Scientific opportunities created by HarmonIT, HarmoniRiB and HarmoniQuA

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Abstract
The European Commission, through its Framework 5 Programme (FP5), has co-funded a wide range of research projects whose collective objective is to develop the understanding necessary for the implementation of the Water Framework Directive. It is the intention that much of this new knowledge will be encapsulated in models, tools and techniques that managers can use and hence many of the projects have a strong systems analysis component. The purpose of this paper is to describe the scientific opportunities that three of these projects, HarmonIT, HarmoniRiB and HarmoniQuA have opened up. These opportunities will be discussed in relation to the main themes of WaterMatex2004.

Keywords
ICT, modelling, OpenMI, uncertainty, quality assurance

INTRODUCTION

In 2000, the European Parliament and Council passed the ambitious directive 2000/60/EC establishing a framework for Community action in the field of water policy, known as the Water Framework Directive (WFD). The key objective of this law is to achieve 'good ecological status' of Europe's water resources by 2015. To achieve this objective a number of activities need to be carried out, leading to an Integrated River Basin Management Plan (RBMP) in 2009. A major part of such a RBMP will be the programme of measures that need to be implemented to achieve the objectives. The difficulty in developing these RBMP's is that a very integrated approach needs to be adopted that covers all the water domains, involves the stakeholders and the general public and is cost effective. Self-evidently, this is a highly demanding requirement, needing a breadth of knowledge and understanding that few people possess. Managers have therefore turned to modelling as a means of analysing the effectiveness of measures and helping them to select the most appropriate combinations.

Europe's river basins vary considerably, not only in relation to their size, climate, ecology and topography but also with respect to the impact of human pressures. Catchment processes are complex and their interactions are imperfectly understood. There is, therefore, a general acceptance that, at present, it is neither possible nor particularly useful to build, or attempt to build, a single model that represents all the processes that take place in a catchment, i.e. a whole system or catchment model, that could be used throughout Europe, though that is a long term goal. Before that can become a realistic objective a much greater understanding of individual processes and how those processes interact with other processes must be achieved. However, that does not mean that

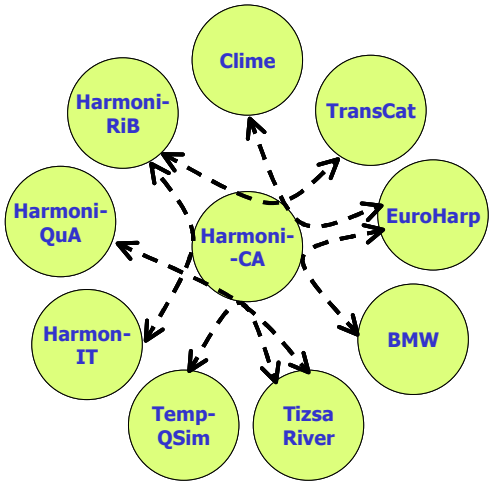

Figure 3: The CatchMod projects (acronyms; for more information see the links on www.harmoni-ca.info). Arrows indicate project interaction possibilities.

no generic solutions are possible, just that they will take time to be developed and applied. In the meantime, it is foreseen that different models and tools will be used at different steps of the WFD implementation and the tools used will vary from river basin to basin. The Directorate General Research of the European Commission realizes this and has therefore sponsored a number of modelling and computer tools projects, clustered in the Catchment Modelling Cluster (CatchMod, figure 1), aimed at moving towards the long term goal.

This paper describes three CatchMod projects, HarmonIT, HarmoniRiB and HarmoniQuA in more detail. These projects provide a model and tool linkage framework, a framework for dealing with uncertainties and a framework for the modelling process. The authors believe that these projects provide significant opportunities for future research in the field of IWA's 'Systems Analysis and Integration Assessment' and the topics of the WaterMatex 2004 conference.

The paper first describes the three projects and then discusses the scientific opportunities they are creating under the themes of the WaterMatex 2004 conference.

DESCRIPTION OF PROJECTS

HarmonIT - IT Frameworks (2002-2005, www.harmonit.com)

The aim of the HarmonIT project is to develop an 'Open Modelling Interface and Environment (OpenMI)'. The purpose of this environment is to facilitate the run-time linking of models. This allows catchment process interactions to be represented in the formulation and selection of sustainable policies for catchment management. Such a modelling interface and environment should resolve or improve a number of complicated linkage issues, such as for example: difference in spatial and temporal scales, feedback loops, differences in spatial and temporal concepts (distributed vs. lumped, steady state vs. dynamic), different units and naming of variables, distributed computing, etc.

Though focussing on data exchange between models in a runtime environment, the OpenMI standard is not limiting: linkages to databases, (real-time) monitoring devices are obvious uses of OpenMI. It can also be used for linking to end-user dedicated user interfaces, and be the base of gaming tools, assessment software (etc.) as well. It is suitable for component-based information systems that do not make use of modelling.

From a scientific perspective the OpenMI will lead to an improved ability to model process interactions, the ability to use appropriate model combinations and the ability to swap in and out

different models of the same process and hence facilitate sensitivity analyses and benchmarking. The OpenMI will improve opportunities for research since it will provide better opportunities to link research models with external models, such as accepted (commercial) software systems, with less or no involvement of the vendor. Obviously only if such external models comply to the standard.
In 2002 an overview of existing frameworks and a HarmonIT requirements report have been published. Based on this a framework architecture has been designed, which has been reviewed by an international panel of experts. Given some minor revisions the architecture is considered stable. Documents can be found for pre-registered HarmonIT users (free registration) on www.HarmonIT.com. In 2003 detailed designs of all software layers have been developed, and core principles of the design have been prototyped. A bi-directional link of two hydrological models has shown that the principles are working. A bi-directional link of two hydrological models means that at the same time step the downstream model requires inflow from the upstream model, whereas the upstream model requires water level from the downstream model for calculations. The test showed, that in this particular case the difference between the original model and the linked parts were negligible, even without iterations. This result is very promising: bi-directional will become increasingly important in integrated systems: Links between surface and groundwater models, river bedding plant growth model and water level river model, sediment model and river model are other examples of illustrating the use of bi-directional links.
In this year (2004) the OpenMI is implemented, including utilities such as the SmartWrapper, which eases the migration of legacy software and minimizes required changes to computational kernels. Much work is carried out to provide guidance on how to use OpenMI. This guidance will be tested from December 2004 onwards, when a number of project partners not involved in the current implementation phase, will migrate a number of their models and tools. Within the project duration partners will migrate about 30 models to the OpenMI environment, covering (aspects of) hydrology (channel flow, groundwater, etc.), water quality, ecology, economy, sewers, real-time control, etc.

HarmoniRiB - Harmonised techniques and representative river basin data for assessment and use of uncertainty information in integrated water management (2002-2006, www.harmoniRIB.com)

The overall goal of HarmoniRiB is to develop methodologies for quantifying uncertainty and its propagation from the raw data to concise management information. To achieve this objective the project will establish a practical methodology and a set of tools for assessing and describing uncertainty originating from data and models used in decision-making processes for the production of integrated water management plans. It will include a methodology for integrating uncertainties on basic data and models and socio-economic uncertainties into a decision support concept applicable for implementation of the WFD. The project results will provide the means to integrate uncertainty issues in the information process. It will support communicating these uncertainties to the decision process, improving the quality of integrated river basin management planning.
A second objective of HarmoniRiB is to provide basin wide datasets, including information on data uncertainty to the modelling research society. The ambition of these datasets is to extend them beyond the data required for HarmoniRiB's case studies, which are carried out to prove the developed methodologies. As many data as possible should be included, such that the datasets are useful for a variety of modelling studies. The datasets form a laboratory dataset, allowing new modelling methodologies to be quickly tested and compared to results of other modelling studies utilizing the same set of real-life basic data. It is important to note that the datasets will also comprise socio-economic information, and will cover time series of appropriate length for modelling research.
In 2003 HarmoniRiB's requirements have been specified. Methodologies on how to record uncertainties have been elaborated, and the database design has been drafted. Currently much work

is carried out on implementing the database and tools to record uncertainties. Facilities for uploading, quality control etc are also on the way. Data upload is commencing in 2004.
Data uncertainties will be represented by probability density functions and spatial and temporal correlation functions (Brown *et al*., 2004). Probability density functions come in many different shapes, with different numbers and meanings of parameters. All these data can be stored in HarmoniRiB's database. Since information on uncertainties is scarce, quite pragmatic approaches will be used to associate probability density functions and parameter values to data in the database. It lies beyond HarmoniRiB's scope to carry out detailed (field) studies on (individual) data uncertainty. Data and associated uncertainties may be used to create random realisations of alternative likely datasets, which can feed into integrated modelling systems e.g. as part of a Monte Carlo analysis. In HarmoniRiB's case studies the combined effect of uncertainties in data, model parameters and model structure will be assessed.
It should be noted that the HarmoniRiB database will be compliant to HarmonIT's 'Open Modelling Interface and Environment (OpenMI)'.

HarmoniQuA - Harmonising Quality Assurance in model based catchment and river basin management (2002-2005, www.harmoniqua.org)
The overall goals of HarmoniQuA is to improve the quality of model based river basin management and enhance the confidence of all stakeholders in the use of models. Although models are widely used in modern river basin management, in many cases the adoption of inappropriate Quality Assurance (QA) procedures has compromised their credibility. Existing modelling guidelines, mostly nationally based, focus on a single domain in contrast to integrated models. Furthermore, these guidelines vary throughout Europe. The resulting models and decisions based on them are often: non-transparent, irreproducible, non-auditable and not fully comparable among different countries. The HarmoniQuA project aims to provide a user-friendly guidance and QA framework for use in model based river management. The guidance will prompt users with the appropriate 'next step' in the modelling process and provide an audit trail to check previous decisions. The approach targets management at catchment and river basin scales with the overall goal of improving the quality of modelling and therefore enhancing the confidence of all stakeholders in them. HarmoniQuA attempts to serve several types of users in a series of water management domains, in jobs of varying complexity and application. Users, such as water managers or modellers, working on a specific job will only be confronted with guidance relevant to them in their present context.
In 2002 a review of state-of-the-art in quality assurance procedures in river basin modelling was compiled (http://harmoniqua.wau.nl/tools/download) and the overall terminology and guiding principles for the HarmoniQuA guidelines established (Refsgaard and Henriksen, 2004). In 2003 the first version of the HarmoniQuA Modelling Support Tool (MoST) comprising guidelines for seven specific domains and various types of users (Figure 2) was publicly released (http://harmoniqua.wau.nl/tools/download). This tool includes a glossary with definitions of about 1000 terms widely used in modelling. The methodologies and associated tools will be tested in two sets of real-life river basin management cases and new improved versions of MoST will be publicly released in 2004 and 2005.

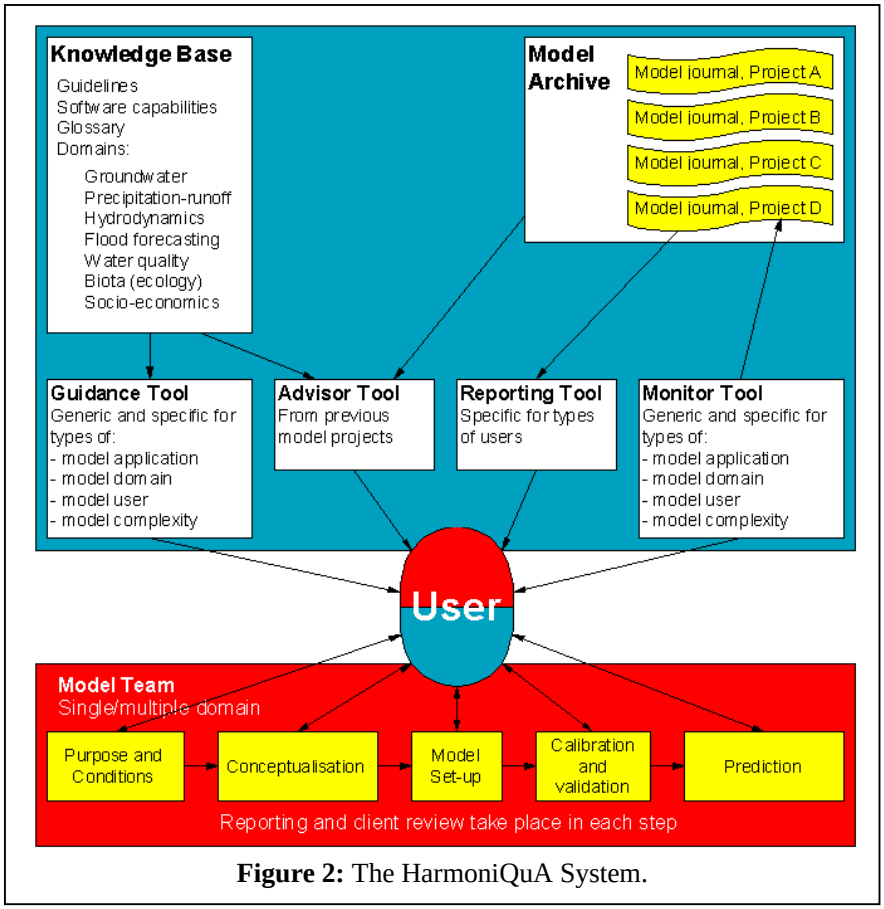

Figure 2: The HarmoniQuA System.

OPPORTUNITIES FOR FUTURE RESEARCH ON THE WATERMATEX 2004 TOPICS

HarmonIT, HarmoniRiB and HarmoniQuA provide opportunities for future research. In this section these opportunities are described for each of the themes of the WaterMatex 2004 conference.

New Paradigms for Modelling

According to Webster's New Universal Unabridged Dictionary (Barnes & Nobel, 1996), a paradigm is an example serving as a model. New paradigms in modelling thus mean that new approaches for modelling are used. In the case of integrated assessment this should include aspects of (underlying) data, model schematisations, the human interface (etc). Given the broadness of integrated, real-life problems in water management, researching the effects of new approaches (new paradigms) and proving the advantages compared to existing paradigms is a complex endeavour. As a result the penetration of new modelling paradigms in real-life water management takes considerable time.

The three projects all provide opportunities to improve this situation. In the first place an open interface (HarmonIT's OpenMI) helps to incorporate a new model type in an integrated modelling system, thus allowing analyses of the overall effect. Furthermore, by swapping different types of models on a single domain, intercomparison of effects is facilitated. On the other hand, this can only be achieved if the OpenMI high-level principles are applicable to the new type of model. As for now, no structural problems have been identified which exclude certain types of models to work within this framework. The HarmoniRiB database supports the research on new paradigms. It provides the raw data of basins to the scientific community, facilitating further collaboration and intercomparison of modelling approaches and data-effects beyond individual research projects. Since the HarmoniRiB database will include uncertainty information, it will provide great

opportunity to future research, since uncertainty becomes more and more an issue in day-to-day water management. Obviously, HarmoniRiB itself researches innovative paradigms for handling uncertainty. HarmoniQuA's methodology and tools provide the opportunity to structure of complex modelling research. As such, it eases the communication on details of modelling and allows to transparently record changes and their effects in integrated modelling systems. Modelling case-bases enhance the possibilities of re-using and comparing of results. However, the HarmoniQuA steps itself may also be subject to paradigm shifts.
In summary, improving the ability to link models, using identical base data and improved methods for recording the modelling effort will ease research on new paradigms.

Uncertainty, Risk and Reliability
Uncertainty, risk and reliability are closely related but quite different research topics. Uncertainty specifically deals with the problem of limited or in-exact knowledge. In modelling, uncertainty mainly relates to data, modelling parameters and model structures. In general, uncertainty also relates to the unthinkable future – events that lie beyond our imagination. Risk is generally defined as the product of hazard and vulnerability, or the probability that an event occurs and the related damage. Obviously both the probability that an event occurs and the estimate of damage are prawn to uncertainty, and risk analysis should include uncertainty analysis. Reliability is a very broad topic ranging from 'confidence, reproducibility and validity of measurements' to (computational) system performance. In this paper reliability is used in the sense of 'confidence in results'.
HarmoniRiB specifically deals with uncertainties in models and data. The project provides methodologies to assess and deal with real-life uncertainties, and provide a database to promote research in this field. It will naturally lead to information on reliability of results of integrated studies. Risk assessment is not a specific topic within the project, but research on reliability of risk assessment (that is risk assessment including the uncertainties of underlying data) may certainly benefit from HarmoniRiB. The HarmoniRiB database provides many opportunities to research on uncertainties. The methodologies provided by HarmoniRiB will be a starting point for further refinement. HarmoniQuA produces the modelling framework that includes uncertainty in modelling (data, parameters, model structures). As such it will provide opportunities to increase (communication of) reliability of modelling due to the transparency of modelling work. HarmonIT does not deal with uncertainty, risk or reliability, but the design of interfaces allows transfer of uncertainty information between modelling components. Furthermore, being able to swap models eases the inter-comparison of modelling systems and thus provides insight in uncertainty and reliability, similar to weather forecasting, where combined results of different models are used.

Foresight, Sustainability and Coupled Natural-Human Systems
Sustainability knows many definitions. 'At its most basic level, sustainable means "meeting the needs of the present without compromising the ability of future generations to meet their own needs." This is Ecology's working definition of sustainability.' (http://www.ecy.wa.gov/sustainability/definition.htm). In sustainability research requires foresight in long-term developments, for example in the effects of available and expected technological innovations. Obviously, this includes the interaction between the natural and the human system.
None of the three projects explicitly researches sustainability and foresight, but all projects include both natural and human (socio-economic) modelling. Research in the fields of "Foresight, Sustainability and Coupled Natural-Human Systems" may benefit from all three projects. HarmonIT will allow speeding up building and adapting long term forecasting systems, including the socio economic aspects. This is especially valuable if the modelling is part of a participatory process, where the modelling system needs to be quickly adaptable to the needs of the process. HarmoniRiB will add to this methodologies to assess the integrated uncertainty associated with the long term developments and finally, HarmoniQuA will provide the means to ensure quality in these

studies, which is especially important due to the complexity of the modelling associated in "Foresight, Sustainability and Coupled Natural-Human Systems" research.

Integrated Assessment

According to the European Environment Agency integrated assessment is an interdisciplinary process of structuring knowledge elements from various scientific disciplines in such a manner that all relevant aspects of a complex societal problem are considered in their mutual coherence for the benefit of decision-making (http://glossary.eea.eu.int/). The three projects provide significant opportunities to integrated assessment. The interface specifications of HarmonIT will ease accessing all different types of data in a integrated assessment environment. Furthermore it may promote the use of advanced modelling in integrated assessment, bridging the gap between modelling and forecasting, and (indicator) assessment. HarmoniQuA's contribution lies in structuring and recording of studies in integrated assessment, even if modelling plays a minor role. HarmoniRiB's contribution is first of all the methodological approach to uncertainty assessment in complex, integrated systems. Furthermore, the datasets provided by HarmoniRiB can be extremely useful to research the effects of different integrated assessment procedures.

Identification, Estimation, Prediction, and Time-series Analysis

Numerous books and articles have been published on the topics Identification, Estimation, Prediction, and Time-series Analysis. None of the three projects discussed in this paper deal with specific examples of methods in this scientific field. The HarmoniQuA guidance and tools however provide the opportunities to improved structuring and recording of scientific work in this field. Time series analysis is frequently a tedious task, in which different steps are repeated many times to meet the objectives. One can easily get lost in all the different steps carried out, and neglect the reasoning behind rejecting or accepting different time series model structures. Lack of information on uncertainty of environmental observation data is a known problem in filtering procedures – HarmoniRiB's uncertainty database may provide the means to advance on this topic. Obviously, HarmoniRiB's database will also be useful as a benchmark dataset in this research area. HarmonIT does not deal with the content of individual models and time series analysis, but the interface standard will provide the opportunities to re-use and compare methods and tools in multiple studies.

Process Control, Stability, and Ecological Resilience

The combined research area of 'Process Control, Stability, and Ecological Resilience' is an emerging research area in which quite different processes, spatial and temporal scales are integrated. Evaluation of a system's ecological resilience and stability is already a very difficult issue – much more research of the linkage to the driving forces with different process dynamics is required to understand the overall interactions. HarmonIT's OpenMI provides the opportunity for in-depth research in the linkage of processes of different spatial and temporal scales, also allowing linkage of complete different modelling concepts. Obviously linking different concepts is a dangerous exercise, and research in this area is required. HarmoniRiB provides two opportunities: First of all, given our limited knowledge integrated uncertainty assessment and sensitivity analysis is a key requirement. Secondly, the HarmoniRiB database will provide many real-life (ecological) data and related uncertainties that can be used by the scientific community. However, these data are not on the detailed level of 'experiments', but on the real-life level of river basins monitoring stations. The contribution HarmoniQuA provides lies first of all in its supporting role in modelling involving many different specialists. Secondly, the modelling case base will help consolidating knowledge.

Inter-disciplinary, Holistic Thinking for Problem-solving

Models and information processing tools in general are very useful in integrated research. Decision support systems (DSS-s) are frequently thought of as 'discussion support systems', since they

facilitate the discussion about and elaboration of a common mental picture on the driving forces, pressures, states, impacts and responses of a socio-environmental system. Besides the technological problems in developing DSS systems reliability, trustworthiness, transparency and reproducibility of the DSS outputs are important success factors for interdisciplinary research. To avoid endless repetition is suffices here to state that the HarmonIT interface specification, the HarmoniQuA procedural support and the HarmoniRiB uncertainty research and database provide valuable tools and opportunities for interdisciplinary research.

CONCLUSION AND DISCUSSION

The three projects discussed in this paper can have significant impact on future research relevant to the IWA's 'Systems Analysis and Integration Assessment' group. The three projects combined provide the framework which allow (1) advanced research in integrating different sources of information of different modelling and data domains, (2) researching methodologies and their effects of (numerical and structural) uncertainties in such complex environments, and (3) transparently and reproducibly record and communicate results of these studies. The main benefits of this framework lie in new opportunities for research, efficiency and inter-comparison. However, from a scientific perspective a framework also poses the danger that it channels thinking and hinders the development of completely new approaches. We are very aware of this potential problem. In HarmonIT not only deterministic models are included, attention has been paid to data-driven models, (stochastic) filtering, agent based models, online information systems, etc. The HarmoniQuA steps in modelling are not meant to be a straight jacket. Steps are not imposed – a main purpose is that some reasoning is recorded on the execution of tasks. But educating future modellers with the tool may influence creativity. Harmoni-RiB's modelling case-base may have a similar effect: using previous research may result in intellectual laziness and even worse, persistence of erroneous approaches and 'de-facto' standard approaches. We feel that the risks of this to happen is quite little due to the openness and flexibility of the guidance and is far outweighed by the benefit of the increased transparency of complex modelling work. HarmoniRiB's main procedural difficulty lies in the procedures that add uncertainty to data. It is undoable to assess uncertainties for each individual observation, and thus the uncertainty included in the datasets are open to much debate. We feel that uncertainty information will get increasing attention in integrated system analysis, and HarmoniRiB will provide a basis for in-depth research in the systems analysis research.

We expect that the projects will substantially contribute to the integrated, interdisciplinary research, first of all as a result of the scientific and technology opportunities but maybe more importantly due to the fact the projects will help communication between many different scientific disciplines.

It should be noted that this paper focussed on the research opportunities of these particular projects. The projects provide many more opportunities to effective water management.

Finally, other projects of the CatchMod projects provide many opportunities for the research community.

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