TEXTE
14/2011

Evaluation and optimization of groundwater protection programs according to EU-Water framework directive

Summary

Umwelt
Bundes
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Für Mensch und Umwelt

| TEXTE | 14/2011

ENVIRONMENTAL RESEARCH OF THE
FEDERAL MINISTRY OF THE ENVIRONMENT,
NATURE CONSERVATION AND NUCLEAR SAFETY

Project No. (FKZ) 3707 28 200
Report No. (UBA-FB) 001412

Evaluation and optimization of groundwater protection programs according to EU-Water framework directive

Summary

by

Petra Kuhr, Dr. Ralf Kunkel, Dr. Frank Wendland
Forschungszentrum Jülich GmbH, Jülich

Ute Baron, Prof. Dr. Hans-Jürgen Voigt
Brandenburgische Technische Universität Cottbus, Cottbus

On behalf of the Federal Environment Agency (Germany)

UMWELTBUNDESAMT

This publication is only available online. It can be downloaded from
http://www.uba.de/uba-info-medien-e/4087.html
along with the complete version (in German) and a German-language summary.

The contents of this publication do not necessarily reflect the official opinions.

Publisher: Federal Environment Agency (Umweltbundesamt)
P.O.B. 14 06
06813 Dessau-Roßlau
Germany
Phone: +49-340-2103-0
Fax: +49-340-2103 2285
Email: info@umweltbundesamt.de
Internet: http://www.umweltbundesamt.de
http://fuer-mensch-und-umwelt.de/

Edited by: Section II 2.1 General Aspects of Water Quality and Water Resources Management, Groundwater Protection
Rüdiger Wolter

Dessau-Roßlau, March 2011

Summary and conclusion

In the framework of the UFO - Plan – project a *Methodology to evaluate and optimize groundwater protection programs aiming at diffuse and point source pollution according to EU-Water framework directive* has been developed. This methodology comprises three consecutive parts:

1. In the first part the interrelations between matter inputs (contaminations), observed matter concentrations in groundwater and the hydrogeological system are analyzed based on a „conceptual model“. In this way the actual status of a groundwater body is interpreted. Already at this stage it can be assessed if the projected measures will show effect at the areas / locations which display the highest contamination / pollution risk for groundwater resources.
2. Based on this a consistent evaluation of programs of measures to reach good status of groundwater is carried out. For this purpose the reduction level necessary to reach quality targets for groundwater and the efficiency of possible (or already introduced) measures is assessed.
3. The third part is an evaluation of the time gap between the introduction of a measure and it’s impact on the status of groundwater. This makes it possible to get idea about the delay which must be taken into account until a certain measure may lead to a significant improvement of groundwater status at the monitoring stations.

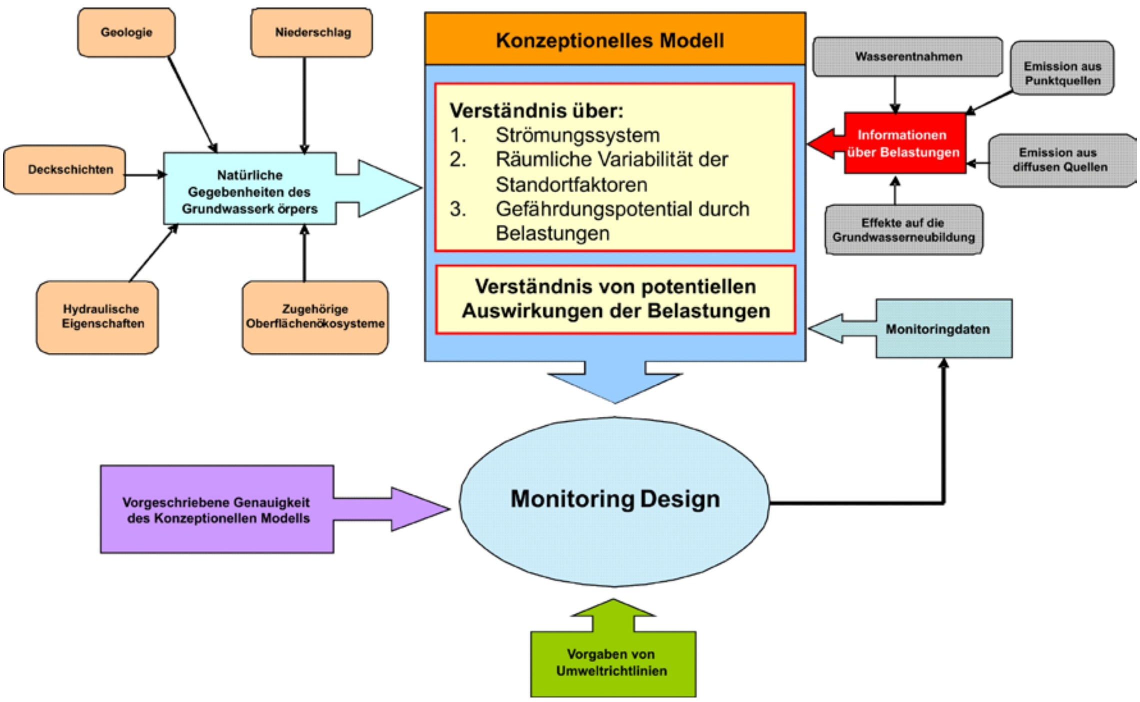

Figure 1: Conceptual model modified according to Littlejohn et al. (2002)

The methodology has been applied in case study areas (groundwater bodies), which display significant differences with regard to hydrogeological site conditions and contamination potentials. Adapted to the sources of contamination (diffuse sources vs. point sources) two procedures have been developed.

Procedure for the evaluation of groundwater contaminations from diffuse sources:

As the majority of diffuse groundwater contaminations in Germany is caused by nitrate leached from fertilized areas under agricultural use, a large-scale conceptual model has been designed for the evaluation of programs of measures, which aim at controlling and reducing diffuse nitrate contamination of groundwater.

The applicability of the large-scale conceptual model to evaluate groundwater pollution from diffuse nitrate leaching was tested for two groundwater bodies in the Federal States of Hesse and Northrhine-Westfalia / Lower Saxony, which display considerable differences with regard to their site conditions and their agricultural structures. Both can be regarded as representative for many groundwater bodies occurring in Germany. The groundwater body "Große Aue" is located between the Federal States of Northrhine-Westfalia and Lower Saxony and is representative for groundwater bodies in the North-German Lowlands. The groundwater body "Schwalm" in contrast can be regarded as typical for an agriculturally used area in the midlands.

For both groundwater bodies it could be shown that already few parameters, such as

- digital available data bases (Land use, depth of groundwater and denitrifcation conditions of soils respectively),
- parameters, which can be derived easily from other data bases (e.g. flow directions of groundwater from groundwater contour maps) or
- available results from model simulations (e.g. nitrate concentrations in the leachate, runoff ratios)

are sufficient to describe and identify areas showing a potentially high nitrate pollution risk for groundwater. Consequently, the simultaneous occurrence of deep groundwater tables, bad denitrification conditions in soils and a high portion of groundwater recharge characterize areas with a high nitrate pollution risk. These areas are identical to the agricultural land, where programs of measures to reduce nitrate pollution of groundwater should be implemented primarily.

In the groundwater body "Große Aue" such accordance of site conditions indicating a high nitrate pollution risk occurs at 25% of the total area. Nevertheless 95% of the available groundwater monitoring stations (19 out of 20) for which high nitrate concentrations were observed corresponds to locations where these three site conditions coincided. Applying the same procedure to the groundwater body „Schwalm" resulted in reducing the areas with high nitrate pollution risk down to 40%. There, all monitoring stations (8) showing significantly raised nitrate concentrations were located in areas showing these site conditions.

In case information about leachable nitrate loads in the soil (such as modelled nitrate concentrations in the leachate and nitrogen surpluses respectively) is available, the N reduction level necessary to reach groundwater quality targets (e.g. 50 mg/l) can be assessed (Abbildung 2). In this way it becomes possible to evaluate the efficiency of both, already implemented reduction measures and additional future reduction measures.

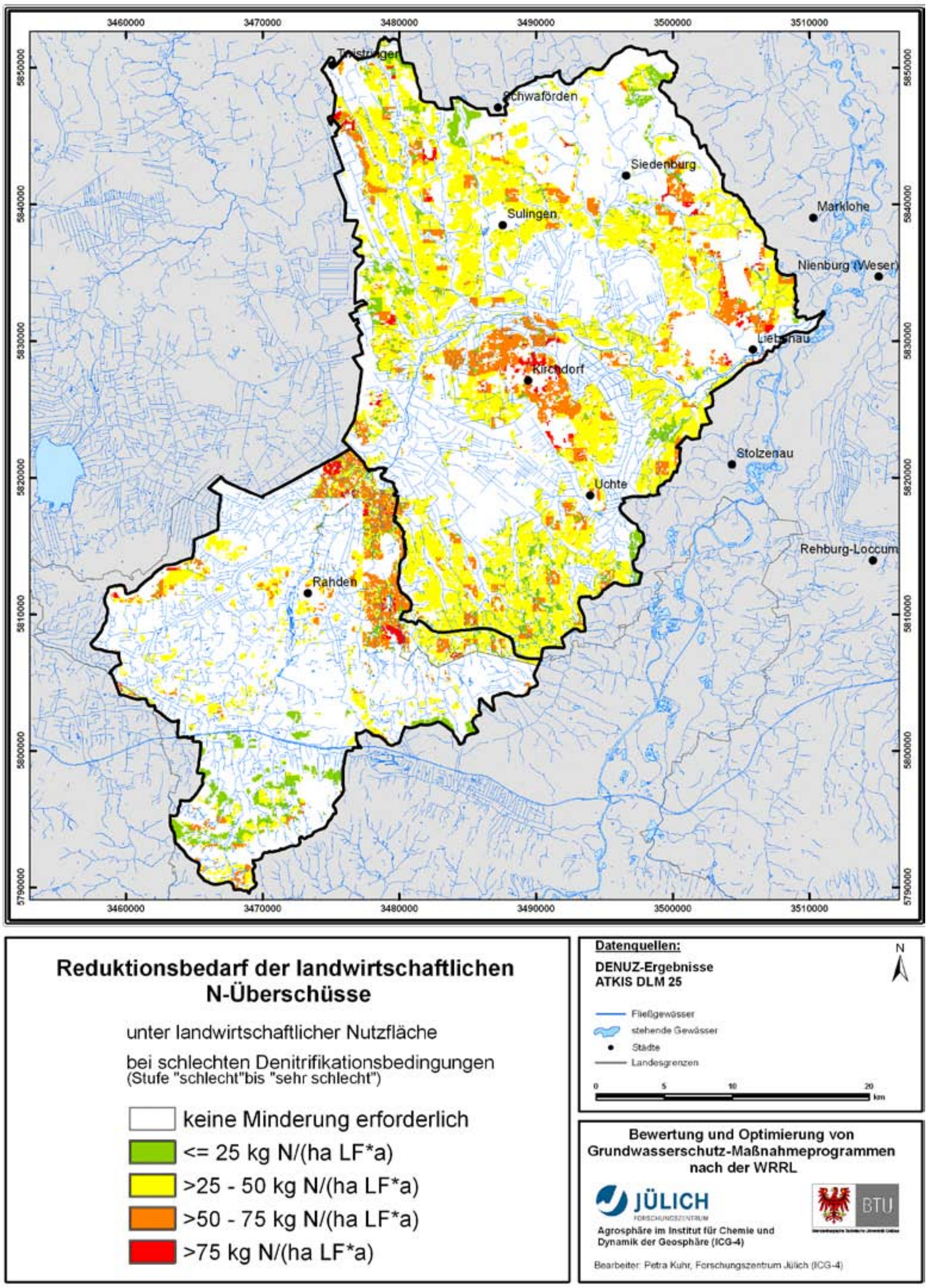

Figure 2: **reduction need of nitrate surpluses to achieve a nitrate concentration in the leachate below 50 mg/l for each grid cell**

It could be shown that in large parts of both groundwater bodies an average reduction of 10 to 25 kg N / (ha*a) is sufficient to guarantee a nitrate concentration in the leachate below 50 mg NO3/l. With the help of measures described in detail in the „LAWA catalogue of measures“ regionally suitable measures with a well defined reduction potential may be selected and applied. In the Southwestern part of the groundwater body „Große Aue“ an area has been identified, in which the reduction level exceeds 25 kg N / (ha*a). In these areas it is possible that the required N reduction levels can not be achieved based on the N reduction potential of applicable single measures or combination of measures. In this way it is possible to identify unerringly and consistently those areas in a groundwater body for which quality targets for the groundwater can not be achieved with the established measures. If necessary, additional measures have to be taken into account.

At any case the regional effectiveness of measures can be verified at the monitoring stations located in a groundwater body. In this connection the assessment of the time gaps after which the implementation of a measure may lead to a significant downward trend becomes important. The mean residence times in the soil, the groundwater covering layers and the aquifer itself can be derived with the help of analytical model approaches. The essential data base (e.g. field capacity of soil, hydraulic conductivity of aquifer, groundwater contours) can be derived German-wide from digital survey maps.

The summation of the residence times in soil, groundwater covering layers and the aquifers has shown in the case of the groundwater body „Große Aue“ that significantly more than six years predominate (Figure 3). Hence, it can be expected that nitrate concentrations at the monitoring sites will not decrease to a value beneath the threshold value of 50 mg NO_3/l until the year 2015 even in case well-targeted reduction measures have already been implemented in 2009.

The assessed time gaps between the introduction of a measure and it’s impact with regard to an improvement of the groundwater quality at the monitoring sites are an important decision support as they may help to justify towards the EU commission that the targets of the EU-WFD can not be reached until 2015, although an implementation of adequate reduction measures has been carried out. Thus the determined residences times may support the application of an extension of timescale (EU-WFD, article 4 section 3, 4).

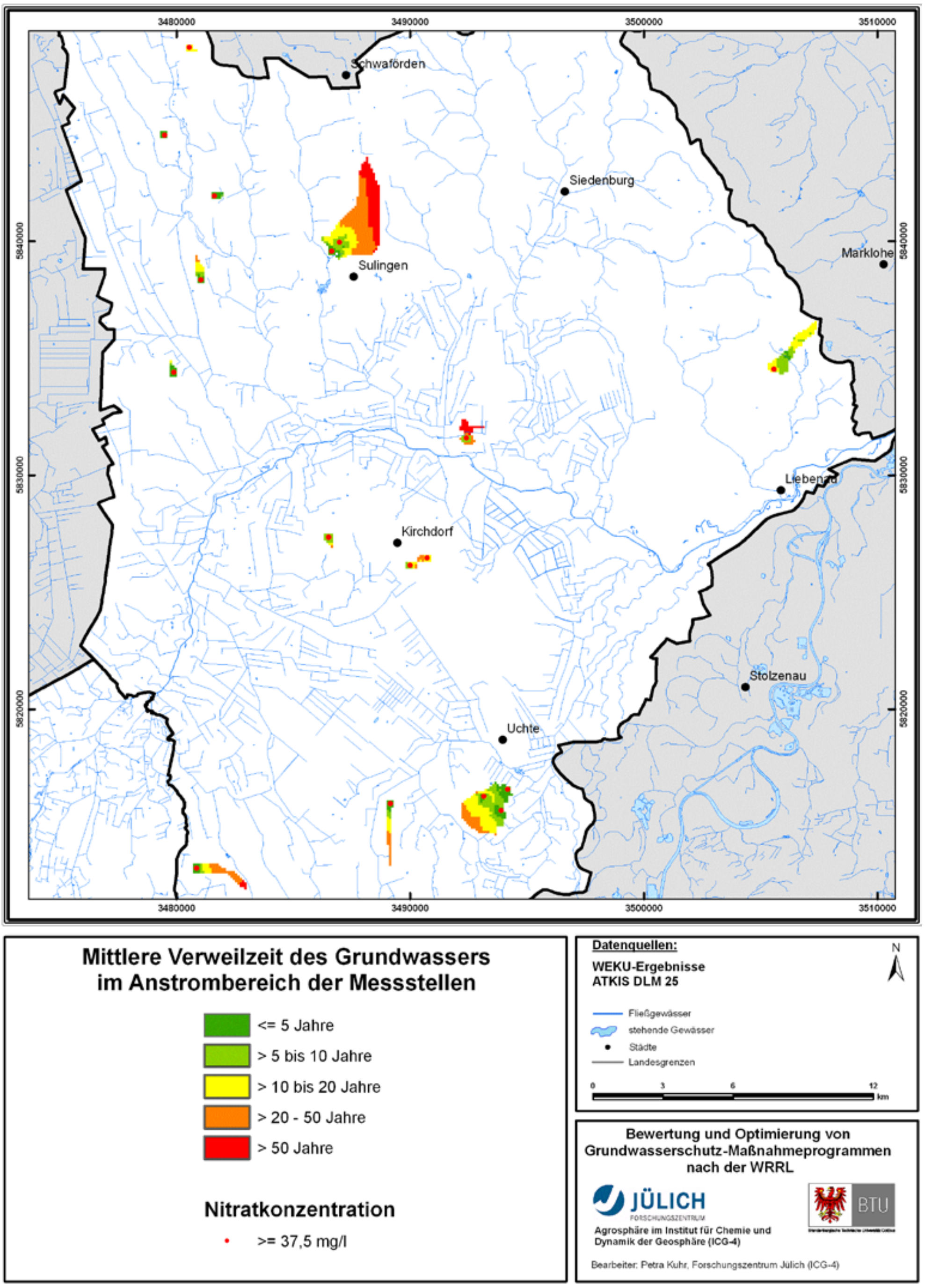

Figure 3: Average summed residence time in the flow field of monitoring stations

Procedure for the evaluation of groundwater contaminations from point sources:

As the majority of point source contaminations of groundwater can not be allocated to well-defined emission sources, the analyses of plumes of different groups of pollutants came in the fore of the small-scale conceptual model

It can be expected that large-scale conceptual models are able to describe the local hydogeological system only in exceptional cases. Hence, the evaluation of programs of measures derived for point source groundwater contaminations (e.g. former industrial sites, landfills) is only possible to a certain extent. Consequently a “local conceptual model” was developed, for which the choice of suitable monitoring sites and monitored parameters plays an important role in the initial phase (Figure 4). In a later phase the results of the local conceptual model with regard to the local groundwater flow system can be used to optimize the existing monitoring network in terms of monitoring sites and parameters. This enables both, a considerable cost reduction for the selective maintenance of monitoring sites and the determination of sites displaying the highest pollution potential.

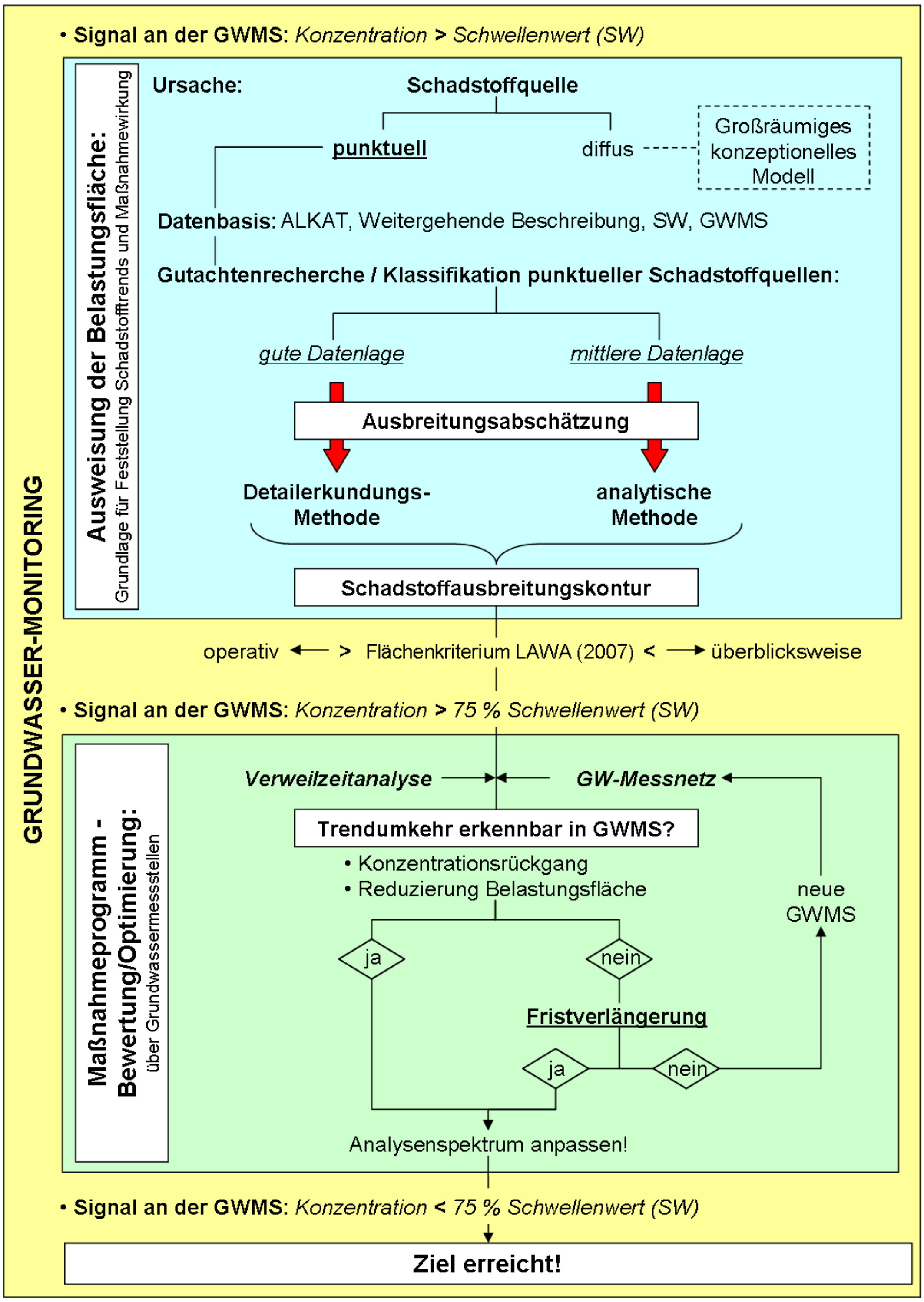

Figure 4: **Conceptual model for contaminations based on point sources**

Consequently the local conceptual model integrates not only information about the hydrogeology of a groundwater body and the monitoring network, but also information about the punctiform contamination sources (input model).

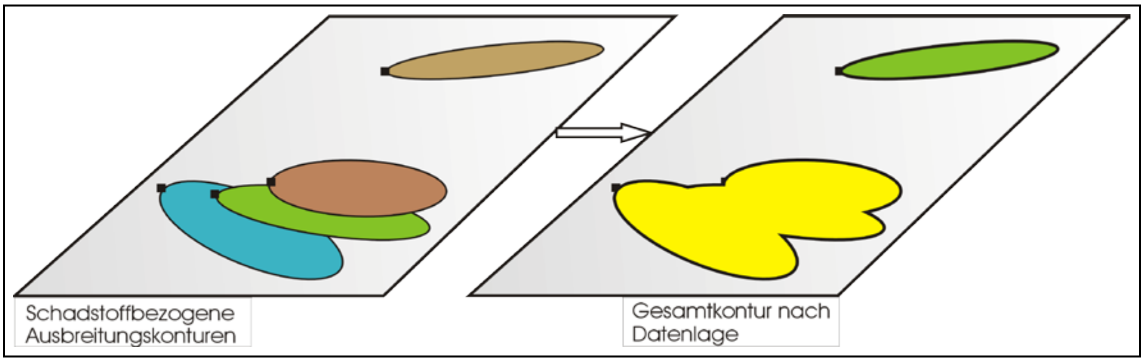

Figure 5: Illustration of the encircling contour based on the contours of dispersal for each contamination

A characteristic feature of the local conceptual model is the classification of knowledge about the individual point source contaminations and the subsequent procedures to present the dispersal of pollutants. In case there is a lot of information available about a site, the contour of dispersal is determined based on interpolation procedures. In case of less information the contour of dispersal is assessed based on an analytical methodology (transport equation). Both procedures result in contours of dispersal which reflect on the real groundwater flow systems and pollution sources as good as possible. As the total polluted area of a groundwater body is determined with the help of the enveloping contour of the individual plumes, the “significance of a pollution risk” can be assessed according to LAWA (2007) (Figure 5).

The time gaps after which the implementation of a measure may lead to a significant downward trend of pollution at the monitoring sites are quantified in the local conceptual model based on a particle tracking approach.

The overlaying of all results may help to understand the interplay of contaminant input, observed contamination and the hydrogeological system. In this way it becomes possible to rank the monitoring sites with regard to the evaluation and optimization of measures taking the plumes and the residence times into account. Additionally changes in concentrations including trend reversals and contaminant contours due to implemented measures can be detected. An optimisation of the geographic positioning of monitoring sites in the plumes of several pollutants extend and the limitation analysed parameters to the relevant ones results in most cases in a minimization of costs.

1. priority monitoring sites are located in the plume of one or several contaminants (Figure 6). With regard to the reaching of the quality targets of the EU-WFD until 2015 these monitoring sites display short residence times of groundwater, so that trend reversals after the implementation of reduction measures can be proved.

2. priority monitoring sites are also located in the plume of one or several contaminants (Figure 6). With regard to the reaching of the quality targets of the EU-WFD until 2015 these

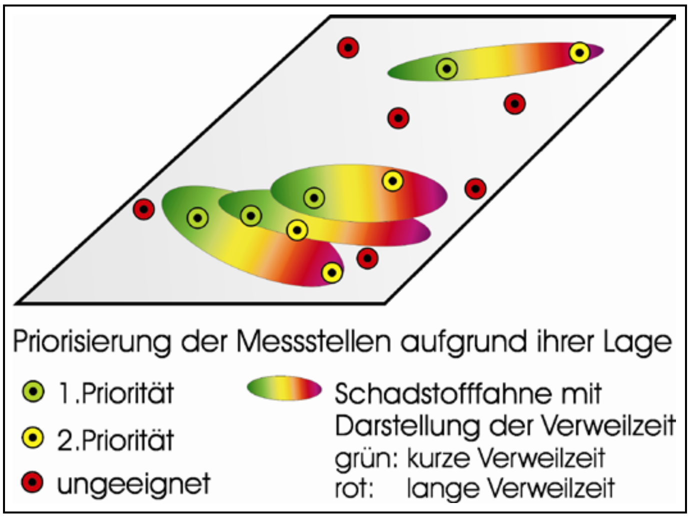

Figure 6: Prioritization of monitoring stations according to their position to the overlaying plumes and the residence time

monitoring sites however display long residence times of groundwater, so that trend reversals after the implementation of reduction measures can not be expected in short terms. Due to the long residence times it has to be checked if an extension of timescale to reach the quality targets of the EU-WFD makes sense.

In case a monitoring station is not located in the plume of a contaminant, it is neither suitable to evaluate the temporal development of a pollution after implementation of reduction measures nor is it suitable to illustrate the interplay of contaminant input, dispersal of the contaminant and the hydrogeological system. Consequently such monitoring sites should be removed from the monitoring network. Instead it should be checked if other monitoring sites are more appropriate or if a construction of new monitoring sites is advisable.

The applicability of the methodology to evaluate groundwater pollution from point sources was tested for a groundwater body in the Federal State of Brandenburg, for which the quality target of the EU-WFD was failed due to contaminations leached from a former industrial site.

An estimation of the expansion of contaminations was made and recommendations for the optimization of the monitoring network were given. Therefore ten monitoring stations with 1. priority and 12 monitoring stations with 2. priority were selected. If an exceedance of the area based criterion by LAWA (2007) is observed, the need to introduce measures is given.

Figure 7 shows the result of the analysis of the residence time in the tested groundwater body in the Federal State of Brandenburg. With this figure the time period can be analysed until the effect of measures become apparent after introducing measures.

Most of the monitoring stations in figure 7 are located inside of the plumes. They are applicable to analyse interrelations between matter inputs, observed matter concentrations and the hydrogeological system. These monitoring stations can also be used to measure modifications of the contamination concentration, of the contaminated area and trend reversal. The time period in which these modifications are possible can be analysed by the location of the monitoring stations in relation to the residence time.

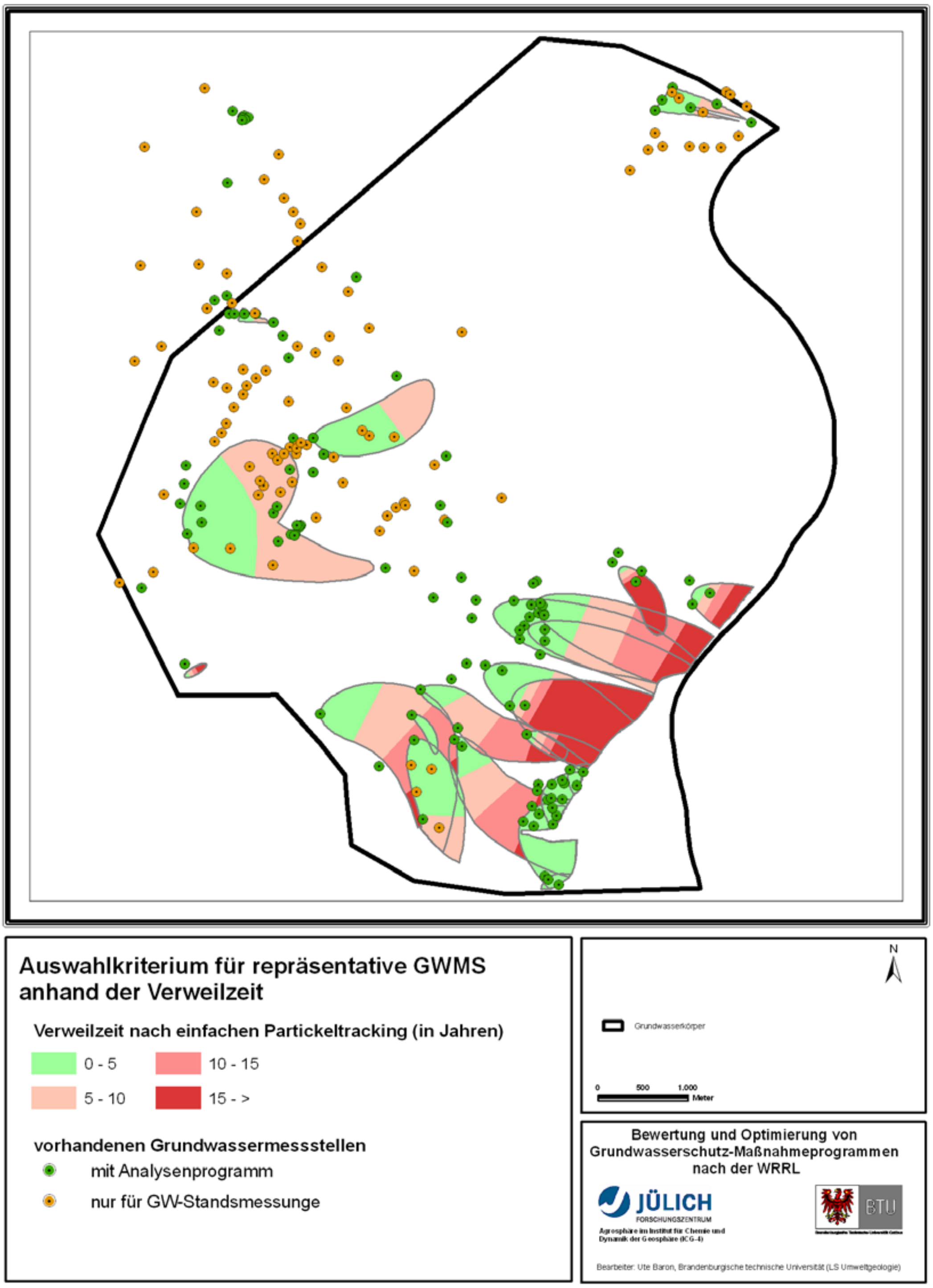

Figure 7: Position of monitoring stations regarding residence time

The success of measures in the groundwater body can in the future be tested by using the conceptual model and sampling the representative monitoring stations.