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Integrated Solution Support System for Water Management

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Abstract: Solving water management problems involves technical, social, economic, political and legal challenges and thus requires an integrated approach involving people from different backgrounds and roles. The integrated approach has been given a prominent role within the European Union's Water Framework Directive (WFD). The WFD requires an integrated approach in water management to achieve good ecological status of all water bodies. It consists amongst others of the following main planning stages: describing objectives, assessing present state, identifying gaps between objectives and present state, developing management plan, implementing measures and evaluating their impacts. The directive prescribes broad participation and consultation to achieve its objectives. Besides the obvious desktop software, such an integrated approach can benefit from using a variety of support tools. In addition to tools for specific tasks such as numerical models and questionnaires, knowledge bases on options and process support tools may be utilized. Water stress, defined as the lack of water of appropriate quality is one issue related to, but not specifically addressed by the WFD. However, like in the WFD, a participatory approach could be used to mitigate water stress. Similarly various tools can or need to be used in such a complex process. In the AquaStress Integrated project the Integrated Solution Support System (I^3S – I-triple-S) is developed. One of the cornerstones of the approach taken in AquaStress is that organizing available knowledge provides sufficient information to improve the possibility to make a water stress mitigation process truly end-user driven, meaning that dedicated local information is only collected after specific need is expressed by the stakeholders in the process. The novelty of the I^3S lies in the combination of such knowledge stored in knowledge-bases, with adaptable workflow management facilities and with specific task-oriented tools – all originating from different sources. This paper describes the I^3S.

Keywords: Integrated approach, Water Framework Directive, Water management, Participatory process, Water Stress

1   INTRODUCTION

Today's water and environmental management frequently requires a participatory approach, since the solutions affect many stakeholders and a variety of policy fields are involved. Europe's Water Framework Directive (European Commission, 2000) provides a good example of this complexity: The directive prescribes broad participation and consultation to achieve good ecological status of all water bodies in the European Union by 2015. From 2009 onwards Integrated River Basin Management plans need to be implemented. The types of measures in such plans are of very diverse nature, for example: upgrading waste water treatment plants, improving the morphological structure of rivers, regulating fertilizer use and many more economic (support) measures, such as taxation and subsidies, and educational measures may also contribute to reach the directive's objectives. Authorities on

different levels, e.g. local, regional and national authorities, and of different domains, e.g. ministries of infrastructure, water management, environment, spatial planning, and economy need to collaborate since the measures affect different policy fields and spatial scales.

Finding an appropriate set of measures to reach the objectives very much depends on the successfulness of the process leading to this selection. Besides the need to involve aforementioned authorities, this also implies involvement of various stakeholder groups and possibly the public. In the WFD, active stakeholder participation is prescribed. In such a process achieving common understanding, trust and confidence are notably challenging. Experts have a particular role in such a process: They need to deliver most of the knowledge and information that is used. If the experts or their information are not trusted this may cause a participatory process to fail [Pahl-Wostl and Hare, 2004].

Though the WFD also deals with water scarcity, water scarcity does not have a prominent role in the WFD implementation. Water stress, defined as the lack of water of appropriate quality is however of growing importance. Since water stress affects many different groups and people, a stakeholder-driven approach may be important. In the AquaStress project the participatory development of water stress mitigation plans and options is the main subject of research.

The aim of the work block four (WB 4) of the AquaStress Project is to develop a system which supports the entire participatory process, by providing a suite of integrated software tools and a knowledge system that allows having both experience and scientific information at the fingertips. The system under construction is called the I^3S (I-triple-S). The tools are of quite different nature, in functionality, user groups, and their moments of use within a participatory process. This paper describes the I^3S.

2   STORY LINE

This section provides a narrative description of the process the I^3S intends to support. An extended narrative description will be used in section 4, integrating and describing actual tools of the I^3S. The phases in this story-line are based on Maurel [2003]: "

1. Starting organization – The objective of the starting phase is to create a process design and achieve clear agreements with both the client and administrator, who may be one and the same person. A preliminary plan on who needs to be involved when should be part of this phase. Other activities are: determining the type of process, a design of the process, boundary conditions and announcement of the process. This first step does not yet include external actors. It involves the core group of persons involved executing / commissioning the participatory process.

2. Actor analysis, context – The objective of this stage is to get a full overview of actors (stakeholders) and fine tune idea's on whom to involve when. This may be done in a participatory setting.

3. Diagnostic of the current situation – The objective of this step is to achieve a broadly agreed upon assessment of the current situation and problem identification. Activities are preliminary investigation; collect knowledge and insights, analysis and ordering of information and knowledge and informing the decisions makers.

4. Search of solutions – The objectives of this step are to search for useful solutions and realistic alternatives. It should also result in design and synthesis of these potential solutions, and transparent choices. The activities include 'ordering and analysis of potential solutions', determining effectiveness, involvement/participation and informing the decision makers.

5. Implementation, evaluation – The key objective is to create an implementation plan and implement it subsequently. Both the previous process and the effects of implementation should be evaluated."

Imagine a certain region water stress occurs. Both the availability of water and its quality are of concern. Water is used by a variety of users, such as farmers, households, tourists and

nature, the latter meaning that a certain amount and quality of water is required to maintain a good ecological status. There are many possible measures to resolve the problems, e.g. improving irrigation, developing reservoirs, desalinisation, reducing water loss in distribution systems, installing water saving tabs, etc. There are also many ways to support the implementation of such measures, such as pricing and subsidies, regulations, education etc. Obviously, many people may be affected by the choice of measures and mechanisms, and financial resources, political and societal support is required to mitigate the water stress situation.

2.1 Starting Organisation Phase

To tackle the problem, the water authority appoints a project manager or project team. The task is to develop a broadly supported water stress mitigation plan.

The project team is convinced that this can only be achieved if relevant stakeholders are actively involved and can influence the decision. They are also aware that the different stakeholders have different perceptions about the problem, and may not always understand the perspectives of others. There is also some distrust due to previous experiences, where they were confronted with problem analysis and mitigation plans. The stakeholders did have little say and had no insight in the validity of the analyses and solutions developed by the experts.

Hence, the project team decides to start an open process, in which stakeholders are the main driving force in the development of the water stress mitigation plan. Given the fact that there will be many people involved, and planning and recording of activities is of paramount importance to achieve trust and transparency, they intend to use a web-based, participatory workflow management tool.

The team also realizes that the information required throughout the process should be demand (stakeholder) driven. To avoid that the process slows down each time information is required, e.g. during a meeting, the team decides that information on other sites can be used as an approximation at such a meeting. After such a meeting local information can be collected and presented if so desired. Due to the effort carried out in AquaStress, information on similar sites that dealt with water stress and potential mitigation options can be found on in a knowledge base accessible though the Internet.

2.2 Actors Analysis, Context

It is now important that the team identifies the stakeholders and actors – the societal context of the water stress situation. Different methods are available to support this activity. In this case the actor analysis is carried out via a desktop study without dedicated software support and a number of meetings with those identified. The process and results of the study needs to be stored for future use.

2.3 Diagnostic of Current Situation

It is important that the team reaches common understanding about the problem. This can be achieved via a number of meetings where the different stakeholders meet and discuss. The process can be facilitated through questionnaires, 'water stress games' and numerous other methods which all aim to increase the common understanding about the problems at hand and their implications for the different stakeholders. The development of appropriated indicators to describe the water stress situation within the context of the site is a major task. Agreement on a measure that best describes the situation and which can be used to evaluate the effectiveness of measures is a major output of this stage.

2.4 Search of Solutions

A number of meetings, discussions and iterations are organised in which the virtual game is replayed with different information and options. The selection of options is based on amongst others extensive information on the effectiveness of options elsewhere. After some pre-selection of promising measures in terms of effect and acceptability, it is decided to use more advance modelling tools to achieve a more accurate estimate of effects.

Based on the outcome a final session is being organised by the team. In this meeting a final deliberation takes place, resulting in prioritisation of options and finally an advice to the water authority.

2.5 Implementation, Evaluation

At this stage the competent authority implements the plan and evaluates the effects. In principle the stakeholders may be involved in this phase as well, but this is beyond the scope considered here.

3 THE I^{3}S' OBJECTIVE, ARCHITECTURE AND COMPONENTS (TOOLS)

3.1 I^{3}S' Objective

According to the mission of work block four (WB 4) of the AquaStress Project key science and knowledge outputs have to be brought together and integrated in a computer based infrastructure [Gijsbers, 2007a, b]. This system must put these outputs at the disposal of the user community finally assisting stakeholders to resolve problems arising from water stress. In that regard the support system's objective is "to enhance the selection process of water stress mitigation options by providing a suite of tools that can effectively support the participatory development of a water stress mitigation plan":

- Selection process of water stress mitigation options in this context includes all the required steps to reach agreement in a participatory setting, starting from nothing and leading to a broadly supported set of options.
- A suite of tools in this context means computer based tools (software) that can support one or more of the steps in the process. Examples are: workflow managers, knowledge bases (KBs), models, databases etc.
- Effectively means that it allows to access knowledge already available and produced within AquaStress, that the tools interact whenever appropriate, reducing tedious work on getting tools to work properly and also allows alternative and new tools to be more easy used in combination with other tools.
- Support means that it helps carrying out a task or tasks. Depending on the task, support is provided to different types of users. For example: A project manager is supported by providing a tool that helps him organize the process; A starting meeting involving different types of stakeholders may be supported by a gaming/social learning tool; A selection between alternative option-sets may be supported by a multi criteria tool.

3.2 Conceptual Overview

According to the ANSI/IEEE Std 1471-2000 [IEEE, 2000] the term architecture is defined as the fundamental organization of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution.

In principal the architecture of a software-system serves as fundamental description to understand or design a system consisting of several components. Hence architecture describes the collaboration or interaction amongst these components in terms of data and control-flows, and constraints of conditions, rather than the design of the individual

components. Moreover the software architecture discipline is centred on the idea of reducing complexity through abstraction and separation of concerns.

Within AquaStress a variety of tools and models are used to collect data and knowledge and to conduct research. The I³S aims to bring this scientific output together in a complex support system that comprises of web-based and stand-alone applications. With that in mind, the architecture is implemented as a combination of:

- A 3-tier web-based Client-Server architecture with "thin-clients" which means most part of the application logic is implemented on the server side; and
- A 2-tier Client-Server architecture with "fat-clients" which means most part of the application logic is implemented on the client side.

Figure 1 illustrates the overall architectural design and the components of the I³S:

Figure 1: Conceptual view on the I³S Architecture

Many of the tools are interrelated with each other or share a common data. To provide an integrated solution it is necessary to determine the kinds of dependency that may exist amongst the tools. One main characteristics of the I³S design is that it is implemented as a (meta-)data-centred architecture, which means that the AquaStress knowledge bases play a central role in linking and integrating the tools. Additionally integration is achieved by using the Process Support Tool (ProST). Besides providing guidance to project teams during all the relevant steps, ProST also provides team members with the necessary information needed to execute the tasks of the participatory process including data and settings for the tools thereby reducing the tedious work of setting up tools.

The I³S accommodates various levels of use:
- Browsing static fact sheets and downloading the relevant component for stand-alone applications;
- Browsing dynamic fact sheets with HTTP-based data retrieval from AquaStress knowledge bases using prescribed XML-formats, and
- Use of standalone tools that communicate with the knowledge bases using HTTP-based communication protocol using prescribed XML-file formats.

The left hand side of Figure 1 represents the 3-tier web based client server architecture. **The client-layer** represents both dynamic and static web contents. Dynamic contents are generated on the server side and provided by the corresponding portlets. Static contents are mainly links to case specific (tailored) HTML-pages. Some of these tools are directly available through the portal. Others tools however are only presented at the website and should be downloaded separately. They are described in detail in section 3.3.

The application layer is implemented as a web-portal that provides the entry point for the various components of the system. The AquaStress web portal is a site that functions as a single point of access to information. It presents information from diverse sources in a unified way and provides a way for stakeholders and users to obtain a consistent look and feel with access control and procedures for most applications. It presents information via fact sheets or dynamic data retrievals on the test sites, water stress mitigation processes, options, indicators, tools etc. Dynamic information retrievals are typically handled via HTTP Post/Get messages. Some of the information may be static HTML pages that contains a link to standalone application (or its contact point). In terms of future scalability purposes it will directly connect to specific web-services.

The persistence layer contains all persistently stored information, including knowledge items, metadata and raw data.

> *The knowledge bases are* at the heart of the system. They contain the knowledge which components in the system can utilize. The I³S knowledge bases hold primarily textual (meta-) information on processes, sites experiencing water stress, mitigation options, indicators, etc. This information can be used by tool components to present the information to the user, to populate applications e.g. for gaming and modelling studies or to retrieve information about the location of raw data. It provides a shared definition of concepts and knowledge items within the project. To enable interaction with knowledge bases, a standardized XML-based data exchange protocol, composed of an XML Schema Definition to standardize the data exchange format, and a set of calling methods have been defined. Components that exchange (numerical) data in real-time should implement OpenMI (www.openmi.org) as a data exchange protocol.

> *The database* contains raw data such as time series required for indicator calculation, but (potentially) also for model inputs and parameters. It can serve as a common data-layer. The database can hold any type of numerical values and associated uncertainties, ranging from meteorology via ecology and hydrology to socio-economic values.

The right hand side of Figure 1 represents a conventional 2-tier client server architecture. The tools are coherent stand-alone applications that are loosely coupled through the shared

information in the knowledge bases. In doing so the desktop-applications can derive meta-information from the knowledge bases including settings for retrieving data from a shared database.

3.3   I^{3}S Components (tools / functionalities)

A number of tools has been developed or used in the AquaStress project to help with identifying relevant issues and solving problems. Some of these tools are tightly coupled with the knowledge bases, databases and other tools. Others are loosely coupled and can function independently. In this section we give a short description of the tools which have actually been used within AquaStress or which have been identified as being useful in the process of solving water mitigation problems. These descriptions consists of 1) a short description of the functionality, and 2) the application objective of the tool.

Table 1. A list software tools and functionalities beneficial for a participatory process of water stress mitigation planning.

Tool / functionality	Starting organization	Actors analysis, context	Diagnostic of current situation	Search of solutions	Implementation, evaluation	Availability in I^{3}S L = Linked A – Available but not linked
e-Glossary	☑	☑	☑	☑	☑	L
Workflow / Process management support tool	☑	☑	☑	☑	☑	L
Knowledge base (KB)	☑	☑	☑	☑	☑	L
Database (DB)			☑	☑	☑	L
Data visualization and processing (including GIS)			☑	☑	☑	L/A
Cognitive map (CMap)		☑	☑	☑		
Uncertainty assessment		☑	☑	☑	☑	A
Questionnaire (Q-tool)		☑	☑	☑	☑	L
Actor analysis		☑				
Computer supported gaming		☑	☑	☑		L
Group support system	☐	☐	☐		☐	
Cost-effectiveness analysis				☐		
Multi criteria analysis (MCA)			☑	☑		L
Case-based reasoning (CBR)		☑	☑	☑		A
Medium to complex modelling, e.g.			☑	☑		
Integrated assessment			☐	☐		
Resource flow modelling			☑	☑	☑	A
Integrated, complex modelling			☑	☑		
System dynamics models (SD)			☑	☑	☑	A
Agent Based Modelling			☑	☑		A
Mini-models – knowledge rule based modelling			☑	☑	☑	L
Querying and presentation tool (QPT)			☑	☑	☑	L

Taken from Blind et. al. [2007] Table 1 shows which software functionalities were considered useful at the outset of the AquaStress project and at what stages in the

participatory process they could be of use. The stages were chosen according to Maurel [2003]. When interpreting the table, one must account for the definitions of the stages; in principle some of the tools may be used in stages other than the ones they are marked for in the table. Moreover, not all the tools indicated are not used in practice. Whether or not a functionality is used depends on the actual process and the needs of its participants.

In the following section a detailed description of the functionality is provided.

3.3.1   e-Glossary

An electronic glossary in general is an invaluable tool for complex participatory processes. It helps to gain common understanding. The I³S contains a glossary which can be used easily by different tools. It contains information on: topic (a list of topics or term groups have to be defined), definition; domain of applicability (e.g. Groundwater, Hydrodynamics, etc.), source, authors, references and language.

3.3.2   Workflow / Process Management Support Tool (PRoST)

Complex (participatory) processes can be supported by workflow management tools. In AquaStress such a tool has been developed: ProST. It consists of scientific and technical guidance specifying managed process steps on how to carry out various tasks to achieve reliable and reproducible results. "Managed" means that tasks within a managed process are described unambiguously, are scheduled and monitored. An effective process management support system distinguishes different types of users, identifies their interests and information needs. ProST allows multiple actors to work on a project. ProST becomes more effective when knowledge bases and tools used to carry out specific tasks are linked, e.g. can export output to the ProST Tool.

The objectives of the process management and support tool within AquaStress are:

- To describe the process flow;
- To describe tasks to be done and any relevant information that can be of use in executing the tasks defined in the process. See also "Storage of knowledge – options, etc; Knowledge bases";
- To leave audit trail of process instances;
- To provide effective reporting facility for finished process instances and process instances in progress.

3.3.3   Knowledge Bases (KBs)

Knowledge bases here stands for a structured collection of relevant pieces of knowledge, preferably to be used by persons and by machines / computers. In AquaStress knowledge bases and the associated knowledge base editor is developed for:
- Miscellaneous Tools;
- Numerical models;
- Sites where water stress occurs;
- Water stress mitigation options;
- A decomposition of what multidisciplinary teams (including stakeholders) have to do to mitigate water stress problems.

The AquaStress e-glossary is also an example of a knowledge storage. By linking the knowledge bases to a workflow system, the knowledge becomes easily available at different steps and can be directly stored for process reporting purposes.

3.3.4   Data Storage / Databases (DB)

A data-storage or data-storages ideally allow storing all different types of data (spatial data, time-series, different domains such as hydrology, economy, ecology etc) in a transparent way such that different tools can easily link to it to retrieve numerical data, but also to store numerical results. In AquaStress the generic database developed in the Harmoni-RiB (http://harmonirib.geus.info) project has been used. It allows to store uncertainty information. For AquaStress, a new data-dictionary, covering data-needs of different tools is developed.

3.3.5   Numerical Data Visualisation and Processing (including GIS)

Complex, participatory processes require visualisation of (usually large amounts) of data (monitoring data, modelling results, spatial data, etc). Human beings are generally not geared to grasp raw data. For decision support with natural resources, spatial and temporal variability is particularly important to visualize. Furthermore, different scenarios can best be compared graphically.

A wide variety of visualisation tools are generally required to present and summarize data graphically, to best suit the human perception. In the I^3S various tools have visualisation capabilities. For further data exploration additional tools are required which are currently not embedded in the I^3S.

3.3.6   Cognitive Map/Fuzzy Cognitive Mapping (CMap)

Cognitive mapping software has the functionality to store for example one's own perception of the reality in a mental map, achieving a mental models (mental models) [Lasut, 2005]. In cognitive maps, the stored concepts are decoded, analyzed and clearly structured through cause and effect relationships, and this is significantly useful both for individual aims (thorough understanding of complex issues) and in group situations. A cognitive map is constituted by nodes, which represents the concepts and are connected to each other by links (also called edges). The edges are directed to show the directions of the cause-effect relationships. There are three main application objectives:

- Elicitation of Stakeholders' knowledge/perspective. Moreover, through questioning on the map structure, the Stakeholders' are also encouraged to find new relationships and solutions and to reach a better issue understanding.
- Improving the communication between Stakeholders'. In depth reflection upon each other maps give also the possibility of finding alternative ways of understanding the problem. Cognitive Maps serves as basis when policies and management options are discussed: the decision-making process is facilitated and conflict solutions are encouraged.
- Options analysis: cognitive mapping techniques allow several options to be examined to see which are the most beneficial and whether more detailed one need to be considered.

Currently cognitive mapping tools used in AquaStress are not integrated within I3S.

3.3.7   Uncertainty Assessment Tools

Trust in complex, participatory processes and in results of modelling and simulation can amongst others benefit from uncertainty analysis. Uncertainty assessment functionality includes all types of functionality that allows uncertainty to be explicitly addressed within AquaStress, including:

- Tools and methods that help to determine sources of uncertainty qualitatively;
- Tools and methods to quantify uncertainty in
  - data,
  - models,
  - both in data and models;
- Tools that visualize uncertainties;

- Tools that help to identify sources of uncertainty within a participatory process (e.g. evaluation of the completeness of stakeholder analysis, discussion on unknown futures.

The objective of applying such tools is to determine, evaluate and communicate the quality of results (either qualitatively or quantitatively) and as such to provide a quality mark on and increase trust about the results expected from water stress mitigation options.
The I3S includes possibilities to use the data-uncertainty engine developed within the HarmoniRiB project (http://harmonirib.geus.info).

3.3.8 Questionnaire

A questionnaire or a list of questions that is used to gain information from certain persons is an important tool in complex participatory processes, where opinions and views of participants are important input to the process and evaluation means.

In the I^{3}S a web-based questionnaire tool is available which supports the development, web-based filling, and evaluation of questionnaires. This tool is linked to the process support tool ProST.

3.3.9 Actor Analysis

Actor analysis results in a list of all relevant people and groups which affect or are affected by a certain problem and mitigation options, the case here being water stress and water stress mitigation options. Relevant actors are: Actors that have an interest in the decision making; Actors that can hinder the decision making; Actors that can enrich the decision making; Actors that has to be involved on moral arguments. [De Bruijn, et al., 2002]

The objectives of applying actor analysis tools are:
- To identify all relevant actors, so that you know whom to involve in your process.
- To learn about different problem perceptions of actors/stakeholders and about different content aspects of the problem situation.
- To estimate how the network of actors will participate and to determine who the 'enemies' are and who your 'friends'. Whom do you need or don't need, etc.

Currently the I3S does not contain a dedicated software tool for actor analysis.

3.3.10 Computer Supported Gaming

There are many definitions of gaming, but based on a system perspective, gaming can be seen as a communication mode that contains a game-specific model, appropriate communication technologies and a multi-player or multi stakeholder interaction pattern. There are also many different game genres, for example:
- Role Playing Games (RPGs) are gaming situations in which players take on their own or other people's roles or behavioural patterns in a real or imaginary context.
- Strategy games cast a player with the ability to manipulate the environment through path finding and simulating the effects of decisions.

In participatory processes games may be used, for example, to raise individual and group consciousness, raise motivation to solve problems, develop knowledge, learning skills, learning, experiencing unknown reality etc. Each game genre has it's own strong points related to the above objectives. In the domain of AquaStress, new information is exponentially generated, the problem situations are integrated and complex and the process is interactive and participatory with stakeholders involved.

The I^{3}S offers the Splash game which will be linked to various I^{3}S information sources.

3.3.11   Group Support System

De Vreede and Muller [1997] define Group Support Systems (GSS) as "... information systems that aim to make group meetings more productive by offering electronic support for a variety of meeting activities." An example is the Group Decision Room (GDR), which is "... a meeting environment in which electronic meeting support is used to help groups address complex problems collaboratively. The GDR consists of a normal meeting room in which every work space is equipped with a computer, these enable meeting participants to work together using an electronic meeting system."

An electronic meeting system or Group Support System (GSS) helps people to generate new ideas (brainstorming), to define concepts, to organize ideas into categories, and to evaluate ideas using various criteria and voting techniques. Groups can use a GSS to perform activities such as project evaluations, strategic planning, work process analysis and design, crisis management, budgeting, and group training.

Though a GDS would be extremely valuable, such a tool is not available within the I3S.

3.3.12   Cost-Effectiveness Analysis (CEA)

Cost effectiveness analysis is a technique in which the cost and effects of an intervention and an alternative are presented in a ratio of incremental cost to incremental effect. The method permits the comparison of alternative interventions (or programmes) in which costs are measured in monetary units and effects (outputs) are measured in non-monetary units. The output can be any indicator addressing quantity or quality aspect of water stress. Since multi-criteria analysis is the preferred method in AquaStress, the I^3S does currently not include a (an integrated) cost-effectiveness analysis component.

3.3.13   Multi Criteria Analysis (MCA)

Multi-criteria analysis is a set of procedures of analysis of complex decision problems involving non-commensurable, conflicting criteria on the basis of which alternative decisions are evaluated. MCA is used amongst others to
- Comparison, interpretation of information on outputs and costs (both monetary and other) of different combination of management options;
- Evaluating and ranking of alternative measures on the basis of their costs and effectiveness as a basis to formulate a water stress mitigation plan of measures;
- In AquaStress it is also used to select indicators for water stress based on participants preferences.
.
A participatory MCA too "AquaDT", is incorporated in the I^3S.

3.3.14   Case-Based Reasoning (CBR)

Case-based reasoning or learning by analogy is a methodology
- For modelling of human cognition.
- Of artificial intelligence (AI) used for electronic encapsulation and reuse of knowledge.
- For development of intelligent computer systems.

It can for example be used to find similar sites to a site under consideration and hence help to find and transfer knowledge from one site to another. Case-based reasoning is hence an important aspect of the I^3S since it improves the possibilities to extract specific knowledge from the knowledge bases. A case-based reasoning tool is developed and loosely linked to the I^3S.

3.3.15   Medium to complex modelling

For the purpose of this position paper it would be to far to discuss all different types of modelling. Within AquaStress we distinguished the following models and classified them to be medium to complex models:

- Integrated Assessment Models: Computer simulation programs representing a coupled natural system and a socio-economic system, modelling one or more cause-effect chains including feedback loops, and explicitly designed to serve as a tool to analyse policies in order to guide and inform the policy process, mostly by means of scenario analysis.
- Resource flow models: In general a resource flow model represents the flow of matter in a system within a defined time period of a spatial unit. It is not geographically explicit.
- System Dynamics Models: System Dynamics Models (SDM) and System Thinking is a methodology for studying and managing complex feedback systems. It started from the idea of applying concepts from feedback control theory to the study of industrial systems. The system dynamics approach is typically used where no formal impact assessment (i.e. simulation models) exist, but could be developed by linking a number of feedback mechanisms.
- Agent based models: An Agent Based Model is a specific individual based computational model for computer simulation extensively related to the theme in complex systems, emergence, Monte Carlo Method, computational sociology, multi agent systems, and evolutionary programming [http://en.wikipedia.org/wiki/Agent_based_model].
- (Integrated) Simulation models: This comprises a range of domain specific (e.g. hydrology, economy, ecology) models.

The different types of models have their merits. They are usually used to increase system understanding and cause effect relationships, making them very valuable to assess the effectiveness of changes to the system (e.g. implementing mitigation options). In AquaStress different models are used in different sites. These models are only applicable in a stand-alone way. The I^{3}S does point towards the different models.

3.3.16   Simple Modelling - Knowledge Rule Based Modelling

Simple models (mini-models) are mathematical equations, which in AquaStress are used to represent the effects an option. The input parameters represent site-specific data from site knowledge base and the dependent variable represents the effect as cost or any other indicator value. In I^{3}S simple modelling is fully integrated within QPT and the knowledge bases.

3.3.17   Querying and Presentation

In AquaStress a querying and presentation tool (QPT) has been developed that acts as an interface for browsing the knowledge bases and execution of simple modelling rules. Users can use this tool to calculate and present the effect of an option to mitigate water stress on a case study at a test site in terms of water stress indicators and indices and show the effect in the i³S web portal.

3.4   System integration

System Integration refers to the practice of combining individual software components into one system. The I^{3}S system brings together a diverse suite of software tools for diverse user profiles. To enable I^{3}S to function as one system and support the entire participatory process we identify the need for three types of system integration. The first type of integration is based a web-portal which provides a single point of access to information and tools to all users. The second type of integration links the various tools through common knowledge bases so that data, metadata and knowledge can be shared. The third type of integration focuses on supporting the participatory process. By enabling integration along

time axis this last integration enables output from one tool to be used as input to another tool at a later stage of the participatory process.

The AquaStress web-portal, as an integration platform, provides access to information as dynamic fact sheets. It also provides static links to the tools. The core of the web portal is the AquaStress querying and presentation tool which together with the AquaStress knowledge bases provides the following functionalities:

- Query options: simple queries to the knowledge base enable the user browse the water stress mitigation options;
- Query indicators: simple queries of to the knowledge base enable user to browse through the AquaStress water stress indicators;
- Query the AquaStress test sites and case studies: simple queries to the knowledge base enable the user to browse through the AquaStress test sites and case studies. More complex queries enable users to calculate the effect of options to mitigate water stress on a case study at a test site in terms of water stress indicators and indices.

A common problem in integrated water management is that users waste valuable time in exporting, converting and importing data from different tools. Therefore, over the years, a number of modelling frameworks for linking models have been developed (refer, for instance, to Gijsbers et al. [2002], Rahman et al. [2003], Argent and Rizzoli [2004] and Denzer [2005]). These solutions are, however, intended for data exchange among models in real-time and not meant for sharing of meta-information amongst different users using the same or different tools. The second type of integration, therefore, focuses on making information available to users and tools using common knowledge bases. The knowledge bases are composed of ontologies and associated instances, but the tools are not required to represent the ontologies internally. Therefore, the primary source of data exchange between the tools and the knowledge bases is based on XML-files following an agreed upon data-exchange schema and HTTP-based communication. The basic exchange format is simple: all tools are required to 'understand' the XML elements *list*, *item* and *category* (*type* of the item being exchanged) and *attribute-value* pairs (see Figure 2). The interpretation of complex value types, for instance *rules* for calculating water stress indicators, are done entirely by those tools that can interpret the *rules*. Other tools are either supposed to render the information to the user or ignore it all together.

The AquaStress process support tool forms the third type of integration. Traditionally integrated support systems are developed either from scratch or by integrating existing tools through major software modifications. Workflow based applications enable reuse of existing tools through removal of data and process flow dependency [Leymann and Roller, 1997]. A process support tool not only guides team members and monitors their activity but it also enables users to launch the tools required for a given task with the necessary data and settings that were made available during previous tasks or during defining the participatory process thereby reducing the tedious work of setting up tools.
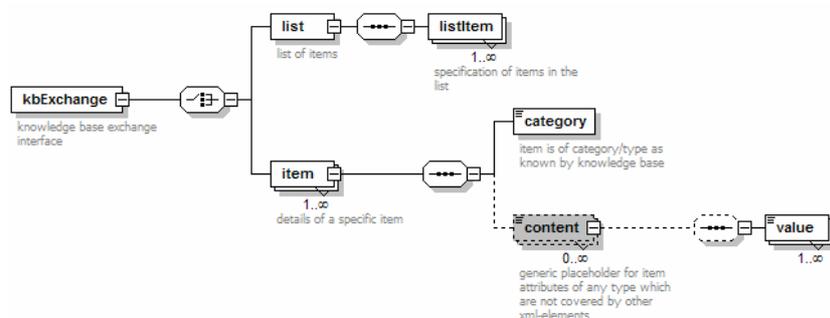

Figure 2. XML schema for data exchange.

4   SOLVING WATER STRESS PROBLEMS WITH I³S

In paragraph 2, a short story line is represented in which the process is described that the I³S intends to support. In paragraph 3, the overall architecture and the possible tools are brought into the spotlight. In this section, these parts will be combined into an abstract use case (Table 2) based on the needs of AquaStress test sites [Ferrand and Blind, 2007]. The intention of the I³S is that it will be available in the future. Therefore, in AquaStress only a start can be made using the information available for a selected number of sites. Note that not all tools can or will be used in all situations, nor are all tools described previously included in the detailed use-case shown in Table 2.

Table 2. An abstract use-case for the I³S
(Abbreviations: AP = Actors panel; KB = Knowledge base; NGO = Non-governmental organisation; PM = project manager; ProST = Process support tool; AT = Competent authority; CT= Citizens; PT = project team; QPT: Query and Presentation Tool; SG = Technical steering group; SA = System analyst)

Step	Tools used	Action	Target group
General monitoring of the water situation is organized with the pre-existing tools.		AT	AT
Non-governmental organisations (NGOs), citizens and NGOs have their own monitoring capacities based mainly on field observation and naive evaluation of the situation.		CT, NGOs	
Based on information from various monitoring systems, water stress becomes an issue in an area; which also becomes clear from citizens feedbacks. Competent authorities decide that something needs to be done.		AT	
PHASE 1: Starting Organisation			
The competent authority appoints a project team and a project manager who are responsible for defining and implementing a strategy.		AT	
The project manager is aware that different groups have different views on the severity of the problem and especially on the solutions. S/He is (vaguely) aware of political, economic and social issues. S/He finally decides to settle a technical steering group with the aim of defining a participatory process.		PM	SG
The steering group looks at the existing water stress mitigation processes available in the KBs. They discuss and proposes a first version of the participatory process. The project team collaboratively refines the process.	QPT, KB editor	SG, PT	
The project manager opens the given process in the process support tool ProST to set-up the process – enlist users, set deadlines, etc. and launches the process in ProST. At later stages the process will be modified as key actors are identified. From now on ProST will be used to guide and log all activities.	ProST	SG	PT
PHASE 2: Actor analysis / context			

Step	Tools used	Action	Target group
The project manager starts a process to identify the key actors. S/He contacts them and validates their participation.		PM	AP
To establish the current state steering group carefully designs a questionnaire.	Questionnaire-tool	SG	AP
The technical steering group processes the questionnaires to establish a first set of indicators and options.	KB editor	PM + SG	
The technical steering group establishes the basic cognitive maps based on the questionnaire collected.	CMap-tool	PM + SG	
Phase 3: Diagnostic of the current situation + Phase 4: Search of solutions			
The project manager calls the first meeting of the actors panel to actually start the participatory process.		PM	AP
At the first meeting s/he presents results including indicators, options and cognitive maps. Participants discuss the remainder of the process.	QPT, ProST	PM + SG	AP
Actors panel members can discuss the cognitive maps and establish new ones, giving their visions of the overall situation.	CMap-tool	PM + SG	AP
The project manager organizes a first multi-criteria assessment about the various issues in order to extract the priorities and actions. Conflicts and coalitions can emerge.	AquaDT, KB editor	PM + SG	AP
The project manager also presents a gaming too (Splash) to roughly explore interactions and cause effects relationships. The game will play a central role in the follow up meeting if agreed by actors panel.	Splash	PM + SG	AP
The project manager asks specialists to tune a first system model, based on the first results.	SD tool	PM + ST	SA
The combines Phase 3/Phase 4 steps may be repeated a number of times.			
The project manager calls a meeting.		PM	SG, AP
At this meeting previous discussion on indicators is re-iterated. The set of selected options is reduced and a common strategy emerges. Using the case based reasoning tool, the strategy is compared to previous cases. The meeting finally decides on the options which need further technical evaluation. The meeting decides if detailed models are required.	CBR-tool, QPT, KB editor	PM + SG	SG, AP
Additional modelling and expertise gathering are carried out. An economic analysis can be started.		SG	
Uncertainty assessment is made on the results.	Uncertainty analysis tool	SG	
Results are communicated to participants. All participants and the authority can exchange detailed information about their preferences.	QPT, AquaDT, KB editor	PM + SG	AP, SG, AT

Step	Tools used	Action	Target group
An operational water stress mitigation plan is instantiated.		PM	AT
The project manager finally reports to the authorities and finalizes the project	ProST	PM	
Phase 5: Implementation, evaluation			

5 CONCLUSIONS AND DISCUSSION

The development of the I^{3}S is a challenging activity, since it attempts to develop integrated software support for complex processes. This novel approach of integrating a diverse suite of software tools for diverse user profiles requires, among others, a high degree of knowledge on software engineering and an organisational capacity to get tool developers to participate in finding a solution to integration that has acceptable properties for 'their' tools.

Initially the process of integration started with identifying use cases and gathering information about the independent tools that are used in water stress mitigation. Next, based on the use cases and the list of tools, tool developers and technical experts determined 1) dependency among the tools in terms of data and knowledge items, 2) potential end users for each tool, 3) how and when users will need the tools, and 4) which new tools are required for integration.

Though such an integrated system is common in the industry, for instance Enterprise Resource Planning (ERP) systems, integration of such a diverse collections of tools is unknown in water management. Building new tightly integrated system is not only not feasible within the capacity and the budget of the AquaStress project but also not desirable. The challenge was, therefore, to build an integrated system using already existing tools. To achieve that (meta-)data centric architecture was chosen with three types of integration: a web-portal, common knowledge bases and process support. The web portal provides a single entry point for the various tools and presents information in a unified way. The knowledge bases enable sharing of meta information and knowledge items among the tools. The process support tool enables the tasks of the participatory process to be scheduled and monitored there by potentially allowing output from one tool to be used as input to another tool.

We started the development of the I^{3}S with the vision that in the future complex participatory processes could be supported by an information system which delivers knowledge and tools quickly for an end-user driven process in an integrated manner. Knowledge bases, a workflow manager, and several tools which can support dedicated tasks should work together in such a way that the process remains transparent and trustworthy, without the time-consuming need to develop much software support during the participatory process itself. Based on the accomplished work we conclude that developing such a system to support complex, participatory processes is feasible. Especially from the technical point of view there are no major barriers. But, there are several challenges ahead; we list the major ones below:

1) Within the project we managed to combine a set of tools. However, adapting them to work properly within the system requires work. If this work will be carried out depends most of all on the benefits the process leaders see in using the system. If the vision that process support is required for the process at hand and/or on the longer term (future participatory processes) is not shared, the willingness to adapt existing tools will be low.

2) We used open standards for connecting the different component in the system, such as XML and OpenMI. However, we needed to define data exchange formats, e.g. using dedicated XML schemes, to define content and semantics. This makes linkages of tools to the system quite dedicated, i.e. I^{3}S specific. Hence, for seamless and more generic integration we need widely agreed upon schema definitions – as OpenMI widely supports linking models in real time, there is a

    need for a meta-model or ontology to exchange meta information amongst tools used in participatory water management.

3) In the project we learned that there is a bigger gap than expected between end-users (stakeholders and project managers) knowledge about potential IT support and what we intended to develop. We must recognize that mainline thinking and knowledge is about individual, sectoral tools, models, and may be Decision Support Systems, but there is less awareness on the potential of knowledge bases and workflow management support. We think that by demonstrating the system awareness will be rising on the benefits of integration and use of functionalities that may help bringing participatory water management forward.

4) One key added value of I^{3}S is the knowledge bases. It should be noted that I^{3}S' success strongly depends on easy accessible information in knowledge bases. Though these knowledge bases were easy to develop, structuring knowledge and populating the system have posed a major challenge. Partly this is due to the over-commitment of staff in other areas within the AquaStress Project; partly due to the lack of knowledge about the usefulness of populating the systems and possibly due to the fear of information being taken out-of context, fear of 'plagiary' and lack of 'credits', compared to writing a report. There are few true drivers to share information.

5) A particular challenge in developing the I^{3}S was the involvement of end-users. In our vision (see the use-case), much generic expert knowledge and some tools required early in the process would be available at the start: work-flow management tools, virtual games and questionnaire functionalities. In the case of AquaStress these need to be developed (and populated), while the participatory processes started immediately. Hence the I^{3}S was not yet available at the beginning of local site studies. We advice that in end-user driven projects serious thought must be given whether or not available information needs to be organized prior to starting the participatory process.

6) In AquaStress, the role of a process manager was not specifically specified at the outset of the project. Much responsibility was put on what we could refer to as 'self-organizing' teams in test sites. The workflow manager however requires different roles to be specifically allocated to individuals or groups of people. We expect that this will not be a main problem in real-life, since responsibilities are usually clearly defined.

In conclusion, in the AquaStress project we managed to develop a suite of linked tools in such a way that we believe they can help making participatory processes truly end-user driven. Technology-wise there remain issues to be tackled, but this will not be the main barrier for further development, acceptance and use of such a system. However, acceptance and use of the system will rely much more on the willingness and capability of people to use such integrated systems, the willingness and availability of resources to populate knowledge bases and most importantly on the willingness of water authorities to invest in transparent participatory approaches in which the authorities will lose some control on the participatory process due to shift of control towards stakeholders.

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