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Editor's Note

In cooperation with the Environmental Agency of the Republic of Slovenia (EARS), DG Enlargement of the European Commission organized in the year 2008, through its Technical Assistance Information Exchange Instrument (TAIEX), a Seminar on Groundwater Modelling – Water Framework Directive. The seminar held in Ljubljana, Slovenia, was through the efforts of local co-organizer, tailored to the needs of Slovenian groundwater professional community that led to the invitation of additional lecturers in the fields of importance for the country.

There was a large number of lectures of high scientific standard at the seminar, prompting an idea to group a core lectures into Symposium on Groundwater Flow and Transport Modelling. The authors were invited to submit papers that are published here as Proceedings of Invited Lectures. The proceedings reflect both Slovenian priorities and the availability of scientific papers. Also, the proceedings are balanced in such a way to include both the papers of foreign and Slovenian authors.

Since, all the lectures and submitted papers were in English, we have decided to publish the proceedings in this common language of the international scientific community. It is expected that the publication comprehensible to the wide readership will reach and be of use to both Slovenian scientists and the scientists abroad.

Zlatko Mikulič

Editor in Chief

Foreword

The mission of the Environmental Agency is to monitor, analyse and forecast natural phenomena and processes in the environment, as well as to reduce natural threats to people and property. Moreover, its mission of exceptional importance is to meet the requirements regarding environmental protection, deriving from the regulations in force, to preserve natural resources and the biotic diversity and to ensure sustainable development of the country. To this aim are the activities in the field of groundwater, being a part of national service for hydrology, of utmost importance. Groundwater in Slovenia is strategically important resource, since it is traditionally practically sole source for drinking water supply.

In the water sector, the agency has a significant role in the process of Water Framework Directive implementation. It is expected that groundwater modelling will contribute a great deal to the various tasks ranging from monitoring to water management. Regional as well as local groundwater models are a good tool in the process of establishing monitoring network, groundwater status assessment and water management plans. They have also a great potential in handling administrative procedures of water use licensing.

This publication is in line with the agency policy of striving for excellence, our continuously improving services and the leading role of our institution in promoting environmental issues. The published papers of foreign and Slovenian scientists will be useful source of reference both to the professionals in our agency and in other institutions dealing with groundwater.

It is my great pleasure to note that we have already established a good cooperation with the scientists publishing here, leading to the joint groundwater modelling project. This cooperation will shortly result in the first map of groundwater recharge for entire Slovenia and enable us to introduce annual groundwater balance assessments important for the implementation of EU and national water legislation, as well as in operational activities of our water management and environment protection services.

Dr. Silvo Žlebir

Director General
Environmental Agency of the Republic of Slovenia

Introduction

Groundwater is very important resource in Slovenia. More than 97 percent of all drinking water is abstracted from groundwater bodies. The major cities are supplied either from alluvial aquifers like Ljubljana and Maribor, or from karst springs like Nova Gorica and Koper.

Groundwater is important in regulating a flow regime of surface waters, since some of major rivers have source and headwaters either in the Alps or other areas with high yield karst springs.

Groundwater is regulating wetlands with important ecosystems like oak forest areas of Krakovski gozd and Murske šume. So, groundwater in Slovenia has all the important roles listed in the Water Framework Directive (WFD).

Flow of groundwater is governed by different physics laws from those in surface watercourses. Also, in case of pollution it follows different scenarios from surface waters. Groundwater has quite a high pollution attenuation capacity, but it has not to be overstretched and misused, since clean up is a lengthy and expensive process.

Recently, we have been facing new challenges regarding groundwater quantity due to the climate change. In this decade we have experienced for the first time a multiannual drought. This type of drought is not common in this part of Europe, where groundwater quantities are usually replenished within the seasons of the year.

In meeting WFD requirements in Slovenia it is not the groundwater quantity the major problem. Due to the bad chemical status, a few Groundwater Bodies (GWBs) are at risk of not reaching good status by 2015. These GWBs are in the alluvial aquifers with high population density and intensive agriculture production.

The major pollution problem now is very high nitrate content and sometimes pollution by pesticides. Usually, it has showed up that problems encountered in other high developed countries of this region are also present in Slovenia. So, as the issue of micro pollutants is taking prominence, it is very likely that it will become soon a problem to tackle in Slovenia as well.

As already mentioned, the groundwater quantity might become an important issue too in the future. The areas at risk are in Prekmurje region with the lowest precipitation amount, being the most sensitive to the climate change, in Štajersko region where the groundwater abstraction is nearing to half the available quantity, and at the Littoral where the local karst spring is already overstretched in the summer season.

Coupling together quantitative data and qualitative information in a predictive framework, groundwater flow and transport modelling can play an important role in the characterisation of each groundwater body. This modelling allows comprehensive testing of the more general conceptual models of the groundwater systems. Through this improved knowledge about the current state of the groundwater systems and about the possible future impacts to the environment, human activities may be directed to achieve sustainable development goals.

Modelling is an efficient tool to determine groundwater status and, water balance, to develop measures for groundwater protection, to investigate impact of human activities, and to suggest possible changes of groundwater regime based on scenario simulations.

The importance of groundwater flow and transport modelling for water management should be clearly recognized and incorporated into decision making.

It is to be expected that the groundwater modelling will be introduced in the future into everyday activities related to water management, being a common tool of civil servants involved in the process of environment protection.

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Groundwater quantitative status assessment in Slovenia

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Abstract: The framework for the integrated water management for the entire EU area has been set in the year 2000, when the European Parliament and Council passed the Directive 2000/60/EU[1], known as a Water Framework Directive (WFD). According to the directive, the evaluation of meeting the environmental objectives is based also upon the assessment of quantitative and chemical status of individual groundwater body. According to the WFD, assessment of quantitative status of groundwater bodies is based on the determination of the available groundwater quantity. This is defined as a long period mean annual renewable quantity of water in the groundwater body, reduced by the quantity of the long period annual groundwater discharge, which is required to meet ecological objectives concerning surface water bodies and to preserve the ecosystems, dependent on the groundwater bodies.

In the paper are presented methodological approach and the results of the first groundwater quantitative status assessment for 21 groundwater bodies in Slovenia. Available groundwater quantities in Slovenian groundwater bodies for the period 1990 to 2001 were assessed to be $1.43 \cdot 10^9$ m^3 / year, and 727.4 m^3 / capita / year, respectively. In the year 2002 abstracted groundwater of $0.23 \cdot 10^9$ m^3 / year was 15 percent of the available groundwater reserves in Slovenia. For all Slovenian groundwater bodies quantitative status was assessed as good.

Key words: groundwater, groundwater body, hydrological monitoring, groundwater quantitative status, Slovenia

INTRODUCTION

To achieve the environmental objectives of WFD in Slovenia and good quantitative and chemical status of the groundwater[2] 21 groundwater bodies have been delineated. In the process of delineating groundwater bodies were used the general hydrogeological criteria, the permeability characteristics of the shallow lithological units being the most important. Additional criteria applied were anthropogenic pressures, as well as the assessment of the groundwater dependent surface, aquatic and terrestrial ecosystems[3].

Groundwater bodies are a tool for water management aimed to meeting the objectives of the WFD. They had to include the aquifers that enable the abstraction of significant quantities of groundwater that is used for drinking water supply and/or enable an important flow of groundwater. In the national legislation the quantitative status of groundwater in the delineated groundwater body was defined by the level of the groundwater abstraction impact on the body. This has to be reflected as a change in the piezometric level, groundwater discharge and the flow direction[4].

METHOD FOR THE GROUNDWATER QUANTITATIVE STATUS ASSESSMENT

Two methods were selected for the assessment of the quantitative status of groundwater, the selection criteria being type of porosity and availability of hydrological data for assessment period[5]. For sixteen groundwater bodies with prevailing aquifers with karst and fractured porosity was carried out an analysis of the impact of significant pressures on the quantitative status. Analysis was based on the baseflow method used to determine renewable quantities of groundwater. For five groundwater bodies with prevailing aquifers with intergranular porosity analysis was based on determining the critical groundwater levels and assessments of the trends. All the data for the 1990-2001 analysis period were retrieved from data bank of the national hydrological monitoring service of The Environmental Agency of the Republic of Slovenia[6].

Figure 1: Groundwater bodies in Slovenia according to the prevailing porosity of the aquifers. Groundwater bodies with aquifers with prevailing intergranular porosity are shaded. Non shaded are groundwater bodies with aquifers with prevailing karst, fracture and mixed porosity[3]

Critical Groundwater Level Method

The method for assessing the groundwater quantitative status in bodies with aquifers with prevailing intergranular porosity is based on the groundwater level statistics of multi-annual data sets. Groundwater level statistics was used to determine available groundwater quantity and to assess statistical significance of groundwater level trends.

The available groundwater quantity was determined as the difference between the average groundwater level (MGW) and the critical groundwater level (NGW_{3M}) in the analysis period of 1990-2001 (Figure 2). Average groundwater level MGW was the average of the annual mean groundwater levels. Critical groundwater level NGW_{3M} was the mean of the low water levels. To ensure representativeness, critical groundwater level was calculated as the mean of the low groundwater levels in a three-month period, covering 45 days before and 45 days after the critical day, when the water levels at the monitoring sites of the groundwater body were the lowest in the analysis period[7].

For groundwater level trends a regression line was calculated from the mean annual groundwater levels for the analysis period, and it was extrapolated for the forecast period. The mean groundwater level for the forecast period was determined from extrapolated trend line values ($MGW_{forecasted}$). Change in the available groundwater quantity was determined as difference between the mean groundwater level of the analysis period MGW and the forecast period $MGW_{forecasted}$.

The reliability of the linear trend line was statistically assessed by the Spearman's rank correlation coefficient and by the Student statistical test with significance level of 95 percent[8]. The statistical indicators were used to classify groundwater bodies into following classes:

- Increasing trend line ($R > 0$) with high statistical significance ($p < 0.05$), meaning an increase in the groundwater level,
- Increasing trend line ($R > 0$) with medium statistical significance ($0.06 < p < 0.50$), meaning a probable increase in the groundwater level,
- Increasing or decreasing trend line ($-1 < R < 1$) with low statistical significance ($0.50 < p$), meaning that there was no trend and changes in the groundwater level cannot be forecasted,
- Decreasing trend line ($R < 0$) and medium statistical significance ($0.06 < p$

< 0.50), meaning a probable decrease in the groundwater level,

- Decreasing trend line ($R < 0$) and high statistical significance ($p < 0.05$), meaning a decrease in the groundwater level.

The effect of the important pressures on the quantitative status of the groundwater body is defined as the change in the available groundwater quantity. Groundwater abstraction is not posing a risk to groundwater body if there is an increasing trend of groundwater levels for more than 75 percent of the monitoring sites. In this case groundwater body is in quantitative balance.

If there is decreasing trend at more than 25 percent of monitoring sites, further examination is necessary. By calculating regression line it is assessed whether the groundwater level in forecast period will decrease below the critical groundwater level (Figure 2). A good groundwater quantitative status is achieved when the critical groundwater level is not reached at more than 25 percent of monitoring sites in groundwater body. There is a risk that the good groundwater quantitative status will not be achieved when the forecasted mean groundwater level is lower than the critical mean low groundwater level (NGW_{3M}) at more than 25 percent of the monitoring sites.

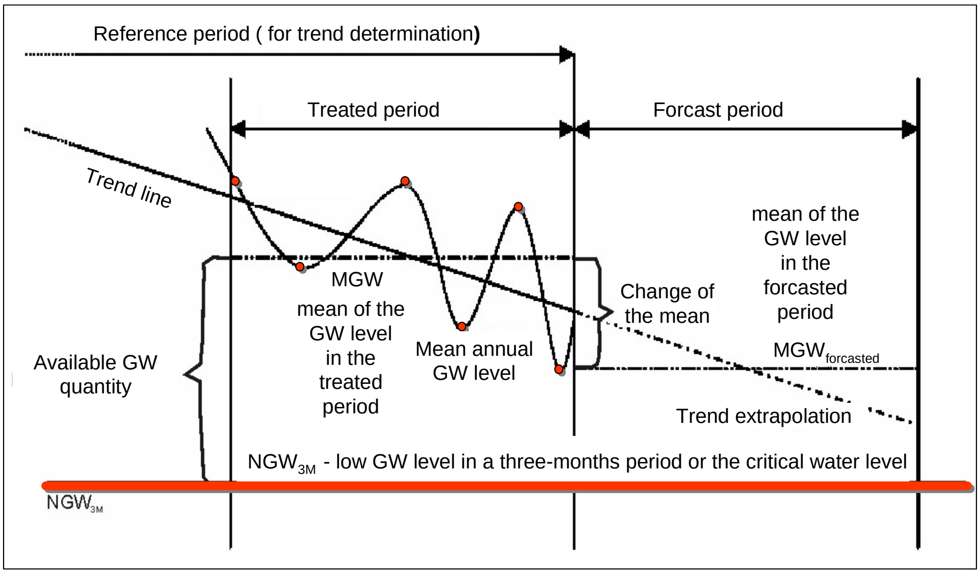

Figure 2: Calculation scheme of the available groundwater quantity for groundwater bodies with aquifers with prevailing intergranular porosity

Modified Wundt Method

The method of assessing the quantitative status in groundwater body with prevailing aquifers of karst or fracture porosity is based on the surface water baseflow analysis of discharge time series at gauging cross-section draining the groundwater body and on the assessments of the water balance catchment areas[9]. The Wundt method is based on defining the low flow at the gauging cross-section. The available groundwater quantity can be calculated from modified Wundt method[5].

When calculating the available quantities of groundwater, it was assumed that the quantity of surface waters recharged from groundwater bodies should not be affected. For this assessment, an assumption was adopted that this value is equal to one half of the difference between the mean and the minimum renewable quantity of groundwater.

The mean renewable groundwater quantity (marked in Figure 4 with a broken line) is the mean of the long-term monthly minima of the analysis period. The minimum renewable groundwater quantity is the lowest annual average of the monthly minima. The available groundwater quantity (marked with a D in Figure 4) is:

D = 0.5 * (the mean renewable groundwater quantity - the minimum renewable groundwater quantity)

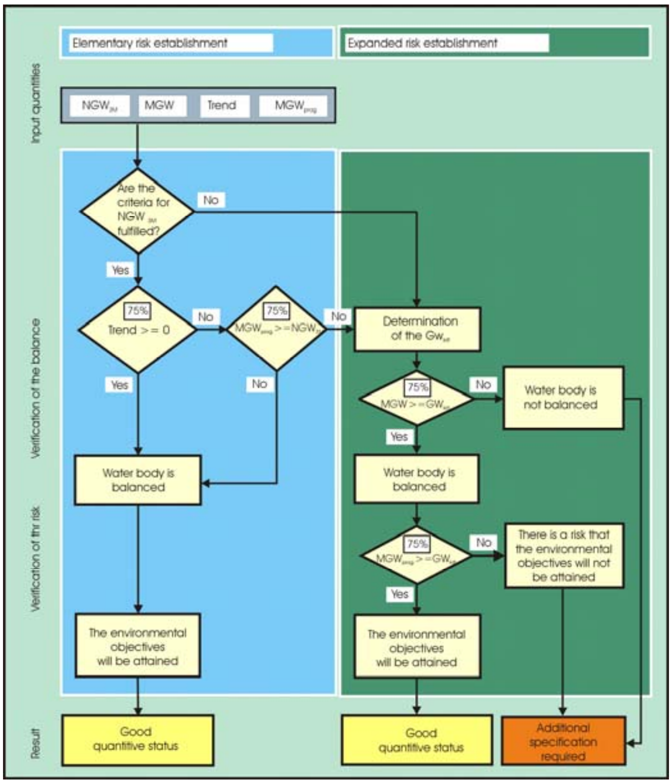

Figure 3: Verifying the balance and risk of not achieving good groundwater quantitative status for groundwater bodies with aquifers with prevailing intergranular porosity

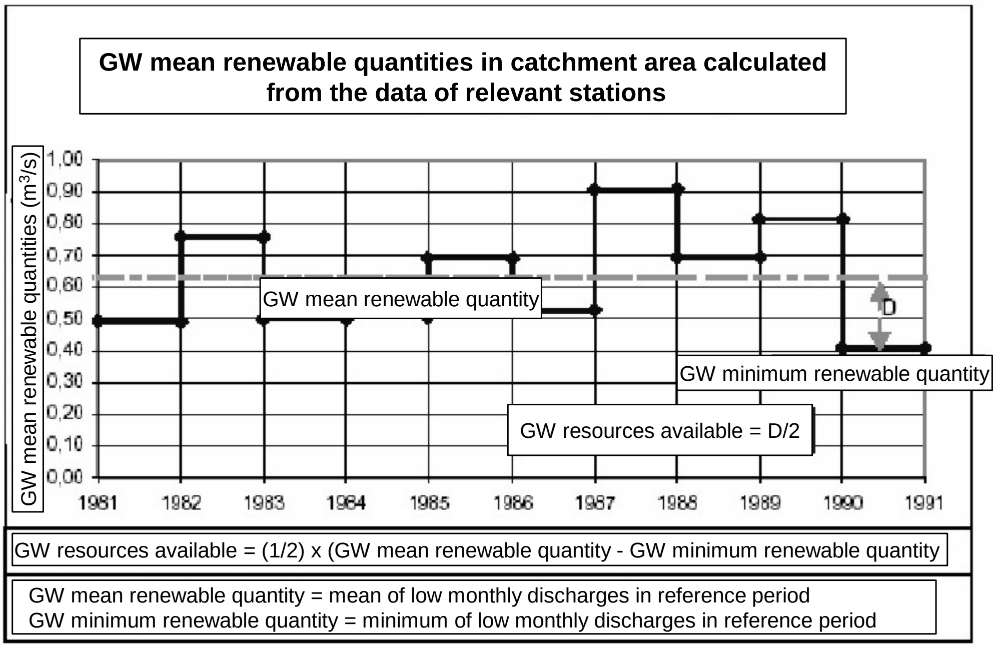

Figure 4: Calculation scheme of the available groundwater quantity for groundwater bodies with prevailing aquifers with karst and fracture porosity

The impact of pressures on groundwater quantitative status in groundwater body is calculated by subtracting abstracted groundwater from available groundwater quantity. A good quantitative status in the groundwater body with prevailing aquifers with karst and fracture porosity is achieved when the abstractions and available groundwater are in balance. There is at risk of not achieving good quantitative status when the sum of all the abstractions is greater than 75 percent of the available groundwater quantity.

The adapted Wundt method was first tested and verified at groundwater body Kraška Ljubljanica[10]. Following this verification of the method it was used for the remaining fifteen groundwater bodies. The assessment was carried out by analysing daily discharge time series of 61 representative gauging cross-sections in selected catchment areas for the period from 1990 to 2001.

RESULTS OF GROUNDWATER QUANTITATIVE STATUS ASSESSMENT

The groundwater quantitative status of groundwater bodies with aquifers with prevailing intergranular porosity

The groundwater quantitative status assessment was carried out for five groundwater bodies with aquifers with prevailing intergranular porosity (Figure 1) by analysing time series from 91 representative monitoring sites in the national hydrological monitoring network[6]. The analysis of groundwater level trend and the risk of not achieving good groundwater quantitative status were carried out for each monitoring site and the results were combined for the entire groundwater body. The results of the statistical analysis of the Spearman's rank correlation coefficients enabled the determination of the character and statistical significance of the trends (Table 1).

The ratio between the number of monitoring sites with decreasing trends and decreasing trends with low statistical significance, and total number of monitoring sites of groundwater body is an important indicator of the groundwater quantity risk. The share of decreasing trends was the lowest in the Murska kotlina (9.52%) and the highest in the Savska kotlina in Ljubljansko Barje (66.67%). In three groundwater bodies: Savinjska kotlina, Krška kotlina and Murska kotlina, increasing trends of groundwater levels were predominant, the share of decreasing trends being below 25 percent. These three groundwater bodies were not at risk to achieve good groundwater quantitative status and they were in good groundwater quantity balance. In two groundwater bodies, the share of decreasing trends was higher than the threshold value of 25 percent. A further examination of the risk and an analysis of the impact of pressures on the groundwater quantitative status were required for the Savska kotlina in Ljubljansko Barje and Dravska kotlina groundwater bodies.

Table 1: Test of groundwater level trend in groundwater bodies with aquifers with prevailing intergranular porosity

Name of groundwater body	Number of monitoring sites	The share of decreasing trends (%)	Is the groundwater body at risk?
Savska kotlina and Ljubljansko barje	24	66.67	Further examination is needed
Savinjska kotlina	13	23.08	No
Krška kotlina	17	23.53	No
Dravska kotlina	16	31.25	Further examination is needed
Murska kotlina	21	9.52	No

For these two groundwater bodies it was examined whether the groundwater levels will drop below critical water level NGW_{3M}. It was done by extrapolation of the trend line for forecast period for all 16 monitoring sites of the Savska kotlina in Ljubljansko Barje groundwater body, as well as for all 5 monitoring sites of the Dravska kotlina groundwater body. The further examination showed that the trend line was crossing critical groundwater level only at monitoring site 0721 Ptuj in the Dravska kotlina groundwater body.

Thus, the share of monitoring sites where groundwater level will decrease below critical groundwater level was lower than 25 percent threshold, meaning that Dravska kotlina groundwater body will not be at risk of achieving good groundwater quantitative status (Table 2).

Table 2: Further examination of groundwater bodies at risk

Name of groundwater body	Total number of monitoring sites	Number of monitoring sites			Is the groundwater body in good quantitative status?
		with decreasing trend	where trend line crossed the critical groundwater level	where groundwater level will drop below the critical groundwater level (%)	
Savska kotlina and Ljubljansko Barje	24	16	0	0.0	Yes
Dravska kotlina	16	5	1	6.25	Yes

The groundwater quantitative status of groundwater bodies with aquifers with prevailing karstic and fracture porosity

For sixteen groundwater bodies with aquifers with prevailing karst and fracture porosity (Figure 1) the quantitative status assessment was carried out with modified Wundt method, by analysing time series from 61 representative gauging stations in the national hydrological monitoring network[6].

The analysis has shown that the greatest available groundwater quantities were in the groundwater body of Dolenjski kras (199.3 million m^3/year) and the smallest in the groundwater body of Goričko (6 million m^3/year). In the 1990-2001 period, the greatest groundwater quantity was abstracted from the groundwater body of Posavsko hribovje do osrednje Sotle (12.79 million m^3/year) and the least from the groundwater body of Goričko (0.13 million m^3/leto) [11].

Groundwater quantitative status of groundwater bodies was assessed, by calculating share of abstracted groundwater as percentage of available groundwater quantity. The largest share of was in the groundwater body of the Posavsko hribovje do osrednje Sotle (36.71%), while the smallest was in the groundwater body of the Julijske Alpe v porečju Soče (1.23%) (Table 3).

The share of abstracted groundwater did not exceed 75 percent threshold value in no groundwater body (Figure 5). For all groundwater bodies was assessed good groundwater quantitative status.

CONCLUSIONS AND RECOMMENDATIONS

All groundwater bodies with aquifers with prevailing intergranular porosity have a good groundwater quantitative status.

In the groundwater bodies with aquifers with prevailing karst and fracture porosity, the share of abstracted groundwater against available groundwater quantity did not exceed 37 percent, which was well below threshold value. Therefore, all groundwater bodies of this type are in good quantitative status. A good groundwater quantitative status without the risk of deterioration by the year 2010 was assessed for all 21 Slovenian groundwater bodies[12]. The analysis has also shown that, from the point of view of assessing the groundwater quantitative status, there is a need for a more detailed delineation of some groundwater bodies. The most prominent need for further delineation and detailed analysis of the smaller parts of groundwater body has been shown in the case of the groundwater body Obala in Kras z Brkini, as well as groundwater body Dolenjski kras. These two groundwater bodies are characterised by great spatial variability in the available groundwater quantity. To the less extent there is a need for such delineation in some other groundwater bodies.

Table 3: The available groundwater quantity by water bodies and the share of groundwater abstraction against the available groundwater quantity

Name of groundwater body	**Available groundwater quantity in groundwater body (10^6 m^3/year)**	**Specific available groundwater quantity (10^3 m^3/year/km^2)**	**Share of groundwater abstraction against the available groundwater quantity (%)**
Julian Alps in the basin of the Sava River	103.9	132.7	1.23
Karavanke Mountains	38.4	95.0	10.93
Kamniško – Savinjske Alps	69.3	62.3	8.54
Cerkljansko, Škofjeloško and Polhograjsko	59.5	70.0	17.00
Posavsko hribovje hills up to central Sotla	34.8	19.4	36.71
Downstream part of Savinja up to Sotla	35.8	25.6	33.97
Kraška Ljubljanica	92.0	70.4	7.54
Dolenjski kras	199.3	59.4	5.59
Eastern Alps	62.6	49.3	6.29
Haloze and Dravinjske gorice	19.6	32.8	13.74
Western Slovenske gorice	12.7	16.8	4.93
Eastern Slovenske gorice	6.1	19.7	4.82
Goričko	6.0	12.1	2.22
The coast (Obala) and Karst with Brkini	36.7	23.1	25.96
Julian Alps in the basin of the Soča River	62.3	76.2	7.74
Goriška Brda and the Trnovsko-Banjška plateau	121.5	84.2	10.85

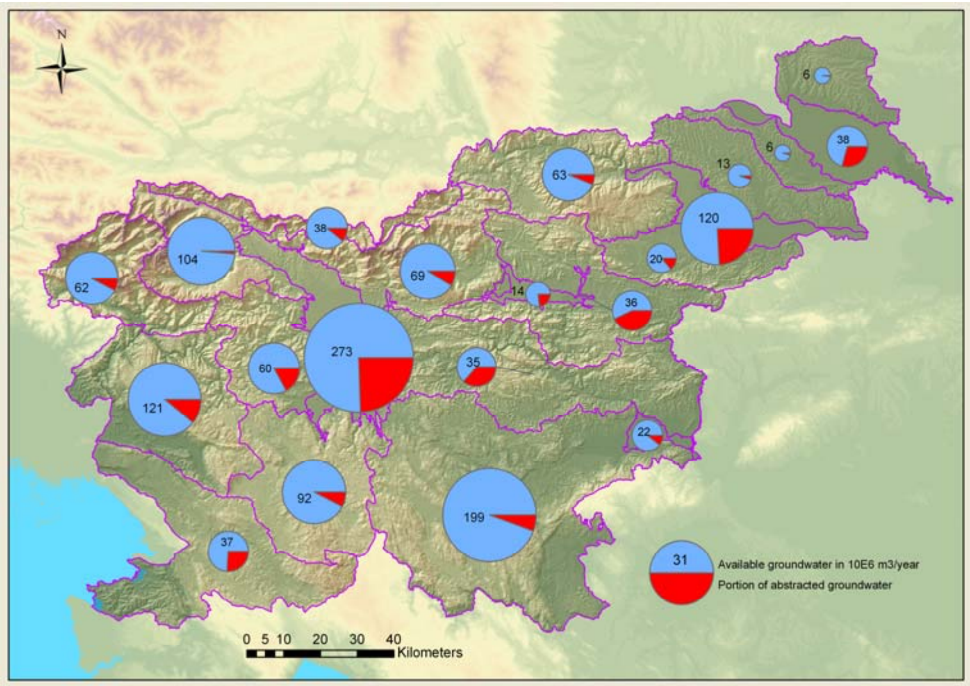

Figure 5: The available groundwater quantity and share of abstracted groundwater

A further detailed delineation of groundwater bodies will also be required in the future, to enable efficient monitoring and remediation measures to mitigate consequences of anthropogenic pressures other than groundwater abstraction[13]. The analysis has also shown a need for additional monitoring sites and upgrading of present national hydrological monitoring network[14]. This need has appeared to be especially prominent in case of groundwater quantitative status assessment of groundwater body Savska kotlina in Ljubljansko Barje.

Despite the good groundwater quantitative status of all groundwater bodies, there are some local and seasonal water supply problems in Slovenia. It is presumed that expected long-term impacts of climate change on the water cycle could lead to bad groundwater quantity status. In such a case further detailed groundwater bodies delineation into smaller units, as well as optimization of national hydrological network will also be required.

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SDSS as a tool for integrated groundwater resources management

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Abstract: In many European countries karstic areas are essential for public water supply. Sustainable development of karstic areas means a maximum use of the environment with simultaneous conservation of natural resources. This is difficult to achieve in practice. Integrated water resource management has to balance spring protection requirements with a variety of demands for land-use activities. This complex issue could be supported by a spatial decision-support system (SDSS), in which legal frameworks and socio-economic aspects with emphasis on land-use activities could also be implemented. SDSS integrates data from various sources and helps to make decision processes more effective and transparent. Successful application of a SDSS depends on its acceptability by stakeholders, which can be improved by integrating a broad range of practical experiences of stakeholders with formal knowledge of experts in a knowledge base. In this paper a methodological aspects for DSS are presented, e.g. activity-effect matrix. The work was done in the frame of INTERREG IIIB project KATERII, which goal was to quantify and assess the impact to land-use activities on environment and water resources in karstic areas. The major studied land-uses are summer and winter tourism, settlements, transport, forestry, agriculture and pasture management.

Key words: karst, groundwater protection, land use, water management, decision support system

INTRODUCTION

Karstic areas are essential for public water supply, since currently karstic aquifers contribute 25% of world-wide water supply. These areas are at the same time highly sensitive and valuable natural environments. Conversely, development of such areas is increasing. Sustainable development of karstic areas means a maximum use of the environment with simultaneous conservation of natural resources. This is difficult to achieve in practice. It requires an exceptional knowledge of natural resources and skill and knowledge of physical planners who have to optimize effects of human activities.

A general lack of awareness of the environmental issues can be attributed to both planners and decision-makers and sometimes even to water users. Short term needs are often given higher priority than long-term protection of water resources. More attention should also be given to training of local staff and users, in order increase awareness and to allow them to play a more active role in water resource protection[1]. Governmental authorities are forced by law to take decisions within the framework of European, national and regional directives in the fields of spatial planning and groundwater and environmental protection. These tasks can be supported by a decision-support system (DSS), which integrates data from various sources and helps to make decision processes more effective and transparent.

Such a decision support system has been developed in a transnational and interdisciplinary INTERREG IIIB project KATERII[2]. Land-uses considered include summer and winter tourism, settlements, transport, forestry, agriculture and pasture management, studied at pilot areas in Austria (Hochschwab, Schneealpe, Rax and Schneeberg), Croatia (Lika Region), Italy

(Molise Region and Veneto Region) and Slovenia (Krvavec). These areas were surveyed and assessed regarding to water cycle, environment and specific land-use activities. The results of those surveys were the basis for the development of a special decision support system (SDSS).

KATER II has concentrated on the knowledge base of decision making and on tools for technical support of decision making process. KATER II thus provides an information base and a knowledge-network which is in line with the current developments of the 'World Water Portal', which also focuses on water information sharing and cooperation. KATER II and the "World Water Portal" share the following objectives (see also: World Water Development Report[3]):

- using common structures, protocols, and standards to provide seamless access to a wide body of water information
- provide technical support (metadata assistance/standards, "good practice" guidance, search and database integration software, development of processes for data acquisition, etc.)
- capacity-building in the area of information management (education and training for both managers and technicians)
- facilitation of working partnerships via a physical and virtual network, the use of reliable information, and the improvement of integrated water resource management decisions,
- providing a water information source for use by decision-makers, resource managers, researchers, students and the public at large.

METHODOLOGY

Decision making requires a lot of different types of knowledge from different fields. To help making decisions different decision support systems have been developed. Basically DSS are computer-based systems, which help decision makers to make „optimal" decisions in uncertain decision environments. DSS don't only help making decisions but they also help predict potential effects. Methods used in the decision process include multi criteria decision making and other types of evaluation deriving from research work. DSS consists of multiple parts (Figure 1):

- special database (e.g. GIS of the pilot area),
- knowledge base and analytical and numerical models for data analysis and
- interactive modelling process.

Decision making is transparent and this is the reason why it is documented. Result of the decision making is a decision supported by text, tables and graphical figures. In the process of decision making are also included remarks and opinions of the decision maker.

The formal methods applied for the decision making process include multi-criteria decision-making and techniques of fuzzy evaluation. They are used to define a system of rules describing the concrete forms of impact of land-use activities (derived from an activity -impact matrix) on the natural environment. This system of rules is the formalised knowledge base and is the core of the decision support system, which helps to make decisions and their potential impacts transparent as well integrative, bridging the gap between different institutions and experts involved in groundwater protection.

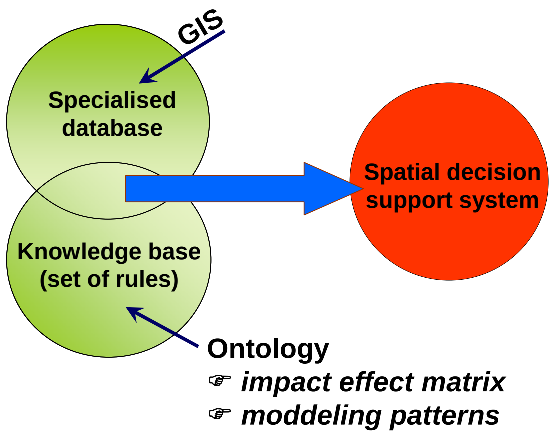

Figure 1: Spatial decision support system

KNOWLEDGE BASE

Development of the knowledge base included gathering the information of impacts of different land-uses on groundwater, which was systematised in an activity-impact matrix. The latter represents a review of all potential negative effects and their consequences on groundwater[4]. The matrix form of presentation provides a valuable starting point for evaluation and analysis.

With the introduction of new land-use activities and infrastructure, tourism may present many potential threats to karst aquifers. Land-use intensifies with growing visitor numbers and major infrastructure construction for residential tourism, transport, communications, ski facilities etc., physically altering the natural environment and introducing many potential pollution sources. At the same time land value and the demand for high quality water supplies are increased. The activity-effect matrix for tourism was divided into several categories, such as winter tourism and summer tourism. The first is divided to skiing tourism, whereas subcategories of summer tourism are mountain tourism, camping, outdoor sports and activities (hiking, biking, mountaineering, caving…), sightseeing and cultural tourism (tourist caves, eco-tourism). Table 1 presents an example for activity-effect matrix for winter tourism - skiing.

In the second part a knowledge base using a computer programme Protégé 3.2 beta was set up. The knowledge base comprises of information and relations of all potential impacts on groundwater and environment. This system of rules is a formalised knowledge base and is a core of DSS. Knowledge base is organised in an ontology. Sowa[5] claims that the subject of ontology is the study of the categories of things that exist or may exist in some domain. The product of such a study, called an ontology, is a catalogue of the types of things that are assumed to exist in a certain domain of interest. An ontology is a formal explicit description of concepts in a domain of discourse (classes), properties of each concept describing various features and attributes of the concept (properties), and restrictions on properties (facets)[6]. An ontology together with a set of individual instances of classes constitutes a knowledge base.

Table 1: An example of the activity-impact matrix for winter tourism (PRO = provokes: it is a general activity provoking activities which are linked to the process; COF = consist of an activity)

Winter tourism	PRO	Traffic facilities: Roads & car parks
	PRO	Traffic facilities: Railway lines
	PRO	Traffic facilities - Trails and footpaths
	PRO	Traffic facilities: Accidents
	PRO	Construction in general
	PRO	Technical Infrastructure (111)
	PRO	Settlements (114) - housing & hotels
	PRO	Domestic water supply
	COF	Spring capture
	COF	Ground water abstraction
	COF	Surface water abstraction
	COF	Water transfer / import
	COF	Water treatment
	PRO	Domestic wastewater production
	COF	Septic tanks - construction, maintenance & leakage
	COF	Wastewater drainage systems - construction, maintenance & leakage
	COF	Wastewater treatment plants - construction & maintenance
	COF	Wastewater treatment plants - sludge disposal
	PRO	Domestic solid waste production
	COF	Recyclable wastes
	COF	Non-recyclable wastes
	COF	Hazardous wastes
	COF	Transport of solid wastes
	COF	Solid waste storage & disposal
	COF	Flytipping / illegal dumping
	PRO	Emission of air-pollutants (traffic, heating)
	PRO	Storage, application & disposal of chemicals
	COF	Storage: household chemicals (paints, solvents, detergents, antifreeze, batteries etc.)
	COF	Storage: agrochemicals (pesticides, herbicides etc.)
	COF	Application of agrochemicals (gardens, roads etc.)
	COF	Storage: fuels for vehicles and machinery

For a successful development of an ontology with the computer program Protégé 3.2 beta modelling patterns (Figure 2) were developed, which were, after a critical overview, inserted into the program.

Protégé 3.2 beta is an integrated software tool used by system developers and domain experts to develop knowledge-based systems. Applications developed with Protégé-2000 are used in problem-solving and decision-making in a particular domain[7].

Working in Protégé 3.2 beta is done based upon a specific course of events.

- Definition of classes and their subclasses;
- Definition on instances;
- Definition of properties and relations between them.

The program also enables us to write comments, definitions and express all newly defined expressions in several languages, thus enabling ontology to be used world wide.

For developing the ontology a world known ontology DOLCE (a Descriptive Ontology for Linguistic and Cognitive) was selected, where a lot of expressions has already been explained and qualified. DOLCE is not an ideal ontology for the needs inside the KATER II project, but it is a very good approximate. In KATER II we used DOLCE as a basic ontology and for the needs of DSS we implemented new expressions and terms. All expressions and terms together in an ontology represent a knowledge base which can be used for different needs.

This simple example (Table 1 and Figure 2) shows how much thematic knowledge is necessary before formal procedures may be applied in the decision process. The definition of this knowledge base has actually started in the early 1990s and was enhanced and formalised in the course of KATER II

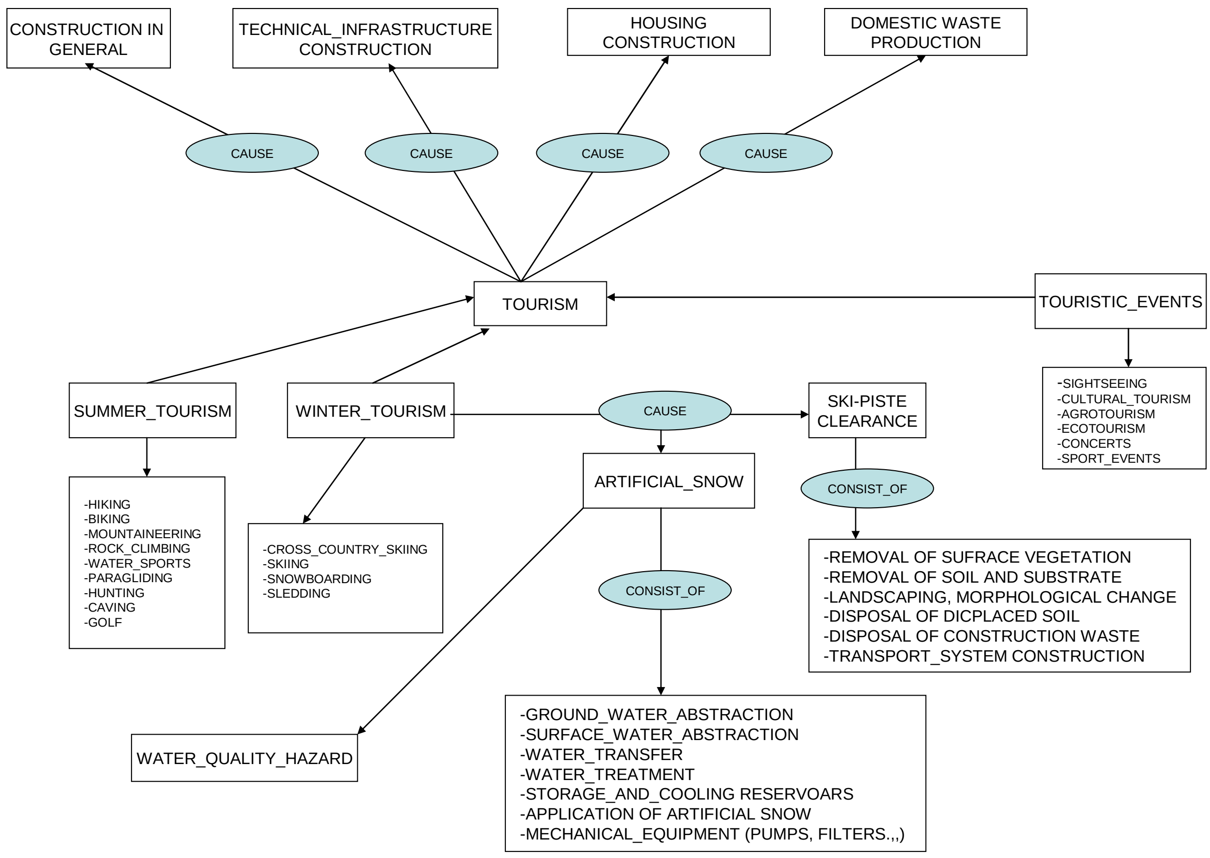

Figure 2: Modelling pattern of tourism

DECISION PROCESS

The formal methods applied for the decision making process include multi-criteria decision-making and techniques of fuzzy evaluation. They are used to define a system of rules describing the concrete forms of impact of land-use activities (derived from an activity impact model) on the natural environment, as described in vulnerability models. This system of rules (the formalised knowledge base) is the core of the decision support system, which helps to make decisions and their potential impacts transparent as well integrative – bridging the gap between different institutions and experts involved in groundwater protection.

DISCUSSION

The decision support system is a tool for solving decision problems in water management. The basic tasks of water management can be divided into:

- administration,
- crisis management and
- planning activities.

A more detailed task list for the roles of 'Water Supply' and ‚Water Protection' can be defined as listed in Table 2[8].

A detailed analysis of tasks shows that the nature of decision making and the time scale of decisions is clearly different between task categories. Planning needs long-term decisions under conditions of low time-pressure, whereas administration and above all crisis management need immediate decisions. The support of decisions in water management must take into account the differing information needs and tailor the decision support system (including the structuring of data access, the way of data presentation and the system functionality) according to user needs.

The discussion above and the experiences of many transnational and intern basic steps on how to proceed in the development of a water management system[8]:

- A common language as knowledge base (defined as ontology), to integrate the views of water issues of stakeholders in the water management process, including scientific disciplines (e.g. hydrology), water authorities, planners and economists as well as people from technological disciplines (information processing...). This increases involvement with and thus acceptance of a project.

Table 2: Task lists for ‚water supplier' and ‚water protection'[8]

Task category	Water supplier	Water protection
Administration	➢ Monitoring of discharge and outlet (water quantity and quality) ➢ Regulation of used amount of water	➢ Property management ➢ Monitoring of land use activities ➢ Monitoring of natural environment
Crisis management	➢ Technical accidents ➢ Water contamination	➢ Elementary natural accident ➢ Global contamination ➢ Local contamination
Planning	➢ Maintenance work ➢ Forecast of quantity and quality ➢ Analyses supply versus demand	➢ Analyses concerning possible changes in interdependences: ➢ Land use with water balance ➢ Natural environment with water balance

- The knowledgebase is a part of the decision support system, as well as numerical modelling (e.g. groundwater modelling). The latter could be incorporated also as ‘living’ model (user can change parameters and run the model again) or only results from particular modelling.
- Metadata deserve highest priority to make the results of any project and data collections process usable. The metadata issue is in many respects directly related to knowledge base.
- A multi-disciplinary approach has to be taken, to integrate the heterogeneous problem views of scientists, authorities, technicians and users.
- SDSS have to be simple in use but allow to integrate wide range of data (of very heterogeneous data quality) and presentation facilities with well developed functions.
- Work-flows provide an important means of communication with SDSS users and a valuable gudeline for the users themselves.
- Use of ontologies for describing decision processes provides the further advantage of extensability without (re)coding and transparence and reproducability of decision processes.

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The Italian "combined" approach in assessing and mapping the vulnerability of groundwater to contamination

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Abstract: Early in the eighties, the Italian scientific community, together with a number of institutional decision-makers, realized how urgent it was to protect the natural and environmental resources. They agreed that an adequate level of scientifically organized knowledge allows the accurate planning and development of environmental systems through the management and direction of effective development processes, but without stopping them.

Since the special VAZAR[1] project was first set up in 1984 as part of the GNDCI-CNR[2] scientific context, it has been the cardinal centre-point of Research Line 4 "Aquifer Vulnerability Assessment". The problem of groundwater contamination was examined for the very first time in this project in Italy, in an organic and extensive manner as a key for forecasting and prevention purposes.

The Italian approaches to assessing and mapping the vulnerability of groundwater to contamination are essentially based on two main methodologies:

- the GNDCI Basic Method[1],[2],[3], a HCS type approach that can be used for any type of the Italian hydrogeological situation, even where there is a limited amount of data. A unified legend and symbols are also defined for each hydrogeological level.
- the SINTACS method[2],[3],[4],[5],[6], a PCSM developed for use mostly in areas with a good database coverage.

The methodological approaches described in this paper now make up the Italian standard, which has been dealt with in recent and very important Italian Law (152/99[3]) and which is now ratified in the national guidelines produced by ANPA, the Italian National Agency for Environmental Protection.

Key words: groundwater, vulnerability, contamination, GIS, SINTACS, Basic Method

INTRODUCTION

In August 2000 in Johannesburg, there were people holding placards with the slogan "Water is a human right", speaking on behalf of many people. The protest was addressed in particular to the UN ambassador for water and sanitation problems. Nelson Mandela warned: "Water is a basic right of all human beings: there is no future without water, water is democracy."

It is a fact that 1.2 million people in the world suffer from water scarcity and that, without effective counter-measures, this number will increase to 3 million over the next 20 years. Pollution, and pollution caused by highly dangerous agrochemicals especially (and, more specifically, the highly persistent types[4]), and over-exploitation threaten water resources over practically the entire globe, with groundwater bodies being under particular threat. These are the most precious resource available for human consumption and, rather than increasing to face the needs of an increasing population, they have already begun to diminish due to climate change, because of contamination or because they have been plundered well beyond their sustainable limit.

Over 15 years ago, the worldwide scientific community, and that in Italy in particular, had forecasted the coming crisis in drinking water resources and understood very well that, in addition to being a question of managing and protecting environmental resources, this was a Civil Defence problem that should be tackled early and resolutely with prevention as the guiding strategy. Applied research, finally directed towards precise objectives, has been carried out by Line # 4 of the GNDCI-CNR since 1985. It is worth relating the principal stages and results achieved in more than 20 years' work.

The Italian programme to search for and apply an organic methodology for protecting aquifers was given the acronym VAZAR (Vulnerability of Aquifers in High Risk Zones). It set itself the goal of assessing the vulnerability[5] of groundwater bodies in a whole series of areas that represent the various hydrogeological and impact settings existing in the country. A score of representative areas were chosen, scattered over the whole territory of Italy, and each area was to have a research unit carrying out research in the field.

In order to operate as uniformly as possible and to produce comparable results in the field, an initial methodology was designed for intrinsic vulnerability assessment and cartography (the GNDCI-CNR *basic method*) with a preliminary legend for the symbols to be used in the intrinsic Vulnerability Maps:

- *point sources of contamination risk* (CSC) and *diffuse sources of contamination risk* (DSC) – the real and potential originators of contamination;
- *subjects at risk* – the points where the groundwater bodies are utilized by the community, particularly when destined for human consumption.

Overlaying information in this way made it possible to assemble an *Integrated Vulnerability Map*, a powerful tool for planning water supplies and activities at the territory itself.

In the early 1990s, another more specific and detailed approach to assessing and mapping groundwater vulnerability was prepared: a new Point Count System Model (PCSM) suited to the hydrogeological and impact settings in Italy itself and, first and foremost, one that could be implemented using a GIS (*Geographical Information System*) to obtain *dynamic assessments and maps*, connected with *databases* that users and managers of the resources needing groundwater protection would be able to update continuously. The new system model, called SINTACS, has been upgraded and, in the current release (# 5), is completely computerised with GIS. This is a very new chapter in operational thematic cartography, giving institutional and non-institutional users a powerful, updatable information medium that provides complete scenarios in real time for land use planners and Civil Defence managers.

Experience gained when the method was applied to a large river basin (in 2000), where the landscape has a distinctly mixed morphology and hydrogeology (hill and plain), stood as another important step in the research. It was noted that, in the hilly zones, the data required in order to apply the parametric model was no longer available, but that the *basic method* could still be profitably applied. Therefore the problem was posed of validating the borderline representing the passage from one methodology to another, without invalidating the complete scenario. After a series of tests, the conclusion was reached that the interface between the two methods could be used to crosscheck each one's validity: from this came the so-called *combined approach,* which solves the longstanding problem of assessing the intrinsic vulnerability in regions with variable morphology.

At the same time, progress was made on other aspects of groundwater protection. VAZAR actually embraces the *defence of the entire territory* and the *defence of specific points*, the former being based on the creation and utilisation of Vulnerability Maps and the latter on applying protection zones for tapping works, using advanced methodologies. Research began then on the definition of the *base quality* and *target quality* of water intended for human consumption, on the need for monitoring networks and for anticipating pollution, with the clear purpose of offering the nation a "basket" of integrated synergic methods for protecting its increasingly precious groundwater resources.

The first aspect will be illustrated and stressed within this contribution.

THE OUTLINE OF THE MAIN METHODS FOR THE EVALUATION OF INTRINSIC VULNERABILITY

The intrinsic (i.e. natural) vulnerability of aquifers to contamination is the specific susceptibility of the aquifer systems, in their various parts and various geometric and hydrodynamic settings, to ingesting and diffusing fluid and/or hydro-vectored contaminants, the impact of which on the groundwater quality is a function of space and time[7]. The intrinsic vulnerability depends on three main factors:

- the *ingestion process and the time of travel* of the water (and/or fluid contaminant) through an unsaturated zone down to the underlying saturated zone of the aquifer system;
- the groundwater (and/or fluid contaminant) *flow dynamics* in the saturated zone;
- the *residual concentration* of the contaminant as it reaches the saturated zone compared to the original concentration, which indicates the aquifer's attenuation capacity of the contaminant impact.

These factors in turn depend on the different possible synergies of several parameters of a hydrogeological and anthropogenic nature, and which are therefore subject to change in each area (Table 1).

The attenuation process that takes place inside an *aquifer system* (i.e. soil + unsaturated zone + saturated zone) as it receives a contaminant (fluid and/or water vectored), depends on the properties and primary concentration of each contaminant but also on the reactivity of the system, which can be reduced or, in the long term, completely depleted in time. Thus, when a CSC impact persists for a long time or if a contaminant is persistent and mobile, the attenuation capacity of the soil dwindles and the vulnerability increases over time. In these cases, groundwater protection is only aided by the travel time – by the thickness of the unsaturated zone. It is also inversely related to the ingestion capacity, the vertical percolation velocity and the mechanical dispersion that are typical of the medium. Many interactions take place between the soil, subsoil, groundwater and contaminants during travelling, the overall result being an attenuation of the contaminant impact. A further and surely not negligible dampening effect takes place as the residual concentration of the contaminant is diluted to a lower degree in the saturation zone, due to the flow velocity, the unit flow rate and hydrodynamic dispersion.

The evaluation of the specific vulnerability of an aquifer should be made on a case by case basis, taking into account all the chemical and physical features of each single contaminant that is present (or *group* of similar contaminants), the type of source (point source or diffuse source), the quantity, the means and the rate of contaminant application[8],[9],[10]. This approach, although scientifically valuable and adequate for evaluating the potential contamination of a CSC in small areas, is quite impracticable where the goal is the assessment of aquifer vulnerability for large areas or when it is carried out as part of contamination prevention and aquifer protection planning.

In the last 30 years, a number of techniques have been developed for the general treatment of data (Table 2). These techniques vary considerably according to the physiography of the areas tested, to the quantity and quality of the data and to the aim of the study. A division into two distinct classes is therefore important: use for any physiographic scenario or use for a particular area. For the sake of simplicity, the terms *universal* and *local* are proposed. However, these two classes can also be subdivided into three basic groups:

- Homogeneous area zoning (hydrogeological complex and setting assessment - hcs);
- Parametric system assessment:
    - Matrix Systems [**MS**];
    - Rating Systems [**RS**];
    - Point Count System Models [**PCSM**]
- Analogical relation (**AR**) and numerical model assessment.

Because of the limited space available for this contribution, the reader can refer to Civita[3] and to Vrba & Zaporozec[11] for an exhaustive discussion of these mentioned methods and a complete reference list.

Table 1: The main factors and basic parameters of intrinsic vulnerability

MAIN FACTORS	BASIC PARAMETERS
TIME OF TRAVEL	Depth to the groundwater (the thickness of the unsaturated zone); thickness, texture, porosity, effective moisture, soil permeability; lithology, stratigraphy, grain size, fracture index, karst index, geometry, structure, vertical permeability of unsaturated zone; average total net recharge; density, viscosity, solubility of the contaminants.
GROUNDWATER FLUX	Aquifer type, structure and geometry; effective porosity, pore size and distribution, hydraulic conductivity, transmissivity, storage coefficient, flow velocity, hydraulic gradient, dispersion and molecular diffusion; groundwater and matrix (rock) temperature; density, viscosity and solubility of the contaminants.
THE ATTENUATION CAPACITY OF THE CONTAMINANT IMPACT	Depth to the groundwater; average net recharge; topographic surface slope; stream network density and linkage to underlying aquifer system(s); thickness, mineral composition and texture, effective moisture, physical and chemical characteristics of soil and unsaturated zone of the aquifer system.

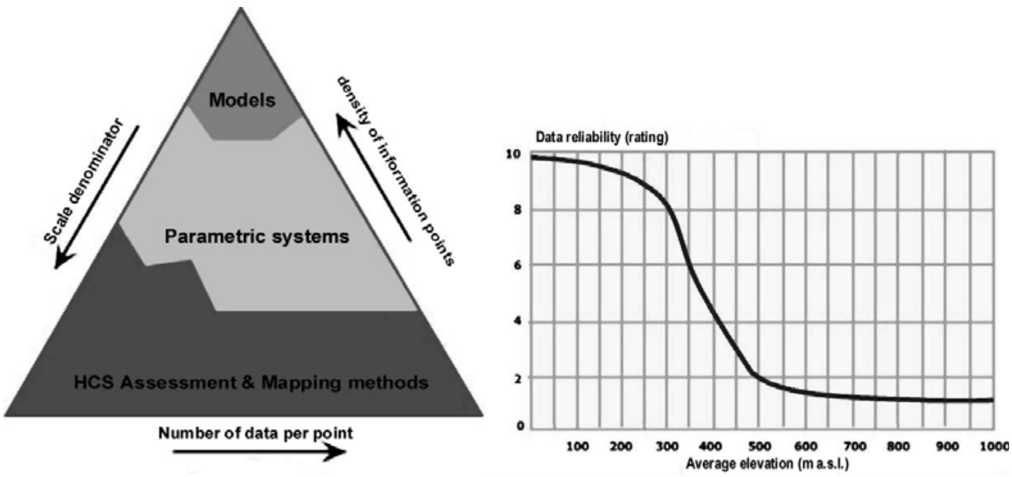


Figure 1: Left: The interaction between the SD, the density of the surveyed points and the number of parameters/amount of surveyed/available data for each point. Right: Variations in the reliability of the basic data with a variation in the mean height in the investigated area [Source: Civita[3], redrawn]

As has been widely verified from the comparison of several different approaches applied to the same sample area (Civita[3]), the choice of the method that is most suitable for building a vulnerability map for a certain area should initially depend on a strictly realistic evaluation of the number, distribution and reliability of the available (and/or surveyable) data. It should therefore be emphasized that an aquifer vulnerability map is an *environmental planning document*. The map must be an integral part of a *land planning scheme* for any order and degree of the administrative territory: it cannot depend on the morphology as it must cover a wide mixture of plain, hilly and mountainous areas, as can be found throughout Italy.

- Considering the recent experience gathered in Italy, it is possible (although only in a qualitative form at present) to indicate the correlation between the three main factors that are necessary in mapping vulnerability, namely the *density of the surveyed points*, the *amount of information secured for any point* and the *scale denominator* (SD) based on which the map can be constructed.

Table 2: Methods of assessing an aquifer's vulnerability to pollution and the relative basic information

METHODOLOGY		BASIC INFORMATION													
					CHARACTERISTICS OF THE SOIL										
REFERENCE AND/OR NAME	TYPE	PRECIPITATION RATE & CHEMICAL COMPOSITION	TOPOGRAPHIC SURFACE & SLOPE VARIABILITY	SURFICIAL STREAMFLOW & NETWORK DENSITY	THICKNESS, TEXTURE & MINERALOGY	EFFECTIVE MOISTURE	PERMEABILITY	PHYSICAL & CHEMICAL PROPERTIES	AQUIFER CONNECTIONS TO SURFICIAL WATERS	NET RECHARGE	HYDROGEOLOGICALAL FEATURES OF THE INS. ZONE	DEPTH TO THE WATER LEVEL	PIEZOMETRIC LEVEL CHANGES	THE AQUIFER'S HYDROGEOLOGICAL FEATURES	THE AQUIFER'S HYDRAULIC CONDUCTIVITY
Albinet & Margat [12] BRGM (1970)	HCS								●		●	●		●	●
Vrana (1968) Olmer & Rezac (1974)	HCS										●			●	
Fenge (1976)	RS				●					●	●	●	●	●	●
Josopait & Swerdtfeger (1976)	HCS									●	●	●		●	●
Vierhuff, Wagner & Aust (1980)	HCS										●	●		●	●
Zampetti (1983) Fried (1987)	AR										●	●			
Villumsen, Jacobsen & Sonderskov (1983)	RS				●						●	●	●	●	●
Haertle' (1983)	MS										●	●			
Vrana (1984)	HCS	●			●						●			●	
Subirana, Asturias & Casas Ponsati (1984)	HCS								●		●	●		●	●
Engelen (1985)	MS								●		●	●		●	
Zaporozec (edit., 1985)	RS				●	●	●	●			●	●		●	
Breeuwsma et al. (1986)	HCS				●	●	●	●	●	●	●	●			●
Sotornikova & Vrba (1987)	RS						●					●	●		●
Ostry et al. (1987)	HCS				●			●				●		●	
Minstr. Flemish Comm (1986) Goossens & Van Damme (1987)	MS				●							●		●	
Carter et al. (1987) Palmer (1988)	MS				●		●	●						●	
Marcolongo & Pretto (1987) method. 1	RS				●					●	●	●			
Marcolongo & Pretto (1987) method. 2	AR					●				●	●	●			
GOD Foster (1987, 1988)	RS										●	●		●	
Schmidt (1987)	RS				●				●		●	●			
Troyan & Perry (1988)	PCSM	●	●				●			●	●	●		●	
GNDCI BASIC (Civita, 1990)	HCS								●		●	●		●	●
DRASTIC Aller et al. [13]	PCSM		●		●					●	●	●		●	●
SINTACS (Civita, 1991; Civita & De Maio, 1997, 2000)	PCSM		●	●	●				●	●	●	●		●	●
ISIS (De Regibus,1994)	PCSM		●		●					●	●	●		●	

The diagram in Figure 1 shows that:

- only when there are a great number of *information points per unit area* (for any of which a variety of ground data are attainable) can complex low SD models be applied;
- for a medium information point density with a fair distribution, a more complex or less complex parametric system (depending on the *amount of data available per point)* can be used;

if the specific basic information is inadequate and/or scarce and scattered throughout the area, as is often the case, an HCS method coupled to a medium-large SD must be used.

One very important consideration that must be made when choosing a method for vulnerability assessment is the *reliability* of the basic data, as inadequate reliability of the data can give rise to a false precision. Even worse, it can completely falsify the results, making them quite useless.

The reliability of the data, moreover, can vary widely with the *mean elevation* of the area investigated. If one tries to give a range between 1 and 10 to the reliability of data, a variation curve of this reliability versus the mean elevation can be plotted. Figure 1 (right) shows a sharp decrease in the reliability of results above a comparatively low altitude (300-400 m a.s.l.) due to the increasing scarcity of data in mountainous areas, a problem that can only be partially resolved through the use of extrapolation techniques. This is true for hydrogeological and hydrostructural data (piezometric levels, unsaturated zone, flow directions, hydraulic conductivity and aquifer geometry), but no less so for pedologic and climatological data (rainfall, evapotranspiration, wind, temperature, etc.).

In mountainous regions and most hilly areas, it may be necessary to avoid the more complex techniques and use HCS or MS systems coupled to medium-high SD mapping instead of the more sophisticated parametric systems. The validity of these is greater in flat areas with high data density and reliability, but they are also suited to adequately low SD mapping.

On the basis of this consideration, it was realized that it is impossible to elaborate an aquifer vulnerability map using one single method.

A new approach based on the overlapping of two different methodologies (named the *combined approach*) was studied and tested for use in any part of the Italian[6] territory:

1. a parametric method (a highly advanced PCSM - i.e. SINTACS Release 5[5]), which as been improved for plain and foothill areas, where the amount and reliability of data, measurements, tests and analysis can be considered to be sufficient for the mapping scale;
2. homogeneous areas zoning, based on the survey of the hydrogeological complexes, characteristics and settings (HCS), to be used in mountainous and hilly areas where a scarcity or lack of underground information is normal (GNDCI-CNR *Basic Method*).

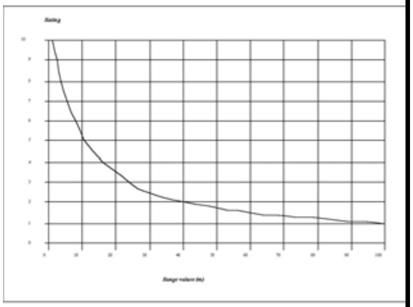
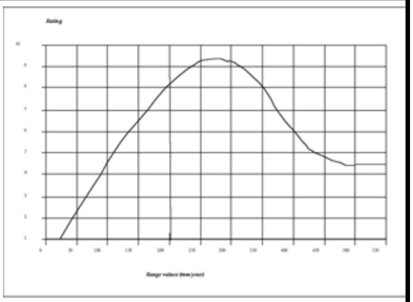
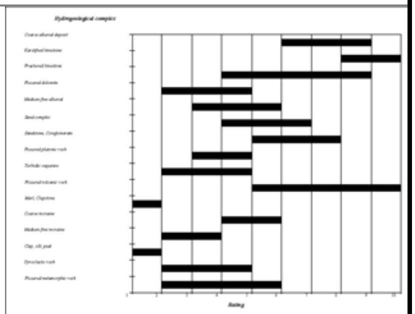
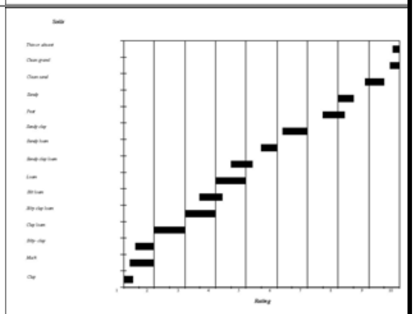
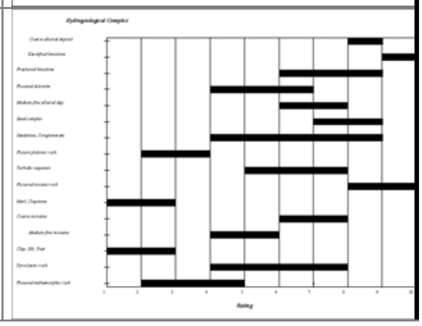
A BRIEF DESCRIPTION OF THE METHODS

PCSM SINTACS R5

The vulnerability of a groundwater body is a function of several parameters, the most important of which are lithology, structure, the geometry of the hydrogeological system, the type of overburden, the recharge-discharge process, the interaction of the physical and hydrochemical processes that regulate the quality of the groundwater and the fate of the contaminants that impact the system.

Where the database is complete and the frequency of the available information is adequate, the factors used to assess the aquifer vulnerability to contamination are selected; a subdivision into value intervals and/or declared types is applied to each factor; a progressive rating (**P**, ranging 1 – 10) is given to each interval as a function of its importance in the final assessment (Tab. 3); the selected ratings of each factor must be multiplied for a choice of weight (**W**) strings, which are used in parallel rather than in series (tab. 4), each one describing a hydrogeological and impact setting that emphasizes the action of each parameter.

Table 3: Description of the parameters and related rating graphs for PCSM SINTACS

	Description	RATING DEFINITION
S	THE DEPTH TO THE GROUNDWATER: is defined as the depth of the piezometric level (both for confined or unconfined aquifers) with reference to the ground surface and it has a major impact on vulnerability because its absolute value, together with the unsaturated zone characteristics, determine the time of travel (TOT) of a hydro-vectored or fluid contaminant and the duration of the attenuation process of the unsaturated layers, in particular, the oxidation process due to atmospheric O_2. The SINTACS depth-to-groundwater rating therefore decreases with an increase in the depth, i.e. with an increase of the thickness of the unsaturated zone within the range 10 ÷ 1.	
I	EFFECTIVE INFILTRATION ACTION: The role that the effective infiltration plays in assessing the vulnerability of an aquifer is very significant because it is responsible for dragging down the pollutant and also its dilution, first during travel through the unsaturated zone and then within the saturated zone. Direct infiltration is the only or most prevalent component of the net recharge in all areas where there is no interflow linking aquifers or surface water bodies or no irrigation practices using large volumes of water.	
N	UNSATURATED ZONE ATTENUATION CAPACITY: The unsaturated zone is the "second defence line" of the hydrogeological system against fluids or hydro-vectored contaminants. A four dimensional[7] process takes place inside the unsaturated layers in which physical and chemical factors synergically work to promote contaminant attenuation. The unsaturated zone attenuation capacity is assessed starting with the hydro-lithological features (texture, mineral composition, grain size, fracturing, karst development, etc.).	
T	SOIL/OVERBURDEN ATTENUATION CAPACITY: This is the "first defence line" of the hydrogeological system: several important processes take place in the soil that built up the attenuation capacity of a contaminant travelling inside a hydrogeological system and therefore in aquifer vulnerability assessment and mapping. Soil is identified as an open, three-phase, accumulator and transformer of matter and an energy sub-system that develops through the physical, chemical and biological alterations of the bottom lithotypes and of the organic matter that it is made up of.	
A	THE HYDROGEOLOGICAL CHARACTERISTICS OF THE AQUIFER: In vulnerability assessment models, the aquifer characteristics describe the process that take place below the piezometric level when a contaminant is mixed with groundwater causing the loss of a small or more significant part of its original concentration as it travels through the soil and the unsaturated layers. Basically, these processes are: molecular and cinematic dispersion, dilution, sorption and chemical reactions between the rock and the contaminants.	

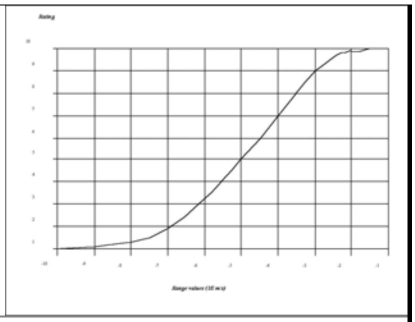
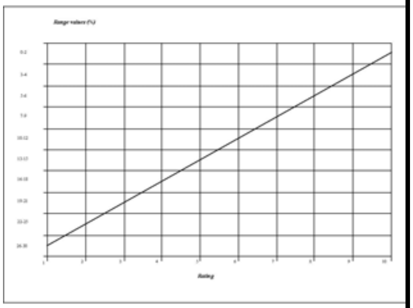
C	THE HYDRAULIC CONDUCTIVITY RANGE OF THE AQUIFER: Hydraulic conductivity represents the capacity of the groundwater to move within the saturated media, and thus also the mobility potential of a hydro-vectored contaminant with a density and viscosity almost the same as the groundwater. In the context of SINTACS assessment, the hydraulic gradient and the flux cross section being equal, this parameter determines the aquifer unit yield and the flow velocity that move toward the effluences or the tapping work, indicating the targets at risk.	
S	THE HYDROLOGICAL ROLE OF THE TOPOGRAPHIC SLOPE: The topographic slope is an important factor in vulnerability assessment because it determines the amount of surface runoff that is produced, the precipitation rate and the displacement velocity of the water (or a fluid and/or hydro-vectorable contaminant) over the surface being equal. A high rating is assigned to slight slopes – i.e. to surface zones where a pollutant may be less displaced by the action of gravity, or may even remain at the outlet favouring percolation. The slope may be a genetic factor due to the type of soil and its thickness and it can indirectly determine the attenuation potential of the hydrogeological system.	

Table 4: The strings of multiplier weights given for SINTACS

Parameter	Normal I	Severe I.	Seepage	Karst	Fissured	Nitrates*
S	5	5	4	2	3	5
I	4	5	4	5	3	5
N	5	4	4	1	3	4
T	3	5	2	3	4	5
A	3	3	5	5	4	2
C	3	2	5	5	5	2
S	3	2	2	5	4	3

* Under evaluation.

The acronym SINTACS comes from the Italian names of the factors that are used, i.e. **S**oggicenza (depth to groundwater), **I**nfiltrazione (effective infiltration), **N**on saturo (unsaturated zone attenuation capacity), **T**ipologia della copertura (soil/overburden attenuation capacity), **A**cquifero (saturated zone characteristics), **C**onducibilità (hydraulic conductivity) and **S**uperficie topografica (topographic surface slope). A vulnerability index is calculated for each cell of a discretisation grid that is overlaid on the basic map of the zone in question:

$$I_{SINTACS} = \sum_{J=1}^{7} p_J w_J \qquad (1)$$

The types of basic information, the necessary elaborations to transform them in SINTACS factors and the definition of the hydrogeological and impact settings used to select the weight strings can be found in Civita[3] and in Civita & De Maio[5], together with a number of application tests.

The GNDCI-CNR Basic Method

This method[1],[14] is based on a standard in which a number (about 20 – see Tab. 5) of hydrogeological settings found in the Italian territory is collected and the intrinsic vulnerability characteristics of the aquifer are identified. This method is highly flexible and can be adapted, if necessary, to other situations not dealt with in the standard system. The lithological, structural, piezometric and hydrodynamic indexes are not rigorously quantified. Beginning with a complete examination of the main Italian hydrogeological settings, representative sites were chosen from those that best define the settings, e.g. the Po river Plain, the carbonatic massifs of the Apennine ridge, the karst settings of Apulia and

Trieste, the volcanic terrain of central Italy, the ancient basement of the Alps and so on. The main factors of the aquifer vulnerability (e.g. depth to groundwater, porosity, fracturing index, karst index, linkage between stream and aquifer and so on) were identified for each representative site. Bearing in mind the dynamics and frequency of the contamination cases collected and previous similar experience at an international level, the settings were distributed over the 6 degrees of intrinsic vulnerability (i.e. contamination potential) that form the synoptic legend of the maps.

Table 5: Standards of Italian hydrogeological settings (GNDCI-CNR Basic Method)

Vulnerability degrees	Hydrogeological complexes and setting features
Extremely high	Unconfined (water table) aquifer in alluvial deposits: streams that freely recharge the groundwater body; a well or multiple well systems that drawdown the water table to below the stream level (forced recharge). Aquifer in carbonate (and sulphate) rocks affected by completely developed karst phenomena (holokarst with high karst index [**KI**]).
Very high	Unconfined (water-table) aquifer in coarse- to medium-grained alluvial deposits, without any surficial protecting layer. Aquifer in highly fractured (high fracturing index [**FI**]) limestone with low or null **KI** and a depth to water of <50m.
High	Confined, semiconfined (leaky) and unconfined aquifer with impervious (aquiclude) or semi-pervious (*aquitard*) superficial protecting layer. Aquifer in highly fractured (high fracturing index) limestone with low or null **KI** and a depth to water of >50m. Aquifer in highly fractured (but not cataclastic) dolomite with low or null **KI** and a depth to water of <50m. Aquifer in highly clivated volcanic rocks and non-weathered plutonic igneous rocks with high **FI**.
Medium	Aquifer in highly fractured (but not cataclastic) dolomite with low or null **KI** and depth to water >50m. Aquifer in medium to fine-grained sand. Aquifer in glacial till and prevalently coarse-grained moraines.
Medium - Low	Strip aquifers in bedded sedimentary sequences (shale-limestone-sandstone *flysch*) with diffusion rates that are highly variable layer by layer. Multi-layered aquifer in pyroclastic non indurated rocks (tuffs, ash, etc.): different diffusion degrees layer by layer close to the change in grain size.
Low	Aquifer in fissured sandstone or/and non carbonatic cemented conglomerate. Aquifer in fissured plutonic igneous rocks. Aquifer in glacial till and prevalently fine-grained moraines. Fracture network aquifer in medium to high metamorphism rock complexes.
Very low or null	Practically impermeable (*aquifuge*) marl and clay sedimentary complexes (also marly flysch): contamination directly reaches the surface waters. Practically impermeable (aquifuge) fine-grained sedimentary complexes (clay, silt, peat, etc.): contamination directly reaches the surface waters. Meta-sediment complexes or poorly fissured highly tectonized clayey complexes low metamorphism complexes, almost aquifuge: contamination directly reaches the surface waters.

The combined approach
From what has been seen, in many areas where it is necessary to cover vast areas identified by administrative (i.e. Municipalities, Provinces, Regions) or physical boundaries (interregional watershed) with a Vulnerability Map, the parametric models that have been set up cannot be applied due lack of data at those points where the terrain changes from a plain morphology to a hilly or mountainous area. In these situations, in the past, a simple method was chosen that was able to perform a less refined and detailed evaluation, but which was applied with good results to many land and environmental problems connected to the contamination of aquifers.

The experience gained over recent years has led to a reconsideration of the methodological problem: why renounce the detail that can be offered by point and weight parametric models[2],[3] in areas with moderate relief where the majority of the CSCs and the DCAs and many of the supply springs are concentrated (that is, the *subjects at risk* - SAR)? On the other hand, how can we carry out evaluation of the vulnerability and risk of contamination for areas with great depth to water, areas that can be described in less detail on the basis of *hydrogeological situations and complexes?*

The solution that has been found for this problem, and which has been tested, is the *combined approach*. This approach allows the GNDCI-CNR Basic method to be combined with the PCSM SINTACS method without continuity solutions: the latter in areas where the data exists that is necessary and sufficient to apply a parametric model; the first in areas where the great depth to water, the hydrolithological and hydrostructural complexity and the lack of certain data on the terrains, the hydraulic conductibility and active recharge do not allow details to be obtained that are comparable to those that can be obtained using SINTACS.

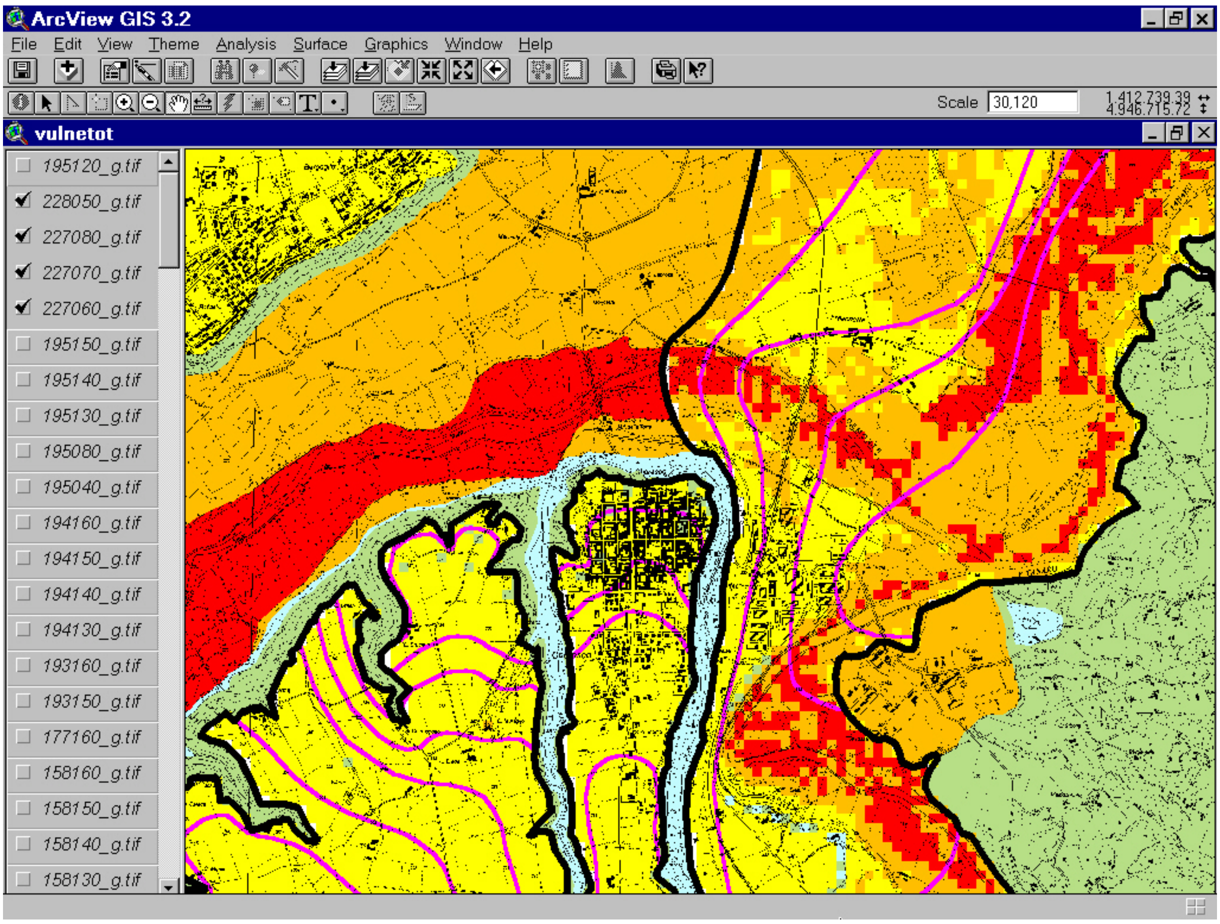


Figure 2: Vulnerability Map: (Red) Extremely Elevated Degree; (Orange) Elevated Degree; (Yellow) High Degree; (Green) Medium Degree and (Cyan) Extremely Low Degree of vulnerability – isopiezometric contour lines in violet

The necessary connection, whether conceptual or cartographic, between adjacent areas where different methodologies should be applied, is supplied by the parametric evaluations. In practice, for those complex places where a parametric evaluation already exists, the same degrees of vulnerability are applied but the different slope and water table conditions are also taken into account.

The application of the combined approach has given excellent results in the Tanaro Project area[15] and led to obtaining a complete covering without any loss of basic information or accuracy of the synthesis. The same numbers of cartographic examples of the vulnerability carried out using the Combined Approach of the two methods are shown in Figure 2. The thick black line in the figure represents the dividing line between the areas treated with the two methods. The homogenization possible with this approach can clearly be seen.

All this is possible thanks to the fact that the calibration with SINTACS was carried out by comparing and cross-referencing (as already mentioned) the SINTACS evaluation with that obtained with the GNDCI-CNR Basic method for over 700 *test-sites* distributed throughout the different Italian areas and territories (Figure 3). The division of the numerical index into 6 degrees of vulnerability, the same as those used for the Basic Method, makes the two methods comparable and the results optimally combinable.

Figure 3: The geographical location of the test sites used to control the subdivision of the SINTACS index in several vulnerability degrees

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[1] The acronym stands for "Vulnerability of Aquifers in High Risk Zones".

[2] GNDCI-CNR stands for National Group for the Defence against Hydrogeologic Disasters, of the Italian National Council of Research.

[3] Law Decree n. 152, May 11 1999 "Orders on the protection of water against contamination" and acknowledgement of the 91/271/CEE Directive regarding the treatment of urban wastewater and the 91/676/CEE Directive regarding the protection of water against contamination by nitrates from agricultural sources.

[4] The so-called POP (Persistent Organic Polluter).

[5] The vulnerability of aquifers to contamination is defined as the specific susceptibility of the aquifer systems to absorbtion, diffusion and also mitigating the effects of, a water-borne pollutant that would cause an impact on the groundwater body in space and over time [7].

[6] The choices that are made, as known, are based on over 13 years of research and experiments in the field, carried out by researchers who have taken part in the GNDCI – CNR Research Line # 4 (Aquifer Vulnerability Assessment). These researchers first worked on the Special VAZAR Project which was then changed to the Special RIAS Project (Contamination Risk to Groundwater).

[7] The time has to add to the normal 3 dimensions that describe the volume and, in this particular case, the TOT should also be added.

Groundwater chemical status assessment in Slovenia

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Abstract: In Slovenia groundwater is the predominant drinking water resource. More than 97% of drinking water is abstracted from shallow, unconfined alluvial aquifers and fractured or karst porosity aquifers. Due to intensive landuse on the recharge areas of shallow alluvial aquifers and their natural vulnerability pollution of groundwater is to be expected. National groundwater quality monitoring has been carried out since 1987. In 2007 monitoring network has been established with sampling sites on all groundwater bodies in Slovenia. Twice to four times a year about 160 different chemical parameters are analysed, among them 100 different pesticides and their metabolites. Groundwater chemical status is assessed according to the national Decree groundwater quality standards[1] by statistical treatment of monitoring results. In 2006 bad chemical status for 3 out of 21 groundwater bodies has been determined. For chemical status assessment representative monitoring network is of crucial importance. This is demonstrated for the groundwater body Savinjska kotlina.

Key words: aquifer, chemical status, groundwater, groundwater body, groundwater quality monitoring, monitoring network

THE IMPORTANCE OF GROUNDWATER IN SLOVENIA

Slovenia is situated at the transition of alpine region, dinaric chain and pannonian basin. Annual precipitations vary from 800 mm/year in pannonian region up to 3000 mm/year in alpine region[2]. The ratio between infiltration and run-off estimated upon IDPR index is higher in karstic and alpine region compared to pannonian region[3]. Most abundant groundwater dynamic reserves are to be expected in regions of high precipitation rate and predominant infiltration.

Considerable part of Slovene area is covered by groundwater aquifers. Groundwater in porous media with 3.726 km² of national territory, and groundwater in karst regions with 12.644 km² of national territory form the most important resource of drinking water, supplying more than 97% of the population. The quality of groundwater is therefore of upmost importance in Slovenia. About 60% of drinking water originates from shallow intergranular porosity (alluvial) aquifers while 40% from fissure and karst porosity aquifers. For about 30 – 40% of drinking water abstracted from aquifers no treatment is needed and drinking water is supplied in its natural state. This is very important advantage and relatively rare in Europe and on other continents. Environmental policies and practice in Slovenia, responsible for the water quantity and quality, declared groundwater as high priority strategic resource which quality should be preserved[4].

Due to intensive landuse in flat river valleys the groundwater quality in shallow alluvial aquifers deteriorated in last decades. Efficient groundwater quality monitoring system and reliable chemical status assessment are the basis for pollution control and remedial actions.

AQUIFERS AND GROUNDWATER BODIES IN SLOVENIA

Aquifer is a geological porous layer with the ability of storing and conducting groundwater. Groundwater within one or several neighbouring aquifers is defined as groundwater body[5].

Major part of Slovenia is covered by sediment rocks with good permeability and intergranular porosity (19.8% of the area), fissure porosity (14.2%) and karst porosity (33.2%). The rest of the area consists of layers with intergranular or fissure porosity with lower conductivity, or rocks with poorer porosity[6].

Alluvial aquifers with intergranular porosity are relatively shallow, flat, gravel – sand alluvial deposits of tectonics depressions along major Slovenian rivers. In the Pleistocene and Holocene of the past two million years of the Earth′s history, surface water deposited great amounts of sediment into tectonic depressions. Alluvial aquifers contribute a vital part to the dynamic reserves of Slovene groundwater (36.8%). Apart from sand and gravel, there are also water bearing layers in limestone, dolomite limestone, sandstone, marl, etc. Karst porosity is typical for the layers of limestone and partly of dolomite, which had been fissured due to the tectonic movements, and were later karstified. For the dolomite layers fissure porosity is characteristic. In fissure and karst porosity aquifers about 62% of dynamic reserves of groundwater in Slovenia are retained[7].

The total amount of dynamic reserves in intergranular porosity aquifers in flat river valleys 18.8 m^3/s while for karst and fissure porosity aquifers the total amount of dynamic reserves is 31.6 m^3/s[8].

According to data of Geological Survey of Slovenia[9] on the Slovene territory there are 165 aquifer systems and 21 groundwater bodies (Figure 1).

LEGAL BASIS FOR GROUNDWATER QUALITY MONITORING AND CHEMICAL STATUS ASSESSMENT

According to Water Framework Directive (2000/60/EC)[5] and Groundwater Directive (2006/118/EC)[10] Member States have to identify and characterize groundwater bodies on their territory and set up groundwater quality monitoring system. Out of the monitoring results chemical status for each individual groundwater body has to be assessed.

The Slovene Environmental Protection Act[11] provides a legal basis for groundwater

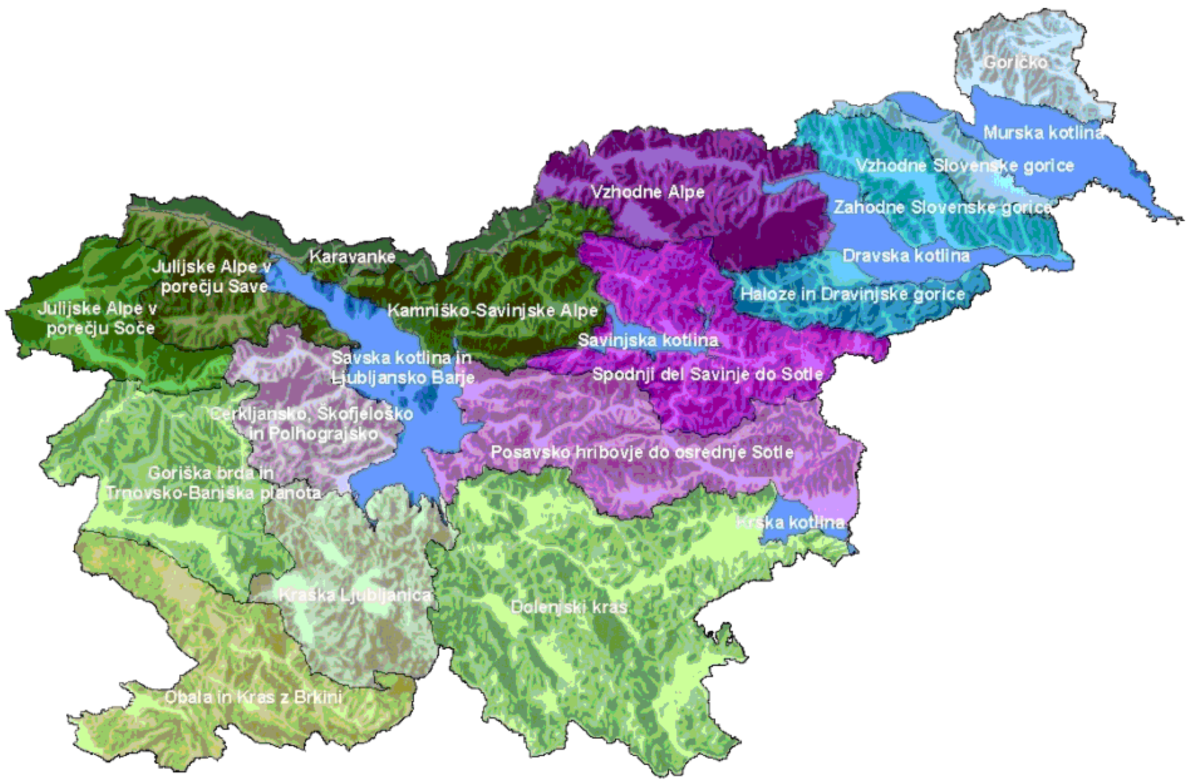

Figure 1: Groundwater bodies in Slovenia

monitoring. Groundwater quality monitoring is carried out according to Rules on groundwater immision monitoring[12]. Decree on groundwater quality standards[1] defines the groundwater quality standards and methodology for chemical status assessment.

Chemical status is additionally assessed by the monitoring results of drinking water abstracted from the groundwater resources. The results are assessed according to the Rules on drinking water[13].

NATIONAL GROUNDWATER QUALITY MONITORING

In Slovenia systematic groundwater quality monitoring on national level has started in 1987. State budget financed national groundwater quality monitoring has been carried out by the Environmental Agency of the Republic of Slovenia (EARS).

Groundwater quality monitoring programme is based on following principles:

Monitoring network

- Monitoring sites (called also sampling sites) have to be positioned according to hydrogeological model of aquifer,
- Monitoring network has to be representative for the whole groundwater body,
- Monitoring sites have to enable sampling of fresh groundwater from the selected aquifer layer without any impact on the groundwater quality,
- Monitoring sites have to avoid direct impact from point sources of pollution,
- Representative monitoring network has to enable reliable chemical status assessment.

Sampling frequency

- 2 – 4 times a year in order to detect seasonal variations in concentrations of individual parameter.

Analysed parameters

- Parameters reflecting geogene (natural) conditions,
- Parameters indicative for human activities on the surface of groundwater body and its recharge area.

In 2007 national monitoring network included 206 monitoring sites and covered all 21 groundwater bodies. Representativity was sufficient for chemical status assessment. Monitoring sites are wells for public drinking water supply, private wells, boreholes, automatic measuring stations and springs. In following years less appropriate monitoring sites will be replaced by boreholes specially designed for monitoring purposes.

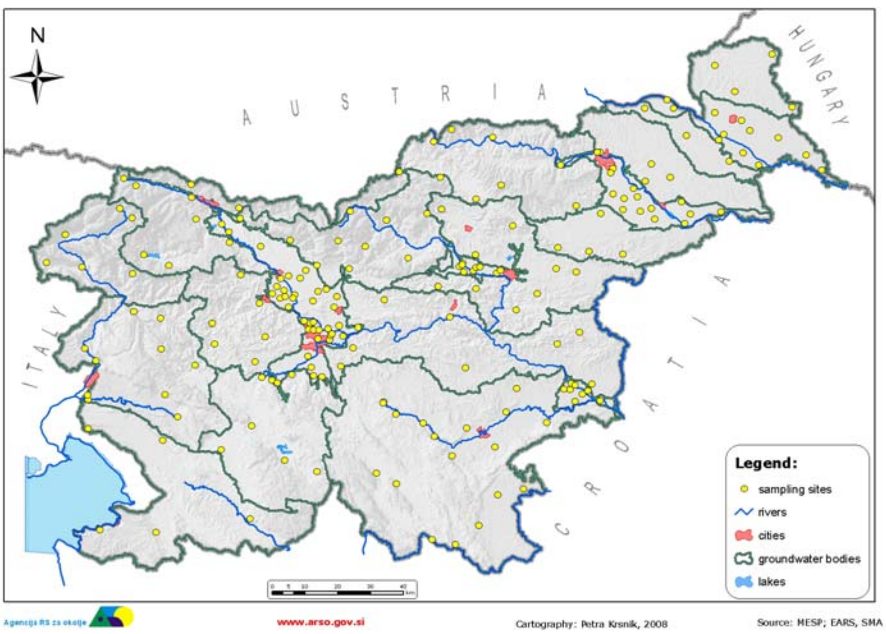

Figure 2: Groundwater quality monitoring network in 2007

The density of sampling sites is higher on alluvial aquifers than on fissure and karst porosity aquifers. Sampling sites on karst aquifers (mostly karst springs) are representative of larger recharge areas compared to alluvial aquifers. On the Figure 2 groundwater bodies with groundwater quality monitoring network are shown.

Five years ago the construction of new monitoring objects specially designed for monitoring purposes started. First two automatic measuring stations (AMS) have been in function since 2003 while the third AMS has been added to the monitoring network end of 2005. AMS have on-line monitoring of following parameters: groundwater level, conductivity, groundwater temperature, pH, oxygen content and nitrate concentration. Every 30 minutes data are transmitted to central computer of the EARS. AMS have multilevel borings which enable sampling of groundwater from different horizons (Figure 3).

Groundwater from all monitoring sites is sampled twice to four times a year and analysed for about 160 different chemical and physical parameters listed in table 1.

Figure 3: Automatic measuring station on the alluvial aquifer of Ljubljana

Table 1: Parameters analysed in groundwater samples

GROUP	Parameters/Groups
Basic chemical parameters	temperature, pH, conductivity, redox, oxygen, COD, TOC, nutrients (inorganic N- and P-compounds), ions of alkaline and earth-alkaline metals, anions, ..
Pollution group parameters	mineral oils, AOX, anionic surfactants, PCB
Metals and metaloids	Al, Sb, As, Cu, Ba, Be, B, Zn, Cd, Co, Sn, Cr, Mn, Mo, Ni, Se, Ag, Sr, Pb, Ti, V, Fe, Hg
Pesticides	triazines, OCP, OPP, phenoxy acetic acid derivatives, phenylurea derivatives, anilines, amides, imides, banzylates, benzonitriles, tia-diazine derivatives
Volatile aliphatic hydrocarbons	chlorinated, brominated and fluorinated derivatives of methane, ethane and ethene
Aromatics	benzene, chlorinated and methylated derivatives

COD chemical oxygen demand
TOC total organic carbon
AOX adsorbable halogenated organic compounds
OCP organo chlorine pesticides
OPP organo phosphorus compounds

CHEMICAL STATUS ASSESSMENT

According to the Decree on groundwater quality standards[1] chemical status is assessed upon:

- Statistically treated results of groundwater quality monitoring
- Results of drinking water monitoring
- Saline intrusion
- Groundwater quality influence on surface waters and dependant terrestrial and water ecosystems

Statistically treated results of groundwater quality monitoring

For individual sampling site yearly arithmetic means (AM) of all parameters are calculated. For all sampling sites of groundwater body representative aggregated values (AM_{SK}) of all parameters are determined. AM_{SK} are calculated out of arithmetic means weighted by surfaces of Thiessen polygons for alluvial aquifers or arithmetic means weighted by recharge areas for karst and fissure porosity aquifers.

Statistically treated results for each parameter of groundwater are compared to the groundwater quality standards (Table 2).

Results of drinking water monitoring

Drinking water monitoring results are evaluated according to standards defined in Rules on drinking water, Annex 1[13]. For non-complying drinking water sampled at the tap the parent drinking water well and aquifer are determined. Only parameters relevant for the groundwater are considered.

Saline intrusion

In Slovenia saline intrusion is feasible only into aquifers of coastal region (groundwater body No. 5019 - Obala in Kras z Brkini).

Table 2: Groundwater quality standards (QS)

Parameters	Unit	Quality standard (QS)
Basic groundwater parameters		
Nitrate	mg NO_3^-/L	50
Individual pesticide or its relevant metabolite	µg/L	0.1
Sum of pesticides and relevant metabolites	µg/L	0.5
Indicative groundwater parameters		
Amonium	mg NH_4^+/L	0.2
Potassium	mg/L	10
Orto-phosphate	mg PO_4^{3-}/L	0.2
Volatile halogenated aliphatic hydrocarbons:		
– Dichloromethane	µg/L	2.0
– Tetrachloromethane	µg/L	2.0
– 1,2-dichloroethane	µg/L	3.0
– 1,1-dichloroethene	µg/L	2.0
– Trichloroethene	µg/L	2.0
– Tetrachloroethene	µg/L	2.0
– Sum of volatile halogenated aliphatic hydrocarbons	µg/L	10
Mineral oils	µg/L	10
Chromium	µg/L	30

Surface waters and dependant terrestrial and water ecosystems

The influence of groundwater quality on surface waters and dependant terrestrial and water ecosystems is going to be studied next year and but will be included in chemical status assessment in following years.

Requirements for good chemical status of groundwater body

1. All individual sampling sites within groundwater body:
   $AM \leq QS$ (for all parameters)

   or for the groundwater body:
   $AM_{SK} \leq QS$ (for all parameters)

2. All drinking water samples abstracted from the groundwater body have to be in compliance with standards for drinking water.
3. No intrusion of saline water into the groundwater body.
4. No chemical status deterioration of dependant surface water bodies.

In case of non-compliance with the requirements chemical status of groundwater body is bad.

CHEMICAL STATUS OF GROUNDWATER BODIES IN 2006

Chemical status of groundwater bodies in 2006 is shown in the Table 3 and Figure 4.

In the year 2006 monitoring network supported chemical status assessment for 13 groundwater bodies (GWB) while for 2 GWB the minimal requirements for representative monitoring network were not achieved. For 3 GWB (Krška kotlina, Dravska kotlina and Murska kotlina) bad chemical status was assessed due to non-conformity with Decree 2005. All 3 GWB are situated in flat river valleys of north-eastern and eastern part of Slovenia, with alluvial aquifers. The pollutants causing bad chemical status were mainly nitrates, atrazine and its metabolite desethyl-atrazine.

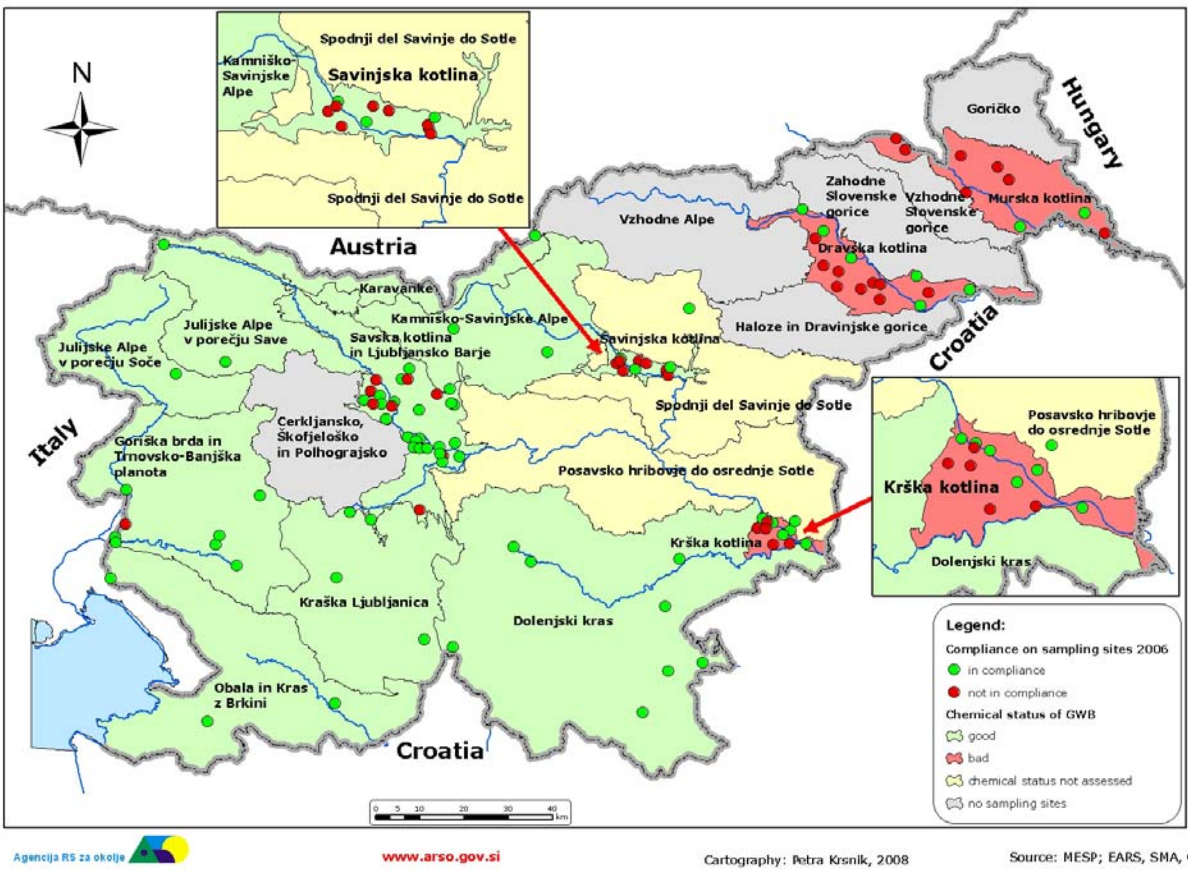

Figure 4: Groundwater quality on sampling sites and groundwater chemical status in 2006

Table 3: Chemical status of groundwater bodies in 2006

GWB code	Name of GWB	Aquifers type	Chemical status		Non-complying parameters	Endangered parts of GWB
			Ground-water	Drinking water		
1001	Savska kotlina in Ljubljansko barje	alluvial	good	good	/	/
1002	Savinjska kotlina	alluvial	good	good	/	/
1003	Krška kotlina	alluvial	bad	bad	nitrates, DAT, BENT	Krško polje, Škocjan-Krško gričevje
1004	Julijske Alpe v porečju Save	karst/fissure porosity	good (estimated)	good	/	/
1005	Karavanke	karst/fissure porosity	good (estimated)	good	/	/
1006	Kamniško-Savinjske Alpe	karst/fissure porosity	good (estimated)	good	/	/
1008	Posavsko hribovje do osrednje Sotle	karst/fissure porosity	0	bad	DAT	Območje Mirne
1009	Spodnji del Savinje do Sotle	karst/fissure porosity	0	good	/	/
1010	Kraška Ljubljanica	karst	good	good	/	/
1011	Dolenjski kras	karst/fissure porosity	good	good	/	/
3012	Dravska kotlina	alluvial	bad	bad	nitrates, AT	Dravsko polje
4016	Murska kotlina	alluvial	bad	bad	nitrates, AT, DAT, BENT, Mn, DCE, TCE, PCE	Apaško polje, Dolinsko-Ravensko polje
5019	Obala in Kras z Brkini	karst/fissure porosity	good	good	/	/
6020	Julijske Alpe v porečju Soče	karst/fissure porosity	good (estimated)	good	/	/
6021	Goriška Brda in Trnov.-Banjška planota	karst/fissure porosity + alluvial	good	good	/	/

GWB groundwater body
AT atrazine
DAT desethyl-atrazine
BENT bentazone
DCE dichloroethene
TCE trichloroethene
PCE tetrachloroethene

GWB of Murska kotlina was additionally polluted by bentazone and chlorinated organic compounds dichloroethene, trichloroethene and tetrachloroethene. According to monitoring results groundwater in karst and fissure porosity aquifers is of better quality. Nitrate concentrations are low (up to 10 mg NO_3/L, mostly < 3 mg NO_3/L), pesticides are rarely detected by the analytical methods applied.

Groundwater quality on individual sampling sites as well as chemical status in 2006 are depicted on the Figure 4.

On the Figure 4 green circles on sampling sites represent groundwater quality in compliance with standards while red circles are used for groundwater being not in compliance with the Decree 2005. Most sampling sites with groundwater not in compliance with standards are in north-eastern part of Slovenia. Groundwater quality of all sampling sites on karst and fissure porosity aquifers is in compliance with standards, concentrations of pollutants being very low or even under limit of detection of applied analytical method. Consequently for all groundwater bodies with karst and fissure porosity aquifers good chemical status was assessed in 2006. Good chemical status for groundwater bodies with predominantly alluvial aquifers was assessed only for 2 groundwater bodies (Savska kotlina in Ljubljansko barje and Savinjska kotlina). In Savinjska kotlina groundwater quality on 8 out of 11 sampling sites was not in compliance with standards. Good chemical status was assessed merely by statistical treatment of results on all sampling sites together. Requirement $AM_{SK} \leq QS$ was fulfilled for all relevant parameters.

RELIABILITY OF CHEMICAL STATUS ASSESSMENT

Reliability of chemical status assessment depends on various factors. Most important factors influencing chemical status assessment especially for groundwater bodies with alluvial aquifers are:

- Knowledge on geological and hydrological characteristics of aquifers
- Monitoring network representative for the groundwater body
- Density and position of sampling sites
- Type, materials and filter position of sampling sites
- Maintenance and control of sampling sites
- Frequency of sampling
- Sampling procedure, transport and storage of samples
- Analytical procedures

The influence of sampling site position on chemical status assessment is demonstrated for the groundwater body Savinjska kotlina in 2005. To demonstrate the influence of monitoring network on chemical status assessment few virtual changes on national monitoring network were induced. The case study was made for groundwater body Savinjska kotlina, which after few years of bad chemical status due to high nitrate concentration was in 2005 for the first time assessed to have good chemicals status. Representative aggregated value for nitrate (AM_{SK}) was slightly lower than quality standard (Table 4). National monitoring network for the groundwater body is shown on the Figure 5.
Positive bias was demonstrated by removing sampling sites with high nitrate content, while in contrary for negative bias sampling sites with low nitrate groundwater were taken out from national monitoring network. Four virtual networks showed comparable representativity. Impact of monitoring network on statistically treated results is demonstrated by representative aggregated value (AM_{SK}) for nitrates for different settings of sampling sites.

Positive bias – removal of sampling sites with high nitrate groundwater:

- Positive bias 1: monitoring network without Šempeter (Figure 6)
- Positive bias 2: monitoring network without Šempeter and AMP Levec (Figure 7)

Negative bias – removal of sampling sites with low nitrate groundwater:

- Negative bias 1: monitoring network without Breg (Figure 8)
- Negative bias 2: monitoring network without Breg and Roje (Figure 9)

Thiessen polygons indicating uniformity of monitoring network setting are drawn for all configurations (Figures 5 – 9).

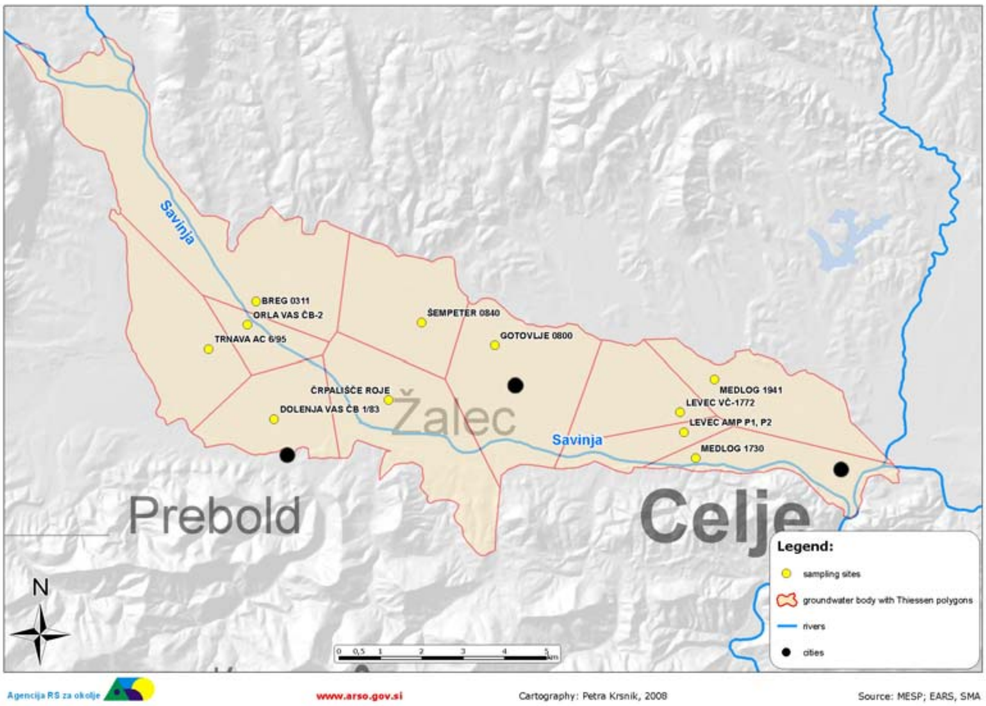

Figure 5: National monitoring network on Savinjska kotlina

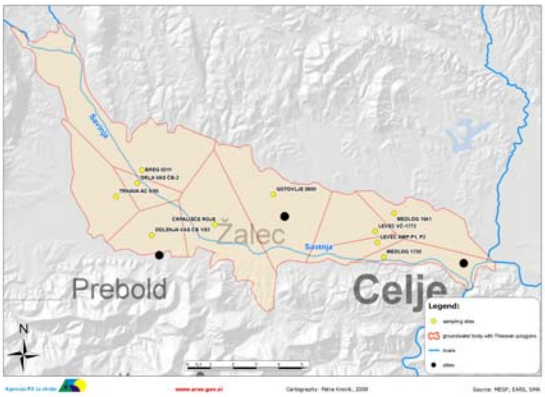

Figure 6: positive bias 1

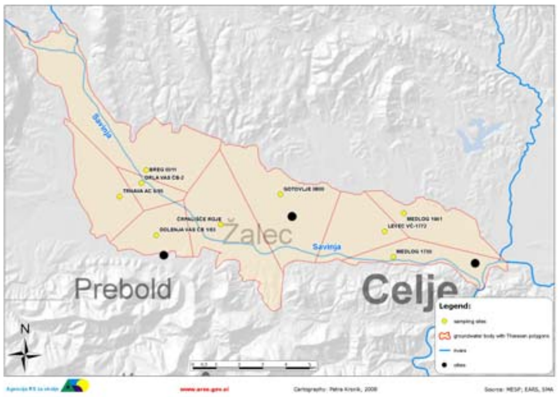

Figure 7: negative bias 1

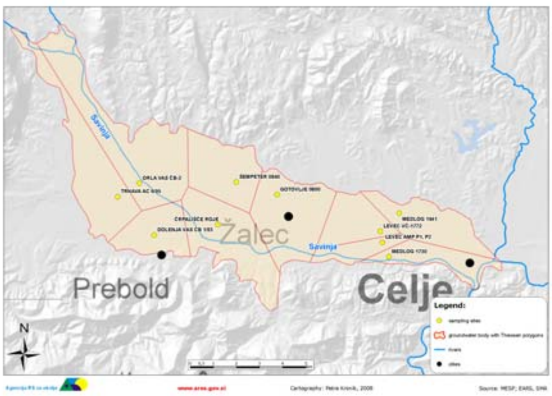

Figure 8: positive bias 2

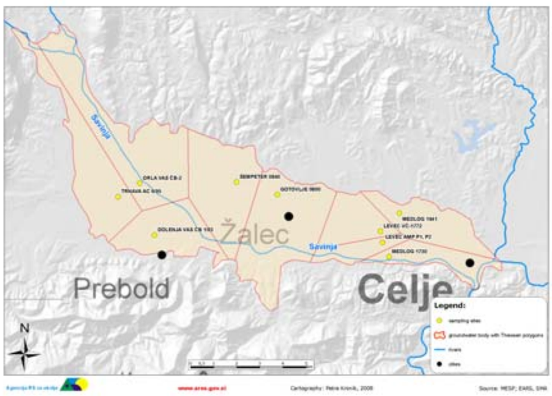

Figure 9: negative bias 2

As seen from the Table 4 removal of only one low nitrate sampling site (drinking water well Breg) would turn the good chemical status to the bad status. Influence of individual sampling site depends on representative area defined by Thiessen polygons and on nitrate concentration.

Table 4: Influence of monitoring network on chemical status assessment

		AM_{SK} for nitrates ($mg\ NO_3^-/L$)	Chemical status
Positive bias 2	MN – 2 polluted s.s. (Šempeter, Levec)	43.5	Good
Positive bias 1	MN – 1 polluted s.s. (Šempeter)	43.9	Good
No bias	National MN	48.8	Good
Negative bias 1	MN – 1 DW well (Breg)	59.1	Bad
Negative bias 2	MN – 2 DW well (Breg, Roje)	65.5	Bad
	QS for nitrates	50.0	

MN monitoring network
s.s. sampling site
DW drinking water
AM_{SK} representative aggreagated value
QS quality standard

CONCLUSIONS

Chemical status is statistically represented state of the whole groundwater body where local pollution often remains unnoticed. Chemical status assessment, highly dependant on monitoring network, is the first step toward classification of groundwater quality. If groundwater quality of all sampling sites is in compliance with standards and all the requirements for good status are fulfilled the groundwater body's chemical status can be assessed as good. On the other hand for groundwater bodies where groundwater pollution has been evidenced on one or even more sampling sites detailed investigation of pollutant concentration together with suspected sources of pollution has to be undertaken.

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The Time-Input vulnerability method and hazard assessment at a test site in the Front Range of the Eastern Alps

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Abstract: The Time-Input Method is a new scheme to evaluate groundwater vulnerability (sensitivity), especially in mountainous areas. The main factors are: (1) the mean travel-time of water and contaminants from the terrain to the groundwater surface (about 60%), enhanced or diluted by (2) the amount of input as groundwater recharges (about 40%). In contrast to most other assessment methods, the vulnerability is expressed in real time and not classified by dimensionless numbers, with the advantage that the final result can be directly evaluated using hydrogeological techniques.

The Index-Method was applied in a well-studied forested dolomitic karst area in the front range of the Austrian Northern Calcareous Alps. The aspect and the dip of the bedding planes towards or away from the groundwater have been incorporated into this method. These are in addition to the traditionally chosen investigation layers such as vegetation, slope inclination, the thickness of the soil, unconsolidated sediment and unsaturated rock and fault zones.

In addition, a hazard assessment method was applied to evaluate the risk of groundwater contamination posed by tourist and logging activities in this area.

Key words: groundwater vulnerability, mean residence time, groundwater recharge, risk assessment, Austria

GENERAL

The Time-Input Method[1] in the frame-work of the European Approach[2] and the hazard assessment were applied in a well-studied forested dolomite karst area in the front range of the Austrian Northern Calcareous Alps (Reichraminger Hintergebirge), 50 km South of Linz. The total 5 km^2 area was split into a fine grid of 20x20m cells. The altitude of the steep mountain ridges ranges between 500-950m. The monitoring sites are divided between the plateau and slope areas. Naturally mixed mountain forest (beech, fir) covers 85% of the area. The rest is bush and grassland.

The annual rainfall ranges from 1500 to 1800 mm and depends strongly on the local relief (slope and orientation). The monthly precipitation ranges from 100 mm (October) to 230 mm (July). The lowest mean monthly temperature (900m) is -0.9°C (January) and the highest is 15.5°C (August). There are 188-198 days with temperatures above 5°C. At altitudes of 900m, snowfalls occur between November and May, with an average snow-cover duration of about 4 months, though this is very variable[3].

Human impacts are logging, hunting, mountain-biking and mountaineering.

THE GEOLOGY AND SOIL CHARACTERISTICS OF THE INVESTIGATED AREA

Tectonically, the Northern Calcareous Alps of Austria form part of the east alpine orogeny, with a clearly north-facing imbricate and folded structures, originating from the Cretaceous and Tertiary orogenies. The project area belongs to the "Reichraming" nappe and is part of the north-vergent "Kreuzeck" anticline.

The main type of rock is Norian (Triassic) dolomite (Hauptdolomit), with a thickness up to 500 metres. In some small areas, the dolomite is overlain by limestone (Plattenkalk) and Upper Jurassic - Lower Cretaceous marls, limestone and radiolarites (Figure 1).

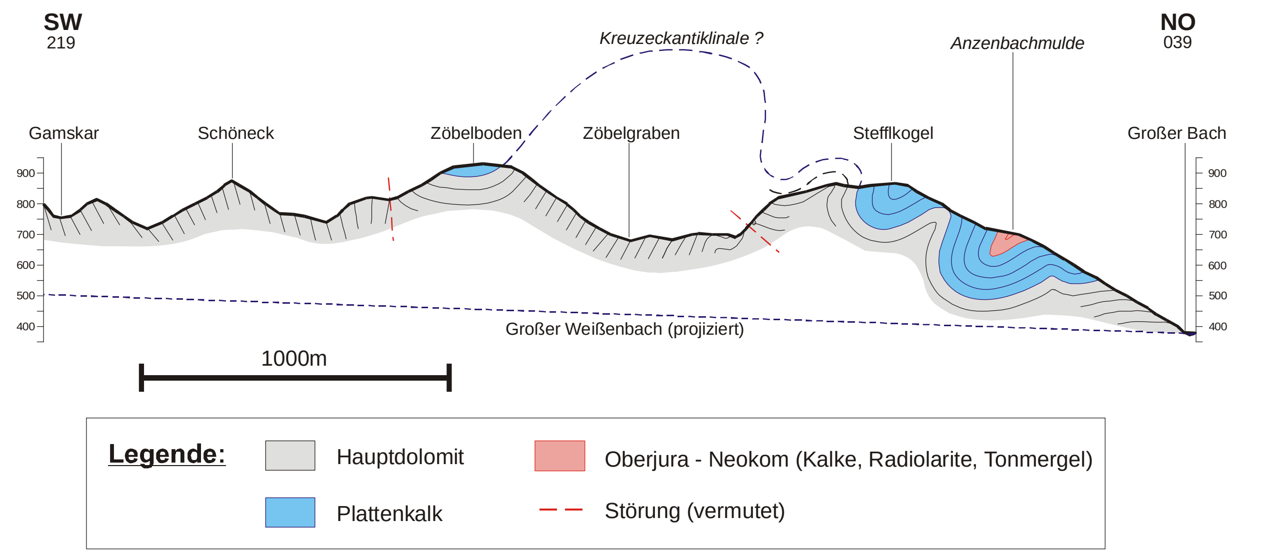

Figure 1: Cross-section of the Zöbelboden dolomite massif

Hydrogeologically, the dolomite is a fractured aquifer with limited karstification along the bedding planes and fault zones indicated by initial doline structures on the plateau of the Zöbelboden.

The occurrence and distribution of soil types mostly depends on the local relief (inclination). According to FAO-nomenclature, the plateau contains mainly medium thick (0.3-0.6m) Cambisol (relictic brown loams most likely formed from weathered dolomite (the whole region was a part of the periglacial zone) and the partly steep (30-45°) slopes show mainly thin (0.05-0.30m) Rendzic Leptosol (colluvially influenced Rendzinas).

Below the soils, coarse-grained dolomite scree (talus) covers the plateau of the carbonate massif and the lower parts of the slopes of the Triassic carbonate rocks. These layers, up to several meters thick, are caused by earlier fluvio-glacial activities or recent ongoing erosion. They form the "aquifer" for a rapid interflow discharge, predominantly during rainstorms and long-lasting rain events.

GROUNDWATER VULNERABILITY ASSESSMENT

The European Approach was applied here by using the Time-Input Index-method for groundwater vulnerability assessment developed for mountainous and structural complex investigation areas in particular.

The Acquisition of Assessment Data

The official Austrian 1:25.000 geographical map was enlarged to a scale of 1:5.000 and the investigation area of 5 km^2 provided with a 20x20m grid. The geological 1:50.000 map of the Austrian Geological Survey and a detailed 1:10.000 hydrogeological map of this area[4],[5] were used for geological background information. These also provided the basis for estimating the thickness of the layers and to delineate areas with the dip of bedding planes towards and away from the groundwater. Usually, soil information was obtained by assigning typical morphologies such as hilltops, plateaux, depressions, trenches, steep and gentle slopes and soil assemblages. This information was obtained from aerial photographs. The mean evapotranspiration decreases from 35% (forest) and 23% (scrub and grassland) to 7% (bare rock). Therefore, vegetation can be simplified into three classes[6].
In addition to the aforementioned interpretation, six days of fieldwork were undertaken in order to obtain necessary additional data and to verify the results.

Evaluation of the Main Factors (Residence Time) and Input (Groundwater Recharge)

The discharge, temperature, electrical conductivity, pH and major ions were measured periodically at twenty springs and surface waters (small sub-catchments). This data was combined with measurements from a main online station with weekly sampling for chemistry. This allows the identification of sub-catchments with an excess or a deficit in the nominal discharge. Likewise, those sub-catchments may be identified with highly variable water composition and rapid travel-times of at least part of the water input.

The significantly lower surface runoff of the southern sub-catchments reflects the importance of the higher evapotranspiration due to the greater input of solar radiation. Excess discharge from the south-eastern and eastern springs and the surface runoff from their sub-catchments indicate rapid groundwater transport from the plateau area and the north-facing catchment areas along tectonic fault zones.

The springs at higher altitudes (700-800m) are very dynamic (high relative standard deviations) in water temperature and conductivity. These south-eastern and eastern springs show a medium response following storms, while the northern springs close to the receiving stream are very constant (Figure 2).

Oxygen-18, Deuterium and Tritium model calculations indicate mean residence times of some weeks, which is in agreement with the vulnerability assessment. Only the northern springs have ages of several months.

Four tracer experiments[7] on top of the plateau close to the fault zones and karstification structures (removed soil covering) indicate a short residence time of 1-2 days (Figure 2) during and after heavy rainfall, as determined previously using the TIME–INPUT method.

Discussion of Time and Input Assessment

The results of this study obtained using of the Time-Input assessment scheme highlight the vulnerability of the groundwater, especially above faults and along the lowest parts of the slopes closest to the groundwater. Most springs emerge in this area in this strongly tectonised bedded dolomite formation and some fault zones seem to be responsible for rapid travel-time to the groundwater, as demonstrated by tracer tests.

Table 1: The attribution of the total bulk infiltration (travel-times) to time classes

Time-Classes	Time-Intervals	Bulk infiltration times in seconds	Vulnerability classes
1	<12 hours	<43200	**extreme**
2	12-24 hours	43200 - 86400	
3	1-2 days	86400 - 172800	**high**
4	2-4 days	172800 - 345600	
5	4-7 days	345600 - 604800	
6	1-2 weeks	604800 - 1209600	**medium**
7	2 weeks -1 month	1209600 - 2592000	
8	1-3 month	2592000 - 7776000	**low**
9	3-6 month	7776000 - 15552000	
10	>6 month	>15552000	

The classification of the infiltration travel-time from the land surface to the groundwater surface into ten classes certainly indicates tendencies rather than accurate estimates. It could also be grouped into three vulnerability classes: High (travel-times of 1-4 days), medium (1-4 weeks) and low vulnerability (> months) during or after a series of major rainfall events (Figure 2; Table 1). The input (groundwater recharge) classes (Table 2) have to be adapted to the climatological conditions in order to obtain the modified time classes for expressing the degree of vulnerability (Table 1).

However, the medium vulnerability classification of most parts of the investigation area, with some minor parts with extreme and high vulnerability, is reasonably confirmed by the evaluation steps.

Table 2: The correction factors for the Input (groundwater recharge by the amount of infiltrating water)

GW-recharge by infiltrating water	Correction Factor *f* (mm)
0-200 mm	1.5
200-400 mm	1.25
400-600 mm	1.0
600-800 mm	0.75
800-1000 mm	0.5
>1000 mm	0.25

HAZARD ASSESSMENT

Introduction

Because the investigation area is situated in a national park area, a hazard assessment method recommended by Hötzl and others[8] was applied in order to evaluate the risk of groundwater contamination posed by human activities.

A Description of the Hazards

Two different kinds of hazards could be identified in the Zöbelboden test site: linear and point hazards.

Linear hazards are shown in Figure 2 as unsecured roads surrounding the test area and two logging roads (in the North and in the centre of the Zöbelboden). They represent a potential source of contamination from transport and traffic. The unsecured roads are frequently used by trucks transporting timber. In summer and especially on weekends, a high number of tourists use the roads visiting the “Calcareous Alps” national park.

The point source hazards are concentrated around houses or parking lots. The houses in the NE of the test area are mainly used for recreation and vacationing; the others are mainly used by forest workers and hunters. The former houses are equipped with septic tanks. In comparison, the houses used by forest workers and hunters have no sewer systems. That means that waste water represents the most likely contamination in this case. Although there are no differences according to the weighting value H, distinctions can be made using the reduction factor R_f (Table 3).
The parking lots suggest another possibility of contamination from transport and traffic (1.4). Here, leaky fuel tanks or dripping oil can pose a threat to the ground water.

Determination of the Hazard Index (HI)

The weighting value **H** was taken from the list of hazards[8] and gives a factor ranging from 0 (not harmful) to 100 (extremely harmful) to indicate the harmfulness of a hazard to the groundwater.
The ranking factor $\mathbf{Q_n}$, ranging between 0.8 and 1.2, can affect the weighting value by up to ± 20% by multiplying it by H. This shows the quantity of toxic substances in comparison to the average.
The reduction factor $\mathbf{R_f}$, ranging from 1 to 0, is an empirical number. If the factor is 0, it means that there is no possibility of contaminating the groundwater, while 1 means that there is no information on whether the groundwater can be contaminated or not.
Multiplying these three values results in the Hazard Index (HI), which describes the harmfulness of each hazard. All hazards mapped in the test area have relatively low (> 24 – 48 points) or very low hazard levels (< 24 points) (Table 3). As a result, the hazards in the test area can be divided between the hazard index classes 1 and 2 (very low and low), according to the classes proposed.

The signature and symbols for the different types of hazards are shown in Figure 2 in the groundwater vulnerability map.

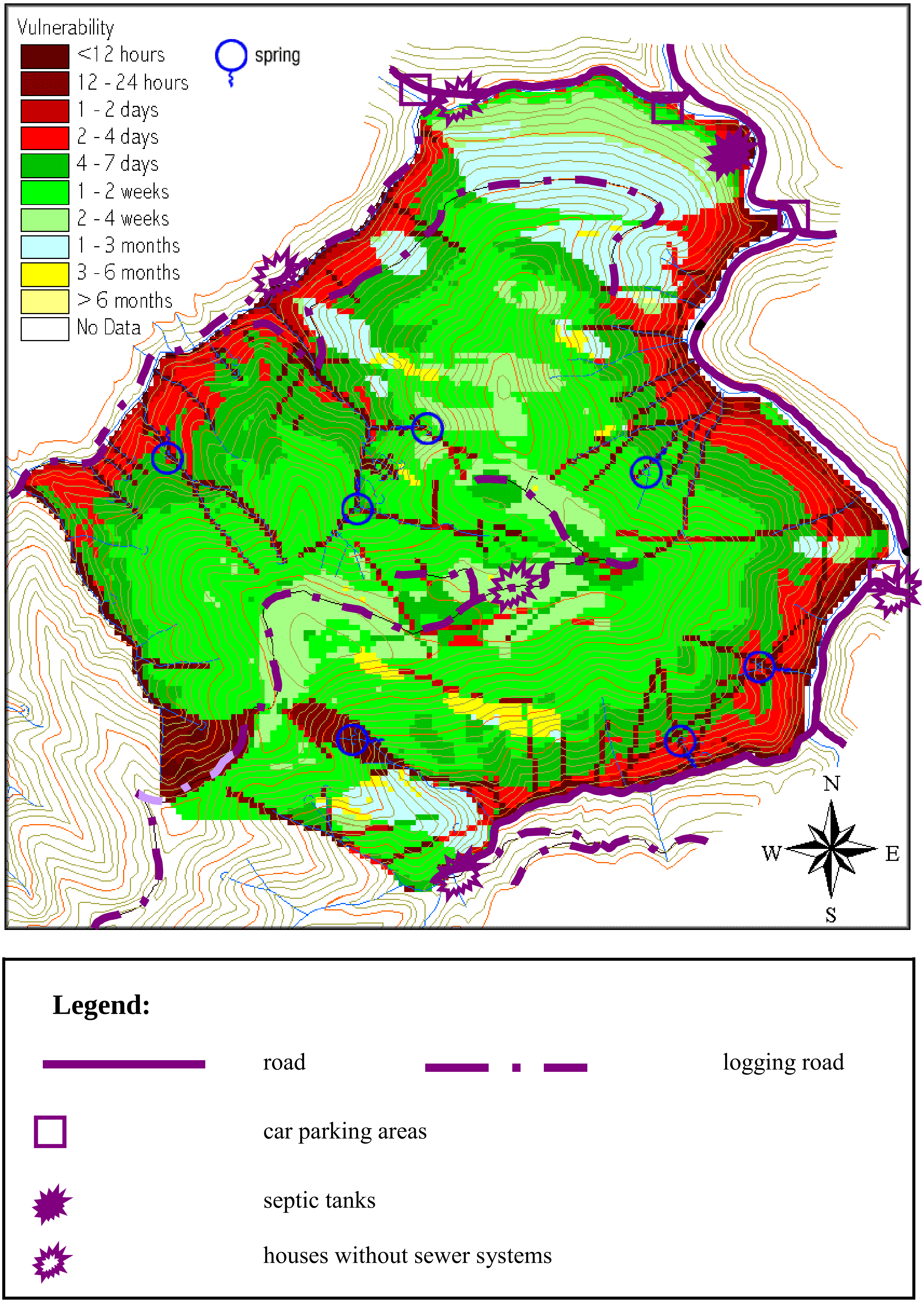

Figure 2: The combined groundwater vulnerability (Vulnerability classes according the Time-Input method[1]) and the hazard map of the Zöbelboden test site (Reichraming, Austria)

Table 3: List of hazards mapped in the Zöbelboden test site

HAZARDS	Weighting Value H	Ranking factor Q_n	R_f	Hazard Index HI
Road, unsecured	40	0.85	0.8	27
Logging road	40	0.8	0.8	26
Car parking area	30	0.85	0.8	20
Septic tank	45	1	1	48
Houses without sewer systems	45	1	0.8	36

Discussion

Hazard and Risk assessment: Due to the introduction of hazard information in the groundwater vulnerability map (Figure 2), sites with an increased risk of groundwater contamination around houses, roads and parking areas can be shown. The houses and roads around the Zöbel massif are located above highly vulnerable areas without protective cover and with quick transfer times to the groundwater. However, due to the relatively small hazards, high dilution (1500-1800 mm precipitation) and small distances to the creeks, the risk of intensive and long lasting groundwater contamination is extremely low. A slightly higher risk of groundwater contamination exists along the logging road that crosses the broad and intensive tectonised fault zone in the Southwest of the investigation area.

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Complex field experiment as a base for modelling of unsaturated zone – case study from Ljubljana Field

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Abstract: Field experiments can serve as a base for modelling or for verification and calibration of the model. Mathematical models enable smaller amount of measurements in a certain area by means of measurements carried out only in characteristic points. Field experiments are very often very time and physical work demanding, so they have to be planed carefully and complex enough to be of cost benefit for researches. Combination of on site measurements and mathematical modelling proved to be an efficient method for understanding of processes in nature.

Key words: field experiment, nitrate leaching, groundwater pollution, irrigation, fertilisation

INTRODUCTION

Nitrogen is one of the most dynamic biogenic elements. It's cycling through the atmosphere, hydrosphere, biosphere and geosphere represents an extremely complicated complex of chemical, physical and biochemical reactions. One of the most common compounds of nitrogen in nature is nitrate, resulting from natural processes in nitrogen biogeochemical cycle. Antropogenous sources and general antropogenous influence on environment have strongly increased natural nitrate flow between individual environmental systems, which has contributed to strong increase of nitrate concentration in soil, groundwater and partly in biosphere. Harmful and unfavourable health and environmental impacts call for immediate response and permanent remedial actions related to the protection of underground water against pollution. Unsuitable agricultural techniques are one of the main pollution sources. How much nitrogen will be accumulated by plants or how much nitrogen will remain in soil and leach into the groundwater depends on several factors: (1) fertilisation intensity, (2) form of nitrogen source, used for fertilisation, (3) time of application, (4) irrigation, (5) soil texture, (6) topography, (7) the age of arable land and (8) physical chemical and biotic processes in soil.

Present water resource protection policy gives priority to the control over non-point pollution sources from agriculture. The consumption of nitrogen fertilisers in Europe decreased in general to meet the demands of the European Union common agricultural policy, however, estimated effect on decrease of nitrate leaching from soils is relatively low[1]. Nitrate leaching still represents a loss of around 19% of total nitrogen applied worldwide for fertilisation[2]. In spite of the importance of this problem understanding of nitrate leaching from different soil types is still insufficient[3]. Increase of effective nitrogen plant uptake is for ground water protection of higher importance than denitrification with which the nitrate quantity, which can leach into the groundwater, is supposed to decrease[4]. A critical parameter is the availability of nitrogen for plants. Preferential consumption of one of the nitrogen forms of certain plant species (organisms) totally changes the ratio of available nitrogen forms for other plant organisms, which is important in natural systems as well as in agriculture. Condition of the root system, mycorisis and physical and chemical soil characteristics are also important factors[5]. Differences in physiological bacterial capacity in soil for the immobilisation and mobilisation of the nitrogen can decisively influence the speed with which soil nitrogen moves into forms, available for the corps or is lost into the groundwater or to the atmosphere[6].

Nitrate tracing techniques using ^{15}N have been used in agriculture for several decades. Most of the experiments were based on the fact that nitrate isotope fractionation in natural systems is insignificant if regarded in absolute terms when a compound with more than some atomic percentages of ^{15}N is used as a tracer. In such case deviation from natural ratio between $^{15}N/^{14}N$ (1/272) can be directly used to estimate the application of added tracer in the ecosystem. Detailed descriptions of the tracer techniques using ^{15}N in various ecosystems are available[7]. In field experiments, ^{15}N diluted by several orders of magnitude is normally used, so that the tracer concentrations move within natural range but are still significantly higher than the background, thus enabling good tracing properties. This enables also the use of various classical analysis techniques, which have to be especially adapted for high ^{15}N concentrations[8],[9].

Most of the nitrogen in the soil is present in the form, unavailable for the plants. Isotopic composition of the total nitrogen is not a suitable parameter for the determination of the isotopic composition of nitrogen, which can be assimilated by plants or can be potentially leached into the groundwater. Compared to the organic nitrogen, soil solute contents of nitrogen are relatively low, but it is that much more susceptible to the changes in the system. Of all the nitrogen forms, nitrate is the most likely to leach[10],[11], therefore it is the biggest potential pollutant of groundwater. Soil complexity often aggravates detailed nitrate storage analysis. Analysis of the nitrate nitrogen in soil is complicated and the choice of the leaching method of the nitrate nitrogen can contribute to substantial differences in measured concentration, especially in isotopic composition. Analysis of the plant root system, especially hair roots is therefore the best way to estimate the quantity of the available soluble inorganic nitrogen[11].

With the help of geochemical and isotopic research it has been determined that the highest recharge source of groundwater in shallow aquifers represents vertical precipitation infiltration which leaches nitrates from the soil directly into groundwater. Groundwater quality is also influenced by groundwater level and temperature, which accelerates organic material decomposition which is reflected in lower $d^{13}C$ values of soluble inorganic carbon[12].

Use of nuclear or isotopic techniques presents an important and internationally acknowledged contribution to the development of sustainable methods for soil and water resource management as well as sustainable agriculture.

Use of stable isotopes as natural or artificial tracers, which are added in the form of heavy-isotope enriched compounds, is the most reliable method for determination of nitrate origin and reactions that influence its isotopic compound. Many interconnected processes influence the isotopic compound of nitrate in the soil-soil water-plant system, such as fixation, assimilation, mineralization, nitrification, denitrification, evaporation, sorption/desorption and others. Experiments to trace nitrogen path through the ecosystem are aggravated by complex isotopic fractionation which occurs between interactive cycles of mineralisation, nitrification, immobilisation assimilation and denitrification in the soil, as well as simultaneously occurring processes which influence transportation and mass flow of nitrogen. Taking into consideration that most of the processes of the nitrogen biogeochemical cycle fractions its isotopes predictably and that fractionation factors are known, the use of stable isotopes is the best possible method of studying the processes in which nitrogen is involved in the system plant-soil solution-groundwater.

A detailed overview of scientific literature from the field of hydrogeology and other sciences dealing with underground water resources shows that during the recent years, two closely related fields of interest have been most investigated: the studying of processes in the unsaturated zone and the migration of pollutants through the aquifer.

While some theoretical principles of groundwater flow and its transportation through the aquifer have long been solved, a detailed view of publications shows that much effort is put into the development of methods to determine the parameters and into their implementation. Much attention in literature is devoted to on-site measurements and interpretation of these measurements in the context of individual cases (case studies). In case studies, especially the influence of antropogenous factors is most dealt with, as these problems are the most urgent with regard to water supply[13],[14],[15],[16],[17],[18].

The research was focused on the whole system plant-soil solution-groundwater. For this purpose, a suitable experimental field was chosen, where mass nitrogen flow in soil and its influence on potential groundwater was monitored. Nitrogen mass flow in the system was traced with the help of the concentration in isotopic compound of the nitrate types in soil, water-soluble nitrogen, root system, plant (leaves) and groundwater. Mass and isotopic balance of the system was made. Stable isotope 15N was used as a tracer. 15N is totally harmless as it appears in natural concentration at around 0.368at%. Therefore it can be used in field or in vivo experiments without restraints. Results of previous research on nitrate pollution sources from agricultural intensive areas and experiences gained with isotopic techniques in environmental studies served as basis for the research with which existing knowledge nitrogen circulation in complex natural systems was upgraded.

Research results are the groundwork for the determination of more efficient fertilisation methods and thus for the definition of lower fertilisation norms than presently accepted and applied in vegetable production techniques, which is interesting for the agricultural sector. On the other hand, the understanding of potential dynamics of nitrate leaching into groundwater can be one of the foundations for decision making on more efficient groundwater quality monitoring, which is interesting for the environment protection sector. Complex research results can be a good base for the determination of individual measurements for agricultural land from which groundwater, important for water supply, is recharged. Results will help with long-term decisions about investments into prevention measure programs and long-term orientations in the field of agricultural and spatial planning in water protection zones.

Generally, the unsaturated zone represents an area of important storage of groundwater and pollutants and plays a key role in the transport of pollutant into the saturated zone used for drinking water extraction.

In situ experiment can provide a more detailed knowledge of factors which are important for the transport of nitrates to the aquifer: chemical processes (dissolution, adsoption, reduction/oxidation, hydrolysis, biological degradation) and of properties of porous medium: area, particle size, structure, mineralogical composition. Results will be used to define parameters for a numerical model.

MATERIALS AND METHODS

General description of the area

The area of alluvial aquifer Ljubljansko polje is certainly one of the most representative cases of high nitrogen load resulting from agricultural and urban environment in Slovenia. At the same time, this is also the most typical case of agricultural area with explicitly high income from conventional agricultural land use and very low share of subsidized agriculture and interest in more intensive production practices (greenhouses, irrigation), which extend exactly in drinking water recharge areas.

Ljubljana Field is an aquifer with intergranular porosity and a dynamic capacity of 3.5 m^3/s, making it one of the biggest drinking water resources in Slovenia. It is a flat area where the interests of agriculture, urbanisation, traffic, industry and public water supply all intersect. Influences of all the activities present in the area are reflected in the quality of the groundwater. Groundwater monitoring has been performed for several decades. Nitrate is one parameter that has varied over time and is regularly increasing. 1990 ha of agricultural land with intensive vegetable production exists inside drinking water protection zones.

The water field watershed is an area of agricultural and forestry use, industrial and light manufacturing development and rapid residential construction. The area has an extensive transportation system, multilane highway with more than 59000 vehicles per day.

The groundwater body of Ljubljana Field is built up from an intergranular aquifer that extends over an area of 95 km^2. The groundwater body is 18 km long, 8 km wide and 35 to 100 m thick. It is one of the biggest and most important aquifers in Slovenia. The area of Ljubljana Field is a bowl-shaped tectonic sink consisting of river sediments reaching to a thickness of more than 100 m in the deepest part. Amongst the alluvium of sand and gravel on the Ljubljana Field there are several layers of conglomerate lenses. Above the lenses, there are many clay deposits, which, together with conglomerates represent a barely permeable complex.

Description of the experiment

On the chosen location on the area of Ljubljana aquifer (outside of water protection zones) (Figure 1), experiment with vegetables was set where various fertigation and irrigation techniques were included. Field experiment was carried out in repetitions throughout the vegetation period in the years 2006 and 2007.

Research hypothesis were:

- correct irrigation decreases nitrate leaching toward groundwater (hypothesis is based on the fact that plants can only accept nutrients when there is enough soil moisture for plants to overcome the force with which water is bound in the soil).
- correctly applied fertilisation with irrigation (fertigation) which is temporally and spatially adjusted to plant demands, enables a qualitatively and economically sound yield with low nitrate content and low nitrogen losses from the soil – plant system.

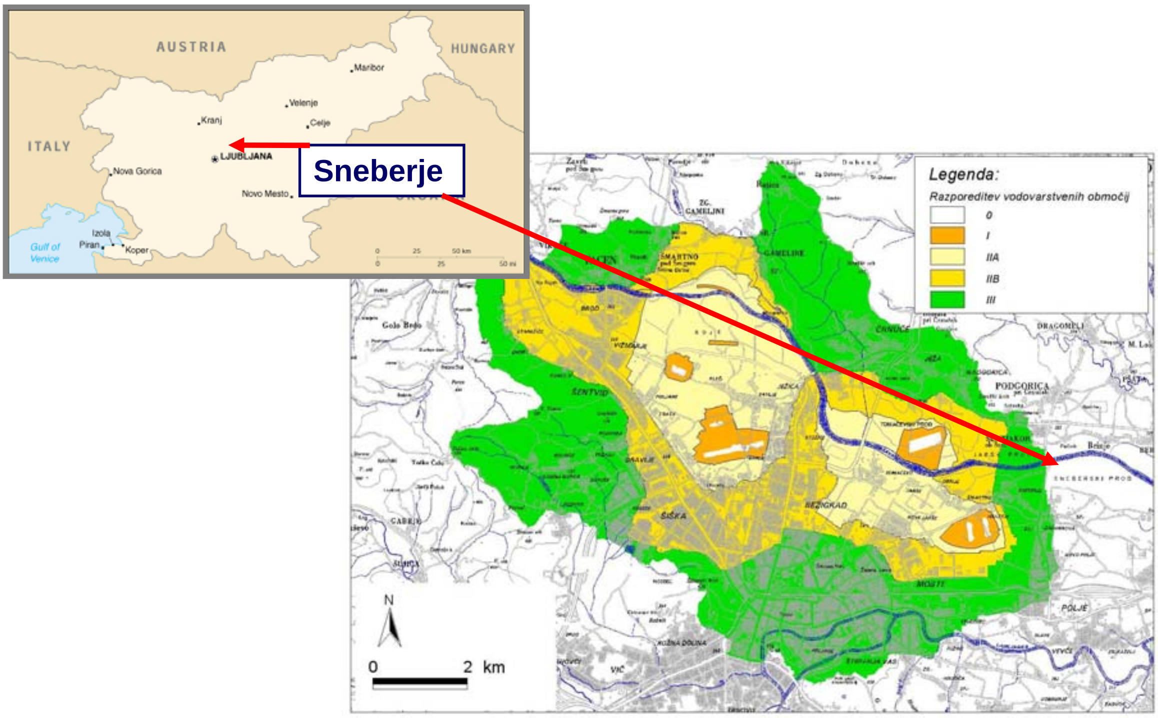

Figure 1: Location of a complex field experiment on Ljubljana Field - Sneberje

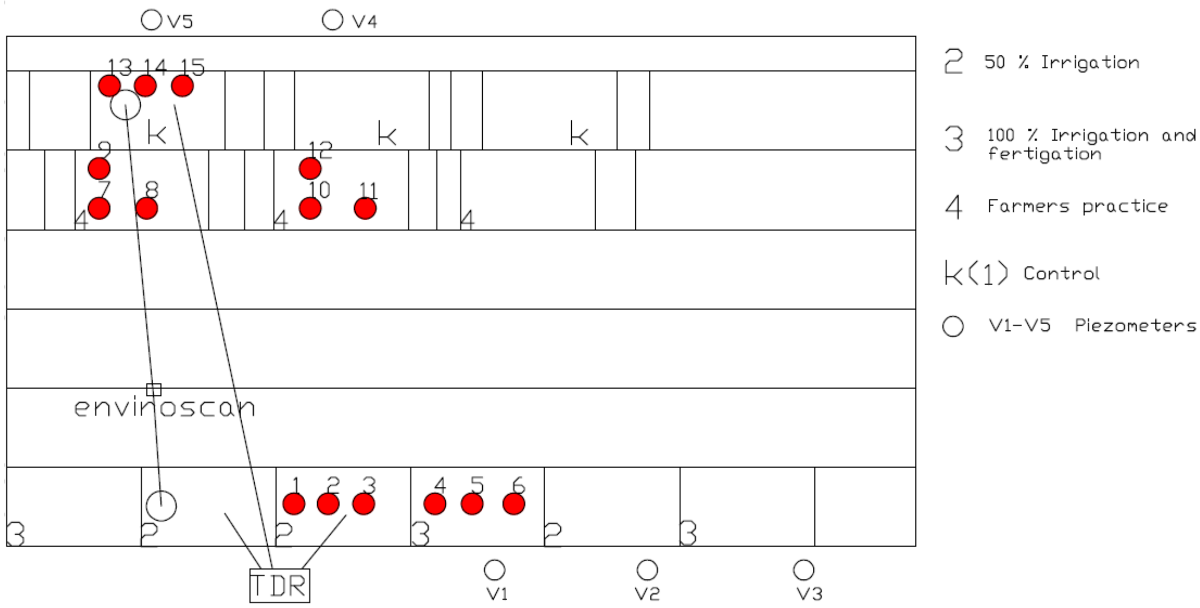

Figure 2: Experimental field in Sneberje on Ljubljana Field. Endive in period from August till October in 2006

Within two seasons farmer's practice of irrigation and fertilization (4) was compared to fertigation with irrigation to meet 100% crop water demand (3), and to farmer's practice of fertilization with irrigation to meet 50 % crop water demand (2). Control plots were without fertilization and irrigated according to farmer's practice (1). All treatments were set in three replicates. In the experiment, ^{15}N labeled KNO_3 (4 at. % ≅ 10350 ‰ ^{15}N) was used as a tracer. In 2006 endive and in 2007 cabbage and lettuce were planted, respectively. During the experiment soil, plant, soil water and groundwater samples were taken and the concentration and isotopic composition of total nitrogen and/or nitrate were determined.

With the help of installed ceramic cups, soil water solution under the root zone depth was sampled and piezometers were used to sample shallow groundwater. To determine irrigation demands and soil moisture monitoring, Time Domain Reflectometry probes (Trase system) and Frequency Domain Reflectometry (Enviroscan system) were used, placed in all versions of the experiment (Figure 2). In determined time intervals (weekly of the vegetation and monthly out of the vegetation period) concentration of nitrogen forms and nitrogen isotopic composition were traced with analysis to determine distribution of added nitrogen in soil – soil water – plant system.

Table 1: Some chemical and physical properties of soil on the experimental field on Ljubljana field

Depth	pH	P_2O	K_2O	$N_{tot.}$	Sand	Silt	Clay	Texture
(cm)	$CaCl_2$	mg/100 g		(%)				
0- 20	7,5	34,4	22	0,18	39,1	47,9	13	Loam
20- 31	7,5	4,4	5,1	0,05	56,9	33,3	9,8	Sandy loam
31- 52	7,6	1,3	3,4		83,6	13,2	3,2	Loamy sand
52- 62	7,6				52,5	39,8	7,7	Sandy loam
62- 78	7,7				91,3	5,3	3,4	Sand
78- 84	7,7				70,3	23,9	5,8	Sandy loam

RESULTS AND DISCUSSION

Only some results from the experiment are presented here as an example. The soil on the experimental field is light, from loam to sand texture (Table 1). Pollutants are very easily leached from such soils and groundwaters very threaten by pollution. Detailed soil data are of crucial importance for modelling processes in soil.

For studying and further on modelling of leaching process of pollutants, it is very important to have data on soil water content (Figure 3) and pollutants concentration in soil water (Figure 4). There is certain difference in data on soil water content measured by TDR and FDR technique on the same experimental variant (only results for TDR technique are presented here). The main reason is probably in very stony soil on the experimental field, what could present some problems for some measurement devices.

Traying to understand and to model uptake of nitrogen by plants and so to understand the fate of nitrogen in more holistic aproach data on isotope composion of nitarte or total nitrogen in soil water, groundwater and plant is useful or needed. Figure 5 shows the dynamic of this year applied fertiliser plant uptake.

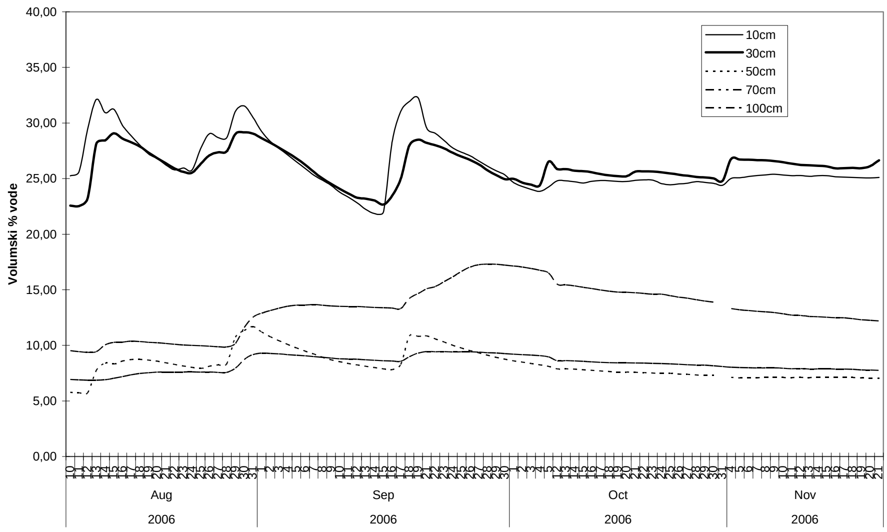

Figure 3: Soil water content (vol. %) on the field experiment Sneberje on Ljubljana Field. Plant: endive. Variant: farmer's practice and control. Year: 2006. Measurements provide with Trase (TDR)

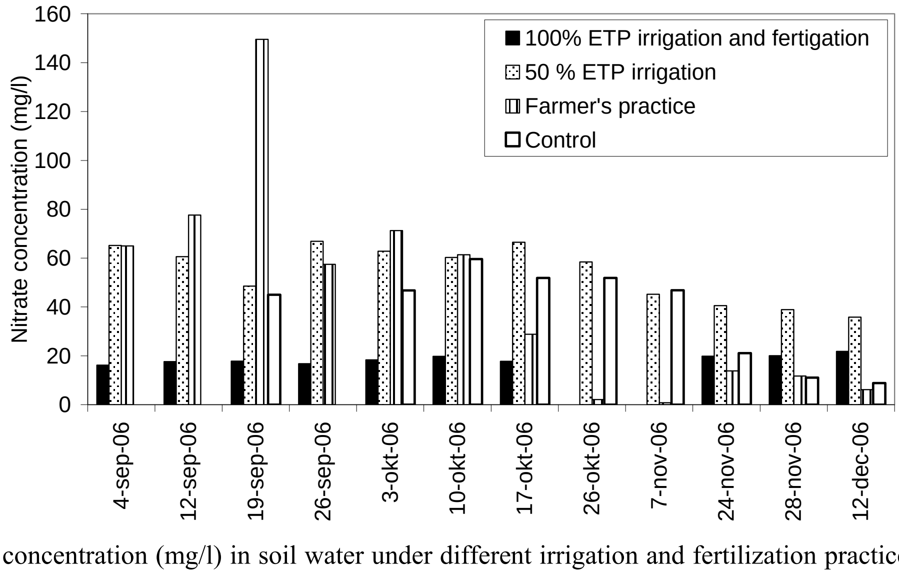

Figure 4: Nitrate concentration (mg/l) in soil water under different irrigation and fertilization practice of endive on the experimental field in Sneberje in 2006

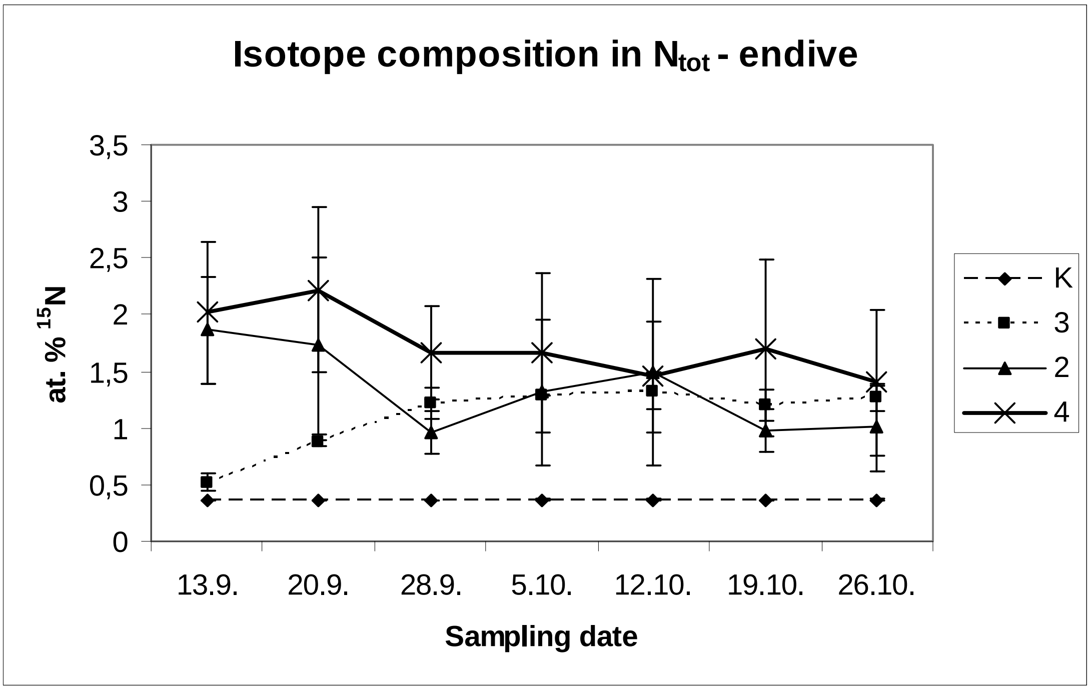

Figure 5: Isotope composition in N_{tot} in endive (at. % ^{15}N) on the experimental field Sneberje on Ljubljana Field in 2006

Previous investigations indicate that agriculture is the most important diffuse source of nitrogen input into the soil and consequently of aquifer pollution load. Therefore, research in the world is presently intensely directed towards the estimation of this pollutant's transport and into the development of agricultural practices that ensure the preservation of good chemical condition of groundwater. Within this scope, models for the estimation of surplus nitrogen after its input into the soil have been developed and applied in our circumstances. These models are too rough and not accurate enough for measure-taking as well on the emission side (in the calculation of surplus nitrogen on soil level) as also regarding the imission (in the calculation of nitrate content in ground water). The objective of further investigations is to develop or upgrade a model of more detailed nitrogen surplus estimation for individual land plots and different agricultural practices and a model of transportation of nitrogen surplus through the upper geological layers into groundwater.

Investigations contribute to a better understanding of vertical flow of groundwater through the unsaturated zone of the aquifer and if physical and chemical processes which occur on the border between sediments and matrix-building rocks in the unsaturated zone and water. Work on the existing experimental field enables to improve the methodology of in situ measurements of parameters and processes in the unsaturated zone. The improvement of these procedures enables to acquire experience and data for the implementation of similar methodologies under comparable circumstances.

CONCLUSION

The third group of investigations comprises the study of nitrogen dynamics in the saturated zone of the aquifer and the development of the conceptual model of nitrate migration in the aquifer. On the basis of data and estimations of surplus nitrogen balance in soil and unsaturated zone, a model of nitrate transport through the aquifer could be elaborated or existing one upgraded. The intergranular aquifer of Ljubljansko polje will be studied as model sample. Special attention will be devoted to the stratification of nitrate concentrations along the aquifer's profile, which will be investigated with a depth environmental probe. As soon as mass nitrogen flows in individual parts of the system are known, a combined model could be developed in connection with the existing hydraulic model of the Ljubljansko polje aquifer. Later on, it will serve also for the needs of aquifer managing and its protection.

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Groundwater status assessment within the scope of WFD implementation in Austria

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Abstract: Water is an indispensable resource for people and the environment. Therefore, it needs to be preserved in its original quality and quantity, for the widest possible uses. The EU Water Framework Directive (WFD) embodies this objective and thus requires all water to achieve at least a good status by 2015 and principally prohibits any further deterioration. Member states must identify and characterise the groundwater bodies and work out the methodologies for quantitative and qualitative status assessment. The following paper provides an overview of the main geographical conditions, the public administration structure and the water management in Austria. The emphasis is placed on the issues of water supply, existing groundwater resources and groundwater monitoring, as well as on the level of groundwater protection. Furthermore, a summary is given of the actual WFD implementation activities with respect to the identification and characterisation of groundwater bodies, to the methodologies for the quantitative and qualitative assessment of risk and water status and to the degree the objectives for groundwater are being achieved.

Key words: Water Framework Directive, groundwater status assessment, groundwater body, groundwater monitoring

GENERAL CONDITIONS

For the implementation of the WFD, it is necessary to take into consideration the geographical conditions as well as the existing administrative structure and the current water management situation. These elements represent an essential framework for developing the required methodologies.

Geographical Fundamentals

Austria is a small, predominantly mountainous country geographically located in Central Europe. It has a total area of 83,859 km². Currently, Austria has nearly 8.3 Million inhabitants.

The territory can be divided into three distinct geographical areas. The major part of Austria (62%) is occupied by the mountains of the Alps in the west. The eastern part shares the Pannonian plain. Finally, the granite massif of the Bohemian Forest, a low mountain range, is located north of the Danube Valley and covers the remaining 10% of Austria's area.

Land-use patterns in Austria change as one move from Alpine to non-Alpine regions. Approximately one-tenth of Austria is barren or unproductive land – extremely Alpine or above the tree line. About 47% of Austria is covered by forests, the majority of which lie in the Alpine region. Less than one-fifth of Austria is arable land suitable for conventional agriculture. The percentage of arable land in Austria increases in the East as the country becomes less alpine. More than one-fifth of Austria is covered by pasture and meadows located at varying altitudes, with almost half of this grassland consisting of high Alpine pastures.

The territory of Austria features a diverse lithologic composition and structure. Several hydrogeological provinces can be distinguished within the territory, characterized by both specific geological compositions and specific hydrogeological properties. The groundwater stored in porous media in valleys and basins, with mainly quaternary sediment and karstic groundwater in the northern and southern

Limestone Alps, represent Austria's most important groundwater resources. Local thermal springs and mineral water sources are also of particular importance.

Austria is part of three international River Basin Districts. The major part of the Austrian territory (~80,700 km² or 96%) is located in the Danube River Basin. The Rhine River Basin covers approximately 2,400 km² (3%) and the remaining part – around 900 km² (1%) – is situated in the Elbe River Basin. So water from the Austrian territory drains into two seas – the North Sea and the Black Sea.

Public Administration

As a federal republic, Austria is divided into nine provinces ("Länder"). These nine states are further divided into 84 regional districts. The districts are subdivided again into about 2400 municipalities. Local competencies are granted to both districts and municipalities, as well as to some major cities. The provinces are not mere administrative divisions but also have a certain legislative power that is independent of the federal government. The provinces are also responsible for the implementation of most of the federal water legislation.

The main instrument for water management is the Austrian Water Act, which regulates the use and protection of water resources. The Water Act generally requires that water use must be permitted. Within the frame of the Austrian Water Act, a number of ordinances concerning groundwater management have been enacted. In particular, these regulations establish the requirements for monitoring and the protection of groundwater as well as the stipulation of quality threshold values.

For the implementation of the WFD, it was necessary to divide the Austrian territory into eight planning units, assigned to the three international River Basin Districts. For the delineation of these planning units, only hydrological criteria were taken into account, irrespective of national borders. The water management in these planning units must be carried out in a coordinated manner by the public administrations in the relevant federal states.

Water Management

Water Balance

In general, Austria enjoys a mostly favourable hydrological situation. From 1961 to 2000, the annual mean values are 1,100 mm of precipitation and 600 mm of runoff, leaving 500 mm for evaporation. This runoff, combined with the 320 mm of water that flow in from surrounding countries, add up to a total annual runoff of approximately 920 mm per year. Precipitation and the inflow from neighbouring countries result in a fresh-water volume of 120 billion m³/year, of which 84 billion m³ are available for use.

Water Utilization

The average total annual consumption of freshwater is about 2.6 billion m³/year (only 3% of the available amount). The water utilization in Austria is divided into three sectors: municipal, industrial and agricultural. More than two-thirds are used by industry and agriculture.

The main consumer of Austrian freshwater resources is industry, which consumes more than 50%. The requirement of freshwater for municipal use (household and trade) is about 1.0 billion m³/year. In comparison to other countries and the worldwide average, the use of water for irrigation and livestock farming is low. Only 5% of the water is used by this sector. This can be attributed to the high precipitation on the one hand and the small amount of arable land on the other.

Water Supply

In contrast to many other countries where drinking water is produced through multi-stage chemical treatment of surface water, Austria mainly uses groundwater resources, which are available in a largely natural quality. First and foremost, this is the result of the high standard of groundwater protection in Austria.

Out of the 8.3 million Austrian inhabitants, about 7.2 million – i.e. 87% of the population – live in areas provided for by a central water supply plant. Roughly 1 million people get their water from private wells and springs. More than 1900 water utilities and more than 4000 water associations provide high quality drinking water in accordance with the drinking water ordinance. In recent years, an increasing number of private companies have been founded to supply villages and cities with drinking water. These private companies are owned predominantly by local municipalities.

The current sources for drinking water are spring water (50%) and groundwater (50%). Treated surface water is used for drinking water only in exceptional cases and on a very small scale.

In Austria, the average daily consumption of drinking water is currently about 135 l per inhabitant per day. This value has not changed or even slightly decreased over the last decades. Taking into account the water use of industry and business, the average daily water consumption is about 230 l per inhabitant.

Groundwater Protection

As has already been pointed out, the main groundwater resources in Austria are to be found in the karstic regions and in the valleys and basins with mainly quaternary sediments. The different pressures (agricultural land use, settlements, traffic, etc) create possible impacts on these high quality groundwater resources. In order to avoid pollution and to ensure future use for drinking water purposes, groundwater resources must be protected as strictly as possible. Hence the Austrian Water Act entails the principle of an overall protection of groundwater. The drinking water standards represent the basis for quality targets for groundwater.

With the aim of protecting the water supply plants, the Austrian Water Act also requires the establishment of protection areas. Such areas can be established to protect both the water supply plants in operation and groundwater resources reserved for future supply. In such areas, the use of the land or water and the operation of existing or future plants or installations may be prohibited or limited by an official regulation issued by the Water Act Authority.

At present, about 200 larger protecting areas, with an average surface area of about 38 km² and a large number of smaller ones (1900) have been defined in Austria. This area comprises a total of about 10% of the Austrian territory[1].

Monitoring

The protection and management of groundwater would not be possible without knowledge of the relevant data. Therefore a comprehensive water monitoring system was established in Austria quite some time before the WFD introduced such requirements.

According to the "Wasserkreislauferhebungsverordnung 2006" (ordinance on the monitoring of the water cycle) and the former "Hydrographiegesetz" (the Hydrography Act), the survey of the water cycle operated by the Hydrological Service in Austria involved observations of precipitation, evapotranspiration, air and water temperature, water level, discharge, sediment and suspended load, subsurface water, groundwater and springs.

Presently the monitoring network for groundwater quantity comprises about 3450 groundwater level gauges, 200 groundwater temperature gauges, 87 spring gauges and 14 stations for the unsaturated zone. Systematic quantitative groundwater monitoring started in early 1940s.

The Austrian programme for monitoring groundwater quality covers the entire national territory with a dense network of sampling sites. A uniform measurement methodology ensures the production of high quality data. 1992 saw the development of a network of sampling sites for groundwater and monitoring according to uniform criteria for parameter selection, frequency and methodology.

The water quality in Austria has been consistently monitored by private and public contractors commissioned by the Federal Ministry of Agriculture and Forestry, Environment and Water Management (BMLFUW). The sampling site network for groundwater currently comprises about 2000 groundwater sampling sites and 230 springs.

The physical-chemical parameters are monitored 4 times a year at groundwater and spring sampling sites. As for physical properties and chemical parameters, the monitoring programme aims to compare the monitoring results collected throughout the country, also allowing for the adjustment of selected parameters. Certain basic parameters are monitored continuously at all sampling sites. Other parameters, for which an overview of the

entire country is required, are monitored at all sampling sites for a limited period (usually one year) at the beginning of a monitoring cycle and then measured a second time after 6 years ("initial monitoring"). In the case of non-significant concentrations, these parameters are no longer taken into consideration during operational monitoring ("repeated monitoring"). Special parameters are specifically analysed in certain groundwater areas, either according to local utilisation and impacts or in the case of the explicit requirements of certain EU directives.
Consequently, for a large number of identified groundwater bodies or groups of groundwater bodies, sufficient data is available to describe their quantitative and qualitative status.
The data collected during the quantitative and qualitative monitoring programmes is published by the BMLFUW in reports like the "Hydrological Yearbook" and the "Water Quality Report". This data provide the basis for implementing the risk assessment required by the WFD.

GROUNDWATER BODIES IN AUSTRIA

Based on the Austrian geological structure, a distinction can be made between groundwater in porous media (like porous bedrock and areas of gravel and crushed stones), groundwater in fractured media (fractured layered non karstic bedrocks), groundwater in karstic bedrocks and deep groundwater bodies.

The Location and Boundaries of Groundwater Bodies

For the identification of groundwater bodies, delineation criteria such as size, homogeneity (geological and hydrogeological), utilisation, economic importance and the risk potential, as well as the existing national monitoring network and the importance of the groundwater for water supply have to be taken in to account.
In accordance with the horizontal guidance document "Identification of Water Bodies" (2003), groundwater bodies should be delineated in both a horizontal and in a vertical manner. According to the criteria given in the guidance paper, a distinction has been made between single porous groundwater bodies and groups of groundwater bodies, as well as shallow groundwater bodies (near the surface) and deep groundwater bodies (approx. below more than 200m).
In particular, with respect to the different geological strata, a further distinction was made between the porous, fractured and karstic types of aquifer.
The analysis of groundwater bodies was based on 64 individual identified shallow groundwater bodies covering a total area of 9,682 km^2, 62 groups of groundwater bodies with a total area of 74,026 km^2, one individual deep groundwater body (thermal groundwater body) and 8 groups of deep groundwater bodies. All single groundwater bodies are located in porous media and the groups of groundwater bodies assigned to the predominately part of the aquifer type (porous, fractured or karstic)[2].

Description of the Attributes - Characteristics of the Groundwater Bodies

For the purpose of delineation of groundwater bodies, a special data sheet has been developed, also available in an online form. This datasheet contains detailed statistical information, such as data on the area of the groundwater body, geological strata, land use, climate, the thickness of the aquifer and the overlaying strata. It was pre-filled on the basis of centrally available information and completed and validated by the responsible provincial authorities.
In addition to this datasheet, which is available for each identified groundwater body (single or a group), a 3-4 page verbal note has also been drawn up on the hydrological situation or the utilization of the groundwater body and also on geological sketches and profiles. This description is attached to the datasheet.
The datasheets provide a general overview of the characteristics of each groundwater body.

RISK ASSESSMENT

The results of the status quo analysis have been laid down in the Austrian "Summary Report"[3]. This report was prepared in compliance with the requirements according to the WFD and it comprises a description and classification of water bodies and a review of the impacts of human activities on the water, including a first assessment of compliance with the quantity and quality objectives. This report was prepared by the Austrian Federal Government and the Federal Provinces. The methods on which the status quo analysis is based are compiled in a special volume called "Methodology".

With respect to the heterogeneous hydrogeology, the different types of groundwater bodies (single and group) and the somewhat varying details of the existing data, it was necessary to develop adequate methodologies for the quantitative and qualitative risk assessment[4]. In this context, the following categories were specified:

Quantitative

a) single groundwater bodies - data available
b) groups of groundwater bodies and single groundwater bodies - data not available
c) deep groundwater bodies

Qualitative

d) groundwater bodies with a representative monitoring network
e) groundwater bodies with partial or no representative monitoring network

a) Single Groundwater Bodies - Data Available

As has already been pointed out, important shallow groundwater bodies have been surveyed in Austria for more than 60 years. In the majority of cases, the monitoring sites are representatively distributed and the available data (groundwater level) for the time period from 1990 to 2001 is sufficient.

Under these pre-conditions, it was possible to base the quantitative risk assessment for single shallow groundwater bodies on the comparison of a critical or adequately low groundwater level with the average groundwater level within the period from 1990 to 2001[5].

Taking into account the quantity and quality of the surface waters and the terrestrial ecosystems associated or directly dependent on the groundwater body, the actual groundwater level is not allowed to fall bellow the critical groundwater level. To avoid the additional workload of working out the critical groundwater level for each groundwater body for the first risk assessment, a previously measured very low groundwater level was selected (the characteristic low groundwater level).

For each monitoring site, the average groundwater level, a characteristic low groundwater level was evaluated and the trend of the groundwater level and an average groundwater level for the 2001 to 2010 period were predicted. By definition, there is no risk of failing the objectives given by the WFD, when a minimum of 75% of the monitored sites have either no trend or an upward trend and if the average predicted groundwater level is above the characteristic low groundwater level.

The quantitative risk assessment concludes that no single groundwater body with a sufficient database needed to be classified as at risk of failing the "good quantitative status".

b) Groups of Groundwater Bodies and Single Groundwater Bodies - Data not Available

For the groups of groundwater bodies and single groundwater bodies without a representative distributed monitoring network or with an insufficient database, it was necessary to develop a method that was based on data on precipitation and long-term annual average rates of abstraction[6].

Considering the hydrological and hydrogeological conditions (precipitation and groundwater recharge), the available groundwater resources were calculated for all groups of groundwater bodies. The following investigations were needed:

- determination of the average groundwater recharge (the WUNDT Method)
- identification of the available groundwater resource as half of the difference between the average groundwater recharge and the minimum yearly groundwater recharge

The WUNDT method is based on the consideration that the average groundwater resources in a catchment area can be calculated from the low flow of the discharge system[7].

These investigations were done in representative small catchments areas, distributed over all the Austrian territory. The aim was to find a relationship between the precipitation and the groundwater recharge, as well as the groundwater recharge and the available groundwater resources, depending on the hydrogeological conditions. Finally it was possible to define a total of 16 different types of potential yield with two coefficients to calculate the groundwater recharge and the available groundwater resource taking the precipitation into account.

All groups of groundwater bodies were assigned one of these 16 types of potential yield. With the existing data on precipitation and the two coefficients, it was possible to designate the available groundwater resources in each group of groundwater bodies.

Due to the fact that the groundwater recharge in single groundwater bodies is influenced by several variables – such as precipitation, infiltration from the receiving waters and boundary inflow – it was necessary for single groundwater bodies with an insufficient database to dilate the method for groups of groundwater bodies. The groundwater recharge was calculated using a combination of the WUNDT method and the fundamental equation for the water balance. The available resources for these groundwater bodies were estimated from the relation of the percentage from groundwater and surface water to the groundwater recharge.

There is no risk of failing the objectives given by the WFD when the abstraction in single groundwater bodies without a representative distributed monitoring network or with an insufficient database or groups of groundwater bodies is not more than 75% of the estimated available groundwater resource.

The conclusion of the quantitative risk assessment is that neither any one single groundwater body with insufficient data nor any group of groundwater bodies needed to be classified as at risk of failing the „good quantitative status".

c) Deep Groundwater Bodies

With regard to sustainable planning in Austria, deep groundwater bodies were identified and delineated although they have no connections with the surface water bodies or terrestrial ecosystems. In general, it is not possible to transfer the methodologies for shallow groundwater bodies to deep groundwater bodies without limitation.

Currently there exists only an inconsistent data set about the groundwater level in the different deep groundwater body groups. Therefore, it was not possible to work out a general risk assessment method for deep groundwater. Hence, the identification of the quantitative and qualitative status had to be based on expert judgement. This was done by experts on a regional level, who brought in knowledge of the deep groundwater bodies in their field of responsibility.

The quantitative risk assessment came to the conclusion that no one group of deep groundwater bodies needed to be classified as at risk of failing the „good quantitative status".

The thermal groundwater in the Malmkarst in the Lower Bavarian and Upper Austrian Molasse Basin was designated as a single deep groundwater body. This is the only important deep groundwater body in terms of the WFD in Austria. It is used for spa purposes and for harnessing geothermal energy. It is a transboundary groundwater body between Austria and Germany and covers an area of about 5,900 km². It is also one of the 11 important groundwater bodies where data on the location, boundaries and characteristics were reported to the ICPDR.

Due to intensive use in both countries, a common hydrogeological model and a mathematical tool were developed, though the prognoses could be further improved and given increased precision. Guidelines have also been elaborated, in order to be able to manage and protect the thermal water resources in a sustainable way and according to the best available technology. These guidelines establish the basis of the German-Austrian cooperation in managing this common deep groundwater body. Part of this cooperation takes the form of coordinated data collection and the exchange of data.

With the established monitoring strategy, surveillance monitoring, early warning monitoring and quality monitoring of spa water supplies could be combined. The evaluation of the data shows that both the groundwater quality and the groundwater quantity are not at risk.

d) Groundwater Bodies with a Representative Monitoring Network

For groundwater quality, the risk assessment is primarily based on groundwater quality data and on national assessment criteria laid down in the Ordinance on Groundwater Threshold Values.

As a first step, it was necessary to verify if the existing monitoring network would be sufficiently representative. For this purpose, the network criteria given by the CIS study group 2.8 for single groundwater bodies were applied. For groups of groundwater bodies, criteria were developed depending on the area assigned to a sampling site. Concentrations of nitrate, atrazine and desethyl-atrazine were used as the relevant parameters for the qualitative risk assessment. The available data from the time period from 1997 to 2002 proved to be sufficient.

For all sampling sites, the arithmetic means of the existing monitoring data for two years (between 2001 and 2002) were calculated for the parameters in question with the algorithm stipulated in the Ordinance on Groundwater Threshold Levels for the so called "presumable target areas for measures". This was supplemented by a study investigating the existence of sustainable upward trends (time period from 1997 to 2002) in accordance with the statistic "WATERSTAT" program, which was developed by the CIS working group 2.8.

For the risk assessment, two criteria need to be taken into account. A groundwater body will not be at risk if, in the considered time period,

- less than 50% of the monitored sites are endangered (a monitoring site is considered endangered if the arithmetic mean of a measured parameter is higher than the relevant threshold level),
- there is no sustainable upward trend (a sustainable upward trend is detected if, in the considered period, the upward trend line exceeds 75% of the limit value of the parameter in Austrian drinking water ordinance).

The quality of the groundwater in Austria is more or less satisfactory, particularly in the western provinces of Austria. In the south-eastern and eastern regions, which are subject to intensive agricultural use, the concentrations of nitrate, atrazine and desethyl-atrazine are significantly higher.

In Austria, 8 groundwater bodies or groups of groundwater bodies were identified as being at risk of failing to meet the qualitative objectives of the WFD. In other words, about 5.9% or eight of the 135 identified groundwater bodies representing about 3.6% (3,003 km²) of the whole Austrian territory are at risk of not achieving the "good chemical status", 1,956 km² of which are due to nitrate pollution.

e) Groundwater Bodies with a Partial or No Representative Monitoring Network

Only a small percentage of the Austrian territory is not covered by the representative monitoring network or by available surveys of quality data. Nevertheless, the quality risk assessment will be based on national assessment criteria laid down in the Ordinance on Groundwater Threshold Values. Nitrate, atrazine and desethyl-atrazine have again been identified as relevant parameters for the qualitative risk assessment.

For the dedicated groundwater bodies or groups of groundwater bodies, a statistical model was elaborated that allows an estimate to be made of the average pollutant concentration. The model is based on a weighted multifactoral regression for particular sampling sites.

The input parameters for the development of the model were selected from approximately 150 parameters. The parameters investigated cover different aspects, such as the properties of the groundwater body, the type of the sampling sites, impact factors (various types of land use, municipalities and potential point sources of pollution), hydrological factors (especially precipitation) and the properties of the overlaying strata.

Finally, for the calculation of the mean nitrate, atrazine and desethyl-atrazine concentration for a groundwater body or a group of groundwater bodies, the altitude above sea level, the long-term mean precipitation, the acreage percent of different field crops, the areas of irrigation and the soil permeability were parameters chosen for the model.

The results of the model are, on one the hand, an estimation of the mean value in a groundwater body of the relevant parameter and, on the other hand, a correlation between the estimated mean value and the percentage of endangered monitoring sites for a groundwater body for the relevant parameter.

A groundwater body is considered as not being at risk if the result from the determined

correlation is that less than 50% of the sampling sites are endangered.
The qualitative risk assessment concludes that none of the groundwater bodies that are not covered or are only partly covered by the representative monitoring network needed to be classified as at risk of failing the "good qualitative status".

THE CURRENT STATE OF THE GROUNDWATER STATUS ASSESSMENT

The results of the analyses of the quantitative and qualitative status assessment comprise an important basis for the establishment of a programme of measures and the elaboration of river management plans for each Austrian river basin.

Quantitative Status Assessment

The monitoring sites for the different groundwater bodies were reviewed. In some cases, the investigations showed that it was possible to reduce the number of monitoring sites without changing the representativeness. In other cases, the monitoring network had to be supplemented to achieve the required degree of representativeness. All in all, the monitoring network had been optimised.
In addition, the available groundwater resources were investigated for all single groundwater bodies with a sufficient database. This additional information will be part of the river management plans for each planning unit.
Based on the present knowledge, it is foreseen that the quantitative status assessment will be carried out using the same methodologies as for the risk assessment. The following quantitative criteria have been identified for single groundwater bodies and groups of groundwater bodies:

- Single groundwater bodies with a sufficient database are considered as being in a good quantitative status if the average groundwater level exceeds the characteristic low groundwater level in at least 60% of the monitored sites. There is no risk of failing the objectives given by the WFD if the average groundwater level exceeds the characteristic low groundwater level in at least 75% of the monitored sites.
- Single groundwater bodies with an insufficient database or groups of groundwater bodies are considered as being in a good quantitative status if abstraction does not exceed 90% of the estimated available groundwater resource. There is no risk of failing the objectives given by the WFD if the abstraction does not exceed 75% of the estimated available groundwater resource.

The Austrian ordinance for monitoring the quality und quantity status of water bodies ("Gewässerzustansüberwachungsverordnung" GZÜV) stipulates the method (groundwater level or groundwater resource) for monitoring the status of each groundwater body or groups of groundwater bodies.
The actual results of the investigations following the risk assessment indicate that there is no need to change the evaluation of the quantitative status of the groundwater bodies and groups of groundwater bodies. All the groundwater bodies in Austria can be reported as in a good quantitative status.

Qualitative Status Assessment

The qualitative monitoring sites within the different groundwater bodies were also reviewed in accordance with the requirements of the WFD. The results are contained in the summary report of the monitoring programmes pursuant to Article 8 of the WFD.
In 2006, the EU Directive on the protection of groundwater against pollution and deterioration (2006/118/EC) became effective. This directive and the Austrian Groundwater Threshold Ordinance are presently the background for the future qualitative status assessment in Austria.
It is provided that the qualitative status assessment will be done using the same methodologies as for the risk assessment. However, the criteria for the percentage of the endangered monitored sites, applied to determine whether a single groundwater body or groups of groundwater bodies are in good qualitative status, is still under consideration. The percentages discussed range from 50% to 30%. The criterion for the sustainable trend will probable not change.
Depending on the results of the discussion on the criteria for the percentage of endangered

monitored sites, the number of identified groundwater bodies or groups of groundwater bodies that are at risk or which fail to achieve a good status may need to be revised.
The implementation of the EU Directive on the protection of groundwater against pollution and deterioration (Groundwater Directive) in Austria requires the introduction of a new Ordinance or a revision of the Austrian Ordinance on Groundwater Threshold Levels, the work on which is currently in progress.

CONCLUSIONS

As a result of its geographical position, Austria is in an enviable situation, having abundant water resources. The territory of Austria features a diverse lithological composition and structure.
Austria started early with the systematic investigation of the quantitative and qualitative groundwater situation. The data generated provides a valuable basis for the delineation and characterisation of the groundwater bodies, as well as for the quantitative and qualitative risk and status assessment.
The experience from the assignment of groundwater bodies according to the WFD in Austria shows that the methodologies for the characterisation of the quantitative and qualitative status of single groundwater bodies and groups of groundwater bodies depends sensitively on the hydrological and hydrogeological situation, as well as on the availability of data.
The methodologies presented take into account the existing national pre-conditions in Austria. The question of whether these methodologies can be transferred to other territories requires careful consideration and should be decided on a case-by-case basis.

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Risk analysis of groundwater pollution hazard in groundwater protection zones

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Abstract: Risk assessment analysis for delineating groundwater protection zones (GPZs) requires a report, which also contains analysis of pollution transport through saturated zone from potential pollution source to the water capturing object. Analysis could be performed either by analytical computation of pollution transport through an aquifer, or by 3D numerical model of material transport in groundwater. Numerical model usually gives better solution of the problem, but analysts do not use it frequently since numerical groundwater transport modelling appears at first glance to be rather complicated task. However, use of numerical modelling in this expert area is relatively simple. The article presents use of commercial numerical modelling tool Visual Modflow, based on program code ModFlow. Special attention is given to recent case study in which numerical modelling was used.

Key words: 3D groundwater flow and transport modelling, risk analysis, water management, water protections zones

INTRODUCTION

Numerical models are not widely used in engineering practice for risk analysis. The problem appears to be user perception of the modelling as a complicated and time consuming process. However, numerical modelling offers quick and more accurate tool than analytical method to assess consequence of potential aquifer pollution. Initial investment in user education is quickly returned by modelling efficiency and increased problem solving capacity.

Water sources protection is based on a travel time of pollution from the pollution source to the groundwater capture installation. Based on the knowledge of hydrological and hydrogeological situation of the research area computations are made to assess the velocity of groundwater transport in the aquifer. According to this assessment groundwater protection zones are drawn. The protection zones are pretty well effective instrument regarding biological pollution, but are not effective in the case of chemical pollution. Any activity posing potential danger of water source pollution requires a risk analysis to assess it. Right in such cases numerical modelling is facilitating this assessment to be easier and better.

Central part of this article is a case study of Ljubljana field aquifer where numerical modelling was used for risk analysis. The modelling was prompted by the plan of the Šiška Heating Plant owner in this area to refit its underground tanks from the use for storing heavy fuel oil to storing the extra light fuel oil. According to the requirements of water protection ordinance for Ljubljana aquifer[1], it was necessary to produce risk analysis of groundwater pollution. Due to the very demanding task, it was necessary to use numerical model for groundwater transport in this area.

Through the case study it is shown that science could be well coupled to decision making of administrators in the civil service responsible for environment protection, by the use of efficient modelling tools. These tools are nowadays widely available and could be easily run on PCs.

WHAT IS A MODEL?

A model is any device that represents an approximation of a field situation. Physical models such as laboratory sand tanks simulate groundwater flow directly. Mathematical model simulates groundwater flow indirectly by means of governing equations assumed to represent the physical processes that occur in the system, together with equations that describe heads or flows along the boundaries of the model. Most groundwater modelling efforts are aimed at predicting the consequences of a proposed action. There are, however, two other important types of applications. Models can be used in an interpretative sense to gain insight into the controlling parameters in a site-specific setting or as a framework. Models can also be used to study processes in generic geological settings. There are two broad categories of how the partial differential equation (PDE) could be solved; either analytical methods, numerical methods, or something possibly in between. Typically, analytical methods solve the groundwater flow equation under a simplified set of conditions exactly, while numerical methods solve it under more general conditions to an approximation. The groundwater flow equation, in its most general form, describes the movement of groundwater in a saturated porous medium. It is known in mathematics as the diffusion equation, and has many analogues in other fields. Many solutions for groundwater flow problems were borrowed or adapted from existing heat transfer solutions. It is often derived from a physical basis using Darcy's law and a conservation of mass for a small control volume. The equation is often used to predict flow to the wells, which have radial symmetry, so the flow equation is commonly solved in polar or cylindrical coordinates. The Theis equation is one of the most commonly used and fundamental solutions to the groundwater flow equation; it can be used to predict the transient evolution of head, due to the effects of pumping one or a number of pumping wells. The Thiem equation is a solution to the steady state groundwater flow equation (Laplace's Equation). Unless there is a large source of water nearby, as a river or lake, true steady-state is rarely achieved in reality. Analytical methods typically use the structure of mathematics to arrive at a simple, elegant solution, but the required derivation for all but the simplest domain geometries can be quite complex (involving non-standard coordinates, conformal mapping, etc.). Analytical solution is also typically simply an equation, which can give a quick answer based on a few basic parameters. The Theis equation is a very simple, yet still very useful analytical solution to the groundwater flow equation, typically used to analyze the results of an aquifer test or slug test. In modelling solutions there are two broad categories of numerical methods used: gridded or discretized methods and non-gridded or mesh-free methods. In the common finite difference method (FDM) and finite element method (FEM) the domain is completely gridded - "cut" into a grid or mesh of small elements. The analytical element method (AEM) and the boundary integral equation method (BIEM — sometimes also called BEM, or Boundary Element Method) are only discretized at the boundaries or along flow elements like line sinks, area sources, etc., the majority of the domain being mesh-free. In the environmental regional groundwater modelling a FDM is largely used, but a FEM is better in descriptions of engineering problems where an area is smaller and much more accurate field description is needed.

Geographical – geological setting of the modelled area

Location of the potential pollution source, fuel tank of the heating plant, is in the industrial zone Šiška of the city Ljubljana (Figure 1). Elevation of this area is between 301 and 304 m a.s.l. About 0.9 km in the northern direction from the tank is the closest pumping well of the Kleče waterworks. The Sava River that is recharging Ljubljana field aquifer flows in an area about 2.1 km to the north and north east of the studied location.

In this area of Ljubljana field, aquifer consists of alluvial Pleistocene and Holocene sediments, mostly gravel and sand. About 1.5 km to the south-west, 3.0 km to the north-west and 4.5 km to the north-east are surfacing outcrops of the aquifer bedrock, composed of Carboniferous and Permian clastic rocks: dark grey schistosuous claystones, mica and quartz siltstones, quartz sandstones and fine grained conglomerates. In the modelled area schistosuous claystones, siltstones and sandstones are prevailing in alluvium bedrock. Layers of sandstones and conglomerate are rare in this area[2]. Ljubljana field is a tectonic basin of elongated depression formed in Pleistocene. Depression has been filled with alluvial sediments. Total thickness of Pleistocene and Holocene gravel and conglomerate layers of Ljubljana field is very varied depending on the depth of pre-Quaternary bedrock. In modelled area (Figure 2) the thickness of the alluvial sediments is quite a large, up to 100 m. Pre-Quaternary bedrock is the deepest in the central part of the Ljubljana field, from the Kleče waterworks to Union brewery ranging from 70 m do 105 m[2]. Another deep depression is in the direction towards the Hrastje waterworks where the alluvial sediments thickness is between 70 m and 80 m. Geology of Quaternary alluvial sediments of Ljubljana field were most systematically described by Žlebnik[3] who delineated in vertical direction from the surface following stratigraphyc units:

- Humus
- Young Pleistocene gravel,
- Clay and clay with gravel,
- Young conglomerate,
- Intermediate conglomerate
- Old conglomerate,
- Pre-Quaternary bedrock (Carboniferous and Permian clastic rocks).

Geomorphology of Ljubljana field is dominated by high Pleistocene alluvial terrace covered by thin humus layer (0.3 m do 1.0 m), while in the flooding area of the Sava River there is a low Holocene alluvial terrace. Thickness of young Pleistocene gravel is between 2 m and 16 m, on average is this layer thick about 6 m to 8 m. In area of the Kleče waterworks gravel layer is about 7 m thick[3]. Below the gravel sediment is a layer of brown clay and clay with pebbles. This about 10 m thick clay layer is in some areas continuous, while somewhere it is discontinued. Young conglomerate unit consists of conglomerate and sandy gravel with thin layers of conglomerate. Below this unit is another thin layer of brown clay with pebbles, which is product of weathering of the intermediate conglomerate unit. The deepest units of alluvial sedimets are intermediate and old conglomerate. In the most south-western and western part of the modelled area alluvial sediments sequence is covered by proluvium of the local brooks. It mostly consists of clayey rubble, clay, organic clay, peat, silt and sand. The alluvium covering layer in this border area is mostly impervious.

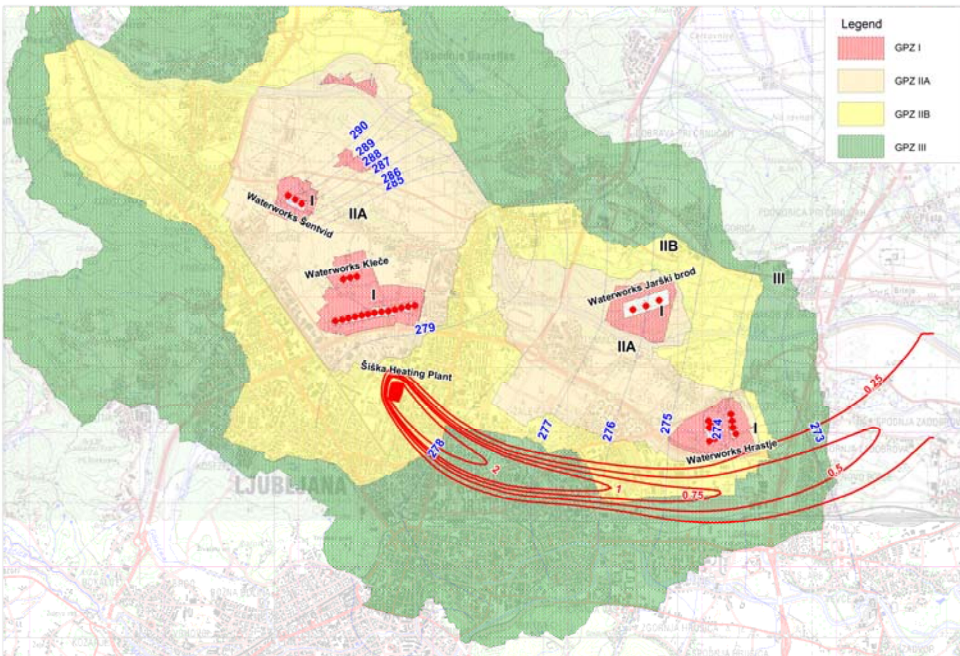

Figure 1: Modelled area of the Ljubljana field aquifer showing groundwater contour lines and pollution plume (after 20 years), together with locations of the most important pumping stations in the area

Hydrogeological setting

The Sava River has very important role in the water balance since it recharges Ljubljana field aquifer. It has been proved that the aquifer is predominantly recharged by the Sava River (51%) and by the infiltration of rainfall (33%), while the inflow from other aquifers contributes minor quantity (16%)[4].

The Ljubljanica River is not hydraulically connected to the groundwater of Ljubljana field aquifer due to the clogging of its river bed. In the Quaternary alluvial sediments of Ljubljana tectonic basin are large reserves of groundwater. In general is the aquifer of Ljubljana field an aquifer with intergranular porosity with unconfined groundwater. Due to local impervious cover and clay layers the aquifer is in some small local areas semi confined or even confined. Carboniferous and Permian schistosuous sandstones, siltstones and claystones of the bedrock are impervious. Depth to the groundwater has been adopted from numerical model using ModFlow 4.2 Pro tool, being in the modelled area around 22 m. Coefficient of hydraulic conductivity has not been measured in-situ, but there are data about it in wider area of the potential pollution source. According to the data available, values of the coefficient of hydraulic conductivity alluvial sediments are in range from 9×10^{-4} m/s to 1.5×10^{-3} m/s[5]. Coefficient of hydraulic conductivity in the area across the Sava River, out of the modelled area, in waterworks of Jarški prod is around 1.4×10^{-2} m/s[6]. In the area of Union brewery values of the coefficient of hydraulic conductivity are in the range between 5×10^{-3} m/s to 5×10^{-2} m/s, depending on the object where the pumping test was performed[2]. On the site of the Šiška heating plant fuel tank, the potential source of pollution, direction of groundwater flow is from northwest to the south east, changing to the easterly direction more downstream (Figure 1).

GroundWater protection regime in the area of potential pollution source

Water protection regime for groundwater body in Ljubljana field aquifer is defined by the ordinance (Ur. list RS 120/04). The ordinance is protecting water sources at waterworks in Šentvid, Kleče, Jarški prod and Hrastje. Protected area is delineated in following zones:

- Area of pumping station (GPZ 0),
- The closest area – Groundwater Protection Zone I (GPZ I),
- Close area with the most strict protection regime (GPZ IIa),
- Close area with less strict protection regime (GPZ IIb),
- Wide protected area (GPZ III).

Location of Šiška Heating Plant with planned tank for extra light fuel oil, is in the area protected by water protection ordinance within GPZ IIb, being an area of less strict protection regime (Figure 1). The closest waterworks Kleče is about 0.9 km far away to the north in the upstream direction of groundwater flow. Groundwater in Kleče is pumped from several wells with total pumping capacity 680 l/s[7]. Depth of the majority of the wells is less than 70 m, and only one well is sunk to the depth over 100 m, reaching into Carboniferous and Permian bedrock. Kleče waterworks are supplying drinking water to the Ljubljana city being the one with the largest capacity in the system of the Ljubljana water supply company VO-KA. In the downstream direction Hrastje waterworks could be in danger of water pollution from the oil tank. This waterworks have already experienced several situations regarding pollution by pesticides and other phyto-pharmaceuticals. These incidents led to decrease of pumping rate in this waterworks down to only 100 l/s in recent time. Depth to the bedrock in the area of Hrastje waterworks is up to 94 m decreasing to 70 m in direction to the west. Already for some time the water supply company VO-KA has been experiencing decrease of water consumption in entire Ljubljana area, most likely due to the decline in industry production and the fact that some large industrial plants are pumping water from their own wells.

Groundwater flow model

The selected area for modelling (Figure 1 and Figure 2) is situated mainly within Ljubljana field aquifer, limited by the Sava River in the north and northeast, by the low hills in the west, by the so called Ljubljana gate between Rožnik Hill and the Castle Hill in the south, and ends just of the Hrastje waterworks in the east. In the south, the most northern part of the Ljubljansko barje (Ljubljana Moor) aquifer was included in the modelling area. The largest and by far the most important surface stream in the research area, both in the geomorphological and hydrogeological sense, is the Sava River. The Ljubljanica River flowing in the southern part, does not affect the groundwater of the modelling area.

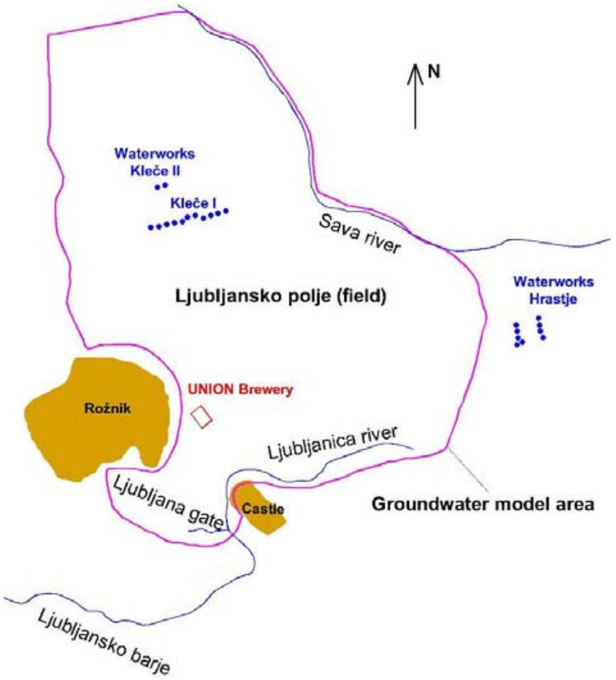

Figure 2: Groundwater modelling area with model boundaries (see also Figure 1)

According to the hydrogeological conceptual model of the Ljubljana field aquifer the following hydrological boundary conditions were set:

Surface water recharge and water loss:

- Rainfall recharge 1700 mm/a,
- Evapotranspiration loss 1100 mm/a.

Line water recharge/discharge:

- From surface water for the River Sava as a river boundary, and
- General-head boundaries represented by piezometric heads on the western and eastern part.

The river boundary condition was used to simulate the influence of surface water body on the groundwater flow. Surface water body such as rivers, streams, lakes and swamps may either contribute water to the groundwater system, or act as groundwater discharge zone, depending on the hydraulic gradient between it and the groundwater system. The MODFLOW river package simulates the surface water/groundwater interaction via a seepage layer separating the surface water body from the groundwater system. The function of the general-head boundary package (GHB) is mathematically similar to that of the river, drain, and evapotranspiration packages. Flow into or out of a cell from an external source is provided in proportion to the difference between the head in the cell and the reference head assigned to the external source. The application of this boundary condition is intended to be general, as indicated by its name, but the typical application of this boundary conditions is to represent heads in a model that are influenced by a large surface water body outside the model domain, but with a known water elevation. The purpose of using this boundary condition is to avoid unnecessarily extending the model domain outward to meet the element influencing the head in the model. As a result, the general head boundary condition is usually assigned along the outside edges of the model domain.

It was decided to use GHBs instead of constant head boundaries (CHBs) because GHBs can be better managed at the model calibration stage. The calibration results (Figure 3) showed that the maximum head error was smaller than 0.6 meters and the standard error was in the range +/- 0.159 m. The maximum calculated velocities in the model domain were high, between 40 and 60 m/day. These results match observed values from tracer tests, which were in the range from 15 do 70 m/day, depending on the tracer detection limits. The average velocities in the Ljubljana field aquifer are generally in the range from 10 to 20 m/day.

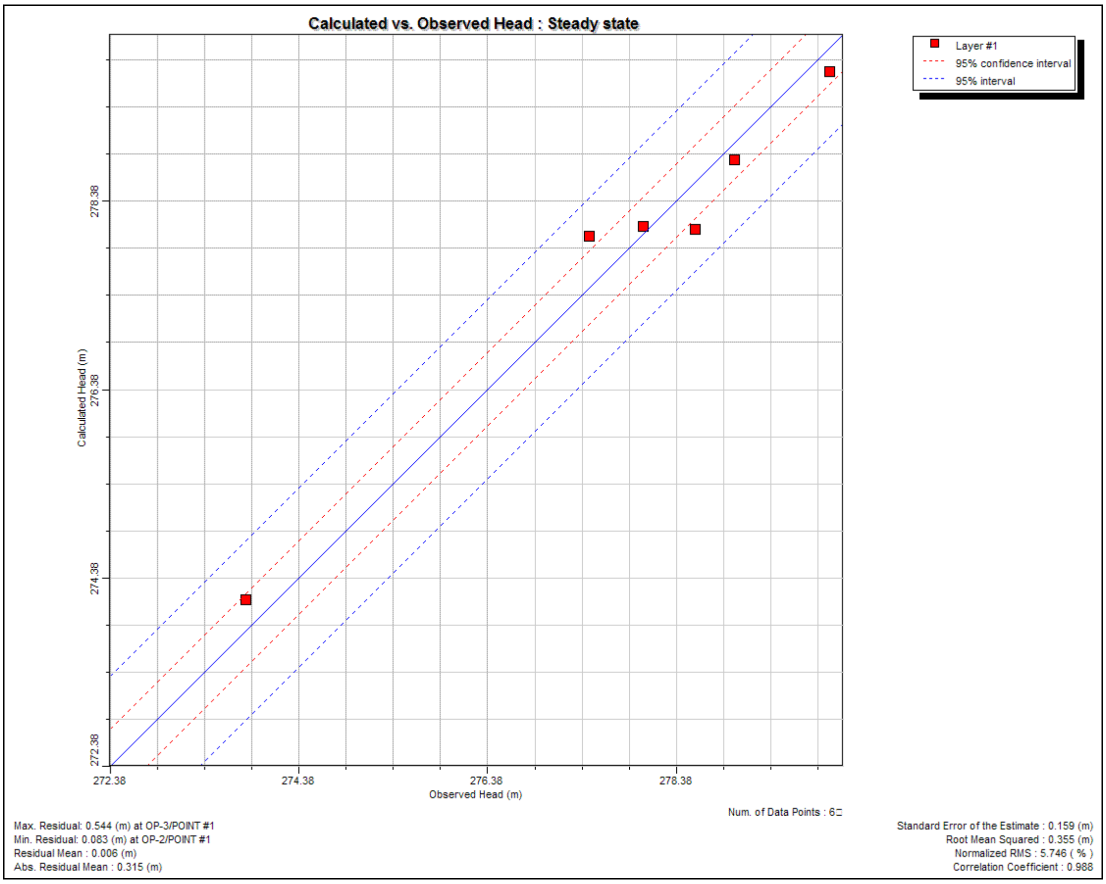

Figure 3: Results of head calibrations. Standard error is of +/- 0.159 m and maximum absolute error is of 0.544 m

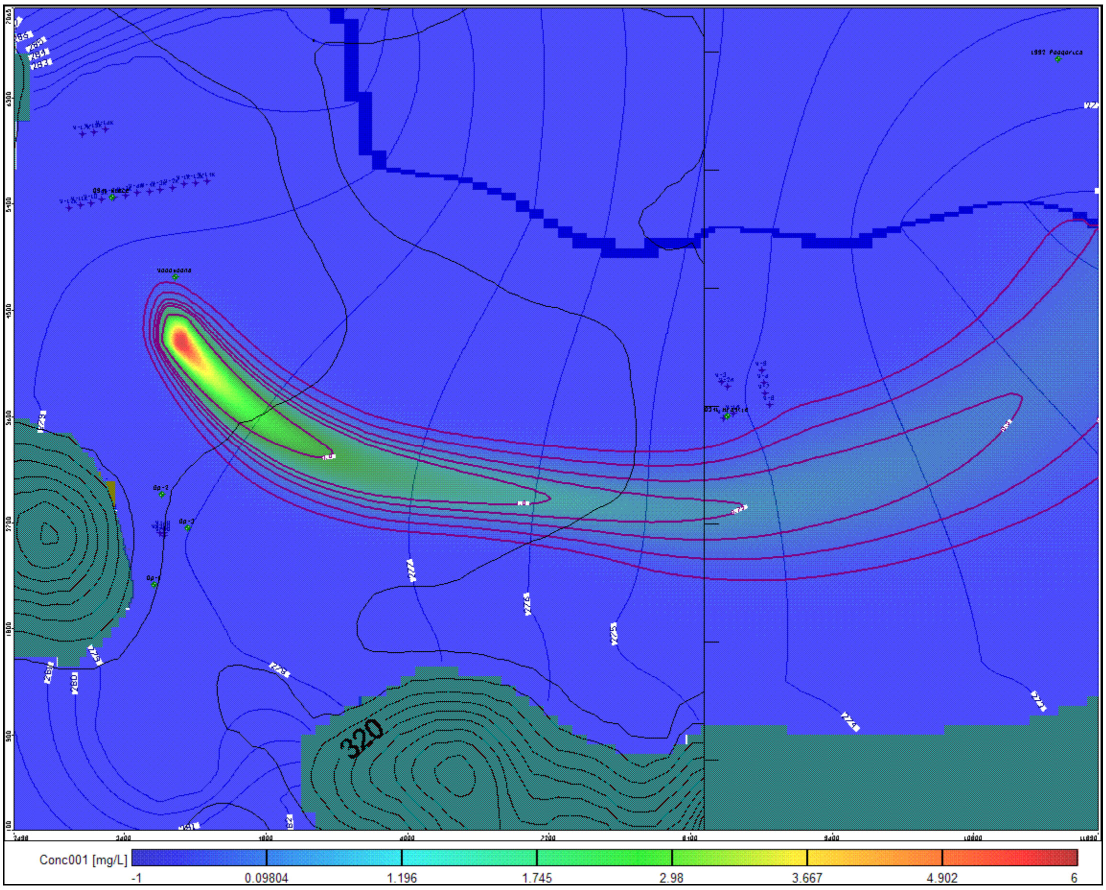

Figure 4: Groundwater piezometric heads and pollution plume in Ljubljana field aquifer after 20 years – base case scenario

Groundwater transport model

According to the previously known hydrogeological model of the Ljubljana field aquifer, groundwater flow from the potential pollution source – planned extra light fuel oil tank, is in the direction to the Hrastje waterworks. In case of the spill from the fuel tank, pollutant would infiltrate through unsaturated zone roughly vertically down and after reaching saturated zone it would be transported by groundwater horizontally in groundwater flow direction. In saturated zone the pollutant would spread by hydrodynamic dispersion both in the flow direction and perpendicular to it. Pollution distribution would follow normal or Gauss distribution[8],[9]. To assess the consequences of potential pollution both to the Kleče and Hrastje waterworks numerical model ModFlow 4.2 Pro was used. Pollutant transport was modelled by MT3D numerical tool, which is a component of the program ModFlow. It was assumed that the leak from the fuel tank at Šiška heating plant would be continuous at the constant rate of 250 mg/l of pollutant. Recharge at pollution source was defined as a rainfall infiltration in that area, being in the case studied nonlinear function of difference between rainfall (1700 mm/a) and evapotranspiration (1100 mm/a), which is nonlinearly decreasing with the depth of infiltration, and was taken into account in computations[10].

Another important factor in pollutant transport is coefficient of dispersion, enabling computation of pollutant plume dispersion. Dispersion is dependent on travel distance of the pollutant. In MT3D is dispersivity a proportionality factor defining change on the length unit. Usually it is order of magnitude value of 0.1. To be on a safer side 10 times higher factor was used in the model. Modelling showed that groundwater pumping rate 100 l/s in pumping station of the Hrastje waterworks practically does not affect groundwater table of the aquifer. To be on safer side again, model was run with 16 times higher pumping rate amounting to 1.6 m^3/s, together with adopting into model the most conservative scenario of tank leakage at heating plant for entire period of 20 years. The model results showed that pollutant plume would pass by the Hrastje waterworks not affecting it (Figure 1 and Figure 4).

MONITORING

Regardless of groundwater transport model result that there is no danger of polluting water source at the Hrastje waterworks, groundwater protection ordinance required plan for monitoring water quality and water level of the groundwater. Again, the monitoring programme was based on groundwater modelling. Since the monitoring should detect on time the slightest leaking of pollutant into the groundwater, exaggerated input parameters, as in the former case of modelling travel direction and extent of pollutant plume, would be inappropriate. This time, for the monitoring programme the same model was run with different input parameters. The pumping rate at the Hrastje waterworks was decreased to the actual pumping values and the model was run for 90 days time. Running time of 90 days was chosen since it is the normal time interval of groundwater sampling. Thus, the model was run with input parameters as listed in Table 1. Scenario used in the modelling forecasted slow or stochastic leakage of extra light fuel oil into groundwater with transport through unsaturated zone by rainfall infiltration. To be on the safe side, area of leakage with constant concentration was increased to the entire ground plan of the Šiška Heating Plant of 52,500 m^2.

Table 1: Input parameters into model for monitoring programme purposes

Amount of leaked pollutant [m^3]	**Infiltration amount [l/m]**	**Area of the tank [m^2]**	**Pollutant concentration [mg/l]**	**Part in the tank volume [promile]**
0.432	600	ca. 2507.6	250	0.012

Taking into account realistic input parameters model showed a real pollution plume needed for monitoring programme (Figure 5). Modelling process to assess risk of water source pollution and modelling for monitoring programme are the same, but depending on the purpose of modelling the model is run with widely different input parameters. In the former case values of parameters were highly exaggerated to simulate the worst case scenario, while in the latter case parameters should be as realistic as possible.

CONCLUSIONS

Experience from the case study showed that the use of groundwater modelling is a good alternative to analytical solutions of pollutant transport in risk analysis of groundwater pollution, which is required by law for any anthropogenic intervention in the water protected areas. Modelling offers better understanding of the processes in the aquifer as well as high flexibility in running different scenarios, leading to better assessment of pollutant travel from the pollution source to the water source at risk.

In modelling risk of water source pollution, parameters that are influencing flow direction and pollutant dispersion should be exaggerated to simulate the worst case scenario. Even if such a model shows that the water source is not at risk, the comprehensive monitoring programme should be planned. Modelling for monitoring programme purposes is done by the same model tool, but with different input parameters. In this case, parameters describing pumping rates, dispersion and time of pollution should be as realistic as possible.

For regional groundwater studies Finite Difference Method models – FDMs are more appropriate, while on local scale are better tool Finite Element Method models – FEMs.

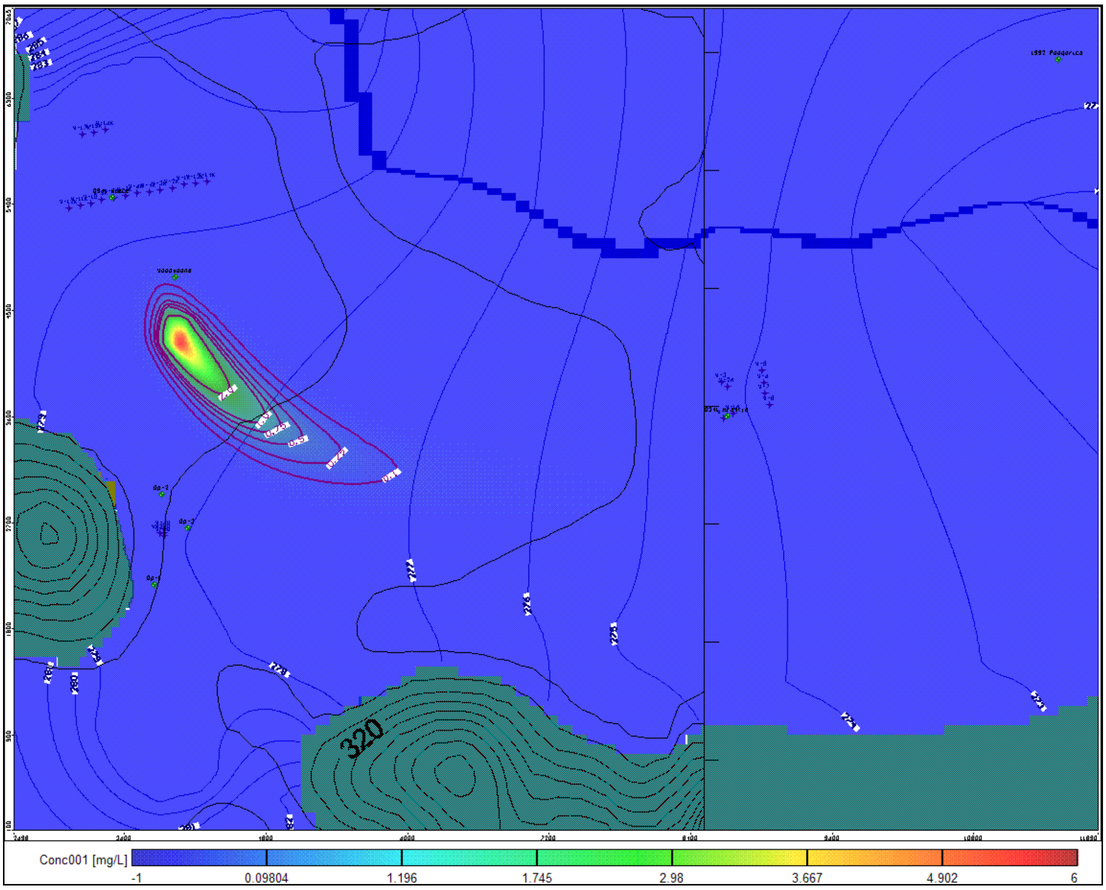

Figure 5: Groundwater piezometric heads and pollutant plume in Ljubljana field aquifer after 90 days – base case scenario

Taking into account availability, affordable price, and user friendly running of the computer packages for groundwater modelling, the study of pollutant travel in the alluvial aquifers should be transferred from merely scientific fields into civil service responsible for environment protection. Hydrogeology professional civil servants trained in groundwater modelling should use these tools in their decision making.

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Area – differentiated modelling of groundwater recharge rate for determining quantitative status of groundwater; Case Study: Federal State of Lower Saxony, Germany

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Abstract: This paper presents the findings of a collaborative research project of the Lower Saxony State Agency for Soil Research (NLfB) and the Programme Group Systems Analysis and Technology Evaluation (STE) of Research Centre Jülich on the GIS based determination of the long term groundwater recharge in Lower Saxony using high-resolution digital data[1]. The model calculations were performed on the basis of the water-balance model GROWA[2] with a spatial resolution of 100 m x 100 m. The accuracy of the calculated groundwater recharge values for the period 1961 – 1990 was verified on the basis of data from gauging stations and displayed a good agreement between observed runoff values and model results.

Key words: water balance model, groundwater recharge, GIS, Germany, Federal State of Lower Saxony

INTRODUCTION

The development of hydrologic models started in the 60s with the Stanford Watershed Model[3]. Up to now the number of models and model systems as well as the number of different model concepts grew considerably as indicated in the surview given by Singh[4]. Most of the models have been developed for a specific scale and the simulation of a specific aspect of the hydrologic cycle. Physically based models like PRMS[5], TOPMODEL[6] or SHE[7], for instance, have been developed for the application in micro – to mesoscale watersheds. The application of these models in areas like the Federal State of Lower Saxony, which covers an area of ca. 48.000 km^2, is limited not only due to the lack of input data needed to run these models but also because of regionalisation issues (e.g. Blöschl & Kirkby[8]).

The problem to apply small-scale models in large catchment areas has lead to the development of models especially designed for macroscale applications. These models differ significantly to micro- and mesoscale models with respect to the representation of the relevant processes and the spatial and temporal resolution. The RHINEFLOW model[9], for instance, calculates the water balance for the Rhine basin using a more integrated approach on a monthly basis. The HBV-model[10] is a more deterministic approach using daily resolution, applicable to larger areas. For modelling the long-term groundwater recharge in large catchment areas or regions empirical models turned out to be sufficient (e.g. Dörhöfer & Josopait[11], Renger & Wessolek[12], Meinardi[13], Kunkel & Wendland[14], DeWit et al.[15]). These models allow a reasonable determination of the long-term water balance as a function of the interaction between the actual land cover and climatical, pedological, topographical and hydrogeological conditions.

OBJECTIVES

The existing studies on the groundwater recharge in Lower Saxony (e.g. NLfB[16]) were based on the method of Dörhöfer and Josopait[11] developed in the late seventies for large-scale water management planning. The method is based on the evaluation of analogue data bases on a scale of 1 : 200,000. The increasing availability of high-resolution digital data (e.g. land use, topography, soil physics parameters) as well as the continuous further development of macroscale water balance models in past years made it seem appropriate to undertake a GIS based methodological updating and regionally more differentiated determination of groundwater recharge. This was carried out within the framework of a collaborative project by the Lower Saxony State Agency for Soil Research and the Programme Group Systems Analysis and Technology Evaluation of Research Centre Jülich[1].

The central topic of the project was the GIS-based determination of the mean long term annual total runoff and in particular of groundwater recharge in Lower Saxony making use of high-resolution digital data bases. Due to the good model results for the Elbe river basin, it was agreed between the project partners that the empirical water balance model GROWA[2],[14] should be used as a basis for the model calculations.

METHOD

The GROWA model consists of several modules for determining the real evapotranspiration, total runoff, direct runoff and groundwater recharge. The real evapotranspiration is calculated according to the following expression:

$$ETreal = fh \cdot [al \cdot Psu + bl \cdot Pwi + cl \cdot \log(Wpfl) + dl \cdot ETpot + el \cdot S + gl] \quad (1)$$

with:
- ETreal: mean annual level of real evapotranspiration (mm/a)
- fh: correction factor for considering the relief of the terrain
- Psu: precipitation in the hydrological six summer months (mm/a)
- Pwi: precipitation in the hydrological six winter months (mm/a)
- Wpfl: quantity of soil moisture available to plants (mm)
- ETpot: mean annual potential evapotranspiration (mm/a)
- S: degree of pavement
- a1, ..., g1: land-cover-dependent coefficients

This formula is based on the method of Renger & Wessolek[12] which was derived from extensive field experiments for determining the actual evapotranspiration for various forms of land use and soil cover (arable land, grassland, deciduous forest, coniferous forest) for plain, rural areas at some distance from the groundwater table. For a general, i.e. area-wide, application several extensions were developed and implemented (Wendland & Kunkel[17]) to calculate the real evapotranspiration in hilly[18] or urban areas[19] as well as for regions close to the groundwater table.

In order to determine the groundwater recharge, a runoff separation is performed in GROWA on the basis of static base runoff fractions, in the course of which the groundwater runoff on the long-term average is described as a constant fraction of the total runoff as a function of certain area properties. A hierarchical approach is taken, i.e. only one site condition is regarded as important for the groundwater runoff fraction. Other parameters are only considered, if the primary site condition is not relevant. The relevant site conditions are then determined including the monthly low-flow rates of a river (MoMNQ) observed at the gauging stations on the basis of a correlation analysis. After Wundt[20] it is assumed that the observed MoMNQ values on a long-term average correspond as a good approximation to the runoff originating from the groundwater and thus represent the groundwater recharge.

In general, a division is made into three groups, each of which is dealt with by a different procedure (see Dörhöfer et al.[1]). In regions of unconsolidated rock, the depth to groundwater, the water logging tendency of the soil and to a lesser extent the hill slope were identified as the dominant parameters for the base runoff fractions. In addition, regions were considered where artificial drainage systems (e.g. drainage ditches) lead to increased fractions of direct runoff. If the site conditions predominant in regions of unconsolidated rock were exclusively considered then this led to an unsatisfactory representation of the actual runoff fractions for regions of solid rock. It became apparent that in the solid rock regions it is primarily the geological structure that is of special significance in quantifying the runoff fractions. The urban areas were divided into two levels of pavement and the base runoff fractions identified using the results of work by Wessolek & Facklam[19].

The groundwater recharge was separated from the total runoff on a catchment-related basis. To this end, a mean base runoff fraction $r_{b,ber}$ was calculated for a total of 39 test areas by summation from the product of the relative area ratio ai of a certain area property and the respective base runoff fraction $r_{b,i}$:

$$r_{b,ber} = \sum_{i=1}^{n} r_{b,i} \cdot a_i \qquad (2)$$

The sum covered all 19 different site features, e.g. in the unconsolidated rock areas the categories of groundwater and water logging influence as well as the hill slope. In the next step, the base runoff fractions were varied so that the sum of the quadratic deviations between the calculated and the base runoff fractions measured in the individual subregions for all test areas considered took on the smallest value (min):

$$\sum_{j=1}^{n} (r_{b,gem,j} - r_{b,ber,j})^2 = \text{Min} \qquad (3)$$

DATA BASES

The modelling was based on digital data sets provided by the Geological Survey of Lower Saxony (NLfB). In selecting the data sets it was decisive that they should be available for the whole of Lower Saxony and also display high spatial resolution (see Table 1).

Table 1: Data bases of the GROWA98 water-balance model

Data base		Scale / spatial resulution	Data source
Climatic data (1961 – 1990)	Precipitation (may – october) Precipitation (november – april) Pot. Evapotranspiration	200 x 200 m² 1000 x 1000 m²	German Meteorological Survey
Soil cover	Land use category	25 ha	CORINE data base
Soil data	Effective field capacity Rooting depth Groundwater influence Influence of perching water	500 x 500 m²	Lower Saxony State Agency for Soil Research
Topography	Slope Exposure	50 x 50 m²	Geobasisinformation Lower Saxony
Geology	Hydrogeologic units	1 : 500.000	Lower Saxony State Agency for Soil Research
Runoff data (1961 – 1990)	MQ MoMNQ 1961-1990		Lower Saxony State Agency for Ecology
	Subcatchment areas	1 : 50.000	

Some of the input data were in a vector format and others in the form of grid data with a cell size of between 50 and 1000 m. Before modelling, the data basis was standardized to a grid of defined dimensions and a cell size of 100 m, which was optimal for modelling purposes.

RESULTS

In the GROWA model, the total runoff is calculated from the difference between precipitation level and real evapotranspiration. For the hydrological reference period of 1961 – 1990, the total runoff in Lower Saxony amounts to approx. 260 mm/a, which corresponds to approximately 35 % of the precipitation

volume. In general, the total runoff increases from the coast (200-300 mm/a) towards the Geest, where it reaches average annual totals of 200-500 mm, and then decreases inland to less than 150 mm/a in some areas (Figure 1).
The highest total runoffs occur in the upland areas of southern Lower Saxony (300-800 mm/a), above all in the Harz Mountains (up to 1500 mm/a). The central and northern Lüneburg Heath also has an abundance of water. Sparse runoff is experienced above all in the Wendland and in the Wolfsburg-Braunschweig area (<150 mm/a).

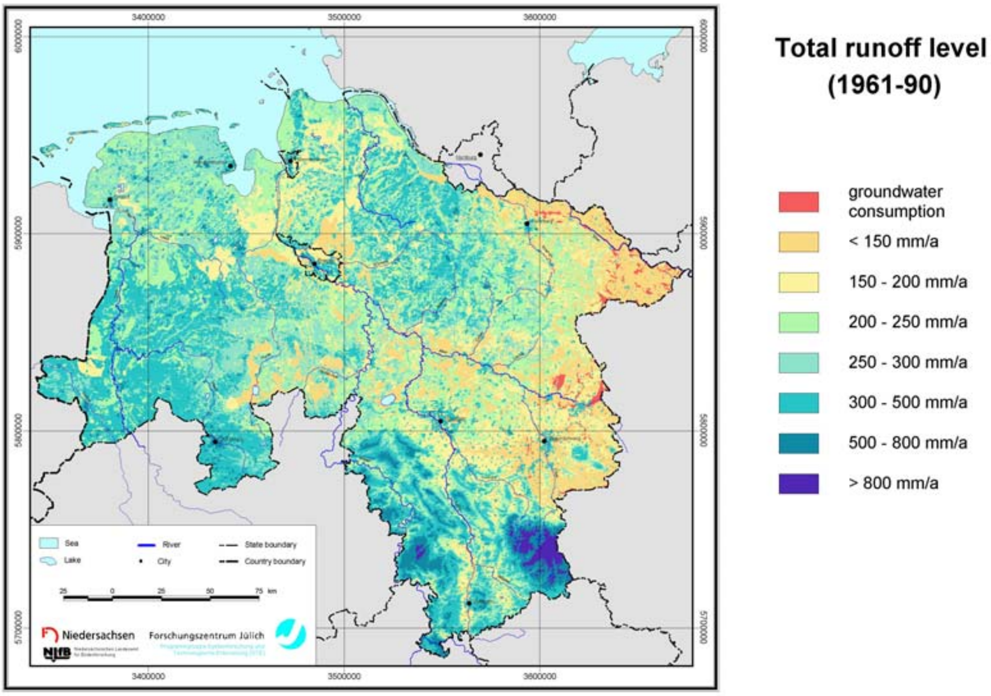

Figure 1: Map of the long-term mean total runoff (1961-90)

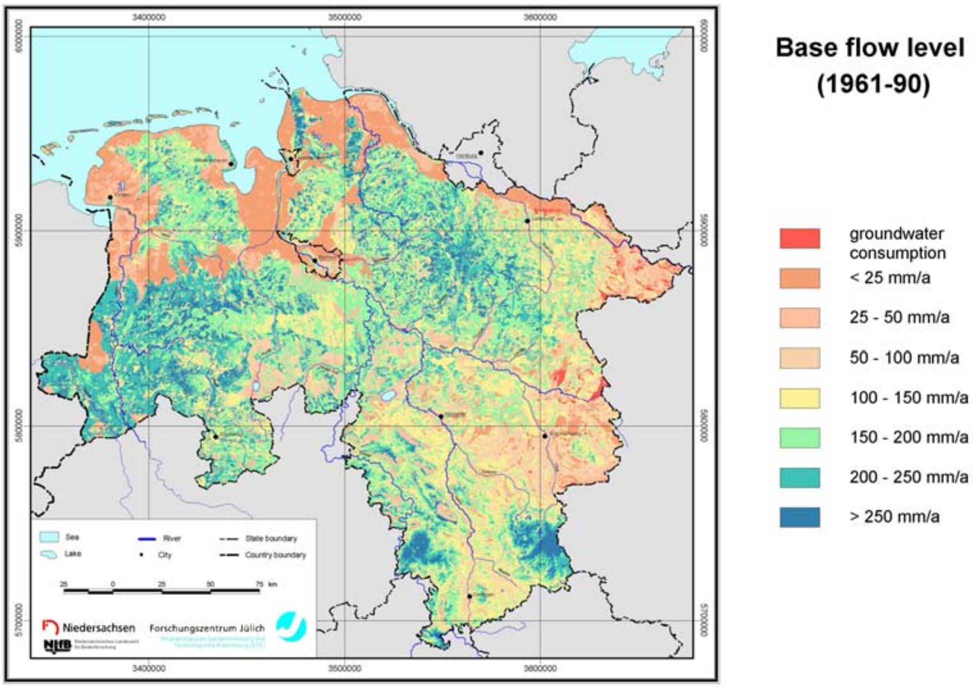

Figure 2: Map of the long-term mean percolation to the groundwater (1961-90)

The calculated groundwater recharge ranges from less than 25 mm/a to more than 250 mm/a. This reflects the diversity of climatic, pedological and geological conditions. In plain unconsolidated rock areas of at some distance from the water table (e.g. on glacial outwash), the groundwater recharge largely corresponds to the total runoff and generally amounts to more than 150 mm/a (Figure 2).

In unconsolidated rock areas influenced by the groundwater and water logging (e.g. in floodlands) the groundwater recharge is less than 50 mm/a. The major runoff fraction (more than 80 %) is discharged in the form of direct runoff and reaches the receiving waters via the soil surface or the unsaturated soil zone. The same is true of areas on Palaeozoic and crystalline rocks where, although the base flow can amount to 250 mm/a and above, the groundwater recharge contributes less than 40 % to the total runoff.

VALIDITY CHECK AND DISCUSSION

The reliability and representativeness of the calculated area-differentiated runoff values were verified on the basis of long-term monthly runoff data from representative gauging stations (cf. Figure 3). In selecting the gauging stations, attention was primarily paid to achieving the greatest possible variability with respect to catchment area size as well as land use and climate. For reasons of continuity, only those gauging stations were selected for which long-term time series were available from the period between 1961 and 1990.

For validation purposes, the calculated runoff values were integrated for each gauge-related catchment area and compared with the measured runoff values at the gauging stations. The total runoff levels were verified by comparing them with the mean daily runoff values (MQ) in 63 subbasins.

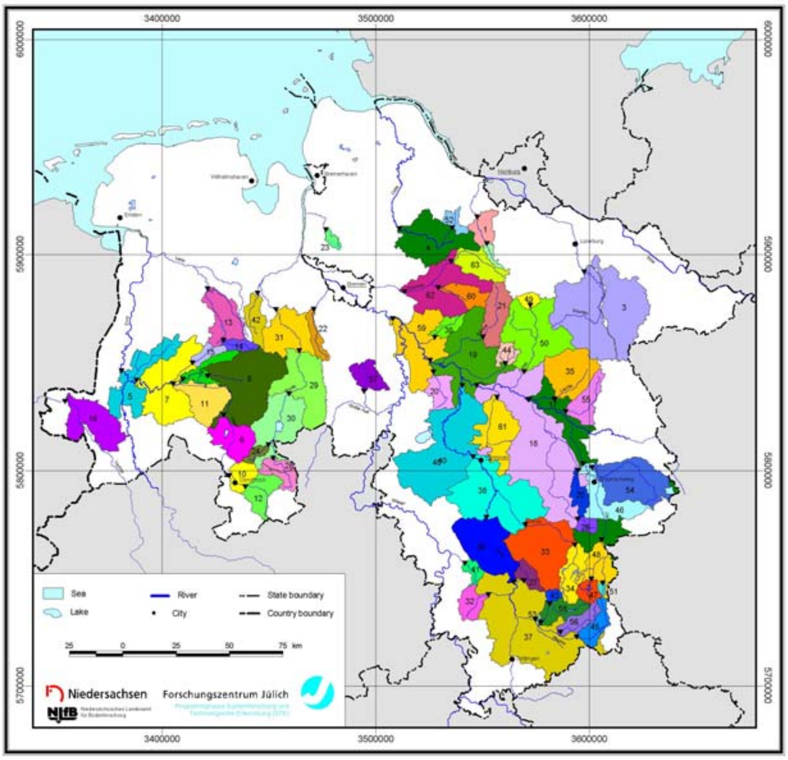

Figure 3: Gauging stations and related subbasins used for validation of the calculated runoff

In order to validate the calculated groundwater recharge, it was assumed after Wundt[20] that the mean long-term runoff fraction originating from the groundwater is represented with sufficient accuracy by the mean of the smallest daily runoff per month (MoMNQ) of the time series. Thirty-nine gauging stations were available for validating the groundwater recharge. Figure 4 shows a comparison of the measured and calculated total runoff and groundwater runoff.

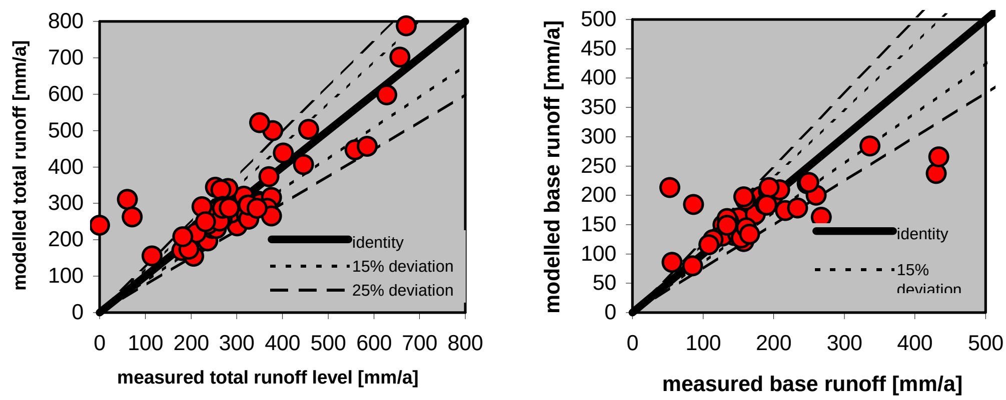

Figure 4: Comparison of measured and calculated total runoff (left) and base runoff (right)

As can be seen from Figure 4, the deviations from the calculated total runoff and also the deviations from the calculated groundwater recharge differ from the measured values for most gauging stations between 0 and ± 15 %. Errors in this order of magnitude lie within the usual variation range of an empirical model. Furthermore, small but unavoidable measuring and interpolation errors are also undoubtedly involved. The deviations occurring tend to be somewhat higher for groundwater recharge than for total runoff. This can be explained by the fact that in separating the groundwater recharge levels deviations from two submodels are superimposed (total runoff modelling, separation of runoff components).

For some of the sub basins considered, the deviations between the measured and calculated runoff levels are above 15%. In order to verify whether these deviations are caused by the model approach itself or by the input data or by water management interventions, the model results of selected sub-basins were submitted to experts from regional agencies of the Federal State for comment. For all sub-basins selected it turned out that the deviations can be explained completely by anthropogenic impacts on the water balance, e.g. water management interventions, such as stream diversion and groundwater withdrawal. However, detailed future investigations for these sub basins are required to enlighten the exact reasons for the observed deviations.

The major focus of the GROWA model is placed on calculating the mean long-term groundwater recharge in large areas, such as the Federal State of Lower Saxony. It was not the aim of the project to consider interannual variabilities. The groundwater recharge observed for individual years (e.g. wet/dry years) or interannual reference periods (e.g. summer/winter six months) may therefore deviate from the calculated values shown in the maps.

In its existing form the GROWA water-balance model is therefore suitable for GIS-based modelling of the water balance in large areas for water management planning on a state and regional basis, e.g. with respect to analysis and evaluation for the sustainable use of the groundwater supply. Therefore, the application of the GROWA approach for practical water resources management issues like the determination of the long term groundwater recharge in river catchment areas as required by the EU water directive can be recommended.

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Regional modelling of nitrate flux into groundwater and surface water in the Ems basin and the Rhine basin, Germany

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Abstract: An integrated model system has been developed to estimate the impact of nitrogen reduction measures on the nitrogen load in groundwater and in river catchment areas. The focus lies on an area wide, regionally differentiated, consistent link-up between the indicator "nitrogen balance surplus" and nitrogen charges into surface waters. As a starting point of the analysis actual nitrogen surpluses in the soil were quantified using the agro-economic RAUMIS-model, which considers the most important N-inputs to the soil and N-removals from the soil through crop harvest. The most important pathways for diffuse nitrogen inputs into river systems are modelled with the water balance model GROWA. Additionally, the time-dependent nitrogen degradation along the nitrogen pathways in soil and groundwater are modelled using the WEKU-model. The two selected river basins in Germany cover a variety of landscape units with different hydrological, hydrogeological and socio-economic characteristics. The results indicate a wide range of annual nitrogen surpluses for the rural areas between than 10 kg N $ha^{-1}•a^{-1}$ and 200 kg N $ha^{-1}•a^{-1}$ or more, depending on the type and intensity of farming. The level of nitrogen inputs into the surface waters is reduced because of degradation processes during transport in soil and groundwater. Policy impact analyses for a nitrogen tax and a limitation of the livestock density stress the importance of regionally adjusted measures.

Key words: diffuse water pollution, river basin management, multicriteria assessment, agro-environmental policy evaluation, denitrification, nitrate leaching

INTRODUCTION

In Germany, considerable progress has been achieved towards the improvement of water quality. However, diffuse water pollution, a source largely attributed to agricultural production continues to be of concern. As described by Gömann et al.[1], a wide range of problems concerning nutrient pollution of water bodies are prevalent in the Ems basin and sub catchments of the Rhine. It is to be expected that political measures towards a solution of these problems will have different effects on the reduction of nutrients in the different water bodies. Thus, the efficiency of measures has to be evaluated, taking into account both socio-economic conditions and natural site conditions. On one hand the different historically evolved and partly established socio-economic conditions in the study area such as agricultural farm structures or the structure of water protection as well as water supply and sewage disposal are an important prerequisite for the development of effective nitrogen reduction measures. On the other hand, natural conditions, which determine pathways and transport of diffuse nutrient surplus into surface waters, have to be considered. The Linkage of the agricultural sector model RAUMIS[2] with the hydrological model GROWA[3] and the reactive nutrient transport model WEKU[4] represents a consistent link-up of the environmental pressure indicator "agricultural nutrient surplus" with the environmental state indicator "nutrient loads of water bodies" and the environmental response indicator "nutrient reduction measure". This paper focuses on the application of the integrated agro-economic/hydro(geo)logic model system for the management of diffuse nitrogen fluxes exclusively.

METHODOLOGICAL APPROACH

Combining agroeconomic and hydro(geo)logical models is a scientific challenge. The most efficient way to homogenize and adjust models from different scientific disciplines is the development of a common model interface for data exchange. This interface has to guarantee a uniform definition (e.g. scope of representation, spatial and temporal dimension) of variables being exchanged within the model network. Figure 1 shows the integration of the agricultural economic model RAUMIS with the hydrological models GROWA and WEKU. A central interface between RAUMIS and GROWA/WEKU are regional nutrient surpluses and land use patterns. According to requirements specified above, it has to be considered that the two models are using different regional resolutions: raster cells in the hydrological models and administrative units in the RAUMIS model. This is due to the different data sources: while GROWA/WEKU uses land use maps, RAUMIS employs agrarian statistical data. For this reason, regional nitrogen balances calculated by RAUMIS as averages for the agricultural areas (AA) in the individual administrative units cannot be directly used as input variables in GROWA/WEKU. As a first step, these nitrogen surpluses are disaggregated and geographically referenced on raster cells as required by GROWA/WEKU.

In the agricultural sector model RAUMIS[2], a set of agro-environmental indicators is linked to agricultural production. Currently, the model comprises indicators such as fertilizer surplus (nitrogen, phosphorus and potassium), pesticides expenditures, a biodiversity index, and corrosive gas emissions. These indicators help to evaluate direct and indirect environmental impacts of policy driven changes in agricultural production. Regarding diffuse water pollution the indicator "nitrogen surplus" is of particular importance. Agricultural statistics with data, e.g. on crop yields, livestock farming and land use, were used to balance the nitrogen supplies and extractions for the agricultural area. The long-term nitrogen balance averaged over several vegetation periods is calculated considering the organic nitrogen fertilization, the mineral nitrogen fertilization, the symbiotic N-fixation, the atmospheric N-inputs and the N-extractions with the crop substance. As a rule, the difference between nitrogen supplies, primarily by mineral fertilizers and farm manure, and nitrogen extractions, primarily by field crops, leads to a positive N-balance[5].

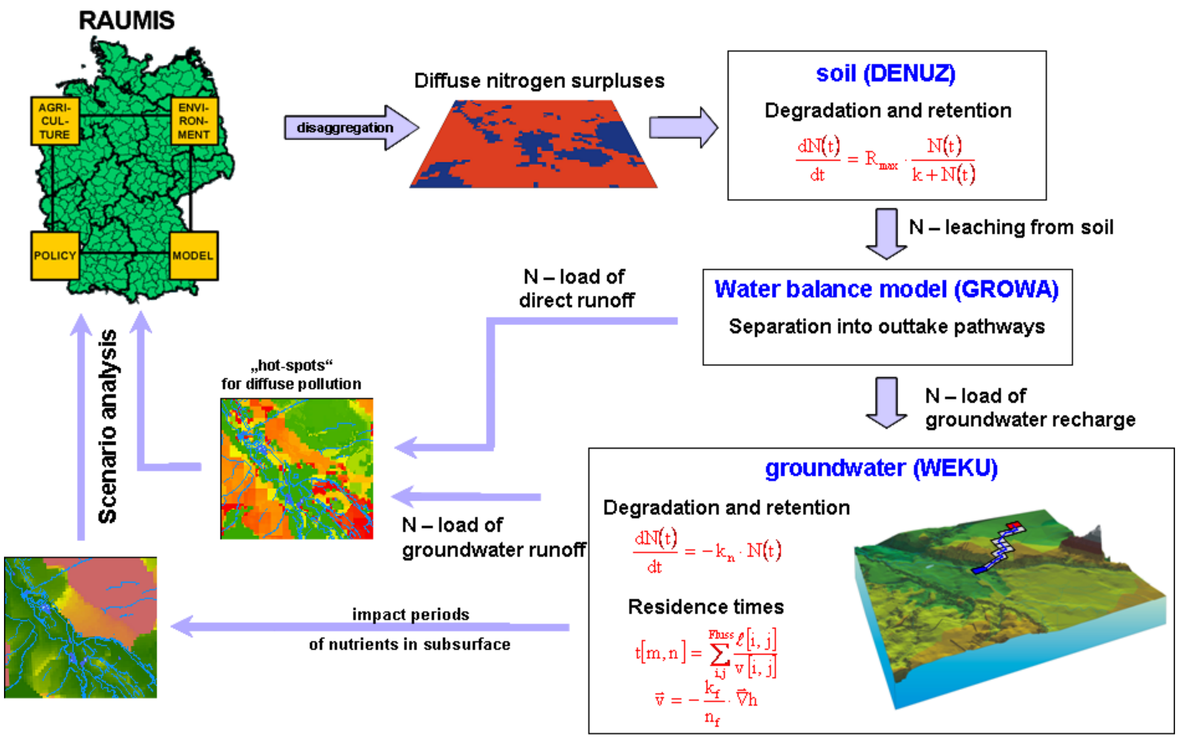

Figure 1: Integrated agroeconomic / hydro(geo)logic model system

The displacement of N-surpluses into surface waters is coupled to the runoff components. Against the background of a long-term treatment for the hydrological period 1961-1990, runoff was distinguished into direct runoff and groundwater runoff. Whereas direct runoff reaches the surface waters within short time periods (within about a week), groundwater run-off needs much more time (years) to percolate into surface waters. The runoff components were quantified area-differentiated considering climate, soil, geology, topography and land use conditions using the GROWA model[3]. The ratio between groundwater recharge and total runoff was taken as a measure for the extent diffuse nitrogen surpluses, which are displaced from soil to groundwater[6],[7].

During transport through the soil and the groundwater nitrogen surpluses may be denitrified to molecular nitrogen. Denitrification losses in the soil occur mainly in the root zone in case of low oxygen and high water contents as well as high contents of organic substances. In a Michaelis-Menten kinetics approach these denitrification conditions were combined with the nitrogen surpluses given by RAUMIS and the residence times of the percolation water in the root zone calculated as a function of average field capacity and the percolation runoff level[8]. Reactive nitrate transport in groundwater was modelled using the stochastical WEKU model[4] on the basis of a first order reaction depending on the nitrogen inputs into the aquifer, denitrification conditions in groundwater and groundwater residence times.

In the first step groundwater velocities are calculated according to Darcy's law from hydraulic conductivity, effective yield of pore space of the aquifer and the slope of groundwater surface (hydraulic gradient). The calculation of the residence times of the groundwater runoff is performed in a second step. Based on groundwater contour maps, a digital relief model of the groundwater surface is generated. This is analysed paying attention to information on the water network as well as the groundwater discharge or transfer areas with respect to lateral flow dynamics and groundwater-effective recipients. The residence times of the groundwater runoff are then obtained for each initial grid by summation over the individual residence times in the grids resulting from the groundwater velocities and individual flow distances along the flow path until they enter a surface water.

The WEKU model was extended by a module for the quantification of nitrate degradation in groundwater. According to an number of field studies a first order denitrification kinetics has been found. Denitrification leads to a halving of the nitrogen leached to the groundwater after a residence time between 1.2 and 4 years. Rather simple indicators, such as the presence of Fe (II), Mn (II) and the absence of O_2 and NO_3 can be used to decide whether a groundwater province has hydrogeochemical conditions in which denitrification is possible or such transformation of nitrogen can be neglected[9],[10].

CASE STUDY RIVER BASIN

Two German river basins, the Ems basin (12900 km^2) and several Rhine sub-catchments, comprising the river basins of the Sieg, Wupper, Ruhr and Erft, (in total 12100 km^2), have been selected as study areas in order to cover a wide range of different landscape units with different hydrological, hydrogeological and socio-economic characteristics. The administrative bodies that correspond to RAUMIS regions ("Landkreise") cover an area of 32700 km^2 in total and thus overextend the catchment areas of about 30%.

The river Ems basin is located in the North-German Plain. Agriculture plays an important role in comparison to the German average: Agricultural area (AA) accounts for about 62 % of total area and production is dominated by intensive animal husbandry which is more competitive on the prevailing less fertile sandy soils than cash cropping. Farmers typically grow fodder crops, such as silage maize and corn-cob-mix on arable land. These generate higher yields than permanent grassland and enable a higher livestock production. This production structure explains the visible correlation between shares of arable land and livestock densities (LD) that are displayed in for the regions within the Ems catchment.

The situation is quite different in the Rhine sub catchments A striking socio-economic difference is the population density being three times higher than in the Ems basin. Settlements, traffic, and industries, in addition to forests, play an important role such that agricultural area amounts to 30 % of total area. Eastern parts of the Rhine sub catchment are located in consolidated Palaeozoic rock areas with high total area runoff levels, dominated by fast (direct) runoff components. These conditions hamper tilling of soil so that permanent grassland dominates land use. Farmers specialise in cattle and milk production on a fairly extensive level. All these regions can be classified as areas with a high risk of surface water pollution, e.g. of reservoirs. On the other hand it can be expected that nutrient reduction measures will improve surface water quality in these areas rapidly. Western parts of the Rhine sub catchment are located in the unconsolidated quaternary rock area of the lower Rhine bay with considerable ground water recharge levels. Because of the very fertile loess soil, intensive cash cropping is the main agriculture production activity. These regions feature a share of arable land of more than 90 % of AA and low live-stock densities.

RESULTS AND DISCUSSION

Nitrogen leaching from the soil

The nitrogen surpluses calculated with the RAUMIS model were calculated for a projection of the development under the current Common Agricultural Policies (Agenda 2000) of the European Union for the year 2010. This surplus is used as reference scenario instead of the actual situation, as comparative static policy impact analyses for a future target year require a scenario of reference because various parameters are changing in the long-run in addition to the variations of policy measures being investigated. Typically the scenario of reference is a projection of the development under "business as usual". Thus, nitrogen surpluses indicate the amount of nitrogen that potentially leaches into groundwater and surface waters. Deviating from the reference scenario, alternative policies and regulations are imposed on the model keeping all other parameters and constraints constant. Comparison to the actual situation would lead to a convolution between the effects of these already implied policies and the effects of the investigated reduction measures.

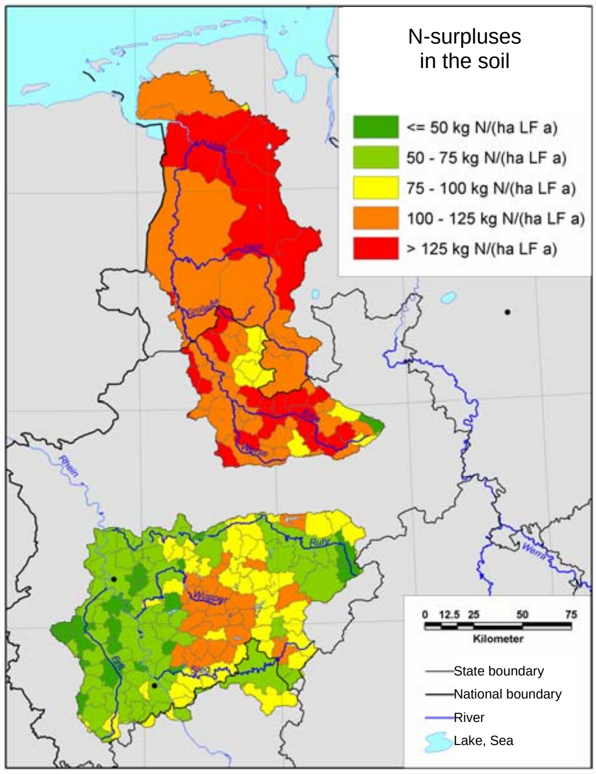

Figure 2: Annual nitrogen surpluses

On average, the calculated nitrogen surpluses for the agricultural acreages based on this reference scenario amounts to about 130 kg N ha^{-1}•a^{-1} in the Ems basin, whereas the average for the investigated sub basins of the Rhine basin is much less (74 kg N ha^{-1}•a^{-1}), due to the generally less intensive agriculture. The nitrogen surpluses from agriculture, calculated as averages on a district level, are disaggregated with respect to the current land use. For this purpose the CORINE land cover land use classes arable land and pasture are used as disaggregating criteria. In addition, atmospheric nitrogen inputs of 30 kg N ha^{-1}•$a^{-1}$and an asymbiotic nitrogen fixation of 1.4 kg N ha^{-1}•a^{-1} have been considered as lump sum amounts. For areas representing non agricultural regions in the REGFLUD study areas, urban areas and forests, only the atmospheric inputs and asymbiotic nitrogen fixation were considered.

In figure 2 the nitrogen surpluses in the soil are plotted. Especially in regions with area-independent animal processing (intensive animal production) nitrogen surpluses result from both animal excretions and mineral fertilizers as well. This kind of land use management occurs mainly in the north-western part of the Ems basin. In addition, the western sub basins of the Rhine basin, dominated by fertile loamy soils and favourable climatic conditions display significant nitrogen surpluses because of intensive growing of commercial and specialty crops. Low nitrogen surpluses are calculated for regions with mostly forage crops production, which is typical for the eastern parts of the Rhine basin.

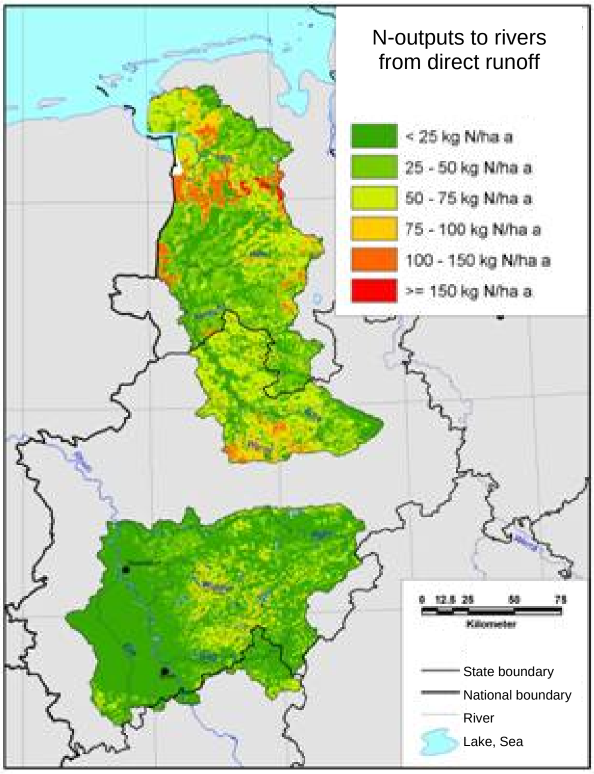

Figure 3: Nitrogen outputs into rivers from direct runoff

Denitrification in the soils has been modelled using a Michaelis-Menten kinetics. In this way the nitrogen surpluses from agriculture were reduced by up to 50 % in some areas, e.g. in areas where loamy soils with a high water storage capacity a high organic carbon content occur. The remaining nitrogen leaching from the root zone is transported to the surface waters either by direct runoff or leaches into groundwater according to the calculated base flow ratio. In the north-western part of the river Ems basin or in the mountainous regions in the eastern part of the Rhine basin, groundwater runoff is not more than 20 to 40 % of the total runoff. In these regions direct runoff is the dominant pathway of nitrogen input into surface waters. In other areas, e.g. the central part of the Ems basin, groundwater runoff is the main pathway for nitrate entries into surface waters.

The results of coupling nitrogen leaching from the root zone with runoff values are shown in figure 3 and figure 4. Figure 3 shows the corresponding nitrogen input into surface waters via direct runoff. In this case no further denitrification in the unsaturated zone is considered. It becomes clear, that N-inputs to surface waters from direct runoff are important especially in the marshy areas of the Ems basin and the mountainous regions in the Rhine basin.

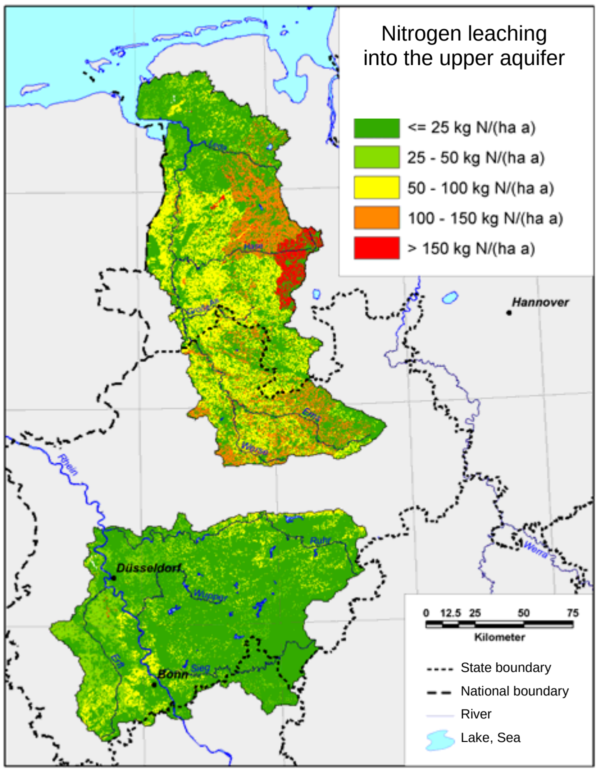

Figure 4: Nitrogen leaching into the upper aquifer

Figure 4 shows the nitrogen inputs into the aquifers via groundwater recharge. High nitrogen leaching to the groundwater is calculated for regions with a high groundwater runoff portion and high nitrogen surpluses, which is important in particular for the central part of the Ems basin. In the sub-basins of the Rhine the nitrogen leaching to groundwater is less important due to the low nitrogen surplus level (see figure 3) on one hand and the large portion of direct runoff in the mountainous regions of the Rhine basin.

Nitrogen inputs into surface waters via groundwater runoff

Transport and denitrification in the aquifer is calculated using the WEKU model taking into account groundwater residence times and natural nitrate degradation in the aquifers. Calculated groundwater residence times range between less than 1 year and more than 150 years. Long residence times result both from small groundwater velocities as well as from long flow paths up to the recipient, pointing at the long time periods, after which nitrate inputs into the aquifer can contribute to the pollution of surface waters in some regions. Short residence times result for areas in the vicinity of rivers and/or regions with high groundwater velocities.

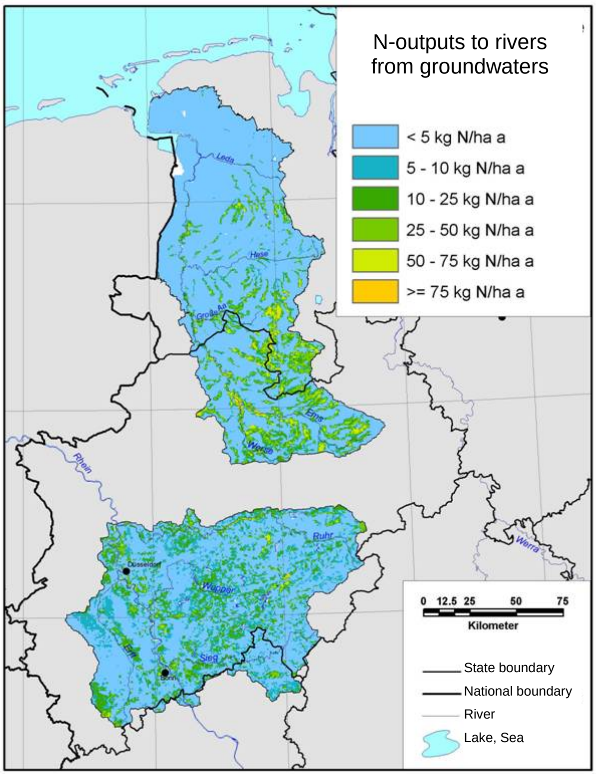

Figure 5: N-outputs to rivers from groundwater

The quantification of the parameters of denitrification kinetics in groundwater was done separately for the groundwater bearing formations occurring in the river basins. In total, about 3300 groundwater samples were evaluated and classified with respect to nitrate degradation capacity. From this analysis the groundwater bearing formations glaciofluviatile sands and moraine deposits, both occurring in the river Ems basin, were classified as nitrate degrading. In contrast, most aquifers in the sub basins of the river Rhine, predominantly consolidated rocks (e.g. shists and limestones), showed usually non-nitrate degrading conditions.

The remaining nitrogen outputs to surface waters from groundwater were calculated by combining the N-leaching into the aquifers and the reactive N-transport in the aquifers. The result is shown for the reference situation in figure 5 for the initial cells for which the inputs into the soil have been calculated. It can be seen that nitrogen intakes in the vicinity of surface waters and high nitrogen leaching levels contribute considerably to the groundwater-borne nitrate inputs to the surface waters. Even with good conditions for a complete degradation of nitrate in the aquifer, the brief residence times are not sufficient for an adequate degradation of high nitrate inputs. There is, furthermore, a hazard potential in many regions where high nitrate inputs are associated with relatively short residence times of the groundwater, as well as restricted and/or insignificant degradation conditions in the aquifer. These regions include almost the whole Rhine catchment area. The loose rock aquifers in the northern part of the Ems basin show an opposite behaviour. There, even high nitrogen inputs into the groundwater systems result only in very slight nitrate inputs to surface waters after transport through the aquifers. Long groundwater residence times and good denitrification conditions cause high denitrification of up to 90% of the inputs into the aquifer systems. As a consequence, groundwater is almost nitrate-free when it enters the rivers after transport through the aquifer systems.

The observed N-loads in rivers represent the sum of all N-inputs by the different diffuse and point source intake pathways. The residence times of direct runoff and groundwater runoff differ significantly not only between the different input pathways but also from intake site to intake site. Thus, the input to surface waters from a certain intake location via direct runoff refers to an input from of less than 2 years ago in general, whereas the inputs via groundwater for the same location refers to an input from some decades ago. Hence, for the calibration and verification of the integrated RAUMIS-GROWA-WEKU model calculations of nitrogen river loads concerning the past inputs have to be considered as well. This has been done using nitrogen surpluses calculated with RAUMIS for the reference periods of the last decades.

The validity of modelled groundwater-borne nitrogen inputs into surface waters was checked following a procedure suggested by Behrendt et al.[11]. At first the measured N-loads were corrected by the point N-inputs[12]. In order to avoid effects of the N inputs by direct runoff, only observed nitrogen concentrations at low flow conditions were considered. Additionally only observed values at temperatures below 5° C were taken as reference in order to avoid effects of nutrient retention in rivers. The comparison of the modelled groundwater-borne nitrogen inputs into surface waters with the observed river load data of 54 sub-catchment areas show only relatively small differences to the observed values (about 10-20 %).

CONCLUSIONS

In Germany, the water pollutions caused by diffuse nitrogen from agriculture are regionally different. Using the nitrogen surpluses as an indicator to detect or classify "hot-spot" regions, the Ems catchment seems to be quite endangered by N-inputs from agriculture. However, a direct inference from the risk indicator "nitrogen surplus" being calculated with the agricultural sector model RAUMIS to actual depositions of nitrogen into water bodies is limited since natural site conditions (e.g. nitrogen degradation capacities, residence times, etc.) vary considerably among regions.
These natural conditions are accounted for in the hydrological and hydrogeological models GROWA and WEKU, which were used to quantify the nitrogen inputs into the surface waters from the different transport pathways. From the results of this study we conclude that in the groundwater systems of the river Ems basin about 90 % of the diffuse nitrogen input into the ground water is degraded in groundwater due to a long groundwater residence time and favourable denitrification conditions. There, groundwater borne nitrate input into the surface waters turned out to be relatively low even if the region were addressed as a "hot-spot" in terms of total nitrogen surplus from agriculture.

The networking of the agroeconomic model RAUMIS with the hydro(geo)logic models GROWA and WEKU has shown, that the very complex interactions between the driving-force indicator "diffuse nitrogen surpluses" and the state indicators "nitrogen loads in surface waters and groundwater" can be analysed in a consistent and regionally differentiated way. The synergetic effects shows the potential of interdisciplinary model networks for the implementation of political measures aiming at the sustainable management of nitrogen fluxes in river basins.

ACKNOWLEDGMENTS

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Program of the Seminar on Groundwater Modelling

European Commission

Technical Assistance Information Exchange Instrument, DG Enlargement

Seminar on Groundwater Modelling – Water Framework Directive

INFRA 25914

Organized in co-operation with

Environmental Agency of the Republic of Slovenia

Ljubljana, 28. – 31. January 2008

Aim of the Meeting

The aim of this meeting is to provide an insight into the capabilities and limitations of groundwater modeling, if used as a tool for the preparation of Water Framework Directive's (WFD) River Basin Management Plans. With the gained knowledge the participants (water managers, decision makers) will later be able to set up, control and evaluate the groundwater modeling process of studies carried out by others (groundwater modelling experts, consulting engineers, etc).

The seminar topics will include the decisions to be taken both at the onset of a study, as to the benefits of the modeling to be expected in the given circumstances, and the decisions related to the interpretation of the modelling results after the completion of the study.

Mon 28 January 2008 (Day I)

Chair:
Casper van de Watering

08.00	Registration of participants
08.30	Welcome and Introduction on behalf of TAIEX ***Casper van de Watering, Slovakia***
08.45	Welcome on behalf of the Environmental Agency of the Republic of Slovenia ***Silvo Žlebir, Director General of Environmental Agency of the Republic of Slovenia***
09.00	Key issues of water policy in Slovenia ***Mitja Bricelj, State Secretary at Ministry of Environment and Spatial Planning, Slovenia***
09.15	Groundwater related directives implementation in the process of River Basin Management Planning in Slovenia ***Joerg Prestor, Geological Survey of Slovenia, Slovenia***
10.00	Groundwater status assessment within the scope of WFD implementation in Austria ***Michael Samek, Federal Ministry of Agriculture, Forestry, Environment and Water Management, Vienna, Austria***
10.45	***Coffee break***
11.15	Principles of groundwater modelling ***Nada Rapantova, Technical University of Ostrava, Czech Republic***
12.30	***Lunch break***
14.00	Systematic approach to groundwater modelling ***Karel Kovar, the Netherlands***
14.50	Case study: Building a groundwater model at the Morava River (transboundary area between Slovakia and Austria) for the WFD purposes ***Jouke Velstra, the Netherlands***
16.00	***Coffee break***
16.30	Karst vulnerability modelling ***Martin Kralik, Federal Environmental Agency, Vienna, Austria***
17.15	Case study: Development of the national water resource model for Denmark (DK-model) - history of model improvements in time ***Anker Lajer Højberg, Geological Survey of Denmark and Greenland (GEUS), Denmark***
18.00	Closure of Day I

Tue 29 January 2008 (Day II)

Chair:
Casper van de Watering

08.00	Registration of participants
08.30	The Point Count System Model SINTACS R5 within the Italian combined approach in groundwater vulnerability to contamination mapping ***Massimo V. Civita, Polytechnic of Turin, Italy***
09.15	A strategy for protecting karst groundwater in Austria ***Martin Kralik, Federal Environmental Agency, Vienna, Austria***
09.45	Case study, examples of application of the national water resource model for Denmark (DK-model): - to define where nitrate may pose risk to nature areas - as a tool for issuing permits for groundwater abstractions ***Anker Lajer Højberg, Geological Survey of Denmark and Greenland (GEUS), Denmark***
10.45	***Coffee break***
11.00	Calibration of groundwater models, including case study ***Jouke Velstra, the Netherlands***
12.00	Pathlines and travel times in groundwater modelling ***Karel Kovar, the Netherlands***
12.45	***Lunch Break***
14.00	Groundwater quantitative status assessment in Slovenia ***Mišo Andjelov, Environmental Agency of the Republic of Slovenia***
14.45	Area-differentiated modelling of groundwater recharge rate for determining the quantitative status of groundwater ***Frank Wendland, Research Centre Jülich, Germany***
15.45	***Coffee break***
16.00	A groundwater model for the assessment of management strategies to improve the surface water quality ***Hans-Peter Nachtnebel, Universität für Bodenkultur Wien (BOKU), University of Natural Resources and Applied Life Sciences, Vienna, Austria***
17.00	Numerical unsaturated flow modelling with case studies from Slovenia ***Mihael Brenčič, Geological Survey of Slovenia***
17.45	Risk analysis of groundwater pollution hazard in water protection areas ***Goran Vižintin, University of Ljubljana, Slovenia***
18.30	Discussion / Questions Closure of Day II

Wed 30 January 2008 (Day III)

Chair:
Casper van de Watering

08.00	Registration of participants
08.30	Case study: Regional modelling of nitrate flux into groundwater and surface water in the Große Aue Basin, Germany ***Frank Wendland, Research Centre Jülich, Germany***
09.15	Identification and assessment of uncertainties in groundwater modelling: study of a regional groundwater system suffering under nitrate pollution from different sources ***Hans-Peter Nachtnebel, Universität für Bodenkultur Wien (BOKU), University of Natural Resources and Applied Life Sciences, Vienna, Austria***
10.15	***Coffee break***
10.45	Modelling of groundwater quality ***Karel Kovar, the Netherlands***
11.30	Case study: Groundwater modelling for Ostrava-Nova Ves area, problems and conflicts in heavily polluted mining-industrial area in Czech Republic ***Nada Rapantova, Technical University of Ostrava, Czech Republic***
12.30	***Lunch Break***
14.00	Case study: Model supported stakeholder initiative at Holten, the Netherlands: Groundwater modelling to study relationship between land use and nitrate leaching near groundwater abstraction site ***Jouke Velstra, the Netherlands***
15.00	Groundwater chemical status assessment in Slovenia ***Marjeta Krajnc, Environmental Agency of the Republic of Slovenia***
15.45	Complex field experiments as a base for modelling of unsaturated zone - a case study from Ljubljana field ***Marina Pintar, University of Ljubljana, Slovenia***
16.30	***Coffee break***
17.00	Monitoring for assessment of effectiveness of Programmes of Measures / Action Programmes (Water Framework Directive & Groundwater Directive / Nitrate Directive), carried out on the national scale of the Netherlands ***Dico Fraters, National Institute of Public Health and the Environment (RIVM), the Netherlands***
18.00	Geographic Information Systems as a tool for groundwater modelling: storage of basic data, their processing for model input data, and processing and presentation of model output data ***Nada Rapantova, Technical University of Ostrava, Czech Republic***
18.30	Discussion / Questions Closure of Day III

Thu 31 January 2008 (Day IV)

Chair:
Casper van de Watering

08.00	Registration of participants
08.30	Case study: Risk-based approach for decision making about multi-source cleanup in Hilversum area, in central Netherlands [based on groundwater pathline analysis] ***Jouke Velstra, the Netherlands***
09.15	DSS, Decision Support System: What is it and how can it be used? ***Nada Rapantova, Technical University of Ostrava, Czech Republic***
09.45	***Coffee break***
10.00	SDSS as a tool for integrated groundwater resources management ***Barbara Čenčur, Institute of Mining, Geotechnology and Environment & University of Ljubljana, and Stefan Kollaris,*** **PRISMA solutions, Austria**
10.30	Reliability of groundwater model results, including case study [reliability of travel times of groundwater] ***Karel Kovar, the Netherlands***
11.15	Groundwater modelling as a tool for development of River Basin Management Plans and Action Programmes in the Water Framework Directive: Discussion and exchange of information (- from perspective of hydrologist) (- from perspective of water manager) ***Introduction and moderation by Joerg Prestor, Geological Survey of Slovenia***
12.00	Discussion / Questions Closure of Seminar by Casper van de Watering

This meeting is being organised by the
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Conclusion

Concluding remarks on the
Seminar on Groundwater Modelling – Water Framework Directive

Seminar on Groundwater Modelling – Water Framework Directive was organized in co-operation with Environmental Agency of the Republic of Slovenia by the European Commission, in the framework of Technical Assistance Information Exchange Instrument - TAIEX. At the seminar, that took place in Ljubljana from 28 to 31 January 2008, lectured 19 lecturers from seven European countries. It was attended by 27 participants from 10 Slovenian institutions.

Through the efforts and active inputs of local co-organizer the initial programme has been enlarged and tailored to the local hydrogeological features and the needs of specialists concerned with implementation of Water Framework Directive in Slovenia.

A broad overview of applicability of groundwater modelling in Water Framework Directive was given through 31 lectures, with special emphasize on following topics:

- Groundwater bodies characterization,
- Assessment of monitoring networks and network upgrading, especially regarding location of monitoring sites and network density,
- Defining action plans to improve chemical and quantity status of groundwater bodies, taking into account surface water / groundwater interaction,
- Cost benefit analysis of measures to improve the status of waters,
- Verification of exceptions to achieving good status by 2015, and
- Evaluation of effectiveness of Programmes of Measures.

In concluding discussion and assessment of applicability of groundwater models in Slovenia foreign experts stressed that two pillars of groundwater modelling are of utmost importance:

- 1st pillar, of good hydrogeological expertise and knowledge of hydrogeology of the country for scientifically sound conceptual models both on regional and local scale;
- 2nd pillar, of good and unified national data base of geological and hydrogelogical data to enable broad use of modelling tools, as well as checking the results together with verification.

Broad discussion among the participants put forward clear need for a comprehensive and easy accessible national data base of appropriate hydrogelogical data, needed for setting up of groundwater models. In Water Framework Directive implementation, due to the hydrogeological heterogeneity of Slovenia, regional conceptualization is recommended as an approach, this being a starting point for setting up local numerical models to simulate impacts of interventions and measures.

There is a need in Slovenia to regulate status of public accessible hydrogeological data, used for modelling, being a basis for model conceptualizations and groundwater modelling within the sphere of Water Framework Directive implementation both on regional and local scale.

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