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FLUX-BASED RISK ASSESSMENT OF THE IMPACT OF CONTAMINANTS ON WATER RESOURCES AND ECOSYSTEMS

«FRAC-WECO»

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J.-P. Thomé, J. Dujardin, O.Batelaan, F.Canters, C.Hérivaux

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Terrestrial Ecosystems

FINAL REPORT PHASE 1

FLUX-BASED RISK ASSESSMENT OF THE IMPACT OF CONTAMINANTS ON WATER RESOURCES AND ECOSYSTEMS

«FRAC-WECO»

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Promotors

Serge Brouyère & Alain Dassargues
Université de Liège, Départment Argenco, Geo³-Hydrogeology
(ULg-HG)
Jean-Pierre Thomé
Université de Liège, Laboratory of Animal Ecology and Ecotoxicology
(ULg-LEAE)
Ludo Diels & Karolien Vanbroekhoven
Vlaamse Instelling voor Technologisch Onderzoek (VITO)
Okke Batelaan & Frank Canters
Vrije Universiteit Brussel, Department of Hydrology and Hydraulic
Engineering / Department of Geography (VUB)
Cécile Hérivaux
Bureau de Recherches Géologiques et Minières (BRGM, France)

Authors

D.Caterina, S.Brouyère, P.Jamin, J.Batlle-Aguilar, A.Dassargues (ULg),
W.Dejonghe, L.Diels (VITO),
S.Crèvecoeur, J.-P. Thomé (ULg),
J. Dujardin, O.Batelaan, F.Canters (VUB),
C.Hérivaux (Brgm)

BELGIAN SCIENCE POLICY

Rue de la Science 8
Wetenschapsstraat 8
B-1000 Brussels
Belgium
Tel: +32 (0)2 238 34 11 – Fax: +32 (0)2 230 59 12
http://www.belspo.be

Contact person: Sophie Verheyden
+32 (0)2 238 36 12

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D.Caterina, S.Brouyère, P.Jamin, J.Batlle-Aguilar, A.Dassargues, W.Dejonghe, L.Diels, S.Crèvecoeur, J.-P. Thomé, J. Dujardin, O.Batelaan, F.Canters, C.Hérivaux ***Flux-Based Risk Assessment of the Impact of Contaminants on Water Resources and Ecosystems «FRAC-WECO»***. Final Report. Brussels : Belgian Science Policy 2009 – 59 p. (Research Programme Science for a Sustainable Development)

Summary of the project

In Belgium, as well as in many other European countries, many contaminated sites have been reported as resulting from a relatively anarchic economical and industrial development during the 19th and 20th centuries. Since the late 1980's, policy makers, stakeholders and the population in general have become more and more aware of the risk posed by these sites and that a sustainable economical development cannot be envisaged without optimizing land use and preserving or restoring natural resources and ecosystems. The promulgation of Directive 2005/35/EC on environmental liability has also reinforced stakeholders' perception of the economic dimension of environmental damages generated by contaminated sites. This directive, which has to be transposed into national legislation by the end of 2007, compels potential polluters to cover the cost of preventive or remediation actions required by the environmental damage they may generate. Other regulations and laws have appeared at various levels, from regional (Flemish Soil Decree, Walloon Region Soil Decree) to national and supra-national scale (EU Water Directive, coming EU Soil Directive…).

The objective of **the FRAC-WECO project** is to study the impact of contaminated sites on the receiving water bodies being the river basin or the groundwater body (serving as a drinking water body). At each phase of the process of soil and groundwater remediation, methodologies and indicators have to be proposed to site managers as a support to decision making associated with the contamination problem, the first decision being at each level to decide to go to the next step or not, based on the evaluated risk. From one step to the other, the complexity of the information and tools required increases together with the costs needed for making a "good" decision. At the same time, the risk of not tackling efficiently the problem is supposed to be reduced as the problem is better worked out.

In order to propose adequate, still economically feasible, remediation measures for contaminated sites, the first step is to evaluate and to quantify as accurately as possible the actual risk associated with these sites for the environment in general, for health (not directly considered here), for water resources and ecosystems in particular, and then to propose remediation measures that are adequate with respect to this evaluation. Based on the analysis performed during the first phase of the FRAC-WECO project, it has appeared that, in terms of policy relevance, it is necessary to manage these contaminated sites at the scale of the groundwater body which is relevant in the context of the Water Framework Directive (WFD). At such a scale, the cumulative effect related to the multiplication of contaminant sources and fluxes often dominates over local contamination problems taken one by one. Contaminated sites have thus to be considered altogether to evaluate the potential and actual damages for water resources and associated ecosystems, considering both their market and non-market functions. In this context, starting from the groundwater body scale risk assessment analysis, the project is developing a methodological framework that will allow to propose management plans and to design programmes of measures aiming at improving the status of water resources and ecosystems at the scale of the groundwater body, based on a cost-benefit analysis.

At the same time, a reliable characterization and remediation procedure relies on several key elements: **i)**water often being the main vector of the mobility of contaminants, an accurate description of surface and subsurface water fluxes is required, from site scale to (ground)water body scale, and from infiltration and runoff to discharge points such as groundwater abstraction points and surface water bodies, **ii)**because of the permanent competition between contaminant

migration and retardation, a sound and process-based description of biogeochemical processes occurring in the subsurface is needed, **iii)** contaminants being specific in terms of physico-chemical behaviour and (eco-)toxicity, detailed information on these aspects is required, and **iv)** risk assessment tools and indicators are required specific to various targets such as water resources or ecosystems.

In this context, the FRAC-WECO project develops an integrated methodology contributing to a multi-level risk assessment of contaminated sites on water resources and ecosystems. Specific objectives are: **i)** to develop a modelling approach for accurately calculating water and contaminant fluxes at various scales, from the contaminant plume to the catchment scale, **ii)** to quantify and to model biogeochemical processes affecting the mobility (speciation), retardation and reactivity of various specific contaminants (heavy metals, PAHs, organochlorinated compounds, emerging pollutants such as VOCls, or even toxic hydrophobic persistent contaminants with Kow >6 …) in the environment, through water resources, **iii)** to validate risk assessment methodologies using datasets coming from representative contaminated sites in Belgium and to develop a flux-based risk assessment indicator for evaluating the impact of contaminants on water resources (groundwater vulnerability) and on aquatic ecosystems (ecotoxicological risk) in relation with the management and cleaning of contaminated sites, **iv)** to evaluate uncertainty on contaminant transport of spatial variability in sub-surface and surface land characteristics and especially to evaluate impacts of uncertainty in the mapping of land-cover characteristics, and **v)** to develop and apply a decision support tool for planning and evaluating integrated management measures aiming at reducing short and long-term impacts of contaminants, inclusive costs and benefits that would result from an improvement of the status of water resources and associated ecosystems currently under pressure of brownfields.

Researches are developed through a strong collaboration of hydrogeologists, soil scientists, ecotoxicologists, remote sensing specialists and socio-economists. Pilot case studies selected in Belgium are used to apply and to evaluate the developed models and guidelines at various scales.

- Methodology

The DPSIR methodology will be considered as a general organizational framework for the project. The DPSIR framework, developed by the European Environmental Agency, has been widely adopted by policy makers, consultants and researchers. It helps in reporting, permits easier exchange and communication between policy-makers and other actors and it simplifies a complex reality. With a set of environmental indicators established by the EEA, DPSIR has three major purposes (Smeets and Weterings 1999): to provide information on environmental problems which allows estimation of their importance, to help in identifying key factors that create pressures on the environment and set priorities, to survey and follow-up the effects of policy responses.

The DPSIR methodology will be considered as a general organizational framework for the project as it presents a chain of causal links between Driving forces (economic sectors, human activities), Pressures (emissions, waste), States (physical, chemical and biological state of the resource) and Impacts on ecosystems, human health and natural resources. This leads to Responses such as prioritization, target setting and indicators (Kristensen 2004).

Following the DPSIR framework, the pressure (P) is the contamination source, more particularly its consequences on the state, i.e. the fluxes of contaminants migrating across the water system. The system ('State') is the water resource and associated ecosystems as affected by contaminants. In terms of water resource, the target can be the groundwater resource 'alone' or the groundwater resource + base flow to discharge points such as surface water or pumping wells (S2). Generally speaking, impacts (I) consist in increaded costs for site rehabilitation, in water treatment costs, in reduction in biodiversity and possibly in health problems fpor neighbouring communities (not the direct focus of this proposal). Based on the research efforts developed during Phase 1, the impacts can be described more accurately as follows. A change in groundwater quality (S) will in turn result in Impacts (I) related to a change in the level of services provided by groundwater to the society (i.e. damage in case of degradation/ benefits in case of improvement) [see D1.2]. Three main types of services and related values can be distinguished: (i) those related to groundwater 'as a resource' (direct use values that can generally be quantified with market based techniques); (ii) those related to groundwater 'itself' (indirect use values and non use values that are more difficult to quantify and require the implementation of valuation methods); (iii) those related to groundwater 'as a discharge into surface water' (indirect use values that can be quantified by methods directly applied to surface water).

The project combines on the one hand process studies contributing to a more comprehensive assessment and modelling of water and contaminant fluxes at various scales ranging from the local contaminated site to the (ground)water body, considering the specific biogeochemical properties (sorption, degradation…) and ecotoxicity of contaminants, on the other hand specific risk assessment indicators for ecotoxicological aspects (including the concomitant effects of contaminants) and for water resources management aspects (e.g. physically-based groundwater vulnerability assessment), which, based on conclusions drawn during phase 1, are two of the most policy relevant aspects related to contamination issues in the sense of the Water Framework Directive. One of the main objectives being to propose a methodological framework for the evaluation of damages related to the existence of multiple sources of contamination in the water body and of potential benefits of their remediation, a flux-based risk assessment framework is required, which allows considering the additive effect of these sources (cumulative fluxes). In the present context, research activities focus on the P-S-I chain and on possible responses formulated in terms of programmes of measures for sustainable redevelopment of contaminated sites, water resources and ecosystems in the groundwater body.

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List of Acronyms/Abreviations

AGIV :	Agency for Geographic Information Flanders
AGW:	Arrêté du Gouvernement Wallon
BTEX :	Benzene-Toluene-Ethylbenzene-Xylene
CAH:	Chlorinated Aliphatic Hydrocarbons
CART	Centre d'Analyse des Résidus en Traces
CILE:	Compagnie Intercommunale Liégeoise des Eaux
DCE:	Dichloroethene
C_{Ri}:	Concentration at Receptor I ($M\ L^{-3}$)
C_S :	Concentration at the source ($M\ L^{-3}$)
DDT :	Dichloro Diphenyl Trichloroethane
DGRNE:	Direction Générale des Ressources Naturelles et de l'Environnement (Région Wallonne)
DOC :	Dissolved Organic Carbon
DPSIR :	Drivers Pressures State Impacts Responses
EC50 :	Effect Concentration
fM_{Ri}:	Contaminant mass flux reaching Receptor I ($M\ L^3\ T^{-1}$)
fM_S:	Contaminant mass flux released from the source ($M\ L^3\ T^{-1}$)
FVPDM:	Finite Volume Point Dilution Method
GADM:	Gravels and Alluvial Deposits of the Meuse
GAF:	Global Attenuation Factor
GIS:	Geographical Information System
GMS:	Groundwater Modelling System
HCH :	HexaChlorocycloHexane
K_d:	Distribution coefficient (M/L^3)
LC50 :	Lethal Concentration

MEC:	Measured Concentration
MISP :	Model for estimating the Impact of Sources of Pollutants
MLP :	Multiple Layer Perceptron
M_{Ri}:	Quantity of contaminant reaching Receptor I (M)
M'_{Ri}:	Contaminant masse reaching Receptor I per unit time ($M\ T^{-1}$)
M_S:	Quantity of contaminant released from the source (M)
M'_S:	Contaminant masse released from the source per unit time ($M\ T^{-1}$)
MT3D:	Modular three-dimensional transport model
NOEC:	No Observed Effect Concentration
OCDE:	Organisation de Coopération et de Développement Economiques
OVAM:	Openbare Vlaamse Afvalstoffenmaatschappij
PAHs:	Polycyclic Aromatic Hydrocarbons
PCBs:	PolyChlorinated Biphenyls
PEC:	Predicted Environmental Concentration
PNEC:	Predicted No Observed Effect Concentration
Q_{Ri}:	Quantity of water flowing across Receptor i ($L^3\ T^{-1}$)
Q_S:	Quantity of water flowing across the source ($L^3\ T^{-1}$)
QSARs:	Quantitative Structure-Activity Relationships
RA:	Risk Assessment
RBCA:	Risk Based Correction Action
RBINSc:	Royal Belgian Institute of Natural Sciences
R_{fi}:	Recovery factor at Receptor i (no unit)
R_i:	Receptor i
RISC Workbench:	Risk Integrated Software for Clean-ups WorkBench
RS:	Remote Sensing
RT3D:	Three-dimensional, multi-species, reactive transport model

RTWS:	Remedial Targets WorkSheet
SEDBARCAH:	SEDiment bioBARriers for Chlorinated Aliphatic Hydrocarbons
SPAQuE:	Société Publique d'Aide à la Qualité de l'Environnement
SPR :	Source Pathway Receptor
SPSS:	Statistical Package for the Social Sciences
SUFT3D:	Saturated – Unsaturated Flow and transport in 3D
SWDE:	Société Wallonne Des Eaux
TCE:	Trichloroethene
UA	Urbanized areas
VC:	Vinylchloride
VOCL:	Volatile Organic Chlorinated Compound
WFD :	Water Framework Directive
WTP:	Willingness To Pay

1 Introduction

1.1 Context of the research

In Belgium, as in many other countries in the European Union and elsewhere in the world, many contaminated sites have been reported as resulting from a relatively anarchic economical and industrial development during the 19th and 20th centuries, without environmental considerations. These last years, people have become more and more aware and informed of the risk posed by these sites and by the necessity to optimize land-use in order to respond to economical development needs while preserving and restoring natural resources and ecosystems. These sites have to be managed both from a risk and economical point of view. This requires:

I. efficient methodologies and norms for screening contaminated sites;

II. evaluation of the possible impact of these sites on the environment;

III. risk assessment for humans, natural resources and ecosystems;

IV. development of tools and methodologies for evaluating, ranking and optimizing remediation measures.

1.2 Objectives of the project

The FRAC-WECO project aims at developing an integrated methodology contributing to a more comprehensive risk assessment of contaminated sites on <u>water resources</u> and <u>ecosystems</u> based on a combination of the 'Source – Pathway – Receptor' approach for conceptualizing the physical system and on the European Environmental Agency "Drivers-Pressures-State-Impacts-Response" concept for integrating the physical and socio-economical components of the analysis into an efficient decision support system for risk analysis.

Specific objectives are:

I. to develop a modelling approach for accurately calculating water and contaminant fluxes at various scales, from the contaminant plume to the groundwater body scale;

II. to quantify and to model biogeochemical processes affecting the mobility (speciation), retardation and reactivity of organic and inorganic contaminants through water resources;

III. to validate risk assessment methodologies using data from contaminated sites in Belgium and to develop a flux-based risk assessment indicator for evaluating the impact of contaminants on water resources (groundwater vulnerability) and on aquatic ecosystems (ecotoxicological risk) in relation with the management and cleaning of contaminated sites;

IV. to evaluate uncertainty in contaminant transport modelling caused by spatial variation in surface/sub-surface land characteristics, especially the uncertainty in land-cover characteristics mapping;

V. to develop decision support tools for planning and evaluating integrated management measures aiming at reducing short and long-term impacts of contaminants.

Research efforts are supported by the use of existing data on contaminated sites and case studies located in Belgium used to apply and to evaluate the developed models and guidelines at various scales.

It is expected to provide a methodological framework which will allow estimating, at the (ground)water body scale, the impact of contaminated sites on water resources and ecosystems, based on the combination of knowledge and tools developed, tested and validated at the scale of the pilot sites (i.e. a single contamination source) and of large-scale modelling, risk assessment tools and a socio-economic analysis framework. Scientific aspects will also include publication of peer-reviewed papers, participation in international meetings, organization of a Belgian workshop and specific reports for relevant regional, federal or international authorities. Vulgarization actions will also include the creation of a website presenting the research and its main outcomes.

1.3 Scientific methodology

The project combines, on the one hand, process studies contributing to a more comprehensive assessment and modelling of water and contaminant fluxes at various scales (local and catchment) and of biogeochemical properties and toxicity of contaminants, on the other hand, impact studies such as risk assessment methodologies so as to propose management tools and indicators for ranking contaminated sites in terms of risks and costs.

The originality of the approach relies mainly on two aspects:

I. a risk evaluation based on the calculation of contaminant fluxes between the source (contaminant emitter) and the receptor(s);

II. the use of a combined DPSIR-SPR approach as a general framework for coupling the physical and socio-economic components of the analysis. To develop that methodology, various skills, tools and concepts are provided and developed by the different research groups involved in the project and it is the sum and the integration of these components that will allow reaching the final objectives.

Thanks to ***Deliverable D.1.2*** “Methodology for integration of process studies and development of a decision support tool”, the integration schema has been defined from the beginning of the project, to guarantee the complementarity and compatibility of the various research efforts. Integration involves on the one hand the physical component of the analysis for which the various process-based researches should contribute to the global objective of the project, which is being able to assess contaminant fluxes between the Source and the Receptor. On the other hand, integration will also make it compatible the physical and socio-economic compounds of the project.

Process studies consist in field and laboratory investigations and in modelling efforts. Field investigations contribute to a better quantification of groundwater recharge, to the development of innovative technologies for field assessment of water and contaminant fluxes in groundwater and to a better evaluation of the ecotoxicity of the contaminated sites. Laboratory investigations consist in better assessing the specific behavior of contaminants (retardation and degradation properties). Groundwater flow and transport modelling efforts will allow integrating all available information on the test sites and specifically calculating contaminant mass fluxes and concentrations at the various receptors at risk, that information being the “entry point” for the socio-economic analysis aiming first at evaluating the damages caused by the contamination of the sites, then at ranking the various remediation alternatives.

Based on the research efforts developed during Phase 1, the impacts can be described more accurately as follows. A change in groundwater quality (S) will in turn result in Impacts (I) related to a change in the level of services provided by groundwater to the society (i.e. damage in case of degradation/ benefits in case of improvement) [see ***D1.2***]. Three main types of services and related values can be distinguished: (i) those related to groundwater 'as a resource' (direct use values that can generally be quantified with market based techniques); (ii) those related to groundwater 'itself' (indirect use values and non use values that are more difficult to quantify and require the implementation of valuation methods); (iii) those related to groundwater 'as a discharge into surface water' (indirect use values that can be quantified by methods directly applied to surface water).

1.4 General organisation of the report

For the sake of clarity, the scientific results obtained in the scope of the FRAC-WECO project during phase 1 are described following the general organization of the project in work packages. At the end of the description of each work package, the key outcomes, with respect to the general objectives of the project, are outlined in the form of a summary table.

2 Results obtained during phase 1 of the project

2.1 Project coordination, management and integration - WP1

Workpackage WP1 does not have detailed scientific objectives as it focuses on project coordination and management issues. However, specific working activities have been performed in the scope of this work package contributing to fitting better the project with the end-users needs and requirements in terms of management of contaminated sites.

2.1.1 Coordination, management and integration

This task is specifically devoted to the day-to-day management of the project (contacts with BELSPO, reporting, follow-up of the production of deliverables etc.). More specifically, important efforts have been devoted to a fluent exchange of information and contacts between the various partners thanks to regular meetings dedicated to presenting the research progresses, interactions between partners and integration of their results.

Meeting type	Location	Date
Project meeting	VUB	6/12/2006
Kickoff meeting / Follow-up committee meeting	ULg	29/03/2007
Project meeting	VITO (Berchem)	08/05/2008
Project meeting / meeting with end-user	ULg / SPAQuE	26-27/06/2007
Project meeting	VUB	29/08/2007
Project meeting	KUL	01/10/2007
Meeting with end-user	OVAM	11/11/2007
Project meeting	ULg	04/12/2007
Project meeting /Follow-up committee meeting	ULg	11/12/2007
Project meeting	VITO	14/02/2008
Project meeting	ULg / VUB	18/03/2008
Project meeting / meeting with end-users	ULg / DGRNE	07/05/2008
Project meeting	ULg	13/05/2008
Project meeting / Follow-up committee meeting	ULg	12/06/2008
Intermediate evaluation of the project	BELSPO	26/09/2008
Project meeting	ULg	19/11/2008
Project meeting / Follow-up committee meeting	ULg	20/01/2009
Project meeting / meeting with end-users	ULg / DGRNE	30/04/2009

Table 1: List of meetings held in the scope of the FRAC-WECO project during the first phase

2.1.2 Integration of physical and socio-economic aspects in the project

In the scope of WP1, the general methodology for integration of research components in the project has been elaborated and updated, under the supervision of BRGM and ULG-HG and with strong links with BRGM research activities in WP5 (socio-economic analysis). This has led to the production of ***Deliverable D1.2*** to which all partners have contributed.

2.1.3 Links with stakeholders and end-users

Strong links have been developed with identified final end-users (SPAQuE, OVAM and DGRNE Water Division). These meetings and exchanges have permitted to better target the objectives of the project with respects to the requirements and expectations of these institutions and to identify case studies and data suited to the research objectives of the project.

Main research outcomes of WP1
➔ Development of the research integration schema from the site scale (i.e. point source - receptor) to the megasite scale (i.e. multiple source – receptors at catchment scale or groundwater body scale) (activity in strong links with WP5) ➔ networking with end-users including their active involvement in the project

2.2 Catchment scale water and contaminant budgeting and routing - WP2

This work package includes research on describing the state of the water-soil-subsoil-sediment system and particularly on water budgeting and modelling, in order to accurately estimate water and contaminant mass balance and fluxes at catchment scale for further downscaling at the level of contaminated sites. This research involves VUB (remote sensing of land cover with respect to high-resolution surface water budgeting, groundwater recharge and run-off modelling, and model uncertainty assessment) and ULG-HG (variably saturated subsurface flow and transport modelling).

2.2.1 High-resolution groundwater recharge simulation and surface runoff routing

2.2.1.1 Object-oriented land cover mapping

In order to produce detailed land-cover information for the Vilvoorde study site, a land-cover map has been produced from high-resolution imagery (Ikonos), obtained from the Agency for Geographic Information Flanders (AGIV). Four different Ikonos image tiles have been used to cover the study area. These images were merged together to create one image covering the area of interest. The first two tiles (2 x 2.5 km) in the northern part of the area cover part of the NGI's topographic sheet 23 (Flemish Region), while the two tiles in the southern part are cover part of sheet number 31 (Bruxelles-Capital Region). Images have a 1-meter resolution for the panchromatic band and a 4-meter resolution for the multispectral bands (blue, green, red and near-infrared). Each band has 11-bit radiometric resolution. Because high-resolution sensors like Ikonos have a limited spectral resolution (only 4 bands), they do not allow distinguishing well between some types of land cover that are important in the context of hydrological modelling, based on spectral information only. Bare soil, for example, is often difficult to distinguish from certain types of artificial sealed surfaces (Thomas et al., 2003). To obtain accurate information on land cover an object-oriented classification approach has therefore been adopted. This approach allows using, next to spectral information, geometric, textural and contextual information, defined at the level of homogeneous image objects.

Image segmentation

The delineation of homogeneous land-cover objects was performed using the segmentation algorithm introduced by Baatz and Schäpe (2000) and implemented in the Definiens Professional v.5.0 image processing software. This algorithm is based on region-merging. Each pixel is first considered as a separate object. Those objects are then iteratively merged by pairs to form larger objects. The merging decision is based on a local spectral homogeneity criterion, describing the similarity between adjacent image-objects. The pairs of objects with the smallest increase in variance are merged. The process terminates when the smallest increase is above a user-defined threshold (scale parameter). A second parameter weights the contribution of color and shape in the variance measure. The last parameter splits the shape factor in compactness and smoothness. The image layer weights allow assessing image layers differently depending on their importance or suitability for the segmentation. The higher the weight which is assigned to a layer, the more of its information will be used during the segmentation process.

For this study, two scale parameters were tested. A first segmentation was done with a value of 40, a second one with a value of 50 for the scale parameter. The object homogeneity to which the scale parameter refers is used as a synonym for minimized heterogeneity. Internally Definiens computes three criteria for heterogeneity: color, smoothness and compactness. The compactness and smoothness represent together the shape criterion. The weights assigned to the color, shape, compactness and smoothness in this project are respectively 0.9, 0.1, 0.5 and 0.5. An image layer weight of 1 was given to the panchromatic image that has a resolution of 1 meter, while a layer weight of 0.5 was given to the other four bands (red, green, blue and infrared), having a 4-meter resolution. The final image classification was based on the segmentation with scale parameter 40, because of the better overall accuracy obtained with this segmentation result.

Image classification

After the segmentation process, image objects need to be assigned to different land-cover classes. To analyze which land-cover classes may be distinguished in the imagery based on the spectral, textural, geometric and contextual information defined for each image object, first a cluster analysis was carried out. Based on the results of this analysis the land-cover classes to be extracted from the imagery were defined and the classification of the imagery was accomplished.

Extraction of spectral and non-spectral information at object level

Each image object is characterized by a range of features, computed based on image objects: spectral features, textural features and morphological features. In this study 39 features were selected as input data for classification. A large set of object features available in Definiens were taken into account, including band-specific spectral features at object level (mean, brightness, standard deviation,…), direction-independent texture measures (derived from the grey-level co-occurrence matrix) and shape-related features (area, length, border length, asymmetry,…).

Cluster analysis and definition of land-cover classes

The cluster analysis seeks to identify homogeneous subgroups in the created image objects, based on the spectral and non-spectral data available for each object. The clustering tries to identify a set of groups which both minimize within-group variation and maximize between-group variation. For this study a hierarchical cluster analysis has been done in SPSS, based on a random sample of 2500 segments. The cluster methodology used is Ward's method. This method calculates the sum of squared Euclidean distances from each case in a cluster to the cluster mean. The clusters merged in each iteration are those that increase the sum the least. In this study the cluster analysis was applied for different numbers of clusters, from 2 clusters to 15 clusters. Based on cluster separability and visual interpretation of the objects that are part of each cluster 8 land-cover classes were chosen for classification: bare soil, grey urban surfaces, red roofs, bright roofs, water, meadow, mixed forest and shadow as an extra image class.

Neural network classification

The classification of image objects was done with the help of a multiple layer perceptron (MLP) model, using the NeuralWorks Predict software. MLP classification is a preferred technique for non-parametric classification, because next to spectral data other kinds of data with non-normal class frequency distributions, like for example textural data, can be used as an input for the classification process. Especially in urban areas, the technique is known to produce accurate results (Van de Voorde et al., 2007). The key to building a robust MLP is to collect many examples or records of input values and corresponding output values for training. The neural network uses this training data to determine a mathematical relationship between the input data and the output data. Building a well performing MLP with Predict involves collecting and pre-processing training data, constructing and training the network, and finally testing and validating it based on a set of proper validation data.

In this study, 100 samples were randomly selected for each land-cover class based on visual interpretation of the imagery. For each image object the full range of features (39 variables) were exported from Definiens and used for training the MLP. During the training phase the neural network tries to define the essential relationships present in the training data. Once developed, the network can be used to interpolate from a new set of inputs to corresponding outputs (full image classification). After the training of the model with 100 samples per class and 39 features, the model was validated on an independent validation set in order to evaluate the accuracy of the classification model. This validation set contained about 50 randomly sampled image objects per land-cover class. Application of the MLP model resulted in an overall accuracy of 77% (objects correctly classified). Substantial confusion remained between bare soil and artificial urban surface types (grey surfaces, red roofs), as well as between water and dark grey surfaces, between bare soil and meadow (some crop fields found outside the target area of research), and between forest and meadow. A substantial part of the mapped area was also attributed to the shadow class (17.6%), which is typical for urbanized areas.

		Reference Data									
		Water	Bare Soil	Meadow	Forest	Grey Surfaces	Red Roofs	Bright Roofs	Shadow	Total	U.A. (%)
Land-cover map	Water	**28**	1	0	0	6	0	0	8	**43**	65
	Bare Soil	0	**34**	2	1	7	4	1	0	**49**	69
	Meadow	0	8	**52**	3	1	0	1	1	**66**	79
	Forest	0	0	4	**54**	1	0	0	7	**66**	82
	Grey Surfaces	0	9	4	2	**57**	0	0	4	**76**	75
	Red Roofs	0	2	0	1	5	**41**	0	0	**49**	84
	Bright Roofs	0	0	0	0	0	0	**49**	0	**49**	100
	Shadow	4	0	4	5	6	0	0	**30**	**49**	61
	Total	**32**	**54**	**66**	**66**	**83**	**45**	**51**	**50**	**447**	
	P.A. (%)	88	63	79	82	69	91	96	60		
										OCC:	**77%**
										kappa:	**0.73**

Table 2: Error matrix for the classification before shadow removal and rule-based classification enhancement

The columns of the confusion matrix show to which classes the objects in the validation set belong (ground truth), the rows show to which classes the objects have been assigned in the image. The diagonal indicates the objects that are classified correctly. If objects are not assigned to the proper class, this gives an indication of the confusion between the different classes in the class assignment. The matrix shows, for example, that classification accuracy is the highest for bright roofs (96%). User accuracies (indicated in the last column of the confusion matrix) are lowest for shadow and water which show some confusion. Also between bare soil and grey urban surfaces some confusion seems to remain with about 10% of the grey urban surfaces assigned to the bare soil class.

To remove shadow and correct for errors in the classification, a context-based post-classification strategy was applied. Context-based post-classification makes use of expert knowledge or data-derived knowledge about the spatial structure of a land-cover scene to re-assign an image object to another class based on the identity of adjacent objects. A finite set of rules was designed for shadow removal as well as for resolving errors caused by class confusion, based on expert knowledge obtained through visual inspection of errors in the classified image. Validation of the shadow relabeling procedure based on an independent sample indicated a correct reassignment of 81% of shadow objects to the correct land-cover class. The rule-set defined for reducing class confusion also substantially improved the overall accuracy of the classification, thus demonstrating the efficiency of the post-classification method proposed. Table 2 illustrates the confusion matrix for the land-cover map after shadow removal and rule-based classification enhancement. Using the same validation set as before the use of the post-classification rules, an overall classification accuracy of 88% and a kappa index of 0.86 are obtained.

		Reference Data								
		Water	**Bare Soil**	**Meadow**	**Forest**	**Grey Surfaces**	**Red Roofs**	**Bright Roofs**	**Total**	**U.A. (%)**
Land-cover map	**Water**	**31**	0	0	0	0	0	0	**31**	100
	Bare Soil	0	**46**	3	1	9	1	0	**60**	77
	Meadow	1	8	**58**	4	2	4	0	**77**	75
	Forest	0	0	6	**86**	2	1	0	**95**	91
	Grey Surfaces	1	4	3	2	**84**	2	0	**96**	88
	Red Roofs	0	0	0	0	0	**37**	0	**37**	100
	Bright Roofs	0	0	0	0	0	0	**51**	**51**	100
	Total	**33**	**58**	**70**	**93**	**97**	**45**	**51**	**447**	
	P.A. (%)	94	79	83	92	87	82	100		
									OCC:	**88%**
									kappa:	**0.86**

Table 3: Error matrix for the classification after shadow removal and rule-based classification enhancement.

Figure 1 shows the final land-cover map (***Deliverable 2.1***), which was used as input for runoff and groundwater recharge modelling.

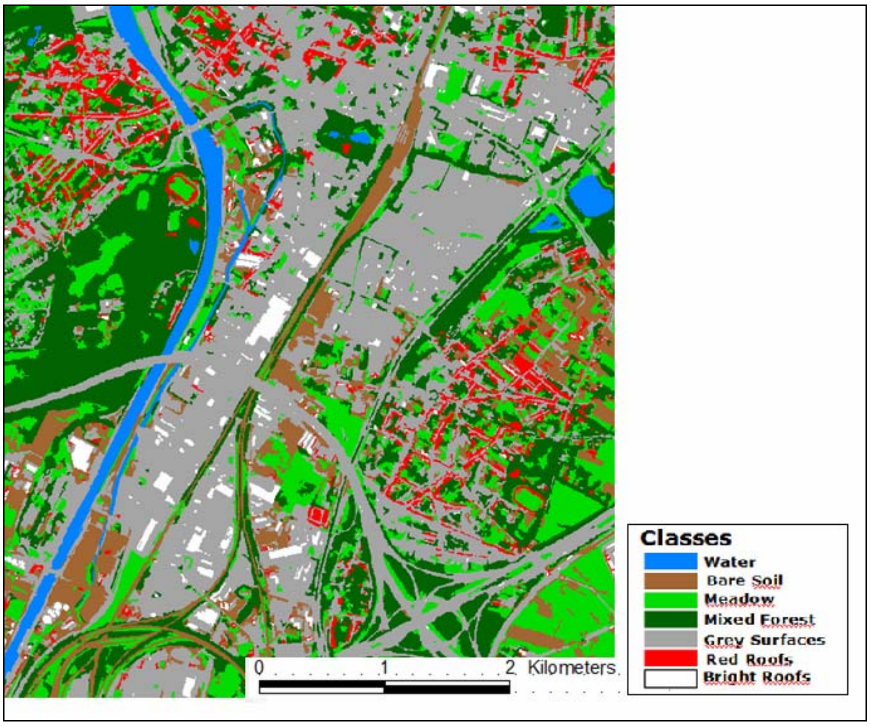


Figure 1: Land-cover map obtained for the Vilvoorde study site

2.2.1.2 Spatially distributed surface water budgeting

Groundwater recharge is varying in space and time, but is not directly measurable from precipitation. No fixed percentage of rainfall is infiltrating into the soil. Development of GIS, remote sensing, spatially variable land cover and soil data leads to an approach that directly takes into account the influence of the spatial variability of soil texture, land cover, slope and meteorological conditions in groundwater recharge estimation, and improves the spatial estimation of recharge. The methodology followed for simulation of the recharge and runoff in this study is based on the distributed seasonal WetSpass simulation model described in Batelaan and De Smedt (2007). The resulting recharge and run-off maps are presented in Figure 2 (***Deliverables 2.2/2.3***). Table 4 presents the average yearly groundwater recharge and its standard deviation as a function of land-cover in the Vilvoorde area. Additional seasonal maps and analysis per land-cover and soil type are given in ***Deliverable 2.4*** (end 2008).

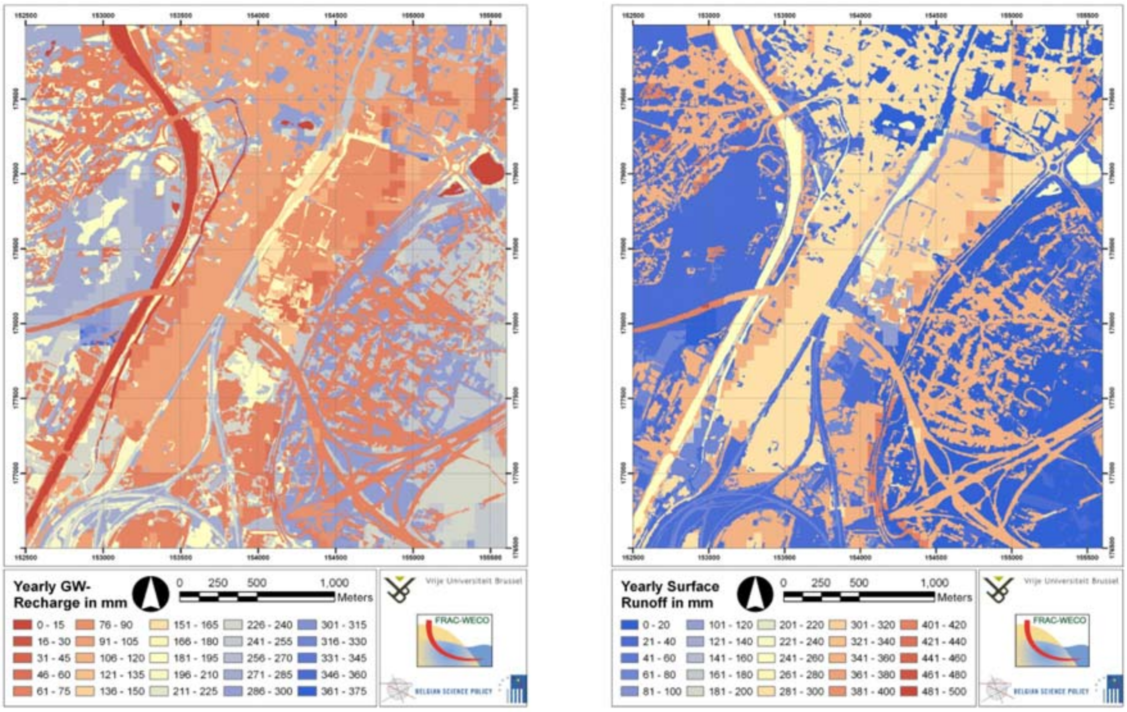


Figure 2: WetSpass simulated yearly long-term average recharge (left) and run-off (right) for the Vilvoorde study area.

These figures and tables show a strong spatial distribution of recharge values over the area. The average recharge for the study area is 159 mm/year, which is considerably lower than the 220 mm/year being the average for the Flemish Groundwater Model area determined using the same methodology with less detailed land-cover data. These values show clearly the strong influence of the high percentage of impervious cover on the recharge. The simulated recharge map has been used in a groundwater model developed for the Vilvoorde area as part of Task 2.2 of the project.

Landcover	Surface Area (10^{-3} km²)	% Surface Area	Avg. recharge (mm)	Standard Dev. (mm)
Built-up	5171	48	79	15
Bare soil	1107	10	456	52
Forest	2545	23	275	20
Open water	325	3	0	0
Grassland	1706	16	216	31
	10854	100	159	92

Table 4: Simulated recharge values for the Vilvoorde study area for different RS object oriented mapped land cover classes.

2.2.2 Variably saturated groundwater modelling

Groundwater modelling is often used as decision support tool by stakeholders and decision-makers for the assessment of problems related to contaminated sites and for the choice of rehabilitation operations. In the specific case of FRAC-WECO, modelling applications are required at two scales. A local scale (i.e. scale of a given contaminated site) modelling applications are tools for computation of water and contaminant fluxes between sources and receptors. At regional scale, they are necessary to assess the relative importance of a particular site within a (ground)water body and thus to "feed" the socio-economic analysis performed in the project. Several available numerical models have been selected and first local scale (Morlanwelz and Vilvoorde test sites) and groundwater body scale (RWM073) modelling applications have started.

2.2.2.1 Survey on processes and models

The SUFT3D, developed by ULg-HG, is a 3D numerical model using finite elements and allows the modelling of variably saturated groundwater flow and transport (including adsorption–desorption introduced by a delay factor) from local scale to catchment scale. In the SUFT3D, it is now possible to model flow and transport using various mathematical approaches with different complexity levels: from a simple linear reservoir to a detailed spatially distributed approach (Brouyère, 2006; Brouyère et al., 2004; Orban et al., 2005). HydroGeoSphere, developed at the University of Laval (Québec, Canada) and the University of Waterloo (Ontario, Canada) under the coordination of Prof. R.Therrien, is a fully coupled 3D flow and transport model using advanced numerical finite element algorithms. GMS, initially developed by the Environmental Modelling Research Laboratory at Brigham Young University (Utah, United States), is a complete program for building and simulating groundwater models. It supports both finite-difference and finite-element models in 2D and 3D (including MODFLOW, MT3DMS/RT3D etc) together with tools for each phase of a groundwater simulation, including site characterisation, model development, calibration, pre- and post-processing, and visualization.

2.2.2.2 Modelling of the Vilvoorde (Zenne) test site

For the Vilvoorde study area an existing model of VITO has been adapted and calibrated. Figure 3 presents the model area and grid as used in the model of VITO and the improved model.

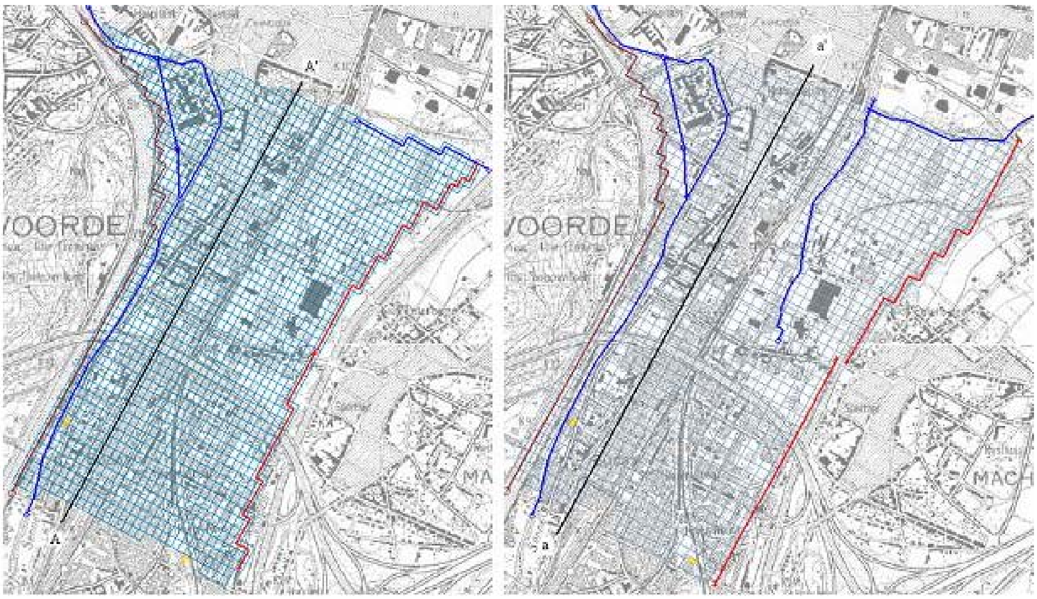


Figure 3: Location of the Vilvoorde study area, the grid for the model of VITO (left) and the adapted model (right).

For adapting the model it showed to be necessary to (re-)evaluate the local geology.

Hence, the information from a 123 drillings and 301 cone penetration tests were studied to refine the hydrogeology. Most important in refining the geology was the location of the partly confining Ghent Formation which is not present in the southern part of the study area.

Boundary conditions were improved and recharge was simulated with the WetSpass model using the land-cover map obtained in WP2. After calibration the model was used to simulate groundwater fluxes to the Zenne River. Measurements of the temperatures in the river bottom sediments provided via heat flow simulation an independent estimate of the groundwater fluxes. These results show an outflow of 50-88 m^3/day per river cell of 50 by 50 m. Water balances have been established for the model area and particle tracking analyses have provided insight in the potential transport of pollutants from four different sources towards the Zenne. Figure 4 shows the simulation results from one of the pollution sites. Advective flow times from the site to the Zenne vary from 15-45 years.

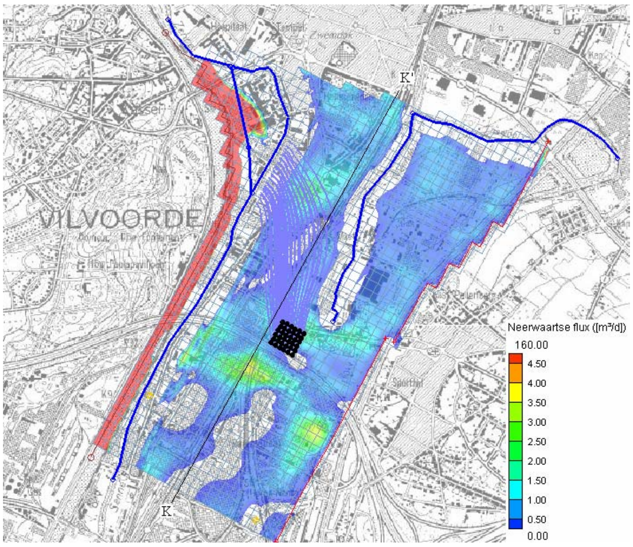


Figure 4: Advective transport of pollutants simulated with MODPATH coming from the SRI/BIOLUX-site (colors are providing groundwater fluxes in m3/day)

Additionally a 1 D vertical heat transport model based on the ecosystem modelling platform FEMME was applied to calculate point estimates of the vertical darcian groundwater flow within the riverbed. Continuously measured temperature profile data of the Zenne river bed at 3 locations along the river bed was used as input. The results represent a point estimate, which is used to verify the results adopted form the groundwater model. The median of 75 weekly simulations from December 2005 and April 2006 as well as October-November 2006 indicate a median groundwater discharge of -34 mm/d, which differs just a few percent from the value obtained with the steady-state groundwater model (-35 mm/d).

2.2.2.3 Modelling of the Morlanwelz test site

A groundwater and solute contaminant model (using GMS with MODFLOW and MT3D) has been developed in order to simulate groundwater flow and contaminant transport for the Morlanwelz test site (Figure 5).

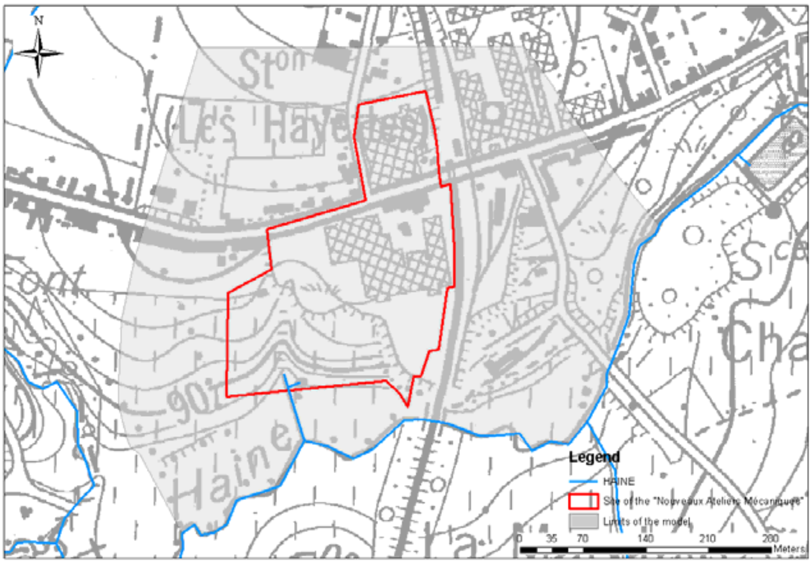


Figure 5: Delimitation of the modeled area

Because data on subsurface characteristics (hydraulic conductivity, etc.) and on water and contaminant fluxes are very limited at this stage, strong simplifying assumptions have been chosen in the adopted conceptual model for allowing to model such a complex problem. In its present form, this model allows a local understanding of the most probable saturated groundwater flow pattern, it facilitates also running first scenarios and defining the most important efforts to be performed in the field to improve the quality of available data for a more detailed modelling.

Considering available data from the SPAQuE, the literature and field measurements, it has been decided to consider two aquifers separated by an intermediate, semi-confining layer. The upper layer is an unconfined aquifer which is made of Tertiary sands and embankments, the intermediate layer is made of marl and the lower layer, assumed as confined, is made of fractured Houiller shale. The types of boundary conditions considered in the model are summarized in Figure 6.

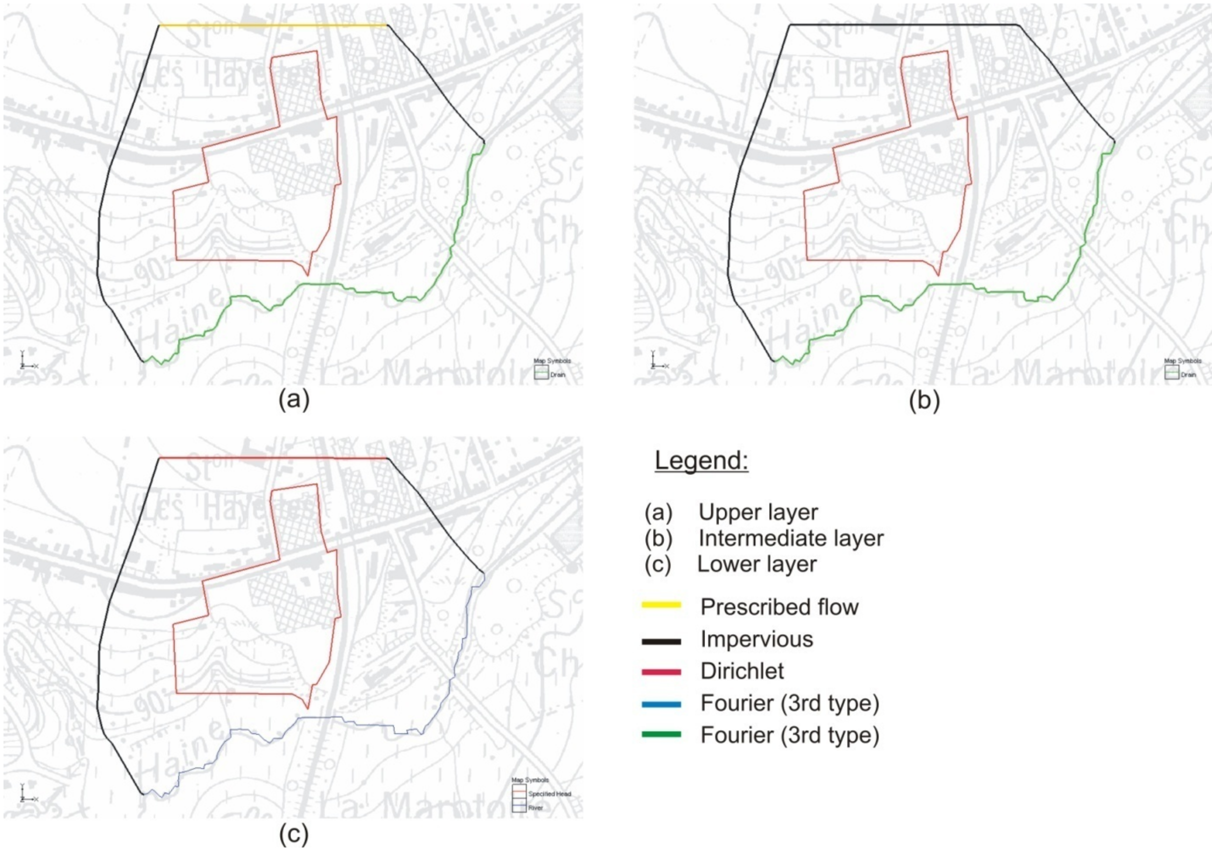


Figure 6: Boundary conditions considered at the various limits of the finite difference model. At the top of the model, a Neumann (prescribed flux) is also applied to account for pluviometric recharge.

A first calibration was performed assuming a steady state regime, based on the available piezometric data. The results show a groundwater flow direction from North to South, the Haine River being the main outlet for groundwater (Figure 7).

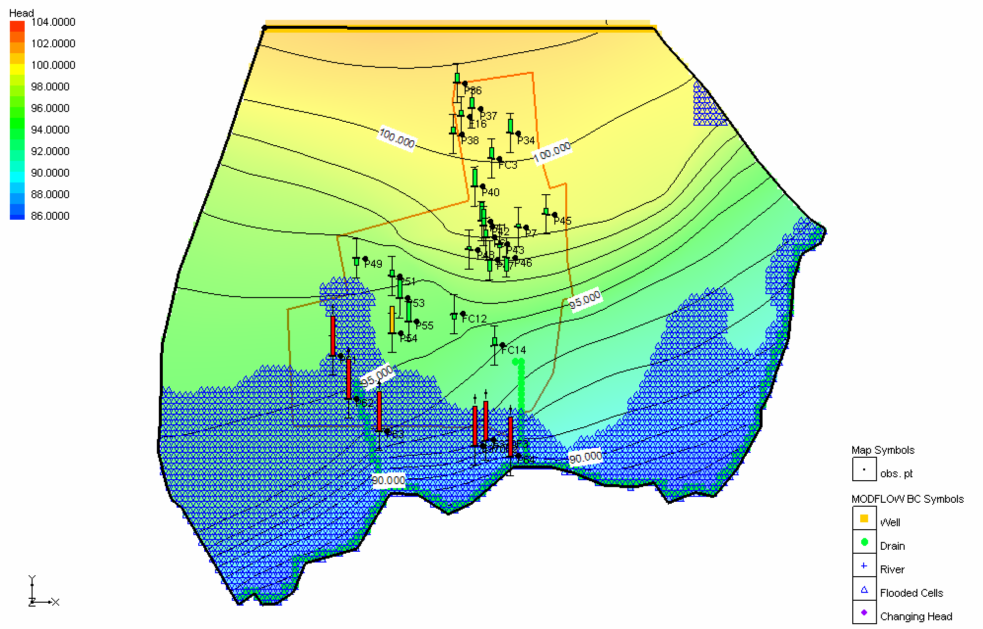


Figure 7: Calculated hydraulic head contours for the upper aquifer layer.

The resulting finite difference model was used to perform first simulations for contaminant migration using orders of magnitude of contaminant properties coming from the literature, for a constant source of TCE of 1100 mg/L. The effective (transport) porosity is assumed to be 10%. Figure 8 shows TCE iso-concentrations after 1.5 years, considering (a) advection and dispersion processes and (b) advection, dispersion and sorption processes (linear partitioning coefficient K_d = 5×10^{-5} m^3/kg). At this stage of the modelling, no degradation is considered.

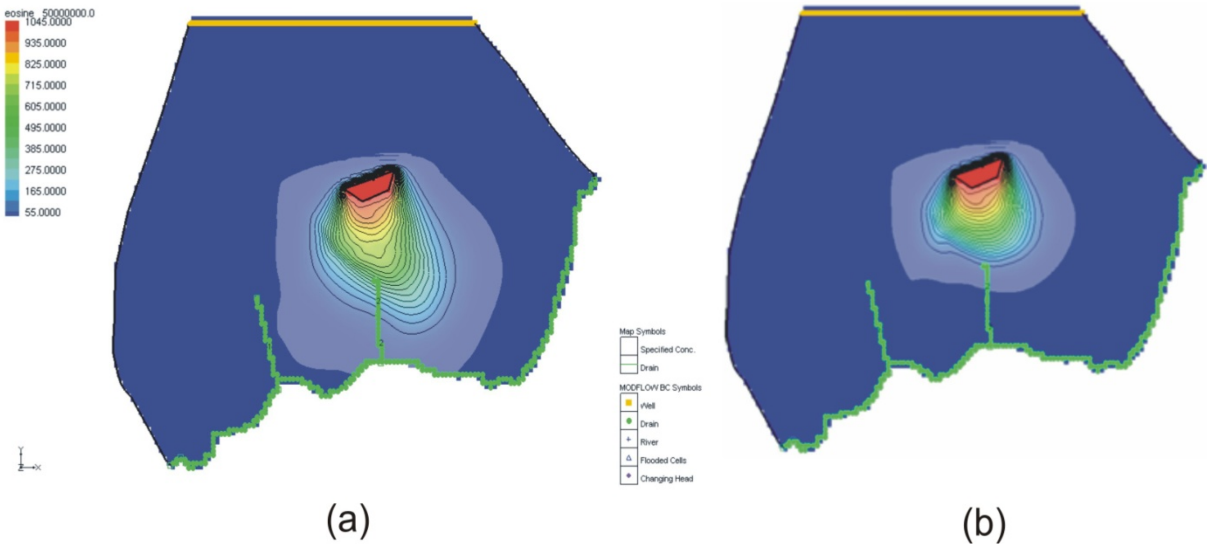


Figure 8: (a) Dispersion and advection, (b) Dispersion, advection and adsorption

Modelling of groundwater body RWM073

In order to assess the risk on water resources as a whole by taking into account the influences of multiple sources of contaminants, it has been decided to upscale the study area to the groundwater body. The proposed case study is the groundwater body RWM073 located between the cities of Engis and Herstal (see Figure 9), made of alluvial deposits of the Meuse River. RWM073 is considered at risk of not reaching good chemical status by 2015 due to the existence of many contaminated sites exerted a high potential pressure on the alluvial aquifer.

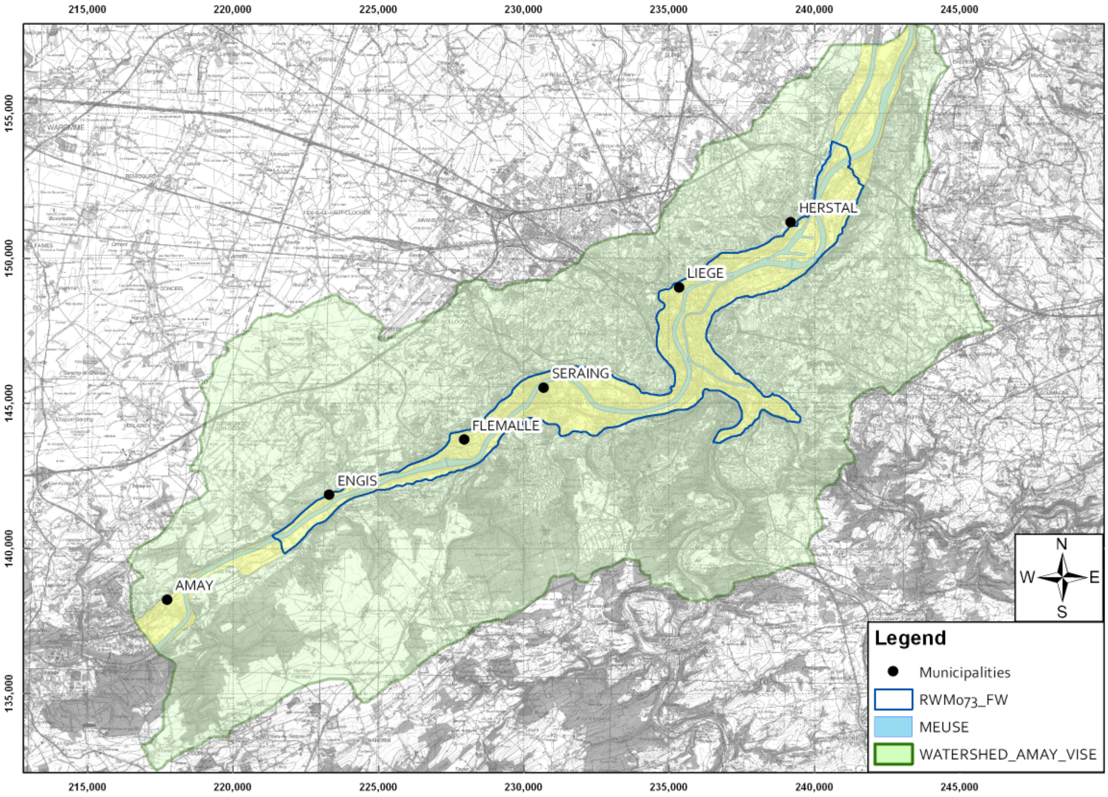


Figure 9: RWMO73 (blue contour) and the watershed around it.

A groundwater flow and contaminant transport model is under development by ULg-HG. Until now, working efforts have been focused on data acquisition and on the development of the conceptual hydrogeological model.

Data acquisition focuses on three steps of the Source-Pathways-Receptors risk assessment schema. The contaminant sources come from numerous databases owned by regional authorities (proved/potential pollution sources, location, type and behaviour of pollutants, concentrations …). Receptors have been identified as point-type receptors (pumping wells) and regional receptors (groundwater bodies, zones of biological interest …). Pathways concern the way for the pollutant to spread through the environment. It includes having an accurate knowledge about aquifer properties, ground water flow and solicitation, surface water and contaminant behaviour. This data mining will continue during the second phase of the project.

In particular, the extent of the modelled area has been adapted from the delineation of RWM073 as defined by the Walloon Region to fit the boundaries between the alluvial plain and the bedrock. The first step of the model is to compute the groundwater flow into the alluvial plain including its lateral extension (the watershed) defined to facilitate the definition of boundary conditions and the interactions of other groundwater bodies such as RWM072. In a second time, contaminant transport will be modelled on the only alluvial plain using the results of the first step as boundary conditions. Land-use mapping and hydrological budgeting will be performed on this area using the same approach as used in Vilvoorde. These data will provide estimates of groundwater recharge for modelling application which will finally lead to qualitative state mapping of the groundwater body and risk assessment on the area.

2.2.3 Sources-Pathways-Receptors database

In order to manage all the data about sources, pathways and receptors as efficiently as possible, the creation of a relational database has been initiated. This database is developed under "Microsoft Office Access". Within this data base, a contaminated site is linked to (1) former/current activity, (2) associated contaminants, (3) environmental data such as hydrogeology, hydrology, soil, and (4) receptors. But it can also serve as a simple tool that can give the most commonly founded pollutant for a certain activity and vice versa. Finally, this database includes a list of selected contaminants (most relevant among micro-organic pollutants and heavy metals) and their physical and chemical properties such as international reference number, solubility, Henry's law constant, sorption on organic matter, air or water diffusion,… The second phase of the FRAC→WECO project will serve to feed this database and finalise its development.

Main research outcomes / key findings of WP2
➔ Land use mapping and hydrological budgeting: contaminated sites are generally located in urbanized, industrialized and heavily modified environments where land use is complex and difficult to characterize. Groundwater recharge is the first key vector of the mobility of contaminants in such site (contaminant leaching). The combined object-oriented land use mapping and hydrological budgeting is an innovative answer to such a challenge as it provides a reliable estimate of recharge for groundwater flow and transport modelling of contaminants at catchment scale ➔ Groundwater flow and transport modelling from site scale to catchment / groundwater body scale: modelling tools of increasing complexity, from basic analytically based risk assessment tools to advanced numerical modelling applications applicable at the catchment scale have been identified, selected and applied to various cases ranging from the pilot site to the groundwater body. These models will be used in the second phase of the project for contaminant routing from sources to receptors, in the scope of the global risk assessment.

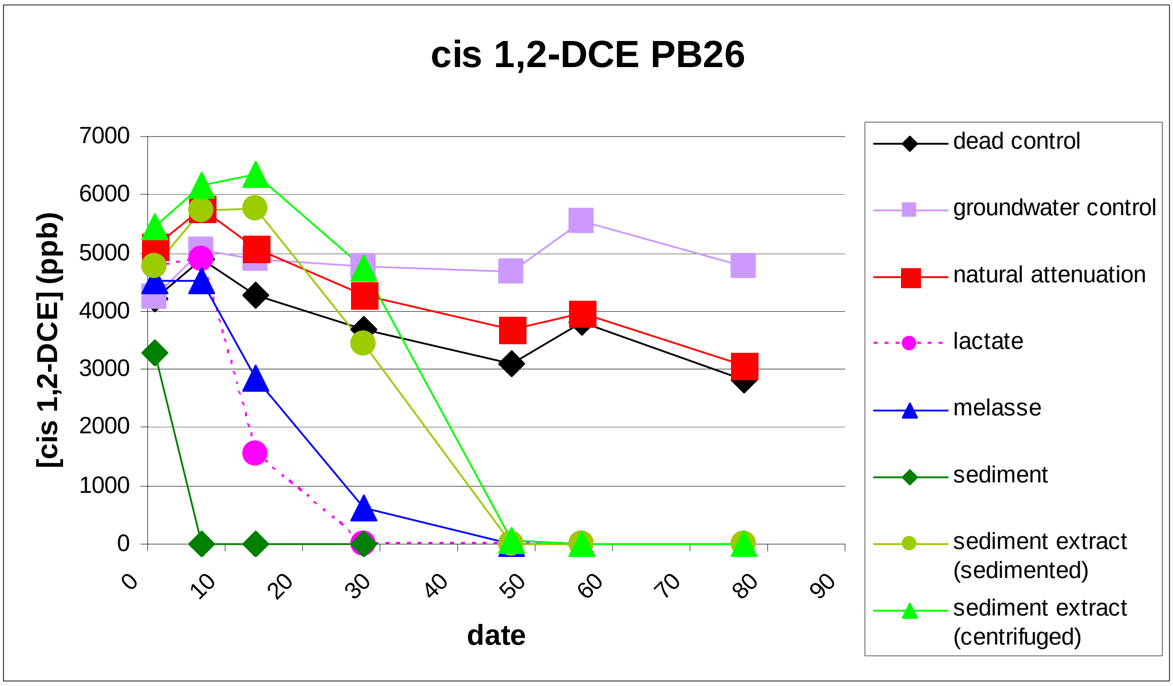
2.3 Contaminant behaviour and properties – WP3

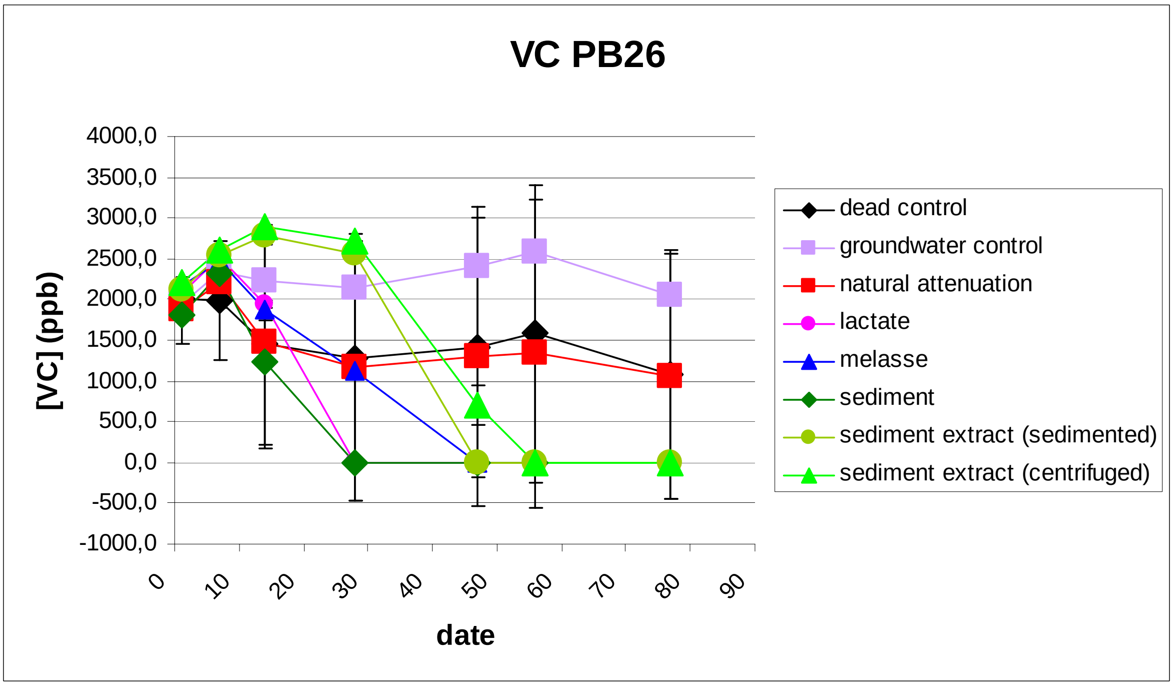
In the scope of WP3, results are related to the estimation of the biodegradation potential of CAHs (VITO) and results on the ecotoxicity of groundwater and surface water at the various test sites (ULg-LEAE).

2.3.1 Biogeochemical processes

Degradation constants of chlorinated aliphatic hydrocarbons (CAH) have been determined at three positions B3, Pb26 and B2 at the Vilvoorde-Machelen site, respectively at the source (B3), in the plume (Pb26) and at the receptor (B2) of this CAH-pollution. Such degradation constants can be used in the risk-model developed so that a decrease in the risk of these CAHs towards the receptor can be taken into account in this model. Such methodologies can be generalized to other kinds of organic contaminants and other case studies.

To determine these degradation constants, batch degradation tests are being performed to investigate the degradation potential towards CAHs at these three locations (see ***Deliverable 3.1*** for more details). Aquifer and groundwater samples were taken in September 2007 at locations B2, B26 and B3 positioned at different distances from the Zenne River. CAHs degradation is studied under natural attenuation conditions but also under stimulated conditions. Stimulation of CAHs degradation is obtained by the addition of the carbon sources lactate or molasses. Next to this, sediments as such and two different types of extracts of sediments (obtained after sedimentation or centrifugation of the extracts) were added to the flaks. By adding different types of sediments, dissolved organic carbon and/or CAH-degrading-bacteria are added to the flasks. All flasks are incubated at 12 °C, corresponding to *in situ* groundwater temperature.





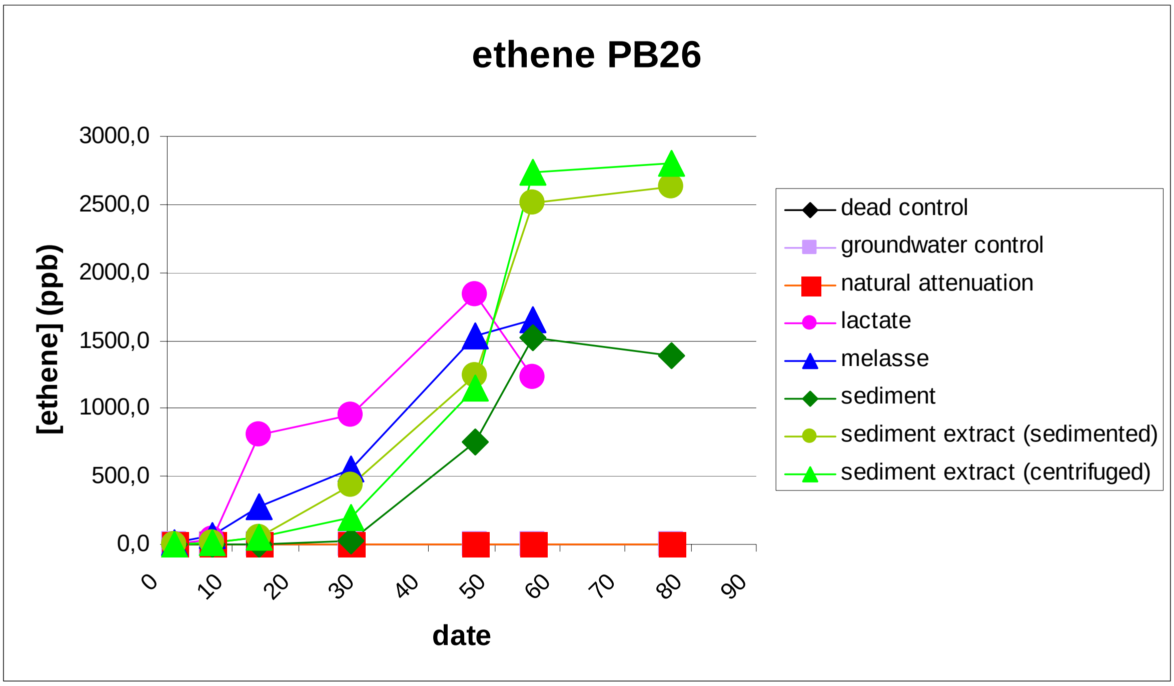


Figure 10: (Stimulated) degradation of DCE and subsequently VC to ethene at the location Pb 26 at the Vilvoorde-Machelen site.

From these batch tests one can conclude that no degradation of VC and DCE is occurring at the three locations B2, B26 and B3 under natural attenuation conditions (Figure 10). However, the degradation of CAHs is clearly stimulated by the addition of the carbon sources lactate, molasses, sediment and sediment extract. During this degradation, DCE is converted to the toxic daugther product VC which is subsequently converted to the harmless product ethene (Figure 10). In addition, the CAH-degradation potential depends on the location in the aquifer: the fasted degradation was observed in the location B26 which is located 200 m from the Zenne.

To better simulate the *in situ* conditions, aquifer columns were set up in the EU-project SEDBARCAH. These columns were filled with aquifer obtained from the location B1 at 28 m from the Zenne. Groundwater polluted with the *in situ* concentrations of CAHs (100 µg/l DCE and 800 µg/L VC) are pumped with a speed of 50 ml/day or 47 m/year over this aquifer. Samples for CAH-analyses are taken at the inlet, outlet but also after different contact distances between the groundwater and the aquifer. First results indicated that no degradation of DCE and VC occurred in the natural attenuation columns. Therefore the CAH-degradation in the columns was stimulated with lactate (0.054 mg C/day), sediment extract (0.054 mg C/day) or by placing a sediment column in front of the aquifer column. This sediment column acts as a bio-barrier since the CAHs are already degraded until a certain extent in this column so that lower concentrations of CAHs are flowing together with dissolved organic carbon and CAH-degrading bacteria from this sediment column into the aquifer column. However, due to the low concentrations of carbon sources, no stimulation of CAH degradation could be observed in the aquifer columns (data not shown). In a further step, the concentration of added carbon sources were increased till a final concentration of 0.5 mgC/day of lactate or sediment extract was reached in the columns. Due to gas formation, we have currently problems with the sampling of these columns. The effect of the increased DOC on the degradation of DCE and VC will be further studied in 2009.

2.3.2 Ecotoxicity of contaminants

Contaminants at large contaminated sites often share critical properties such as high acute and/or chronic toxicity, high environmental persistence, often high mobility leading to contamination of groundwater, and high lipophilicity leading to bioaccumulation in food webs.

Ground- and surface water sampled on the selected polluted sites (Morlanwelz, Zenne and Chimeuse) show similar physico-chemical parameters results (pH, oxygen concentration, conductivity, redox potential, temperature) throughout the first phase of the project. During the sampling campaigns of year 2008 at Morlanwelz site, the Haine River was fed by the baseflow from groundwater.

As no invertebrate was found at the different studied sites, typical groundwater crustacean (family Niphargidae) were sampled by the scientific team of Dr. P. Martin at the RBINSc (Royal Belgian Institute of Natural Sciences, SC2) at reference sites, located in the Walloon Region, which are expected to be unpolluted. Two species were collected and *Niphargus schellenbergi* was the most abundant one (*Niphargus fontanus* is the other one). These typical groundwater animals were cultured in the laboratory until enough organisms were available to perform an acute toxicity test. Niphargidae survived at the laboratory conditions during maximum 266 days.

Samples of ground- and surface water were also analysed for Polychlorinated Biphenyls (PCBs) and selected organochlorinated pesticides (lindane, HCH, aldrin, dieldrin, DDT and its metabolites). These chemicals were analysed because, even if their use is restricted or banned, they persist in the environment due to their chemical properties (high lipophilicity, low watersolubility, long half-life in the environment…). Except for Zenne River, the concentration of these pollutants was lower than the background level defined in the AGW of September 12th 2002. This level is 7 ppt (ng/L) for PCBs sum and 100 ppt (ng/L) for DDT and its metabolites sum. Zenne River is contaminated with PCBs, even if their concentration decrease compared to 2007 (0.314µg/L on September 2007 and 0.017µg/L on September 2008). It can be explained by their bioaccumulative properties, by a lower content of suspended matter and by the activation of a new sewage treatment plant situated upstream from Machelen-Vilvoorde studied site.

All samples were analysed for other contaminants: CAHs and BTEX by VITO, PAHs by the Laboratory of Food Analysis (CART, ULg – SC3a) and heavy metals by the Laboratory of Oceanography (ULg – SC3b). Chimeuse is particularly contaminated with heavy metals and is characterized by a great spatial heterogeneity, with hotspots of As, Cu, Ni and Zn concentrations above legal intervention values (figure 1).

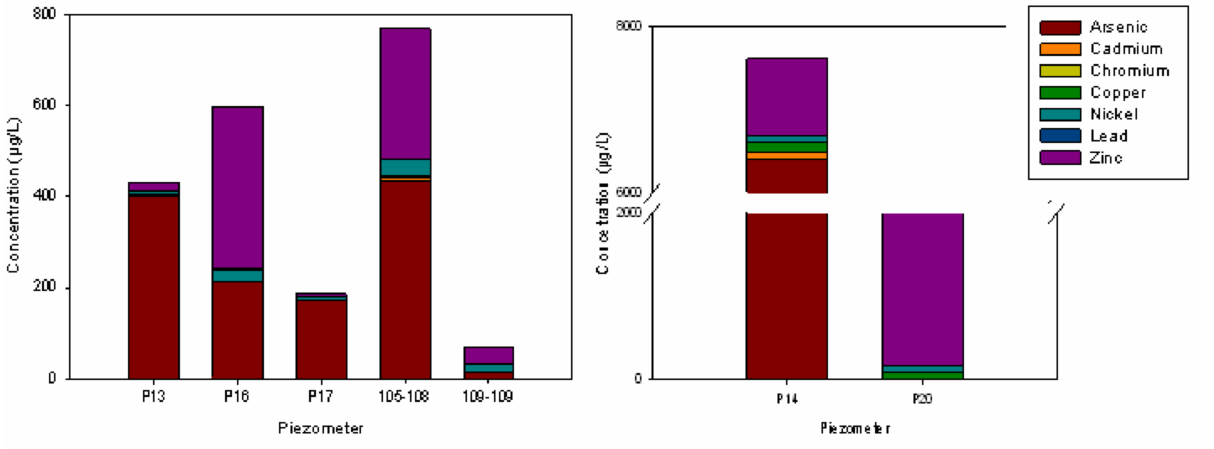


Figure 11: Heavy metals proportions measured at Chimeuse site (2008)

On the contrary, Morlanwelz and Machelen-Vilvoorde are contaminated with chlorinated solvents (vinyle chloride, cis-1,2-dichloroethene and trichloroethene). PAHs concentrations at the different sites are generally lower than the limit of quantification. Clustering analysis (STATISTICA, version 8.0 Fr) were realised for Morlanwelz site to determine pollution similarities between the different sampling points (Figure 2). Haine up- and downstream are less polluted as well as P16 piezometer. On the contrary, P3 is the more contaminated sample.

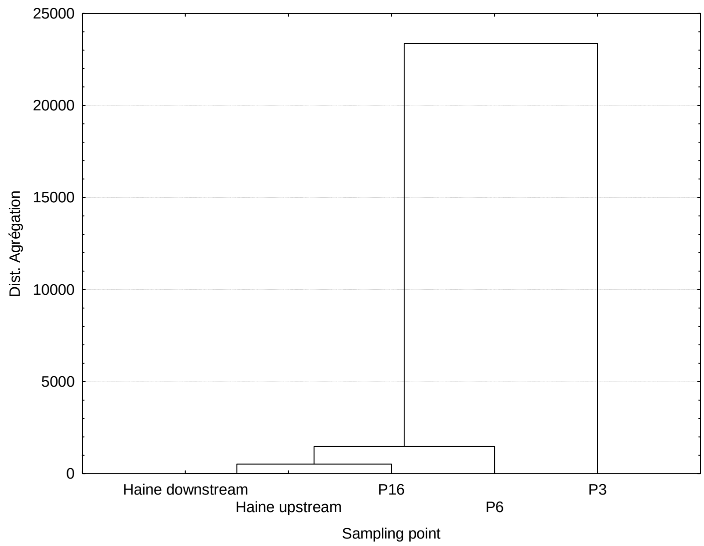


Figure 12: Clustering analysis between pollutant concentrations in ground- and surface water samples (STATISTICA, v. 8.0 Fr)

In the laboratory, ecotoxicological tests (acute and chronic toxicity tests), using *Brachionus calyciflorus* (Rotifera), *Gammarus pulex*, a typical freshwater crustacean, and Niphargidae were performed on samples from the selected polluted sites containing a **mixture** of pollutants. The $L(E)C_{50}$, *i.e.* concentration of test substance which results in 50% population mortality (50% inhibition of the reproduction rate) relative to control, was estimated for each sample.

Generally, chronic toxicity (EC_{50}) is more sensitive than acute toxicity (LC_{50}).

Results vary according to the studied site, the sampling period, the concentration of pollutant, but remain similar during the first phase of the project (Figure 13, Morlanwelz site).

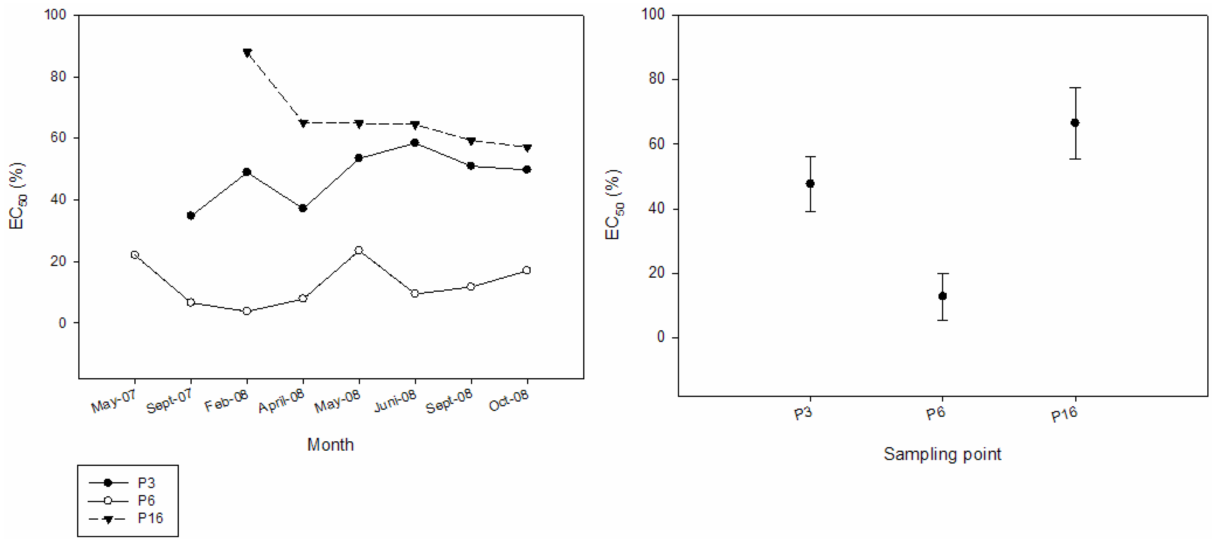


Figure 13: Chronic toxicity (EC_{50}) results evolution (left graph) and mean chronic toxicity results (right graph) at Morlanwelz site

The chronic toxicity results are expressed in percentage of the dilution of the water sample (*e.g.* 100% means the substance as such, 10% means the substance diluted 10 times).

At Morlanwelz site, all the three groundwater sampling points were toxic to *B. calyciflorus* after 48 hours exposure and their EC_{50} ranged from 66.47% (P16 – less toxic) to 12.24% (P6 – more toxic). EC_{50} could not be calculated for Haine River as there is less than 50% of inhibition of the reproduction rate (less than 48%) in the pure sample.

Acute toxicity tests were also performed on a sample from Morlanwelz site (P6) using both Niphargidae species and *Gammarus pulex*, a typical freshwater crustacean which both belong to the same phylogenetic order (Crustacean Amphipoda) but have not exactly the same morphology. Results of these tests show no mortality in the pure sample after 96 hours. Information from these tests revealed no difference in sensitivity to the industrial polluted water (P6 at Morlanwelz) between groundwater species (Niphargidae) and a taxonomically comparable surface water species (*Gammarus pulex*). Additional ecotoxicological results are given in the ***Deliverable D.3.2.*** of December 2007 and 2008.

On the one hand, toxicity values are available **for a mixture of pollutants** from laboratory tests (task 3.2.4) and, on the other hand, a risk can be assessed **for each pollutant** separately using measured concentrations and data from literature (task 4.2).

But, first of all, as the ecotoxicological impacts are different according to the type of xenobiotics, identification sheets were written for each compound present at polluted sites. These sheets summarize the physico-chemicals properties of the pollutant, sources and releases in the environment, bioaccumulation potential, health effects and so on…

Main research outcomes / key findings of WP3
➔ physico-chemical properties of contaminants: field investigations and lab studies have contributed to a better understanding of the specific behaviour of common industrial contaminants mobile in groundwater (such as CAHs). These investigations will provide relevant data and information for modelling the fate of these contaminants in the underground, using models from WP2 ➔ Ecotoxicity of contaminants in groundwater: significant progresses have been made in the development of a methodology for ecotoxicological indicators applicable to contaminated groundwater (where no specific fauna can generally be identified)

2.4 Development of risk assessment tools and indicators - WP4

2.4.1 Groundwater vulnerability mapping and flux-based risk assessment

2.4.1.1 Application and validation of existing risk assessment tools

During Year 1, an important review of risk assessment tools and methodologies has been performed. It is the subject of ***Deliverable D2.5***. Several methodologies for the management of contaminated megasites were described and a synthesis of existing risk assessment tools was proposed based on a detailed literature review and a classification of these tools according to general criteria such as: the type of risk concerned, the type of contaminants managed, the possibility to model transport of dissolved contaminants …).

For the comparison and validation of risk assessment tools (***Deliverable 4.1***), it was decided to focus on the transport of dissolved contaminants using suited software tools: RBCA Toolkit, RISC Workbench, MISP and Remedial Targets Worksheet (RTWS). These four tools (see their characteristics in Table 5) were tested on two case studies using real data.

	RBCA	RISC Workbench	MISP	RTWS
Developed by	GSI Environmental Inc.	BP oil International	BRGM	Environment Agency
Source zone	Constant concentration source	Finite mass of pollutant	Constant concentration source, but possibility to define a finite mass of pollutant	Constant concentration source
Transport processes in the unsaturated zone	Advection, «soil attenuation factor » and degradation	Advection, diffusion-dispersion, degradation, sorption/desorption		Only advection
Transport in the saturated zone	Domenico solution	Galya solution	Galya solution	Ogata-Banks or Domenico solutions
Transport processes in the saturated zone	Advection, diffusion-dispersion, degradation, sorption/desorption			

Table 5: Main characteristics of analytical models included in tested RA tools

The first case study corresponds to the Sclaigneaux site, an industrial area located near the city of Andenne in the alluvial plain of the Meuse River where soils and backfill deposits are contaminated with mercury. The idea was to simulate the transport of contaminant from a source located above the groundwater table (= in the unsaturated zone) to a fictitious observation well located 50 meters downstream in the saturated zone. Unfortunately, it turned out that a detailed comparison and validation of such tools using "real data" alone was difficult because of the uncertainties in the field data and conditions were overlapping with conceptual and mathematical differences from one tool to another. This led to the conclusion that a more detailed comparison and validation of RA tools required a more systematic comparison using, as a benchmark, synthetic examples inspired from case studies and modelled using more advanced numerical flow and transport approaches.

A second case has thus been studied considering a source of contaminant located in the saturated zone. That case is inspired by the brownfield of the Flémalle former coke factory located again in the alluvial plain of the Meuse River (inside RWM073). The site has already been investigated in details in the scope of the FP6 Integrated project AquaTerra (Batlle-Aguilar, 2008), including an analysis of the risk of benzene dispersion to the Meuse river, through groundwater discharge, based on detailed field investigations and advanced numerical groundwater flow and transport modelling (Batlle-Aguilar 2008). Simulations provided by the tested RA tools have been compared to results provided by a numerical model built with the HydroGeoSphere code considering a constant source of pollution (benzene) located in the saturated zone whose hydraulic properties are those of alluvial gravels as described in Batlle-Aguilar (2008). Contaminant concentrations calculated by analytical models in 3 different observation wells in function of time were very similar to those provided by

HydroGeoSphere: same contaminant first arrival and same order of magnitude for concentration at stabilization (see example of results in Figure 14 for a specified set of parameters).

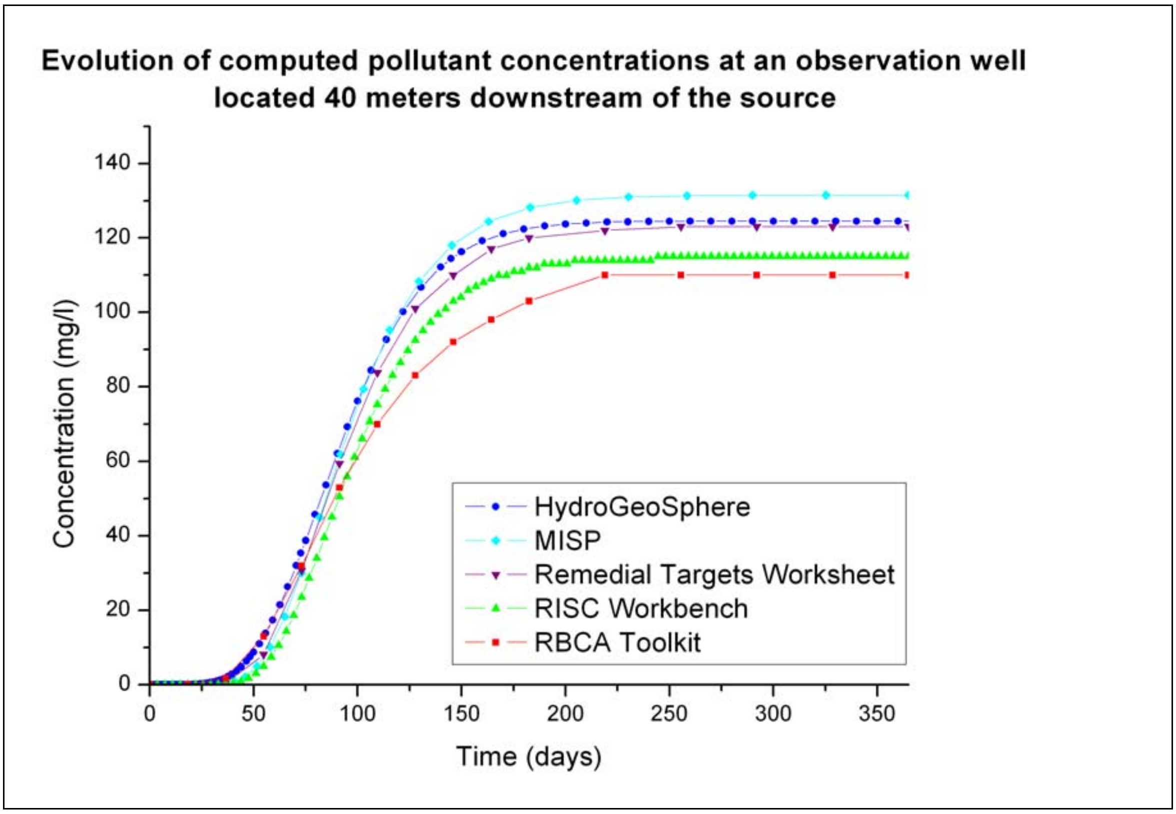


Figure 14: Evolution of contaminant concentrations "analytical *vs* numerical models"

A sensitivity analysis on main parameters influencing the transport of dissolved contaminants in groundwater was also performed showing only minor differences between analytical models and the numerical model.

Efforts have been made at the end of phase 1 and will continue at the very beginning of phase 2 to compare and validate analytical models considering a source of pollutant located in the unsaturated zone as for the Sclaigneaux case (described above). Unfortunately, due to great differences in approach used to describe the transport of contaminants in such a zone, analytical models included in RBCA Toolkit, MISP and RTWS are hardly comparable with HydroGeoSphere. The comparison with the numerical model is only conceivable with RISC Workbench. However, first results have shown that there were some important differences between those two models that are due to difference in parameters used to describe the unsaturated zone.

What appeared to the analysis of selected RA tools, and more particularly to their ability to simulate the transport of dissolved contaminants in the saturated and unsaturated zones through the use of analytical models, is their ease of use and the fact they do not require too much information regarding the complexity of the environment to model. This can be seen as an advantage compared to the numerical models sometimes requiring complex data.

Next to that, tools such as RBCA Toolkit and RISC Workbench offer large chemical and toxicological databases what is an additional asset for advocating their use in the scope of the project.

2.4.1.2 Groundwater specific vulnerability risk assessment and mapping

With respect to this task, significant progress have been made when preparing ***Deliverable D1.2*** which has already clarified the general framework for developing the concepts for groundwater specific vulnerability and risk assessment and mapping. Indeed, ***Deliverable D1.2*** describes the general indicators proposed for the various components of the combined DPSIR-SPR approach based on the determination of contaminant fluxes between the identified Source and Receptors, using preferentially mass-discharge indicators that compare the quantity of contaminant reaching each receptor to the quantity of contaminant that is released from the source.

The simplest way is to express this in the form of a recovery factor R_{Fi} (no unit) which is the mass ratio between the quantity of contaminant reaching any Receptor R_i, M_{Ri} (M) and the quantity of contaminant released at the source, M_s (M):

$$R_{Fi} = M_{Ri} / M_S$$

Since most risk assessment norms are generally concentration-based (ECB, 2003; EPA, 1996; ITRC, 2005), one can derive concentration-based indicators from the contaminant mass flux indicators as follows:

$$C_S = fM_S / Q_S$$

$$C_{Ri} = fM_{Ri} / Q_{Ri}$$

Where,

-fM_s and fM_{Ri} are the contaminant mass fluxes released at the source S and reaching the different receptors Ri ($M L^3 T$-1);

-Q_S and Q_{Ri} are the quantities of water that flows across the source S and the different receptors R_i, respectively ($L^3 T$-1).

Starting from these basic considerations, one can define representative variables for each component of the SPR system (Figure 15). For the Source and for each of the identified Receptors, one can define a group of indicators. Details on these indicators can be found in ***Deliverable D1.2***.

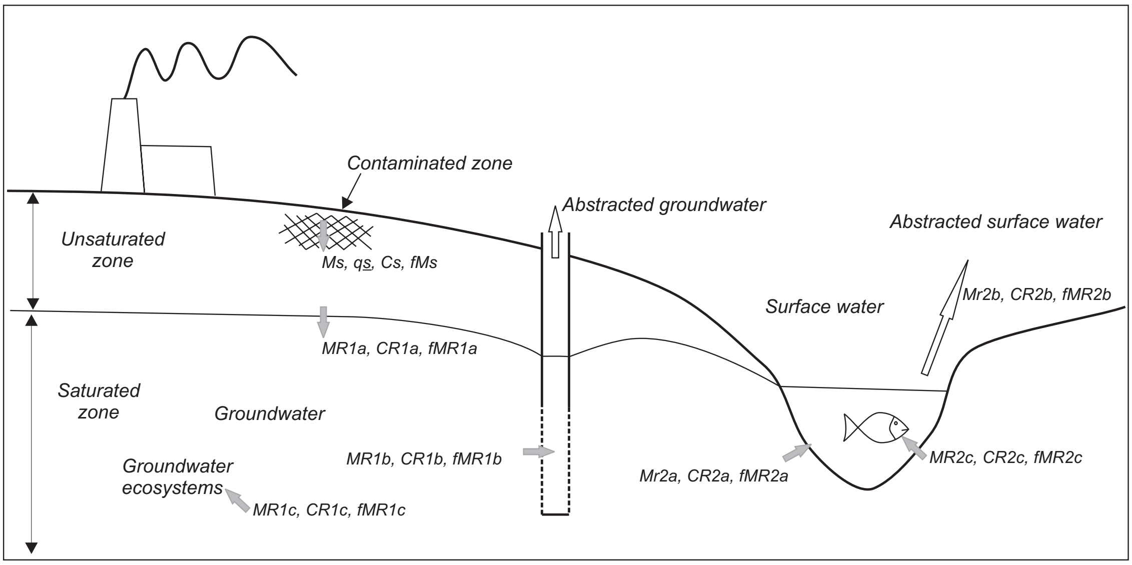


Figure 15: Risk assessment indicators defined for the source of contaminant and for the various receptors.

During year 2, it has been decided to work at the larger scale of the groundwater body for integration with the socio-economic analysis. The approach proposed in ***Deliverable 1.2*** in terms of groundwater specific vulnerability risk assessment and mapping however states for a "single" source – receptor context. For the case of multiple sources – multiple receptors, as it is the case for the groundwater body scale, specific research efforts will be devoted, at the very beginning of Phase 2 (already started at the end of year 2) in order to define specific risk assessment indicators required for evaluating the cumulative impact of contaminated sites on the groundwater and/or surface water body, using a combined flux-based - mega-site approach. This indicator will be based on the aggregation of modelling results (water and contaminant fluxes and concentrations) at the scale of the groundwater body or associated surface water body, in the form of a "mean" contamination level to be compared with threshold values decided in common with decision makers (DGRNE, SPAQuE...).From discussion with these decision makers, it has been decided to work with the quality indicator SEQ-ESO (Rentier, 2004) currently used within the Walloon Region, tyo assess the groundwater body quality. Each contaminant plumes simulated by the groundwater transport model will be delineate with a volume of same quality based on the SEQ-ESO indicator. Then the volume of poor quality water will be integrated on the whole groundwater body. After some adaptation, this approach will be flexible enough to deal with both "simplified" risk assessment tools, with contamination sources that are not well documented and studied, and with advanced numerical modelling techniques and results (such as MODFLOW/RT3D simulation results) for contamination sources very well characterised.

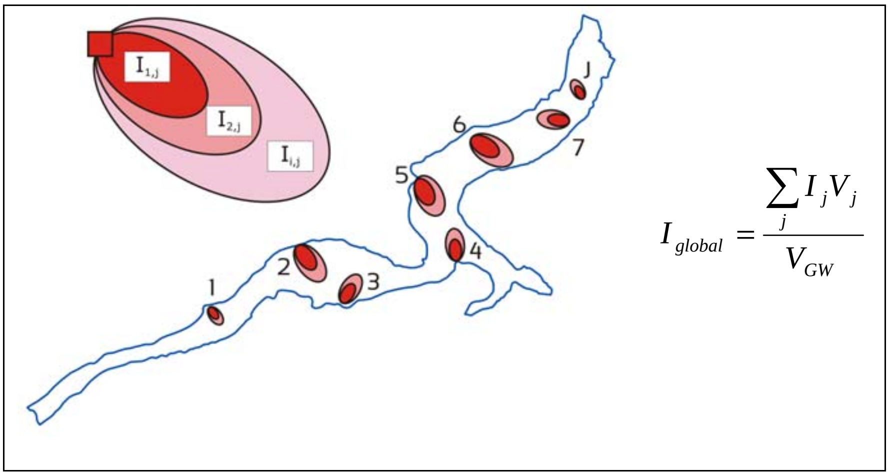


Figure 16: Risk assessment indicators defined for the source of contaminant on the groundwater body RWM073.

2.4.2 Ecotoxicological indicators for groundwater and surface water ecosystems

Hazard of a substance to the environment can be estimated as PEC/PNEC ratios. The Predicted Environmental Concentration (PEC) is the estimated or the measured concentration (MEC) of a chemical in an environmental compartment. The Predicted No Observed Effect Concentration (PNEC) is the concentration below which exposure to a substance is not expected to cause adverse effects (ECB, 2003).

If PEC/PNEC < 1 → No hazard is expected for the environment

If PEC/PNEC > 1 → Hazard for the environment

Usually, established OCDE tests are performed to determine the ecotoxicity of substances. Toxicity values can be available in the literature, otherwise QSARs can be applied to estimate L(E)C50 and/or NOEC values. These (Quantitative) Structure-Activity Relationships estimate toxic effect concentrations based on physical and/or chemical properties, without the use of experiments. PNEC is then estimated using statistical extrapolation method (for data rich substances) or applying safety factors from 10 to 1000, depending on the amount of toxicity data available, on the lowest acute LC50 or EC50 or, preferably, from the lowest chronic NOEC.

So, the PEC/PNEC ratio can be calculated for each pollutant (Figure 4).

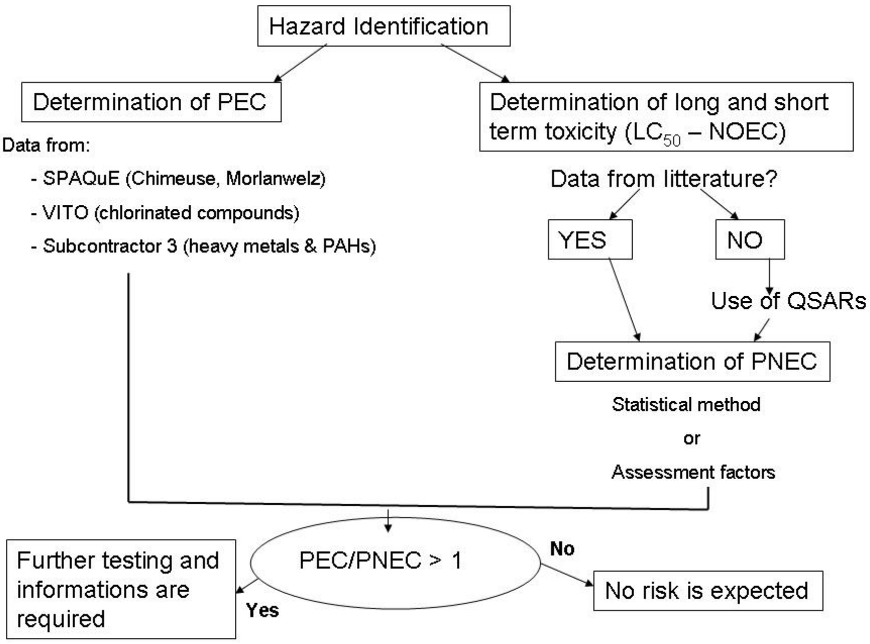


Figure 17. Different steps to assess an environmental/ecotoxicological risk

Several pollutants show hazard to the environment, differing from one polluted site to another. The risk at Vilvoorde site is especially related to CAHs contamination. On the contrary, heavy metals (As, Cu, Ni, Pb, Zn) are problematic at Chimeuse. At Morlanwelz, high concentrations of CAHs and of several heavy metals have been detected and may pose a risk to the environment. These analytical results can be compared with the ecotoxicological data obtained in the laboratory. For example, a comparison was done between the risk linked to the different pollutants and the EC50 values at Morlanwelz site (Figure 5).

Figure 5: Risk estimation compared to EC50 values at Morlanwelz site (2008)

Based on samples taken in Haine River, it has been assessed that, up to now, the river water shows quite low risk and is also relatively not toxic. Groundwater sampled at P16 piezometer showed also a least toxic response (EC50 = 66.47%) and the ecotoxicological risk estimation caused by Cu, Zn, Ni and trichloroethene is also lower. P6 and P3 piezometers are characterised by higher risk. But toxicity response at P3 is not so high because CAHs easily volatilise when performing the ecotoxicological test. Additional results are given in the Deliverable D.3.2. of December 2007 and 2008.

In relation to a decision support to obtain a good ecological and chemical status, the objective is to prevent measured or estimated contaminant concentrations in the environment (PEC) to exceed the PNEC. In some instance the established norm value exceeds the PNEC value (e.g. this is the case for the heavy metal Ni). So, even if the pollutant concentration is below the normative value, a risk can be identified. On the contrary, in some cases normative values are below the PNEC (e.g. dichloromethane) and are too strict towards ecotoxicology.

In consequence this approach gives a helpful decision support in order to determine the micro-pollutant concentrations which can not be exceeded in the environment to prevent ecological damages to the ecosystem. It will also allow quantifying remediation efforts to be applied to restore a good ecological status.

Main research outcomes / key findings of WP4
➔ Efficient tools identified and selected for simplified risk assessment from a single site to catchment scale or for re-using concepts / databases…   ➔ flux-based groundwater vulnerability and risk assessment indicators developed   ➔ ecotoxicological risk assessment indicators developed

2.5 Socio-economic analysis to support risk assessment and risk management of contaminated sites - WP5

2.5.1 Damage assessment

2.5.1.1 Typology of potential environmental and economic impacts due to the contamination of the state of water resources

Main results of this step area (see ***Deliverable D5.1***):

- A typology of potential damage/ benefits related to a change in groundwater quality. A change in groundwater quality will result in a change in the level of services provided by groundwater to the society (i.e. damage in case of degradation/ benefits in case of improvement) (***Deliverable D1.2***). A typology of services provided by groundwater was proposed (Figure 18) as a basis to valuate damage/ benefits related to a change in groundwater quality (***Deliverable 5.1***). The typology can be adapted to each specific groundwater unit under study. Three main types of services and related values were described: (i) those related to groundwater 'as a resource' (direct use values that can generally be quantified with market based techniques); (ii) those related to groundwater 'itself' (indirect use values and non use values that are more difficult to quantify and require the implementation of valuation methods); (iii) those related to groundwater 'as a discharge into surface water' (indirect use values that can be quantified by methods directly applied to surface water).

- An overview and selection of economic valuation methods that can be used. Economic valuation methods to be used strongly depend on the type of services provided by the groundwater to the society. ***Deliverable D5.1*** made an overview of the methods that could be used as part of FRAC-WECO. Two meetings were organised with end-users to discuss key findings of this deliverable (27^{th} June 07 in Liege, 12^{th} November 07 in Mechelen). This lead to the selection of two kinds of method to assess damage/ benefits related to a change in groundwater quality as part of the FRAC-WECO project (Figure 18): (i) market based methods (excluding cost of illness method since health is beyond the scope of the project) will be used to assess changes in the level of services provided by groundwater 'as a resource' (use/ option values only) and (ii) contingent valuation will be used to assess the total damage/ benefits (including the patrimonial value/ non use value) related to a change in groundwater quality by asking people in a social survey format for their willingness to pay (WTP) for a pre-specified environmental change.

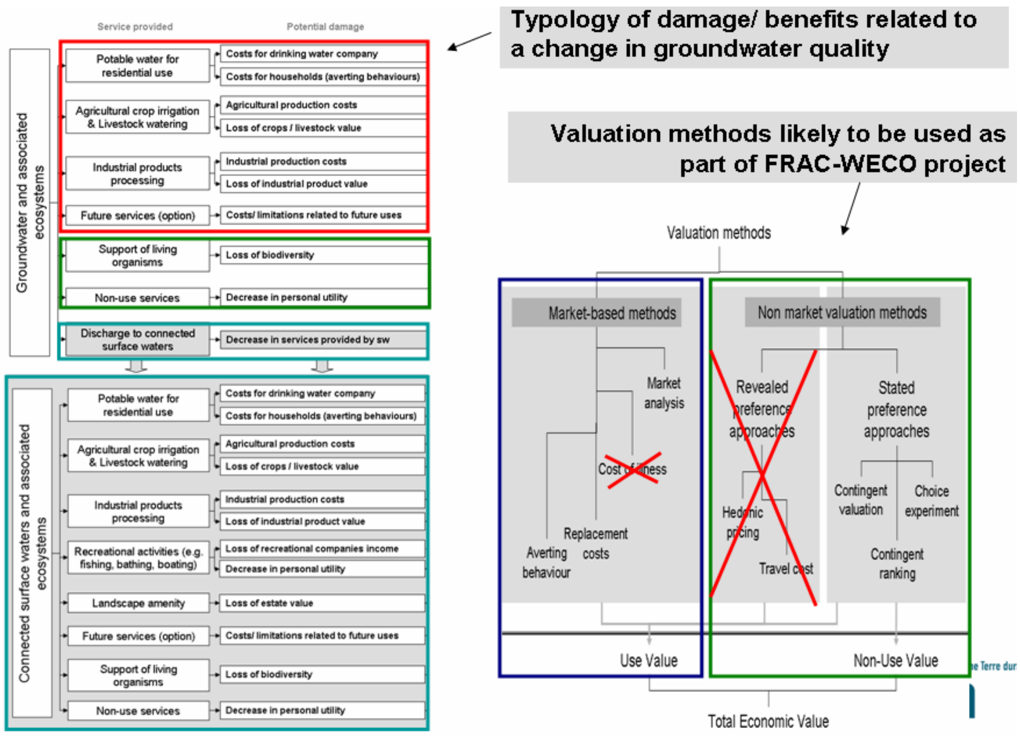


Figure 18: Typology of damage and selection of valuation methods.

- The choice of the groundwater body as a relevant scale. FRAC-WECO project is located at the boundary of two different management issues: soil/contaminated site management (scale: local site) and groundwater quality management (scale: groundwater body). Key differences between these two types of issues were highlighted in ***Deliverable D5.1*** (e.g. policy context, competent authorities, management scale, risk assessment, financial versus economic analysis, water standards, and regional versus European framework, see Figure 19). In order to select the best scale to carry out economic analysis, three meetings were organised with project partners and end-users involved in contaminated sites and/or in river basin management (18th March 08, 7th May 08, 11th May 08). The main objectives of these meetings were to discuss key findings of ***Deliverable D5.1*** (e.g. the fact that research works focusing only on local site level would not enable to assess impacts due to groundwater quality degradation by brownfields, especially in densely former industrial areas where combined effects of several contaminated sites on a groundwater body should be taken into account to assess the degradation of the resource) and to discuss how the economic analysis carried out as part of WP5 could suit the best the end-users' needs. These meetings lead to the conclusion that (i) it is necessary to combine as part of FRAC-WECO two different management scales ('individual site level'= Pressures level, and 'strategic level'= State level); (ii) the groundwater body scale is the most policy-relevant scale to analyze impacts of contaminated sites on groundwater resources (cf requirements of the Water Framework Directive and the Groundwater Directive).

	PRESSURES →	STATE
	Soil/ contaminated site management	(Ground) water management
Policy context	Mainly at the regional level: - Flemish Decree on Soil remediation and protection / Vlarebo (2007) - Law of the Walloon Government for the cleaning of contaminated sites and rehabilitation of brownfields (2004), still not in force	Mainly at the European level: Water Framework Directive (2000) Groundwater (daughter) Directive (2006) But ≠ implementation methodologies at the regional level...
Competent authorities	OVAM SPAQuE & DGRNE	International Scheldt Commission CIW DGRNE & Ministère de l'équipement et des transports
Management scale	Local site (xx ha)	Water bodies (xx km²) Sub-basins River basin district (xxx km²) International river basin district (xxxx km²)
Risk assessment	- VLIER-humaan model (Human health risk only) - Auditsol ® (Environmental risk/ human health risk)	Risk of not reaching good chemical and ecological status by 2015: SEQ ESO system
Economic analysis	Remediation cost assessment Cost comparison between different remediation technologies (e.g. BATNEEC)	- Cost recovery of water services - Cost effectiveness analysis for the selection of programmes of measures - Cost-benefit analysis in case of disproportionate costs
Water standards	Background values/ Clean-up standards Reference value/ Trigger value/ Intervention value	Environmental quality standards (EQS) Drinking water standards (DWS) Threshold values (TVs)

FRAC-WECO

Figure 19: Key differences between soil and (ground)water management.

2.5.1.2 Qualitative and quantitative damage assessment

Two steps were completed during this sub-task. Each step was associated with a deliverable.

Qualitative assessment

Main results of this step are (see ***Deliverable D5.2***):

- The selection of the RWM073 as a pilot case study for economic analysis (and for the project as a whole in phase 2). During these meetings, the groundwater body RWM073 'Gravels and alluvial deposits of the Meuse' located in the Meuse river basin district of the Walloon Region appeared to be the most relevant to be studied as part of the FRAC-WECO project: this groundwater body was characterised at risk of not reaching good chemical status by 2015 due to very high pressures exerted by contaminated sites (highest density of former contaminated sites: 99.8 km²/100km²). In response to WFD requirements, a program of measures should thus be designed to improve RWM073 status, costs and benefits will have to be compared in case of disproportionate costs.

- Characterisation of the RWM073 groundwater body. Data collection started in June 08 in order (i) to identify and to describe polluting pressures exerted by brownfields (on the basis of data provided by SPAQuE from the WALSOLS database) and (ii) to identify and to describe economic sectors likely to benefit from an improvement of the groundwater quality (on the basis of data provided by DGRNE).

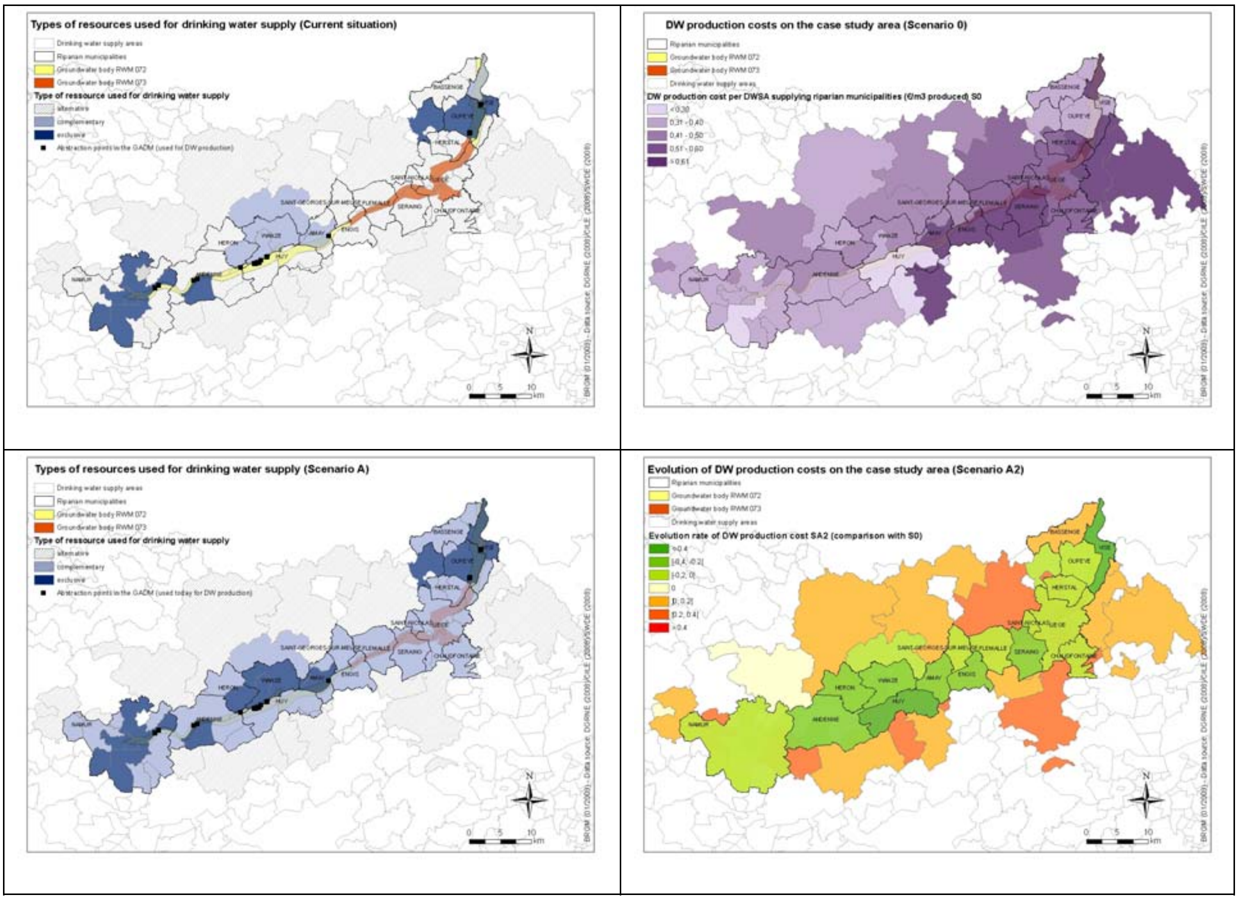
Quantitative assessment

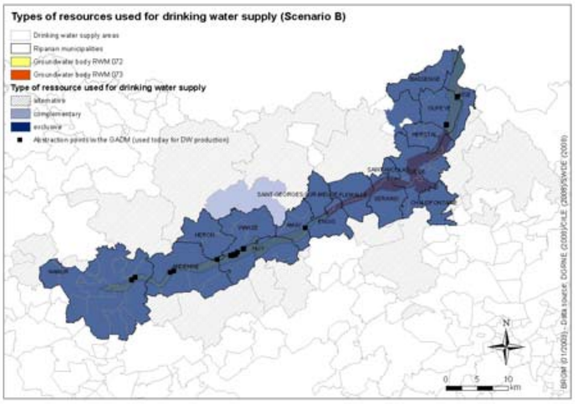
Main results of this step are (see ***Deliverable D5.3*** to be completed by the end of January 09):

- Development of a methodological framework to assess potential market benefits that may arise from an improvement in the quality of groundwater resource currently degraded by brownfields.

Potential market benefits are likely to arise mainly for the economic sectors using water as a resource. Distinction is made between water users connected to the drinking water network and those supplied by themselves. Main methodological steps are: (i) delimitation of the study area; (ii) understanding of the current situation in terms of water supply strategies (types of water resources used and reasons); (iii) design of scenarios of water supply strategies in the future in case of groundwater quality improvement (with a baseline scenario and one or several breaking scenarios); (iv) assessment of the potential economic impacts of the breaking scenarios.

- Application on the RWM073 pilot case study. The case study area is extended to the gravels and alluvial deposits of the Meuse (GADM) aquifer as a whole (RWM072 + RWM073 groundwater bodies). Three main changes in water supply strategies are expected from an improvement of the RWM073 groundwater quality: (i) a decrease in water treatment costs, (ii) a turning from drinking water network to private supply and (iii) an increase in the use of GADM as a resource. These changes in terms of water supply strategies are likely to have economic impacts on the case study area. In order to assess these economic impacts, several sets of data were collected (with the help of DGRNE, AQUAWAL, CILE, SWDE) and completed with the consultation of representatives of the drinking water sector (15th October in Liege, 24th November in Herstal) and other economic sectors that may be impacted by a groundwater quality improvement (24 interviews with companies abstracting water from the aquifer). Potential annual market benefits related to a change in water supply strategies (as a result of the RWM073 quality improvement) were assessed on the 2008-2060 period. Final quantitative results of the analysis are available in ***Deliverable D5.3***.





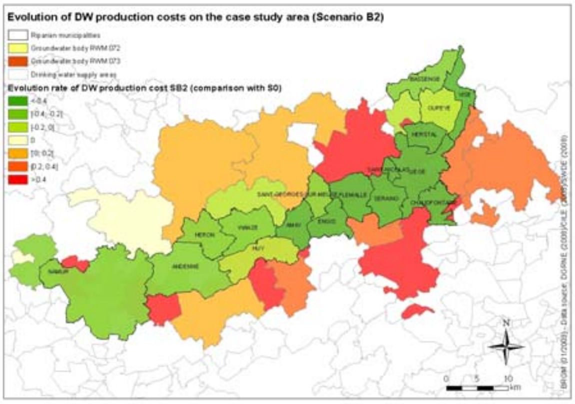


Figure 20: Baseline scenario (Scenario 0) and breaking scenarios (Scenario A & B) designed to assess the impacts of an increase in the use of GADM for drinking water production (left: types of water supply strategies, right: impacts in terms of drinking water production costs)

Main research outcomes / key findings of WP5
➔ Typology of potential damage/ benefits related to a change in groundwater quality ➔ Definition of the appropriate scale for the combined risk – socio-economic analysis: the groundwater body ➔ methodological framework to assess potential market benefits that may arise from an improvement in the quality of groundwater resource currently degraded by brownfields

2.6 Test sites – WP6

Research developed in this project need to be supported by real data coming from existing contaminated sites in Belgium. For efficiency, it has been decided to focus on sites that are currently investigated to beneficiate a maximum from existing data. However, complementary investigations are required in relation with the project specific needs in terms of information and data (samples, field monitoring etc), such as borehole drilling, fauna sampling, and chemical analyses of specific contaminants. Much information on the activities of the research groups in the test sites have already been provided throughout the report and they will not be repeated here. It is focused here mostly on the selection of the test sites and on data mining performed for these test sites.

2.6.1 Site selection and data mining

A set of contaminated sites representative of the most relevant contamination cases in Belgium has been considered.

The ZENNE alluvial plain (downwards to Brussels), heavily contaminated with CAHs, BTEX, oil and heavy metals, has been selected. This site was studied thoroughly in the SEDBARCAH project by VITO. A hydrogeological characterization, a groundwater flow and transport model and a characterization of the CAH-pollution of the site have already been completed. The site of 'Les Nouveaux Ateliers Mecaniques' in MORLANWELZ has been selected because it is currently investigated by the SPAQuE and presents a heavy pollution of VOCls, mineral oils, heavy metals (As, Pb, Zn and Cr) and PAHs. A characterization study of the site has already been performed by SGS Belgium. The CHIMEUSE site contaminated by PAHs, mineral oils, heavy metals, cyanides and located in the alluvial plain of the Meuse River is also considered and investigated by the SPAQuE.

Available data for each of these sites have been collected (geology, hydrogeology, hydrology, site history, etc) and fed into a project's database. However, it is necessary to complete the data bibliography by performing some new field investigations.

As already explained above, the groundwater body RWM073 has been incorporated during year 2 as a large-scale case study for the economic analysis. Data mining on that groundwater body has started in close cooperation with and assistance from end-users (DGRNE and SPAQuE).

2.6.2 Investigations on selected sites

Field works were carried out to complete the existing dataset.

Two piezometric campains have been performed on the Chimeuse site. A monitoring network consisting in three probes and one pluviometer has been installed during the first months of 2008 on the site of "*Les Nouveaux Ateliers Mécaniques*" in Morlanwelz. New measurements of groundwater piezometric levels in the different piezometers and flow rate measurements in the Haine River have also been performed during year 2. The objectives are to study interactions between groundwater and the Haine River. First results of this monitoring are now available. For example, Figure 21 illustrates data collected for the period of April to June 2008 by two probes located in the alluvial plain of the Haine River: one is in the upper aquifer made of alluvia (blue line) and the second is in the lower aquifer made of shale from Houiller (red line).

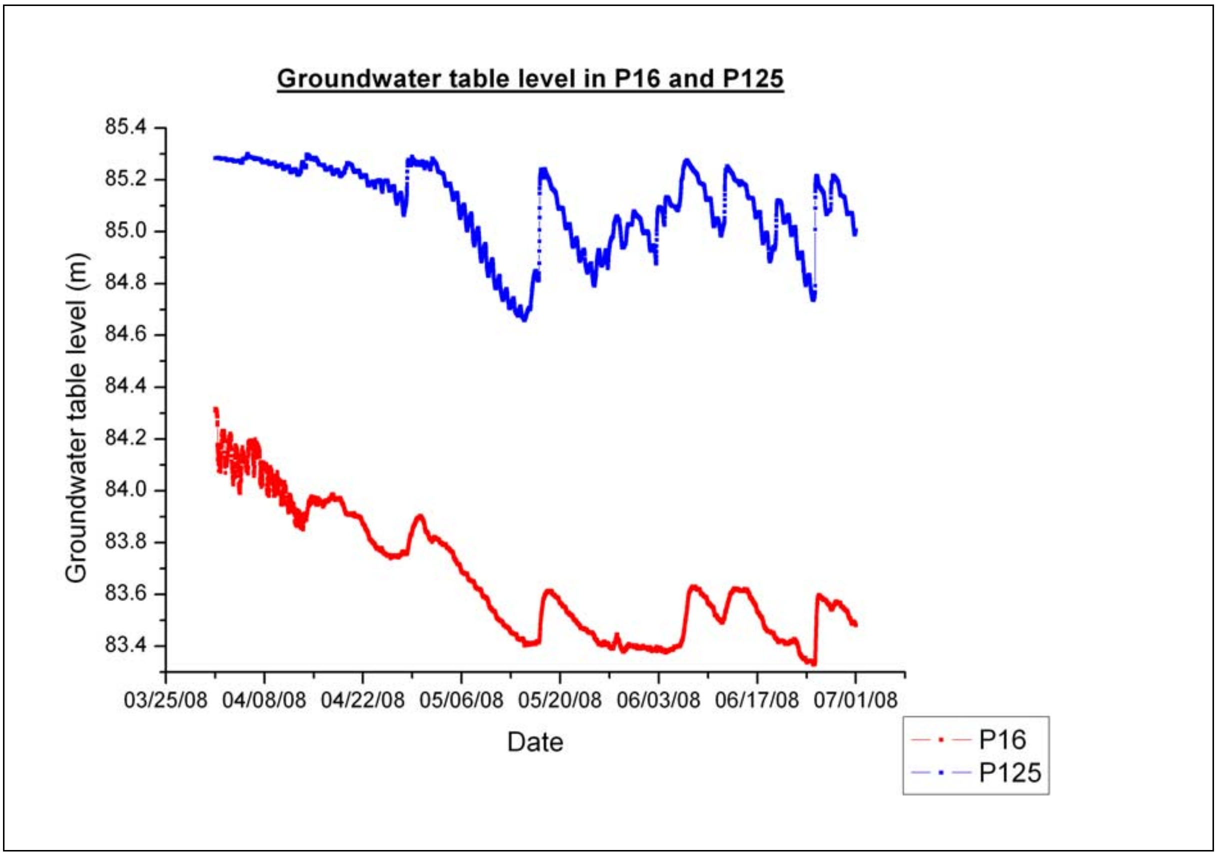


Figure 21: Groundwater table levels in the upper aquifer (P125) and in the lower aquifer (P16)

These correlations will be further analyzed more in details using statistical tools as soon as more data will be available.

Next to these first results, efforts have been made to perform an application of the Finite Volume Point Dilution Method (FVPDM) in Vilvoorde. The FVPDM is an efficient tracer technique developed by ULg-HG (Brouyère et al., 2008) to quantify and monitor the variations with time of Darcy fluxes in relation with changes in hydrogeological conditions. In Vilvoorde, available wells to perform the technique are SB2, located near the Zenne River and PB9, located further from the river. Pre-calculation needed for the design and dimensioning of the tests were produced. Unfortunately, due to the simultaneity of a low hydraulic conductivity (estimated using slug tests), a low hydraulic gradient, small screen lengths and small diameters of the wells, the estimated time of tracer injection was estimated as being very long, with a very small required injection rate. This has required adapting the tracer injection system to use a syringe pump able to inject tracer at a very low rate (about 0.5 l/h) in the piezometer. FVPDM tests were performed in the last three months of year 2. As an example, the result of the test performed in PB9 is presented in Figure 22. Based on the interpretation, the natural transit flow rate crossing is estimated to $6*10^{-7}$ m³/s (= 0.0518 m³/d), which correspond to an apparent Darcy flux of $6*10^{-6}$ m/s (= 0.518 m/d). When comparing this result with the ones of the numerical model built in the scope of WP2 (PB9 being located in the middle of the southern boundary of the model, see Figure 4), the same order of magnitude in terms of flux is observed (around 0.5 m³/d).

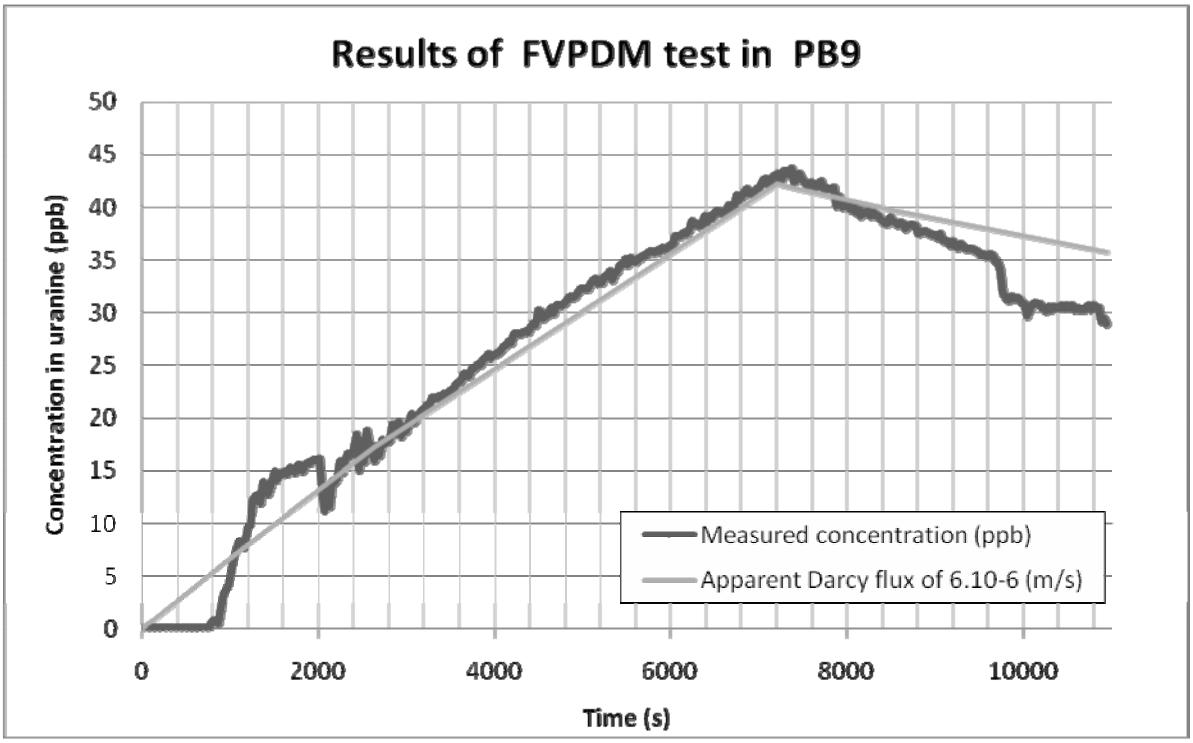


Figure 22: Results of FVPDM test performed in PB9

Main research outcomes / key findings of WP5
➔ Selection of representative case studies from site scale (Morlanwelz, Vilvoorde…) to groundwater body scale (groundwater body RWM073) for application of the project developments ➔ Data mining for the case studies ➔ Development of specific field investigations for the assessment of water and contaminant fluxes

3 Conclusions at the end of phase 1

As described and summarized here before, the first phase of the FRAC-WECO project has enabled to collect all pieces of information required to go a step further into the development and application of a risk assessment approach for water resources and ecosystems. Such information relates to concepts (risk assessment indicators, ecotox indicatords, typologies for socio-economic analysis…), specific tools (land use mapping, groundwater flow and transport modelling…), lab and field measurements (degradation of contaminants, water and contaminant flux measurements…), case studies and, the critical issue of the scale of investigation.

All these research compounds will be assembled and articulated in the second phase of the project to built the expected decision support system for managing risks posed, for water resources and ecosystems, by contaminated sites within a given groundwater body.

More specifically, the first groundwater modelling applications developed have highlighted the fact that modelling tools planned to be used as a support to flux-based risk assessment not only require to be able to calculate reliable estimates of groundwater levels but also of water and contaminant fluxes.

The work on the Vilvoorde test site also clearly demonstrates the importance of having access to detailed information on urban land cover and on the spatial distribution of impervious surfaces, in order to obtain reliable estimates of run-off and groundwater recharge. Satellite data with a spatial resolution of 1m like Ikonos are an interesting data source for obtaining such information and object-oriented image interpretation allows extracting reliable information on urban land-cover distribution from these data, which may then be used as input for runoff and recharge modelling within urban catchments. Comparing recharge simulations, which were based on medium resolution remote sensing derived land-cover (standard land-cover product of the Flemish Agency for Geographical Information) with this high resolution land-cover data shows that the standard deviation of the recharge increases, indicating a stronger spatial variability in recharge values. Capturing the spatial recharge variability is of high importance for further pollution transport simulation.

VITO developed an approach to determine the degradation potential of the microbial community towards a certain pollutant that is present in an aquifer. As a test compound Chlorinated Aliphatic Hydrocarbons (CAH) was chosen. Its degradation was studied in batch and column tests containing aquifer and groundwater from three positions B3, Pb26 and B2 in a CAH plume at the Vilvoorde-Machelen site. From these batch tests one can conclude that no degradation of VC and DCE is occurring at the three locations B2, B26 and B3 under natural attenuation conditions. However, the degradation of CAHs is clearly stimulated by the addition of the carbon sources lactate, molasses, sediment and sediment extract. During this degradation, DCE is converted to the toxic daugther product VC which is subsequently converted to the harmless product ethene. In addition, the CAH-degradation potential depends on the location in the aquifer: the fasted degradation was observed in the location B26 which is located 200 m from the Zenne. Degradation constants and biomass numbers will be determined from these results and used in the risk-model. To better simulate the *in situ* conditions and to study the influence of the groundwater velocity on the CAH-degradation, aquifer columns were set up. However, due to technical problems, no data are yet available about the stimulated degradation of CAHs in these columns.

In terms of ecotoxicity of contaminants, first results indicate that LC_{50} and EC_{50} depend on the studied site, the space, the sampling period, the concentration of pollutant… Chimeuse is especially contaminated with heavy metals, whereas Machelen-Vilvoorde and Morlanwelz sites are generally polluted with CAHs.

Concerning ecotoxicological risk assessment, the results obtained in the laboratory using water samples which contain a mixture of pollutants and the ecotoxicological risk assessed for each contaminant separately using measured concentrations and data from literature, were comparable. So, the global toxicity measured in ground- and surface water samples was confirmed by the risk assessment. The method developed in order to identify the toxicity of mixtures compare to risk assessment can be used at any contaminated site and at a larger scale. So, as far as the groundwater body scale is concerned, the same steps will be performed on each sample: ecotoxicological tests will be achieved on ground- and surface water samples and, after analysing pollutant concentration, the ecotoxicological risk will be assessed.

Groundwater body scale appears to be the relevant scale for the FRAC-WECO project. A close linkage with WFD requirements is necessary: management plans are under development at the groundwater body scale to mitigate the impacts of brownfields but lack of knowledge to design the programmes of measures and assess the costs and benefits of such programmes as required by the European Water Framework Directive (In case of risk of not achieving good chemical status by 2015 a programme of measures is required based on a cost-effectiveness analysis. In case of disproportionate costs, a cost-benefit analysis is required to justify potential derogations).

First results show that potential market benefits that may arise from an improvement of the groundwater quality may not be sufficient to compensate the costs of program of measures. Non market benefits should be studied and this is the purpose of phase 2.

4 Perspectives for the second phase

4.1 Catchment scale water and contaminant budgeting and routing

4.1.1 High-resolution groundwater recharge simulation and surface run-off routing

The decision to upscale the approach of FRAC-WECO to the level of the groundwater body in the second phase of the project will have implications for the work on the land-cover mapping. Because of the large area covered by the RWM073 catchment we will have to make use of lower resolution data. Most likely we will opt for SPOT5 data with a multispectral resolution of 10 m and a panchromatic resolution of 5 m. This will allow us to cover the entire study area with one image. The land-cover mapping strategy developed on the Vilvoorde study site will therefore have to be adapted for application on the RWM073 catchment. Based on our experience we expect that a stratified approach will be required, distinguishing between built-up areas (mainly urban and industrial land use) and natural/agricultural land use. This may make necessary the use of sub-pixel classification approaches, characterising the proportion of land cover types at the sub-pixel scale.

To improve discrimination between land use types that are characterized by a different multi-temporal variation in land cover, images will be acquired for different periods of the same year (before, during, after the summer growing season) and coregistered. Results obtained with the multi-temporal approach will be compared with mono-temporal classification results in terms of land-cover class separability and classification accuracy, using the same set of reference data as in 2.2.1.

The derived land-cover maps will be used in different WetSpass simulations, resulting in high-resolution estimates, varying in space and time, of water fluxes to and in the contaminant site.

4.1.2 Variably saturated groundwater modelling

During the first two years of the project, different modelling tools, ranging from analytical solutions implemented in risk assessment tools to more advanced numerical models have been identified and used. During year 3, it is expected to use analytical solutions for calculating contaminant fluxes and concentrations at local receptors and when available data and site characterization do not enable more advanced calculation of water and contaminant fluxes between identified sources and receptors. Numerical models will be used to calculate water and contaminant fluxes at the groundwater body scale for the calculation of “global indicators” for groundwater and surface water risk (damage) assessment.

Numerical codes used for modelling flow and transport at catchment scale will be coupled with WetSpass, as a water budget and groundwater recharge calculation module. Model coupling will also concern the integration of analytical (risk assessment tools) and numerical solutions (numerical models) into a single calculation module for contaminant transport at groundwater body scale. Ongoing modelling efforts will continue on the previously selected local scale case study (Vilvoorde). However, the integrated model will rather be used to model surface / subsurface flow and transport in RWM073 used as a reference case study for validating other research results (vulnerability and risk assessment tools…), for calculating pertinent contaminant quantities at different targets (rivers, pumping wells …) in order to provide other research modules with required data, i.e. concentrations and mass fluxes in the unsaturated zone and groundwater (VITO), to surface waters for ecotoxicological analysis performed by ULg-LEAE…) and for running socio-economical scenarios (BRGM).

4.2 Contaminant behaviour and properties

4.2.1 Biochemical processes

In the batch- and column-tests the effect of the added carbon sources lactate, sediment and sediment extract on the degradation of DCE will be further studied. In addition, the VC and DCE degradation constants as well the numbers of bacteria (biomass) that are involved in this degradation will be determined from these batch and column tests.

4.2.2 Ecotoxicity of contaminants

The sampling of ground- and surface water will take place on the RWM073 groundwater body (alluvial deposits of the Meuse River between Engis and the North of Liège). Same steps will be performed on these samples (*i.e.* PAHs, PCBs, heavy metals and CAHs analysis, chronic toxicity tests…). First of all, pollutant concentrations and other available ecological or ecotoxicological data will be collected. Then, the ecotoxicological risk will be assessed using the results found in the literature (task 4.2).

4.3 Development of risk assessment tools and indicators

4.3.1 Groundwater vulnerability mapping and flux-based risk assessment

Investigations on selected RA tools will be continued at the beginning of year 3, with the objective in mind of a clarification of the impact of various hypotheses done in the RA tools and concepts such as "global attenuation factors" (GAF) defined in many classical risk assessment tools, but difficult to relate to physical processes such as dispersion, dilution or degradation. Comparisons will also be possible using data and models developed for selected case studies (such as the Zenne – Vilvoorde, Morlanwelz or Flémalle) through an intercomparison of RA using simplified and advanced modelling approaches.

During phase 1 of the project, the physically-based point of view for the concept of groundwater resource/ source vulnerability assessment developed by HG-ULg has been used as a general framework for the development of a flux-based risk assessment method for water resources and ecosystems. This framework is presently under development for the integration of contaminant specific processes such as contaminant sorption and/or degradation (defined in close collaboration with VITO) in the calculation of a global attenuation factor (concentration or mass-flux reduction) between contaminant sources and identified receptors in the variably saturated underground medium. These developments will be finalized during year 3.

4.3.2 Ecotoxicological indicators for ground-and surface water ecosystems

Ecotoxicological risk will be assessed using PEC/PNEC ratio and will be compared with chronic toxicity (EC_{50}) values obtained in the laboratory, using Rotifera.

The test organism rotifer (*Brachionus calyciflorus*) and *Gammarus pulex* used in the first part of this project as model organisms for ecotoxicity assessment will be of great interest to the extent of the study to the groundwater body scale. Indeed, these test species are common in Meuse River.

Whole mixture effects can be assessed by testing the mixture in its entirety (done during the 1st phase of the project). However, this approach will not identify the chemicals responsible for interactions. Actually, the overall toxicity of the mixture could be equal to the sum of each pollutant toxicity (additivity), less than the sum (antagonism), or greater than the sum (synergism).

So, during the 2nd phase of the FRAC-WECO project, if possible in the risk assessment (task 4.2) the relations between the different pollutants of the mixture (synergism, antagonism, additivity) will be included.

The majority of hazard and risk assessment takes into account the impact of individual pollutant but not directly the impact of the mixture containing different pollutants. Majority of environmental quality guidelines did not incorporate the toxicity of mixtures. As a consequence, the possible synergism or antagonism is not taking into account.

After bibliographic research, we have to choose the best approach before integrating the toxicity of mixtures in the risk assessment.

4.4 Socio-economic analysis to support risk assessment and risk management of contaminated sites

4.4.1 Cost-benefit analysis of alternative management strategies

The objective of this task is to develop and apply a methodology to assess the costs and benefits of program(s) of measures that could be implemented at the RWM073 groundwater body scale. This task is structured into 3 main parts:

- Design of program(s) of measures and the assessment of the cost required for its (their) implementation (sub-task 5.2.1)
- Analysis of public perception and willingness to pay for a groundwater quality improvement (sub-task 5.2.2) through the implementation of a contigent valuation survey in the area.
- Cost-benefit analysis of the program(s) of measures (sub-task 5.2.3): Total costs and benefits of groundwater protection will be estimated and compared through a cost-benefit analysis. In particular emphasis will be made on the comparison of results obtained when using benefits assessed by market-based techniques (first phase of the project) and benefits evaluated by contingent valuation survey.

4.5 Test Sites

4.5.1 Site selections and data mining

This task was completed during phase 1 of the project. There will however be a continuation of data acquisition and mining for ongoing investigations in the test sites, in particular in RWM073.

4.5.2 Complementary field investigations on selected test sites

Ongoing monitoring and experiments will be continued and further sampling campaigns will be organized. On RWM073, specific field investigations are not expected.

4.5.3 Application of the integrated methodology on the test sites

The integrated methodology and decision support tools will be tested and applied on groundwater body RWM073 during the second part of year 3 following the different research efforts described in the previous work packages.

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