4.1 Final publishable summary report

4.1.1 Executive Summary

The overall objective of GENESIS was to integrate pre-existing and new scientific knowledge into new methods, concepts and tools for a better future management of groundwater resources. The research should: i) use tracers to characterize groundwater flowpaths, ii) improve the understanding of pollutant leaching from different land-uses both in time and space considering also uncertainty, iii) develop a better understanding of how ecosystems depend on groundwater, iv) increase the knowledge on how these systems should be modelled to better understand how changes in land-use and climate affect the groundwater and dependent ecosystems, and v) develop better cost-efficient management and monitoring tools. The research results should be transferred to research community, stakeholders and end-users for better management. GENESIS should provide input to the revision of the Ground Water Directive (GWD).

GENESIS is a multidisciplinary research project with 25 partners from 17 countries that focus various aspects of groundwater systems research (Fig.1). In GENESIS research is carried out on hydrology, water resources, hydrogeology, agronomy, soil science, modelling, economy, sociology and legal aspects. The work was organised in eight Work Packages (WPs as in Fig. 1). The first WP1 harmonized monitoring practices between partners. The main scientific research work on groundwater and ecosystems processes was be carried out in the WPs 2-6. This comprised studies on water flow paths with tracers (WP2), pollutant transport and leaching processes (WP3), groundwater ecosystems (WP4), modelling (WP5), management and engineering (WP6). A work package (WP7) was devoted to integration of results and dissemination.

In the project aquifers, groundwater systems and ecosystems were studied in different regions of Europe covering different climatic regions, various land use pressures and socio-economic systems. At these sites human pressures were analysed, methods tested on flow path characterization, leaching and pollutant processes studied, ecosystem interactions revealed, modelling applied to reply to relevant management questions, and the systems analysed from a viewpoint of social, economic and policy. Common research activities where several research groups were involved include:

- use of environmental tracer methods. Partners were guided by experts to introduce cost-efficient methods for flowpath characterization and hydrological analysis. The outcome was a successful integration of the traditional and tracer-based methods for studying interactions between the aquifers and the groundwater dependent ecosystems.
- analysis of conceptual models in a framework of DPSIR and derive an analysis of pollutant sources, leaching mechanisms and potential transport pathways. A review paper was produced on the topic and later on EU picked this up for wider dissemination.
- benchmark of different leaching models for N and pesticides using high quality dataset from Austria and Norway. The model comparison show that leaching is not yet well described in models used for e.g. assessment of pesticide risks (licensing).
- methods for analysis of groundwater dependent ecosystems were significantly developed from an interdisciplinary viewpoint covering issues of hydrology, ecology, land use, socio-economic issues, policy issues and modelling aspects. Impacts of climate change and land use was reviewed and analyzed.
- different models were tested for various sites. Sequential coupled models are a powerful and flexible approach to combine surface and groundwater processes while keeping the simulation details offered by each model. It is especially recommended when some

processes are required to be modelled in detail, such as nitrate leaching, mass transport or specific soil phenomena (e.g. frost, thawing).

- With studies at 6 case sites, the project improved the state of the art by testing and analyzing different economic or hydro-economic methods and tools for analyzing and selecting sustainable cost-efficient measures and management strategies to achieve a good quantitative and chemical groundwater status.

The overall outcome of the project increase the understanding of groundwater systems from an integrated point of view and provide new methods or good examples of how different systems need to be studied.

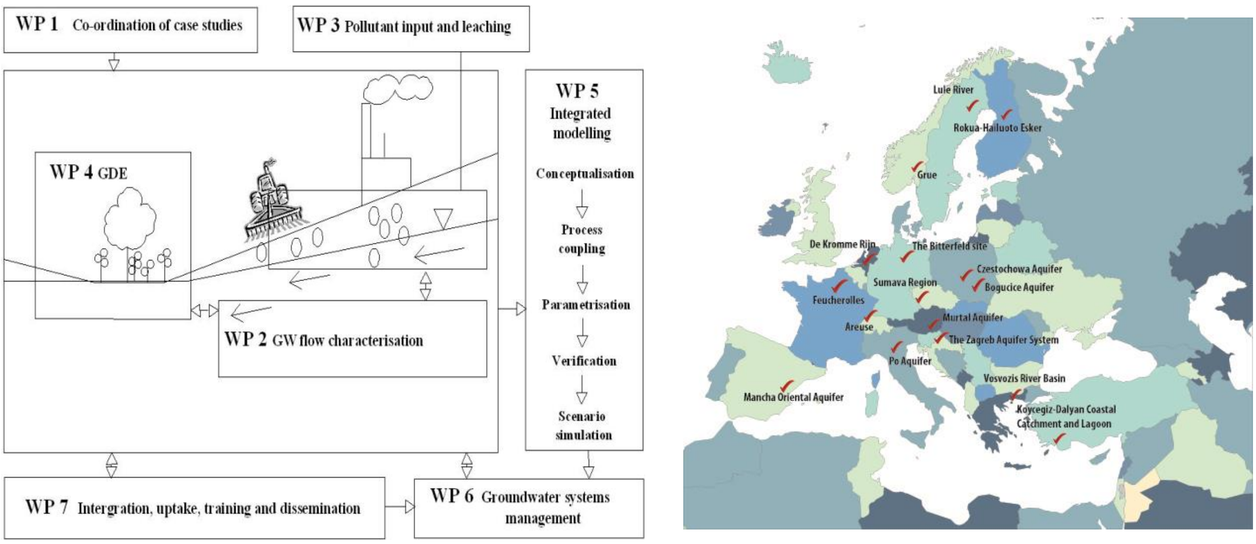

Fig. 1 Linkages between Work Packages (WPs) and location of case studies. The cases were used in an explanative and explorative way to test project hypothesis, understand systems, and develop tools for monitoring and management.

4.1.2 Summary description of project context and objectives

Project context

Groundwater resources are facing increasing quantitative pressure from land-use and consumption pressures. In some areas, groundwater levels have been reduced and this has resulted in negative impacts on water quantity and quality and important ecosystems relying on groundwater. In many areas, groundwater has been contaminated by diffuse loading resulting from land-use activities (e.g. agriculture) or point sources (e.g. industry). There is a strong need to reduce input of pollutants to prevent groundwater pollution. Additional threats from climate change are unknown, highly interwoven and complex.

Groundwater provides an important source of water for ecosystems and humans, especially during droughts and in dry climate. Increasing use of groundwater has led to groundwater level declines in many part of the world resulting in major concerns about future availability of this resource in a world with increasing demand for food and animal protein requiring large amount of water. Reduced groundwater levels have resulted in changes river flow affecting riverine ecology. Reduced river flows have also altered levels in lakes and wetlands. Besides the changes in quantity, increased use of groundwater for irrigation has also resulted in increased pollution from fertilizers and pesticides. In future management, a complete knowledge of groundwater systems and the influence of land use on the services groundwater provides must be understood. For future planning purposes the impacts of groundwater abstraction and irrigation must be understood. On a long term planning horizon, the land use impacts must be understood to assess if the land management plans complies with given environmental policy and the set restrictions on e.g. groundwater quality standards. Also land use must consider farmer income and increasing need to food and energy in different regions with different level of socio-economic development.

Integrated management of groundwater has not received much attention compared to the integrated management of surface water systems. For groundwater resources, integrated management would mean that considering groundwater system should include also hydraulic links to surface waters (lake, river, ocean) and groundwater dependent ecosystems. The management should include socio-economic and political issues that evidently relates to future land use and food production (self-sufficiency, farmer income, ecological agriculture etc.). For groundwater systems the key issues to consider is assessment of future groundwater consumption and recharge, pollution and environmental impacts. Besides assessment of direct effect of abstraction for human water use also impacts of climate change on groundwater renewal rates must be assessed. For future management, also new methods to assess and reduce impacts of land use are essential.

The EU Water Framework Directive (WFD), Groundwater Directive (GWD) and also Nitrates Directive, Landfill Directive, and the proposed Soil Framework Directive provide means to protect groundwater (GW) aquifers from pollution and deterioration (Quevauviller, 2006). The legislation intends to safeguard groundwater resources while maintaining important land-use such as agriculture, forestry, urban development and industry. In the GWD, maximum limits of pollutant concentrations have been set for nitrate and pesticides in groundwater bodies. Actions must be taken i) not to exceed these limits, ii) reverse trends in pollution iii) prevent completely emission of hazardous pollutants. The criteria set should provide groundwater for human consumption as well as for ecosystems depending on groundwater.

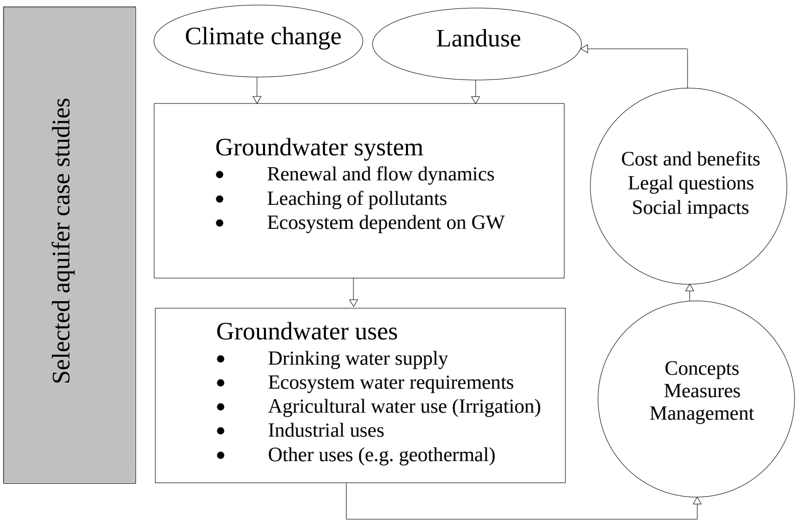

Fig. 2. Concept of GENESIS. Climate change and various land-use activities affect groundwater. This changes the groundwater capacity to provide legitimate uses. New criteria are needed for groundwater system protection and the update of the GWD. New concepts, measures and management are needed to change land-use and water use patterns. For these measures the costs and social impacts must be assessed.

The overall concept of GENESIS is outlined in Fig. 1. The groundwater status is affected by several direct and indirect drivers (boundary conditions) the most important being various land-use activities and the climate change. These drivers cause changes in groundwater recharge and flow dynamics, leaching of pollutants and groundwater quality. Changes in water quantity and quality directly effect ecosystems relying on groundwater. **Scientific research is needed to improve the understanding of how different drivers affect groundwater systems. New process understanding must be incorporated into mathematical models and assessment tools. Scenarios will be simulated to assess impacts in an integrated way taking account of uncertainties present in such simulations**. Changes in the groundwater system have impacts on the functions that groundwater provides to socio-economical uses (water supply, irrigation, industry) and ecosystems. Research is needed to develop methods to safeguard these functions.

The way forward to safeguard the groundwater resource requires modifications in land-use and water use practices. These changes may be costly and can affect many European citizens. To ensure that new practices are adopted, a legislatively sufficient frame must be provided. The socio-economical consequences of changing practises on e.g. agriculture, farmers and forestry must be better known. Also the measures suggested must fit into common agricultural policies (see section 1.3). Adaptations should be based on scientific evidence, as well as cost-benefit analyses of the consequences to better justify and communicate suggested changes. GENESIS included development of new scientifically based methods for analysis of economical impacts of changing land and water uses as shown in Fig. 2. This provides a link between legitimate water uses and efficient land-use management. The change in uses and increases of benefit of protective measures will be quantified and demonstrated for decision makers.

Project objectives

Future groundwater management should provide safe drinking water and safeguard important ecosystems. The European aquifers differ by their geology, climate, and threats to aquifers, which must be taken into account when new policies are developed. **The main objective of GENESIS was to review and develop new scientific knowledge on groundwater systems and incorporate this knowledge into input for i) Ground Water Directive (GWD) and ii) new tools for better integrated groundwater management.**

The overall objectives of research in different **work packages** (WPs) was to: **i)** link the present knowledge to an integrated model from sources of pollution to the recipient ecosystem, **ii)** improve the understanding of pollutant leaching from different land-uses both in time and space considering also uncertainty, **iii)** develop a better understanding of how ecosystems depend on groundwater, **iv)** understand how changes in land-use and climate affect the groundwater and dependent ecosystems, and **v)** develop better cost-efficient management and monitoring tools and transfer the research results to stakeholders and end-users for better management. The final output for the directives are e.g. guidelines for the protection of ecosystems, indicators to test vulnerability, best management practices to reduce pollution, guidance for the design of monitoring networks and action criteria for trend reversal.

<u>The research short, medium and long term objectives were:</u>

Short term (year 2009-December): To review impacts and threats to groundwater and ecosystems (history of land-use and corresponding changes in groundwater levels and concentration). To develop conceptual models to deliver an improved understanding of groundwater systems. To develop methods for quality assurance and control for case study measurements.

Medium term (year 2011-November): To provide new scientific basis on for the revision of the groundwater directive. The work will give direct input into all GWD Articles and its Annexes and reply to questions mentioned in points 1-25 (preamble). The research will solve specific issues related to: protection and limitation of pollutants (GWD Annex I, 3rd paragraph), methods to define starting points for trend reversal (Annex IV), best practice measures to reverse trends (Article 6), methods to observe changes (Article 5), best practices to detect and control pollution and protect ecosystems from deterioration (GWD, point 20). New conceptual models will be updated and used as basis for simulating for relevant scenarios on environmental change. The conceptual models and examples from aquifers will be provided for groundwater management. A cost-efficient methodology for assessing changes in land-use will be developed considering the legitimate uses of groundwater.

Long term (year 2013): To develop new scientific knowledge, indicator methods and tools for future integrated groundwater management and monitoring. Integrated model simulations on representative European groundwater systems will be made with new components on climate, land-use and pollution input changes. This will clarify e.g. the role of biogeochemical processes in pollutant degradation and the vulnerability of groundwater systems. The modelling will be an "appropriate investigation" as mentioned in GWD Article 4C to show if the groundwater pollution presents an environmental risk. New methods will be developed for assessing cost-efficiency and the social impacts resulting from changes in groundwater management practices.

<u>Specific objectives were:</u>

- To develop improved methods to assess groundwater renewal, residence times and groundwater connectivity to ecosystems based on the combined use of tracers and numerical modelling.
- To describe relevant hydrological processes at "groundwater boundaries" at the interface between groundwater and surface waters (including wetlands), groundwater and unsaturated zone, top soil and the atmosphere.
- To develop new methods to assess leaching of pollutants at different scales in space and time and the transport into aquifers from diffuse land-use (e.g. agriculture) and point sources (describe how land-use results in 3-D distribution of pollutants in aquifers).
- To increase the understanding of groundwater dependent ecosystems and to develop management tools such as indicators for assessing changes and criteria for protection and restoration of these ecosystems (the developing of groundwater protection areas.
- To integrate new scientific knowledge on biogeochemical processes occurring in the soil layer (pollution to groundwater), the saturated layer and the surface-groundwater interaction zone into advanced descriptions in open-source simulation models.
- To simulate, with newly improved integrated models, the impacts on groundwater systems of changes in land-use and climate in an integrated way (taking account of the groundwater systems as whole) for the most relevant aquifer scale (depending on type of aquifer and dependent ecosystem).
- To integrate new scientific knowledge for the efficient design of networks intended to monitor both the status and the trends of indicators
- To develop quality assurance and quality control (QA/QC) protocols to decrease uncertainties related to modelling and vulnerability assessment and management in groundwater.
- To simulate for different groundwater cases the "point of action" for concentration trend reversal and set criteria based on local factors affecting vulnerability (see Fig. 8).

- To analyse through simulations and by developing indicators how vulnerability should be assessed, and how potential change in groundwater should be measured and detected.
- To test the methods developed in case aquifers and generate new information on future expected changes in groundwater and connected surface water systems based on climate change, land-use and water consumption scenarios.
- To develop management methods that take into account several scientific, economical and social objectives linked to aquifers with problems and conflicts related to water scarcity, quality and ecological deterioration (such as desiccation, loss of biodiversity, recreation).
- To develop user-friendly concepts to estimate impacts and vulnerability of groundwater and dependent ecosystems from changes in agricultural practice, land-use, pollutants, soil cover, soil properties and climate change.
- To provide advice to the institutional and legal frame and policies.
- To integrate and disseminate the results into practice by involving stakeholder and providing training courses, eLearning methods, and guidelines/guidebooks, workshops on newly developed methods.

4.1.3 Description of main S & T results/foregrounds

Overall results and response to set general objectives

As required by the main objective, GENESIS integrated past and new result to provide input required for Ground Water Directive and new tools for better integrated groundwater management. In GENESIS, the results developed are presented in deliverables, as critical reviews in peer-reviewed journals on some relevant topics e.g. pollutants and leaching, GDEs, climate change, and use of tracers. The reviews outline the scientific research status and research needs also set from a policy context providing also outcomes relevant for policy is also discussed and presented. The project produced high amount of individual research papers (about 60), special issue sin 2 journals (HESS and STOTEN) and many events and end-user contacts which is more outlined in section 4.ve 1.4.

The initial overall objectives of research in each WP and the outcome of GENESIS is shortly presented below. The objective was to:

- *link the present knowledge to an integrated model from sources of pollution to the recipient ecosystem.*
    - To meet this objective studies were carried out on groundwater body scale and smaller scales to study infiltration, leaching, groundwater flow patterns and the connection to surface water systems. Also a review was made on pollutant leaching issues (Balderacchi et al. 2013, EC newsletter) and GDEs in general (Klöve et al 2010 a and b).
- *improve the understanding of pollutant leaching from different land-uses both in time and space considering also uncertainty*
    - To meet this objective pollutant leaching (N, pesticides and metals, organic contaminants to some extent) were studied at different sites. A benchmarking was carried out to test leaching models.
- *develop a better understanding of how ecosystems depend on groundwater*
    - To meet this objective common reviews were prepared on this topic (Klöve 2010 a and b, Klöve et al. 2014 a and b) and individual studies set up to study hydrology and ecology.

- *understand how changes in land-use and climate affect the groundwater and dependent ecosystems*
    - This objective was included in all case studies, model work and most summary reviews prepared. Changes of land use included impacts of agriculture (pollution and abstraction), urbanization, forestry, and hydropower. Climate change was studied by producing scenarios of change, developing indicators showing impacts of CC, studies of climate variability, studies on the value of climate change information (published also by EC in a newsletter on environment and policy)
- *develop better cost-efficient management and monitoring tools and transfer the research results to stakeholders and end-users for better management.*
    - Methods related to modelling and monitoring (e.g. tracers, hydrological monitoring) were tested and developed in all WPs. In WP6, several management methods were tested for the first time for groundwater management. The research conducted within the EU GENESIS project on the application of a broad range of economic, hydro-economic and multicriteria techniques to the analysis of different groundwater management issues 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.
    - Hydrological and tracer methods were used in GDEs in different ways. An indicator matrix and hydrological indicators were developed to test impacts including also impacts in GDEs. Biological methods to test impacts were also tested in GDEs (springs) which has not been much done before.

The final output for the directives are e.g. guidelines for the protection of ecosystems, indicators to test vulnerability, best management practices to reduce pollution, guidance for the design of monitoring networks and action criteria for trend reversal.

- To meet this objective, guidance was produced on how to monitor changes in ecosystems, how to protect ecosystems, indicators to test vulnerability and management practices. Numerical models were tested for various cases and benchmarked. Models were used to simulate future scenarios. Models are a good way to estimate land use impacts for trend reversals.

Summary of results from each WP research area

The general objective of **WP1** was to provide the link between the different processes oriented working packages (WPs 2-4) by introducing a large range of European aquifers and GDEs to pinpoint relevant and current impacts and threats on groundwater systems. Thus, case studies are being provided for hypothesis testing and model development and their mathematical implementation. WP1 was active in the beginning of the project.

In WP1, the Work tasks 1 to 3 consist of identifying impacts and threats (1) to groundwater dynamics, recharge and water balance of groundwater systems, (2) from substances leaching to groundwater aquifers due to different land-uses and (3) to groundwater dependent ecosystems from groundwater surface water interactions. The results of these work tasks were synthetized into D1.1 entitled impacts and threats to groundwater which was finished in month 12. Furthermore, work on work task 4 “measurement protocol and data flow” was completed which is intended to ensure high quality of measurements throughout GENESIS by providing common strategies and quality assurance on measurement protocols and handling of data. GENESIS partners work on a large range of problems and hence apply very diverse data collection and analysis procedures but all adhere to corresponding ISO guidelines and apply validated operating methods to guarantee the integrity and comparability of the data.

The scope of **WP2 "Groundwater flowpath** characteristics" was to develop and implement operational tools for characterizing flow in groundwater systems with emphasis on the integrated application of tracer techniques and mathematical modelling. The context of this work is related to the requirements of the Water Framework Directive and the Groundwater Directive as well as to concepts presented in some of the Common Implementation Strategy Guidance Documents. According to this legislation and documents knowledge of groundwater flow conditions, recharge rates and percolation times is essential for characterizing groundwater bodies at risk. Particular attention is in this regard paid in WP2 to two issues: temporal aspects of contaminant transport and to interactions between groundwater and the related aquatic and terrestrial ecosystems.

In the initial stage of the project, activities were focused on identification of research questions and design of experimental work in the diverse case studies of the project. The open workshop on flowpath characterization helped harmonize approaches applied by project partners and contributed to dissemination of tracer methods. Work in WP2 is essentially linked and sometimes inseparable from efforts undertaken in Work Packages 3-5. The particular role of WP2 lies in exposing the problematic issues related to physical characterization of groundwater systems and in promoting use of environmental tracers as they integrate groundwater system characteristics over a wide range of spatial and temporal scales and constrain the conceptual and numerical models of flow and transport. Approach based on application of tracers has proven effective in addressing specific and poorly understood issues, such as infiltration in cold and mountainous areas, interactions between groundwater and river water and GDEs.

Guidelines on flow characterization prepared as Deliverable 2.2 provide state-of-the-art presentation of key issues in characterization of groundwater flow and transport and of tracer-based methods to solve them. Deliverable 2.3 provides a critical review of methods used for assessment of groundwater vulnerability. The deliverable discusses different understandings and methods of vulnerability assessments. Understanding of the concept of groundwater vulnerability is very diverse and the resulting multitude of approaches leads to the relative and unstandardized measures of vulnerability. Instead of these subjective indices the mean travel time of water is recommended as an objective and operational indicator of groundwater vulnerability. Such approach is in line with the requirements of the WFD and GWD that pay attention time frames set up for water quality improvements and observations of trends in water quality Use of this approach was demonstrated in several case studies of the project.

The awareness of the crucial role that time scales of groundwater flow and contaminant transport have in understanding of groundwater systems and in assessments of their vulnerability among the policy makers and groundwater managers is very limited. The activities of WP2 were aimed at dissemination of these concepts and providing relevant recommendations for amendments of the GWD and the related technical documents. The policy-relevant conclusions of WP2 are presented in Deliverable 6.5. These recommendation concern the Groundwater Directive, Water Framework Directive and Common Implementation Strategy and also the national level policy.

Leaching assessment is one of the issues that is studied in more detail in **WP3 "Leaching of pollutants"** due to the demand for information and knowledge about direct and indirect drivers that exert influence on the groundwater status. The understanding of how different drivers affect the status and dynamics of recharge rates, groundwater levels and concentrations in groundwater systems need to be improved. The directives and guidelines related to pollutant leaching to groundwater are reviewed, with an emphasis on the European regulations: Groundwater Directive 2006/118/EC, Nitrate Directive 91/676/EEC1, Water Framework Directive (WFD) 2000/60/EC, EU Regulation 1107/2009/EC targetted at plant protection products, Directive for Sustainable Use of Pesticides 128/2009/EC, Registration, Evaluation Authorisation and Restriction of Chemicals (REACH regulation), Directive 2001/82/EC related to veterinary medicinal products and Directive 2001/83/EC related to medicinal products for human use, Directive 2008/105/EC on environmental quality standards in the field of water policy amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC, The proposal for amending the directives Directive 2000/60/EC and Directive 2008/105/EC (COM(2011)876 final), Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used, Report on the Implementation of the Sewage Sludge Directive 86/278/EEC.

A number of biogeochemical processes that influence the chemical quality of groundwater bodies has been reviewed. The review aimed to aims to identify biogeochemical processes insufficiently covered in leaching models and GW risk assessments. Processes which are currently not well described in leaching models and some recent advances in biogeochemical processes knowledge is presented and the question is discussed about "What should be implemented in leaching assessment methods in the future?" The following processes are highlighted:

- Nitrogen cycle in agro ecosystems as a souce for nitrate leaching and the role of denitrification in soil and subsoil
- Kinetics of organic pollutants / trace elements
- Microbial degradation of organic pollutants and metabolites
- Dissolved organic matter
- Sulphate and sulphur species
- Freezing and thawing effect on leaching of contaminants

Tools for leaching assessment are presented for different spatial scales: the field scale, the aquifer of watershed scale and the (pan-) European scale. The tools differ widely in their operating range with respect to questions to be answered, their demand for input data and their complexity. The present regulations and procedures of leaching assessment are assessed for nitrate, pesticides and organic compounds.

Recommendations for leaching assessment methods and procedures are formulated on the basis of the assessment and on the basis of some experiences in the GENESIS case studies. The aquifer scale case study for the Murtal (Austria) focusses on the fertilizer recommendation to farmers and the posibilities to find optimal crop rotation patterns. The recommendations of the Vosvozis river (Greece) is related to method of calculating nitrate leaching rates by the SWAT model. The experiences with the Pan-European modelling effort, based on the existing MITERRA model with validation on the European dataset of reported nitrate concentrations (Nitrate Directive, Article V) has yielded a critical evaluation of the usefulness of the database. Recommendations for pesticide leaching assessment was included based on outputs from the pesticide leaching benchmark study.

Recommendations for the leaching of organic compounds are discussed on the basis of 1) a literature review; 2) an assessment of European directives and guidances and 3) on the basis of the experience in the GENESIS case study "Caretti site".

The WP reviewed current knowledge on mitigation strategies to reduce contaminant inputs into groundwater. Measures include changes in the regulation, change of land use, change of management practices, the use of buffer zones or protection areas. This concerns also strategies of reduction of the use of chemicals in agriculture (fertilization, pesticides) and the design of more sustainable cropping systems. Nitrate, pesticides are reviewed as well as trace metals. Some synthetic substances are also considered such as being petroleum hydrocarbons, chlorinated aliphatics and organic-waste contaminants for both point and non point contamination.

Several GENESIS case studies serve to evaluate some of the reviewed potential measures or their combination and their effectiveness when applied in practice or in the frame of simulations with models. This mainly concerns improved risk assessment for pesticide leaching, change in cropping systems and rotation, change in agricultural management (fertilization, irrigation, organic waste recycling), mitigation of point source contamination using constructed wetlands. For some case studies, an attempt to assess practicability and cost-effectiveness of some recommendations was proposed at the farm and catchment scale.

The work in **WP4 on groundwater dependent ecosystems (GDEs)** includes new studies at different case sites, and integration of past knowledge from different scientific, management and legal aspects. The work included studies on groundwater hydrology, groundwater surface water interaction and ecology. The studies also looked at land use and climate change impacts such as impacts of water extraction, drainage, agriculture and river regulation.

In WP4, research from individual studies has given new information on groundwater and ecosystem interaction, methods to observe, model and manage GDEs. For example predictive ecological modelling has been used for the first time on springs to show impacts of land use. Tracers have been used in GDEs along with more traditional hydrological measurements. This has provided methods to show groundwater dependency and interaction. Numerical models have been used for some cases to model and show GDE interaction with groundwater. Indicator methods were also presented as tools for groundwater management considering ecosystem protection.

From the start of the project WP4 has had a strong emphasis on the main objective of the GENESIS project "*the integration of pre-existing knowledge and new scientific knowledge into new methods, concepts and tools*". The emphasis has been to provide a holistic and integrated approach on GDEs which was developed in several project meetings and in common deliverables. A key task in also for WP4 is to integrate with policy making. The relevant issues from policy making have been discussed and taken into individual research and common discussion at meetings that has led to common papers on GDEs (4 papers published in Environmental Science and Policy, Journal of Hydrology, Water Policy). The intention of these papers has been on one hand to disseminate results but on the other hand to integrate different knowledge, science, and management aspects.

By studying individual systems more information has been generated on important ecosystems connected to different types of aquifers such as:

- Quaternary deposits that for main aquifers in northern Europe. New information has been gained on Eskers connected to lakes and peatlands, and river floodplain interactions. The impacts of drainage, climate and river regulation has been studied that are threats to GDEs in Northern Europe. Also methods to monitor, model and manage these systems have been studied and tested in collaboration with WP2, WP5 and WP6.
- Alluvial plains in contact with costal ecosystems has been studied in the Mediterranean climate. The aquifer interaction with river, lake and sea has been clarified under pressure of extensive groundwater use. The impacts of salt water intrusion has been studied.
- Multi-layered confined aquifer under extensive exploitation pressures and a potential fen ecosystem contact has been studied in Poland.
- Other systems such as Riverine systems have been studied in several cases (rivers Luleå, Kalix, Sava, and Pfyn), Coastal lagoons (Turkey), Springs (Switzerland and Finland).

The range of cases, climate and systems studied has provided important knowledge for integrated groundwater management.

The overall research highlights from WP4 are:

- Hydrology and ecology has been integrated to a better understanding of GDEs
- Integrated approaches of coupled systems GW and GDE has been developed
    - GW and GDE interaction
    - Development of conceptual models
    - Knowledge development of individual GDEs
- GDE vulnerability assessment approaches have been developed
    - Indicators matrix have been set up
    - Hydrological indicators have been developed
- Methods for measuring groundwater dependency (interaction) have been tested
- Protection principles have been developed
- Methods to link numerical model output to ecology has been discussed and ideas presented.

In **WP5 "Groundwater Modelling"** process knowledge on groundwater hydrology, GDEs, land-use and pollutant input derived from WPs 2 to 4 has been integrated into numerical modelling schemes to improve the understanding of the groundwater system as a whole. As a result, enhanced tools to predict impacts on groundwater and related ecosystems based on defined scenarios have been developed that include effects of climate change along with changes in land-use and leaching. Thus, WP5 also provides the link between the process oriented WPs (2-4) and the management of groundwater systems (WP6).

WP5 is structured in seven work tasks and four deliverables that in essence describe the procedure of applying a numerical groundwater model given the overall GENESIS scope and objectives. The WTs encompass identification of modeling requirements; coupling various processes to groundwater models; identification of simulation models for case scenarios; model development, validation and uncertainty assessment; scenario selection and definition of relevant boundary conditions; development of sub-models for GDE interaction; simulation of impacts of different scenarios on land-use and climate change.

Due to the diversity of GENESIS test sites and the investigated research questions the modeling requirements vary over a wide range. Coupling between several components of the hydrologic cycle is discussed in general terms in D5.1 where the focus is on coupling techniques, suited models and integration platforms. In D5.2 conceptual models are presented on a broad basis including the discussion of the individual development steps and the refinement process. Based on the conceptual model developed for each study site an appropriate simulation method including codes for flow and transport is evaluated and groundwater flow and transport models are set up and validated at each study site. In D5.3 modeling guidelines have been developed encompassing the discussion of the land use and climate change projections and how the related uncertainties influence modeling the impact on groundwater systems. Finally, in D5.4 the complete specific model chain related to modeling the impact of measures and scenarios on groundwater quantity and quality applied at the respective test sites is being described with particular emphasis on calibration and validation procedures and uncertainty assessment. The findings of the case studies are synthesized and generalized to derive a clearer understanding of what kind of conclusions can be expected from such modeling work.

Research highlights covered in WP5 embrace a wide area of varying topics. Among these modeling the interaction between crop growth and groundwater flow processes represents a dominating research field. This broad topic has been coped with in the context of model coupling, integrated regional hydrologic simulations of groundwater quantity and quality under climate scenarios, change of nitrogen budgets with increasing CO_2 concentrations and mitigation options of pesticides considering different crop rotations and irrigation techniques. The last two subjects nicely show the interconnectedness between work in WP3 and WP5.

Further research highlights in WP5 include the combination of climate and land use changes with a hydro-economic framework (integration with WP6) for optimal management of groundwater nitrate pollution from agriculture and the comparison of uncertainty related to multiple conceptual models to the uncertainty related to different climate change projections. With respect to GDEs the influence of ecohydrologic feedbacks has been investigated and the effect of peatland drainage and restoration on esker groundwater resources has been studied by new methods. After all, a hydrological model of Europe has been built to assess the impact of climate change on the hydrology and water quality (including uncertainty assessment).

Progress beyond the state of the art and research highlights can be listed as follows:

- The importance of feedbacks in a crop-soil-aquifer system with shallow groundwater levels was investigated.
    - Integration of subdomains for unsaturated zone hydrology, groundwater and surface water flow resulted in a coupling scheme that preserves continuity of both hydraulic heads and water flows.
- The hydro-economic modelling framework integrates agronomic simulation, nitrate leaching and unsaturated and saturated groundwater flow and mass transport into a management framework (optimization model) that yields the fertilizer allocation that maximizes benefits in agriculture while meeting the environmental standards.
- Sequentially coupling of various hydrologic models was implemented to model climate and land use change impacts on groundwater flow and nitrate concentrations at different test sites.
    - The most powerful and versatile models representing the relevant subcomponents of the subsurface flow path can be combined.
    - Methods have been developed to account for uncertainties on groundwater state variables due to unknown land use and aquifer heterogeneities.
- Coupling of land-use and ecosystem processes to groundwater systems have been implemented by a stochastic approach.

WP6 dealt with various aspects of groundwater management. The EU WFD integrates economics into water management and policy making. Economics is to have a decisive role in the development of river basin management plans and the design of water pricing policies for efficient water use and cost recovery. The main objectives of WP6 are to develop 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 19 to 36) focused on the realization of the surveys and the statistical analysis of results (nonmarket valuation studies), development of production functions (micro-econometric approaches), and application of the hydro-economic modelling approach to Mancha Oriental, assessing tradeoffs between two alternative economic instruments for diffuse pollution control: fertilizer quotas and fertilizer prices. A Bayesian network model was developed to assess the impact of several policies for integrated management with different objectives under uncertainty. Deliverable 6.2 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. The Multi Attribute Value Theory was also applied to assess stakeholders preferences, identifying potential conflicts and common ground, and find policy solutions that will be socially and economically acceptable whilst meeting new ecological standards. In the third reporting period (months 37 to 48), the work focused on an in-depth analysis of results and their policy implications, as well as the analysis of the different methodologies and their value for the assessment of economic and legal/institutional implications of groundwater management (D6.3). The last reporting period (months 49 to 60) has focused on the development of D6.4, with a framework for the application of valuation techniques to assess the benefits of groundwater quality improvement, including and original database of existing applications of environmental valuation studies to value groundwater have been also developed and made public through the project webpage. And deliverable 6.5 includes a synthesis and policy-relevant conclusions and recommendations from the project.

Research highlights covered in WP6 embrace a wide area of issues related to groundwater management, economics and legal and institutional conditions. 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. The EU GENESIS project has contribute to this with the development, test and analyze of different economic or hydro-economic methods and tools for analyzing and selecting sustainable cost-efficient measures and management strategies to achieve a good quantitative and chemical groundwater status. For that purpose, six case studies across Europe were selected, which differ in 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 hydro-economic modelling framework integrates agronomic simulation, nitrate leaching and unsaturated and saturated groundwater flow and mass transport into a management framework (optimization model) that yields the fertilizer allocation that maximizes benefits in agriculture while meeting the environmental standards. 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 conducted for three cases. Finally, multicriteria studies (MAVT technique) were also applied to three selected cases in order to assess stakeholder preferences and identify potential conflicts as well as common grounds.

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.

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).

The project has also review past development of the policy framework and theoretical concepts of sustainable use of groundwater and related ecosystem services, and presents practical examples to identify key knowledge gaps and to demonstrate problems in groundwater resource management. Recommendations are given for integrated groundwater management that takes better account of uncertainty, sustainable use and ecosystem services of GDEs (Klove et al., 2011).

Some relevant conclusions related to economic and hydroeconomic approaches are (D6.5):

- Groundwater is generally undervalued and underpriced, which leads in many cases to poor management practices that cause aquifer depletion and pollution. Quantifying its value is critical for determining what measures are appropriate for its remediation and improvement in status.
- Hydroeconomic models, by integrating natural and socio-economic systems into a comprehensive analysis framework, can yield results that are more relevant for policy making than traditional groundwater management models.
- There is no a single standard approach to deal with groundwater economic and management issues, but each case will require individual approaches tailored to the availability of data and market prices; the scope of the study and the policy questions being addressed; the physical setting; the economic drivers; the legal and institutional framework; and the amount of time, resources and expertise available for the study.
- The different methods provide complementary information: while the hydro-economic model suggests optimal groundwater management policies and potential impacts, the economic valuation techniques allow assessment of the benefits of improving the status of the groundwater system.
- Political instability can affect stakeholder willingness to pay for measures affecting water resources and their valuation of groundwater

Some relevant conclusions related to the inference of stakeholder preferences (public participation) are (D6.5):

- Use of Multi-attribute value theory can be a useful approach for eliciting stakeholder preferences to certain water resource management alternatives and pinpointing possible conflicts between them. Case study applications propagated negotiation and compromise, and also helped bridge the gap between scientific research and acceptable solutions.
- Selecting optimum alternatives across disparate groups of stakeholders is difficult. Because application of MAVT encourages stakeholders to identify their preferred solution individually, the scope for apparent conflict is high, despite the fact that ranking of the whole range of alternatives across varying groups is actually quite similar.
- Combinations of measures are likely to be more preferable rather than focusing on a single choice.
- Bayesian networks may be useful to assist stakeholders and decision makers in reaching agreement on the impacts of different policies on ecological and economic aspects of water use under uncertain conditions.

Some relevant conclusions related to the legal framework are (D6.5):

- Problems with implementation of the WFD/GWD are related both to quality of transposition and to institutional and technical infrastructure, and are similar across member states. Relevant factors that appear to apply across Member States include: the quality of monitoring networks, institutional fragmentation, and potentially the superimposition of WFD requirements on to existing water and land use management frameworks.
- Control of diffuse pollution and incorporation of ecological quality standards in water use management is proving to be difficult.
- There are questions regarding the general level of awareness of the EU legal context for environmental management. Diffuse pollution control and protection/improvement of ecological quality are generally poor. Especially critical in the north given important role of land use management as an adaptation measure in response to climate change.
- Legal case study evidence suggested that problems with transposition may be greater where WFD approach is overlaid on existing legal frameworks rather than where root/branch reform is undertaken.
- Approaches to management of diffuse pollution must take account of monitoring and enforcement capacity, but binding standards and improvement to monitoring networks should be strongly considered.

The work in **WP7 focuses on integration and dissemination** of research activities. This is explained in the next section below.

4.1.4 Potential impact and main dissemination activities and exploitation results

GENESIS project had impact to groundwater science and engineering, management practice, policy and on groundwater knowledge in the society.

Summaries of different work and final outputs related to groundwater flowpaths characterization, leaching, GDEs, and management can be found in final deliverables (D2.3, D3.4, D4.5, D6.5). The report D7.8 work as a summary report of the project with focus on groundwater vulnerability.

The dissemination is dealt with in separate sub-chapter.

Impact to policy during the project (compared to DoW)

A key objective of GENESIS was to provide a scientific basis for update of the GWD. A dialog was established with WG C by appointing members to the GENESIS advisory board. This pointed to 2 main issues relevant for policy on short and medium term, which were II) revision of list of substances in Annex II and II) on a bit longer term a methodology to test if groundwater quality of quantity has a significant impact on GDEs (provide scientific basis to evaluate decision trees prepared by WG C). In the first part of the project (2009-2011) GENESIS:

- provided guidance on technical issues related to pressures and impacts in groundwater bodies and groundwater dependent ecosystems. The needs of WGC and Common Implementation Strategy (CIS) and procedures for groundwater systems was reviewed and the potential uncertain issues in CIS was discussed. The research output was targeted to ensure that the required uncertain issues mentioned in the Groundwater Directive and the CIS guidelines was covered. This was especially done by making reviews that dealt about urgent policy related issues (pollution, GDEs). This output is seen in D3.1 and D4.1 and in papers:

  Balderacchi, M., Benoit, P.; Cambier, P.; Eklo, O.M.; Gargini, A.; Gemitzi, A.; Gurel, M.; Kløve, B.; Nakic, Z.; Preda, E.; Ruzicic, S.; Wachniew, P.; Trevisan, M. 2013. Groundwater pollution and quality monitoring approaches at the European level. *Critcal Reviews of Environmental Science and Technology* 43:323-408.

  Kløve B., Ala-aho P., Bertrand G., Boukalova Z., Ertürk A., Goldscheider N., Ilmonen J., Karakaya N., Kupfersberger H., Kværner J., Lundberg A., Mileusnić M., Moszczynska A., Muotka T., Preda E., Rossi P., Siergieiev D., Šimek J., Wachniew P., Widerlund A. 2011. Groundwater Dependent Ecosystems: Part I - Hydroecology, threats and status of ecosystems. *Environmental Science and Policy* 14, 770 – 781.

  Kløve B., Ala-aho P., Allan A., Bertrand G., Druzynska E., Ertürk A., Goldscheider N., Henry S., Karakaya N., Karjalainen T.P. ,Koundouri P., Kværner J., Lundberg A.., Muotka T., Preda E., Pulido Velázquez M., Schipper P. 2011. Groundwater Dependent Ecosystems: Part II - Ecosystem services and management under risk of climate Change and Land-Use Management. *Environmental Science and Policy* 14, 782-793.

- worked on characterization of GDEs and the development of conceptual models of the cases study systems based on partners diverse knowledge in hydrogeology, ecology, pollutant biogeochemical processes, and socio-economic tools.
- Provided more knowledge on groundwater and ecosystems understanding. In particular more information on groundwater hydrology, ecosystems, modelling and management.

This is seen in e.g. deliverable D2.3, D4.5 and the paper:

Kløve, B. Ala-Aho, P. Bertrand, G. Gurdak, J. J. Kupfersberger, H. Kvœrner, J. Muotka, T. Mykrä, H. Preda, E. Rossi, P. Bertacchi Uvo, C. Velasco, E. Wachniew, P. Pulido-Velázquez, M. 2014. Climate Change Impacts on Groundwater and Dependent Ecosystems. *Journal of Hydrology* (accepted).
Kløve, B. Balderacchi, M. Gemitzi, A. Hendry, S. Kværner, J. Muotka, T. Preda, E. 2014. Protection of groundwater dependent ecosystems: Current policies and future management options. *Water Policy* (accepted)

During the project GENESIS replied to the medium and long term impacts (as set in the DoW) by:

- Rewiewing methodology described in CIS guidance on groundwater chemical status and threshold values for identifying threshold values.
- Increasing conceptual understanding of the aquifer systems, processes and particularly interactions of groundwater with ecosystems.
- Worked on methods to assess signigicant impact in ecosystems (principles, indicators).
- Set up modes and compared models that can be used to study issued relevant for GWD such as reversal of trends change in land use practice.
- Providing a model of integrated and multidisciplinary approach to assess complex interactions between surface and groundwater and GDEs.
- Development of integrated modelling tools assessing also the uncertainty involved.
- Development and testing of methods used in management (social, economy, legal).

The output of these topics is found in many deliverables.

Long term input to policy and groundwater management

The overall policy input of GENSIS can be found in D6.5 From the set objectives many general inputs can be defined:

- GENESIS increased the scientific basis for the assessment of i) groundwater flowpaths, ii) biogeochemical processes, iii) methods to observe and reduce pollution, iv) ecosystem interactions, and v) integrated management. This sets the basis for future and better groundwater management to prevent deterioration of groundwater resources.
- GENESIS compared different leaching models and numerical modelling methods. This provides better solutions to identify groundwater pollution changes in time and space and provides criteria for assessment of status. GENSIS showed weaknesses and strength in such modelling. Thus, GENESIS provides better tools to assess the scientific basis on how to assess points for trend reversal (as in Article 1 point b, see Fig. 8).
- GENESIS worked on assessment of methods to determine if groundwater quality or quantity changes cause significant damage to GDEs. Methods to assess these damages were presented from a scientific viewpoint.
- GENESIS develops, as mentioned in Article 4 Procedures to assessing GW chemical status, tools that cantn be used to assess good chemical status of groundwater bodies (point 2). GENESIS provides information on best monitoring practice to detect changes in groundwater (point 3). GENESIS defines measures needed to protect ecosystems (Point 5-see Fig. 9 for details).
- GENESIS provided results on land-use histories, climate change, and its impact on water quantity and quality (pollution). The review of impacts and threats gave the background on

why the groundwater systems have changed. This directly and facilitate the required reporting for the river basin plans as in Article 5 Identification of significant an sustained upward trends and the definition of starting points for trend reversal. Moreover, the work on setting criteria for risk management areas in Fig. 9 improves the methodology for setting criteria to control point pollution (Article 5, point 5).

- GENESIS provides knowledge on how diffuse pollution can be reduced by sustainable and realistic Best Environmental Management practices (Article 6, point 1b and point 2). The knowledge on pesticide, nitrate and pollutant degradation results in better conceptual and mathematical simulation models and tools to assess the impact of measures and the risk of pollution taking into account degradation. This replies to needs of Article 6 Measures to prevent or limit inputs of pollutants into groundwater. The project has illustrated how different management strategies for controlling groundwater diffuse pollution can be simulated and compared in terms of cost and effectiveness using integrated models (e.g. fertilizer quotas vs. fertilizer taxes for controlling groundwater nitrate pollution),

Impact on the use of numerical models in groundwater management

The benchmark of Nitrate Leaching models was carried out using Wagna lysimeter data-set (Austria). Six leaching models, frequently used among European researchers were tested (ARMOSA, COUP, DAISY, EPIC, SIMWASER/STOTRASIM, SWAP/ANIMO). Within the performance assessment a blind test, a calibration and a validation phase was completed for a low input agriculture system where different catch crops were part of the crop rotation. All models were able to identify years and crops with high and low leaching rates. However, none of the models performed well for all of the statistical metrics computed. This may be due to the combined effects of the model structures and the lack of knowledge to describe relevant processes by appropriate sets of parameters. It was concluded that to maximize the predictive power of the models measures of water content and water and nitrate fluxes have to be included in the objective function of the model calibration. With respect to assessment of future climate and land use changes the process oriented dynamic models evaluated are useful for hypothesis testing.

The pesticide fate models PEARL, PRZM and MACRO are recommended by FOCUS (Forum for International Co-ordination of pesticide fate models and their Use) to evaluate potential movement to groundwater in the EU registration process. The models are often used to describe pesticide fate at field, regional and country scales and can be used for reporting chemical status according to the Water Framework Directive and the Ground Water Directive. Through FOCUS, the EU has developed model scenarios for some of the pedo-climatic conditions prevailing in Europe, but these do not cover Nordic conditions with winter frost and snowmelt on frozen ground. The performance and ability of the models MACRO, PEARL and PRZM to describe leaching of pesticides under cold climate conditions were examined in a benchmark study using a data set from the Grue site in Norway. Soil temperatures and soil water dynamics were successfully simulated except in winter and early spring The models were not able to simulate leaching of metribuzin well,. Poor performance of the models in Nordic climate could be explained by insufficient model routines for freezing and thawing conditions. Further development of the FOCUS models is necessary to obtain a good description of the fate and leaching of pesticides to groundwater in cold and temperate climate with snow frost where recharge is dominated by infiltration of water from melted snow.

Modelling at case study sites – lessons learnt

Different models were tested at partner case study sites (D5.4). The approaches used varied among study sites. Based on modelling work done, the following lessons were learnt:

- Sequential coupled models are a powerful and flexible approach to combine surface and groundwater processes while keeping the simulation details offered by each model. It is especially recommended when some processes are required to be modelled in detail, such as nitrate leaching, mass transport or specific soil phenomena (e.g. frost, thawing).
- Sequential coupled models are highly needed tools to assess future impacts of anthropogenic and climate-related pressures, and support management decisions based on the expected impacts and simulated effects of potential adaptation measures.
- The main driving force on global change depends on the region: in Mediterranean areas climate change appears as the main stressing factor whereas in alpine and northern areas land use change influence seems to be higher.
- Since land use change can be well controlled current land management adaptation strategies should be validated updated if needed with new generation climate change projections.
- Also modelling was done on European scale (as promised in DoW)
- Models integrating physical processes, institutional constraints and economics (the so called hydroeconomic models) are useful for testing impacts of potential management decisions for improving groundwater status

Different indicators suitable for GDEs tested

The different indicators were tested and developed in GENESIS (D4.3) that will have an impact on future ecosystems assessment. These indicators range from ecological, hydrologic and to simple pressure indicators. The results show that:

- Tracers are indispensable for detecting flow paths in aquifers and assessing relationships between groundwater and dependent ecosystems: identifying the occurrences of groundwater in the ecosystems, quantification of groundwater contribution to water budgets, reliance of the ecosystem on groundwater. Tracers help to evaluate vulnerability of GDEs to pressures on groundwater by: identification of connections between GDEs and source areas of (potential or actual) contamination, quantification of time lags in propagation of impacts of pressures to GDEs (WP2)
- Biological indicators were used at sites in Finland, Italy and Turkey. The use of these indicators in GDEs is fairly new and the work present first attempts on the use of such indicators (WP4).
- Hydrological indicators were tested and developed for river flow data to show impacts of e.g. Irrigation, river regulation and climate change.
- An indicator matrix was developed in D4.3 to simply test impacts of groundwater management on GDEs

Groundwater Management – the way foreward

Within studies on social, economic and legal aspects (WP6) the following key points result:

- Groundwater is generally undervalued and underpriced, which leads in many cases to poor management practices that cause aquifer depletion and pollution. Quantifying its value is critical for determining what measures are appropriate for its remediation and improvement in status.
- Hydroeconomic models, by integrating natural and socio-economic systems into a comprehensive analysis framework, can yield results that are more relevant for policy making than traditional groundwater management models.

- There is no a single standard approach to deal with groundwater economic and management issues, but each case will require individual approaches tailored to the availability of data and market prices; the scope of the study and the policy questions being addressed; the physical setting; the economic drivers; the legal and institutional framework; and the amount of time, resources and expertise available for the study.
- The different methods provide complementary information: while the hydro-economic model suggests optimal groundwater management policies and potential impacts, the economic valuation techniques allow assessment of the benefits of improving the status of the groundwater system.
- Political instability can affect stakeholder willingness to pay for measures affecting water resources and their valuation of groundwater
- Use of Multi-attribute value theory can be a useful approach for eliciting stakeholder preferences to certain water resource management alternatives and pinpointing possible conflicts between them. Case study applications propagated negotiation and compromise, and also helped bridge the gap between scientific research and acceptable solutions.
- Selecting optimum alternatives across disparate groups of stakeholders is difficult. Because application of MAVT encourages stakeholders to identify their preferred solution individually, the scope for apparent conflict is high, despite the fact that ranking of the whole range of alternatives across varying groups is actually quite similar.
- Combinations of measures are likely to be more preferable rather than focusing on a single choice.
- Bayesian networks may be useful to assist stakeholders and decision makers in reaching agreement on the impacts of different policies on ecological and economic aspects of water use under uncertain conditions.
- Problems with implementation of the WFD/GWD are related both to quality of transposition and to institutional and technical infrastructure, and are similar across member states. Relevant factors that appear to apply across Member States include: the quality of monitoring networks, institutional fragmentation, and potentially the superimposition of WFD requirements on to existing water and land use management frameworks.
- Control of diffuse pollution and incorporation of ecological quality standards in water use management is proving to be difficult.
- There are questions regarding the general level of awareness of the EU legal context for environmental management. Diffuse pollution control and protection/improvement of ecological quality are generally poor. Especially critical in the north given important role of land use management as an adaptation measure in response to climate change.
- Legal case study evidence suggested that problems with transposition may be greater where WFD approach is overlaid on existing legal frameworks rather than where root/branch reform is undertaken
- Approaches to management of diffuse pollution must take account of monitoring and enforcement capacity, but binding standards and improvement to monitoring networks should be strongly considered

Dissemination

The project integrated past and new result to provide input required for Ground Water Directive and new tools for better integrated groundwater management. The outcomes produced can be classified as shown in Fig. 3 below.

Dissemination activities included active participation in conferences with special sessions related to GENESIS work (IAH, IWA, Nordic Water, Hydroeco, EGU etc.). A training workshop on tracers were held in 2010 in Munich (D2.1). A final conference and course was held in March 2014 in Prague (see separate deliverable on this).

Research results have been published in scientific papers by individual partners and collaboration between partners in various WPs. Several papers integrating results across work packages have been developed and published in journals with high impact. The journal publications are presented in separate section of the final report.

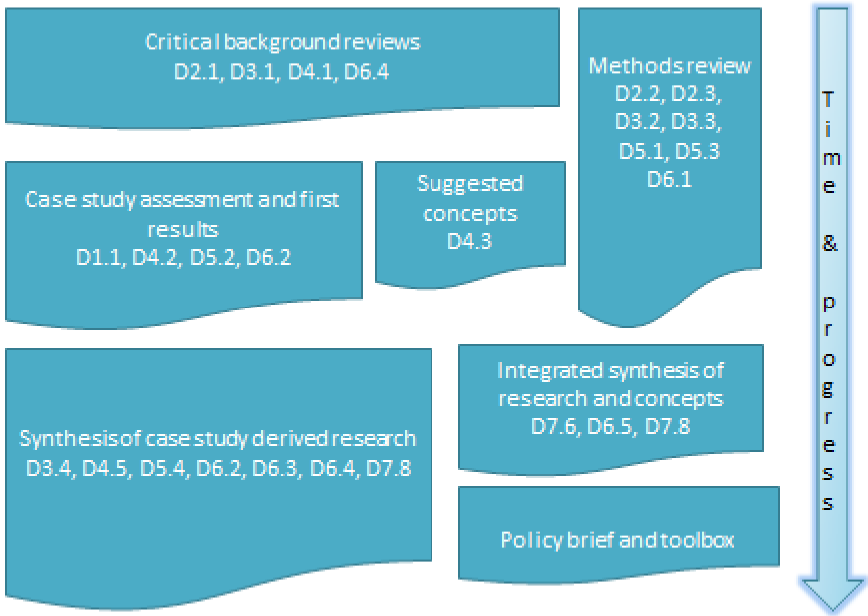

Fig. 3 Presentation of GENESIS project outcomes, methods and tools in project deliverables.

The **key deliverables** (and related review papers) relevant for this report are and referred to later in different sections are:
D2.2: Guidelines on flowpath characterization, dynamics and GW renewal
D2.3: Critical review of methods for assessment of vulnerability of groundwater systems
D3.1: Pollutant input, leaching and background (see also Balderacchi et al. 2013)
D3.2: Assessment methods to detect pollutant leaching to groundwater
D3.3: Report on sustainable measures to protect groundwater bodies
D3.4: Final report on pollutant and leaching to groundwater
D4.1: Baseline study on GDE ecohydrology (see also Kløve et al. 2011 a and b)
D4.2: Groundwater surface water interaction in GDE
D4.3: New indicators for assessing GDE vulnerability
D4.4: Report on GDE protection (see also Kløve et al. 2014a)
D4.5: Land-use and climate change effects on GDE (see also Kløve et al. 2014b)
D5.2: Conceptual models and first simulations
D5.3: Modelling protocol for land-use and climate change effects

D5.4: Impacts of measures and scenarios on groundwater quantity and quality
D6.1: General hydro-economic modelling blueprint
D6.2: Management and policy analysis for each case study
D6.3: Legal and institutional analysis, public participation and stakeholders involvement
D6.4: Application of valuation techniques to assess the benefits of groundwater quantity-quality improvement
D6.5: Synthesis and policy recommendations

Dissemination to WFD Common Implementation Strategy – Work Group C

The input needed by GWD was clarified by the commission set work group (WG) C of the WFD common implementation strategy. This group works toward developing of the GWD and is set up by members from each EC and EEA countries and include also several stakeholders.

The discussion with WGC continued throughout the project. GENESIS participated at each meeting held approximately every 6 months. At these meetings GENESIS was presented and relevant issues discussed. The topics of interest to be presented was decided by WG C and our advisory board (some WG C members).

In the first part of the project the focus was on substances and the need for update Annex II of the directive. The GENESIS experts presented their views on this topic in the WGC meeting in Budapest 2011. The outcome of GENESIS was presented on all WGC meeting and the feedback processes continued in GENESIS partner meetings to further discuss and develop solutions to relevant issues such as update Annex II and impacts on GDEs.

The results were disseminated to end-users in many events which are listed in the partner specific annexes 4th periodic report. This includes TV interviews, newsletters, articles in local language, seminars, end user oriented events etc. A systematic approach was used to disseminate results to end-users and stakeholders in WP6 through participatory processes.

A GENESIS-Toolbox has been made to demonstrate the results and where different deliverables can be found (see www.thegenesisproject.eu). Research outcomes have been published as policy briefs to facilitate uptake. A training course has been planned related to facilitate main project outcomes. The course will focus on groundwater and ecosystems providing an integrated approach to groundwater resources management. Special issues are made for journals HESS - *Hydrology of earth System Sciences* and STOTEN – *The Science of the Total Environment*.

STOTEN special issue:

Title for the special issue: From the assessment of the of pollutant input into groundwater systems to the measures for protecting them, via the assessment of the effect of climate and land-use change

Special Issue Editors:
Prof Marco Trevisan, Università Cattolica del Sacro Cuore, Italy
Prof. Bjørn Kløve, University of Oulu, Finland and Bioforsk, Norway
Dr. Piet Groenendijk, Alterra Wageningen UR; The Netherlands
Dr Pierre Benoit, UMR INRA AgroParisTech, France
Matteo Balderacchi, Università Cattolica del Sacro Cuore, Italy

Start date & end date of submission: December 2013 and March 2014

Scope of the special issue: Aquifers are facing severe pressure from water extraction and irrigation. In many regions groundwater tables have declined considerably and aquifers have become polluted by various pollutants such as nitrates. The changes observed in groundwater quantity and quality are a threat (i) to the crucial ecosystems services groundwater provides such as drinking and irrigation water provision, natural attenuation processes, storage functions and habitats, as well as (ii) to groundwater dependent ecosystems such as springs, rivers, wetlands, and lakes.

In order to provide sustainable solutions new methods are needed in groundwater management where groundwater systems are seen in a more holistic and integrated way. The Impact-response ecosystem service models are a model class useful to show potential known or predicted changes, among those the European Commission adopted the DPSIR framework that defines the Drivers that by Pressures affect the water Status causing Impacts and Reponses. However the full application of the DPSIR requires the development of different conceptual models. The one related to biogeochemistry requires the identification of the the sources and pathways of contamination and the biogeochemical processes that have influence on the transfer of the contaminants from the soil to the groundwater.

Once the conceptual model is well developed is possible to use software tools for assess the leaching at different scales and it is possible to apply the impact response model assessing the impact of future scenarios considering climatic and land-use changes.

The special issue call asked to investigate on the assessment of the of pollutant input into groundwater systems and on the measures for protecting groundwaters, considering also the assessment of the effect of climate and land-use change. Case study and reviews are reported. The substances that are stated in the issue are trace metal, salt, nutrient, pesticide and organic waste water contaminants.

Status of SI: Fifteen manuscripts have been sent to the journal for evaluation; one of those was from a scientist out of the GENESIS project. The finishing of the review process is expected at the end of June.

HESS special issue:

Title for the special issue: Groundwater resources and their ecosystem services: new methods and management practices

Special Issue Editors:
Prof. Bjørn Kløve, University of Oulu, Finland and Bioforsk, Norway
Dr. Christine Stumpp, Helmholtz Zentrum München, Germany
Dr. Prezmislaw Wachniew, AGH University of Science and Technology, Poland
Dr. Hans Kupfersberger, Joanneum Research Forschungsgesellschaft mbH, Austria
Ass. prof. Manuel Pulido-Velazques, Universidad politecnica de València, Spain
Dr. Andrew Allan, University of Dundee, United Kingdom
Prof. Jesus Carrera, IDAEA, CSIC, Geosciences, Barcelona, Spain

Start date & end date of submission: October 2013 and May 2014

Scope of the special issue: Aquifers are facing severe pressure from water extraction and irrigation. In many regions groundwater tables have declined considerably and aquifers have become polluted by various pollutants such as nitrates. The changes observed in groundwater quantity and quality are a threat (i) to the crucial ecosystems services groundwater provides such as drinking and irrigation water provision, natural attenuation processes, storage functions and habitats, as well as (ii) to groundwater dependent ecosystems such as springs, rivers, wetlands, and lakes.

In order to provide sustainable solutions new methods are needed in groundwater management where groundwater systems are seen in a more holistic and integrated way. A new way of management is needed where groundwater hydrogeology is better integrated with hydrology and ecology. Sustainable solutions are needed that take into account socio-economic values and ecological aspects of groundwater and dependent ecosystems. In many cases management will also include new methods and principles for policy, legal and institutional aspects.

The special issue welcomes scientific papers and critical reviews on groundwater systems and their management. This includes contributions on how hydrological measurements can be linked with environmental tracer methods and numerical modeling to provide management solutions for a more integrated understanding of groundwater systems and groundwater dependent ecosystems. Further, papers are welcome addressing new hydrological and ecological indicators for sustainable management of groundwater and dependent ecosystems. Submissions can also cover studies demonstrating how aquifers are connected to aquatic and terrestrial ecosystems, and how land use, water extraction or climate change affect groundwater and connected ecosystems. New methods to manage aquifers will be presented that take into account options for future land use as well as socio-economic and legal aspects; particularly in context of the implementation of the EU-Water Framework Directive and the Groundwater Directive. All contributions should provide knowledge on new methods or processes on how groundwater systems and their ecosystem services should be managed in the future.

Status of SI: About 12-15 manuscripts have been sent to the journal for evaluation. Of these about 7 have been rejected upfront and currently 7 are considered for review (in the process). Three are from non GENESIS members. We have requested an extension to the original deadline has been extended as about 4-5 more papers from GENESIS are expected. The finishing of the review process is expected at the end of August/September.