BRIDGE
Background cRiteria for the IDentification of Groundwater thrEsholds

Specific targeted Research Project
Scientific Support to Policies (SSP)

Publishable final activity report

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Dissemination Level

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1. Project execution

Background cRiteria for the IDentification of Groundwater thrEsholds

1.1. Context and project objectives

The BRIDGE project is funded by the European Union’s Research Directorate-General, within the frame of the 6th Framework Programme, under the priority 8: Scientific Support to Policies (Contract No. 006538 -SSPI). It started on 1 January 2005 and its duration is 2 years.

This project is a contribution to the global European effort which focuses on the sharing of a community approach of Water Management and a common implementation of the Water Framework Directive. This latter requires Member States to assess the “Status” of their water bodies at the beginning of each river basin management plan (RBMP) cycle, that is every six years. The “Status” is to be assessed against predetermined quality and quantity criteria and for quality these are referred to as “Threshold Values”. The GWDD and Annex II (Part B) set out when Threshold Values (TV) should be established. A Threshold Value should only be determined for a pollutant which is causing the groundwater body, or an associated surface water body /terrestrial ecosystem to be characterised as “at risk” and a minimum list of potential pollutant substances has been agreed.

The overall aim of BRIDGE has been to develop and test a method for the derivation of these pollutant threshold values for groundwater bodies in support of the Status provisions of the Water Framework Directive (WFD) and the Groundwater Daughter Directive (GWDD). The project has been carried out at European level, involving a range of stakeholders and efficiently linking the scientific and policy-making communities. The specific objectives of BRIDGE were:

- To evaluate and assemble scientific outputs to set out criteria for the assessment of the chemical status of groundwater. These criteria are data for characterisation of natural and anthropogenic pollutants, parameters indicative for pollution, data for characterisation of groundwater bodies as hydrologic and hydro-geological parameters,
- to derive a plausible general approach, how to structure relevant criteria appropriately with the aim to set representative groundwater threshold values scientifically sound and defined at national river basin district or groundwater body level,
- to check the applicability and validity of this approach by means of case studies at the European scale,
- To carry out an environmental impact assessment taking into accounts the economic and social impacts.
1.2. Composition of the consortium

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<td>fz-juelich</td>
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1.3. Summary of the main results

- Reference Database relevant to environmental threshold values in European Groundwater, European data sets for a Groundwater quality Database,

- A reference report reviewing the behaviour and effects of natural and anthropogenic groundwater pollutant relevant for the determination of groundwater TV. These include the occurrence and behaviour of inorganic and organic substances, the environmental chemistry of emerging substances, the (eco-) toxicological effects of contaminated groundwater well as monitoring, sampling and analytical aspects to set TV for substances in groundwater.

- A report describing the available scientific information on hydro-geological and hydrogeochemical characteristics of European aquifers relevant for determination of groundwater TV. This includes the definition of an aquifer typology as a practical framework to describe occurrence, fate and transport of substances in groundwater, the description of processes between groundwater and surface water or dependent terrestrial ecosystems and the impact of changes in groundwater quantitative status on groundwater quality.

- A procedure for threshold values setting in groundwater, which is based on a tiered approach and on knowing the nature of the final receptor at risk. The first tiers take account of the Natural background level and refer to existing standards or reference values. Further tiers allow to take into account dilution and attenuation processes. Nevertheless, it is not intended that every groundwater body needs to be assessed at every tier; costs and data and time availability determining the level of investigation.

- Two reports on Sampling, Measuring and Quality Assurance and Integrated Data Aggregation Methodology which are prerequisites to get an integrated understanding of the interdependencies between the implementation of groundwater monitoring to the derivation of groundwater threshold and are considered as possible starting points for the discussion on compliance regimes.
- A test of the proposed method for TV derivation on 14 case studies representing most of the major European aquifer typologies defined within the project and most of the ecoregions defined in the Water Framework Directive. The synthesis of the results is discussed in terms of simplicity and suitability of the method for groundwater status evaluation, and hence for protection of human health and groundwater as well as groundwater dependent ecosystems.

- A methodological framework for the identification of economically efficient groundwater threshold values. The application on 6 case studies has demonstrated the use and usefulness of the economic methods in sustainable groundwater policy and management.

1.4. Major achievements

The Groundwater Directive (GWD) requires that threshold values for particular pollutants should be established in such a way as to take account of the behaviour of each substance (the origin of the pollutants, including any natural occurrence, their dispersion tendency and their persistency potential). Moreover, the GWD requires that thresholds in groundwater be established for groundwater bodies shown to be at risk and also for surface waters and dependent terrestrial ecosystems that are at risk and are fed by groundwater bodies. Deciding on a threshold then requires knowledge on both the intrinsic properties of the potential pollutants on hydro-geological and biogeochemical characteristics of media through which they move. The purpose of the two first WP was to synthesise the available information on these topics.

1.4.1. WP 1: Survey of representative groundwater pollutants

The aim of this work-package was a review of all information relevant for the determination of threshold values for potentially harmful substances in groundwater. Most of the work was planned in the first year with a draft of the Reference report on month 9 to be used for the development of the methodology in WP3 and Final report planned on month 15.

Groundwater Quality Data Base (GQDB)

The following two main types of information were collected: written sources (literature references, documents and web pages) and data sources (groundwater quality data sets). The written sources were collected from all BRIDGE project partners by means of a questionnaire and were processed in a database called the RefBase. The groundwater data sets were collected via the questionnaire and by individual approach to the partners and stored in the Groundwater Quality Data Base (GQDB). It stores groundwater quality data of many reference aquifers from EU countries in a standardised form. The data were processed and presented in a user-friendly form (inorganic contaminants). The statistical analysis of the GQDB is a first attempt to compare a large range of groundwater data from EU partner countries in Europe on the level of individual aquifers.

The data sets within the GQDB were designed to be as representative as possible. Representative means that the datasets of reference aquifers should cover the main hydrogeological regions in Europe, and individual datasets may cover both non altered and polluted aquifers. Ideally, each set should typically have 30-40 analyses and refer to a single aquifer or lithology. This approach to data collection is the same as in the BaSeLiNe project, but the existing set of 24 reference aquifers from BaSeLiNe was extended to 63 in an attempt to enhance the balance of representative data for those countries in EU that did not
participate in BaSeLiNe and for other lithologies. In addition, we were able to extend the BaSeLiNe reference aquifer concept to statistically evaluate a wider set of data

Locations of reference aquifers. Red circles indicate data from BaSeLiNe project, green circles indicate new data added in the BRIDGE project

**Statistical analysis, selection of parameters, and graphic presentation**

The overall goal of the statistical analysis and its graphical presentation was to summarise the groundwater data effectively for all inorganic components. The selection comprises all macro parameters (pH, SEC, Ca, Mg, Na, K, HCO3 -, TOC), the inorganic components of the WFD list (As, Cl, Cd, Hg, NO3, NH4, Pb, and SO4) and the priority list (Cd, Ni, Pb), and a number of other trace components not on one of these lists (Al, Ba, B, Cu, Fe, Mn, Si, Sr, Zn). The results for Al, As, Cd, Cl, Cu, Ni, NO3, NH4, Pb, SO4, and Zn were individually discussed. The statistical analyses were applied to three data levels:

- all data - no grouping, all data sets pooled
- the group level - data sets grouped on aquifer lithology: carbonate, hard rock, sandstone or unconsolidated material
- the individual level - data considered as the original data set of the individual aquifer

On all levels a number of percentiles, including the 68.3, 95.4, and 97.7 percentiles (1, 2, and 3 times standard deviation from the median respectively) were calculated. For level 1 and level 2 data, the 10, 50, 68.3, 90, 95.4, and 97.7 percentiles were reported as summary statistics for the indicated components, because they often occur in baseline and/ or threshold values studies. For level 3 data only the medians were reported. The complete statistics were used to produce cumulative frequency plots. These plots show the cumulative frequencies on a probability scale versus the data on a log scale. A log normal distribution shows a straight line, while bi-or multi modality tends to produce S-shaped curves. Cumulative frequency plots were produced per component for the valid cases of level 2 and 3 data sets. The observations below DL were not plotted, because the DL values were not known in many cases. However, below DL observations were labelled as a negative number and therefore could still be included in the percentile statistics. For this reason, some
cumulative frequency plots could start at a percentages significantly higher than 1, depending on how many observation were below DL.

![Cumulative frequency plot for arsenic showing data of each lithology group. The vertical line represents the maximum admissible concentration (MAC) of arsenic in drinking water (10 µg/l)](image)

**State of the art report**

A state of the art report, including information about the geochemical and related aspects (ecotoxicology, analysis, monitoring and sampling), was produced. It describes the state of the art concerning the occurrence and behaviour of potentially harmful natural and anthropogenic substances in groundwater environments, the impact of these substances on aquatic, terrestrial as well as groundwater ecosystems, and analytical, monitoring and sampling practise as far as it has an impact on deducing threshold values for groundwater bodies. The report focuses on three main groups of substances: the WFD pollutants, the 33 EC priority pollutants (see EC Decision no. 2455/2001/EC) and the so called emerging substances. The latter are organic substances that obtain increasing environmental attention since recently, because of widespread occurrence and potential toxicological or ecotoxicological effects.

**Hydrogeochemical processes**

The reactions that usually control the groundwater composition have been grouped into:

- precipitation/dissolution reactions,
- redox reactions, incl. organic degradation,
- aqueous complexing,
- sorption reactions,
- gas transfer and volatilization

Not all reactions can occur for a substance and the types of reactions that are relevant for a substance typically depend on the hydrogeological setting as well as the load at the infiltration area. The first 4 types of reactions are in general relevant for anorganic substances in groundwater systems. The fifth may only occur for gaseous substances such as methane or oxygen. For organic microcontaminants, the two major types of reactions in groundwater are degradation and sorption; volatilization which is a kind of gas transfer may occur at the gas-pore water interface and aqueous protonation/deprotonation may occur for some organic chemicals. Different types of sorption may occur for both organic and anorganic substances, depending on characteristics of the substance and the composition of
the rock matrix. Ion filtration and osmosis are relevant in some geological media, but have not been considered.

Controls on the major groundwater composition

The general chemical quality of groundwater is determined by a variety of factors, where the petrographic properties of the rocks in the vadose and groundwater saturated zone, and the regional hydrological and hydrodynamic conditions are the major natural factors. Additional to these “natural” factors groundwater quality is also highly influenced by anthropogenic influences, in particular land use.

![Factors influencing groundwater quality (Kunkel et al., 2004)](image)

The major groundwater composition has a strong control on the behaviour of individual microcontaminants due to varying acidity, redox status and salinity. The typical major groundwater composition varies between geographical regions due to differences in geology, climate and hydrodynamics as well as anthropogenic inputs. To illustrate the relationship between major groundwater composition and hydrogeology a case-study from Germany was made. The German study was executed in the framework of a study to derive natural background levels in Germany (Kunkel et al., 2004). The hydrogeological units chosen for the description of the major groundwater environments take into account two major factors influencing groundwater composition: Petrographic properties of the vadose zone and the groundwater bearing rocks and physical hydrogeology of the geological setting.

Inorganic substances

A state-of-the-art survey of the hydrogeochemistry of inorganic groundwater pollutants defined by the WFD and the Priority Substances List has been included (deliverable D7). It also presents a selection of groundwater data for 60 reference aquifers situated all across Europe. The inorganic substances described here are with one exception on the WFD and/or the priority list (As, Cl, Hg, NO3, NH4, SO4 and the heavy metals Cd, Cu, Ni, Pb, and Zn). The exception is aluminium, which is likely to be added to the Priority List in the near future. Each substance is discussed in a standard format as follows:

- general geochemistry and abundance
- aqueous geochemistry and speciation
- natural background concentrations and natural extremes
- anthropogenic sources and pollution
Ammonium (a) and iron (b) versus nitrate. Horizontal and vertical lines indicate graphical separation of sample clusters. Vertical lines separate aerobic and anaerobic groundwater using the 2.5 mg/l NO₃ threshold. The horizontal lines separate (a) high ammonium waters or (b) high Fe waters from lower concentrations. Both (a) and (b) show highest concentrations in the anaerobic clusters, however, for ammonium there a clear overlapping zone (0.10 - 0.30 mg/l) between the aerobic and anaerobic clusters.

Occurrence and behaviour of organic substances in European groundwater

Behaviour and occurrence of xenobiotic organic compounds in groundwater are addressed in deliverable D7 as well. Xenobiotic organic compounds (XOCs) can broadly be defined as ‘all organic compounds that are released in any compartment of the environment by the action of man and thereby occur in a concentration that is higher than natural’ (Leisinger, 1983). The number of known XOCs increases with time as better methods for analysis are developed. The occurrence and behaviour of xenobiotic compounds in groundwater environments has mainly been studied in landfill leachate plumes and industrially polluted sites. To date, more than 1000 organic chemicals have been identified in groundwater (Christensen et al., 2001). Even though XOCs typically constitute less than a few per cent of the total dissolved C in groundwater, the fate of XOCs in the affected aquifer is of major concern. This group of pollutants pose a potential health risk (Brown and Donnelly, 1988) and strict drinking water standards are enforced in many countries, with acceptable concentrations often as low as 0.1 μg/l for individual XOCs. The organic compounds of the WFD pollutants and the EC Priority Substances are subject of this review. Focus lies on the occurrence and attenuation of these chemicals in groundwater. Attenuation of XOCs is (besides dilution) due to sorption and degradation. For some volatile compounds, volatilization may also occur. However, this is only important at shallow depths and in unsaturated zones. In this section, the current knowledge on sorption and degradation in different redox environments is reviewed.
Biodegradation of organic pollutants

Review of the environmental chemistry of emerging substances

Information on some emerging compounds which have been identified as endocrine disrupting compounds and pharmaceuticals not included at this time in the priority list of the WFD 2000, have been examined:

- Additive phenols: Bisphenol A, tetrabromobisphenol A
- Alkylphenol ethoxylates
- Alkylphenol acetic acids
- Steroids: 17α-estradiol; estrol; estrone; estriol; 17α-ethinylestradiol, bisphenol A
- Some pharmaceuticals: ibuprofen, ketoprofen,

Some data on the physico-chemical properties of these substances (Kow, water solubility, vapour pressure) has been presented together with their behaviour along the water treatment process and in the environment. Finally the analytical methods used for their monitoring in water including their performances and their occurrence in water.

(Eco) toxicological effects of potentially harmful substances in groundwater

A chapter in D7 aims at providing an overview of the present knowledge about effects of chemical contaminants on the ecology of groundwater, differences in the ecological characterisation of groundwater communities among polluted and non-polluted groundwater bodies and environmental standard setting for chemical contaminants in groundwater (no effect levels on the ecosystem). Ecotoxicological information has been collected and analysed. Attention focused on protection of ecology and not on protection of human health. Two substance groups are evaluated in detail, namely WFD substances and EU Priority substances. A third group, called emerging substances, is treated as well. Substances can also be categorised as substances naturally occurring in groundwater on the one hand and substances not naturally occurring in groundwater, usually introduced by anthropogenic
activity, on the other. In the present study it is chosen to list and discuss the data for the WFD and EU priority substance group. The naturally occurring and anthropogenic substances are spread among the WFD group as well as the EU priority substances group.

Analytical aspects concerning to set threshold values for substances in groundwater

The development or introduction of a new analytical method requires right, exact and repeatable results. When a new method is under development it must be properly tested and the results of the tests carried out must be statistically analysed. This process is called the method validation, which gives information how accurate and reliable the results given by the method will be. The validation will show and verify systematically the suitability of the method for its purpose. The different factors affecting the validation of an analytical method have been analysed.

Illustration of the significance of the measurement uncertainty in relation to the threshold value

1.4.2. WP 2: Study of groundwater characteristics

The objective of WP2 was to elaborate an inventory of all key hydro-geological parameters to be potentially taken into account within the development of the European approach to establish environmental groundwater thresholds. The main part of the work was scheduled during the first year. Final report, describing groundwater characteristic was planned month 15.

Common features of European aquifers that may be relevant to the fate and transport of pollutants, as a basis for a methodology for threshold values establishment have been highlighted. Some recommendations for the development of conceptual models of groundwater bodies including the interactions between groundwater and surface water and dependant terrestrial ecosystems are then produced.

Typology of the aquifer

The WFD defines groundwater bodies (GWB) as the relevant management units. However, the delineation of such bodies by the Member States has been carried out by some very different methods applying different classification criteria, for example, water abstraction and
hydrogeological criteria. Among the latter, lithological characteristics as well as hydraulic properties have been used.

In other words, the groundwater bodies may highlight hydrogeological characteristics as well as intrinsic vulnerability criteria or human pressures and the relative importance of each of these varies depending on the Member State. As a result some GWB may include several aquifers leading to much hydro-geochemical heterogeneity within a given GWB. To decrease the effects of such heterogeneity (which would otherwise cause difficulties in the determination of threshold values at the groundwater body scale), the advice of the BRIDGE team is to consider aquifer properties. A common basis for description of hydro-geochemical characteristics of groundwater, a so-called “aquifer typology”, that could be used in the threshold derivation method is proposed.

The proposed typology is composed of 2 levels of parameters:

- primary parameters which relate to the origin of compounds and include for example lithology and salinity- they lead to the definition of 10 basic units
- secondary parameters which relate to processes and include for example hydrodynamics, redox conditions, geological age and particular occurrences within aquifer material such as organic matter, oxides and sulphides minerals

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Basic units of aquifer typology "proposed for hydro-geochemical characterisation of groundwater"

The ten basic units are listed. When appropriate, they may be merged into four groups shown in the left hand column above. As part of BRIDGE, cumulative frequency plots for several pollutants for each of these merged groups have been made available (Deliverable D7). Conversely, when necessary each unit may be detailed by applying secondary parameters of the typology as it has been implemented for the drawing of the hydro-geochemical unit’s map of the first aquifer compartments in several European States. The ten basic units of the typology provide one basis for determination of natural occurrence of pollutant in groundwater, the so-called Natural Background Level. The secondary parameters contribute to explain the variability of groundwater composition within a given aquifer.
Response time-lags of aquifers

De facto, both dispersion and persistency of pollutants within aquifers are linked with the residence time of groundwater. Increasing residence time favours dilution of pollutants but also their persistency. The GWD requires that threshold values will be established in such a way that, should the monitoring results at a representative monitoring point exceed the threshold, this will indicate a risk that one or more of the conditions for good chemical status are not being met. However, many European aquifers have response time-lags to anthropogenic inputs of many decades which indicates a clear need for anticipation of any further spread of pollution. A particular concentration of a given pollutant in a groundwater, dating from the beginning of a major change of land-use, cannot have the same meaning from the groundwater chemical status point of view, than the same concentration in a more recent groundwater recharged at the time of maximum anthropogenic input.

Taking account of dispersion and persistency of pollutants obviously implies inclusion of monitoring points reaching very recent groundwater. Within an aquifer, the estimation of residence time’s distribution in the aquifer is often based on the use of flow model. Appropriate information can be provided by the use of environmental tracers such as $^3$H, $^3$H/$^3$He, CFC, SF$_6$, δD, δ$^{18}$O.
Residence time of groundwater in European aquifers

The response time-lags of aquifers to anthropogenic input are not only due to transfer within the groundwater but also within the vadose zone. Relative low attention has been paid on transfer time through vadose zone compared to that in groundwater. Some studies have however highlighted that it can take several decades for a pollutant before reaching water table and this zone can stock high concentrations of pollutants. However, range of transfer time in vadose zone of European aquifers is not available.

Dilution during the interactions between groundwater and its associated surface waters and terrestrial ecosystems

It is well known that many surface water features rely in part on groundwater to supply some that water. The proportion of water entering a surface water system or groundwater-dependant terrestrial ecosystem (GWDTE) from a groundwater is often referred to as “baseflow” and is a key parameter in potential dilution of pollutants. The lithology of a groundwater body, for example as described by the basic units of the typology is important for the baseflow. However many other variables also influence the baseflow including recharge, surface cover, drift, land use, climatic conditions etc. and as a result the issues are too complex and data are too scarce for us to propose any range of baseflow contribution to surface water applicable to European scale. Nevertheless, a range of methods exist (both physical and hydrochemical method) for determining baseflow. A tiered approach has been proposed to select best method which is based on existing methods.
From Tier 2, the approach allows a spatial understanding but its implementation is not easy in term of data and numerical model availability. There is a clear need of simple modelling tools to develop considering the links between groundwater bodies and surface water systems or groundwater dependent terrestrial ecosystems.

**Attenuation**

Pollutants may be attenuated by a wide range of physical, chemical or biological processes which act to decrease the flux of the substance. Clearly then, these processes may affect the persistency of pollutants. Moreover, these attenuation processes are common in European aquifers. Depending on the pollutant and the conditions, attenuation may take place through one or more processes including precipitation, sorption, cation exchange, volatilization and biotic or abiotic degradation.

The driving parameters of such processes include presence of:
- Carbonates (precipitation and sorption)
- Oxides, clays (precipitation, sorption, cation exchange)
- Organic matter (sorption, degradation)
- Sulphide minerals (precipitation, degradation)
- As well as the
  - pH value (precipitation, sorption, cation exchange, volatilisation, degradation)
  - Salinity (precipitation, cation exchange)

The proposed typology constitutes a valuable framework for an overview of some of the potential attenuation capabilities of an aquifer; the driving parameters of attenuation including a primary parameter of the typology (e.g. salinity) as well as the secondary parameters which relates to processes. According to the lithology, the frequency of occurrence of these driving parameters is more or less important.

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</table>

**Occurrence of attenuation driving parameters vs. the different units of aquifer typology (x → xx: increase of frequency)**

When degradation of a pollutant is limited in the aquifer itself, it may nevertheless be important in the riparian and hyporheic zones, or within the GWDTE. However, at present, data are limited; studies have been carried out at local scale, but difficulty lies in the scale up to the catchment’s scale.

Where attenuation occurs it is important that the longevity and sustainability of the processes are understood along with the potential for eventual re-mobilization of pollutants. The main
reasons for decrease or cessation of attenuation processes include: a) saturation of sorption sites of oxides, clays, organic matter b) exhaustion of redox compounds as organic matter and/or sulphides minerals c) limitation of carbonates minerals availability for co-precipitation of pollutants. Particular conditions that may result in pollutant re-mobilization within riparian, hyporheic zones and GWTDE need also to be elucidated.

Possible controversy on pollutant origin

The origin of a pollutant may be natural (geogenic), whereas its concentration is strongly impacted by anthropogenic activities. Several situations occur through Europe where modifications of water-rock interactions take place in aquifer following either the input of some pollutants or any change of hydrodynamics (quantitative status of groundwater) leading to an increase of pollutants concentrations. The most common situations include (not applying in order of importance):

- irrigation which favours soils salinisation that in turn promotes leaching of some elements (B, Se, Mo, As, F, … ) impoverishing soils and enhancing concentration in groundwater with considered elements;
- groundwater withdrawal from coastal area which favours intrusion of saline water. The increase in salinity then induces increase of calcium and metal ions concentration by cation exchange. Formation of metallic complexes (with chloride) also contributes to increase metal concentration;
- more generally, groundwater abstraction from aquifer (confined or not) which induces lowering of piezometric levels. The main consequences on chemical composition of groundwater are driven by mixing through leakage/ drainage between aquifer as well as by mobilisation of some metals from sulphides minerals, Fe- hydroxides, and clays
- denitrification, a very common process in European aquifer, which induces also leaching of sulphate and metals from sulphides minerals as well as desorption of metals bounded on organic matter. Particular attention has to be paid on these processes to avoid any confusion with the natural background level of concerned elements within the groundwater.

1.4.3. WP 3: Criteria for environmental thresholds and methodology to define a good status

The overall objective was to develop recommendations on a methodology and criteria for an European approach how to establish environmental thresholds for groundwater bodies. Accordingly the WP aimed at translating scientific knowledge and proposing a sound but also practical approach for a methodology to define the good status for groundwater bodies and a general structure of criteria, giving guidance on the derivation process for environmental thresholds.

The method for status determination and threshold setting relies initially on knowing the nature of the final receptor at risk and on knowing the natural quality of the groundwater concerned. A tiered approach is adopted which allows the targeted use of resources both in assessment and any remedial measures. To assess groundwater quality at local scales it is quite common to make use of natural background levels and generic reference values according to possible receptors, which are in general ecosystems and human uses. As status assessment can be understood as being an integrated assessment at the large scale of groundwater bodies, both these criteria have to be included. Moreover status assessment has to take into account that the general chemical quality of groundwater as well as fate and transport of contaminants are determined by a variety of factors, where lithologic properties of rocks in the vadose and groundwater saturated zone, regional hydrological and
hydrodynamic conditions and hydrogeochemical processes controlling the behaviour of natural and anthropogenic substances are of major importance. Thus status assessment needs to go beyond quality assessment and consider attenuation criteria like dilution, diffusion, retardation, and degradation. These criteria are specific to the properties of contaminants, hydrogeological units where specific hydrogeochemical processes govern, and the interaction with surface waters.

**Assessing the Natural Background Level (NBL)**

In the past there have been many local and regional studies of the ambient quality of groundwater in terms of both the naturally– occurring and anthropogenic substances that may be present. More recently, cross border and EU-wide projects such as EU BaSeLiNe (Ref EVK-CT-1999-00006) have provided a good basis for understanding the natural background level of some substances in groundwater. The procedure allows NBL determination from monitoring data or by comparison with known similar aquifers in the typology. The GWDD recognizes background level as a concentration or value of a substance or indicator in a groundwater body corresponding to no, or only very minor, anthropogenic alterations to undisturbed conditions. Given this definition it is understood that the future regulatory framework asks to determine background level as ‘natural background levels’ as they have been discussed within BRIDGE.

Depending on data availability Natural Background Levels (NBLs) can be defined following a hierarchy of possible options. To unify the starting point for groundwater status assessment BRIDGE has proposed a European aquifer typology, classifying 16 types (see PAUWELS et al, 2006), and also has referenced NBLs from national studies accordingly. These NBLs might be used if no appropriate groundwater quality data are available but only the hydrogeological units of a specific groundwater body can be described. Given a groundwater body where a limited set of data on the chemical composition of groundwater is available, a second option by a simplified and practical approach to determine NBLs based on a pre-selection method can be employed. As a prerequisite for applying a simplified pre-selection method common minimum requirements for groundwater quality data (e.g. deviation of the ion balance < 10 %) and appropriate pre-selection criteria to identify groundwater samples showing no significant anthropogenic impact (e.g. Nitrate < 10 mg/l) are to be defined. Finally given a groundwater body where a broad set of quality data is available, the third option to estimate NBLs is to apply scientifically sound methods (e.g. hydrochemical simulations, component separation by concentration separation analysis), which already have been established at national or international level. Clearly, the procedure described only accounts for substances which occur naturally, whereas for substances that are purely synthetic with no natural sources (for example, TCE) then the NBL will be zero.

**Selection of the Reference Quality Standard**

Generic reference values selected according to receptors which might be harmed by groundwater contaminants are to be used. Giving a focus to ecosystems and human uses means consequently that environmental quality standards (EQS) for surface waters or drinking water standards (DWS) are to be transferred and linked into groundwater status assessment. The mentioned reference values might be defined at European level or at national level. With respect to the variety of possible substances contaminating groundwater it is also likely that for some substances no reference values are available at all. As a hierarchy of options exist, it can be envisaged that unified European standards like e.g. the EQS for priority substances set out by the proposal of the European Commission are preferable to, and therefore overrule national standards. If no agreed European standards
exist, national reference values can be used. The EQS to be introduced in groundwater status assessment need to be expressed as annual average values. Finally for substances without established receptor-oriented reference values at European or national level a survey and evaluation of human toxicity or ecotoxicity data will be necessary. Depending on data availability the evaluation of these toxicity data should again be based on and refer to either agreed European procedures or national agreements. The WFD and the GWDD are understood to outline the following receptors:

- Aquatic ecosystems (surface water quality and ecology)
- Dependent terrestrial ecosystems (plants, vegetation)
- Drinking water supply
- Other legitimate uses (e.g. irrigation or crop washing)
- Groundwater

**Attenuation Criteria**

Pollutant attenuation may occur along the flow path of groundwater, at the interface in between groundwater and surface waters (the hyporheic zone) and at the surface water itself. General consideration might be given to dilution, dispersion, diffusion, volatilisation, sorption and chemical and biological degradation. The physical, chemical and biological processes which occur in aquifers and which may act to naturally attenuate pollutants are well known and widely reviewed for the purposes to assess point source pollution. The same processes can also act over much larger scales like groundwater bodies. Still it needs to be recognised that a real in depth conceptual understanding of the groundwater and receptor system is needed and the demand on specific data increases consequently. The current situation for the surface water interface (the hyporheic zone) is that knowledge is not sufficient at the moment and science is on its way. In contrast, the description of attenuation at the receptor surface water might be described easily, as in general dilution will be the major attenuating process. The estimation of quantity relationships of groundwater flow against surface water flow can be done rather easily by a variety of methods to estimate the baseflow (e.g. by hydrograph separation, temperature or water quality surveys, tracer analysis). Therefore a pragmatic approach is to consider dilution at the receptor surface water as a separate generic criteria, whereas the description of all other attenuating processes would need a series of in depth investigations, which might be appropriate to be established at some groundwater bodies at the body scale or are necessary for a final status assessment taking account of local specificities which can not be considered for the derivation of threshold values.

Once the receptor has been identified and the NBL determined then the tiered method below may begin to be employed. In essence, the method relies on a series of steps in which the impact on the receptor from pollution in the groundwater is defined with increasing precision. In the early Tiers the concentration of pollutant in the groundwater is compared with NBL and receptor based standards (for example drinking water standards) whereas in the later Tiers the possible mitigating effects of dilution of the pollutant with water from elsewhere (for example, surface water) and then the attenuation (loss) of pollutant due to (bio)geochemical reactions is considered. Note that, it is not intended that every groundwater body need be assessed at every Tier. The assessment should proceed to the most appropriate Tier based on factors such as data availability, costs and time available etc. The Tiers are summarised in the Figure below and discussed. The tiers are:
Tier 1: NBL. For those pollutants that are synthetic the appropriate NBL is zero

Tier 2: The receptor based quality standard, which refers to existing relevant standards or reference values (e.g. EQS for priority substances set out by the proposal of the European Commission, COM(2006)397 final, or national EQS; DWS according to the Council Directive 98/83/EC, or national DWS). Regarding groundwater as a receptor an intermediate step (2a) is introduced to Tier 2, where natural background levels (NBL) are used as the generic environmental criteria and at low concentration ranges a relationship against a reference standard is used to allow and limit minor anthropogenic impacts.

Tier 3: This Tier allows account to be taken of the proportion of the pollutant mass flow that is due to the groundwater. For many water features there may not be a single source of water but two or more, for example a river may be supported by both surface water drainage and discharge from groundwater. If the main source of pollutant is from the surface water drainage then the groundwater status should not be penalised unnecessarily. The concept of the Dilution Factor (DF) is intended to provide a mechanism where the proportion of the final impact that may be rightly ascribed to groundwater pollution can be taken into account.

Tier 4: This final Tier allows consideration of any attenuating processes that may occur to diminish the impact in the final receptor (water body) from pollutants present in the groundwater. For example if it is known that the pollutant will react chemically with the rocks of the groundwater body such that it will not reach the receptor, then groundwater Status should not be penalised unnecessarily. The concept of the Attenuation Factor (AF) is intended to provide a mechanism where the proportion of the final impact that may be rightly ascribed to groundwater pollution can be taken into account.

The comparison of observed pollutant within each Tier determines whether it is worthwhile progressing to the next Tier remembering that, in general, progressing to a higher Tier will incur increased data needs and increased cost of assessment.
Whereas the different tiers have been numbered according to a scientific logic on how to progress in assessing groundwater quality, administrators might for practical reasons and seeking efficiency at the status assessment process change the order of applying tiers and criteria accordingly. For example for undisturbed groundwater bodies where it is likely that there are hardly any anthropogenic impacts a quick first control of monitoring data by comparison against a reference value could facilitate the status assessment like being a ‘one-stop-shop’. The definition of receptors relevant for a specific groundwater body has to be done by the Member States and the competent authorities appointed to set up river basin management plan. The following sections try to briefly introduce how to apply the procedure for the different receptors.

**Determining a threshold for a surface water receptor**

Starting the tiered approach to determine a groundwater threshold value for protecting a surface water receptor becomes necessary if the groundwater body and the surface water body are characterised as being at risk for a specific pollutant, or there is any other evidence for a substantial transfer of pollutants from groundwater to a surface water (e.g. from groundwater monitoring data). Following the GWDD and the procedures described within this report the determination of groundwater threshold values is a rather straight forward procedure using surface water EQS or equivalent reference data. Expert judgement might be needed for groundwater bodies with long groundwater residence times, to define whether it is appropriate (due to long travel times) to apply a threshold value for the surface water receptor in the recharge zone, or to limit the compliance regime to areas of limited flow times (e.g. 20 to 50 years) close to the discharge area at the surface water.
Determining a threshold for a dependent terrestrial ecosystem

Neither within the WFD nor in other Directives have status objectives been defined in a general way. Although it is generally recognized that quality of groundwater is very important for the presence and development of plant species and vegetation in wetlands, there is also hardly any scientific knowledge to describe possible effects of chemical pollution of groundwater (GRIFFIOEN et al., 2006). This lack of legal and scientific background made it impossible to develop a methodological approach on how to determine groundwater thresholds for dependent terrestrial ecosystems.

As terrestrial ecosystems are often situated along surface waters it might be generally assumed that both aquatic and terrestrial ecosystems would need to adapt to similar natural conditions. Provided this assumption holds true surface water EQS could be introduced for a simplified Tier 1 assessment establishing an approximately similar level of protection for terrestrial ecosystems and plant communities as for surface waters. As soon as this simplified Tier 1 assessment or monitored damages on dependent terrestrial ecosystems indicate that pollution of groundwater might be the origin of effects on wetland vegetation, a specific assessment regarding dependent terrestrial ecosystems needs to be started. As a second preparatory step to complete this kind of pre-assessment other possible factors which might impact wetlands will have to be excluded. Major factors governing the environmental conditions for plants are groundwater quantity (groundwater level alterations), pH, buffering effects, and oxygen and nutrient concentrations. Given that these factors are not the driving factors for deterioration of wetlands, a specific investigation coordinated together with ecologists will have to be undertaken.

Determining the threshold for groundwater

Along the work within BRIDGE major discussions took place regarding the understanding of the legal system established by the WFD and the GWDD, in particular, the point of view that groundwater should be protected against deterioration in its own right (e.g. see recitals of the GWDD). Whereas this main topic was addressed by the very first conceptual paper by introducing a receptor ‘groundwater as a resource’ it was agreed to acknowledge a scientific point of view of a strong groundwater protection regime by renaming this receptor as ‘groundwater by itself’. It has to be admitted that although agreeing that groundwater should be protected in general and anthropogenic impacts should be minimized the consortium did not manage to agree on a common understanding of the WFD and GWDD and the role of threshold values (e.g. such as described in Annex 6). Therefore the following tries to explain different possible approaches when groundwater is addressed as being the receptor at risk. Necessarily the issue of understanding the legal system established by the WFD and the GWDD needs to be addressed and clarified at the administrative level under the Common Implementation Strategy of the WFD. Given this clarification the approaches discussed below could be revised and adopted for implementation.

Groundwater as a resource

The WFD and the GWDD provide some elements of groundwater status assessment which are understood to recognise groundwater as being one of the most important freshwater resources. In particular these are the following requirements: nitrates and pesticides or pollution which might significantly impair the ability of the groundwater body to support human uses o saline intrusion.
Quality Standards for nitrates and pesticides are given by the WFD and the GWDD. Further substances will have to be taken into account, if the groundwater body is characterised to be at risk from specific substances and monitoring establishes evidence of widespread impacts to the groundwater body. For these further substances (and only if the body is at risk from these substances) any relevant reference standard related to uses, like drinking water standards, irrigation standards, any other standard in Member States legislation has to be taken into account. To assess status, threshold values need to be used to evaluate monitoring data at each single monitoring station (Tier 2), as well as applied to aggregated and weighted results across the groundwater body. Therefore threshold values determined under these elements of status assessment are not receptor-oriented but try to control the average concentration of substances of all stored groundwater (‘aquifer-storage based’). To address saline intrusions again specific considerations are necessary. To identify saline intrusions threshold values have to be set according to NBLs for relevant parameters (e.g. electric conductivity, chloride, sulphate). The exceedance of NBLs is an indication of a possible impact on the groundwater resource. Further investigation will have to clarify whether elevated concentrations are due to anthropogenic activities (like linked to abstraction pressures) and if the extent of any intrusion is likely to impact the freshwater resource significantly.

**Groundwater ‘itself’**

Many, if not all, of the bodies determined as “at risk” in the characterisation process will relate to identifiable receptors external to the groundwater itself: for example drinking water supply or surface water ecology. According to the point of view that groundwater should be protected against deterioration in its own right (e.g. see recitals of the GWDD) there is an understanding that threshold values have to help and are to be applied to prevent increasing pollutant concentrations in groundwater (itself). Clearly this could cause some difficulty as few Member States have such groundwater quality standards and there are no community values available except for nitrate and pesticides. BRIDGE therefore discussed alternative options for the derivation of, in effect, Tier 2a values where no suitable standard exists, which is based on the NBL of groundwater in a body. By the results of the case studies the finally described option is felt to be a pragmatic approach referring to NBLs as the only available sound environmental criteria but also recognising that a policy of ‘zero’-pollution is not possible as alterations of environmental conditions due to human activities can not be avoided totally.

**Groundwater as an ecosystem**

In contrast to status objectives for surface waters the WFD does not give recognition to an “ecological status” of groundwater bodies. Furthermore the knowledge of the ecology of groundwater and aquifers is considered as far too basic to allow the development of scientifically sound values based on sub-surface ecology. As there are hardly any data for ecotoxicity tests with groundwater organisms available, a transition of test results with aquatic organisms seems to be generally recognised as appropriate approximation (NOTENBOOM et al, 1999; German LAWA 2004). Given long residence times and the relatively slow dynamics of groundwater emphasis could be given to exotoxicity data on chronic effects. Referring to the Commission Proposal on EQS for priority substances [COM(2006)397 final] these would be the annual average EQS or data derived in a comparable way. Corresponding to Annex I, Part C of the mentioned Commission proposal flexibility is to be left to Member States to take account of natural background concentrations for metals if they are higher than the EQS value or if other water quality parameters (e.g. pH, hardness) affect bioavailability of metals.
Remarks regarding the definition of compliance regimes

BRIDGE had no mandate or objective to work on and discuss aspects on a compliance regime for different receptors. Nevertheless it has to be pointed out, that a sound concept of status assessment needs to build its compliance regime as a complementary approach to the implemented monitoring concept and considerations relevant for threshold value determination. Furthermore BRIDGE tried to provide further information as possible starting points for the discussion on compliance regimes, which are the reports on Sampling, Measuring and Quality Assurance (WITZAK et al., 2006) and integrated data aggregation methodology (SCHEIDLEDER et al., 2006).

Two aggregation methods for calculating the percentage of monitoring points not exceeding a quality standard or TV

1.4.4. WP 4: Representative sites / water body studies and compliance testing

The main objective of WP4 was to evaluate the preliminary methodology for derivation of groundwater threshold values proposed by BRIDGE WP3 at selected European representative sites and provide feedback about the feasibility of the developed methodology.

Location and type of investigated groundwater bodies

The investigated groundwater bodies are located in 12 of the 25 eco-regions for rivers and lakes defined in the Water Framework Directive, and they cover most of the important aquifer typologies in Europe. Hence most of the major climatological and hydrogeological settings are represented by the suggested selection of sites. The maps on the following pages simply
serve as a means of illustrating the geographical distribution of the investigated groundwater bodies, the aquifer typologies, and their location in relation to major ecoregions as defined in the water framework directive. They are not necessarily representative for the general or average conditions in the eco-region to which they belong, and not all of the investigated groundwater bodies interact significantly with an aquatic or terrestrial ecosystem.

Location of the 14 groundwater bodies selected for the representative site case studies. The type of aquifer or other earlier or on-going programs in which the groundwater bodies are studied, is also indicated.
Ecoregions with investigated groundwater bodies for evaluation of the proposed methodology for derivation of groundwater threshold values. The base map is a modified version of the map of “Ecoregions for rivers and lakes” developed for the EEA and included in Annex XI of the Water Framework Directive. Ecoregions with investigated groundwater bodies are marked with a red square.

<table>
<thead>
<tr>
<th>No.</th>
<th>Country</th>
<th>Name</th>
<th>Ecoregions for rivers and lakes</th>
<th>Ecoregions for coastal waters</th>
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<tbody>
<tr>
<td>2</td>
<td>Belgium</td>
<td>Central Caminpe system (GWB-CKS_0200_GWL_1)</td>
<td>13. Western plains</td>
<td>4. North Sea</td>
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<td>4</td>
<td>Denmark</td>
<td>Odense Pilot River Basin</td>
<td>14. Central plains</td>
<td>4-5. North Sea / Baltic Sea</td>
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<td>5</td>
<td>Estonia</td>
<td>NE Estonia</td>
<td>15. Baltic province</td>
<td>5. Baltic Sea</td>
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<td>6</td>
<td>Finland</td>
<td>ISS - group of GWB’s</td>
<td>22. Fenno-Scandia</td>
<td>5. Baltic Sea</td>
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<td>7a</td>
<td>Germany</td>
<td>France/Upper Rhine</td>
<td>8. Western highlands</td>
<td>4. North Sea</td>
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<td>7b</td>
<td>Germany</td>
<td>Black Forest</td>
<td>9. Central Highlands</td>
<td>4. North Sea</td>
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<td>7c</td>
<td>Germany</td>
<td>Swabian and Franconian Alb</td>
<td>9. Central Highlands</td>
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<td>Hungary</td>
<td>Transdanubian Central Mountains</td>
<td>11. Hungarian Lowlands</td>
<td>7. Black Sea</td>
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<td>Tevere Pilot River Basin</td>
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<td>6. Mediterranean Sea</td>
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<td>Joniskis (LT 00102)</td>
<td>15. Baltic province</td>
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<td>Portugal</td>
<td>Vouga River Basin</td>
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</table>

List of investigated groundwater bodies (GWB’s). The “Ecoregion for rivers and lakes” (Fig.3) in which the GWB is located, and the “Ecoregion for coastal waters” to which their associated river basin discharge is also indicated.
Summary of performed evaluations

The BRIDGE case studies cover 5 out of 8 major groundwater body typologies defined in BRIDGE. These are carbonates, volcanic rocks, crystalline rocks, sand and gravel, and sandstone. Chalk, schist and marls, evaporites and clays are not covered. The elements and substances for which natural background levels and reference values have been derived in a minimum of two different case studies, at tier 2 or at higher tiers, are shown in the table.

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Elements and inorganic substances evaluated in more than one of the 14 BRIDGE case studies. X indicates which studies have derived NBLs and TVs for the specific substance. Highlighted elements and substances are examples with results presented in further detail in the deliverables.

Overall conclusion

The proposed method for TV derivation has been tested in 14 case studies representing most of the major European aquifer typologies defined in D9 (Pauwels et al. 2006, Wendland et al. 2006) and most of the ecoregions defined in the Water Framework Directive. The methodology is simple to use and it seems a suitable tool for groundwater status evaluation,
and hence for protection of human health and groundwater, as well as groundwater dependent ecosystems, as requested by the Water Framework and Groundwater Directives.

The tiered approach was found appropriate, and the application of both the natural background levels and relevant reference values for groundwater itself (tier 1-2a) and/or reference values for groundwater dependent ecosystems (tier 1-4) for derivation of groundwater threshold values, was found to be logical, suitable and easy to understand and apply. It does, however, require increasing expert participation as well as data amounts and understanding of the system, to move to tier 3 and 4 where dilution and attenuation in the groundwater bodies are taken into account.

As discussed in the previous chapter, methods for derivation of natural background levels and reference values are or can be based on scientific studies. We find that both the natural background levels and the reference values have to be included in the derivation of the groundwater threshold values in order to constrain the threshold values as suggested in the proposed method. Application of a reference value (or a natural background level) by itself may not protect human health or the environment sufficiently.

It is therefore crucial that the natural background levels and reference values are derived properly, as the derived threshold values will be sensitive to the applied natural background levels and reference values. Hence, a sound understanding and delineation of aquifer and hydrochemical typologies are of great importance.

The final selection of a method for derivation of threshold values as a management tool for the protection of the environment and human health, includes a political component, and has also to some extent to take into account socio-economic as well as environmental and health impact assessments and considerations. The proposed method is found to acknowledge this fact. The evaluations performed in the BRIDGE case studies generally conclude that the finally proposed method for TV derivation (D18, Müller et al. 2006) seems to derive reasonable threshold values. Detailed evaluation of the socio-economic effects and environmental and health impact assessment have to follow to investigate this further. The case studies in work package 5 demonstrate examples of such studies (Brouwer and Strosser 2006).

The derivation of groundwater threshold values based on natural background levels and reference values such as environmental quality standards for dependent ecosystems or for groundwater itself is in its infancy, and research is strongly needed to develop and apply this concept in an appropriate and efficient way. The derivation of groundwater threshold values based on e.g. reference values for dependent aquatic ecosystems requires more detailed information on groundwater and surface water interaction than is generally available at present.
Percentile (quantile) plots of estimated NBLs at the 90th percentile and derived TVs for selected substances in all investigated groundwater bodies. Note that the NBL and TVs are identical when the NBL is greater than or equal to the reference value (in this case the drinking water standard / dashed red line). The data set represents samples with NO3 less than 10 mg/l as described by the proposed preselection criteria. TV1 is the threshold value estimated by originally proposed procedure with three cases: Case 1: 1/3REF < NBL < REF => TV = \( (NBL+REF)*0.5 \); Case 2: NBL \leq 1/3REF => TV = 2*NBL; Case 3: NBL \geq REF => TV = NBL. TV2 is derived by the method of the final proposal (D18) by only two cases: Case 1: NBL < REF => TV = \( (NBL+REF)*0.5 \); Case 2: NBL \geq REF => TV=NBL

1.4.5. WP 5: Economic and social costs linked to the establishment of groundwater threshold values

The main objective of WP5 was to support the identification of economically efficient threshold values for groundwater pollutants based on socio-economic impact assessment procedures, following as much as possible the requirements of the economic analysis in the EU Water Framework Directive. This means the assessment of the costs and benefits of feasible measures to achieve groundwater threshold values and their distribution across different interest groups in society. It was based on case studies.
Environmental objectives

The WFD is one of the first European Directives in the domain of water, which explicitly recognizes the role of economics in reaching environmental and ecological objectives. The Directive calls for the application of economic principles (e.g. polluter pays principle), approaches and tools (e.g. cost-effectiveness analysis) and for the consideration of economic instruments (e.g. water pricing methods) for achieving good water status for water bodies in the most effective manner. The Guidance Document on the Economic Analysis prepared in 2002 by the European Water and Economics Working Group (WATECO) advises that the various elements of the economic analysis should be integrated in the policy and management cycle in order to aid decision-making when preparing the river basin management plans. The integration of economics throughout the WFD policy and decision making cycle is presented.

The role of economics throughout the WFD implementation process

The main elements of the economic analysis are found in Articles 5 and 9 and Annex III in the WFD. Economic arguments also play an important role in the political decision-making process surrounding the preparation of RBMP in Article 4 where derogation can be supported by the strength of economic arguments when setting environmental objectives. The economic analysis can be summarised as follows:
1) Economic characterisation of the river basin (Article 5)

- Assessment of the economic significance of water use in the river basin
- Forecast of supply and demand of water in the river basin up to 2015
- Assessment of current cost recovery by estimating the volume, prices, investments and costs associated with water services in order to be able to assess cost recovery of these water services, including environmental and resource costs

2) Cost-effectiveness analysis (Article 11 and Annex III)

- Evaluation of the costs and effectiveness of the proposed programme of measures to reach the environmental objectives.

3) Disproportional costs (Article 4)

- Evaluation whether costs are disproportionate.

4) Cost recovery and incentive pricing (Article 9)

- Assessment of the distribution of costs and benefits and the potential impact on cost recovery and incentive pricing.

The three main steps in the economic analysis identified by Wateco (2002) and the associated time path are illustrated in the figure. The first step, the economic characterisation of river basins, has recently been completed. In the following the preliminary risk analysis carried out so far for the different European river basins will be further elaborated (including the more detailed definition of environmental objectives) and a start will be made with the identification of additional measures needed to reach good water status in a second step.
Steps in the economic analysis in the WFD and corresponding time path (modified from the WATECO Guidance Document)

By the end of 2007 each EU Member State has to produce an overview of its basic and additional measures according to Article 11, from which the most cost-effective programme of measures will be selected in step 3 by the end of 2008. Based on a cost-effectiveness analysis of programmes of measures, the question whether the total costs of additional measures to reach good water status are disproportionate will be addressed by the end of 2009. Finally, the financial implications of the basic and additional measures for different groups in society has to be evaluated by 2010, including the level cost recovery, changes in the use and level of economic instruments (e.g. levies, taxes, water prices) and their role in achieving a more efficient and sustainable water use.

Location and type of investigated groundwater bodies

- Upper Rhine valley quaternary aquifer, France
- Scheldt basin in the Netherlands
- Lahti, Finland
- Aveiro Quaternary Aquifer in Portugal
- Riga, Latvia
Overall conclusions and key recommendations

- One of the main objectives of BRIDGE is to develop, apply and test economic methods for the identification of economically efficient groundwater threshold values. The objective is not to derive threshold values for specific groundwater pollutants for which no threshold values are available yet, but to demonstrate the use and usefulness of the economic methods in sustainable groundwater policy and management.

- In this field, the work focuses explicitly on practical and feasible groundwater management to reach possible groundwater threshold values. Corresponding with the way environmental objectives are set in the WFD, i.e. based on some ecological reference situation, the BRIDGE methodology to establish groundwater threshold values excludes any a priori economic considerations or criteria. Economic criteria start playing a role after the threshold values have been set, namely in the design of practical groundwater management measures. For example, measures have to be cost-effective according to the WFD, meaning that the environmental threshold values have to be reached at their lowest cost.

- Hence, the work in WP5 starts where work packages WP1 to WP4 stop, i.e. with the practical implementation of the groundwater quality objectives through concrete groundwater management actions and measures, and in particularly their economic implications in terms of costs and benefits and the distribution of these costs and benefits across various stakeholders (direct and indirect users and non-users of groundwater resources). This integrated environmental-economic impact assessment provides the basis for the evaluation of possible disproportionate costs, and consequently the basis for possible objective or time derogation as in the WFD, i.e. lowering environmental objectives or delaying them in time.

- The role of economics in establishing groundwater threshold values is comparable to the role of the economic analysis in the implementation of the WFD, where environmental objectives can be lowered or delayed in time if the costs of reaching the objectives are considered disproportional (WFD article 4). In order to be able to evaluate and assess whether the economic costs of reaching environmental groundwater threshold values are disproportional, an important step is to evaluate and assess the cost and effectiveness of possible practical management measures to reach these threshold values, including their distribution across various stakeholders, and compare these with the corresponding environmental, social and economic benefits.

- The economic analysis is one important input in the decision-making procedure about disproportionate costs, but not the sole decision-making criterion. The definition of ‘economic threshold values’ or benchmarks for the assessment of disproportionate costs is subjective and political. In practice they will not be derived on the basis of an economic cost-benefit analysis only. Concrete national or European benchmarks for disproportionate costs do not exist, also not in comparable directives such as the IPPC Directive where the concept of best available techniques not entailing excessive costs (BATNEC) is introduced or the Habitats Directive which refers to ‘imperative reasons of overriding public interests, including those of a social or economic nature’ to justify exemptions.

- In the WP5 case studies the researchers and analysts are unable to judge whether the estimated total costs are disproportional compared to their economic benefits. In the economic analysis it is observed that some courses of action are economically beneficial, while others are not. Two characteristic features of the economic analysis presented in the case studies are (1) the explicit examination of costs and benefits for different groundwater quality threshold values, including natural background levels, and (2) the spatial distribution
of these economic costs and benefits for different groundwater threshold values. This distribution can be skewed and therefore be used as an important criterion to argue for disproportional costs.

- For example, in the Dutch case study it is concluded that setting the groundwater threshold value at 50 milligrams per litre is economically speaking justified for most groundwater protection measures, but a threshold value of 25 milligrams is not. In the latter case the investment costs in this public decision-making context can be as high as 10 times the estimated benefits to reach a threshold value of maximum 25 milligrams nitrate per litre. In the Portuguese case study we find, for example, that up to 65 percent of the total costs for groundwater protection measures in agriculture are born in one specific (northern) area of the aquifer, while most of the benefits of improved groundwater quality (35%) accrue largely to the inhabitants in a specific other (central) part of the aquifer. The question whether a higher threshold value of 25 milligrams for the whole basin compared to the current threshold value of 50 milligrams results in disproportional costs or whether the skewed 65-35 distribution of costs and benefits across the aquifer depends on policy maker assessment of disproportionality. Different policymakers may hold different views depending on the available alternatives and their perceived viability, that is the political support they perceive to receive for the implementation of these measures from the affected sector and actors.

- Another important role of the economic analysis in WP5 is to estimate the economic value of sustainable groundwater resources management by making the various use and non-use values of groundwater resources more explicit than currently is the case. This includes the so-called ‘existence’ value of groundwater, i.e. the value attached to groundwater protection and preservation for the sake of the resource itself as one of the ‘receptors’ in the BRIDGE methodology.

- Improving groundwater quality is expected to yield direct economic benefits in that better quality will result in a reduction of the purification costs of groundwater used for human consumption. However, there may also be important so-called non-market benefits associated with the improvement of groundwater quality. The economic value of these non-market benefits is measured in terms of public willingness to pay for groundwater quality improvement. In large-scale public surveys, local residents are asked in the case studies for their knowledge, awareness, perception, attitudes, preferences and valuation of different groundwater threshold values. Although economic use values dominate the economic values found for different groundwater threshold values, we find substantial non-use or existence values for groundwater protection in all case studies, providing support for the receptor-based approach advocated in BRIDGE.

- For the purpose of measuring public perception and values of groundwater quality threshold values, a ‘groundwater quality ladder’ was developed and tested in the public surveys in the WP5 case studies, reflecting different use and non-use related economic values of groundwater quality. In order to be able to make the public at large understand the meaning of different groundwater quality threshold values as proposed in the Groundwater Directive, these threshold values have to be translated into ready understandable terms. We use for example irrigation, drinking water and a natural situation mimicking natural background levels as key triggers to inform local residents about the social and economic implications of different groundwater quality threshold values. In the Portuguese case study half of the local population has a private groundwater well, of whom 25 percent uses their well water directly for consumption and 80 percent for irrigating their crops and gardens. Public belief in the information provided in the survey about the current and expected groundwater situation plays a significant role in the case studies where the public survey was carried out.
• Asking local stakeholders who are and will be affected by future groundwater policy, either through extra taxes or an increase of their water bill, to inform policy makers about the importance and value these local stakeholders self attach to groundwater protection in term of their willingness to pay for different groundwater quality threshold values can be used as one of the possible ‘economic’ threshold values for disproportional costs, accounting for their ability to pay. In the Dutch case study we find, for example, that the cost of a more stringent groundwater threshold value up to 25 milligrams per litre for the whole basin should not exceed 30 euro per household per year over and above what local residents currently pay for water in their basin. This is what local residents are willing and able to pay for groundwater quality improvements up to 25 milligrams if policy makers would ask them to help decide.

• Risk and uncertainty are key concepts in the environmental and economic assessment of different groundwater quality threshold values. The environmental and human risks of groundwater quality are surrounded by uncertainty about the correct dose-pathway-effect relationships. This fundamental lack of knowledge was clearly demonstrated in the French case study for volatile organic compounds (VOC). Feasible management options for sustainable and cost-effective groundwater management cannot be identified and evaluated if the extent of the problem (i.e. risk of not meeting a threshold value or ‘gap’ between expected and desired quality level) cannot be identified and to some degree quantified first. Establishing threshold values and assessing their implication for different environmental and socio-economic receptors is in itself surrounded by fundamental sources of scientific uncertainty. These scientific uncertainties are translated and found back in the policy realm by adopting an ‘adaptive management’ approach based on for example the precautionary principle as in the overall BRIDGE ‘tiered approach’.

• The risk of not meeting certain threshold values is highly dependent on the limited available data and information and the confidence the analyst and policy-maker have in these data and information. In principle, economics also has a role to play here: in the development and design of alternative groundwater quality monitoring systems to inform policy makers and groundwater managers about the appropriate course of action. In the case of setting up new monitoring systems or modifying existing monitoring networks, the economic value of additional information plays an important role, where the economic costs of extra monitoring will be weighted against the perceived additional benefits of better and more sustainable groundwater management. In other words, economic criteria are expected to be an integral part of the actual adoption and implementation of any groundwater monitoring and management plan.

• Assessing the environmental impact of programs of measures on water quality with some degree of confidence is one of the most important problems in the implementation of the WFD, and will also be one of the most important challenges in the implementation of the new European Groundwater Directive. Given the fact that the groundwater threshold values are fixed in terms of pollutant concentration levels, the effect of policy measures has to be evaluated in terms of their impact on water quality basin-wide. This is currently the weakest link: the relationship between socio-economic activities (pressures) and the actual impact of these activities or changes in these activities on groundwater quality. This includes groundwater-surface water interactions and the impact of groundwater quality on terrestrial ecosystems. In none of the WP5 case studies these links could be thoroughly established.

• The effects of most measures are evaluated in terms of their emission reduction potential, not their impact on water quality measured through the change in pollutant concentration levels basin-wide. Also in most WP5 case studies the relationship between pressure reduction (emission of a pollutant) and the actual impact on groundwater quality is weak and surrounded by uncertainty. More research is needed here in scientific models built with
the help of expert judgment to better understand this relationship in time and space. Although common practice in the actual implementation of the WFD in many if not most European Member States, the use of qualitative expert judgment only in the selection of cost-effective programs of measures is considered a second-best alternative to more quantitative basin-wide modelling of the impacts of different measures on surface and groundwater quality. This should be a focal point in future EU water-related research programs.

2. Dissemination and use

The overall aim of BRIDGE has been to develop and test a method for the derivation of pollutant threshold values for groundwater bodies in support of the Status provisions of the Water Framework Directive (WFD) and the Groundwater Daughter Directive (GWDD). Consequently it was not the purpose of BRIDGE project to deliver exploitable results, defined as knowledge having a potential for industrial or commercial application in research activities or for developing, creating or marketing a product or process or for creating or providing a service.

The main outcome of the Bridge project is a procedure for threshold values setting in groundwater, which is based on a tiered approach and on knowing the nature of the final receptor at risk. The project has been carried out at European level, involving a range of stakeholders and efficiently linking the scientific and policy-making communities.

Linkings between scientific and policy-making communities have been ensured through presentations to

Specific meetings of WG 2C :
Presentations of the progress of BRIDGE on:
- 28 January 2005,
- 7 June 2005,
- 12 October 2005.
- 14 February 2006
- 22 June 2006
- 2 October 2006

With participations of several BRIDGE partners (UBA-A,IGME, BRGM, LGT, FzJulich, UNI-AVEIRO, GEUS)) This is of main importance on aspects related to EU policy development and specific requests such as emerging issues in EC working groups, which could be addressed within the scope of the project.

Stackeholders were also invited to attend BRIDGE Workhops
20-21 June 2006: Workshop in Vienna (linked with European Groundwater conference) for information of Stakeholders
15 December 2006: Final meeting at UNESCO headquarters (Paris) in presence of Stakeholders

Bridge provided public reports available on the website:
http://www.wfd-bridge.net
-D5: Reference overview of EU-funded research, national reports and reference base
-D7 State-of-the-art knowledge on behaviour and effects of natural and anthropogenic groundwater pollutants
-D10 Impact of hydrogeological conditions on pollutant behaviour in groundwater and related ecosystems
-D13 Summary report on groundwater quality monitoring network designs for groundwater bodies
-D14 Report on National Methodologies for Groundwater Thresholds Values
-D16 Summary Guidance and Recommendations on sampling, Measuring and Quality Assurance
-D17 Report on the integrated data aggregation methodology
-D18 BRIDGE Final Proposal for a methodology to set up groundwater threshold values in Europe
-D22 Application and evaluation of a proposed methodology for derivation of gw thresholds
-D25 Alsace socio-economic Case Study report
-D26 Netherlands_Scheldt socio-economic case study
-D27 Finland_Lahti socio-economic case study
-D29 Latvian socio-economic case study
-D42 Slovenia socio-economic case study
-D33 Bridge project presentation

A CD-Rom for divulgation of the results of the project to the general public is going to be completed.