios and makes them available to the models within the Model platform. Geographically the Model Platform will include the whole of the Rhine/Meuse basin, The Netherlands and the North Sea.

Handling the vast amounts of data and the different numerical models is far from easy. These tasks are taken care of by the DELFT-FEWS system. . Delft-FEWS is used to provide a consistent user interface and data storage. In addition, it runs models and retrieves and analyses results. The different models within the Model Platform are linked using time series of boundary conditions. The Model Platform is designed to be able to run scenarios up to 150 years in length. Detailed models like high resolution versions of the North sea model cannot be included into the Model Platform without adjustments because running these kind of models for 150 years is not feasible due to computing power restrictions. We use the same procedure as already pioneered in FEWS-NL GRADE that simulates the discharges in the Rhine and Meuse basin (de Wit and Buishand, 2007). Here, fast running models are employed for the whole period using daily time steps. However, during periods of interest, more detailed models that have longer run times (and require smaller timesteps) may be run. Within the Model Platform it is possible to run models at daily time steps and use the results of these runs as a starting point for modeling certain periods at smaller time steps.

We use the climate forcing data as-is assuming that the climate data that the Model Platform ingests is the best available. The Model Platform enables to apply bias correction but no bias correction development is done within this project. Earlier work with Delft-FEWS and seasonal forecasting systems (Schellekens et al., 2008) showed that Delft-FEWS could handle the tasks needed for bias correction of climate models easily.

Geographically we identify the following systems (see also Figure 6.1):

- Systems that include models to predict the flow for the main rivers (Rhine and Meuse) upstream of the Dutch border

- Systems that (in detail) model the main rivers within The Netherlands

- Systems that model the local (e.g. Waterboard) systems within The Netherlands (excluding Lake IJssel)

- Systems that include models for the coastal water level in the North sea and the Waddenzee

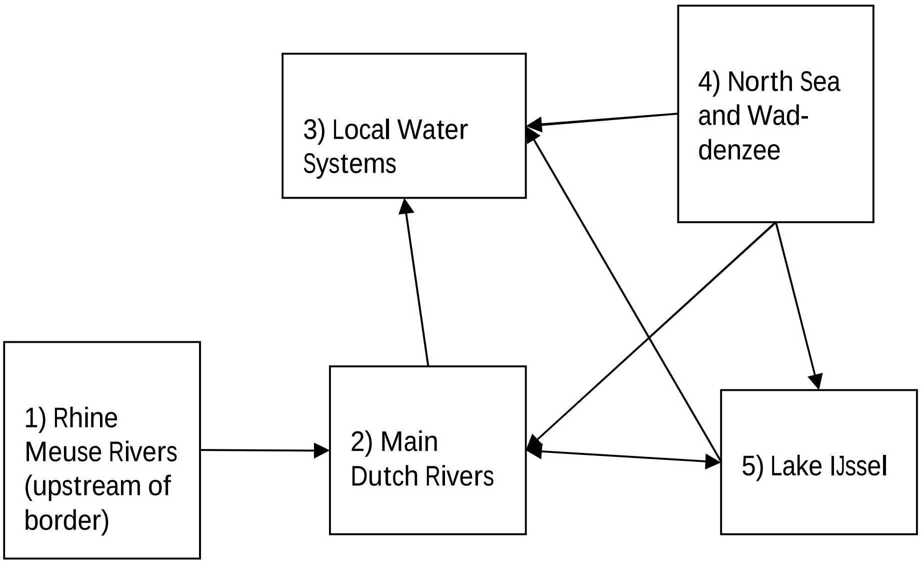

Figure 6.1 Schematical layout of the available systems. Arrows indicate assumed connections, either one-way or two-way

The philosophy of Delft-FEWS is to provide an open shell for managing data and models. The modular and highly configurable nature of Delft-FEWS allows it to be used effectively both in simple systems and in highly complex systems utilising the full range of hydrological and hydraulic modelling. Delft-FEWS can be deployed either in a stand-alone, manually driven environment, or in a fully automated distributed client-server environment (see Figure 6.2).

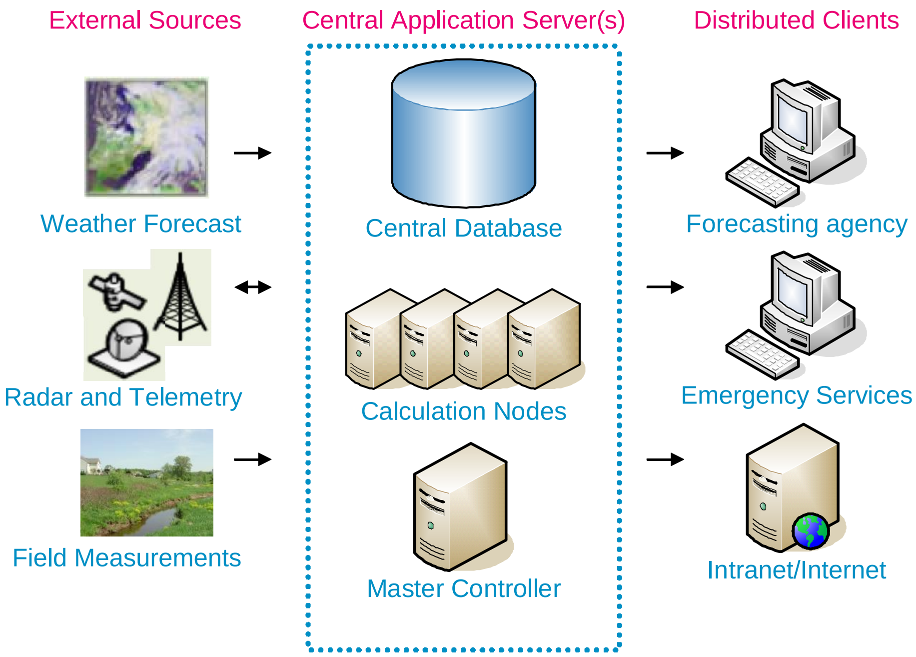

Figure 6.2 Components of Delft-FEWS in an operational setup

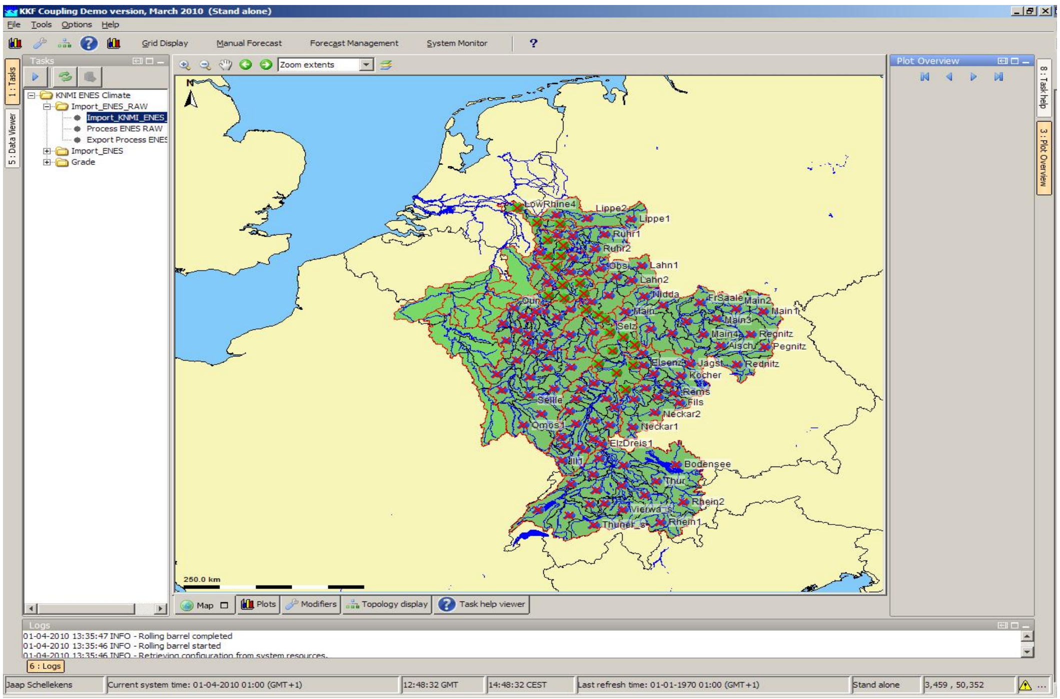

Figure 6.3 User interface (Based on Delft-FEWS) of de model and data platform

Delft-FEWS has the ability to run multiple models simultaneously and distribute the workload over several computers which is beneficial when having to run a large number of models. Originally designed for forecasting, Delft-FEWS has been extended over the years. At the moment it runs the National Groundwater Modelling System (Farrell, 2009) in the U.K and the NHI system in The Netherlands. By placing all models under the control of Delft-FEWS a consistent user interface is obtained. The interface allows detailed inspection of data in graphs and tables but also provides a graphical overview of the model domain and status of the system. In addition, reports can be configured to show key statistics of the results of a scenario run without needing to know the system in detail. The user interface of the system is shown in Figure 6.3.

Based on the inventory and the results of a workshop the first setup of the Model Platform is build upon the following existing models and systems (see Figure 6.4):

1 The hydrological and hydrodynamic models from GRADE are used to calculate flows and water levels for the Rhine and Meuse basin up to Lobith and Borgharen. The Delft-FEWS GRADE setup is used as the base to link to other models/systems.
2 For the Main Rivers GRADE (SOBEK) and SOBEK-NDB is used. SOBEK-NDB is already coupled to GRADE in FEWS. It is also possible to run the DM model (District model) for the main rivers stand alone (not coupled to MOZART). In that case a file is needed that drives the water distribution at the DM nodes. For critical periods during the full 150 years of climate data 2D WAQUA models may be used later if needed.
3 NHI Light is suited to model the Local Water Systems. DM which is part of NHI-light has added value to the SOBEK models of the Main Rivers system because it deals with water allocation. For critical periods during the full 30 years of climate data NHI light will be used. For the whole period only the DM model will be used.
4 DCSM (Dutch Continental Shelf Model) covers the North- and Wadden Sea and will be coupled to SOBEK-NDB and SOBEK-Bekken. A coupling with DM is questionable because DM always assumes it can discharge to its boundary nodes (North Sea in the case of Northern Delta Basin). More detailed models like ZUNO, Kuststrook and even more detailed models may be used during critical periods within the full 150 years of climate data.
5 For Lake IJssel the SOBEK-Bekken model is used. This model is coupled to DSCM and DM. WAQUA/ SWAN models may be used for this system during critical period within the full 150 years of climate data.
6 Habitat is linked (as a post operation) to the outputs of the IJsselmeer model to determine habitat development over the whole simulation period

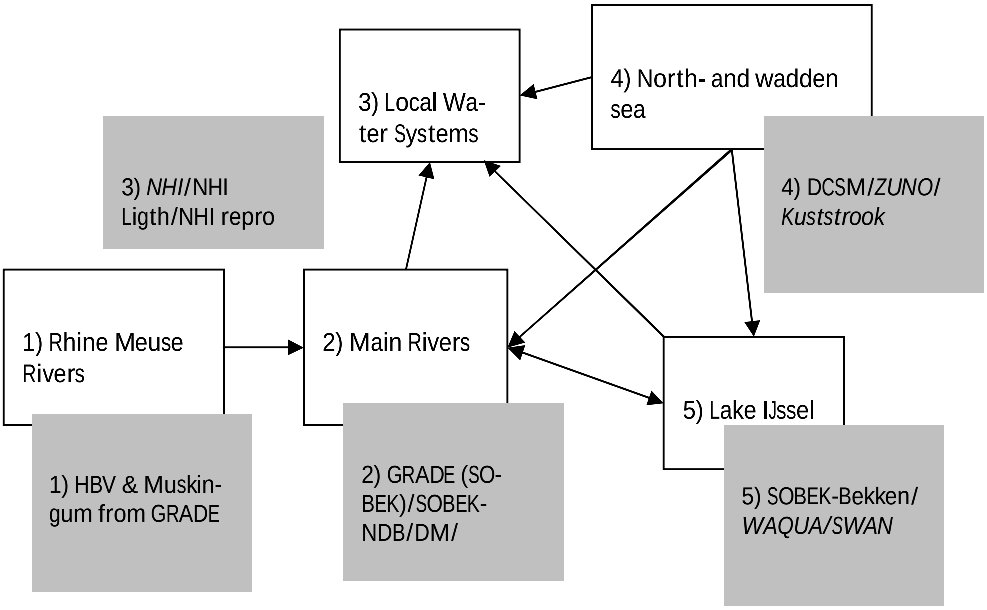

Figure 6.4 Schematical layout of the available systems (detailed models in italic)

6.2 Air quality modelling

Ozone and particulate matter have an adverse impact on the health of humans and other organisms. Their concentrations depend not only on emissions but also on meteorological conditions. In a changing climate, their ambient concentrations are therefore expected to change. However, even the sign of the changes is still highly uncertain, especially for particulate matter. Due to the complex interaction of meteorology and air quality, which is different for different species, and would ideally include feedback mechanisms, the best approach to study the effect of climate change is to use an air quality model that is coupled to a regional climate model, and analyse simulations that are performed with the coupled models. In this section the main results are presented, for the underlying figures and tables the reader is referred to the technical report (Manders et al., 2011).

The chemistry transport model LOTOS-EUROS was coupled to the climate moded RACMO.The coupling consisted of a one-way coupling in which LOTOS-EUROS was able to read the meteorological fields form RACMO, furthermore LOTOS-EUROS was adapted to run in parallel, using openMP and a faster heterogeneous chemisty routine (EQsam instead of Isorropia). The first result of the project is that the coupled system works and that runs can be performed within an acceptable amount of computation time. A full simulation of 1970-2060 using the coupled RACMO--LOTOS-EUROS models took about 45 days on 32 processors at the ECMWF computing facility. Below, the simulations that were performed with the coupled models and their main results are described. At this stage, the emphasis was on the identification of biases in meteorology and air quality for the present-day climate by comparing the set-up with RACMO to the set-up with the ECMWF analysis meteorology that is generally used for LOTOS-EUROS and with observational data of air quality.

First, a RACMO run was performed for 1989-2009 using ERA-interim fields at the boundaries, and coupled to a LOTOS-EUROS run. A comparison of this meteorology with ECMWF analysis meteorology for 2003-2007 showed that for variables that are important for air quality, namely daily maximum temperature, daily average wind speed and wind direction, the correlation was very good with minor biases. Only for rain, which is also highly important, the correlation was poor, but annual totals were comparable. Rain is notably difficult to model and due to its discrete character small mismatches already lead to poor correlations.

From a comparison of modelled air quality with observed concentrations for LOTOS-EUROS runs with ECMWF meteorology and with the RACMO-ERA_interim meteorology for the years 2003-2007, it followed that in general, modelled concentrations are correlated with observed concentrations for both runs and that their dependency on wind, temperature and rain is comparable. However, some biases were found in both runs. Ozone is under predicted for high temperatures. Nitrate and ammonium are too sensitive to high temperatures and not sensitive enough for low temperatures and tend to be underestimated, even more so in the RACMO-LOTOS-EUROS run with EQsam. Sulfate is underestimated but its temperature dependency seems to be represented correctly. For black carbon and sea salt, no validation could be done due to a lack of observations.

Finally, a run with LOTOS-EUROS using RACMO meteorology with ECHAM5r3 A1B climate scenario boundary conditions was performed for 1970-2060. A preliminary analysis was done, restricted to 2003-2007. This already revealed differences in the meteorology: when using the climate scenario there were overall lower daily maximum temperatures, higher wind speeds and more rain, resulting in lower ozone and particulate matter concentrations. The period of 5 years is too short for a solid bias characterization of the meteorology and will be extended to the full ERA-interim period (1989-2009) to get more reliable estimates.

In general, the sensitivity of the model to changes in meteorology is good enough to use the model for a study on the impact of climate change to air quality, although great care should be taken to account for biases. When LOTOS-EUROS is driven by RACMO with the ECHAM5r3 A1B scenario, lower concentrations of ozone and PM were found, which is consistent with the identified relationships between modelled (and observed) concentrations and the meteorological variables. The present analysis will be extended to both 1989-2009, to identify biases on a more solid basis, and to 2039-2059, to study the impact of climate change. This will be part of a follow-up of the project (KvK 2nd tranche). In order to get more insight in the uncertainties of the climate models, also a run with meteorological boundary conditions from the global climate model MIROC will be performed. Runs with different emission scenarios, both anthropogenic and natural (additional NOx due to flashes, additional mixing in of stratospheric ozone), and land use may follow. In addition, it is intended to establish a two-way coupling be-tween RACMO and LOTOS-EUROS, so that RACMO can use aerosol fields modelled by LOTOS-EUROS to model their effect on cloud formation and radiation. Ultimately, the interaction between air quality and climate is taken into account, although there is still a long way to go. First steps to-wards a two-way coupling of LOTOS-EUROS and RACMO have been taken.

6.3 Inventory of social economical models (Land Use and flood damage)

Land use plays an important role in the assessment of climate change impacts. Also, scenarios of land use change are useful because land use change in a densely populated delta strongly related to (changes in) the demand for land from a multitude of other sectors (e.g. housing, work, infrastructure, agriculture, and nature). Hence, scenarios of land use changes can be regarded as indicators of the resulting spatial pattern of changes in the latter sectors. Moreover, land use is a key component in water safety due to its double-sided impacts on flood risk (defined as probability x consequences). Firstly, upstream changes in land use can lead to changes in infiltration, evapotranspiration, and runoff, and hence to changes in the frequency and magnitude (hazard) of floods (Kundzewicz and Schellnhuber, 2004; Milly et al., 2002). Secondly, land use changes in flood prone areas (e.g. urbanisation) can cause an increase in potential damage or loss of lives in the event of a flood (Kundzewicz and Schellnhuber, 2004). The alteration in risk as a result of the latter two factors also influences land use decisions, for example people may prefer not to settle in risk prone areas. Moreover, many adaptation measures involve land use changes through spatial planning (for example limitations of urban development in flood-prone areas, establishment of water retention areas, and reforestation on steep slopes and upper parts of catchments).

Hence, the coupling of land use change models/scenarios with other physical impact models (e.g. hydrological models) provides a very useful way to include key socioeconomic drivers and impacts of climate change in a coupling platform such as that strived for in this study. Preliminary offline couplings of the impacts of land use change on runoff have been made for the Rhine and Meuse catchments, showing the possibilities of such an approach (Hurkmans et al., 2009; Ward, 2008).

Here we discuss some essentials when considering the coupling of *(a)* a land use model with a hydrological model to simulate the impacts of changes in land use on discharge; and *(b)* a flood damage model with a hydrological model to simulate the impacts of changes in land use and climate (and other factors) in flood prone areas on flood-risk.:

- *Spatial resolution*: Does the spatial resolution of the land use model support the spatial resolution needed for hydrological modelling and/or flood damage modelling? Some land use models work at a high spatial resolution, but for larger areas the driving factors are often not available to support such high resolution simulations, and uncertainties are therefore high. For damage modelling it useful to have land use data at a relatively high resolution, e.g. 100m x 100m, since land use in flood prone areas may be heterogeneous, and is a key factor in defining the potential damage. However, the socioeconomic data needed to make such detailed land use predictions are not always available and several studies have shown that predictability of land use change at high spatial resolutions is normally very low (Pontius et al., 2008);

- *Time-span*: Most simulations of land use change only consider a time-span of approximately 20 years (e.g. until 2030). However, the largest changes in climate, and thus impacts on hydrology, are expected later. Moreover, the differences in projected climate conditions between different emissions scenarios become greater in the second half of the 21st Century (Solomon and others, 2007). Uncertainties in land use modelling become very large after 2030.

- *Land use classes*: when coupling a land use model with a hydrological model and a damage model, it is important to note that the land use classes needed for the hydrological component and the damage component may differ. For hydrological modelling it is important to use classes that differentiate in terms of factors such as evapotranspiration whilst for damage modelling differentiations must be made primarily in terms of the potential damage per land class. For example, for hydrological modelling it may be useful to have several sub-classes of the land use class “nature” (due to different impacts on evapotranspiration, water retention, etc.), whilst for damage modelling the most important differentiation of sub-classes is likely to be needed between different urban classes (due to differences in potential damage).

- *Output-input compatibility*: the output of one model should, in principle, be able to be used as input for the next model in the model platform, without the need for major adjustments. The type of data of the output of the first model should, ideally, be directly compatible with the next model (i.e. land use as direct input for a damage model designed to work with land use). When this is not the case, the input for the next model should be able to be derived with relative ease from the output of the first model (e.g. crop factors derived from land use to drive a hydrological model). If the next model requires a different type of input than is available from the first (i.e. number of employees, cars or other objects for a damage model), coupling will require extensive manipulation of the output (with associated uncertainty in the result) in order to be useful up to a point that coupling is not feasible anymore.

The purpose of coupling a land use model with the hydrological model is primarily to assess the change in hydrological response as a result of land use change. These changes can be in terms of changes in mean discharge, but also changes in the return period of high-flow events (e.g. flood with return period of 1250 years) or periods of low-flow. Land use models often themselves consist of a number of interacting coupled models: land claims and macro-level influences are often determined by macro-economic multi-sectoral models (e.g. GTAP), whilst in allocating agricultural areas, changes in agricultural yields also need to be accounted for, which requires biophysical models (Verburg et al., 2008). The land use models themselves, such as CLUE and Ruimtescanner, allocate these claims for different land uses in a spatially explicit way. These spatial allocation results can then be used as input to hydrological models.

Basd on the review of models and data the following recommnations are made:

- For a study of changing land use, climate, and hydrology in the Rhine basin, it is recommended to modify existing modelling platforms for this purpose. If the Rhine basin as a whole is to be considered, we recommend the use of the CLUE/CLUE-Scanner models; if only the Netherlands is to be considered we recommend the use of the Ruimtescanner given the specialisation and experience of these modelling frameworks in these regions. For the macro-economic scenarios, use can be made of the large number of scenarios already available within the EURURALIS project (http://www.eururalis.eu)..

- For the land allocation model, a specification of the land use classes targeted at an optimal fit with the hydrological and damage models is recommended. This could be achieved within the currently operational models but requests a considerable amount of time. A quicker option is to use the existing modelling framework, and to link the land use classes as well as is possible to hydrological characteristics (Hurkmans et al., 2009).

Figure 6.5 Land use classes in the existing CLUE model configurations for the Rhine and Meuse

Nr.	Land cover class
0	Built-up area
1	Arable land (non-irrigated)
2	Pasture
3	(semi-) Natural vegetation (including natural grasslands, scrublands, regenerating forest below 2 m, and small forest patches within agricultural landscapes)
4	Inland wetlands
5	Glaciers and snow
6	Irrigated arable land
7	Recently abandoned arable land (i.e. “long fallow”; includes very extensive farmland not reported in agricultural statistics, herbaceous vegetation, grasses and shrubs below 30 cm)
8	Permanent crops
9	Arable land devoted to the cultivation of (annual) biofuel crops
10	Forest
11	Sparsely vegetated areas
12	Beaches, dunes and sands
13	Salines
14	Water and coastal flats
15	Heather and moorlands
16	Recently abandoned pasture land (includes very extensive pasture land not reported in agricultural statistics, grasses and shrubs below 30cm)

Recommendations and requirements for coupling in KKF-platform

- The simplest coupling for the definition study would be in the form of a “soft” coupling, whereby the output land use maps are simply produced offline, and then provided as input files for the hydrological model. To carry out this option would require approximately three weeks, comprised of the following. The preparation of new, simple, scenarios or configurations towards the KNMI climate scenarios would require 2 weeks (1 week for preparation of scenario and 1 week running/analyzing model), and the preparation of output data and documentation would require approximately 1 week. Note that extra time would be required to achieve further disaggregation of the “built up” land use class for use in the damage model. Alternatively, the scenarios of land use for the Rhine Basin of the Ruimtescanner could be used in the damage modelling component, though this would then involve a coupling of both CLUE and the Ruimtescanner in the platform.

- An improved model coupling could be carried out in a later phase of the KKF-coupling project, depending on the user-needs and level of integration. Large innovations can be made by improving the harmonisation of hydrological, damage, and land use models (including economic modelling), including the definition of land use classes specifically tailored to the needs of the hydrological and damage models. Strongly improved model integration would require an effort of several months to years. Small improvements can be made relatively easily by gathering more specific data for the Rhine catchment, improving the economic model by regional economic modelling that would improve the representation of urban growth and allow a proper simulation of different urban land cover types.

In the Netherlands, there are currently two main flood damage models, namely HIS-SSM and the Damagescanner. The Damagescanner is a simplified model based on HIS-SSM principles, the main alteration being that the land use data are given only in the form of land use classes. This means that an eventual link with the previously mentioned coupling of land use model-hydrological model is relatively easy to realise (if the required land use and inundation maps are available).

In the Damagescanner, each land use class is assigned a maximum potential damage (in Euros), based on empirical data derived from HIS-SSM. Stage-damage functions (SDFs) are used in the model to calculate the actual proportion of this maximum potential damage that would occur for a given inundation depth. A requirement of the Damagescanner (and all inundation based damage models) is a map showing the inundation extent and depth associated with a given flood (for example a flood with return period of 1250 years). In principle, a coupling within the KKF-platform would ideally include a hydraulic/hydrodynamic component, so that maps of inundation depth can be produced under the new scenarios. Hence, we also recommend the inclusion of such a component in the final modelling platform, as this is often seen as a missing link between hydrological and flood impact modelling. However, hydraulic/hydrodynamic models of this nature are not currently included in the KKF-platform, and indeed such models are intensive in terms of computation time. An alternative approach is that used in the project Attention for Safety. In this project, an existing inundation map for a given flood return period (and associated discharge) is used, for example the Rhine Atlas. Then, the hydrological model is used to simply estimate the change in probability of occurrence (return period) of a high-flow event of this magnitude. In this way, the change in risk can also be calculated since an estimation of the change in probability of a given inundation depth is known. We stress, however, that innovative advances could be made in the final modelling platform by coupling the hydrological model with a hydraulic/hydrodynamic model, and then coupling the hydraulic/hydrodynamic model with a damage model. This would also allow for transferability of the tool to basins where no prior inundation maps are available.

6.4 Linking models in NHI

Starting from 2006, Deltares, Alterra, Netherlands Environmental Assessment Agency and RWS Waterdienst have combined to create a single hydrological model for the Netherlands, the Netherlands Hydrological modeling Instrument (NHI). The model aims at unifying the hydrological foundation under Dutch water management. The model combines the latest available data from different national databases with some of the latest modeling techniques. The NHI aims at modeling the complete interconnected hydrological system. The model was set up with several requirements in mind. A key requirement of the model building process was consensus among the participating institutes, all with different historical backgrounds in hydrological modeling

The instrument is used by the ministries involved in national water policy matters, for instance drought management, manure policy and hydrological scenario calculations related to climate change. The Netherlands Hydrological modeling Instrument is also used in emergency planning during pronlonged dry periods. The Netherlands Coordination Committee on the Distribution of Water determines the distribution of water in periods of extremely low river discharges.

The Netherlands Hydrological modeling Instrument makes full use of available national databases. Nationwide data is becoming increasingly available at ever finer resolutions. The NHI uses amongst others topographical data, elevation data, soil data, land use data water management data and data on the subsurface.

The basis of the modeling instrument is a state-of-the-art on-line coupling of the groundwater system (MODFLOW) and the unsaturated zone (metaSWAP). Optionally a national surface water module (MOZART-DM) can be added, in which surface water distribution, discharge and supply are accounted for.

Saturated groundwater flow in the NHI is modeled using a MODFLOW model (McDonald and Harbaugh, 1988). The model area covers the entire mainland of the Netherlands, excluding only the southernmost part. The horizontal resolution of the model is 250 meters. Including a buffer area to minimize boundary effects, the model area consists of 1300 x 1200 cells. The NHI opted for a seven-layer vertical discretization of 6 aquifers, 6 aquitards and the phreatic surface.

The hydrogeological schematization of the model was based on the REGIS system. The REGIS system stores regional hydrogeological information of the subsurface of the Netherlands (VERNES and VAN DOORN, 2006). In the REGIS system, coring data is hydrogeologically interpreted and translated into a hydrogeological model of aquifers, aquitards and faults of the subsurface of the Netherlands. An automated procedure was used to translate the available hydrogeological information of the subsurface into the seven-layer model schematization of the NHI. In the procedure aquifers and aquitards were combined using pre-defined rules to form the model layers. This flexible approach allowed for expert influence on the model schematization, yet retains full reproducibility.

The unsaturated zone is modeled using an on-line coupling of MODFLOW with the metaSWAP model. The metaSWAP model (Veldhuizen et al., 2006) has been developed as a meta-model of the SWAP model. The SWAP (Soil Water Atmosphere Plant) model is a deterministic column-model of the unsaturated zone, and the interaction of the soil with its supported vegetation and the atmosphere. Comparison of metaSWAP with the original SWAP model shows excellent agreement, while calculation times have been reduced (van Walsum and Groenendijk, 2008). The metaSWAP model operates on the same spatial resolution as the MODFLOW model.

Surface water flow is accounted for in the coupled water balance models MOZART and DM. The regional surface water system is schematized in MOZART using drainage basins of around 2 km^2. The model accounts for drainage, precipitation and evaporation and local water management including level control, water distribution and flushing. Topographical and elevation data have been combined with information on weirs to calculate discharge-stage relationships in an automated procedure. Local water boards were interviewed for information on local water management rules. The DM model calculates water distribution at the nation scale. The model allows for the simulation of water allocation to drought-affected areas. Water management rules are based on current practice by the Ministry of Transport, Public Works and Water Management.

Supporting effective policy analysis not only requires modeling the effect of scenarios on the hydrological system, but also on the functions it supports. The Netherlands Hydrological modeling Instrument therefore occupies a central place in a larger framework of models and effect-models, such as AGRICOM for agriculture, GeoPearl for pesticides, STONE for nutrients and SMART-SUMO for nature.

The four model components (groundwater, soil water, regional surface water and water distribution) are coupled in different ways; four relevant couplings can be distinguished:

1. MODFLOW and a metaSWAP: Online in a fully integrated model code. MetaSWAP is invoked by MODFLOW as though it was a MODFLOW package; ground water recharge is computed; calculations and exchanges take place on a daily basis.

2. MOZART and metaSWAP: Online with separate codes, the coupling is done for a demand and allocation phase; runoff and irrigation are computed; metaSWAP calculations are on a daily basis, the MOZART and exchange time step is one decade.

3. MOZART and MODFLOW: Online with separate codes, the coupling is done for a demand and allocation phase, MODFLOW calculates the exchange between groundwater and surface water; MODFLOW calculations are on a daily basis, the MOZART and exchange time step is one decade.

4. MOZART and DM: Online with separate codes, the coupling is done for a demand and allocation phase; the exchange of surface water between the regional surface water and the main surface water system is computed; the time step for both models and the exchange time step is one decade.

This project puts heavy constraints on the computing time needed of the indivual components. For the sake of this project therefore an important part of the coupling schemes have been improved. This concerns a new and improved metaSWAP-MODFLOW model code and an online connection to MOZART and the salt transport module TRANSOL. State-save options are implemented for MODFLOW, metaSWAP and TRANSOL. The code has been restructured such that the control of the individual modules takes place through the main program.Existing NHI coupling software is analyzed in detail and dramatically cleaned up and put in a library.The coupling with MOZART is achieved using a control file. Finally the NHI control batch files were updated. As a result, calculation times have been reduced by 50 %.

The coupling schemes have been implemented in Delft-FEWS. Model adapters transform imported data (stored in the Delft-FEWS database) into model input files, After a model run, the adapters read data from the model output files and store these data in the Delft -FEWS database. In this way, an adapter can be seen as the connection between Delft -FEWS and the models. Each day, a model run is performed to calculate the actual state of the system. For the coupled MODFLOW-MetaSWAP model, this implies that precipitation and evaporation are read from the database and written as input files for MetaSWAP. Surface water discharges are taken from the database as input for the MOZART/DM model.

All model output is post-processed by the adapters and stored in the DELFT-FEWS database. Users can visualize relevant output data within DELFT-FEWS. For drought forecasting, water demand and water shortage are essential parameters. Based on this information, the National Coordinating Committee for Water Distribution can advise on the water distribution and, for example, can suggest to reallocate water.

Additionally, in this project the link between AGRICOM and the NHI has been reflected, improved and implemented in FEWS. AGRICOM is an acronym for Agricultural Cost Model. It is an agro-economic model based on the results of a hydrological model calculating costs and benefits for the agricultural sector in the Netherlands. This concerns the effects of too dry, too wet or salty conditions in the Dutch agriculture. The concept of AGRICOM dates from the early eighties. In 2009 an update and improvement of AGRICOM concept was initiated, based on the AGRICOM definition study (Bakel et al., 2009). AGRICOM is to be used in connection with the Delta Program.

AGRICOM consists of three consecutive programs that are invoked subsequently: first the NHI results are made suitable for AGRICOM (subprogram NHI2ACM), then AGRICOM itself performs its calculations. Finally the AGRICOM results are summarized in tables and grid files.

6.5 Nature

Within this project no actual link to nature models has been made but the possibilities were examined. A full description of the work is given in Barendracht et. al. (2011).

In this section the available models that can be applied in the Netherlands are evaluated. Unfortunately, most models are based on the present conditions and cannot incorporate the higher CO_2 concentrations or the changes in precipitation. Models that are “climate-proof” are in construction, but these will probably not available in the near future.

Figure 6.6 gives and overview of the available vegetation prediction models and their properties.

Figure 6.6 Overview of vegetation prediction models and their properties

Model	Applicability	Input hydrological variable	Other input variables	Output
MOVE	Common, The Netherlands	Change in moisture (undefined) from index numbers	pH and nitrogen	Chance of species occurrence
NTM DEMNAT	Common, The Netherlands; Wet Parts	Change in moisture, Groundwater level (from index numbers),	Soil and pH	Nature value and ecotope completeness

Model	Applicability	Input hydrological variable	Other input variables	Output
		composition		
ICHORS ITORS	Surface water and Groundwater controlled systems in the West of The Netherlands	Change in hydrology and surface chemistry. Groundwater from field observations	Complete ion balance and soil / morphology	Chance of species occurrence
SMART2-SUMO2-MOVE4	Common, The Netherlands	Change in moisture. Partly from soil type, partly from index numbers.	Soil type, pH and succession stage	Chance of species occurrence
NICHE PROBE	Dunes in The Netherlands (recent changes suggest a wider application with PROBE2 may be possible)	Change in water levels and management. (from field observations)	Soil composition and structure. Management influences	Chance of vegetation type
NUCOM	Dry sandy soils (Veluwe)	Changes in water stress (from field observations)	Environmental conditions (> 100 variables)	Chance of species occurrence

We can distinguish four types of models that are available to predict the effects of a change in conditions on the vegetation / plant species.

1. models that use expert knowledge as starting point in the modelling;

2. models that use data from the field to model with regression analysis. One of the problems is that these ecological models cannot be applied in a chain of models: the hydrological and chemical changes have to be incorporated.

3. A third type of models uses different sub-models (soil & water, succession, ecology) and gives the results of one sub-model as input to another model.

4. A fourth type of models is based on the mechanical modelling of all known relations in an ecosystem; this is possible for a defined ecosystems but not for all ecosystems.

The *Natuur Technisch Model* and the DEMNAT model can calculate possible changes in the value of a nature area and the completeness of the ecosystem. A link with GIS systems can be used to give a country wide image for The Netherlands. This system does not include the processes in the soil and the availabilities of nutrients. This means that a large number of assumptions are needed to assess how these variables may be influenced by the (future) climate.

Alternatively the linked sequence of models SMART2-SUMO2-MOVE4 can be used. Here, SMART models the soil processes assuming the soil responds similarly to a future climate as it does to the current. By linking this set of models the effects of changes in hydrological variables can be translated to changes in soil properties and eventually biotic variables. Country wide assessments can be performed by linking the models to appropriate GIS layers. How well this sequence of model works in a different climate is not known (e.g. length of summer, changing temperature and CO_2 concentrations). In addition, changes in salinity (that will probably occur in the west of The Netherlands as a result of a changing climate) are modelled with Ellenberg-numbers but the quality has not been verified. These numbers have been derived from central-European datasets without the maritime influence present in the Netherlands. Clearly, this will not be an issue outside of the coastal zone in The Netherlands.

The approach used in the ICHORS-ITORS system (based on field measurements of site variables for different plant species) can quickly evaluate different the physiological optimum of many species using solute concentrations, salinity and water levels as a driving force. Soil parameters that explain the nutrient availability are not modeled and are part of the model forcing.

Based on the above we suggest applying a system of sub-models that are connected in calculations. The most promising example is the series SMART2-

SUMO2-MOVE4 mostly based on the fact that they match well with the results delivered by the hydrological and meteorological models, with the suggestion to add the impact of salinity and phosphorus to these models (see Barendregt et al., 2011 for details).

6.6 Application of KKF-pilot system in case studies

A pilot model and platform has been established in Delft-FEWS using a suite of already existing hydrological and hydrodynamic models. The inventory of models and a description of the system are given in section 6.1. The goal of this work was to test the pilot system and to demonstrate its capabilities including the sort of information the system can provide. Therefore, two case studies have been performed (see Schellekens et al., 2011b for details). The goal was not to analyze results in detail and draw conclusions from it, as this would require a full, bias-corrected input dataset. This work is targeted for in tranche 2 of KvK (in Theme 6).

The first case study investigates the joint probability distribution of extreme discharges from the main rivers and extreme water levels at the North Sea. The case demonstrates if the Model Platform is capable of computing the joint occurrence of extremes from the main river and the North Sea using a continuous and long time series of climate inputs.

In the second case study, HABITAT models of the Marker and IJsselmeer, integrated in the Model Platform system are run using decadal averaged statistics on water levels. This information is derived from the SOBEK-Bekken model of the IJsselmeer area. HABITAT stationary computes the suitability of ecotopes, based on the environmental conditions in the area considered. The Model Platform can theoretically be used to assess such ecotope conditions in a transient mode.

To be able to perform the case studies, a long enough time series of input data to FEWS-KKF is needed. A 30-year (2001-2030) dataset from the “Ensemble SimulationS of Extreme weather events under Nonlinear Climate change” (ESSENCE) project is used, containing wind speed, temperature, dew point temperature, surface pressure, precipitation and radiation. For more details on the content and format of the dataset, we refer to Schellekens et al. (2011b). The available series are short, relative to the goals of the case studies. However, longer time series are expected to be available after the finalization of the ESSENCE project. The input data has been used as is, without any bias correction of the ESSENCE variables. Bias correction is planned to be included in the KvK Theme 6 project in cooperation between Deltares and KNMI.

The large quantity of global data necessitates subsetting to smaller files. This is done in a separate routine, outside the model platform[1]. Furthermore, the data were spatially subsetted within the Model Platform to cover a smaller extent, covering only the domains of the models, used in this study. Finally, the smaller domain gridded data is converted into the required model inputs within the pilot system.

For the IJsselmeer area case study, a number of additional models have been added besides the already implemented hydrological and hydrodynamic models in the GRADE system on which the Model Platform is based. First of all, the SOBEK-BEKKEN model for the IJsselmeer area were implemented in the model platform. This model simulates water levels in the Markermeer and IJsselmeer. Water level estimates are needed to force HABITAT models of the Markermeer and IJsselmeer, which can consequently estimate ecotope suitability based on changes in water level conditions. Two HABITAT models of Markermeer and IJsselmeer, that were originally built to estimate the effect of a 1.5 meter rise of the water level according to the Veerman plan (Maarse, 2009), were implemented in the Model Platform without making any changes to the models themselves. HABITAT is not designed to perform transient computations. Therefore a number of work-arounds are required to make this possible. These are described in detail in the case study report (Schellekens et al., 2011b).

The 30 years of pre-processed ESSENCE data are used to make a 30-year model run in the model platform. The following model systems were run at a daily time step:

- GRADE Rhine/Meuse
- SOBEK Northern Delta area (boundary conditions from GRADE and DCSM)
- Delft Continental Shelf model (North and Wadden Sea)
- SOBEK-Bekken (IJsselmeer area, boundary conditions from DCSM and GRADE Rhine/Meuse)

The daily simulations are performed in subsequent workflow runs of 20 days each in which each next run starts from the initial conditions (hotstart) saved at the end of the previous run. The average run time of one run is about 45 minutes per 20 days, which gave a total run time of 17.5 days for 30 years of simulation. The DCSM model takes most of the time (about 39 minutes per run).

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[1] A new development in Delft-FEWS made for the NMDC (Nationaal Modellen en Data Centrum) alleviates this problem allowing the system to directly get (subsets of) data from a KNMI OpenDAP server.

The dynamics of ecotopes have a long time scale. Therefore, the results from the SOBEK-Bekken model are aggregated to time scales of 10 years and used to force the HABITAT models at a 10-year time scale. The HABITAT models require long-term information about the conditions in the lakes. The original HABITAT models use fixed winter and summer levels as input. In this model experiment, these levels are derived from the SOBEK-Bekken outputs and averaged over 10-year periods. The derived water depths are consequently used to determine the habitat suitability for several species in the IJsselmeer and Markermeer. The above-mentioned depths and resulting habitat conditions are calculated for 3 periods: 2001-2010, 2011-2020, 2021-2030. These periods may be too short to represent climate change. During the analysis, it was found that the natural variability, resulting from the SOBEK-Bekken model runs was relatively small. The regulation of lake ijssel appears successful in maintaining the water level over the period under investigation. Therefore, the HABITAT results are also expected not to vary significantly from decade to decade.

From the 30-year model run, the joint probability for yearly maximum water levels occuring at both Hoek van Holland (North Sea) and Dordrecht (Rotterdam harbour area) are estimated. The joint probability of exceedance of combinations of these water levels is estimated by accumulating the joint probability density function (see Figure 6.7). According to the analysis with the 30-year dataset, the recurrence time of exceeding of the alarm level at both locations is 3 to 4 years. This recurrence time seems rather short. This could be due to the lack of bias correction of the ESSENCE input data.

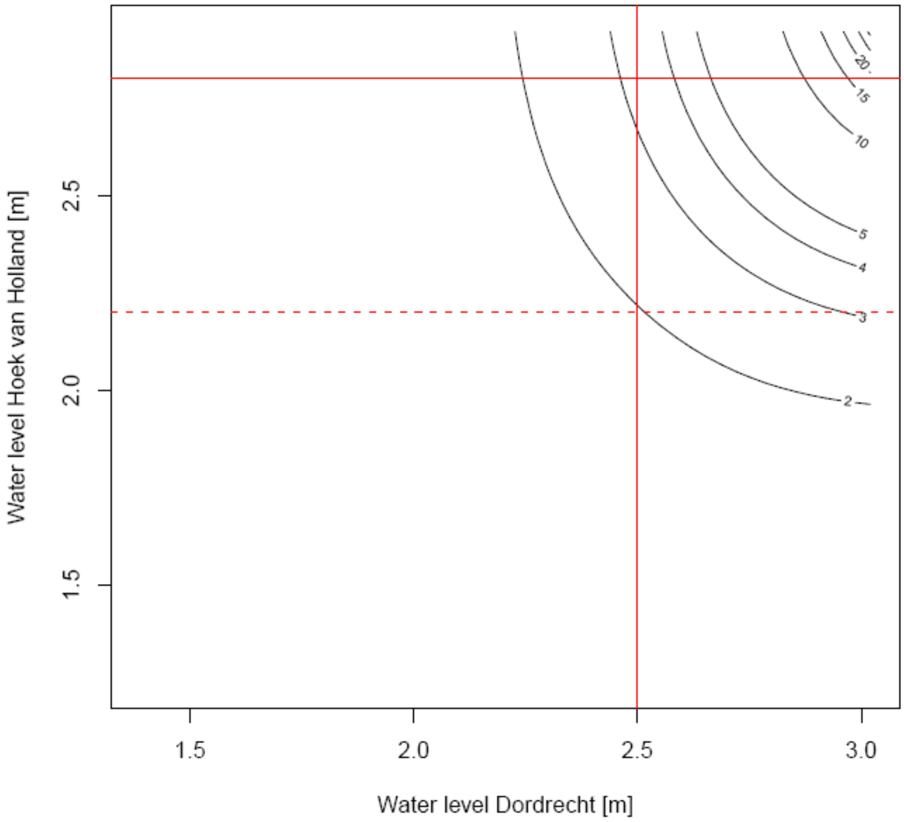

Figure 6.7 Contours of return periods [year] for water levels at Dordrecht and Hoek van Holland

The experiment shows that HABITAT models can be run and forced by the model platform. The decadal HABITAT model results show an insignificant difference from decade to decade. This is on the one hand caused by a too insignificant change in climate over the 30 years of data, and on the other hand because the survival rules which determine whether a species can occur within a pixel or not, are based on static information on long-term averaged, fixed water levels only. Given the fact that the Model Platform computes water levels dynamically, more complex survival rules could be implemented, for instance dependent on the rate of change of water levels. Also, the effect of specific extreme events could be taken into account and the presence of species combinations could be modelled as a transient state. Such an extension would make the HABITAT models more realistic and more useful for transient simulations.

7 Discussion and Conclusions

The linking of the models can facilitate the preparation of climate scenarios in the investigated areas (water, air quality, nature, land use). By formalizing the model linkages in a data and modeling platform, the consistency of the different scenarios is also increased. A full coupling of all models (hydrology, air quality, nature) is not feasible yet, but progress has been made within the separate areas.

Hydrological models

The inventory of existing models revealed enough models that can be sensibly linked using the Delft-FEWS framework. The resulting data and model framework is capable of running the long timeseries that are required in climate modeling and can be fed with one consistent climate scenario. Run times for the chosen set of models are acceptable. However, several detailed models should only be run for specific periods of interest, a strategy that has successfully been used in earlier research (i.e. GRADE). The case study results have led to the following conclusions:

- The Model Platform is capable of running long series of climate data. This requires decomposing the input data into small temporal and spatial domains and decomposing the computation into small temporal slices due to memory constraints.
- The 30-year run resulted in a number of issues where models were not producing any output. These issues are being investigated.
- The results of a run with the Model Platform can be used to estimate joint probability distributions of events.
- HABITAT models can be implemented within the model platform, but require at the moment of writing, some work-arounds to take care of the non-transient character of these models.

The following recommendations are made based on the case study results

- Impose projected sea level rise on the DCSM model results for more realistic scenarios.
- Replace typical profile downstream boundary conditions of SOBEK-Rhine and SOBEK-Meuse (as part of GRADE Rhine and Meuse) for astronomical tides for more realistic boundary conditions.
- Perform bias-correction of the ESSENCE input data or use other (corrected) climate model results.
- Perform longer simulations to provide more samples to better estimate joint probability density functions, and in order to observe changes in HABITAT conditions.
- Introduce more complex survival rules in the HABITAT models, (e.g. rate of change of water levels and occurrence of extreme events) and make the species occurrences transient states.

Recent work in KvK by KNMI (Kew, in preparation) suggest that the occurrence of a high surge after a large precipitation event in the Rhine basin has a higher probability of occurrence than what would have been if the two events where to be totally independent. Based on an analysis of 17 ESSENCE ensemble members they concluded the change of a high surge after a high discharge can be four times higher than expected from independent events. It is suggested to use the same dataset with the set of models linked here to see if similar results are obtained using the combined modelling as opposed to the simple 2-20 day precipitation sum for the Rhine used by Kew as a proxy for Rhine discharge. Results from this work may have an impact on the current methods used to determine dike heights in the lower parts of the Rhine river.

The Netherlands Hydrologic Instrument (NHI) describes the water movement in groundwater and surface water as well as the management conducted for the major part of the Netherlands. The NHI constitutes a vital link to the effects of climate change on water-related functions. Under this project, the entire logistics of the NHI have been improved, formalized, accelerated and then placed in Delft-FEWS so it can be part of the Model Platform. This concerns the link between the land system (MODFLOW-metaSWAP) and the surface water system (MOZART-DM), including transport of salt (TRANSOL) and the link with the agricultural effect model AGRICOM. This operation, among other improvements led to an acceleration of the instrument by a factor of 2 and greatly improved the ease of use and the possible application in climate change studies.

No effort has been made to make NHI more ‘climate-proof’. The effects of climate change on crop growth and agricultural management can greatly affect the future water demand in the Netherlands. It may even be necessary to model crop development on-line in order to take into account the feedback between climate and hydrology.

Air quality model

The one-way coupling between RACMO and the LOTOS-EUROS air quality model works and after parallelization of LOTOS-EUROS and technical implementation of scripts to run the two models together, a climate run of the coupled system was feasible. At the ECMWF computing facility, this run was done for the period 1970 to 2060. The run took about 45 days on 32 processors which is reasonabe for the present purpose. In general, RACMO seems to be fit to downscale global meteorological fields for the purpose of air quality modelling. A comparison with ECMWF analysis fields for 2003-2007 revealed that RACMO forced by ERA-interim data reproduces the ECMWF analysis fields well except for rain. For daily average wind speed and direction and for daily maximum temperature good correlations were found, and RACMO was up to few degrees warmer on the warmest days. However, when RACMO was used with boundary conditions from the climate model ECHAM5, for the investigated period, the modelled present-day climate was less warm, had less calm days and more precipitation than in reality, thus showing serious biases. These biases stem from biases in the global climate model. One should note that these conclusions are preliminary, since a five-year period is too short to form a solid basis to quantify biases. LOTOS-EUROS itself models the air quality fairly well in the set-up with ECMWF and RACMO-ERA-interim meteorology, with slightly higher ozone, ammonium and nitrate concentrations when RACMO and EQsam were used. In general, the sensitivity of the model to changes in meteorology is good enough to use the model for a study on the impact of climate change on air quality, although great care should be taken in the quantitative interpretation because of biases.

The intention is to extend the present analysis to include both 1989-2009 (to identify biases on a more solid basis) and 2040-2060, to study the impact of climate change on air quality as part of a follow-up of the project. Also a run using meteorological boundary conditions from the global climate model MIROC will be performed to give an idea of the uncertainty and consistency of the results of the coupled system. Also uncertainties in the emissions for future scenarios should receive attention. It would be interesting to investigate the possibility of using the output of the model (concentration and deposition of pollutants) for ecological models. Another extension of the project could be to investigate the impact of a different land use map on air quality and deposition in the future.

Nature models

Most nature models models are based on the present conditions and cannot incorporate the higher CO_2 concentrations or the increased/decreased precipitation. Models that are “climate-proof” are in construction, but will not be available within the next few years. Prediction of the fauna in future climate conditions cannot be performed yet. We can indicate four types of models that are available to predict the effects of a change in conditions on the vegetation / plant species. Some models use expert knowledge as starting point in the modeling; some others use data from the field to model with regression analysis. One of the problems is that these ecological models cannot be applied in a chain of models: the hydrological and chemical changes have to be incorporated in the model. The third type of model uses different sub-models (soil & water, succession, ecology) and gives the results of one sub-model as input to another model. The fourth type of model is the mechanical modeling of all known relations in an ecosystem; this is possible for defined ecosystems but not yet for all Dutch examples; however, the model PROBE2 is in its last phase of development. The most realistic example is the series SMART2-SUMO2-MOVE4 also based on their ability to be connected to the hydrological and meteorological models.

Land use

It is clear that land use plays a key role in the assessment of climate change impacts. On the one hand, scenarios of land use change are useful because land use change itself is (among other things) dependent on changes in the demand for land from a multitude of other sectors (e.g. housing, work, infrastructure, agriculture, and nature). Hence, scenarios of land use changes can be regarded as indicators of the resulting spatial pattern of changes in the latter sectors. Moreover, land use is a key component in water safety due to its double-sided impacts on flood risk (defined as probability x consequences). Hence, the coupling of land use change models/scenarios with other physical impact models (e.g. hydrological models) provides a very useful way to include key socioeconomic drivers and impacts of climate change in a coupling platform such as that strived for in this study.

Social and economical models

The simplest coupling for the definition study would be in the form of a “soft” coupling, whereby the output land use maps are simply produced offline, and then provided as input files for the hydrological model. An improved model coupling could be carried out in a later phase of the KKF-coupling project, depending on the user-needs and level of integration. Large innovations can be made by improving the harmonisation of hydrological, damage, and land use models (including economic modelling), including the definition of land use classes specifically tailored to the needs of the hydrological and damage models.

To link hydrology with flood risk in a changing climate the Damagescanner is suggested as an appropriate tool to estimate damage under given inundation scenarios. The Damagescanner is currently available in several formats, including ArcGIS, PC-Raster, and MATLAB. The model is simple to re-programme into any other computing language, and therefore a direct coupling should be relatively easy, assuming that the necessary input data are available. The most practical coupling may be to re-programme the Damagescanner in the language of the KKF-modelling platform, so that it can be directly incorporated. It is recommended to include a hydrodynamic component in the KKF-platform to simulate inundation extents and depths in flood events. This can serve as input for the Damagescanner, and make large advances in coupled flood damage modelling.

8 Lessons learned

8.1 Techniques for model coupling

To make a tool that is easy applicable, computer run times have to be acceptable. To obtain this, one should critically review the separate models on their performance. In our tool the possibility to run several detailed models only for specific periods of interest was introduced. As a result, the framework with several coupled models is capable of running long time series in acceptable run times. The framework made here will be used as a starting point for the production facility of the Deltamodel.

A simple sequential coupling was sufficient for many of the models. This allowed us to capitalize on existing (Delft-FEWS) technology. The use of open standards means that the links made in this project can be used by others also. Extra work done as part of the NMDC has extended the framework with a link to OpenDAP servers. This allows the framework to tap into the large amount of data made available through OpenDAP and at the same time publish the results similarly. In addition, an open system allows other researchers to revisit the work done with the system and draw their own conclusions.

8.2 Application of coupled models in research on the impact of climate change

Decision makers in the Netherlands face the complex task of taking robust decisions now, in order to obtain a ‘climate proof’ country in 2050 and beyond. The outcomes of these decisions aim to ensure water safety, and adequate water resources for nature, agriculture, industry, inland shipping and drinking water. Measures for water safety and, for example, spatial planning, affect water resources, and vice versa. In other words, water management in the Netherlands is an integral issue and involves many disciplines.

The information on the impacts of climate and land use change that reaches those decision makers, however, is very scattered. Different institutes provide at various moments different projections for changes in precipitation, temperature, air quality, discharge, groundwater, salt intrusion, nature and agriculture.

The coupled models can be a platform to cluster scattered projections, and combine them into a consistent projection for all those impacts. In this way, the outcomes for different sectors can be compared. In addition, coupled models enable more detailed research on the impact of climate change, for example by investigating feed-back mechanisms between land use change and meteorology.

One particular interesting application is the occurrence of high surge in the North Sea after a high precipitation event in the Rhine. Recent work by KNMI (Kew, in preparation) suggests the events are not independent. The platform developed here allows us to investigate the effect thereof in more detail.

8.3 Further work in Theme 6 – High quality climate projections

The outcomes of this project proofed to be very useful, but it was acknowledged that further work is needed to optimize the model platform for practical application in climate science. Therefore, in Theme 6 (High quality climate projections), we defined a work package called 'WP3 - Scenario development for climate change impact'.

In Theme 6, we will build on the available knowledge and software from this project. Based on the results, recommendations and lessons learned, the following projects were defined:

1. Exploring effective methods to apply information on climate change and its effects for the design of climate adaptation.
2. Coupling of climate data and agronomic models.
3. Scenario development for nature using ecosystems models.
4. Scenario development for water using hydrologic and land use models.
5. Coupling of climate and air quality models.
6. Dealing with uncertainty in adaptation application.

More information is available at:

http://knowledgeforclimate.climateresearchnetherlands.nl/highqualityclimateprojections

and

http://public.deltares.nl/display/KvKThema6/Home

8.4 Link to NMDC

Recently, the Nationaal Modellen en Data Centrum (NMDC) has been established (see http://www.nmdc.eu). Within that centre a project has been established that uses the framework developed here as a case study. Extensions to the system in the form of an OpenDAP reader have been developed as part of this project and a better connection with the SMART-SUMO nature models is now in the making. In addition, NMDC may host the system developed here on it's servers allowing the system to develop further run faster and provide access to a large community.

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To develop the scientific and applied knowledge required for Climate-proofing the Netherlands and to create a sustainable Knowledge infrastructure for managing climate change

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