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Monitoring Information Systems to Support Adaptive Water Management

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1. Introduction

Decision making in water resources management is widely acknowledged in literature to be a rational process, based on appropriate information and modeling results. Information plays a fundamental role in improving our understanding of the consequences of, and trade-off among, the alternatives in water resources management.
Environmental monitoring networks have the potential to provide a great deal of information for environmental decision processes. Monitoring is widely used to increase our knowledge both of the state of the environment and of socio-economic conditions. Environmental monitoring has demonstrated its capacity within resource management to support decision processes providing knowledge of baseline conditions, to detect change, to establish historical status and trends, to promote long-term understanding or prediction, and to establish the need for, or success of, interventions.
Our knowledge of the complexity of water system processes is increasing, together with our awareness of the uncertainty and unpredictability of the effects of water management on system dynamics. Consequently, the demand for environmental information is growing posing new challenges to monitoring system design. This chapter discusses these new challenges and proposes an innovative monitoring design approach to deal with complexity. The conceptual architecture of an Adaptive Monitoring Information System (AMIS) is proposed. The AMIS properties are used in this work to define a framework to assess the capabilities of current monitoring systems to support water managers to cope with complexity and uncertainty. The framework is used to identify the main limitations and to define the potential improvements of TIZIANO monitoring system, developed to monitor the state of groundwater monitoring in the Apulia Region (South Italy).

2. New challenges for monitoring systems and information management in Adaptive Management (AM)

Incorporating uncertainties about future pressures on river basins into water resources management sets new challenges for environmental resources management. One learning process being developed to address this challenge is Adaptive Management (AM) (Holling 1978). Learning more about the resources or system to be managed and its responses to management actions, in order to develop a shift in understanding, is an inherent objective of AM (Walters, 1997; Fazey et al., 2005). 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 (Campbell et al., 2001).

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. 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.

When defining the cognitive model to be used as basis for a monitoring system, it is essential to address certain issues related to complex system dynamics. Firstly, the issue of scale must be tackled, since complex systems have structures and functions that cover a wide range of spatial and temporal scales. The impact of a given management action may vary at different scales (Campbell et al., 2001). Moreover, structures and processes are also linked across scales. 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).

To deal with interaction between scales, we assume that the complex web of interacting systems can 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. The hierarchical structure of relationships between systems and subsystems (Campbell et al., 2001) implies that working on a particular scale often requires insights from at least two

other scales, i.e. the level below, to understand the important processes that lead to the emerging characteristics of the level considered, and the level above it. 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. 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. Using this inter-scale cognitive model as a basis for the design phase allows us to define a monitoring system capable of dealing with complex relationships between different scales, thus overcoming one of the main drawbacks of traditional monitoring practices.

However, adopting this inter-scale approach usually results in a demand to monitor a broader set of monitoring variables than traditional monitoring approaches. Some of these variables are fairly cheap to measure, but others, such as trends in very rare and important species, can be very expensive to monitor (Walkers, 1997). Thus, the development of an affordable monitoring program to support Adaptive Management involves substantial, scientific innovation in both method and approach, aimed at simplifying the set of monitoring variables by identifying the key components of the system.

The key components of the system, or key variables, 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, who are frequently focused on fast variables. These 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). 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.

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. 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.

Integrating system modelling and monitoring iteratively highlights the importance of collecting information on trends. In fact, the availability of time series of data on the different variables allows the behaviour of the system variables and the trajectory of the system to be defined. The detection of trends can support the revision of the hypothesis concerning system dynamics, which is at the basis of the models. For these reasons it is fundamental to develop a monitoring system which is sustainable over time. To this aim, two important issues needs to be addressed, i.e. the need firstly to increase the adaptability of the monitoring system to policy and learning processes, and secondly to reduce monitoring costs through the adoption of scientific and technical innovation in information collection.

3. Adaptive monitoring and information system

Considering the issues described in the previous section, the conceptual architecture of a monitoring system for AM was defined (figure 1). From now onward, we refer to this system as Adaptive Monitoring Information System (AMIS).

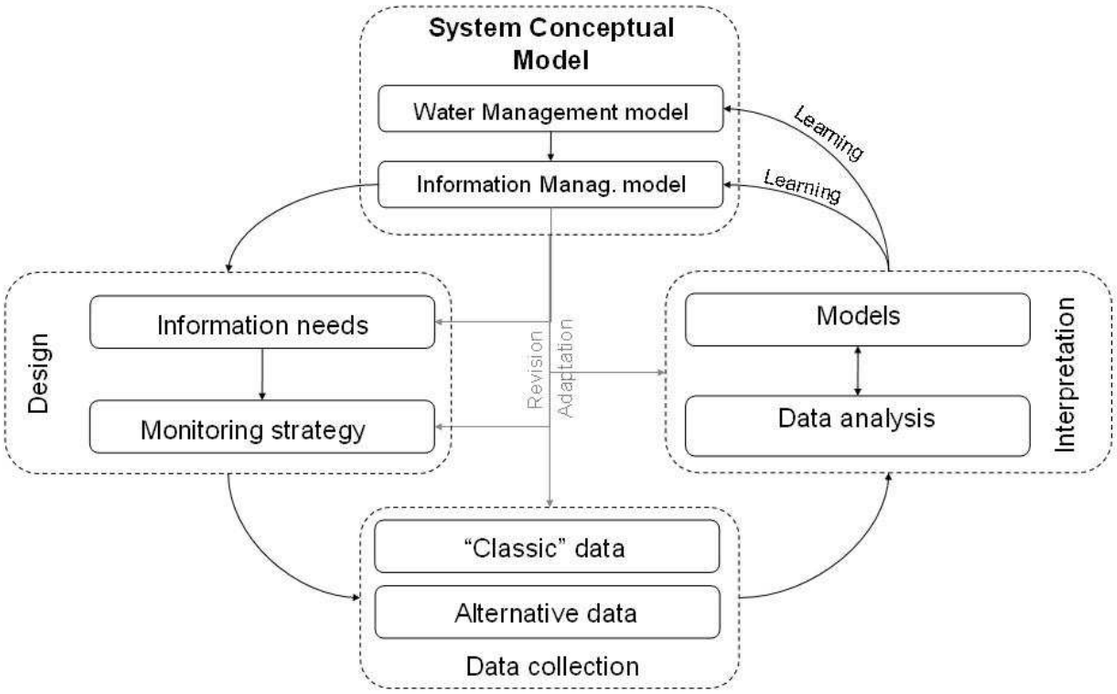

Fig. 1. AMIS conceptual architecture. The figure has been adapted from the Information cycle elaborated by Timmerman and others (2000), to emphasise the two learning processes.

As described previously, the basis for AMIS design is the conceptual model of the system, which simplifies the system and makes the key components and interactions explicit. The definition of this model is based on the integration between a participatory process, allowing experienced stakeholders to provide their understanding of the system, and models able to simulate future scenarios. The conceptual model is structured using the integration between Cognitive Maps and Causal Loop Diagrams.
Two different conceptual models, i.e. the "water management conceptual model" and the "information management conceptual model" are defined as the basis of AMIS. The former concerns the interpretation of the problem considered, while the latter concerns the information needed to solve the problem considered, and the "frames" used to interpret the information (Pahl-Wostl, 2007; Kolkman et al., 2005).
The AMIS architecture consists of four main boxes, i.e. Conceptual model elicitation, Design, Data collection and Interpretation. The links between them represent the iterative process of monitoring design, which is at the basis of AMIS. The figure was elaborated starting from the information cycle developed by Timmerman et al. (2000). This cycle depicts a framework where information users and producers communicate information needs that link the

monitoring and decision processes. The monitoring program needs to be adapted to the different stages of the policy definition process, because each stage requires different types of information (Cofino, 1995; Ward, 1995) to make water management and governance adaptive.

Two possible learning processes can be identified. 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.

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. Furthermore, the available budgets may restrict the number of indicators that can be measured or the intensity of the network in terms of locations and frequency. New information sources may become available (e.g. progress in remote sensing technologies, etc.).

To this aim, an important innovation in AMIS concerns data collection methods. AM often results in a demand to monitor a broad set of variables, with prohibitive costs if the monitoring is done using only traditional methods of measurement. This is particularly true in developing countries, where financial and human resources are limited. In these areas, the monitoring network may cover only small part of the territory or the grid may be too sparse, making the monitoring data unsuitable for the decision process. Furthermore, traditional monitoring is costly, reducing its sustainability over time. The resulting works may be still valuable as one-off assessments, but they do not provide information about the trends of environmental resources and the evolution of environmental phenomena. Thus, the outcomes of environmental policies are often difficult to assess.

To deal with these issues, AMIS is based on the integration of alternative sources of knowledge. Thus, AMIS can be considered as the shared platform through which traditional monitoring information and innovative information sources (e.g. remote sensing monitoring, community monitoring, etc.) are integrated. Therefore, AMIS is able to adapt to data and information availability, supporting adaptive management even in data poor regions.

In Table 1, a comparison between the conventional approach and monitoring to support IWRM and AM is proposed.

Current monitoring practices	Needs for IWRM
- Based on monitoring objectives and disciplinary needs - Information users have unrealistic expectations of the information that will be produced - Data accessibility is limited - Abundant and detailed information is provided - The information provided is highly specialised - The available information is divided over various organisations - Information is transferred to the information users	- Based on policy objectives and information users' needs - The information that will be produced is jointly agreed between information users and producers - Data are publicly available and accessible - The information provided is concise and addresses the policy objectives - The information is targeted towards specific audiences - The information combines results from various organisations and is integrated over disciplines - Information is communicated to the information users and a broader stakeholder or public audience and evaluated before being incorporated into policy support
	Additional needs for AM
- The outcomes of the monitoring program (data) are the focus. - The purpose of the monitoring program is to evaluate environmental status set against target values. - Monitoring follows management and policy implementation.	- The monitoring program design and the responses on this design are as important as the results: the focus is on learning. - Monitoring becomes the primary tool for learning, i.e. understanding the system, assessing the effectiveness of management activities evaluating the system changes, and measuring progress towards participatory defined goals. - Monitoring, management and governance are interdependent.

Table 1. Comparison among current, IWRM and AM monitoring

3.1 Learning process using AMIS

Learning aspects in the AMIS are not about the monitoring as a simple process or its data, but about an increase of the system understanding, communication between stakeholders to influence decision making (McIntosh et al., 2006). While giving floor to and later using knowledge, concerns, demands, and expertise from different points of view, which result from a stakeholder involvement, one will indeed achieve better decision making with more alternatives of choice on the one hand, and a broader and more balanced acceptance of the decision making in management.

To initiate and later-on ensure learning processes using a monitoring system, all relevant stakeholder groups need access to it. Being involved when objectives are defined, data and processes transparently observed, stakeholders get enabled to learn about variables and

interactions of "their own" systems and "their own" decisions which could lead to a revision or adaptation of management decisions (Pahl-Wostl, 2007. Further, this creates the feeling that stakeholders "buy in" into the product, that the monitoring system is "their" and therefore deserves more credibility (McIntosh et al., 2006). According to recent approach, the involvement of stakeholders can be extended to monitoring activities and not only to the design phase. The use of local knowledge enhances the understanding of environmental system, particularly in data poor areas. Moreover, adopting a community-based approach to monitoring can promote the public awareness of environmental issues.

Thus the intensive dialogue between science and many different stakeholders offers the opportunity for a mutual development, assessment, enhancement and implementation of new or already existing concepts, methods and tools, and helps improve the quality and acceptance of the decisions that are made. Last not least when using success-stories in management, based on the AMIS design, for the further development and enhancement of the monitoring system, the learning cycle is closed.

The following criteria, implemented into an AMIS, are indispensable to serve as a learning tool (cf. McIntosh et al., 2006):

1. **Understandability**: for each group of participants one should use "professional" indicators and perception-oriented "public" indicators to support learning processes for both of them
2. **Representativity** in involvement. Regardless of the method used to solicit user groups of the AMIS, every attempt should be made to involve a diverse group of stakeholders or broad audience that represent a variety of interests regarding the issue addressed. While key stakeholders should be invited to the process of indicator formulation, there should be also an open invitation to all interested parties to join the evaluation of the system. This adds to the public acceptance and respect of the results of the AMIS. If a process is perceived to be exclusive, both key members of the decision-making community and the wider public may reject monitoring.
3. **Scientific credibility**. Although participatory monitoring as it is understood in the AMIS design incorporates values and beliefs, the scientific components of the monitoring system must adhere to standard scientific practice and objectivity. This criterion is essential in order to maintain credibility among all groups, expert-decision-makers, scientists, stakeholders, and the public.
4. **Objectivity**. The stakeholder community must trust the facilitators of a participatory monitoring as being objective and impartial. In this regard, facilitation by university researchers or outside consultants often reduces the incorporation of stakeholder biases into the scientific components of the monitoring system.
5. **Understanding uncertainty**. Understanding scientific uncertainty is critically linked to the expectations of real world results associated with decisions made as a result of the modelling process. This issue is best communicated through direct participation in the modelling process itself.
6. AMIS' own **adaptability** to incorporate new users groups, changed frameworks and newly gained (quantitative and qualitative) data. The monitoring system developed should be relatively easy to use and up-date by the administrators. This requires excellent documentation and a good user interface. If non-scientist users cannot understand the monitoring system as a source to work with, local decision-makers will not apply it to support real management problems.

3.2 Technical adaptability of an AMIS

In this section some technical aspects related to the adaptive degree of AMIS are described.
Firstly, AMIS should be flexible and able to incorporate new information and data, of different type and with different formats. Using a relational database (RDBMS) is a sound basis to be open for new information requirements, because it is very flexible and extendable. The information can be well structured and redundancy can be avoided. The user can create new tables and link them to the existing database.
To satisfy the information needs of various user groups according to their knowledge of environmental system behaviour, different types of information for different purposes must be produced. One important aim of the AMIS is to provide the user with various methods and predefined algorithms to produce information. AMIS should provide the user with user-friendly predefined methods and algorithms to produce information, such as data visualisation tools as well as automatically generated information from incoming data.

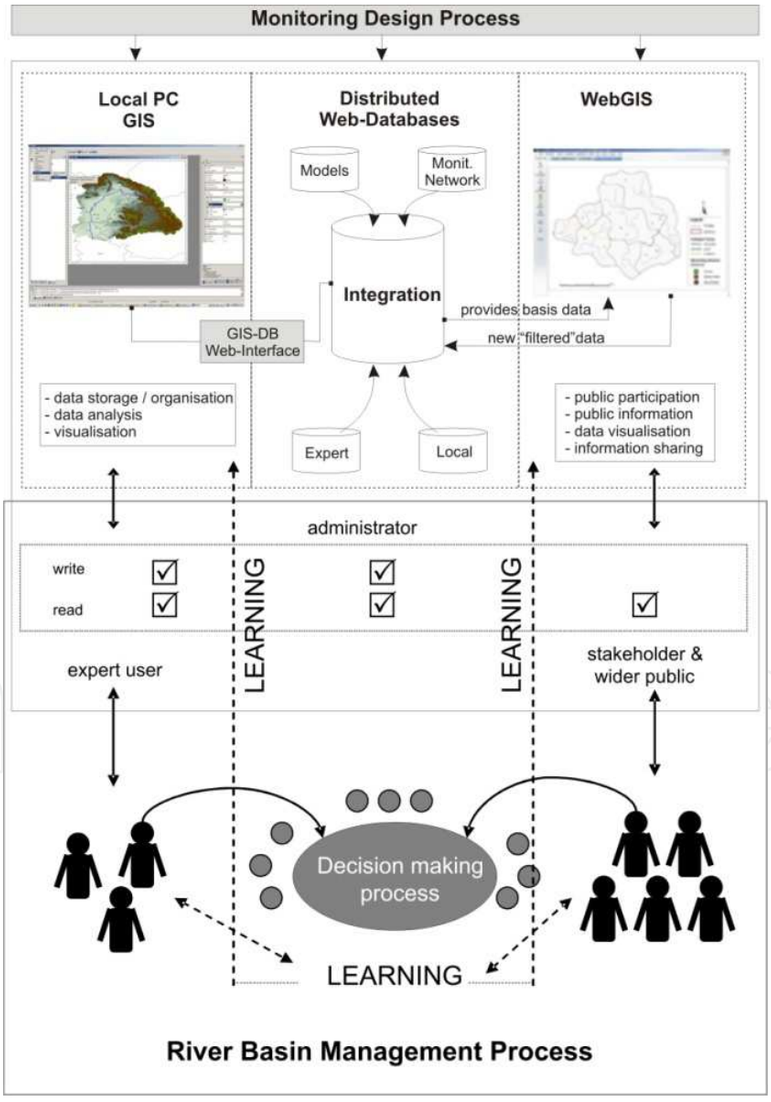

Fig. 2. Technical components of AMIS.

Another aspect of being flexible and extendable is to provide the possibility to add new modules easily, for instance hydrological or economical models, methods to analyse map layers etc. This kind of flexibility is of interest for developers or advanced users with programming skills. A modular or object oriented software structure is necessary to permit this task.
Taking the above mentioned arguments into consideration the information system is quiet flexible and open to include new information. But it is impossible to foresee what kind of requirements will be demanded from the information system in a few years. Thus, it should be possible to improve, maintain, and extend the software for everybody with programming knowledge. To be "technically sustainable" open source software should be used and local IT experts involved in the development process, particularly, if the software prototype will be produced within a project over a certain period and not by a company. One should emphasise the problem here that after a project has finished, often the developers are not available or not in charge for the product anymore. To facilitate future improvements the AMIS must be equipped with a sound documentation of the source code.

4. The adaptability of the groundwater monitoring system in Apulia Region: Main drawbacks and potential improvements

The aim of this work is to criticize the current approaches to monitoring design, highlighting the main drawbacks which hamper the adaptability of monitoring system. Moreover, potential improvements are discussed. To this aim a framework to assess the adaptability degree of monitoring design approach has been developed. The framework is structured as shown in the following table.

Criteria	**Meaning**
- Information producer/information users interaction	- Is the monitoring system based on the elicitation of the decision-makers' information needs?
- Degree of participation	- How many actors have been involved in the process of monitoring system design? At which level? In which phase?
- Multi-scale monitoring	- Is the monitoring system able to collect information at different spatial and temporal scale?
- Integration of information sources	- Is the monitoring system based on the integration of different sources of data and information?
- Long time sustainability	- Is the monitoring system capable to provide long time series of data?
- Monitoring/modelling interaction	- Is the monitoring system integrated with modelling to support data analysis and interpretation?
- Policy evaluation	- Is the monitoring system capable to support the evaluation of the policy impacts and suggest improvements?
- Monitoring evaluation	- Does the monitoring program provide for an evaluation and adaptation of the monitoring strategy?

Table 2. Comparison among current, IWRM and AM monitoring

This criteria have been used to evaluate the adaptability of the groundwater monitoring system of the Apulia region (Southern Italy).
The groundwater monitoring network of the Apulia Region was established in 2006 to meet the wide range of standards set by the water related national legislation adopted in 1999 (Italian Legislative Decree n. 152/1999). Consequently, the monitoring network was designed, realized and finally used in order to produce water quality and quantity information useful to characterize the environmental status of the main regional groundwater bodies.
The monitoring network has been promoted and financed by the regional offices in charge of the collection, storage and processing of data collected in accordance with relevant regulations. The network design and implementation and the enforcement of the monitoring practices fall within the scope of the project called TIZIANO whose completion is scheduled for the end of 2011.

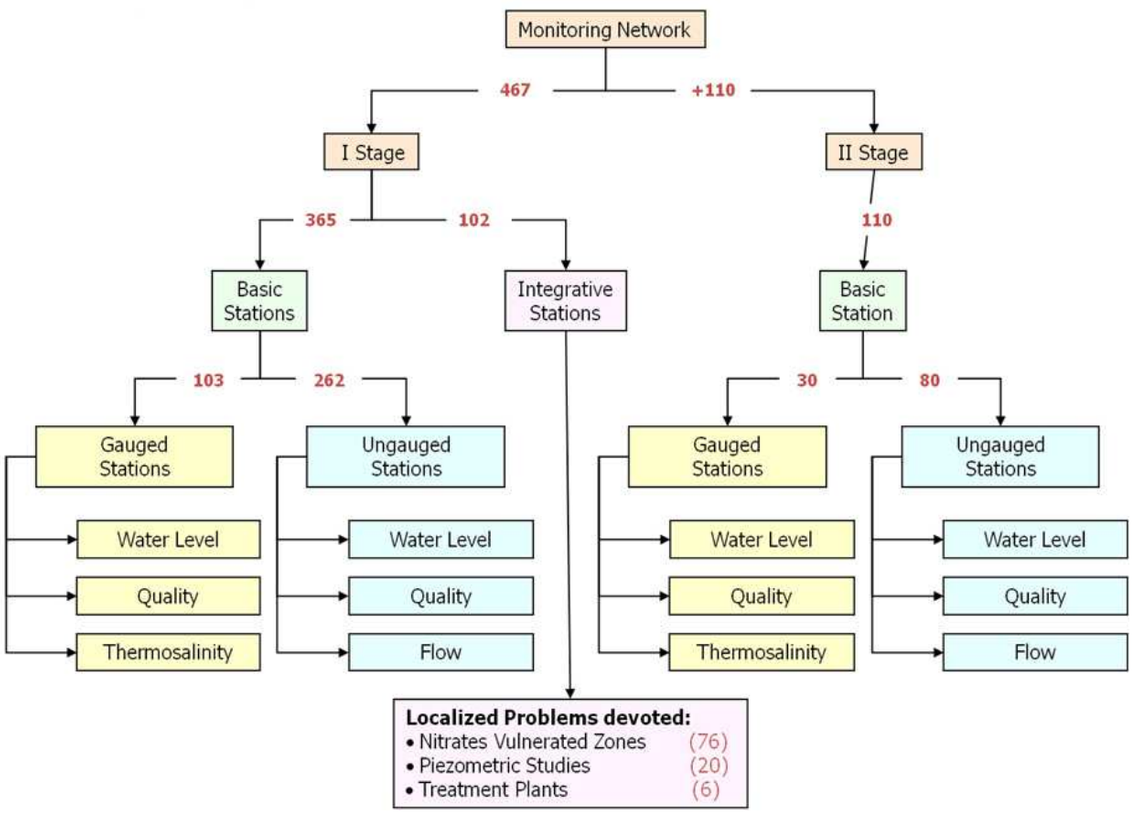

Fig. 3. TIZIANO monitoring design and number of monitoring stations. The process was composed by two main phases to identify the monitoring stations.

The TIZIANO monitoring network is made of more than 600 wells mostly spread within the boundaries of the four main aquifers of the region even if some tens of them have been located within some minor groundwater bodies. About 130 wells have been equipped with automatic probes for continuous measuring of groundwater level. During the last five years hundreds of quality and quantity measures have been made on site and thousands of samples, collected in the wells of the network, have been analyzed in laboratory in order to

determine the concentration of the main chemicals, metals, organic compounds, pesticides and level of harmful microorganisms. The huge amount of information, collected during the last five years, was stored in a Geographic Information System (GIS) specifically designed for the project. It allowed regional decision-makers to assess the environmental state of the aquifers and plan and carry out specific actions to improve it, when not good, or reverse worsening trends, when they were to lead to adverse conditions of groundwater quality and quantity.

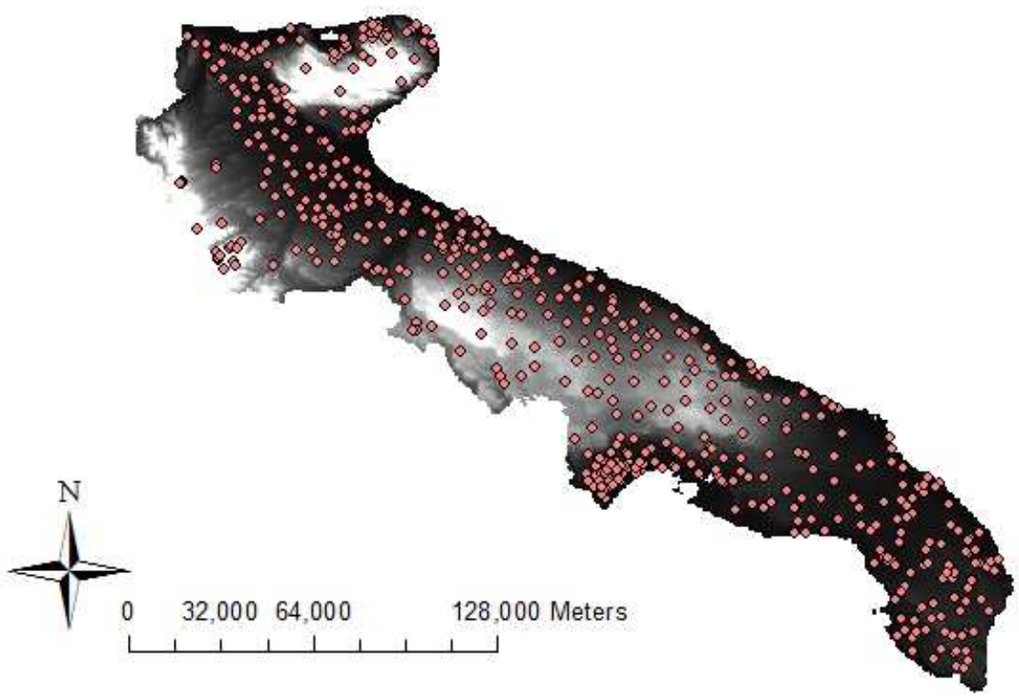

Fig. 4. Distribution of the monitoring station.

As reported above, the TIZIANO monitoring network started late in 2006, but the administrative process which led to its design and funding started several years early, at the turn of the century. In the meantime the European Union issued the Water Framework Directive (2000/60/CE), which was implemented in Italy exactly in 2006 (Italian L.D. n. 152/2006), and the, so called daughter Groundwater Directive in 2006 (2006/118/CE), recently implemented in Italy with the L.D. n. 30/2009. Although the Italian L.D. 152/1999 would herald a number of rules, then enshrined in European directives, it is evident that the future implementation of the decrees of 2006 and 2009 have clarified and modified, sometimes substantially, type, detail and timing of information to be acquired by monitoring and all management activities resulting from its processing.

4.1 Information producer/information users interaction

The Region already had a modest, monitoring network made of about 100 piezometers equipped with water level gauges, where some sporadic sampling was collected during the early 90s. Nevertheless, because of various causes, this network was abandoned after some years of functioning. At this point, within the regional offices in charge of water resources

management and protection, arose the need of recovering and, possibly, potentiate the network.
In the meantime several important water related, European directives (e.g.: the Nitrate Directive, 1991/676/EEC) and national decrees had been promulgated, which forced regional water offices to move toward a detailed knowledge of the qualitative and quantitative state of water resources in order to protect such resources and restore their original natural status.
The evaluation of the institutional, legislative, technical and scientific needs and expectations led to the design of the regional groundwater monitoring network by a small team of super-experts which were careful to meet the requirements coming from various and different parts. Measures of water level and physical-chemical parameters were carried out following rules and times required by national environmental legislation implementing EU rules and a number of scientific measures and controls were preformed in order to give responses to the scientific community.
The information provided by the new monitoring system was essential, among other, in order to assess the environmental state of the Apulian groundwater bodies or delimit Nitrate Vulnerable Areas, and design and plan specific actions of different complexity and socio-economical cost, able to recover and protect groundwater.
Summarizing, measures of water level and physical-chemical parameters were carried out following rules and times required by national environmental legislation implementing EU rules and a number of scientific measures and controls were preformed in order to give responses to the scientific community.

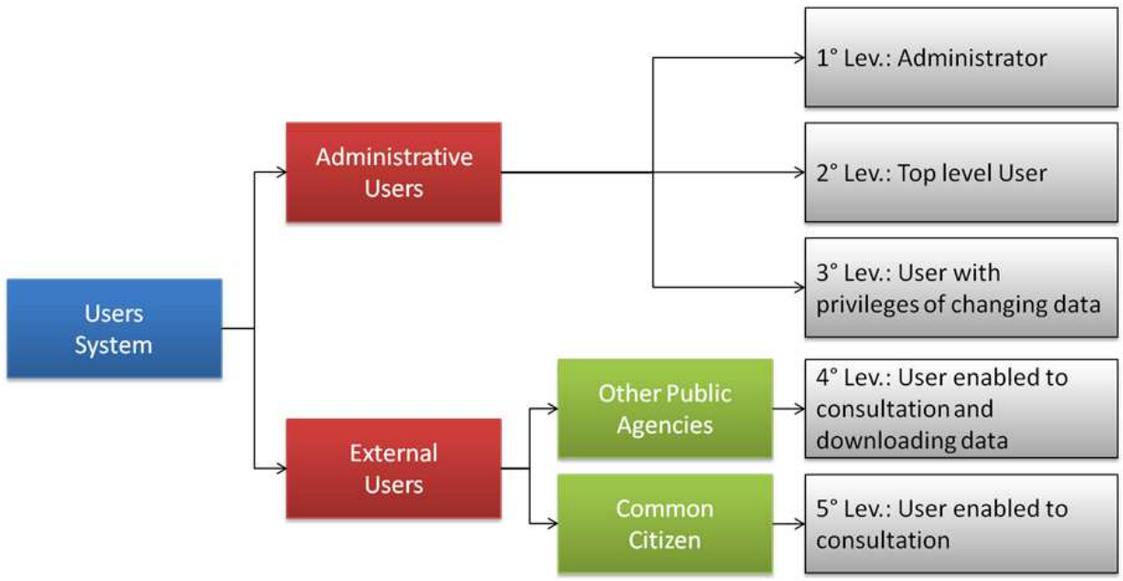

Fig. 5. Information accessibility according to TIZIANO monitoring program.

4.2 Degree of participation

From what said above derives that the position of the decision-makers in the design of the monitoring system was rather weak, i.e. the Apulian Region's role was limited to promote and fund the design. The role of decision-makers in the functioning of the TIZIANO monitoring network is strong and constant. Regional offices are in charge of producing,

controlling and processing monitoring information in order to assess environmental indices and plan and execute actions for recovering deteriorated resources.

4.3 Multi-scale monitoring

Given the multi-objective frame of the monitoring each class of data has been collected with different spatial and temporal resolution. Let's have a short description of classes of data and related time-space scale starting from groundwater level.

In order to capture the cyclic behaviour of groundwater levels in the wells, measures are taken on site almost every three months. About 130 wells have been equipped with automatic water level gauges capable of acquiring and transmitting a measurement every 15 minutes. These equipped wells have been located at strategic sites, in order to use them as controlling stations. So, the project database stores groundwater levels measured at different temporal scales at different locations all over the aquifers extension. Nevertheless, there is no analysis of the inter-linkages among the process at different scales.

4.4 Integration of information sources

Given the complexity of the monitoring network, the data collection system is extremely various and includes manual and automatic measures, on site and laboratory analysis, coastal and inland exploration, airborne remote sensing. The whole amount of collected data is stored in GIS after a validation phase. Nevertheless, data coming from different platforms are sporadically integrated. The different measures follow a separated path, which passes through a separated validation step. In conclusion, the monitoring system is not based on a strong integration between sources of data.

4.5 Long time sustainability

The whole monitoring system, as currently conceived, is particularly expensive. Let's report some of the main weakness of the project concerning its own costs.

The monitoring area is objectively wide and the number of monitoring points huge, while the location of the monitoring teams is centralized and, consequently, they need to travel hundreds of kilometres during the monitoring surveys or for maintenance. Instrumentation need to be constantly maintained and often replaced due to theft.

Moreover the costs of the system are rather high due to the frequent outsourcing of monitoring activities. Costs could be reduced dramatically, if most of the monitoring practices were carried out by Regional Agencies and Offices and only very specialized activities were outsourced. In conclusion, only if an intelligent redistribution of activities within public institutions will be put in place, with a consequent cost reduction, the network is likely to become a long-term system.

4.6 Monitoring/modelling interaction

Various statistical, geostatistical, hydrogeological and hydrogeochemical, deterministic and stochastic, simple and complex models have been applied to process data collected and stored into the GIS. Nevertheless, it was not specifically designed to be compliant to any particular model. In fact, given the wide range of expected uses of the different dataset stored the design choice was to keep the organization of data extremely simple, and then easily adaptable to different kinds of models just through a simple pre-processor. In the TIZIANO monitoring project, the monitoring/modeling interaction is one-directional. That

is, monitoring provides data to models, but the models are used to support the evaluation and, eventually, the re-design of the monitoring network.

4.7 Policy evaluation

Theoretically speaking, the TIZIANO groundwater monitoring system should be capable of supporting regional decision-makers at each step of the decisional path. In few words, the network should support: 1) Assessing the initial state of the natural system and reporting negative trends; 2) Controlling the effects of environmental actions and politics; 3) Alerting for undesired evolutions.
The spatial extension of the monitoring network and the number of monitoring wells should be revised at each step. Step one should be performed extensively over the monitoring area and step two should focus around risk area. Step three should be suitably designed in order to be capable of capturing any warning signal, at this step the position of the monitoring points, the parameters to be measured and the frequency of measurement need to be carefully evaluated. The TIZIANO monitoring network performed very well the first step (Assess). Unlikely, we have less evaluation elements concerning the monitoring network suitability during the second phase (Control). Finally, concerning the third step (Alert), the monitoring activity have been moved and increased around area considered mostly at risk and reduced in the rest of the region.

4.8 Monitoring evaluation

The monitoring program does not contain an evaluation phase. This means that the second learning process described in figure 1 cannot be supported.
The critical analysis of the TIZIANO groundwater monitoring system can be summarized as shown in table 3.

Criteria	**Evaluation**
- Information producer/information users interaction	- Mainly based on scientific requirements and legislation
- Degree of participation	- Weak in the design phase, strong during the implementation
- Multi-scale monitoring	- There is no analysis of inter-linkages between different scales
- Integration of information sources	- There is no integration
- Long time sustainability	- The monitoring costs are too high
- Monitoring/modelling interaction	- One-directional flow of information
- Policy evaluation	- The impacts on groundwater are monitored
- Monitoring evaluation	- The learning process is not supported

Table 3. Results of the evaluation

5. Conclusion

Starting from the results of the critical analysis, some drawbacks and potential improvements for the TIZIANO monitoring program have been identified and discussed in the following sections.

5.1 Main drawbacks

According to the results of the critical analysis, we can infer that the TIZIANO groundwater monitoring network cannot be considered as adaptive and it is not suitable to support the adaptive management. Firstly, the excessive cost for collecting and analyzing data have a strongly negative impact on the long term sustainability of the program. This, in turn, would reduce the capability of the monitoring system to detect the long term unintended consequences of the groundwater management policies.

Secondly, the monitoring system is not integrated in a wider program aiming to analyze the different potential impacts of the policies – e.g. socio-economic impacts. The TIZIANO monitoring program is based on the sectorial approach to environmental resources management which is still common is socio-institutional contexts characterized by a centralized and command-and-control regime. A more holistic and systemic approach is required.

Thirdly, there is no integration between different sources of information. This has a negative impact on the flexibility of the monitoring program. In fact, if the data collection is based only on traditional "static" devices – i.e. monitoring stations – then the adaptation of the monitoring program to modified information needs would be difficult: changing sensor is not always easy and/or cheap, the position of the station cannot be modified easily, even the time schedule for data collection cannot be changed easily. Although remote sensing data are mentioned in the program, the integration of this source of data with the traditional information sources is still far from being achieved.

Finally, an adaptive monitoring system requires an evaluation phase. That is, a critical analysis of the suitability of the designed monitoring system is crucial. This phase has not been considered in the current monitoring program. This means that the revision of the program depends exclusively on the political willing of the local authorities and on the availability of further funds.

5.2 Potential improvements

Some improvements to make the TIZIANO monitoring program more suitable to support the adaptive water management were defined:

- Monitoring costs: the current monitoring costs could be reduced only if an intelligent redistribution of activities within public institutions will be put in place. This means that the outsourcing activities have to be strongly reduced. Moreover, since the costs are mainly related to laboratories analysis, the integration of different sources of information would have a positive impact on monitoring costs.
- Systemic analysis of the policy impacts: the increasing awareness of the complexity of the real world forces us to adopt a system dynamic approach to monitor and analyze the different and interrelated policy impacts. Although the aim of the TIZIANO network is to collect data about the physical and chemical state of the groundwater, it has to be integrated in a more systemic monitoring program, able to detect even the socio-economical impacts.
- Integration between different sources of information: The integration of different sources of knowledge seems particularly useful to design a multi – variate and multi – scale monitoring system for adaptive management. The Use of alternative sources of information increases the flexibility of monitoring program and reduce the costs. Among the alternative sources of information, local knowledge is increasingly considered as crucial (see as example the Hyogo Framework for Action). The analysis of

the literature review on this issue allowed us gain some hints. The key to guarantee the long term involvement of local community members in monitoring is to keep the monitoring activities as simple and similar to the traditional methods for environmental assessment as possible. Moreover, the involvement in monitoring is easier if the monitoring activities are incorporated in the community members' daily activities. The key to guarantee the actual usability of local knowledge in monitoring activities is: 1) fully integrating local knowledge into existing traditional institutions; and 2) structuring local knowledge so that it is transformed into meaningful and relevant information for decision-making. The integration between local and scientific knowledge allowed to enhance the reliability of local knowledge.

- Learning process in monitoring activities: as widely discussed in the scientific literature, the design of a monitoring system cannot be considered as a linear process. It is rather a cycle of design – implementation – evaluation – adaptation. The information needs can change due to several reasons. Adaptive monitoring system should be able to follow these changes. To this aim an evaluation phase should be formally included in the monitoring program. The evaluation should be based on the interaction between policy and decision makers (information users) and monitoring system managers (information producers).

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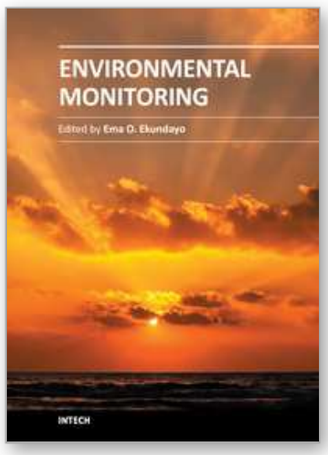

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"Environmental Monitoring" is a book designed by InTech - Open Access Publisher in collaboration with scientists and researchers from all over the world. The book is designed to present recent research advances and developments in the field of environmental monitoring to a global audience of scientists, researchers, environmental educators, administrators, managers, technicians, students, environmental enthusiasts and the general public. The book consists of a series of sections and chapters addressing topics like the monitoring of heavy metal contaminants in varied environments, biolgical monitoring/ecotoxicological studies; and the use of wireless sensor networks/Geosensor webs in environmental monitoring.

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