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The EU FP7 GENESIS project on groundwater systems. Contributions to the analysis of economic, legal and institutional issues of groundwater management with selected case studies

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The EU FP7 GENESIS project on groundwater systems. Contributions to the analysis of economic, legal and institutional issues of groundwater management with selected case studies.

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Abstract: The EU Water Framework Directive clearly integrates economics into water management and policy making, and economics is to have a decisive role in the development of the programme of measures and the new river basin management plans. This paper provides a brief overview of the contribution of the EU GENESIS project with the application of different economic or hydro-economic methods and approaches for analyzing and/or selecting sustainable cost-efficient measures and management strategies to achieve a good quantitative and chemical groundwater status in six selected case studies across Europe that differ in their physical settings, drivers, pressures, impacts, and management and policy issues. Three main economic approaches have been employed: hydro-economic modelling combining simulation and optimization techniques, non-market valuation (choice experiment) and econometric analysis to derive relevant policy insight from specific surveys in the area. The Bayesian network technique was also tested to assess the impacts of several polices for integrated multiobjective groundwater management. Given that any feasible policy has to be designed considering the conditions of the legal and institutional framework, a in-depth analysis of the legal and institutional conditions was

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Key words: groundwater management; Water Framework Directive; hydro-economic modelling; choice experiment; multicriteria analysis

Introduction. The EU WFD and GW Directives and the GENESIS project.

The complexity of groundwater management requires methods for integrating technical, economic, environmental, legal and social issues within a framework that allows for the development of efficient and sustainable water use strategies. Groundwater management in the EU Member States has to comply with the environmental and water quality requirements of the EU Water Framework Directive (Directive 2000/60/EC; WFD onward) and the Groundwater Directive (Directive 2006/118/EC; GWD onward). The WFD requires that Member States take the necessary measures to “protect, enhance and restore all bodies of groundwater”. The objective for groundwater bodies is to reach a *good groundwater status*, which implies both, a good quantitative and a good ecological status. The *good groundwater quantitative status* is the one in which the available groundwater resource (long-term recharge rate constrained by the flow required to achieve the ecological quality objectives for associated surface waters) is not exceeded by the long-term annual rate of abstraction. A *good groundwater chemical status* requires that the concentration of pollutants of the groundwater body does not exhibit the effects of saline/intrusions, do not exceed the quality standards, and are not such as would result in failure to achieve the environmental objectives for associated surface waters or any significant damage to dependent terrestrial ecosystems. The GWD includes criteria for assessing good groundwater chemical status and identifying upward trends and starting points for trend reversals. The WFD clearly integrates economics into water management and policy making, and economics is to have a decisive role in the development of the programme of measures and the new river basin management plans. To meet the environmental objectives, the WFD calls for the application of economic principles (e.g. polluter pays), approaches (e.g. cost-effectiveness analysis) and instruments (e.g. water pricing). The Directive requires cost recovery of water services including not only financial cost (capital, OMR and administrative costs), but also environmental and resource costs. Cost-effective combinations of measures should be implemented to achieve good groundwater status. When disproportionate costs are identified, time derogation or less stringent objectives are allowed. These analyses need from the economic characterization of groundwater uses, with enough information to make the relevant calculations for applying the principle of cost recovery of water services, with long term forecasts of supply and demand.

The EU 7th FP GENESIS project, “Groundwater and Dependent Ecosystems: An Integrated Research Project to Support Groundwater Systems Management”, is a large integrated project (60 months, 25 partners from 17 countries) with the aim of reviewing and developing new scientific knowledge on groundwater systems and incorporate this knowledge into the implementation of the GWD and the generation of new tools for better integrated groundwater management. The multidisciplinary project focuses on hydrology, processes, and ecosystems, linked together by mathematical modelling. New process understanding must be incorporated into the mathematical models and assessment tools to improve understanding of pollutant leaching from different land-uses, of how ecosystems depend on groundwater, and how changes in land-use and climate affect the groundwater and dependent ecosystems. Socio-economic issues and legal aspects are also covered, and new tools will be developed for better management of groundwater under external pressure. Scenarios will be simulated to assess impacts in an integrated way considering uncertainties present in such simulations. The project involves nine work packages (WP) on: Impacts and threats to groundwater and groundwater-dependent ecosystems (WP1), Groundwater flow characterization (WP2), Pollutant input and leaching to groundwater aquifers (WP3); Groundwater dependent ecosystems: groundwater-surface water interaction (WP4), Integrated modeling of groundwater systems (WP5), Groundwater systems management (WP6), and Integration, Coordination and Dissemination WPs. Fig. 1 shows GENESIS’ 16 case studies across Europe. This paper provides a brief overview of the contribution of the EU GENESIS project with the application of different economic or hydro-economic methods and approaches for analyzing and/or selecting sustainable cost-efficient measures and management strategies to achieve a good quantitative and chemical groundwater status in selected case studies, including water pricing and water valuation issues, as well as the analysis of the conditions imposed by the existing institutional and legal framework.

Analysis of groundwater systems management: scenarios, risk, cost-efficient measures and legal aspects (WP6)

Within the GENESIS project, WP6 focuses on developing an integrated socio-hydro-economic modelling framework for selecting sustainable cost-efficient measures and management strategies to achieve a good groundwater status, and the analysis of scenarios, policies and legal and institutional framework, with application to selected case studies. The work is structured in 10 tasks and reported in 5 deliverables. During the first reporting period (months 1-18) the work focused on analysis and selection of the case studies, physical and socioeconomic characterization, decisions on the approaches to be applied to each case, and initial stages of designing non-market valuation questionnaires and development of a hydroeconomic modelling framework for controlling groundwater nitrate pollution from agriculture. Interviews with experts and stakeholders were essential for focusing the legal and institutional analysis, and the preliminary design of the multicriteria questionnaires to assess stakeholder preferences. A hydro-economic modelling framework for selecting sustainable cost-efficient measures and management strategies to achieve the good (quantitative and chemical) groundwater status in the context of the EU WFD and Groundwater Directive (*Deliverable 6.1*).

The second stage (months 18 to 36) has focused on the realization of the surveys and the statistical analysis of results (nonmarket valuation studies), the development of production functions (micro-econometric approaches), and the application of the hydro-economic modelling approach to Mancha Oriental. The contribution of economics and hydro-economic modelling to the analysis of sustainable management strategies in the application of the WFD/GWD has been reported in *Deliverable 6.2* for six selected cases: Mancha Oriental (Spain), Czestochowa (Poland), Vosvozis (Greece), Zagreb (Croatia), Dalyan lagoon watershed (Turkey), and Rokua (Finland). The case studies differ in their physical settings, and in the main drivers, pressures, impacts and management and policy issues. Three main economic approaches have been employed: *hydro-economic modelling*, *non-market valuation* (choice experiment) and *econometric analysis*, to derive relevant policy insight from specific surveys in the area. A *Bayesian network model* has been also developed to assess the impact of several policies for integrated management with different objectives under uncertainty in Mancha Oriental. The deliverable describes the approaches, their implementation to the case studies, and the relevance of the results provided to the implementation of the EU WFD and GW Directives. Given that any feasible policy has to be designed considering the conditions of the legal and institutional framework, we have conducted an in-depth analysis of the legal and institutional conditions in three of the cases, assessing the transposition of the Directives and identifying difficulties (*Deliverable 6.3;* see Allan et al., 2013*)*. The deliverable also presents the application of the *Multi Attribute Value Theory* (MAVT) to these cases to assess stakeholders preferences, identify potential conflicts and common ground, and find policy solutions socially and economically acceptable for meeting the environmental standards. Different theoretical and empirical methodologies that allow indirect estimation of the scarcity rents of in-situ groundwater and the shadow price for groundwater quality, and to derive inference on the potential for managing this resource, has been also analyzed in the GENESIS project (*Deliverable 6.4*), through the application of the selected case studies, and the role of their contribution to the implementation of the WFD/GWD has been discussed (see Koundouri et al., 2013-this conference).

Valuing groundwater (1). Market-based valuation techniques

Water is often under-valued and underpriced. Stakeholders and policy makers are often unaware of the total economic value of the resource. As a consequence, groundwater is often mismanaged and increasingly under threat of pollution and depletion. Quantifying the economic value of groundwater resources is essential for a sound groundwater management. Value estimates can play a major role in focusing policy-makers and public attention on threatened undervalued resources. Value estimates are also critical in order to evaluate the level of investment in groundwater development, protection, monitoring and management that can be economically justified. The total economic value of groundwater includes not only use values (for example, extractive and in situ values), but also non-use values (for instance, bequest and existence values). There are a number of techniques for assessing the value of both use and non-use values. Market valuation techniques measure values through actual prices in market transactions. For example, groundwater supply in irrigation; there is a market for this water, so it is possible to use statistical techniques (econometric methods) to infer this. Unfortunately, there are many effects that are not reflected in market transactions (groundwater quality improvements, impact on groundwater dependent ecosystems, etc.).

In the *Vosvozis* case (Northern Greece), groundwater level decline induces recharge from Vosvozis River and Ismarida Lake, diminishing an important source for the life of the wetland ecosystem and causing seawater intrusion in the wetland area (Gemitzi, 2012). Data from production surveys to farmers in the Vosvozis area were used to estimate the marginal value of groundwater in the aquifer (shadow price) through a microeconomic approach (distance-function approach). This value is relevant for the implementation of the WFD/GWD, because it allows the calculation of the current level of cost recovery (as the difference between the current price and groundwater marginal value) or the marginal impacts of groundwater quality changes due to potential policy measures. The study reveals individual farmer’s valuation of groundwater, showing that groundwater in this study area is undervalued, and economic instruments can provide incentives to a more efficient use by the agricultural sector, incorporating the notion of total economic value.

In the *Dalyan* case study, data from a survey are used in an econometric approach to derive a stochastic production frontier to assess the average demand for groundwater by the agricultural sector (main groundwater user). The estimated frontier is then used to analyze agricultural use of groundwater and marginal impacts of groundwater quality changes due to potential policy measures (e.g. relative measures of farms' efficiencies, estimates for the elasticity of groundwater demand, and potential quality changes due to various policy measures).

A different approach has been used for the *Mancha Oriental* case study, Spain. In this case, irrigation is the main water use by far (98%), the main crops being wheat, maize, alfalfa, onion and barley. Crop yield (production functions) and nitrate leaching functions were estimated with a GIS-based crop-growth model integrating a bio-physical EPIC model. The integration with the GIS tool was necessary in order to simulate the spatial and temporal dynamics of the major processes of the soil-crop-atmosphere-management systems. The model uses six types of input data: information on location (latitude, longitude, DEM and slope), climate data, soil physical parameters, land use data, plant parameters, and management data (such as irrigation and fertilizer application). The crop yield functions were used to estimate crop the benefits, while the nitrate leaching functions provided the nitrate input in the groundwater system needed to assess the resulting groundwater nitrate concentrations. Both types of functions have been embedded in the hydro-economic model described in a section below (Peña-Haro et al., 2013-this conference).

Valuing groundwater (2). Nonmarket valuation techniques.

These techniques are used where there is no price available or where prices for groundwater goods and services do not reflect the real value, but we still need to estimate the value of the resource for the purpose of decision-making. There are two main groups of techniques: revealed and stated preference methods. The first infers the values from observed market transactions implicitly related to groundwater (for example, hedonic pricing to determine the economic value of groundwater dependent ecosystems). The second estimates willingness to pay for services from hypothetical markets (for example, contingent valuation, CVM, or choice experiments, CE).

Rokua in Northern Finland is a groundwater dependent ecosystem very sensitive to climate change and natural variability. Water level of most of the lakes is a function of the level of the groundwater table of the esker, which is naturally recharged, and human activities (mainly peatland drainage by forest industry) are provoking decreased groundwater and lake levels, inducing losses of ecosystem services and recreation. There is high uncertainty on the actual system dynamics, potential climate change effect, and long-term impacts. General public's elicited values through a CE and a CVM highlight the importance of water management policy which contributes to the sustainability of groundwater dependent ecosystems. Five attributes were considered in the CE: water quantity, recreation (sum of all values - direct and indirect - derived from recreational activities), land income, investment in research, price. The results reveal that there is a high willingness-to-pay for scientific research (33-37€/household), showing the value of uncertainty reduction from improved scientific information (Koundouri et al., 2012).

A CE was also run for the *Vosvozis* case previously described in order to illustrate the nonmarket benefits from improving groundwater quality (salinity and nitrates) and quantity (lake area). Results illustrate farmers' valuation of management plan to maintain water quality and local ecological conditions. The results support the implementation of measures to modify current agricultural practices and indicate farmers' willingness to incur costs to sustain their future agricultural production (Kountouris et al., 2013a-this conference). The results of a CE survey reflect the nonmarket benefits from reducing groundwater nitrate pollution in the *Czestochowa* aquifer (Poland), an important source of potable water for the region, under threat from increasing nitrate concentration primarily due to limited coverage of the residential sewage system. Three attributes were considered: nitrate pollution level, time to improvement, and additional water charge. The results illustrate the value attached to improving water quality in the region. A CE approach was also applied to the valuation of a conservation programme for the *Zagreb* aquifer (source of potable water supply for the city of Zagreb), linking water quality to the three main groundwater pollutant sources: urban, agriculture and industries (Kountouris et al., 2012). Kountouris et al. (2013a-this conference) examine the effect of a change in the political environment on WTP estimates, testing how WTP from non-market valuation was sensitive to changes in the prevailing political conditions and the emergence of political instability.

Hydro-economic modelling and Bayesian networks

The combination of economic concepts and indicators with the modelling of the groundwater systems provides results and insights more relevant to management decisions and policies. Hydro-economic models can be used to assess economic impacts of certain policies or to simulate hydrologic implications of the application of economic instruments. The tools can be used to estimate the cost of certain policies and their effectiveness in meeting the environmental objectives of the WFD. They can also assist in the design of effective economic instruments for certain targets or objectives or to meet certain requirements. Economic instruments, where appropriately used, can be effective tools for meeting some of the environmental objectives of the directive. Hydro-economic models can assist in the design and assessment of effective economic instruments.

A hydro-economic modelling framework has been developed and applied to the *Mancha Oriental* case (Spain) for exploring optimal management of groundwater nitrate pollution from agriculture. An optimization model suggests the spatial and temporal fertilizer application rate that maximizes the net benefits in agriculture constrained by the quality requirements in groundwater at specific control sites. The analysis accounts for key underlying biophysical processes linked to the dynamics of nitrogen in the soil and the aquifer, as well as the crop yield responses to water and fertilizer application. The approach allows to assess the tradeoffs between two alternative economic instruments for diffuse pollution control: fertilizer quotas and fertilizer price (Peña-Haro et al., 2010). The results show the required reduction of fertilizer application in the different crop areas depending on its location with regards to the control sites, crop types and soil–plant conditions, groundwater flow and transport processes, time horizon for meeting the standards, and the cost of implementing such a policy (Peña-Haro et al., 2010 and 2013–this conference). A stochastic framework is also proposed to deal with uncertainty in the pollutant concentration predictions due to uncertainty in the spatial variability of the hydraulic conductivity (Peña-Haro et al., 2011).

One alternative approach for hydro-economic modelling of water resources management is the use of Bayesian networks (BNs), increasingly applied to model environmental systems, due to its advantages to incorporate and explicitly represent uncertain information, integrate data and knowledge from different sources, and handle missing or qualitative data. The modular architecture facilitates iterative model development, based on a relatively simple causal graphical structure; the network can be built without highly technical modelling skills and be understood by non-technical users and stakeholders, a very valuable feature in the context of natural resource management, with interdisciplinary and participatory processes. An integrated BN Decision Support System has been also developed to assess the impact of several policies for integrated groundwater management in Mancha Oriental. In order to cover the different requirements of the WFD, water quality, and economic, hydraulic, legal and ecological issues are integrated. The main advantage of the application of the BN approach to this case is the great amount of available information on the groundwater system behavior (including groundwater flow and mass transport models, agronomic simulation, hydroeconomic model, etc.) and especially, on the impact of several water management policies that have been recently implemented. However, the approach is very flexible and can be applied to deal with different groundwater issues in other case studies in which less information is available or there is more uncertainty on the impacts (Molina et al., 2012).

Legal and Institutional issues. Multicriteria Assessments.

The WFD and GWD have been transposed into national legal frameworks. However, there are problems with respect to the implementation, relating in particular to issues like the management of diffuse pollution, the incorporation of ecological quality standards, discrepancies between monitoring capacity and legal requirements, and antagonism between stakeholder preferences and legal requirements regarding ecological protection. Through a detailed analysis of legislation, institutional frameworks, case law, policy and financial incentives, the project has examined the Finnish, Spanish and Greek contexts closely, identifying gaps in the implementation efforts, and making preliminary recommendations on scientific practice that might enhance implementation. Implementation could be improved through: involving farmers directly in development of measures for reducing diffuse pollution, improving treatment of emerging pollutants (e.g. pharmaceutical and personal care products), use of indicator-based frameworks for assessing vulnerability of groundwater, dependent ecosystems, and the use of environmental tracers as part of groundwater characterization efforts (Allan et al., 2013).

Decision making in groundwater quantity and quality management is complex because of heterogeneous stakeholder interests, multiple objectives, different options, and uncertain outcomes. Conflicting stakeholder interests are often an impediment to the realization and success of any regulations, policies, and measures. Multicriteria Analysis aims to attain aggregated measures of the attractiveness of each outcome for the stakeholders within a set of options/alternatives. The application of the multi-attribute value theory (MAVT) involves these main steps: definition of the problem, identification of stakeholders, identification of objectives and attributes, identification of alternatives, impact assessment of alternatives, quantification of stakeholders preferences, ranking of alternatives, and assessment of results. The approach has been applied to three selected case studies: Mancha Oriental case, Rokua and Vosvozis (Stefanopoulos et al., 2013, this conference), showing its potential to assess stakeholder preferences and identify potential conflicts as well as common ground.

Conclusions

This paper has presented the research conducted within the EU GENESIS project about the application of a broad range of diverse economic, hydro-economic and multicriteria techniques to the analysis of different groundwater management issues. The results have proven the value of an integrated, interdisciplinary approach, and the utility of these tools to address the challenges of the implementation of the EU WFD and GWD. A generic lesson that can be derived from this analysis is that there is no a single standard approach to deal with groundwater economic and management issues, but each case will require an specific approach according to the scope of the study and the policy questions, the data availability, the physical setting, the economic drivers, the legal and institutional framework, etc. Moreover, these methods provide complementary information: while the hydro-economic model suggests optimal groundwater management policies and potential impacts, the economic valuation techniques allow to assess the benefits from improving the status of the groundwater system, and the MAVT method identifies a ranking of alternatives of action according to the stakeholder preferences.

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web page: www.thegenesisproject.eu

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