Appendix C: Project Description

C.1 Summary

HYdrological Modelling for **A**ssessing **C**limate Change **I**mpacts at differe**NT** **S**cales (**HYACINTS**) will develop new methodologies and tools to enable easier and more accurate use of regional scale climate and hydrological models to address local scale water resources problems.

A new fully dynamic coupling exploiting OpenMI technology will be established between the climate model code HIRHAM and the distributed physically based hydrological model code MIKE SHE. Based on the coupled model system, an integrated climate-hydrological model for the entire Denmark will be established by combining the regional climate model HIRHAM and the national hydrological model (DK model). As part of the coupling a statistical downscaling and bias-correction method will be developed for conversion of data from large (25 km) climate grids to small (e.g. 1 km) hydrological grids. Remote sensing data and techniques will be utilised and further developed with respect to assessing and downscaling of global precipitation datasets in mountainous areas where precipitation is controlled by orographic effects. In order to facilitate downscaling of hydrological models from regional models (e.g. the existing DK model) to local scale models with more detailed geological and topographical resolution, improved grid refinement methods will be developed. Furthermore, improved methods will be developed for handling complex geological environments when changing model scale. The total uncertainty in hydrological change predictions taking all sources of uncertainty into account will be assessed and an improved methodology for assessing the effects of geological uncertainty will be developed.

HYACINTS has 12 partners: two universities, two research institutes, one GTS institute, one SME research and consulting company, one large consulting company, three water companies from the largest cities in Denmark and two Environment Centres.

C.2 Project objectives

The overall objectives are to establish improved tools and methodologies for assessing effects of climate change on water resources at both regional and local scales and to test these on cases relevant for the water supply sector in Denmark and for an international case relevant for export of Danish water resources management expertise. The specific scientific objectives are:

- To make a full dynamic coupling of a climate model code (HIRHAM) and a distributed physically based hydrological model code (MIKE SHE).
- To further develop precipitation downscaling and bias correction methods when converting climate model results to hydrological model inputs.
- To develop grid refinement methods for hydrological models and methodologies for optimal conceptualisation, simulation and downscaling of complex geological environments.
- To develop new methods for estimation of precipitation from remote sensing data, particularly aimed at mountainous regions with poor data coverage.
- To establish a coupled climate-hydrological model for the entire Denmark based on the regional climate model HIRHAM and the MIKE SHE based national hydrological model (DK-model) and to assess the hydrological change at local scale at selected cases.
- To assess the uncertainties related to prediction of climate change effects on water resources at local scale, including all sources of uncertainty (climate scenarios, model structure, geological interpretations, model parameters and adaptation strategies).

C.3 Expected main project results

The project will develop new methodologies and tools that enable easier and more accurate use of regional scale climate and hydrological models to address local scale water resources problems. The expected main project results are:

- A migration of two state-of-the-art model codes (HIRHAM and MIKE SHE) to the OpenMI standards and establishment of a full dynamic coupling between the two model codes. Making the two codes OpenMI compatible ensures that the coupling can survive future regular developments of the two codes and it enables both model codes to be easily coupled with other model codes.
- A coupled climate-hydrological model for Denmark comprising DMI's regional climate model (HIRHAM) and GEUS' national hydrological model (DK-model) that is based on the MIKE SHE code. This will improve our ability to make more reliable climate and land-use change assessment.
- A methodology and software tool for statistical downscaling of precipitation from a regional climate model grid to hydrological model grids. This will be implemented as part of the coupled model for Denmark.
- A methodology and tool for assessing and downscaling of precipitation from remote sensing datasets in areas where orographic effects are important.
- Improved facilities in MIKE SHE for grid refinements, so that regional scale hydrological models can easier be used with finer grids at local scale.
- Improved methods for handling complex geological environments, particularly aiming at situations where a local scale groundwater model is built on the basis of a regional model, and where the local model can resolve much more of the geological complexity than the regional model.
- An analysis of the uncertainty of hydrological change predictions at local scale. This will include an assessment of how much the individual sources of uncertainty, such as climate scenarios, model structure, geological interpretation, model parameters and adaptation strategies, contribute to the total prediction uncertainty.
- An improved methodology for assessing the effects of geological uncertainty on hydrological model predictions.

C.4 Concept and background for project

Increasing CO_2 levels cause an intensification of the global hydrological cycle, with an overall net increase in temperature, rainfall and runoff, and will increasingly do so (Huntington, 2006). Rising CO_2 levels are also likely to reduce evaporation and there is some evidence that recent increases in river flows globally are due to this effect (Gedney et al., 2006). Although the predictions of future rainfall are fairly uncertain, there are indications, for example, that the Mediterranean region will see reductions of rainfall while more temperate regions, such as Scandinavia, will see increases (IPCC, 2007). The seasonality will also change, causing new, and sometimes unexpected, vulnerabilities.

Denmark has a leading position within hydrological and climate change research. Advanced numerical model codes have been developed including the climate model HIRHAM (Christensen and Christensen, 2003) and the hydrological model MIKE SHE (Graham and Butts, 2006). Additionally, methodologies for comprehensive modelling have been developed (Christensen and Christensen, 2007; Refsgaard and Henriksen, 2004). The two modelling systems have recently been used for quantification of the hydrological impacts of future climate change, also referred to as hydrological change (Roosmalen et al., 2007).

However, the research on hydrological change is still in its infancy both with respect to model accuracy and uncertainty. Traditionally, the analysis of hydrological climate change impacts has been decoupled from climate research as such. Based on the output of global or regional climate models, hydrological models have been run as stand alone models (e.g. Hagemann et al., 2004; Roosmalen et al., 2007; Graham et al., 2007). This means that the feedbacks to the atmosphere (Kim and Entekhabi, 1998) are neglected which has an unknown impact on the predictions of the climate change, particularly at the local scale. Furthermore there is an inherent contradiction in this approach since climate models include their own (very simplified) hydrological model component. For Denmark, the important processes of the groundwater flow and surface runoff through river networks and the interaction between the groundwater and river systems are not represented in current climate models (e.g. HIRHAM; Christensen et al., 1996). So far, only the scientific framework for coupling of the two model types has been investigated (Overgaard et al., 2007) whereas operational models on regional scale has not yet been developed.

Scaling between the climate models and the regional hydrological model (Wood et al., 2004), where the model domain and the grid size is reduced in steps, causes significant problems that have not been solved yet. Climate models operate at spatial and temporal scales that are much larger than the scales required to analyse the effects on the hydrological system. Data on climate change scenarios are available at spatial and temporal resolutions (typically 25 km grid and daily values) that are very coarse for direct application in hydrological modelling addressing local scale problems. Remote sensing data of relevance for hydrological studies such as global rainfall (Dinku and Anagnostou, 2006) have the same problem as data from climate models, namely that they are available at large spatial and temporal scales and require downscaling for most practical application.

Regional hydrological models are increasingly being used as a basis for water resources management, both at national and European scale. The national DK hydrological model (Henriksen and Sonnenborg, 2003; Henriksen et al., 2003) will for instance be made publicly available digitally via the internet in the near future. However, in order to make full use of such regional models to address local scale problems, and in this way ensure coherence in the local and national water resources management, a number of downscaling problems need to be solved. These include model technical issues related to grid refinement (Mehl and Hill, 2004) and issues concerning how to ensure consistency in geological conceptualisation when changing between different scales in complex geological settings.

Geological interpretations are recognised as maybe the primary source of uncertainty in hydrological modelling (Neuman and Wierenga, 2003; Højberg and Refsgaard, 2005). No previous studies have evaluated the total uncertainty on hydrological change predictions including both uncertainties on greenhouse gas emission (Nakićenović et al., 2000), climate model uncertainty (Déqué et al., 2007) and hydrological model uncertainty (Refsgaard et al., 2006).

HYACINTS will develop new methodologies and tools that enable easier and more accurate use of regional scale climate and hydrological models to address local scale water resources problems.

C.5 Innovative value, impact and relevance

In Denmark, the future changes in climate are expected to result in more extreme hydrological conditions. Higher precipitation is predicted in winter resulting in flooding and water logging in low lying areas, whereas reduced precipitation and higher evapotranspiration are predicted during summer resulting in decreasing water tables, dry root zones and reduced low flows in streams. Additionally, rising sea levels and intensified storm events may have important impacts on coastal zones. This is expected to influence future decisions with respect to e.g., planning of infrastructure and urban structures, recreational areas and water resources management. However, the existing tools have important limitations on the accuracy and reliability of predictions of the impact of the future climatic conditions.

The proposed project is expected to result in innovative and operational solutions for quantifying the effects of climate change on the hydrological system at both regional and local scale. The methodologies and tools developed are expected to result in more accurate predictions of the impact of climate changes. Additionally, the uncertainty of the predictions will be quantified and hereby the robustness of the predicted impacts can be evaluated. Both results are important if assessment of the vulnerability as a function of location, present climate, geological settings, land use and season should be produced. It is expected that the results of the project can be used as the basis for generation of a climate impact atlas for e.g. Denmark, which will be highly relevant for future management of the water resources. The methods developed will be generic and will therefore be applicable to not only Denmark but also other places in the world. The export potential of the proposed project deliverables are therefore expected to be high.

The project is also expected to generate novel research results on scientific subjects such as coupling between hydrological and atmospheric models, downscaling over several scales from climate models to regional hydrological models and further to local hydrological models, uncertainty assessment of results generated under several sources of errors and uncertainties, and assessment of climate change impacts in ungauged catchments typically located in third world countries by utilizing new remote sensing products.

C.6 Methodology and expected results

The intention of the present project is to develop the scientific basis for the next generation of hydrological impact assessment methodologies caused by future climate changes. The project will provide the foundation for operational hydrological change assessment with higher accuracy and better precision than previously developed. The project is organised in four scientific workpackages

WP1 Coupling of HIRHAM and MIKE SHE model codes

Modelling the effects of climate change on the hydrological cycle requires a proper understanding of the water and energy exchange between the atmosphere and the land surface. This exchange is a two-way coupling that can have a significant impact on the hydrological cycle under a changing climate (e.g. Overgaard et al., 2007).

To address these limitations a coupled hydrological and climate modelling system will be developed using the two state-of-the-art model codes: the climate model code HIRHAM (Christensen et al. 1996) and the hydrological model code MIKE SHE (Graham and Butts, 2006). The coupling will exploit new OpenMI technology (Gregersen et al., 2007) that has recently emerged from the water sector for coupling model components. OpenMI provides a standardized interface to define, describe and transfer data on a time basis between software components that run simultaneously thus supporting systems where feedback between the modelled processes is necessary (Gregersen et al., 2007). Therefore, OpenMI is ideally suited to linking hydrological and climate models and allows linking with different spatial and temporal representations and across different platforms. This new technology will also be effective in linking the two scientific modelling communities.

The coupling will be made such that HIRHAM’s standard, simple land surface parameterisation scheme (hydrological model) will be utilised in regions not covered by the MIKE SHE model. This will make it possible to apply the coupled code without having to set up MIKE SHE on the entire regional scale covered by HIRHAM and it will therefore save both personal time and computational power.

The statistical downscaling method developed as part of WP3 will be built into the coupling.

The coupled code will be verified by testing against data from a small Danish catchment.

WP2 Scaling of hydrological models

Often, assessments of climate change impacts are required at a local scale. Hence, there is a need for downscaling of the regional hydrological model to the local scale. Flexible numerical grids are required for accurate descriptions of the interaction between streams and groundwater, the flow near large well fields, the flow in cities and for the resolution of complex geological units (e.g. faults, buried valleys, enclosed pinch-outs). Several methods for grid refinement that provide a flexible technique for changing the resolution of the mesh are currently available, including nested grids (Mehl and Hill, 2004), local model builder (Refsgaard et al., 1998) and finite element techniques (Cornaton et al., 2004). The present project will instead focus on development of a new approach exploiting the potential within OpenMI (Gregersen et al., 2007) to develop dynamic coupling between local and regional models. This approach will be evaluated against the traditional refinement methods.

The analyses in this work package will be based on extensive case studies of geology and groundwater flow in areas with complex geology. For each study the national DK hydrological model (Henriksen and Sonnenborg, 2003; Henriksen et al., 2003) will be used as an already existing regional scale groundwater model. In addition, the case studies will be selected so that comprehensive geological and geophysical data are available for a smaller (local scale) geologically complex area. Alternative conceptual geological models will be developed for the smaller area using various geological modelling tools, e.g. MIKE Geomodel (http://www.dhigroup.com/Software/WaterResources/MIKEGeoModel.aspx); GeoScene3D (http://www.i-gis.dk/Default.aspx?tabid=92) and Leapfrog3D (http://www.leapfrog3d.com/). The alternative conceptual geological models will vary from layer based, over pixel based, to very complex models. Some of these models can be built into finite difference based as well as into finite element based groundwater models; others can best be built into finite element based models. The existing regional groundwater model is either refined in the local area or tied to a refined local model, and each of the alternative local conceptual geological models is transferred to the local-scale groundwater model. The alternative groundwater models are used to simulate for example groundwater flow paths and well head protection zones within the local area (Harrar et al., 2003; Højberg and Refsgaard, 2005). For the various cases it is thus investigated to what extent the simulation results are sensitive to the choice of conceptual geological model and to the choice of numerical flow and transport simulation technique. On this basis guidelines are given on how to develop conceptual geological models for geologically complex areas, and on how to numerically simulate groundwater flow and transport in such areas.

WP3 Hydrological change

When dealing with data poor catchments typically found in third world countries remote sensing data are often the best data source both with respect to precipitation and evapotranspiration. However, a serious problem when using remote sensing based precipitation data is that these data are only available at large spatial and temporal scales, typically daily values at 25 km resolutions. In mountainous areas the precipitation is controlled by orographic effects resulting in large inhomogeneities in actual rainfall intensity within the resolution of the remote sensing image. Therefore, downscaling is required, but statistical downscaling methods like those suggested below for application in Denmark are not useful, because time series of precipitation measurement within the catchment is inadequate and because they do not directly address orographic effects. To enable use of hydrological models to assess hydrological change in data poor areas the study will investigate new remotely sensed data products for topography and new data products for precipitation that can be obtained for most parts of the world (Dinku et al., 2007). A methodology will be developed for downscaling precipitation in areas with significant orographic effects based on digital elevation models and a limited number of ground rainfall stations. Additionally, the impact of climate change will be quantified using results from climate models and applying the methodologies developed in the project.

To improve the description of the exchange of water vapour and energy between the land surface and the atmosphere the national DK hydrological model (Henriksen and Sonnenborg, 2003; Henriksen et al., 2003) will be coupled to the regional climate model HIRHAM (Christensen et al., 1996). A coupled climate-hydrological model at a national scale will be novel for the scientific community and is expected to move the ability to carry out accurate hydrological impact assessment significantly forward. A full coupling between the two models will ensure the best possible estimates of water exchange (especially precipitation from the climate model and evapotranspiration from the hydrological model) between the two spheres. However, bias-correction of the climate model results, especially precipitation, might be required for the coupled model (Graham and Bergström, 2001; Graham et al., 2007). An advanced geostatistical downscaling procedure of the low resolution (25 x 25 km) climate model results will be developed based on rainfall observations from rain gauges and radar measurements. The analyzed precipitation events will be subdivided into classes according to the weather system that generated the precipitation (e.g. frontal rain, convection rain). It is expected that the spatial distribution of precipitation and hence the downscaling procedure will be different for the alternative weather systems. Additionally, it will be examined if the bias-correction depends on weather type.

Finally, it will be investigated if the algorithm developed specifically to handle orographic effects can be utilised to improve the above statistical downscaling method to be developed for use over Denmark.

WP4 Uncertainty

To evaluate the significance of results on hydrological change, it is necessary to quantify the uncertainty on both the climate model results (Nakićenović et al., 2000; Déqué et al., 2007) and the error propagation through the hydrological model (Refsgaard et al., 2006; Refsgaard et al., 2007). The climate model uncertainty is a function of greenhouse gas emission scenarios, uncertainties related to the climate models including bias-correction and downscaling methods, and uncertainty with respect to anthropogenic water resources development in the future (management scenario uncertainty). The climate scenario uncertainty will be considered using different greenhouse gas emission scenarios. The uncertainty because of the climate model will be quantified by utilizing the results of the EU project ENSEMBLES (concluded 2009), where the uncertainty including both the differences between multiple climate models and the uncertainty of the individual model predictions are quantified. Management scenario uncertainty will be investigated by defining different scenarios for groundwater abstraction, irrigation, and land use. The effects of these uncertainties will be combined with the uncertainty on the hydrological model which primarily is a function of model scale, model structure, and parameter uncertainty. Focus of the project will be to quantify the uncertainty on the difference in hydrological variables (e.g. groundwater level and stream discharge) when the present and the future climate is used as input. Emphasis will be put on the effect of model structure and model scale on the uncertainty. Multiple model structures will be considered, using e.g. different geological interpretations or stochastic realizations, different model descriptions of the unsaturated zone or using different descriptions of land use and evapotranspiration (Neuman and Wierenga, 2003; Butts et al., 2004; Højberg and Refsgaard, 2005; Refsgaard et al., 2006). The effect of scale, e.g. regional scale compared to local scale, on the uncertainty will be analyzed in relation to catchment heterogeneity and variability in stresses (Refsgaard, 2007). With respect to parameter uncertainty standard methods will be used to transfer the statistical uncertainty on the parameters to uncertainty on the model results.

Real-life tests

The developed methodologies and tools will be tested on real-life cases within their respective work packages. Each of the three water companies will supply a case with the necessary data and the problems to address will be defined in a dialogue with the environment centres. In addition, a fourth case will be identified in a third world country in order to test the methodologies in an international catchment, where the data availability typically is much less than in Denmark. All the developed methodologies and tools will not be tested in all four cases. The test cases will instead be designed so that they have complementary focus.

C.7 Project plan

HYACINTS will be organised in five work packages (WPs). Each of the four scientific WPs is composed of a few subprojects mainly staffed by PhD and PostDoc, see the figure below that also shows an overall time schedule.

Work Package/Tasks – (PhD/PostDoc projects)	2008				2009				2010				2011				2012			
1 Coupling of HIRHAM and MIKE SHE model codes																				
1.1 Coupling of HIRHAM and MIKE SHE (PhD)	░	■	■	■	■	■	■	■	■	■	■	■	■							
Protocol for coupling		■	■	■																
Programming and initial test					■	■	■													
Test on catchment							■	■	■	■										
Reporting (papers)											■	■	■							
1.2 HIRHAM migration to OpenMI (post doc)	■	■	■	■	░	░	░	░	░	░	░	░								
1.3 MIKE SHE migration to OpenMI (scientist)	■	■	■	■	░	░	░	░	░	░	░	░								
2 Scaling of hydrological models																				
2.1 Telescopic mesh (scientist)				░	░	░	░	░	░	░	■	■	■	■						
Dynamic coupling of local and regional models							░	░	░	░	■	░	░	░						
Test on case study (OV and MCO)				░	░	░	░	░	░	░	░	■	░	░						
Reporting (papers)													■	■						
2.2 Complex geology (PhD)	░	░	■	■	■	■	■	■	■	■	■	■	■	■						
Identify case study, data analysis			■	■																
Establish alternative conceptual models				■	■	■														
Apply groundwater flow models (FD and FEM, both with large/small grid sizes)						■	■	■	■											
Test on case study (together with AKV)									■	■	■	■								
Reporting (papers)												■	■	■						
3 Hydrological change																				
3.1 Precipitation (PhD)	░	░	■	■	■	■	■	■	■	■	■	■	■	■						
Identify test case, data analysis			■	■																
Develop methodology and algorithms				■	■	■	■	■	■											
Test on international case study									■	■	■	■								
Reporting (papers)												■	■	■						
3.2 International test case (post doc support)									■	■										
3.3 Coupled model for Denmark (PhD)									■	■	■	■	■	■	■	■	■	■	■	■
Statistical downscaling methodology and tools									■	■	■	■								
Parameterisation and calibration of SVAT (part of coupled code)												■	■							
Establish model for Denmark													■	■	■					
Test on case study (together with KE and MCR)															■	■	■	■		
Reporting (papers)																		■	■	■
3.4 Conversion of DK model to coupled model (post doc)									■	■	■	■								
4. Uncertainty																				
4.1 Geological uncertainty (post doc)							■	■	■	■	■	■	■	■						
Identify case study (identical to one of the other case studies)							■	■												
Develop methodology for characterising conceptual uncertainty								■	■	■	■									
Test methodology											■	■	■							
Reporting (papers)													■	■						
4.2 Uncertainty on hydrological change (PhD)									■	■	■	■	■	■	■	■	■	■	■	■
Develop framework for uncertainty analysis									■	■	■									
Assess individual sources of uncertainty											■	■	■	■						
Integrated uncertainty analysis														■	■	■	■	■		
Reporting (papers)																		■	■	■
5. Co-ordination																				
5.1 Project management and dissemination	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░

■ Full-time activity
░ Part-time activity

The allocation of resources per partner and per WP is given in the table below.

Partner	**Type**	**Person month**					
		WP1	WP2	WP3	WP4	WP5	**Total**
Geological Survey of Denmark and Greenland (GEUS)	Research Organisation	1	2	**14**	**27**	12	**56**
University of Copenhagen	University	3		41	3	1	**48**
University of Aarhus	University		**39**		2	1	**42**
Danish Meteorological Institute	Research Organisation	**57**		2		1	**60**
DHI	GTS	20	12			1	**33**
Watertech	Large Enterprise			7	26	1	**34**
GRAS	SME			39		1	**40**
Odense Water Ltd	SME		6			1	**7**
Copenhagen Energy	Large Enterprise			16		1	**17**
Public Utilities of Aarhus, Water & Waste Water	Large Enterprise		7			1	**8**
Environment Centre Odense	Authority		5			1	**6**
Environment Centre Roskilde	Authority			5		1	**6**
		81	**71**	**124**	**58**	**23**	**357**

Research education is given high priority in HYACINTS. The project includes five PhD positions. Additionally, three PostDoc positions are formulated for recently graduated PhD candidates. The project will cooperate closely with the International Research School of Water Resources (FIVA) that has all HYACINTS research/GTS organisations as active members. Both the PhD and the Post Doc positions will be associated to FIVA. With the establishment of HYACINTS it is furthermore expected that partners will direct coming research applications towards the same topics, so that it will be possible to fund additional PhD positions in related fields. The results generated by the project will serve as the basis for PhD courses on the subjects covered. These courses will be offered to both Danish and foreign PhD students and hereby serve as a platform for communication with climate/hydrological change researchers world wide. Furthermore, the HYACINTS results will be utilised both in MSc programmes at the universities and in continued education courses offered by the Network of Research based Continued Water Resources Education (EVA) that has been established by a subgroup of the institutions comprising HYACINTS. EVA provides an excellent opportunity for communication of the developed methods and tools to potential customers and users of the project deliverables.

C.8 Legal and ethical aspects, etc.

The project does not include data security, health, environmental or ethical issues.

C.9 Publication and promotional strategy

The research results will be presented at international conferences and published in leading international peer reviewed scientific journals.

A public website will be established. It will contain general information about HYACINTS and will regularly be updated with results, reports, articles and other deliverables from the project.

To support dissemination of results to national users a User Forum will be established. The User Forum will be open to all interested members from industry, consulting companies, water authorities and research organisations. The main activities will be regular workshops and electronic newsletters, where preliminary results will be presented and discussed.

To disseminate project results internationally a seminar will be organised in a developing country. This will most likely take place in Asia depending on the site for the international test case to be selected in Task 3.2. The possibility of involving the local Danish Embassy in the seminar will be pursued. The target group for the seminar comprises organisations from the region, including universities/research institutes and potential customers for the HYACINTS products.

In addition to direct dissemination to third parties the HYACINTS partners themselves will utilise the results in their daily work. The water companies will use the tools and knowledge to solve practical and urgent problems related to groundwater protection and abstraction. The consulting firms will make use of the results in their consultancy activities and expect that HYACINTS will improve their national and international competitiveness.

C.10 Innovation

HYACINTS aims at developing innovative tools tested at a prototype level. The key innovative tools will be:

- An OpenMI version of the HIRHAM code (software).
- An OpenMI version of the MIKE SHE code (software).
- A dynamic coupling of HIRHAM-MIKE SHE with a built-in statistical downscaling (software).
- The coupled climate-hydrological model for the entire Denmark. This tool opens a window of opportunities for novel types of applications to support water resources management.
- An algorithm for assessing and downscaling precipitation data from a combination of satellite data and topography.
- Improved facilities for grid refinement exploiting finite element and OpenMI technologies and guidance on scaling in complex geological environments. This opens up new types of applications, where environment centres, water companies and consultants much easier can make use of the DK model to establish local models.

In addition to the tools HYACINTS will develop new methodologies and make novel assessments, e.g. in relation to uncertainty aspects.

The HYACINTS consortium will during the first project year make agreements on partner rights to exploit the HYACINTS products. These agreements will be based on the principles of Background and Foreground rights that are widely used in e.g. EU RTD contracts. The key principles are that (i) all partners will have access right to all the developed tools during the project; (ii) a partner that brings a product into HYACINTS where it is further developed will maintain the exclusive rights to exploit and further develop this product; and (iii) the research and commercial rights for the HYACINTS products after the project will be formulated in a consortium agreement.

C.11 The participating parties

Brief descriptions of the 12 HYACINTS partners are provided below. Professor, Dr. Scient Jens Christian Refsgaard, GEUS will be the Project Leader. The Project Leader as well as many of the other key persons are well recognised international researchers that, by leading and participating in many EU research projects, have developed a comprehensive network of active contacts in the international research community.

Geological Survey of Denmark and Greenland (GEUS)

The Geological Survey of Denmark and Greenland (GEUS) is a research and advisory institution in the Ministry of the Environment. The work field of GEUS - geoscientific studies, research, consultancy and geological mapping - primarily covers Denmark and Greenland. GEUS is partner in Geocenter Denmark.

Department of Geography and Geology, University of Copenhagen (KU)

Research activities include the classical disciplines within geography and geology. The department has a strong earth observation and water resources group dealing with hydrogeology, surface water hydrology, catchment modelling and remote sensing. The staff includes about 80 researchers, 65 PhD students and 42 employees in technical and administrative positions. The study programmes attract more than 660 students, of which around 360 students follow the M.Sc. programme. University of Copenhagen is partner in Geocenter Denmark.

Department of Earth Sciences, University of Aarhus (AU)

The Department of Earth Sciences covers most aspects of the geosciences from geomorphology to geophysics. Recently the department declared hydrogeology and –geophysics one of its focus areas. The department has a permanent scientific staff of 27 and a similar number of technical staff and has excellent laboratory facilities. About 25 M.Sc. and 5 Ph.D. students graduate from the department annually. University of Aarhus is partner in Geocenter Denmark.

Danish Meteorological Institute (DMI)

DMI has about 400 employees and is composed of the Forecasting Services Department, the Observations and Data Processing Department, the Research and Development Department, the Danish Climate Centre and the Centre for Ocean and Ice. About 100 of DMIs employees are scientists. DMI contributes to the education of PhD students through the Copenhagen Global Change Initiative (COGCI) and the International Research School of Water Resources (FIVA).

DHI

DHI is an independent, international consulting and research organisation authorised by the Danish Ministry of Science, Technology and Innovation as an Approved Technological Service Institute (GTS). DHI's activities are based on the development and application of know-how and advanced technologies within coastal, river, ports and offshore engineering as well as ecology, water resources, urban and industrial water and other areas related to the water environment. The DHI group includes the main office in Denmark and 18 international offices with a total staff of approximately 650, the majority of whom are professional engineers and scientists with post-graduate qualifications (35% have a PhD). DHI will therefore provide a strong platform for the national and international exploitation of the HYACINT developments.

Watertech (WT)

Watertech a/s is a 100% Danish owned consulting company specialized in the aspects of water. The current number of employees is around 50. Of these 46 hold a Master's Degree and 20% of these also hold a PhD degree in environmental, civil or mechanical engineering or natural science disciplines. Watertech provides consulting services concerning water resources, water supply, waste water and sewage, water related environment and IT. Watertech often works in close co-operation with universities and other public institutions to develop new methods or integrated approaches. Watertech has main office in Aarhus and an office in Roskilde. In addition Watertech has extended international activities. Watertech is a part of Birch & Krogboe A/S and as such a large enterprise.

GRAS

Geographic Resource Analysis & Science A/S (GRAS) is an innovation company aiming at bridging between research and the applied use of new remote sensing methods and data and Geographical Information Systems (GIS). Assessment of bio-physical parameters, change detection and all types of mapping are the main activities. The clients include companies and institutions within consultancy, infrastructure, water resources, the marine environment, oil and gas exploration, wind energy and agriculture as well as public authorities. GRAS was established in 2000 jointly by the Institute of Geography, University of Copenhagen and DHI. The company has today four permanent employees and is a small and medium enterprise (SME).

Odense Water Ltd. (OV)

Odense Water Ltd. is a limited company which manages operational and construction projects within water supply and wastewater treatment. The primary activities of the company include the production and distribution of drinking water, together with the disposal and treatment of wastewater. In 2006, Odense Water Ltd supplied water to more than 150,000 inhabitants, institutions and industries. Many years' experience, combined with advanced technology and highly trained employees make Odense Water Ltd. to one of the leading water companies in Denmark. Odense Water Ltd. has a staff of 160 and an annual turnover of 260 million DKK and as such is a small and medium enterprise (SME).

Copenhagen Energy Ltd., Water Supply (KE)

Copenhagen Energy is a multi utility company that includes water supply, sewage, gas and district heating. The water supply side has expertise in water management, groundwater protection, water quality monitoring, artificial recharge and maintenance of water supply systems. Also early warning systems are used as a part of the sustainable abstraction strategy that is carried out by Copenhagen Energy. Copenhagen Energy Ltd is a limited company owned by the Municipality of Copenhagen. The company has a staff of more than 1,500 and an annual turnover of 5,300 million DKK. KE is a large enterprise.

Public Utilities of Aarhus, Water & Waste Water (AKV)

AKV supplies 260,000 inhabitants and industry with 18 million m^3 of drinking water per year. It ensures most of the supply of water for the Municipality of Aarhus. AKV is in charge of the water supply plants and the mapping of the fields etc. AKV is presently a public authority under the Municipality of Aarhus. AKV will be converted to a limited company with effect from 1^{st} January 2009. It will then become a large enterprise.

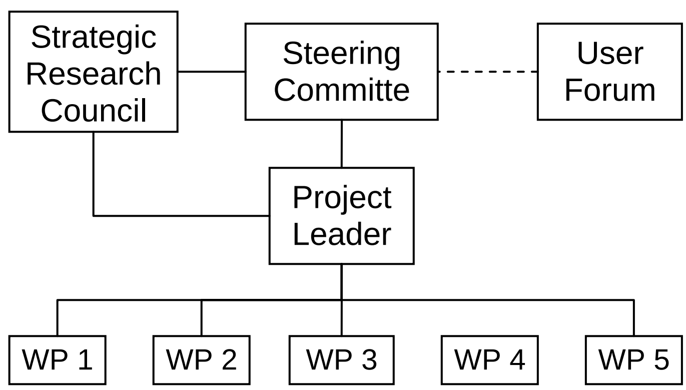
Environment Centres, Odense and Roskilde (MCO and MCR)

Environment Centre Odense and Environment Centre Roskilde are two of seven regional centres under the Ministry of Environment with responsibility for amongst others planning of groundwater protection and implementation of the Water Framework Directive.

C.12 Project organisation and management

Project management

The organisational structure of HYACINTS is shown on the figure to the right. The overall co-ordination and decision body will be a Steering Committee comprising one representative for each partner and a person appointed by the Strategic Research Council. The Steering Committee will have the overall responsibility for the project plans and will approve necessary changes in project plans, including changed allocation of project funds among partners.



Each WP is headed by a WP leader who has the responsibility for co-ordination of the WP work. The WP leaders refer to the Project Leader who has the responsibility for (i) the daily management in collaboration with the WP leaders; (ii) the implementation of decisions made by the Steering Committee; and (iii) the dialogue with the Strategic Research Council. The Project Leader, Professor, Dr. Scient Jens Christian Refsgaard has a well proven record from leading major national and international research projects. To strengthen the project leadership, the Project Leader controls unallocated contingency funds of 0.5 million DKK.

Research training

The PhD and the post docs studies will be supervised by senior researchers from several HYACINTS partners. This co-supervision will contribute significantly to the scientific co-ordination of the project activities. The HYACINTS partners have very positive experience with such jointly supervised PhD studies from the FIVA research school, where this has been a requirement for getting access to FIVA supported scholarships. As an example an ongoing PhD study (Lieke van Roosmalen) has the same four supervisors as the PhD projects 1.1 and 3.3.

Senior HYACINTS researcher	**Project role**	**Supervisor role**											
		1.1 phd	1.2 post doc	1.3 scientist	2.1 scientist	2.2 phd	3.1 phd	3.2 post doc	3.3 phd	3.4 post doc	4.1 post doc	4.2 phd	5.1 User Group
Jens Christian Refsgaard (GEUS)	PL, WP3-L, SC	Co			Co				Co	SU		Co	PL
Torben Sonnenborg (GEUS)	WP4-L, SC					Co					SU	Co	
Flemming Jørgensen (GEUS)						Co							
Lisbeth Flindt Jørgensen (GEUS)	UF												UFD
Karsten Høgh Jensen (KU)	SC	SU							SU				
Peter Engesgaard (KU)												SU	
Inge Sandholt (KU)	SC						SU						
Steen Christensen (AU)	WP2-L, SC				Co	SU							
Jens Hesselbjerg Christensen (DMI)	WP1-L, SC	Co	SU	Co					Co	Co			
Michael B. Butts (DHI)	SC	Co	Co	SU	SU			Co	Co	Co			
Jens Baadsgaard Pedersen (WT)	SC							SU, TC			Co		
Mikael Kamp Sørensen (GRAS)	SC						Co						
Troels Bjerre (OV)	SC, UF				Co, TC								
Gyrite Brandt (KE)	SC, UF								TC				
Jørn Ole Andreassen (AKV)	SC, UF					TC							
Dirk-Ingmar Müller-Wohlfeil (MCO)	SC, UF												UFD
Jens Asger Andersen (MCR)	SC, UF												UFD

Project role:
PL Project Leader
WPn-L Leader of WPn
SC Steering Committee member
UF User Forum

Supervisor role:
SU Principal supervisor
Co Co-supervisor
TC Responsible for test cases
UFD Responsible for dissemination

International cooperation

HYACINTS will establish comprehensive co-operation with international research groups. The co-operation will have different forms such as:

- *Exchange of knowledge*. As documented by joint publications many HYACINTS partners have comprehensive international networks, amongst others from participation in EU research projects. This will be utilised to gain state-of-the-art knowledge and ideas in the research fields.
- *Guest researchers to Denmark and PhD and post doc visits abroad*. Internationally recognised guest researchers will visit Denmark and HYACINTS researchers. Primarily the PhDs and postdocs will make visits to international research groups as part of their research. So far agreements have been made with the following international research groups:

- Professor Axel Bronstert, Universität Potsdam, Germany and also associated as scientific advisor to Potsdam Institut für Klimafolgenforschnung (PIK). Axel Bronstert is leading a German initiative to get funding from the German research councils (Deutsche Forschnungsgemeinschaft) to a major new research programme (Priority Programme) in Hydrological Change.
- Dr. James Brown, Hydrologic Ensemble Prediction Group, National Weather Service, NOAA, Maryland, USA. James Brown is a leading expert in uncertainty assessments.
- Dr. Gerard Heuvelink, Wageningen University, The Netherlands. Gerard Heuvelink has comprehensive experience in scaling and uncertainty assessment for environmental models.
- Dr. Phil Graham, Rossby Centre, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden. Phil Graham is a leading expert in coupling of atmospheric and hydrological models.

Agreements will be made with more groups. Funds to support the international cooperation can be allocated from the HYACINTS contingency funds managed by the Project Leader.

- *Involvement in EU FP7 research projects*. The HYACINTS partners will actively seek to get involved in EU research projects under the 7th Framework Programme.

C.13 Centre and network functions

The existing research infrastructure on hydrological change is scattered over several research groups in Denmark. The main groups are partners of HYACINTS.

As a minor strategic research initiative the major justification and function for HYACINTS are to perform novel innovative research rather than to carry out centre and network functions. Irrespective of this, HYACINTS will automatically facilitate an enhanced cooperation among its partners. In this way HYACINTS will enable the Danish research community to respond stronger and more relevant to the needs for enhanced future research in this field and it will improve the possibilities of Danish researchers to contribute to hydrological change research on the international scene.

C.14 References

Butts MB, Payne JT, Kristensen M and Madsen H (2004) An evaluation of the impact of model structure on hydrological modelling uncertainty for streamflow prediction. Journal of Hydrology, 298, 242-266.

Christensen JH, Christensen OB, Lopez P, van Meijgaard E, Botzet M (1996) The HIRHAM4 Regional Atmospheric Climate Model; DMI Scientific Report 96-4. Danish Meteorological Institute.

Christensen JH, Christensen OB (2003) Severe summer time flooding in Europe, Nature, 421, 805-806.

Christensen JH, Christensen OB (2007) A summary of the PRUDENCE model projections of changes in European climate by the end of this century, Climatic Change, doi: 10.1007/s10584-006-9210-7.

Cornaton F, Perrochet P, Dietsch HJ (2004) A finite element formulation of the outlet gradient boundary condition for convective-diffusive transport problems. International Journal for Numerical Methods in Engineering 61(15): 2716-2732.

Déqué M, Rowell DP, Lüthi D, Giorgi F, Christensen JH, Rockel B, Jacob D, Kjellström E, de Castro M, van den Hurk B (2007) An intercomparison of regional climate simulations for Europe: assessing uncertainties in model projections, Climatic Change, doi: 10.1007/s10584-006-9228-x.

Dinku T, Anagnostou EN (2006) TRMM calibration of SSM/I algorithm for overland rainfall estimation, J. Applied Meteorology and Climatology, 45(6), 875-886.

Dinku T, Ceccato P, Grover-Kopec EK, Lemma M, Connor SJ, Ropelewski CF (2007). Validation of satellite rainfall products over East Africa's complex topography. International Journal of Remote Sensing, 28(7): 1503-1526

Gedney N, Cox PM, Betts RA, Boucher O, Huntingford C, Stott PA (2006) Detection of a direct carbon dioxide effect in continental river runoff records. Nature 439: 835–838.

Graham DN, and Butts MB (2006) Flexible, integrated watershed modelling with MIKE SHE, In Watershed Models, (Eds. V.P. Singh & D.K. Frevert) CRC Press. Pages245-272, ISBN: 0849336090.

Graham LP, Bergström S (2001) Water balance modelling in the Baltic Sea drainage basin – analysis of meteorological and hydrological approaches. Meteorology and Atmospheric Physics 77 (1-4): 45-60.
Graham LP, Hagemann S, Jaun S, Beniston M (2007) On interpreting hydrological change from regional climate models, 81 Suppl. 1, 97-122. doi: 10.1007/s10584-006-9217-0
Gregersen JB, Gijsbers PJA, Westen SJP (2007) OpenMI: Open modelling interface. Journal of Hydroinformatics, 09.3, 175-191. doi: 10.2166/hydro.2007.023.
Hagemann S, Machenhauer B, Jones R, Christensen OB, Déqué M, Jacob D, Vidale PL (2004) Evaluation of Water and Energy Budgets in Regional Climate Models Applied Over Europe. Climate Dynamics, 23: 547-567.
Harrar WG, Sonnenborg TO, Henriksen HJ (2003) Capture zone, travel time, and solute transport model predictions using inverse modeling and different geological models. Hydrogeology Journal 11(5): 536-547.
Henriksen, HJ, Troldborg L, Nyegaard P, Sonnenborg TO, Refsgaard JC and Madsen B (2003) Methodology for construction, calibration and validation of a national hydrological model for Denmark. Journal of Hydrology, 280/1-4, 52-71.
Højberg AL, Refsgaard JC (2005) Model uncertainty - parameter uncertainty versus conceptual models, Water Science and Technology, 52(6), 177-186.
Huntington TG (2006) Evidence for intensification of the global water cycle: Review and synthesis. J. Hydrol. 319: 83–95.
IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Kim CP, Entekhabi D (1998) Feedbacks in the land-surface and mixed-layer energy budget. Boundary-Layer Meteorol., Vol 88, 1–21.
Mehl S, Hill MC (2004) Three-dimensional local grid refinement for block-centered finite-difference groundwater models using iteratively coupled shared nodes: a new method of interpolation and analysis of errors, Advances in Water Resources, 27(9), 899-912.
Nakićenović NJ, and 27 co-authors (2000) IPCC special report on emission scenarios, Cambridge University Press, Cambridge, UK, pp 599.
Neuman SP, Wierenga PJ (2003) A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites, U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research Washington, DC 20555-0001.
Overgaard J, Butts MB, Rosbjerg D (2007) Improved scenario prediction by using coupled hydrological and atmospheric models. In: Quantification and Reduction of Predictive Uncertainty for Sustainable Water Resources Management (Eds: Boegh E, Kunstmann H, Wagner T, Hall A, Bastidas L, Franks S, Gupta H, Rosbjerg D, Schaake J), IAHS Publ. 313, 242-248.
Refsgaard JC (2007) Hydrological Modelling and River Basin Management. Doctoral Thesis. Geological Survey of Denmark and Greenland (GEUS). Special Issue. Copenhagen.
Refsgaard JC, Sørensen HR, Mucha I, Rodak D, Hlavaty Z, Bansky L, Klucovska J, Topolska J, Takac J, Kosc V, Enggrob HG, Engesgaard P, Jensen JK, Fiselier J, Griffioen J and Hansen S (1998) An integrated model for the Danubian Lowland – methodology and applications. Water Resources Management, 12, 433-465.
Refsgaard JC, Henriksen HJ (2004) Modelling guidelines - terminology and guiding principles, Advances in Water Resources, 27(1), 71-82.
Refsgaard JC, van der Sluijs JP, Brown J, van der Keur P(2006) A framework for dealing with uncertainty due to model structure error, Advances in Water Resources, 29(11), 1586-1597.
Refsgaard JC, van der Sluijs JP, Højberg AL, VanRholleghem PA (2007) Uncertainty in the environmental modelling process – A framework and guidance. Environmental Modelling & Software, 22, 1543-1556.
Roosmalen Lv, Christensen BSB, Sonnenborg TO (2007) Regional differences in climate change im-pacts on groundwater and stream discharge in Denmark, Accepted for publication in Vadoze Zone Journal.
Wood AW, Leung LR, Sridhar V, Lettenmaier DP (2004) Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs, Clim. Change 62(1–3):189–216.