Early warning groundwater quality monitoring

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Groundwater quality monitoring plays an important role in the policy of groundwater protection and quality conservation and effectively supports sustainable groundwater quality management. It provides a valuable base for assessing the current state and forecasting trends in groundwater quality and helps to clarify and analyze the extent of natural processes and human impacts on groundwater system in time and space. Credible and accurate groundwater quality data should be available and readily accessible through data management systems to planners, regulators, decision and policy makers and managers. The data should also help to increase the public active participation in the process of groundwater quality protection.

Existing monitoring strategies tend to focus attention primarily on identification and control of consequences of groundwater quality deterioration and not for preventive protection of groundwater quality. This strategy reflects a fatalistic approach which leads to a series of *ex post facto* sequential managerial activities: a) groundwater quality degradation of production wells is made known; b) studies are conducted to find the sources of groundwater quality deterioration and design usually long time possible remedies; c) production wells have to be closed because groundwater pollution is found as an irreversible process; d) water quality standards are changed to accommodate the need for continued use of groundwater source (Vrba at al., 2001).

Clearly, an early warning monitoring strategy is needed that detects groundwater quality problems before massive groundwater quality degradation occurs. This strategy supports sustainable groundwater quality management and protection policies and helps in identifying human impacts when they are still controllable.

Early warning groundwater quality monitoring is an activity or sequence of activities that makes it possible to identify and to foresee the outcome of a process leading to groundwater quality deterioration with enough anticipation so that desired measures can be taken in order to change or reduce the magnitude of the impact of the said processes (Vrba at al., 2001).

Early warning, as an integral part of groundwater quality monitoring, is broad in nature, has different objectives, requires a progressive and gradual approach and covers both short term and long term policies. The early warning groundwater quality monitoring strategy supports:

- Evaluation of the chemical composition and evolution of natural groundwater
- Identification of new groundwater quality deterioration risks
- Problem solution at a controllable and manageable stage
- Decision making considering potential risks, conflicts and competitive factors between social and health implications, sustainable economic development and groundwater quality protection activities.

Early warning groundwater quality monitoring plays also important role in the identification of changes in groundwater quality caused by aquifers excessive abstraction. Monitoring should be focused particularly on: early detection of saltwater intrusion into coastal aquifers, intrusion of low quality surface water into adjacent aquifers, penetration of a contaminants into the groundwater system from point and non-point pollution sources and from irrigation return flow, lateral movement of a pollution plume to the abstraction wells, upward penetration of high mineralized water from underlying aquifers into exploited superposed aquifers, protection of public groundwater supplies and protection of wetlands.

Different approaches must be applied for early warning groundwater monitoring according to the specific characteristic of the studied groundwater system. Various monitoring methods which facilitate the early detection of changes in groundwater quality have to be implemented, mainly remote sensing methods, soil gas surveys and deep profiling of unsaturated zone and saturated aquifer through specially located and designed monitoring wells. Due to the very heterogeneous possible scenarios where early warning monitoring method could be applied (for example contact between two overlying aquifers, saltwater - groundwater interface), it is quite difficult to give a general methodological approach. There is, however, a basic fundamental principle: in an early warning monitoring system the employed sampling and/or in situ detection technique should give a considerable time lag between contaminants detection in the monitoring system and contaminants arrival into protected target area. The desired time lag should be established according to available response methods to overcome the problem.

Groundwater quality early warning monitoring systems will alert managers about groundwater quality deterioration at an early stage allowing them to plan and operate aquifers system so that water is supplied according to available quality standards. For public water supplies, early warning monitoring systems include pumping production wells or springs and monitoring wells located in protection zones that cover usually the catchment area of the water supply source. Monitoring of vulnerable and recharge areas of the source is of paramount importance.

Early warning groundwater quality monitoring is not only technically demanding, but also a financially expensive process in terms of capital, installation, operation and maintenance costs. However, the implementation of a groundwater early warning monitoring strategy is many times less expensive than the costs related to aquifers remediation and investments needed to overcome social and ecological damages of groundwater quality degradation. It is worthwhile noting that, in spite of huge budgetary investments and long period of operation for various remediation cases, there are only few cases where permanent restoration of aquifer conditions to acceptable groundwater quality levels were achieved.

Governmental institutions and water supply organizations in many countries of the world may not be yet prepared to accept the needs of groundwater quality early warning monitoring strategy. However, the reality in the field and the restoration costs of affected aquifers suggest that early warning monitoring may be strategically an important cost-effective approach for preserving the quality of groundwater resources.