WP 1.6

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THE ADAPTIVE MONITORING INFORMATION SYSTEM

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Table of contents

1 Introduction

This deliverables aims to draw final conclusions concerning the main lesson learned during the development of an Advanced Monitoring Information System for AM and its implementation in NeWater case studies.

In this work, we start from the theoretical findings described in the previous deliverables – mainly D1.6.1 and D1.6.3 – concerning the properties of a monitoring information system to support AM. Then, a comparison with the experiences made in the case studies – described in D1.6.5a and b – allow us to complete and, in same case, introduce changes in the description of these properties.

The activities carried out in WP 1.6 have been focused on two main topics. On one side, the properties of a monitoring and information system able to support AM have been defined. On the other side, we investigated the possibility to define a degree of adaptability for the monitoring system itself. That is, we assume that the learning process in AM requires also learning in the information production and management.

The deliverables is organized as following: section 2 describes the properties of a monitoring an information system able to support AM. Section 3 focuses on the definition of an adaptive monitoring. The architecture of the adaptive monitoring information system is described in section 4..

2 An advanced monitoring information system to support AM

Monitoring system plays a fundamental role in Adaptive Management (AM). In fact, the importance of learning in AM leads to a focus on the role of feedback from the implemented actions. Such feedback-base learning models stress the need for monitoring the discrepancies between intentions and actual outcomes (Fazey et al., 2005). Monitoring becomes the primary tool for learning about the system and its performance under different management alternatives.

To this aim, we assume that learning can be defined as a change in a person-system relationship, that is, the understanding of a person's place in the system and how they perceive it (Fazey et al., 2005). This definition implies that, because understanding is the goal which is achieved by the learner, each person may understand the environmental system differently and, therefore, act differently (Fazey et al., 2005). From the information production and management point of view, this implies that mental models influence an actor's perception of a problematic situation by influencing not only what data the actor perceives in the real world and what knowledge the actor derives from it (Timmerman and Langaas, 2004; Pahl-Wostl, 2007; Kolkman et al., 2005), but also what is noticed and what is taken to be significant (Checkland, 2001). It is important in information production and management that there should be a clear understanding and sharing of information users' mental models.

Therefore, contrarily to the traditional approach, in which information needs elicitation was intended in a top-down perspective, the design of a monitoring system for AM should begin by bringing together the interested parties to discuss their understanding of the system, the management problem, the information needed and how this information should be used. This implies involving a wide variety of stakeholders (i.e. scientists, managers, policy makers and members of the public at large) in a debate in which assumptions about the world are teased out, challenged, tested and discussed (Checkland, 2001), leading to the establishment of a common understanding about the system to be managed (Pahl-Wostl, 2007). This shared understanding can be structured in a system cognitive model, which allows the emergent properties of the system (i.e. variables to be monitored, thresholds, etc.) to be identified.

Among the different methods for Cognitive Modelling, an integration between Cognitive Maps (CM) and Causal Loop Diagrams (CLD) would seem particularly interesting to support monitoring system design (Giordano et al., 2007). Given the peculiarities of the two modelling devices, CM can be used to disclose individual understanding of the system and to support the debate among participants, whereas CLD has great potentialities to simulate system dynamics. A methodology for the integration of CM and CLD was described in Giordano et al. (2007). In this methodology, CM are used to inform the development of CLD.

The cognitive models should be used to identify the key components of the system, or key variables, which are those that influence the system dynamics and bring about the most important changes (Walker et al., 2006; Campbell et al., 2001). Since these variables influence the overall dynamics of the system, they are of direct interest to managers. These variables represent the central points of the decision-makers' mental model, the elements used by them to assess the state of the system and to take decisions. They represent, hence, the most important elements of the information needs. The conceptual models developed integrating the stakeholders' understanding of the system can be used as a basis for identifying the key variables (Campbell et al., 2001). To this aim, the analysis of CM can provided information about the relative importance of the different variables, by analysing the complexity of the causal chain. Those nodes whose immediate domain is most complex are taken to be those most central and, thus, the most important (Giordano et al., 2007).

The key variables operate at different scales and with different speeds of change. The slowly changing variables determine the dynamics of the ecological system, whereas the social systems can be influenced by slow and/or fast variables (Walker et al., 2006). Therefore, during the definition of the cognitive model to be used as basis for the monitoring system, it is fundamental to address some important issues related with complex system dynamics. Among them, the issue of spatial and temporal scale plays a fundamental role. In fact, complex systems have structures and functions that cover a wide range of spatial and temporal scales. Management actions may have impacts on different scales. The definition of the most appropriate scale to assess an action's impact is fundamental since it can be assessed as being positive on one scale and negative on another (Campbell et al., 2001). Moreover, structures and processes are also linked across scales based on the interaction between slow and broad structures and processes as well as those that are fast and small. Thus, the dynamics of a system at one particular scale cannot be analysed without taking into account the dynamics and cross-scale influences from the scales above and below it (Walker et al., 2006). The definition of the most appropriate level at which to assess system performance depends on problem bounding.

To deal with interaction between scales, we assume that the dynamics of a complex system has to be considered as a co-evolutionary process involving interacting systems in a common environment, in which each system follows its own path of self-organisation in response to the challenges of its particular environmental circumstances. The complex web of interacting systems can then be broken down recursively into a network of individual systems, each of which determines its own fate and affects that of one or more other systems (Bossel, 2001). Therefore, the variables forming the cognitive model have to be able to describe the performance of the individual system and its contribution to the performance of the other systems. A key element of such a study is the recursively repeated relationship of affecting system vs. affected system (Bossel, 2001). Most of the relationships between systems are hierarchical, with systems controlling subsystems, and subsystems contributing to the dynamics of the systems. This hierarchical structure implies that working on a particular scale often requires insights from at least two other scales, i.e. the lower level, to understand the important processes that lead to the emerging characteristics of the considered level, and the higher level (Campbell et al., 2001). Two sets of variables have to be considered for every system-subsystem pair. One set is required to describe the properties of the subsystem, whereas the second set is needed to describe the contribution of the subsystem to the performance of the whole system. This duality should be repeated at every level of the system hierarchy (Bossel, 2001).

Therefore, during the participatory process aimed at developing the cognitive model, participants should be required to think about their understanding of the total system, its essential component systems and the relationships that exist between them, adopting a multi-scale approach. Thus, a multi – scale/multi – steps cognitive modelling approach should be adopted to support the definition of the cognitive model as basis for the monitoring system. The first step should aim to structure the participants' understanding of the whole system, trying to identify the key elements of the system according to their opinions. Then participants should be required to debate about the existence of subsystems, which can be considered as small geographically well defined areas, characterized by specific problems. This leads the discussion to downscale the cognitive model and to identify the key elements which influence the sub-system dynamics. The key elements should be assumed as links between the different scales. That is, the downscaling of the cognitive model should start from the downscaling of the key components.

The outputs of this process are: a general cognitive model representing the decision makers' understanding of the whole system, which can be used to elicit the key elements at large scale; a certain number of sub cognitive models representing the decision makers' understandings about the behaviour of the sub-system. All this information can be used to identify the information needs in a participatory way.

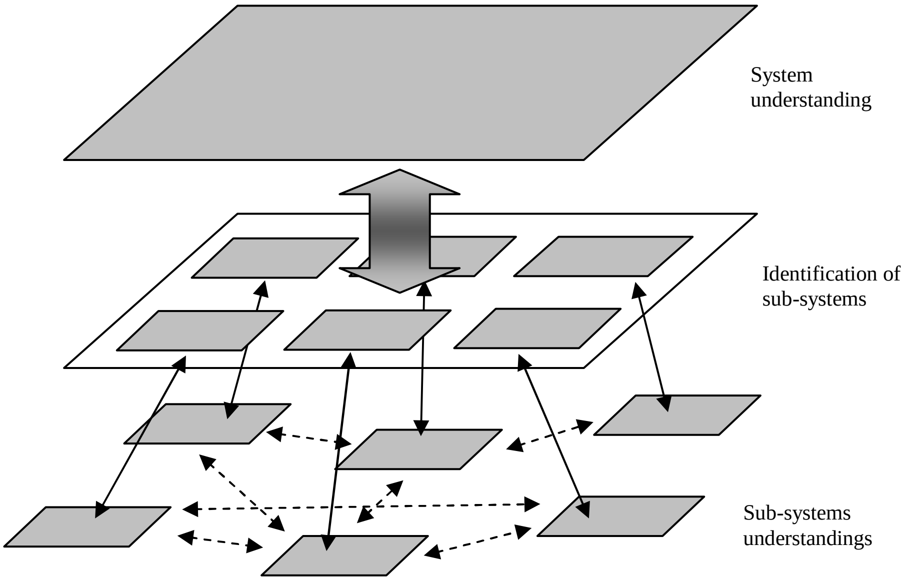

Fig. 1: Multi – scale approach in environmental monitoring

The identification of the key variables can also be supported by a strict integration between system monitoring and system modelling. This, in turn, is essential to any analysis of the implications of water policies. It allows the difficulties in understanding the dynamic feedback of the systems to be overcome, a particularly difficult task in an environmental context because of the number of factors involved. Moreover, humans have a limited capacity to understand the complexity of feedback in ecological systems (Fazey et al., 2005). This leads to erroneous connections between cause and effect and, thus, to erroneous conclusions about the impact of management actions. Conversely, models suggest which variables may be critical to monitor the impact of management actions, by posing elaborate hypotheses of which variables and relationships are critical to understanding the problem in question. The models then consider the dynamic implications of these hypotheses through the simulation of different scenarios. This allows monitoring networks to be designed (and re-designed) according to the model results. The potential of models to simulate future scenarios can be exploited to support the categorisation of the variables according to speed of change, i.e. slow changing variables and fast changing variables. Scenario simulation can draw attention to the role of the slow-changing variables in influencing system dynamics (Walker et al., 2006). The categorisation of variables according to speed of change can be used to program the frequency of data collection, making it easier to identify each variable's trend.

The integration between monitoring and modelling has to be considered as an iterative process. In fact, while models can simulate system dynamics, allowing the identification of key variables, the availability of new data allows the revision and updating of models. Moreover, the speed of change of the variables can also be considered iterative. Indeed, variables classified as slow changing in the model may be identified as fast changing by the monitoring system. In this case, the monitoring sample interval has to be changed. Thus, clearly a re-assessment process is needed both in models and in monitoring.

Simulation of system dynamics facilitates the identification of thresholds, which can be broadly defined as a breakpoint between two states of a system. When a threshold is exceeded, a change in system function and structure results. Such changes regard the nature and extent of feedback, resulting in changes of directions of the system itself (Walker and Meyers, 2004). The changes can be reversible, irreversible or effectively irreversible (Walker et al., 2006). Two different types of thresholds can be defined, i.e. positive and negative. A positive threshold represents a desirable change in the state of the system. Such a change can be due to implemented management actions. A negative threshold can be considered as the starting point of a non-acceptable system trajectory. The recognition of these thresholds is particularly important in the case of irreversible changes. In this situation, actions are needed in order to avoid exceeding the threshold. The integration between monitoring and modelling provides information about the current state and the future trajectory of the system.

The position of the threshold is strictly linked to past experience. There are no examples where a new kind of threshold has been predicted before it has been experienced. Typically, the identification of thresholds is based on an analysis of systems similar to the one under investigation (Walker and Meyers, 2004). To this aim, a database is going to be implemented to collect empirical data on possible regime shifts in socio-ecological systems (Walker and Meyers, 2004). Some authors suggest using variances in variable trends to detect an impending system change (Brock and Carpenter, 2006). Integrating these two different approaches can be very useful. In other words, the existing experience regarding regime shifts, coming both from other systems and from the tacit knowledge of experienced and highly skilled people, can be structured and included in the system model. The variance can be calculated using monitoring data and the position of the threshold can be changed.

In order to comprehend the importance of monitoring – modelling interaction to support AM, it is important to highlight that one of the most important outcomes of AM implementation is the definition of "flexible" management strategies, which should be suitable under different, and initial unknown, conditions. The models can simulate the different scenarios, characterized by different effects of the management strategies under different conditions. The reliability of models outputs is strictly linked to the reliability of the data inputs, which are mostly provided by the monitoring system. This results in an increasing importance of the interaction between monitoring and modelling. If monitoring and modelling has to be coupled then the variables to be monitored strictly depend on the data requirements of the models. How often the data should be collected also depends on models requirements.

An important conclusion that can be drawn from what has been said previously is that the information needs to develop a monitoring program for AM should be based on the strict interaction between monitoring – modelling – decision making. Moreover, the role of the local legal normative on data collection should be taken into account.

The elements to be taken into account during the elicitation of information needs are represented in the following figure.

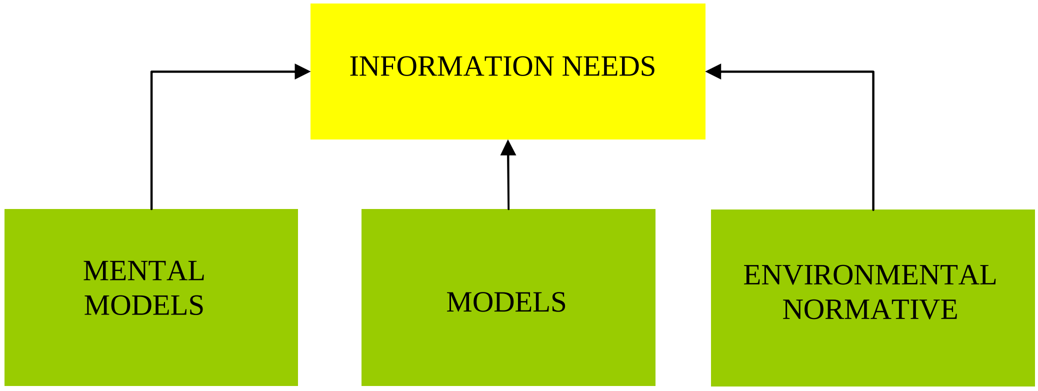

Fig. 2: Elements influencing the information needs for the monitoring system

The interaction between this three elements is not linear. There are many feedbacks allowing learning process also in information production. This topic is discussed in the next section.

The AM requires to adopt an integrated and multi – scale approach which often results in un unsustainable increase of the monitoring costs. As we stated before, the collection of long time series of data is fundamental to detect trends in system dynamics and, hence, to identify system changes in the early stage. Therefore, the economic sustainability of the monitoring system is of outmost importance. The integration of different sources of information, able to collect data at different scales, can results in an increase of information availability without increasing the monitoring costs. This issue has been addressed in previous deliverables.

The following table tries to summarizing the theoretical and practical outputs concerning the definition of a monitoring system able to support AM:

Table 1: *Expected properties of an advanced monitoring information system for AM*

Topic	**Advanced Monitoring Information System for AM**
Focus of monitoring	Monitoring system should provide information on both positive and negative feedbacks of implemented management actions, in order to support learning process.
Domain integration	In order to detect unintended side effects, the monitoring system should be based on an integrated approach. Monitoring should focus on different aspects of a complex problems, contributing to identify possible relationships.
Sources of information	Different sources of information should be integrated, ranging from the more traditional – scientific methods to innovative approach (i.e. remote sensing, locally-based monitoring, etc.)
Information needs	The process to elicit information needs should be based on an iterative interaction between information users (decision – makers) and information producers. This results in an increased use of information for the decision process.

Mental models	The design of the monitoring system should take into account the existence of multiple and often conflicting understandings of the system to be managed. Design process should start from a participatory process to elicit mental models.
Role of modelling	The interaction between monitoring and modelling is fundamental. It allows to identify important properties of the system to be managed.
Spatio – temporal scale	AM requires gaining reliable information about different parts of the spatial and temporal continua. An inter – scale approach is required.
Monitoring costs	The monitoring costs should be reduce in order to increase the economic sustainability of monitoring, allowing the collection of long time series of data. This is fundamental to detect system changes for AM.
Access of information	Monitoring information should be easily accessible and understandable by different stakeholders groups, in order to support participatory process and social learning.

3 An adaptive monitoring information system

The properties described previously refer to a monitoring system able to support AM. Nevertheless, if we assume that learning from experiences might results in changes in decision making, and that the interaction between information production and system management is fundamental, then we should infer that monitoring system should be characterized by a certain degree of adaptability.

This means that two learning process has to be considered. The first one concerns the water management conceptual model. Once information has been examined, a perspective is developed, and an insight is gained and integrated into the conceptual model itself (Kolkman et al., 2005). Information may prove initial models to be wrong and support the debate between actors, which may lead to a revision of models, through reflection and negotiation, in a social learning process. This learning may, in turn, support changes in the water management conceptual model. Moreover, feedback on management actions may generate new questions or new insights. This may make the originally agreed upon information appear inadequate, resulting in new information needs. Thus, the information needed to support a decision process evolves according to the actors' learning process, leading to revision/adaptation in monitoring strategies and data interpretation.

Several authors suggested methodologies to define a flexible monitoring program able to adapt to changed conditions. Ward and others (1985) dealt with water monitoring. They define the monitoring system as containing a number of tasks to convert a sample of water in the environment into accurate understanding of it (fig.1).

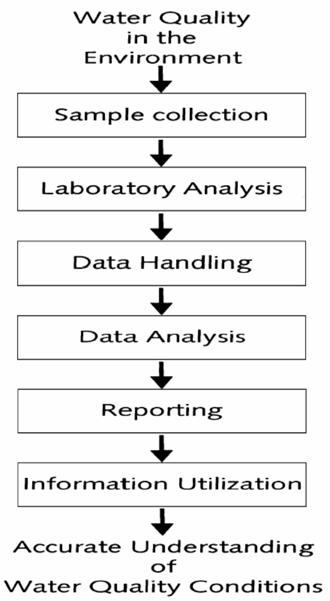

Fig.3: Flow of information in a monitoring system

Ward stressed the need to customize monitoring efforts. Nevertheless, there is no space for feedbacks and learning process.

MacDonalds (1994) proposed a methodology composed by 12 steps to design and execute monitoring program:

1. Propose general objectives
2. Define approximate budget and personnel constraints
3. Review existing data
4. Define specific objectives and hypotheses
5. Determine variables to be monitored, sampling locations, sampling procedures, and analytic techniques
6. Evaluate hypothetical or a comparable set of real data
7. Reassess the specific objectives and compatibility with available resources
8. Initiate monitoring on a pilot basis
9. Analyse and evaluate data from the pilot project
10. Reassess monitoring objectives and compatibility with existing resources, and modify the monitoring project as appropriate
11. Continue monitoring
12. Prepare regular reports and recommendations

Even if these steps are quite descriptive and not easily reproducible by information users, MacDonalds emphasizes the involvement of management as information users in defining monitoring objectives.

MacDonalds also describes the importance of feedbacks of monitoring results to management (fig.2):

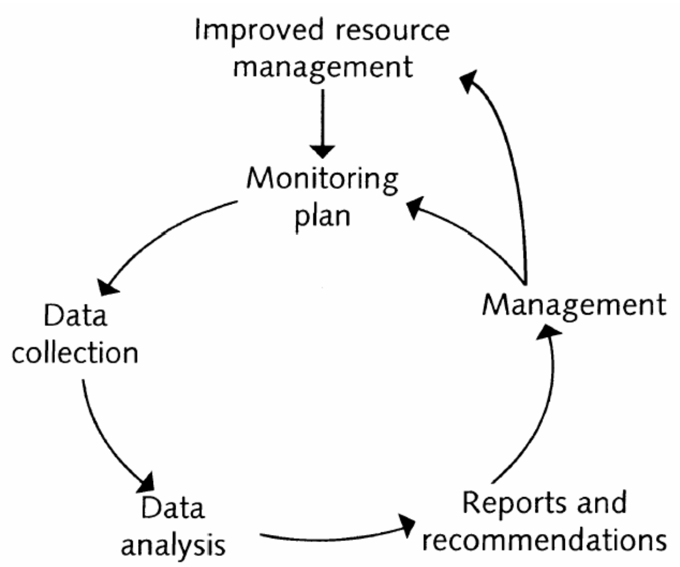

Fig. 4: Monitoring feedback loop developed by MacDonalds

Cofino (1995) introduces the concept of quality of information, which is high if the information meets the needs. The content and detail of required information depends upon the stage in the policy cycle. Thus, the information needs change through the respective policy phases.

Cofino defines the process of monitoring design using the quality spiral scheme (fig. 3) which emphasizes the iterative nature of monitoring activities:

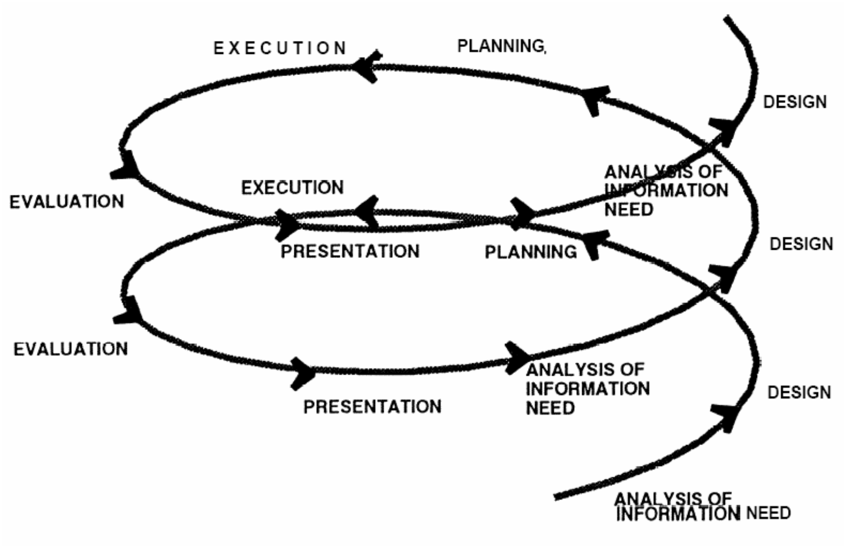

Fig. 5: Quality spiral for the monitoring process

According to this framework, monitoring is an ongoing activities. The process starts with the specification of information needs and expectations. During monitoring targets maybe reached or policy may change, implying that monitoring strategies may need to be adapted (Cofino, 1995). The ongoing evaluation of monitoring plan plays a fundamental role.

Starting from these results, Timmerman et al. (2000) developed the information cycle as a framework to state the essential steps in continuous process of information production (fig. 4).

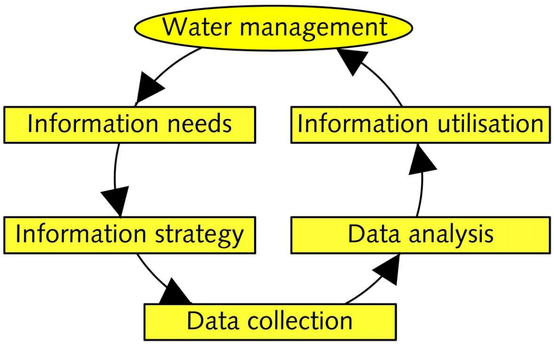

Fig. 6: Information cycle

The information cycle is a framework to describe how monitoring in the broad sense of collecting information to support integrated water management should be developed and implemented. It is a framework for communication between policy makers and scientists (Timmerman et al., 2000) as it is easily understandable for someone who is not familiar with the information production process and provides a clear link between the decision making process depicted by the water management activity in the top of the figure and the information production elements. The cycle describes the essential elements in the process of information collection, which is inextricably bound up with water management. The information user is regarded as being inside the water management activity.

All these methodologies are based on the need to establish an interaction between decision-making process and information production and management. Based on this interaction, the monitoring program should be able to follow changes in the understanding of water management. If learning from management experiences results in changes in mental models of the decision makers, then also the information needs can change. That is, a different understanding of the system can be based on different key variables. This means that different information should be collected in order to support decision making. The monitoring program should be able to follow these changes, continuing to provide useful information for the decision process. By iteratively reviewing and adjusting the information needs and the data collection methods and plan, the monitoring system could be adapted to the learning.

To support the process of adaptation of monitoring system, an extensive series of reflective events to support critical thinking, occurring alongside with data collection, should be organized. Therefore, during the monitoring design phase, it's important to plan a series of learning events. During these events, information users and producers should be involve in a debate to critically analyze their understanding of the system, and to identify possible changes as results of the learning process.

A possible way to encourage this critical thinking is to regularly ask to information users and producers their views about the system and the information the monitoring system is collecting. The basic questions that can be used to structure the debate are:

- What was your original understanding or assumption?
- What is your revised understanding or assumption?
- Are changes needed in monitoring program?
- What changes do you suggest?

This process can result in changes in information needs and monitoring practices due to changes in water management mental models. These changes are due to learning from management experiences. The monitoring plan should be adapted to this changed conditions.

Our approach lies on the idea that the adaptive degree of monitoring program is also linked to the learning process related to the implementation of monitoring activities. That is, the second learning process relies on feedback from applied monitoring practices. As a result of experience in implementing the monitoring program and assessing its results, adaptation to monitoring may be needed (Cofino, 1995; Smit, 2003). The causes for adaptation can be found within monitoring practices: too little attention may have been spent on specifying the information needs; the information needs may have been specified in such a way that no adequate information can be produced from it, or so that it does not reflect the actual information users' needs; the selected indicators may not adequately measure what they are purported to measure; or the strategy to collect information may not have produced the right information.

This learning process concerns exclusively the information management mental model and it can happen even if the management mental model does not change. The learning is based on a critical analysis of the effectiveness of monitoring strategies. Thus, an open debate between information users and producers should be organized in order to evaluate the effectiveness of the monitoring program.

The basic questions to lead the discussion are:

- Is the monitoring program providing enough information?
- Is the quality of information enough to support decision process?
- Does the monitoring provide not useful information?
- Is the monitoring information comprehensible?
- What weakness do you identify in monitoring plan?
- What improved action do you suggest?

The key variables of the water management mental models should be assumed as basis for the discussion. At the end of the debate, the effectiveness of the monitoring program should be done and possible improvements should be identified. Possible improvements concern the data to be collected to describe the key variables, the program for data collection, the methods, the way in which the information is provided to the users, etc.

In case of participatory monitoring the update of monitoring program due to learning in monitoring is even more important because participant knowledge about monitoring increases as they implement it. Their opinions about what is a good indicators, or what methods exists and are the best, how often the data should be collected and what information is actually useful can change.

The changes described previously can be considered as “internal” at the monitoring program. However, changes in monitoring program can be needed because of external factors as well. Among them the budget, the monitoring technologies and the scientific progress can have an important role. The available budget may restrict or enlarge the number of data that can be collected. Moreover, the budget has a strong influence on the intensity of the network in terms of locations and frequency. Progresses in science and technology (e.g. progress in remote sensing technologies, etc.) can disclose new methods to collect data or they can reduce the costs of monitoring.

4 The architecture of the AMIS

Starting from the theoretical findings described in previous sections, and from the experiences collected in NeWater case studies, the conceptual architecture of the Adaptive Monitoring Information System (AMIS) has been developed (fig. 7).

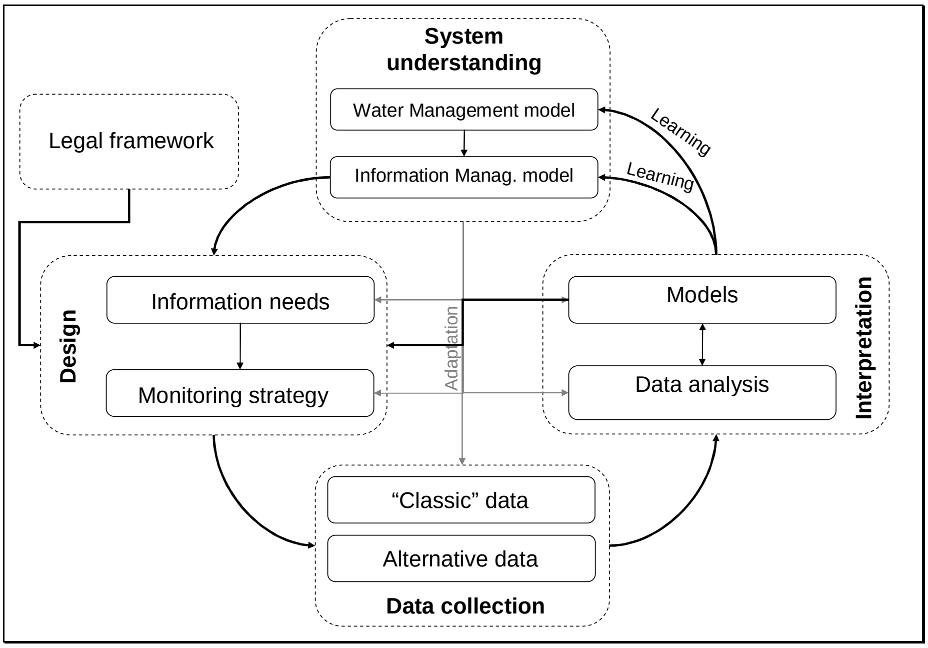

Fig. 7: AMIS architecture

The AMIS conceptual architecture has been developed starting from the information needs cycle, developed by Timmerman and others (2000), with the addition of new elements and connections to take into account the results of the research activities in NeWater case studies.

In this architecture, three main phases of the monitoring program have been identified: i.e. design of the monitoring system, data collection, data interpretation. The interaction between information production and system management is represented by the addiction of the "System understanding" module.

As stated previously, the design of the monitoring program should start with the definition of the information needs, which allows the development of the monitoring strategies. According to our experiences, information needs elicitation is influenced by different elements. Firstly, the decision makers' system understanding, described as mental models, which can be used to identify the key variables, that is the components of the system which have to be monitored in order to enhance the understanding of the systems and its dynamics under different conditions. In other terms, the key variables are those used by decision makers to learn about the effects of management strategies on the system to be managed.

The information needs are also influenced by the interaction between monitoring and modelling. Particularly, models support the selection of the key variables, and the definition of monitoring strategies providing suggestions about the frequency of data collection for the different key variables. Moreover, given the role of modelling in AM (see section 3), monitoring system should provide enough information to be used as input for the models. This also influences the information needs.

Several laws, both national and international, describe in a clear way the data that has to be collected and the process for data collection in order to have reliable information. Therefore, the process of information needs elicitation cannot disregard these legal obliges. The legal framework has a strong impact on the definition of both information needs and monitoring strategies.

One of the lesson learned during AMIS implementation in NeWater case studies concerns the steps for the information needs elicitation. The process should start with the review of national and international environmental legislation. Then the information needs of decision makers and of models should be added.

During the design process it is important to take into account that the an advanced approach to monitoring system is based on the integration of different sources of information, ranging form the more traditional ones (i.e. professional monitoring methods), to more innovative (i.e. remote sensing, locally-based monitoring, etc.). As stated previously, the integration among different information sources allows to increase the availability of information without increasing the monitoring costs. This results is particularly important in AM framework, because of the necessity to collect long time series of data, in order to detect unintended system changes in the early stages.

Nevertheless, the integration of alternative sources of information requires additional efforts for data interpretation. In fact, the information collected through these “unconventional” methods is not often not easily understandable by the decision makers and, hence, not immediately usable to support decision making process. As an example, the experiences described in D1.6.5 b suggest that the information collected by local communities cannot be used directly in the decision process, because of its qualitative nature. Therefore, a GIS-based system able to deal with qualitative information has been developed in order to analyze this information and make it reliable for the decision making process.

In the box “Data interpretation” we included also models. They are fundamental to interpret the monitoring data and to support the learning process of AM. The models should be used to simulate scenario of the system’s state, starting from monitoring data, in order to identify potential thresholds. This is particularly important in case of negative threshold, as explained previously.

Two learning processes are represented in the AMIS conceptual architecture, which result in adaptation of the monitoring program. The first learning is a result of monitoring data interpretation and can provoke changes in system understandings and mainly in the water management mental model. The second learning results from the critical analysis of the monitoring activities and influences the information management mental model.

The importance of these two learning processes has been described in previous section. Here it is important to describe how the need to adapt the monitoring strategies can be addressed in practical terms. The experiences done in NeWater case studies, and the analysis conducted in other river basins, suggest that adapting a monitoring system to changed conditions is not easy, particularly if the program is based on traditional monitoring practices. In this case, even if the information needs change due to changes in system understanding and/or in water management, it is not easy to change the monitoring network. Due to its high inflexibility, changing to the network can be done only with high costs, which are often not sustainable for water management agencies. Therefore, often it is preferable to develop a new monitoring network while the previous one continues to provide information which are not really useful for the decision makers.

The adaptability of the monitoring program can be achieved only if it is assumed as one of the main goal during the design phase. Therefore, the information producers should based their work on the awareness of the increasing complexity and uncertainty of the real world and of their impacts on the effectiveness of monitoring program. Adopting this approach, critical reflective events should be planned during the design phase, in order to support the identification of needed changes to the program. The implementation of this changes is strictly dependent on the flexibility of the monitoring program.

Two possible strategies can be applied to this aim. On one side, we can suggest the development of a semi – dynamic monitoring network, which can be obtained integrating a static network (traditionally based on monitoring stations which are located in some areas of the territory) with dynamic monitoring stations which can fill data gaps. Examples of this semi – dynamic monitoring network are those used in cases of natural hazard. In this cases, mobile monitoring stations are used to collect data in areas not covered by the traditional network.

On the other side, the introduction of alternative sources of information can play an important role. They can fill data gaps, without changing the structure of the traditional monitoring network. This results in a reduction of the needed costs to adapt the monitoring program to changed information needs. The selection of the type of information sources strictly depends on the available human and economical resources. Moreover, the actual access to information and communication technology should be taken into account.

5 Conclusions

In this deliverable the findings concerning the monitoring system for AM, from both theoretical and practical point of view, have been described. The theoretical findings concern the issues to be addressed in order to take into account the properties of complex systems. The practical findings have been deducted from the experiences made in NeWater case studies. Hints on how to implements such monitoring strategies are provided.

Starting from the importance of monitoring role in AM framework, two different aspects have been described in this work. On one side, the properties of a monitoring system to support AM have been described. From this point of view, the monitoring system should be able to provide information to define the system dynamics and, hence, to detect undesirable system changes in the early stage. The monitoring design should be based on a strict interaction between monitoring and management, and an integrated and multi – scale approach should be adopted. Since detection of trends requires long time series of data, the reduction of monitoring costs is an important issue in order to assure the economical sustainability of the monitoring system.

Beside, we also investigate the properties of an adaptive monitoring information system, that is, a monitoring system which is able to adapt itself to changing conditions. The need for adaptation derives from two learning process, i.e. learning in water management, and learning in monitoring practices. In both cases, learning requires changes also in information production. To meet this needs is fundamental to support the interaction between monitoring and management.

The adaptability of monitoring system depends on capability to organize critically reflective events besides data collection, involving both information users and produces, and on the integration of different sources of information in order to increase the information availability without increasing the monitoring costs.

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