NeWater

WP 1.6

TASK 1.6.1

CRITICAL REVIEW ON EXISTING MONITORING SYSTEMS

Report of the NeWater project -
New Approaches to Adaptive Water Management under Uncertainty

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Executive Summary

Overview

This report is the first deliverable of the WP 1.6 of the NeWater Project. The NeWater Project aims at the development and the implementation of methodologies and tools to support a stepwise change process in water management from the current management regimes to a more adaptive one.

Within the NeWater frame, WP 1.6 - *Transition to advanced monitoring systems* will define a monitoring system to support adaptive management process. the WP 1.6 aims at defining the architecture of a new monitoring system able to overcome the limits imposed by the data scarcity, particularly in data-poor regions. To reach these aims different sources of information have to be integrated.

The Task 1.6.1 carries out a review of the state of the art concerning monitoring systems (both methodologies and technologies) for integrated water management and adaptive water management. Along with this review of existing technical systems, an inventory of user's experiences with these systems has been performed with aim to sketch first set of characteristics for a design of new type of monitoring systems.

The project has started in January 2005 and will run until December 2008.

Information requirements and new monitoring system

Policies and decision making processes on environmental issues have to be based on appropriate information and modelling results, as widely acknowledged in literature. Sound knowledge, reliable information and accurate data are vital for good environmental decision-making.

Increasing knowledge of the complexity of the processes in water systems has led to a growing demand of environmental information. Over the last two decades, water management has changed from a focus on distinct sectors, to a more integrated perspective.

The importance of the environmental information increased along with the necessity to ensure an appropriate access to the information concerning the environment to all the parties interested in the decision-making.

Dealing with the role of information in the decision-making process, some issues as to be taken into account. The first one concerns the role of the information in the rationalization of the decision process. In fact, although the decision-making processes are mainly rational, the use of information in environmental decision-making has proven to be rational only up to a certain point. Another issue that has to be considered concerns the so called "knowledge gap" between the sources and the receivers of information. To support the policy development process, the information have to be adequately understood and accepted as relevant and reliable by those involved in the decision process, creating knowledge. (Chapter 2)

In this "informational" perspective of the environmental decision-making, the environmental monitoring networks play a fundamental role since they have been widely used to increase the knowledge of the state of the environment.

The monitoring activities can be conducted for a broad range of reasons, i.e. to measure the environmental effects of human activities, to predict or give early warning of problems so that they can be mitigated before irreversible damage occurs, to verify the efficacy of regulation and legislation or that certain negative effects will not occurring, to understand the behaviour and functions of ecosystem for scientific purposes.

Traditional environmental monitoring is unsuccessful in providing timely identification and warning of emerging environmental problems; in delivering effective feedback on the adequacy of policies and programs; in providing policy-makers with a sound basis for action. But, above all, traditional monitoring systems are less successful in delivering information to the public, stakeholders, research

personnel, and managers so as to raise awareness, educate and provide the basis for informed decisions and choices.

The changing nature of the resource management towards a more adaptive approach is also changing the role of the information. In fact, in such an approach, the outcomes of the decision process need to be monitored closely during the implementation to confirm their effectiveness, and to help refine future actions. Thus the monitoring activities have to support the increase of the knowledge and the improvement of the management plan (Chapter 4).

An innovative monitoring system should Be relevant and decision supportive; it should take into account consideration of scale and type; it should be based on conceptual system model that explicitly recognise relationships between society and environment; it should allow for an overall integrated evaluation of the system, collecting different type of measures and integrating the human systems as a subset of the ecosystem which supports them.

Above all, an innovative monitoring system has to be adaptive and flexible, able to deal with environmental changes and to adapt to changes in political context and societal values, to incorporate new information, technologies and scientific researches, and it has to be tailored for specific ecosystems (Chapter 6 and 7).

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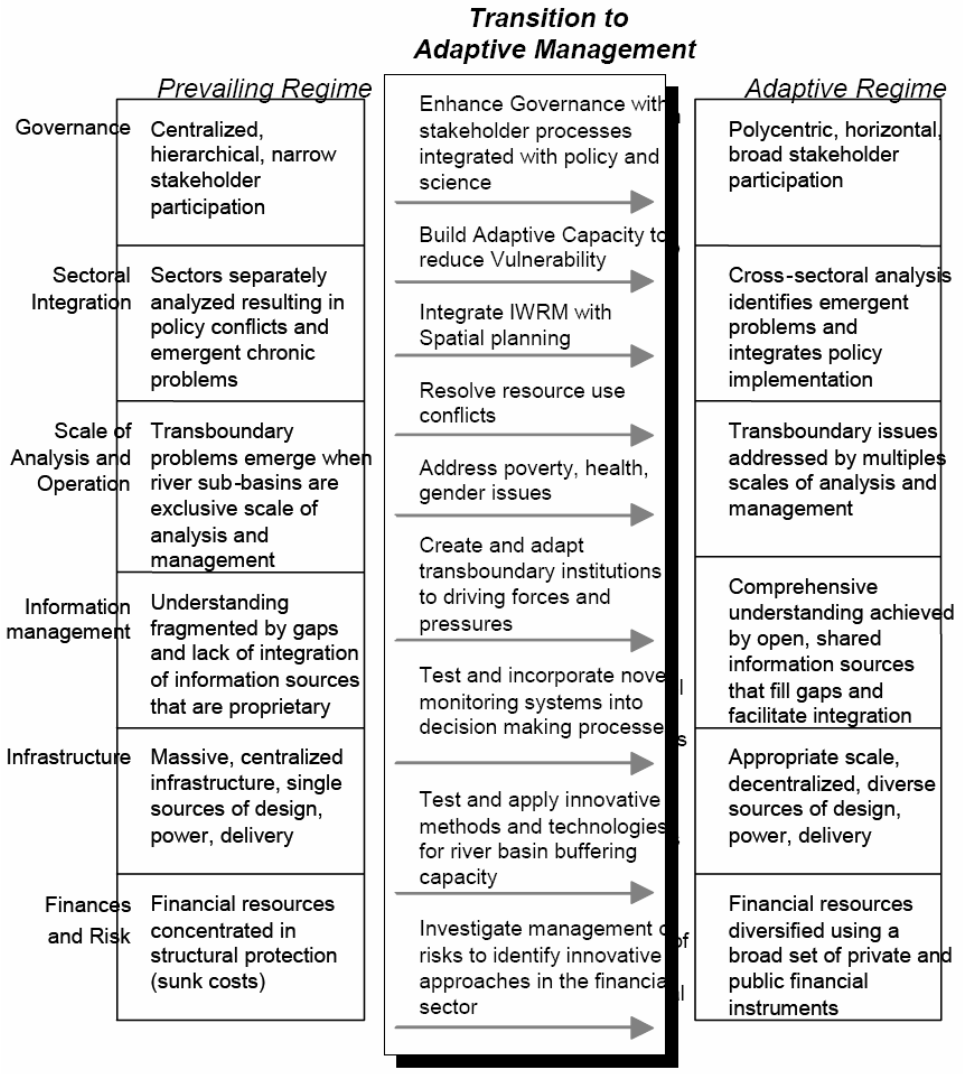
1 Introduction

The NeWater Project aims at the development and the implementation of methodologies and tools to support a stepwise change process in water management from the current management regimes to a more adaptive one. NeWater identifies key typical elements of the current water management system and focuses its research on processes of transition of these elements to adaptive IWRM. Each key element will be studied using novel approaches.

The information management is one of the key elements driving the transition process, as reported in the following figure:



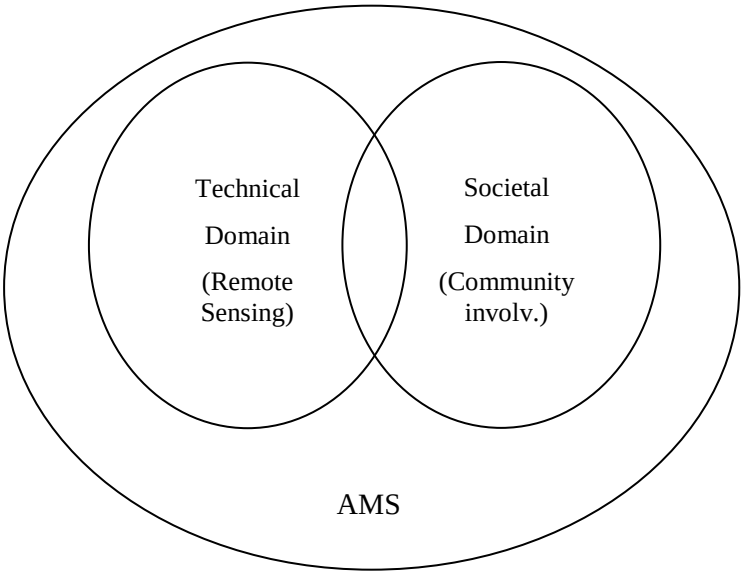
Within the NeWater frame, WP 1.6 - *Transition to advanced monitoring systems* will define a monitoring system to support adaptive management processes. WP 1.6 is a part of WB 1, that focuses on the definition of conceptual frameworks and practical methodologies for transition to adaptive management.

Defining the aims of the WP 1.6, we recognize that the application of support tools in water management requires a large amount of rather detailed data, which are often not available, incomplete or inaccurate, or not easily accessible.

Furthermore, the problem of the "understandability" of the information has to be considered. In fact, often the traditional environmental information are structured to support environmental engineers, analysts and other experts. On the contrary, these information are not easily understandable by non-expert people, reducing their capability to participate in the environmental resources management. Thus, often the traditional monitoring systems are not suitable to support the transition to the Adaptive Management.

Therefore, the WP 1.6 aims at defining the architecture of a new monitoring system able to overcome the limits imposed by the data scarcity, particularly in data-poor regions.

To this aim, different sources of information have to be taken into account. In the definition of the *Advanced Monitoring System*, two domains are combined as reported in the following scheme:



On one side, the Remote Sensing technologies could play an important role in Adaptive Water Management providing frequently updated information on hydrology, land use, demographic data and other relevant data. Therefore, the Remote Sensing can contribute to fill the gap in the environmental data also in area with a not reliable monitoring system, providing low-cost information.

Another source of information is related to the community involvement in environmental monitoring activities. In the WP 1.6, the architecture of a Community-based Monitoring System (CBMS) will be proposed.

This report carries out a review of existing monitoring network systems at river basin level, as reported in the DoW. A review of the state of the art concerning monitoring systems (both methodologies and technologies) for integrated water management and adaptive water management has been conducted. Along with this review of existing technical systems, an inventory of user's experiences with these systems has been performed with aim to sketch first set of characteristics for a design of new type of monitoring systems.

The report is organized as follows: section 1 is devoted to the description of the role of information in the decision process. In the section 2, the results of the review on the monitoring system role in water management are reported, highlighting the drawbacks of the

current monitoring system in an adaptive perspective. In section 3 and 4 the characteristics of a monitoring system able to support the Adaptive Management process are described. Section 5 contains some preliminary considerations on the definition of an adaptive monitoring system.

2 Information and Decision Processes

Decision analysis is founded on a set of axioms that philosophically imply that the attractiveness of alternatives should be based on the likelihoods of the possible consequences of the alternatives and the preferences of decision makers for those consequences (Keeney, 1992).

According to the decision analysis, a Structured Decision Process (SDP) is formed by several steps, starting form the definition of the problem to be addressed, the objectives that matter for this decision, the alternative to be considered, the consequences of the alternatives, the uncertainties regarding the consequences, the tradeoffs among the alternatives, etc.

The structured decision process approach is not based on the full knowledge and formal rationality of the participants. It assumes that the participants are interested in the consequences of the decision to participate in the decision process, using the best available information to be used for quantitative and qualitative evaluation and for the comparison of the alternatives (McDaniels and Gregory, 2004). Generally, decision-making is largely considered as a rationale process based on the use of all available information. Therefore, the information can support different phases of the decision process, ranging from the problem definition, to the alternatives construction and evaluation (Keeney, 1992). Moreover, the information availability and how it's communicated can influence also how the decision in framed.

This broad concept has to be extended also to the decision processes dealing with the environmental resources management. Policies and decision making processes on environmental issues have to be based on appropriate information and modelling results, as widely acknowledged in literature. Sound knowledge, reliable information and accurate data are vital for good environmental decision-making (Haklay, 2003).

The connection between the environmental management activities and the information collection dates to the early phases of the modern environmental movement. One of the milestone is the USA – National Environmental Policy Act (NEPA), enacted in the 1969, which explicitly binds the environmental politics and the production and use of information.

Increasing knowledge of the complexity of the processes in water systems has led to a growing demand of environmental information (Timmerman et al., 2000). Over the last two decades, water management has changed from a focus on distinct sectors, to a more integrated perspective. To construct and to select the most suitable alternatives for water management, a holistic approach has to be adopted. In water resources management domain, increasing interest is posed to the integrated assessment, that is emerging as a new discipline that integrates different kind of knowledge to be used in all phases of the decision process. The water management is a complex process involving many actors, with different knowledge and at different levels. The success of management initiatives in such a context is dependent on the capability to facilitate the cooperation between the actors and the integration between different sources of knowledge. Thus, the flow of information between these actors, the analysis of the ways in which networks of actors and institutions communicate internally and externally is vital (Timmerman and Langaas, 2004).

One of the main aspects of integrated water management is the integration among different sources of knowledge. In particular, the integration among the knowledge as resulting from the application of "formal" methods, mainly based on mathematical models, with that deriving from stakeholders-based approaches has become an active area of research (Pahl-Wostl, 2002). The role of the participatory process in water management is also established

by the European Community Water Framework, which strongly encourages the active involvement of all the affected parties in the resource management.

Thus, in water resources management domain, increasing interest is posed in enhancing public participation, allowing all possible stakeholders, both individuals and organizations, to participate in the decision process and to provide their own knowledge. In this perspective, the importance of the environmental information increased along with the necessity to ensure an appropriate access to the information concerning the environment to all the parties interested in the decision-making. In fact, according to the UN conference on "Environment and Development", hold in Rio De Janeiro (1992), the authorities have to facilitate and encourage public awareness of the environmental issues and public participation in the decision process by making information widely available. Moreover, the Agenda 21 document pays particular attention to the role of the information in the sustainable environmental resources management. In a sustainable development perspective, everyone is a user and provider of information. The need of information arises at all levels, from the decision-makers at national and international level to the grass-roots and individual levels (UN, 1992). The principle of access to environmental information is directly connected to the goal of improved public awareness to environmental issues and improved participation in environmental decision making. In fact, to achieve public participation in environmental decision-making, the public must gain access to environmental information, data and knowledge (Haklay, 2003; Gouveia et al., 2004).

The success of IT tools, such as computer-supported environmental models and the environmental information systems, has contributed to enhancing the importance of information in the decision-making process. The Environmental Information System (EIS) makes information available to mangers in many forms and are able to integrate spatial data and dynamic simulation model (Argent and Grayson, 2001). ICT can have a significant role in providing access to timely, accurate and understandable environmental information, which has been a major issue within environmental monitoring (USEPA, 1998a). The spatial nature of the environmental data has favoured the use of Geographic Information System (GIS) and associated technologies. GIS have been used mainly for data exploration and visualization, improving communication among the decision-makers. Moreover, different attempts have been made to improve the user interface of these tools in order to allow non-expert people to access useful information.

Many EISs are available on the web, aiming at facilitating the involvement of people in decision making using a remote interaction. Traditionally, this tools have been developed to support a "one-direction" flow of information, from the information producers to the end users. Thus, the WWW has been used mainly to publish the information. Applications that explore the spatial characteristics of the data, such as webmapping applications, have been developed (Gouveia et al., 2004). More recently, the awareness of the role that the "lay knowledge" has to play in the environmental resources management is leading towards the development of IT tools for a "two-way" information flow, to collect information and knowledge from the end users to be used in the decision process. Collaborative spatial information systems have been developed to allow the integration of multiple sources of data, facilitating data access, visualization and communication.

The ICT tools have been used also to support the monitoring activities. Examples of ICT application to environmental monitoring exist within all the major activities: from data acquisition, storage and management to data processing and communication (Gouveia et al., 2004).

Within ICT, the use of distributed database systems and spatial based tools has an impact across all the environmental monitoring (EM) activities due the large volumes of temporal and spatial data collected within monitoring systems. The pervasive use of the web is having

a major impact in all EM activities, since it has created new forms of data collection, access, processing and communication.

Dealing with the role of information in the decision-making process, some issues have to be taken into account. The first one concerns the role of information in the rationalization of the decision process. In fact, although the decision-making processes are mainly rational, the use of information in environmental decision-making has proven to be rational only up to a certain point (Timmerman and Langaas, 2004). The use of information is not unambiguous, containing elements of cultural and habitual behaviour that can be referred as individual mindframes. The mindframe is the window through which people view the world. Therefore, the same information can be interpreted in different ways by different people. This could lead to misunderstanding and difficulties in the communication between different actors (e.g. Dewulf et al, in press).

Another issue that has to be considered when dealing with information and decision process concerns the so called "knowledge gap" between the sources and the receivers of information (Timmerman and Langaas, 2004). The information producers often do not speak the same language as the information users. Information users tend to oversimplify and have unrealistic expectations, whereas information producers fail to address the management needs (MacDonald, 1994). The technical language used by scientists must be translated into lay terms for the information to be useful for decision-makers and stakeholders. To support the policy development process, the information have to be adequately understood and accepted as relevant and reliable by those involved in the decision process, creating knowledge. This cannot be done without policy makers specifying their information needs (Timmerman and Langaas, 2004).

In this report, starting from the consideration described in this section, the role of monitoring system as information producer will be analysed, highlighting the characteristics of the current monitoring system that have to be made suitable to the new adaptive perspective. In the assessment of the current monitoring system, the opinions of the end users have been used. The last sections of the report are devoted to the description of the characteristics of an adaptive monitoring system.

3 Information Production and Monitoring

As stated in the previous section, the information can be considered as the basis of the environmental decision process. This information is mostly provided by the environmental monitoring networks, that have been widely used to increase the knowledge of the state of the environment (Gouveia et al., 2004).

The monitoring information can be used in different phases of the decision process. According to Timmerman et al. (2000), three information categories can be identified:

- ✓ Information for policy evaluation. The information should show to what extend problems are still relevant and measures have had the desired effect.
- ✓ Information for policy preparation. Policy preparation needs information on present status and future development.
- ✓ Information for operational water management. Operational water management needs direct usable information. Essential information for operational water management is real-time available to allow for instant reaction.

According to the scientific literature, one of the basic reasons to invest time and resources in monitoring activities is to measure the environmental effects of human activities. These monitoring projects basically are local and short-term.

The monitoring activities can be also conducted for a much broader range of reasons:

- o Some measures can predict or give early warning of problems so that they can be mitigated before irreversible damage occurs.
- o Regulations and legislations require monitoring to verify the efficacy or that certain negative effects will not occur.
- o Monitoring can be also done for scientific interests, e.g. to understand the behaviour and functions of ecosystem.

As we will see in the following, more recently the scope of monitoring has broadened.

The importance of monitoring activities as information producer has been established by the EU Water Framework Directive (WFD). Particularly, the Article 8 establishes the requirements for the surface water status, groundwater status and protected areas. The WFD introduces the monitoring programmes to establish a coherent and comprehensive overview of water status within each river basin district.

Different methods have been used to support the monitoring activities, ranging from the chemical and biological analysis to remote sensing technologies. The analysis of these methods is not the aim of this report. In the following, we mainly focus on the process of information production, highlighting the drawbacks of the traditional monitoring system and proposing some improvements.

The development of any monitoring programs stems from a conceptual model of how the system works. This is the perspective and assumption behind how the problem is framed and how the monitoring process is designed to extract information. One of the most diffused model is the stress-response model. The assumption is that when an ecological system is subject to a pressure, it changes in some way. The stress-response model attempts to link the stress to the system responses in order to predict or provide an early warning (Boyle, 1998).

Some approaches attempt to expand the stress-response model by enhancing its capability in identifying and diagnosing a problem. These monitoring programs generally use a set of indicators to detect if a problem exists (Boyle, 1998).

New approaches to monitoring environmental health and integrity evaluate the status of the environment as a whole, since it's impossible to determine specific threats or link system changes to a specific cause. A parallel advanced in monitoring theory is the inclusion of cumulative effects, that is compounding the effects of more than one source of stress.

A shift is also occurring in the motivation of monitoring programs. People are increasingly concerned with living in a sustainable way and wish to assess progress towards this goal. In the last few years, many attempts have been made to define sustainability monitoring programs.

The elements of a monitoring program can be summarised as follows (Boyle et al., 1996):

- A set of human goals: a clear articulation of the goals and the users of the information is the foundation of any monitoring program;
- A conceptual model of the world: it serves to delineate the system which should be monitored;
- A set of indicators: they characterised the system being monitored in a meaningful way for the users;
- A methodology for data collection: procedures to address the practical and technical issues involved in data collection must be established to ensure accuracy, consistency and statistical robustness;
- A methodology for calculating indicators: often the collected data have to be manipulated in order to derive values for the indicators;
- A process for synthesis: synthesising the information into an overall picture of the system status is essential to assess the progress towards the goals;
- A methodology for reporting: the collected information has to be reported to the users in a comprehensible manner.

The environmental monitoring has demonstrated its capacity in supporting the decision process in such areas as: characterization of baseline conditions; surveillance, detection of change; description of recent status and trends; long-term understanding or prediction of processes; establishing historical status and trends; resource management, and establishing the need for, or success of, interventions.

In the EU, many initiatives have been carried on to establish databases on the water resources, developing a better understanding of hydrological variability and similarity across different regions through the mutual exchange of data, knowledge and techniques. One of the aim of the HarmoniRiB project is to collect information on the current practices with respect to the water resources monitoring. The project concentrates particularly on the ways users can access the data. Moreover, HarmoniRiB identifies the challenges that have to be met in creating a database suitable for supporting the Water Framework Directive (Refsgaard, 2005).

Although the linked process between environmental monitoring and decision making is widely acknowledged, according to the scientific literature, there are two key deficiencies in traditional monitoring networks. The first is that they are restricted to physical and chemical data with no attempt to bring together data on economics, demography or institutional arrangements for water management. The second is that such networks do not provide information on uncertainty. Concerning the latter, some attempts to deal with uncertainty in hydrological studies have been made by HarmoniRiB project. This project assumes that understanding the limitations of environmental data is essential for managing environmental systems effectively, since a decision maker has to make decisions based on available information. In most cases these information are deficient, incomplete and uncertain, affecting the decision making process outcomes. The overall goal of HarmoniRiB is to develop methodologies for quantifying uncertainty and its propagation from the raw data to concise management information.

Traditional environmental monitoring is less successful in providing timely identification and warning of emerging environmental problems; in delivering effective feedback on the adequacy of policies and programs; in providing policy-makers with a sound basis for action. But, above all, traditional monitoring systems are less successful in delivering information to the public, stakeholders, research personnel, and managers so as to raise awareness, educate and provide the basis for informed decisions and choices. The data collected by these systems are not always available to the public or are not easily understandable, limiting data access and consequently the public debate on the state of the environment. Thus, the issues of information availability and comprehensibility have to be dealt with.

Concerning the NeWater case studies, information about the characteristics of the existing monitoring systems will be collected by involving the local stakeholders. A survey to the users of the monitoring system in the selected river basins (e.g. municipalities, decision-makers, water agency, etc.) will be conducted. Furthermore, other local stakeholders will be contacted to obtain information about the accessibility and understandability of the environmental data by non-expert people. The information concerning the monitoring system that will be collected are:

- Regulatory framework;
- Actors involved in the data collecting (water management agencies, environmental protection agencies, etc.) and data management;
- Actors involved in data use (who does utilise the data? How do they use the data? – time frame – regularly, once a year?, need for time series?);
- Data for model use? If yes, which kind of models?
- Description of the monitoring system (type of data [GIS or GEO data, database, vector, raster, report …?], frequency of data collection, tools, spatial distribution and spatial reference [projection, spheroid …], etc.);
- Data diffusion (availability of the data)
- Costs of the data gathering (or public availability).

This information will be useful to discover the strengths and the weakness of the existing monitoring system, according to the stakeholders opinion. Following the agenda of the stakeholders meetings and workshops in the NeWater case studies, we decide, in agreement with the project coordinators, to link this missing part to the Task 1.6.2 – Identification of data information needs.

The usability of the monitoring information for the decision process has to be considered. Nowadays policy makers and water managers are overwhelmed with data and information that may or may not be of use to them. Therefore, there is a call today for less quantity of information and more targeted, tailor-made, information. The information needs is the crucial step in the information-producing process to decide what it's needed to know. The information needs are different for different stakeholders. This requires to elicit from stakeholders their information needs. Therefore, the stakeholders' involvement in the monitoring system design is one of the fundamental characteristics of the innovative monitoring system able to support the Adaptive Management, as better explained in the following sections.

Many authors (e.g. MacDonald, 1994) stated that in the traditional monitoring system little attention is given to the importance of the feedbacks for the efficient design and execution of monitoring projects. Therefore, the traditional information production can be considered as a linear process, starting from the information producers to the information users.

Several attempts are mentioned in the scientific literature dealing with the definition of a framework of an innovative monitoring system (e.g. Timmermenn et al., 2000). The development of such a system involves six steps:

- ✓ Identify the performance questions;
- ✓ Identify the information needs and indicators;

- ✓ Know the needed baseline
- ✓ Select the data-gathering methods
- ✓ Identify the practical support for information gathering
- ✓ Organize and analyze the feedback and identify changes.

A performance question helps focus the information-seeking and information-analysis processes on what is necessary in order to know if the project is performing as planned.

A baseline serves as a point of comparison useful to:

- ✓ Compare the situation before the project started with the situation after it started;
- ✓ Compare changes inside the project area with those in similar location outside the project area.

Among the peculiarities of a successful monitoring system, the scientific literature emphasizes the significance of feedbacks of monitoring results to better manage the information production process. A successful monitoring system is able to evolve over time according to the changes in the understanding what information is useful. In fact, as the monitoring project evolves, activities will change, groups of people will evolve, and the understanding of what information is useful will grow. Therefore, a regular revision of the list of information needs and indicators could be useful. To this aim, the dialogue between the information producers and information users.

Some attempts have been made to define a common framework to facilitate this dialogue. An example is the information cycle (Timmerman et al., 2000), in which the information collection is inextricably bound up with water management. In going from information required to information obtained, the following steps can be distinguished (Timmerman et al., 2000): the information users, interacting with the information producers, can define the characteristics of the information needed. The information producers, in cooperation with the information users, decide upon the best way to collect information. The collection of data is the next step of the cycle. The collected data are analyzed and the results are interpreted according to the information sought. The resulting information is presented and transferred to the information users in a proactive manner.

The information cycle framework allows us to adapt the information production process to the changing nature of the resource management towards a more adaptive approach. In fact, in such an approach, the outcomes of the decision process need to be monitored closely during the implementation to confirm their effectiveness, and to help refine future actions. Accordingly, successful resources management must be based on the linked process of monitoring and adaptive management, or “learning-by-doing”.

In an adaptive perspective of the water management the information cannot be considered just as an input for the preliminary phases of the decision process, but the two process, i.e. information production and decision making, have to be strictly linked in all phases, mutually supporting the improvement phase. That is, on one hand the information are useful to monitor the efficacy of the management action and to propose same changes. On the other hand, the implementation of the management action can lead to some changes in the environment, causing changes also in the information needs. The linked processes of monitoring and adaptive management are accepted as an integral component of decision making.

4 Monitoring System for Adaptive Management

As stated in the previous section, the transition towards an adaptive approach to the water resources management is causing changes also in the role of information in decision-making.

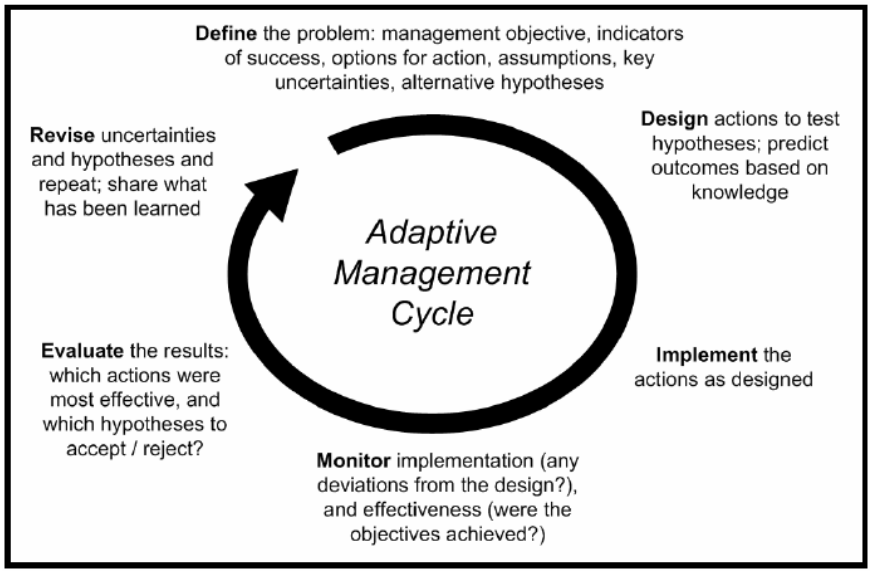
The idea of adaptive water management derives from the success of complexity theory and from the awareness of the difficulties in predicting future pressure on ecosystems, as well as the awareness of the inherently limited knowledge of the system behaviour and responses. Therefore, the management has to be adaptive, that is, it has to change according to new insights (Pahl-Wostl, 2005). Adaptive management refers to a "learning by doing" process in which the outcomes of the implemented strategies are used to iteratively refined and improve the management policies. Adaptive management proceeds from the premise that policies can be treated as experiments in which monitoring and evaluating outcomes, and judging what has been learned are fundamental steps (McDaniels and Gregory, 2004).

Adaptive management is designed to identify and address key uncertainties about resources dynamics and to iteratively use feedback information from the system being managed to reduce those uncertainties. It is a systematic approach to improving management and accommodating change by learning from the outcomes of management policies and practices (Holling et al., 1978; Walters, 1986). It improves managers' understanding of ecosystem functioning through the implementation of carefully designed management interventions and monitoring programs. There is also uncertainty in the response of humans. Hence adaptive management should also help to better understand human behaviour affecting ecosystems.

Further, it permits management to proceed in the absence of a complete scientific foundation for action (McAllister and Peterman, 1992). The adaptive management acknowledges that the action is necessary or appropriate although knowledge may be imperfect. Knowledge far from perfect is likely to be the rule in ecosystem management.

One of the challenges posed by adaptive management is that it requires learning to occur during the decision and implementation process. Adaptive management argues that learning should be considered an implicit objective when creating and analyzing management policies. Many aspects of the decision process can benefit from learning, creating new alternatives or improving the existing ones, increasing the understanding about the consequences of the alternatives (McDaniels and Gregory, 2004).

Several framework have been proposed to describe the adaptive management process, but in all of them great importance is given to the monitoring and evaluation phase as source of information to support the learning process (Crawford et al., 2005):



According to this framework, responding to information gained through monitoring activities is fundamental to the adaptive management approach. Information distilled from monitoring is used both to determine the effectiveness of implementation activities, and to test the hypotheses that originally formed the basis of the management action. Corresponding adjustments are made to implementation activities, management objectives, and any models used to make original forecasts.

Within the decision analysis, the importance of the information in learning process is also established by the Value of Information (VOI), that is, the indicator commonly used to evaluate learning. The VOI analysis evaluates the benefit of collecting additional information to support the learning process. Within the VOI, the learning is related to the new information usable for the decision process. In this perspective, information has value only if the potential to change the choice within the current decision.

The information, the ability of the actors to use new information and the quality of communication process in actor networks play an important role. The role of the network is to provide a means to navigate information and to provide some of that basic information for others to produce a true community based network (Mayfield, 2001). The availability of new information and the ability of a system to process this information are at the basis of the adaptive capacity of the system (Pahl-Wostl, 2005). Thus, the information production activities have to support the increase of the knowledge and the improvement of the management plan.

To play this fundamental role in the adaptive management, novel monitoring systems are required to support the decision making process, able to provide timely identification and warning of emerging environmental problems and effective feedback on the adequacy of policies and programs. Moreover, the novel monitoring systems have to be able to provide information also in data poor area integrating different sources of information.

The transition towards an innovative information production process starts from the understanding of the gaps in the information, facilitating the integration between different sources of information. Moreover, this novel concept of monitoring system has to overcome the drawbacks of the existing ones and it has to address the issues related to the information production in adaptive management, as described in the previous sections.

In an adaptive perspective of the water management, the information cannot be considered just as an initial input for the decision process, but they have to be pervasive, supporting all

the phases of the Adaptive Management cycle. Particularly, in the preliminary phases, the monitoring information should support the problem definition, the design of the alternatives and their evaluation.

After the implementation of the designed alternative, the monitoring information should support the decision-makers to assess the system responses, evaluating the efficacy of the management action. Moreover, the monitoring information should support the decision-makers in revising the selected policies, introducing some adjustments. Adaptive ecosystem management requires monitoring as essential feedback to management to ensure that necessary or appropriate action is taken, despite the fact that knowledge about the ecosystem being managed may be limited. Monitoring becomes the tool for learning about the system and assessing the management strategies.

5 Characteristics of the innovative monitoring system

As stated previously, adaptive management is based on the integration between different sources of knowledge. The monitoring system has to be joined with the shared platform through which the different sources of knowledge that can support the adaptive process are integrated. In particular, how best to integrate the scientific knowledge, resulting from the implementation of "formal" monitoring activities, with that deriving from a stakeholders based approach is becoming an interesting field of research. These approaches recognise that science alone cannot provide all the answers, and must be combined with a structured process of local participation that emphasises shared learning and locally-relevant indicators and methods. The challenge is to bring local and scientific knowledge systems together into a single structured information system.

Collecting local knowledge can facilitate the establishment of the "two-way" flow of information which recognise that knowledge must be understood in context by all those involved. This acts to reduce conflict, encourage participation and provide a co-learning environment.

Many attempts have been made to design monitoring systems able to collect local knowledge to be used in the decision-process. The environmental data collected by citizens have been used to keep communities, elected officials, and government agencies informed about the problems that need to be addressed, increasing public awareness.

The data can include "non-formal" types of information, such as opinions, objective and factual information (it can include texts, photos and video), measurements.

Community-based Monitoring System (CBMS) is defined as a process where concerned citizens, government agencies, industry, academia, community groups and local institutions collaborate to monitor, track and respond to issues of common community concern. Emphasis is placed on monitoring designed to promote sustainability, leadership of monitoring by the community rather than individual organizations and use of monitoring data to inform decision-making (Whitelaw et al., 2003).

The involvement of community in environmental monitoring has many advantages (Gouveia, 2004):

- Promote public awareness on environmental issues: the participation of citizens within monitoring generates a more informed and educated public concerning environmental problems.
- Enhance collaboration among all the stakeholders: development of a cooperation culture where citizens develop a sense of being involved in assessing environmental quality.
- Financial benefits: the participation of the community can be a cost effective method to maintain data collection activities under limited funding. Furthermore, the use of community allows to widen the geographic area and time period monitored since community can gather data at odd hours and cover wider geographic areas.
- Support the development of early warning systems: communities can collect real-time data providing an almost instantaneous picture of what is happening.

Among the advantages deriving from the community involvement in the monitoring system, particular attention is given to the diffusion of knowledge. In fact, as stated previously, access to the data collected by environmental monitoring systems is crucial to support public participation within any environmental decision-making process. Currently these data are not always available to the public and are not usually available in a format that is understood by

all the different stakeholders (Gouveia et al., 2004). To overcome this drawback it's fundamental to involve the community in the early stage of the monitoring system design, allowing them to express their information needs. Therefore, referring to the work of Timmerman et al. (2000), in an innovative monitoring system design the distinction between information users and producers is not as clear as in the traditional monitoring system. In fact, on one hand the stakeholders need the monitoring information to deepen their knowledge in order to participate in the decision process. On the other hand, they take part also in the information production process as elements of the community-based monitoring. Thus, in an innovative monitoring system the information needs have to be defined in a collaborative environment, allowing all the stakeholders to highlight the interesting information and to define the way to collect the information.

Moreover, in an adaptive perspective of management, the community based monitoring can be used during the "post-decision" phase, providing information on whether the actions taken achieve the expected outcomes. Therefore, this application of CBM has significant potential to inform public debate, influence local governments and promote adaptive management (Whitelaw et al., 2003).

Another important characteristics of an innovative monitoring system is information diffusion. Dissemination of information is crucial to the development of a learning-oriented management system. Improved access to information and public participation in decision-making enhance the quality and the implementation of decisions, contribute to public awareness of environmental issues, give the public opportunity to express its concerns and enable public authorities to take due account of such concerns (UN/ECE, 1998). To achieve public participation in environmental decision making, the public must gain access to environmental information, data and knowledge (Haklay, 2003).

The Information and Communication Technology (ICT) can have an important role in supporting public access to timely, accurate and understandable environmental information. Examples of ICT applications to environmental monitoring exist within all the major activities: from data acquisition, storage and management to data processing and communication (Gouveia et al., 2004). Additionally, many projects use their web sites as a knowledge-repository, which includes tutorial materials and the participation of experts, supporting the creation of virtual communities.

The collaborative monitoring requires tools able not only to support the interaction between the participants, but also to assist them in publishing their information, drawing other people's attention to their major findings.

The web is a suitable platform to promote collaborative environmental monitoring, since it allows the participants to add their own knowledge to a broader system and to communicate with others to obtain useful information (Gouveia et al., 2004).

Until now, the collaborative environmental monitoring has been hampered by many disadvantages:

- Data credibility: the issues of precision and accuracy remain unresolved in the view of many government and regulatory agencies and so the use of data and information obtained through community-based efforts has been restricted;
- Non-comparability of data: often the data collected by citizens are not easily comparable with other data;
- Usability of the information: the knowledge of local communities should be systematized, making it comprehensible for the decision-makers and functional for the decision process;
- Integration of different sources of data: it's fundamental to address the issue of the integration between the data collected by the community and the "scientific" data in a common platform.

The definition of an innovative monitoring system requires the following characteristics:

- Data collection: the innovative monitoring system should allow all the stakeholders to input data on the state of the environment, promoting the visibility of such information and reuse by others. The system should support participants to input data in "non-conventional" forms (video, text, images, etc.).
- Data access and exploration: the system should facilitate the access of the information collected by the other participants, including search and retrieval tools that are enabled to deal with quantitative and qualitative data. Moreover, it's fundamental to provide different level of data, according to the different level of participants' expertise.
- Data validation: any system that intends to promote the collaborative monitoring should contain a framework for data validation. Such framework may include tools and methodologies intending to support participants to produce data of known quality as well as to help system users to extract useful information from the data.
- Data significance: the system should support the users in defining which data could be significant to support the decision process.
- Data integration: the scientific and local knowledge cannot be considered as mutually exclusive in a decision process, but complementary a new and integrated view of resource management schemes. Thus, an innovative monitoring system should provide a platform (e.g. GIS) to integrate the different sources of information.

Moreover, an innovative monitoring system should:

- Be relevant and decision supportive: it should be relevant to issue of concerns; be relevant to users, to fulfil its intended purpose; it has to provide in a timely manner information understandable for the decision makers or the targeted audience, so that early warning can avoid problems.
- Take into account consideration of scale and type: it should cover a wide range of spatial and temporal scale, providing data at appropriate scale; it has to be sensitive to changes.
- Be based on conceptual system model that explicitly recognise relationships between society and environment;
- Allow for an overall integrated evaluation of the system, collecting different type of measures and integrating the human systems as a subset of the ecosystem which supports them.

Above all, an innovative monitoring system has to be adaptive and flexible, able to deal with environmental changes and to adapt to changes in political context and societal values, to incorporate new information, technologies and scientific researches, and it has to be tailored for specific ecosystems.

In the following section, the characteristics of an adaptive monitoring system are described.

6 Towards an Adaptive Monitoring System

In the previous section the characteristics of an innovative system able to support the adaptive water management have been described. At the end of this report, some preliminary consideration on the possibility to define an Adaptive Monitoring System are provided.

From our point of view, the adaptive degree of a monitoring system is strictly related to the significance of the feedback between information production and the decision-making processes. In fact, the adaptive approach to monitoring design iteratively refines the monitoring design as a result of experience in implementing the monitoring program, assessing its results and interacting with the users. Thus, the importance of learning in an adaptive perspective can be extended also to the information production process. In this perspective, the information needs are not "static", but they have to follow the dynamics of the environmental phenomena to be monitored. In fact, the fundamental question "Are the policy goals achieved?" may not be able to be answered accurately because the monitoring program does not provide the needed information to formulate this judgement. There can be many reason for this. One example being that the indicators do not adequately measure what they are purported to measure. Or there are few indicators to provide the needed information, or the parameters to be evaluated and the intensity of the monitoring activities has to be varied. In any case, the process must return to the design of the monitoring program elements.

The information needs could change also according to the decision-making phase. That is, in an adaptive management perspective, the information to be collected could change since different impacts of the management policy on the environment can be monitored.

Furthermore, the information needs can change according to the participants perspective. In fact, one of the main objectives of the adaptive management is learning. Therefore, the knowledge of the participants about the issue at stake is expected to evolve during the decision process. Accordingly, the information that they need to know can change.

An adaptive monitoring approach would not only incorporate feedback on management action, but would also rely on feedback to applied monitoring practices (Smit, 2003). In both cases of amending the management policy, or revising the monitoring program to answer the appropriate questions, modification are made based on new information. This observation actually describe a learning process. Thus, in an adaptive monitoring, the focus is not on the results but on the learning. The process of monitoring design (i.e. information needs definition, indicators development, etc.) is as important as the results of the monitoring activities.

The information needs definition has to be considered as an iterative process that should meet both users and producers needs. From the users' side, the monitoring should support natural resources managers, policy makers, and the public in refining the monitoring questions, revising the implementation of management plans, and setting monitoring priorities. Regarding the information producers, the adaptive monitoring should support monitoring system designers in revising the monitoring design by providing a tangible foundation for discussing user needs; gaining the insights necessary to minimize the most prominent technical barriers; enhancing the efficiency of the collection, analysis, and assessment systems; and refining the monitoring questions.

The difference between the traditional approach to monitoring design and an adaptive approach is that in the adaptive approach the barriers to monitoring design are overcome by adaptively implementing monitoring rather than waiting for new information or designing a system that does not anticipate new information (Ringold et al., 1999).

In the following table, a preliminary comparison between the conventional and the adaptive approach to environmental monitoring is proposed.

Conventional Approach	Adaptive Approach
Monitoring is perceived as an isolated activity.	Monitoring, management and governance are interdependent.
The outcomes of the monitoring program (the list of indicators and the information they provide) are the focus.	The monitoring program design and the indicators development process are as important as the results: the focus is on learning.
The purpose of the monitoring program is often to provide early warning so that they maybe averted.	Monitoring becomes the primary tool for learning, i.e understanding the system, assessing the effectiveness of management activities, and measuring progress towards goals.

A plethora of literature exists describing the adaptive environmental management approaches and the use of monitoring system to direct management action towards defined goals and to enhance the knowledge on the system. In contrast, there is a paucity of literature on the adaptive monitoring.

Some examples of the adaptive monitoring application concern the use of multi-agent system to adaptively monitoring the electronic or telecommunication network. Since the use of a multi-agent architecture, this monitoring system is scalable, distributed (each agent performs locally), and adaptive, that is the agents adapt their action according to the monitored data.

In the environmental resources management domain, some attempts have been made to apply the adaptive monitoring concepts (Ringold et al., 1999; Lavado Contador, 2005; Allen et al., 2001). All of them focus on the iterative nature of the adaptive monitoring. Ringold et al. (1999), for example, propose an adaptive approach to monitor forest plant species. This approach refines habitat characterization, monitoring, and management efforts as more information becomes available. A key feature of this approach is that it integrates communication, or feedback, between information producers and users so that efforts improve knowledge of habitat–species relationships and support management decision making, and improvements to methodologies halt when the marginal return no longer improves decision making.

Allen et al. (2001) propose an adaptive monitoring system mainly based on the involvement of the local community in land-use monitoring. They refer to the Integrate System for Knowledge Management (ISKM) as a framework for their research. The ISKM framework focuses on strengthening participation and self-help in natural resource management. The ISKM stresses the need to develop feedback loops to maximise the benefits from monitoring and evaluation and develop a collaborative-learning/self-improving environment. One of the most interesting results of this research work, from our point of view, is the development of the Tussock Grasslands Management Information System (MIS) to provide background ecological knowledge and best practice guidelines for different vegetation states. This information system draws on both farmer, conservation manager and science knowledge which has been discussed between the stakeholders. In addition, this information system allows the participants in providing their monitoring information.

The results of the literature review carried out for the task 1.6.1 will be used to define an innovative monitoring system to support the Adaptive Water Management in selected case

studies. In the early phases of the definition of such a system, we mainly refer to the importance of the involvement of the stakeholders in monitoring program and to the significance of the dialogue between information producers and users.

Therefore, the activities to be carried on in selected river basins will aim at the experimental application of the adaptive monitoring system in real case studies, as reported in the following:

- Identification of *information needs* (in conjunction with the literature review and the specific experts consultation performed in ***Task 1.6.2*****:** the definition of the information to be collected by the new monitoring system should also be driven by user demand. In our perspective, users could be both institutional and non-institutional actors interested in environmental data collection and use. Interacting with the local stakeholders, the information needs will be defined.
- Negotiation on *Information Needs* (***Task 1.6.2***): A negotiation phase will be organized to create consensus among the stakeholders on information needs. We will support the negotiation considering the information needs for the Integrated Water Resources Management.
- Definition of the Indicators (***Task 1.6.3***): concerning the Community-based Monitoring System the indicators development should be consensus oriented. In fact, in order to involve the stakeholders in data collection, it's fundamental that they develop a sense of "ownerships" towards the indicators. Thus, a negotiation phase concerning the community-based indicators development will be carried out.
- Define data-gathering methods (***Task 1.6.3***): this phase regards both the remote sensing data collection (we should provide a table of the gathered or utilised remote sensing data sets – sensor, spatial and temporal resolution, costs, availability, type of classification or processing …) and the community-based monitoring. With regards to the former, methodologies and technologies will be reviewed to identify those useful to satisfy the information needs. Moreover, meetings will be organize with the stakeholders to reach an agreement on the how to collect data and to communicate them (ICT technology will be tested).

After months 18, in the ***Task 1.6.5*** a survey across selected NeWater basins will be conducted. The feedback from the users will be analyzed, and specifications of the tools developed will be revised as input for future improvements. To this aims interviews and stakeholder workshops will be organized.

7 Conclusion

The information is one of the fundamental elements of a structured decision process. It's usefulness is clear in all phases of the decision process. The information are used in the problem definition phase, supporting the decision-makers in the definition of the state of the system to be managed, in the identification of the main issues to be addresses and in the elaboration of the different alternatives. Moreover, the information can be used to evaluate the different courses of action, identifying the most suitable alternatives.

The increasing interest in enhancing public participation in the water resource management domain, allowing all possible stakeholders, both individuals and organisations, to participate in the decision process is posing new challenges in the field of information production and management.

A decision process can be considered participatory if all the participants are fully informed, that is, if all the participants have enough information on the problem to be considered. Thus, the availability and accessibility of information become really important. In a participatory perspective, these two concepts are not related only to the "quantity" of information available for the different stakeholders, but also to its comprehensibility.

In fact, if on one hand it's widely agreed on the concept of information as power, on the other hand it's important to highlight that information really generates power only if it is easy understandable by the users. This comprehension transforms information in knowledge. Therefore, information can support the empowerment process only if it becomes knowledge.

Further, the success of the adaptive management is changing the role of information in the decision process. In fact, while in the traditional approach the information are considered as an input for the decision-makers, in an adaptive perspective the two process, i.e. information production and decision making, have to be strictly linked in all phases, mutually supporting the improvement phase.

One of the challenges posed by adaptive management is that it requires learning to occur during the decision and implementation process. Adaptive management argues that learning should be considered an implicit objective when creating and analyzing management policies. In this perspective, the information plays a fundamental role since it becomes the primary tool to support the learning, facilitating the understanding of the system and its responses to the management policies. Therefore, the focus of the monitoring activities is not only on the results (i.e. environmental data) but it's also on the learning.

In the last part of the report, the characteristics of a monitoring system able to support the adaptive water management have been defined.

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