Integrated Concept for Groundwater Remediation INCORE

[final report]

Concept

Innovation

Demonstration

Implementation

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INCORE site in Stuttgart: The Neckar valley – industrial landuse in groundwater capture area

Fig. 1: Project area Stuttgart with complex contamination patterns

Basic concept

Most European cities are located in river basins using groundwater from local shallow aquifer systems. Industrial development in the 20th century was rapid and caused urban groundwater pollution, often exceeding the legal limits. Changes in land use during this period have created complex contamination patterns, such as heterogeneous distribution of contaminants, the presence of different contaminants and large areas of landfill (Fig. 1).

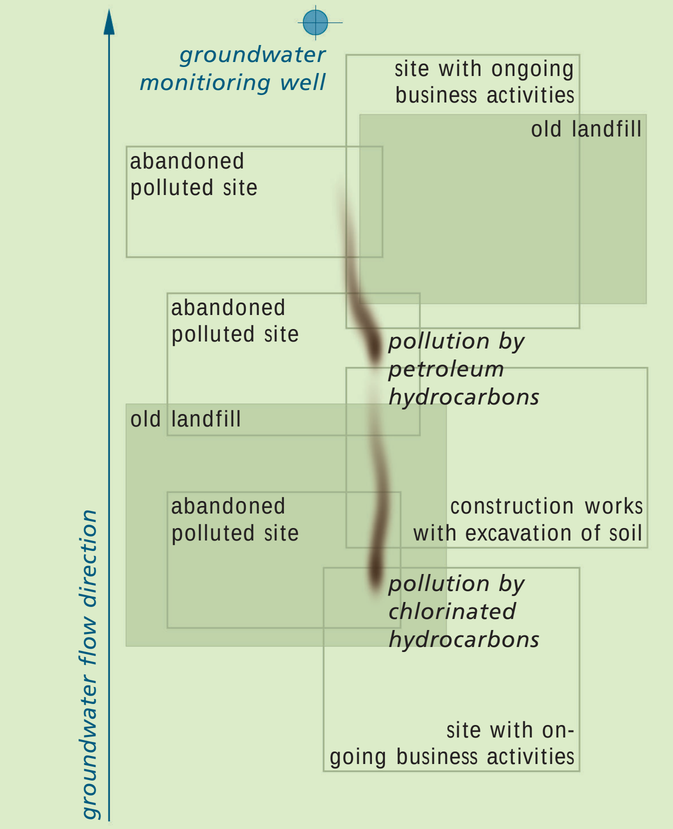
As well as damage to the wider environment, existing soil contamination has resulted in incalculable costs for long-term groundwater remediation. Healthy residential and working conditions can be guaranteed only on uncontaminated ground. The presence of environmental pollution can limit investment in urban development on brownfield sites. However, structural changes now in place offer an opportunity to improve soil and groundwater quality. Considerable thought must be made in order to reach sustainable improvements – this is exemplified by the integral procedure developed by INCORE.

The current legal approach to treatment of soil and groundwater pollution is focussed on a particular set of problems caused by a specific polluter. All measures aim at a rapid reduction in environmental damage so that risk to the public associated with a particular property is removed. However, this approach fails in heavily polluted areas with different property owners and complex pollutant patterns (Fig. 2).

Large amounts of private and public money are being spent to identify and assess point sources of contamination without being able to reliably quantify their impact on the groundwater quality; numerous remediation schemes are undertaken without an economic evaluation of their long-term performance.

Five European cities, Stuttgart, Linz, Strasbourg, Milan and Bydgoszcz, which share the similar groundwater problems in their industrialised urban areas, committed themselves to jointly develop suitable solutions. Specific local conditions vary in these five INCORE project

***Fig. 2:* Complex pollutant situation**



areas; they vary with respect to groundwater conditions, existence of public and private monitoring wells, type of pollutants, size of problem areas, rising groundwater problems etc.. Therefore they provide a representative range of the conditions to be expected across Europe. In order to achieve the INCORE project goals in a cost effective way, different parts of the anticipated tool set were applied and evaluated at different levels of detail in the five selected areas.

Integral quantification of total contaminant emissions

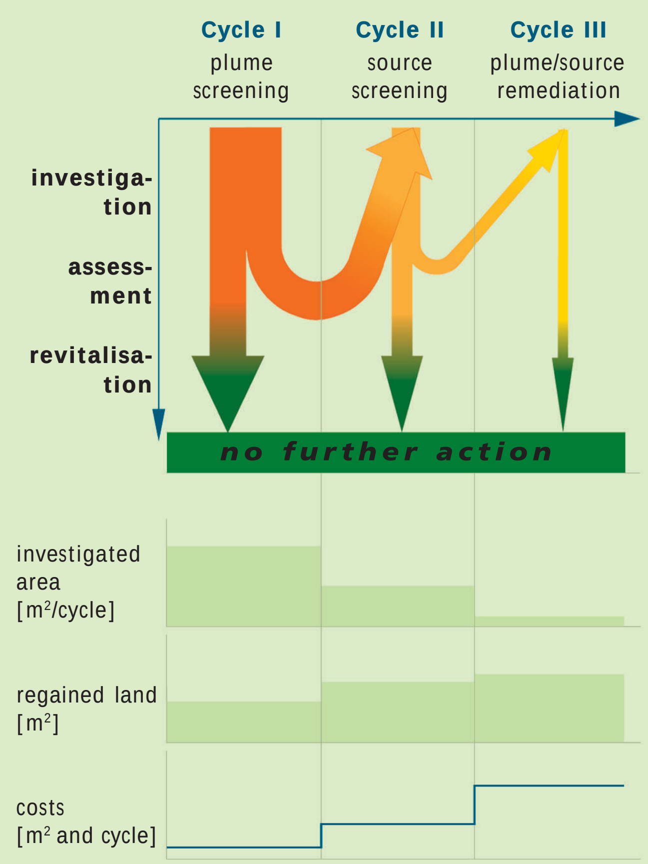
The proposed INCORE strategy for the investigation, remediation and revitalisation of industrial areas is based on an integrated quantification of total contaminant emissions. It considers entire industrial areas instead of particular single sites, in order to achieve a high level of confidence in the investigation results.

An innovative cyclic approach is proposed beginning with the screening of groundwater plumes at the scale of entire industrial areas, and ending with the remediation of individual source areas or the containment of plumes. The major advantage of this approach is that the number of local scale sites, or the size of the area to be considered, is reduced stepwise from one cycle to the next. Thus, a large potentially contaminated area would be screened but ultimately only a small area may need to be remediated. Figure 3 presents a schematic of this new approach.

This new approach repeats an investigation/assessment/revitalisation cycle three times at different scales:

- **Cycle I** – the groundwater quality is screened downstream of the potential source areas.
- **Cycle II** – only those sites where groundwater quality is not acceptable are considered further. In these cases analytical methods are used to backtrack and identify sources of contamination.

***Fig. 3:* INCORE cyclic approach**



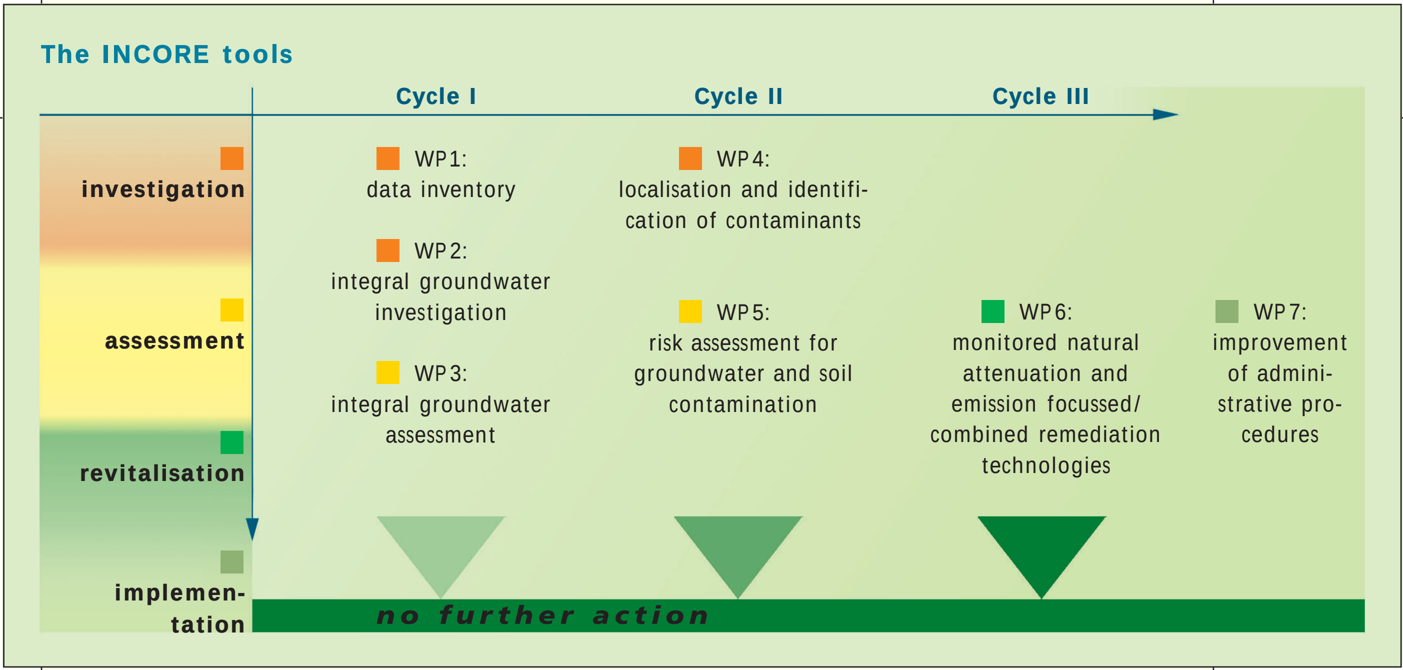


Fig. 4: Tools for groundwater revitalisation in urban industrial areas

- **Cycle III** – the characteristics of the source zones are considered for remediation to control emissions, or implementation of monitored natural attenuation. The most appropriate technology is selected by establishing what level of contamination reduction is required, considering the proposed future use of the site.

This "no further action" approach provides a cost effective set of tools (Fig. 4) for the optimised investigation, evaluation and management of contaminated groundwater and land in industrialised urban communities.

The INCORE approach – strategy, flow chart

This INCORE phased approach is illustrated in a strategy flowchart. Following this chart guides the application of the approach and, where required, enables the user to go straight to more detailed explanations in the extended report (enclosed on the CD).

Plume screening

Before commencing any activity the existing and future use of land and groundwater in the project area needs to be clearly defined so that the objectives for the whole revitalisation process of the area under consideration can be established. A survey of historical information is compiled, reviewing:

- potentially contaminated areas,
- former land/groundwater use,
- former industrial processes and activities that might have caused environmental pollution,
- relevant contaminants, their fate and transport characteristics.

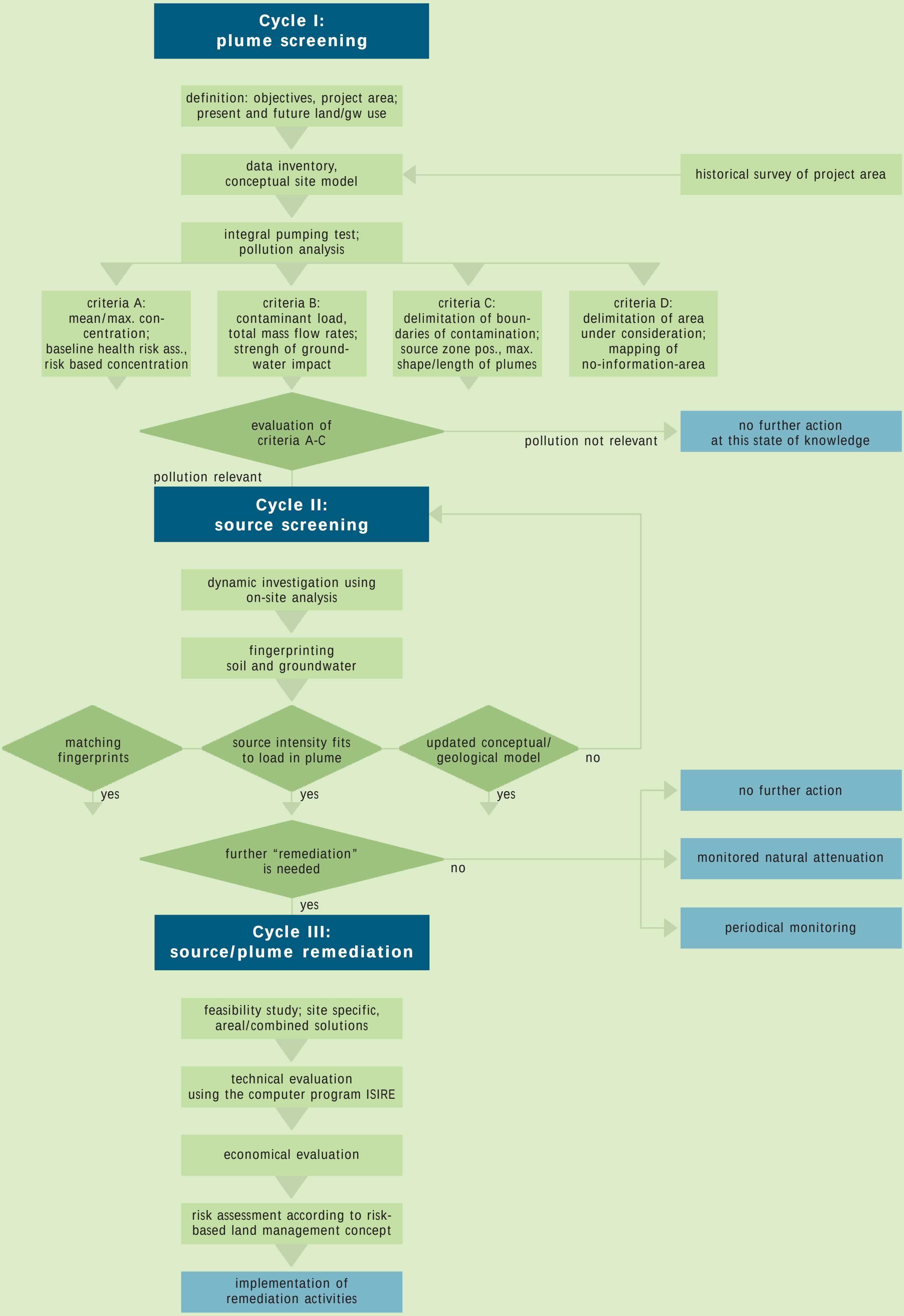
Finally a conceptual site model, a functional description of the problem, has to be developed. Based on this model the position and length of control planes for groundwater investigation (see p. 10) can be outlined in the area under consideration. The main decision variables are:

- the number and position of wells – distance between control planes,
- pumping rates and time,
- sampling intervals.

Assessment of integral pumping tests (IPT, see p. 10) provides quantitative results for the following major decision criteria A-D:

A Mean/maximum concentrations of pollutants for well defined areas, which can be used as input to a model for a qualitative and quantitative characterisation of risk.

Fig. 5: **Flow chart (simplified; extended INCORE guide see CD-ROM)**



B Contaminant load or mass flow rates transported by the groundwater. This quantifies the impact of a contaminant source on the groundwater and allows an estimation of the pollutant concentration at the source.

C Combining a backtracking technique with plume length statistics (see p. 12) or application of estimated decay rates for different contaminants, it is possible to delineate, approximately, the location of plumes and their source zones.

D The assessment modelling provides a method for delimitation of contamination boundaries. Parts of the project area for which no information has been gathered by the groundwater investigation will be identified.

Source screening

The main inputs to cycle II are the size of the area affected by contaminated groundwater and the number and position of potentially contaminated spots. This is followed by deciding upon the most appropriate and cost-effective sampling and backtracking strategy.

Dynamic site investigation (see p. 15) uses adaptive sampling and analysis programmes. These programmes itselves rely on on-site analysis and is continuously adapted, based on the data from drilling, sampling, analysing and interpretation in the field. This dynamic investigation and its interpretation lead to the identification of size and position of contaminant sources within the area to be considered.

Detailed fingerprinting studies in soil and groundwater using biomarkers and stable isotopes (p. 16) clarify which contaminant sources are responsible for the identified plumes. In cases of multiple sources the extent of contribution from each source can be determined.

For the final confirmation of source-plume relationships the following criteria need to be cross-checked:

- Are there corresponding general patterns of contamination and matching fingerprints both at the source and at the plume?
- Does the intensity of the source (area, concentration, solubility) fit with the identified contaminant load in the plume?
- Are all the data plausible and in agreement with the updated conceptual site model?

Administrative decisions at the end of each cycle define further action

Administrative decisions on the need for future remediation activities can then be taken for each source zone identified. If no remediation is implemented, the administrative decision would have been for one of the following:

- no further action,
- a long-term programme for monitoring natural attenuation,
- a periodic monitoring programme or an option on investigation in the future combined with a re-assessment at a defined date.

Thus, cycle II results in site-specific decisions about required remediation activities.

Source/plume remediation

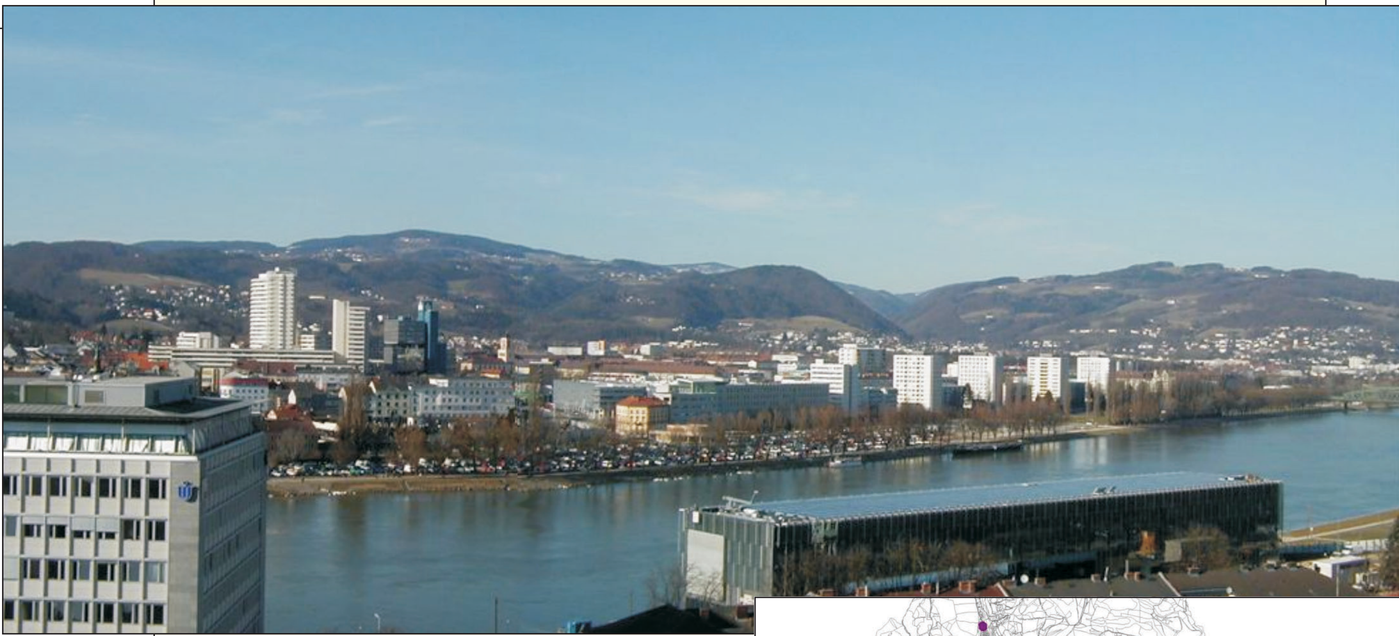
The first step of cycle III consists of carrying out feasibility studies for site-specific remediation options. This comprises the evaluation of options for remediation of the source, the plume and integral or combined source-plume solutions.

A feasibility study has to be performed in a similar way whether considering an area (rather than a specific site), or combined solutions (rather than single solutions). Studies focus on the advantages and limitations of remediation scenarios considering combined remediation of clusters of pollution or a joint activity addressing areas affected by several plumes (see p. 20).

The technical feasibility can be checked according to well-established criteria, e.g. with support of the newly developed computer program ISIRE (see p. 21). The feasibility study, combined with the economic evaluation, results in a comparison of the cost-effectiveness of the different options that appear to be suitable.

According to the principles of risk-based land management, the source-pathway-receptor concept, future use and the general rules of appropriateness and proportionality will be taken into account for a final decision.

Data inventory of the project areas

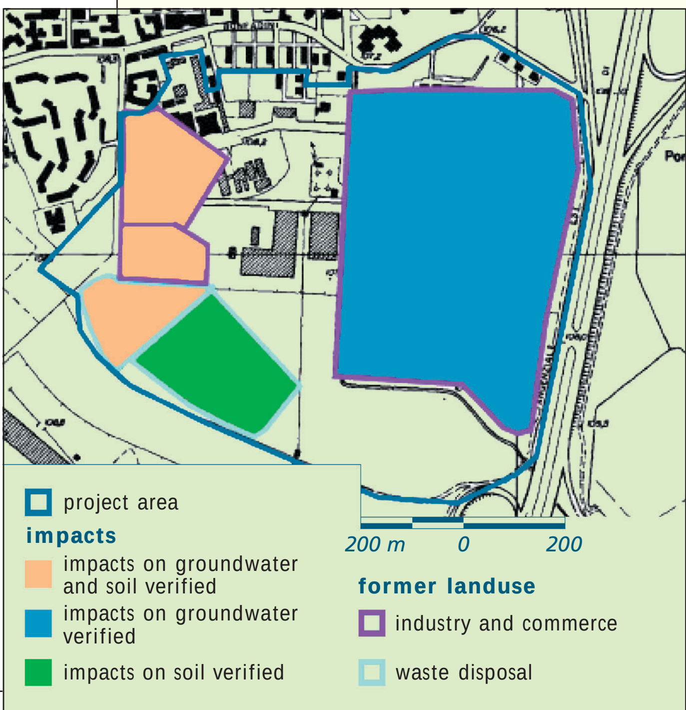


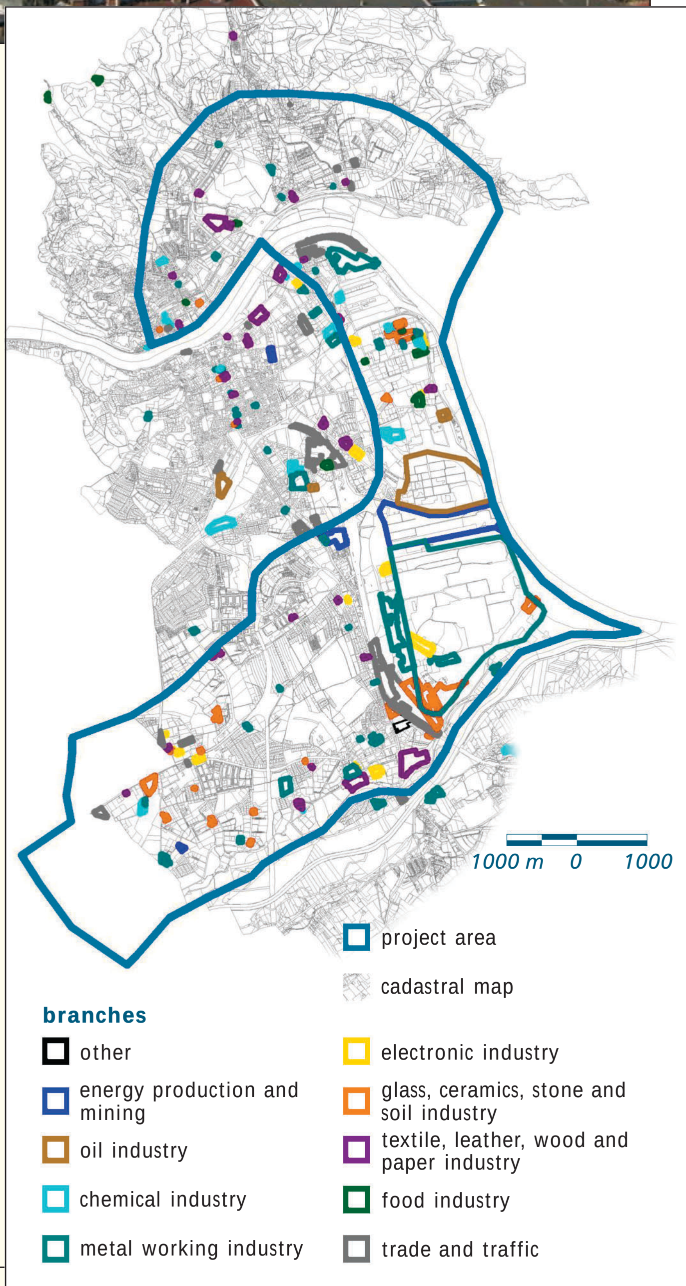
The general objective of the first work package (WP1) was to produce comparable data inventories for four different project areas as a basis for the conceptual site models and to visualise obtained data in combination with geographic information.

Linz

Fig. 6, 7, 8: Project area in Linz (above, fig. right) and in Milan (fig. below)

The initial project work in Linz considered nearly two thirds of the city area (Fig. 6, 7). As the aim of WP1 was to collect relevant data to assist the selection of suitable areas for the integral pumping tests the definition of a large





inventory area was opportune. The sub-areas cover different types of problems, for example, commercial activities on the smaller sites date from the 20th century, whereas large industrial activities near the waterfront of the Danube River started with steel production during World War II. These industrial and commercial activities are the most relevant polluting sources in the investigation area.

Milan

The project considered a large industrial site "Meton" (660,000 m^2, with up to 2,500 workers), situated in the south east of the city of Milan (Fig. 8). From 1914 until 1980 the industrial plant produced inorganic chemicals. Pesticides and herbicides were produced on site from 1980. In 1988 an urban redevelopment plan for the area commenced. According to this plan, which is currently being implemented, the site is to be mainly occupied by green areas, residential housing and commercial buildings. Remediation works began in 1993 an are still in progress.

Strasbourg

The "Plaine des Bouchers" site is situated in the south of the city of Strasbourg (Fig. 9). Industrial activities on the site date from 1918. The industrialisation of the area began after the building of railways in the region and is dominated by the metal industry and the chemical industry. The project area is currently under industrial and commercial land use. Only small parts in the north are designated as green areas and car-parking areas.

Stuttgart

The area investigated is located in the eastern part of the city in a valley along river Neckar (Fig. 10). The industrialisation of the Neckar valley started with the first railway there in 1845. Management of the river enabled industrial settlements within the alluvial meadows and flood zones in the 1920s. The area became a major industrial zone in 1958 with the opening of the Stuttgart harbour.

The area is no longer economically viable. The impacts of pollution from the site on people and the wider environment are well known.

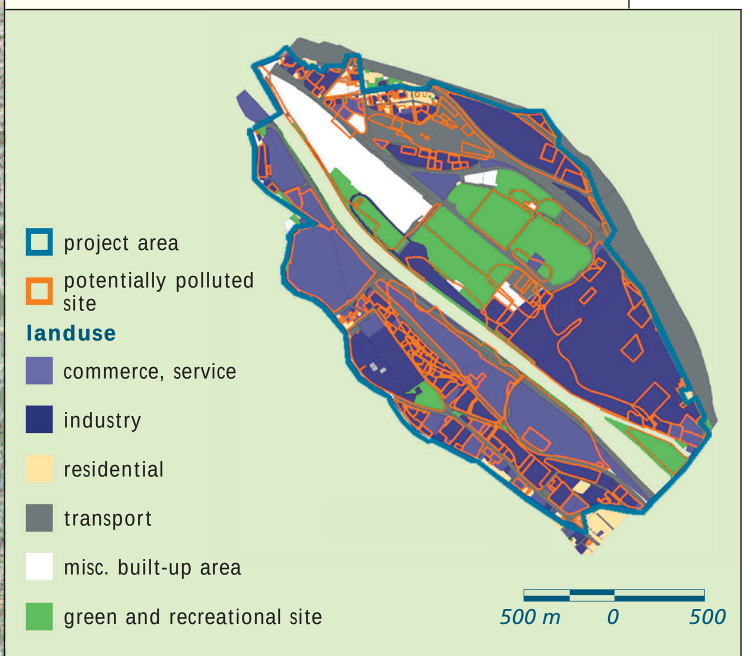


Fig. 9, 10: Project area in Strasbourg (left) and in Stuttgart (right)

Integral groundwater investigation

The basic idea of the integral groundwater investigation method (TEUTSCH et al., 2000; PTAK & TEUTSCH, 2000) is to cover a whole cross-section of a contaminant plume downstream of a pollutant source, employing pumping tests with multiple contaminant concentration measurements at the pumping wells.

To apply the integral investigation method, one or more pumping wells are placed along a control plane (control cross-section) perpendicular to the groundwater flow direction and operated simultaneously, or in subsequent pumping campaigns, downstream of a suspected pollutant source zone. The positions, pumping rates and pumping times are designed in a way to allow well capture zones to cover the overall width of the potentially polluted area (Fig. 11). During pumping, as the capture zones increase, the concentration of contaminants and/or other groundwater quality parameters is measured as a function of time at each of the pumping wells used.

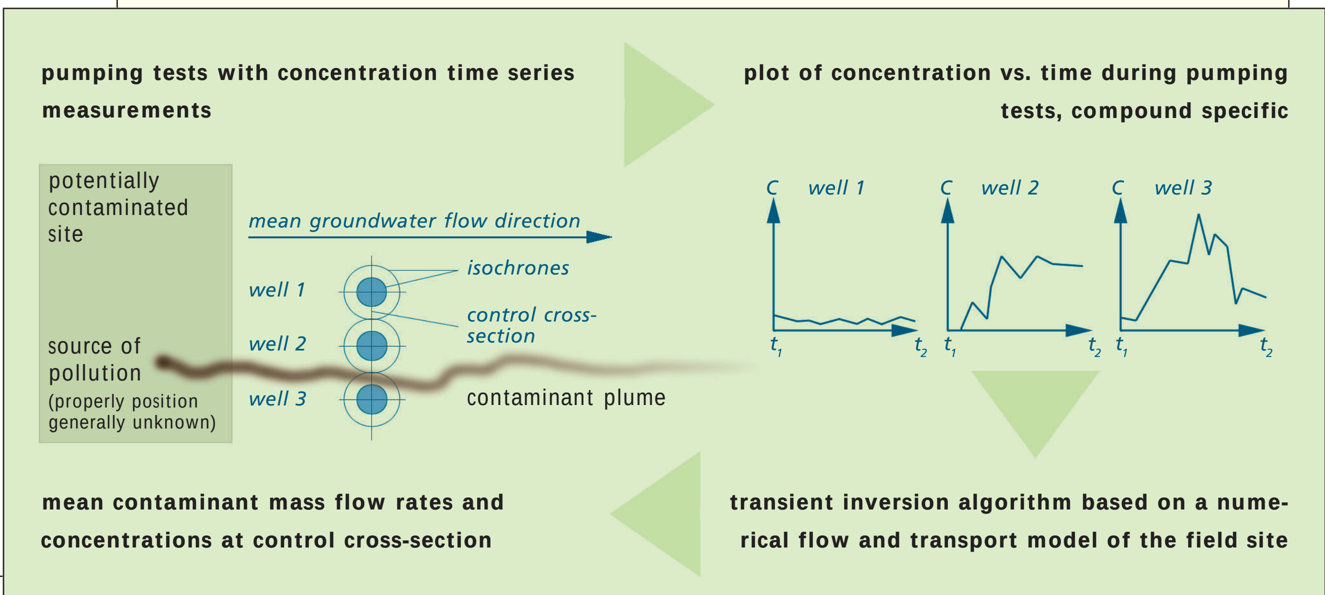
Since each concentration value within measured concentration time series is representative of a distinct aquifer zone, information on the spatial distribution of both concentrations and mass flow rates can be obtained, in addition to the mean concentration and the total mass flow rate. For the interpretation of the concentration time series, a transient inversion technique was developed (PTAK & TEUTSCH, 2000; BAYER-RAICH et al., 2002), which is based on a time dependent calculation of isochrones and mass balances for the increasing capture zones. As no interpolation of point scale concentration measurements is required, investigation results at a high level of certainty are obtained.

Application in Linz

As an example, Figure 12 shows the application of the integral investigation method in Linz in the Danube river valley. The aquifer was screened for possible sources of tetrachloroethene (PCE). Contamination had been detected in a water supply well in the 1980s. Since the early 1990s efforts have been made to enable re-establishment of this public water supply in the future. Locations of potential sources of PCE were identified by a historical survey, focusing on dry cleaners and other companies using PCE (Fig. 12).

Three control planes were designed (CP1-CP3), consisting of a total of 10 pumping wells. Pumping rates and pumping times were chosen to yield a full coverage of the control planes. Each of the wells was pumped for a time period of about five days using a constant pumping rates of up to 15 l/s. Using the measured concentration-time series (up to 11 groundwater samples) and the inversion algorithm, average PCE concentrations and PCE mass flow

Fig. 11: Integral investigation method for the qualification of groundwater contamination (PTAK & TEUTSCH, 2000)



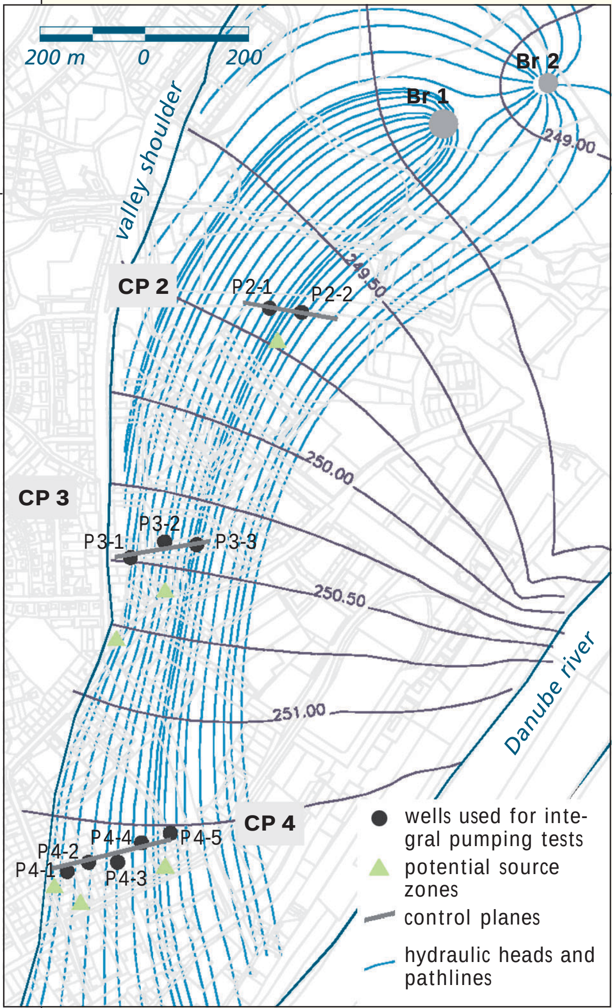


Fig. 12:
INCORE study site in Linz

rates across the capture zone of each pumping well were calculated, on the basis of a numerical flow model of the study site. The results of the inversion are given in Table 1. The inverted concentrations in the aquifer under the assumption of a symmetrical concentration distribution around the pumping well are shown for each control plane in Figure 13.

PCE concentrations were found to be highest at CP3 where two plumes are present. A large plume is present at CP2, which is not completely covered by the control plane. The groundwater upstream at CP4 is only slightly polluted.

Conclusions

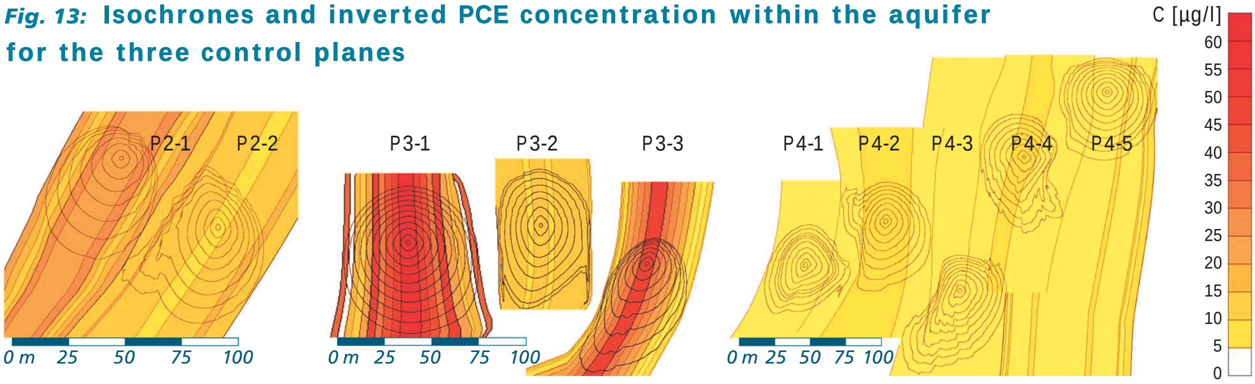
INCORE has demonstrated that this approach using control planes as an integral investigation method can serve as a highly effective tool for the investigation of groundwater contamination, especially at sites with a complex pattern of contamination. Employing the integral investigation method, the compound-specific average contaminant concentration, the spatial distribution of concentration values along a control plane, and the total contaminant mass flow rates downstream of an area under investigation can be estimated quickly and with a high level of certainty.

Results from the integral investigation obtained at

***Table 1:* Results of the inversion for PCE**

Well	maximum diameter [m]	water flow across well capture zone [m³/s]	mean concentration [µg/l]	max. concentration [µg/l]	mass flow rate [g/d]
P2-1	48.87	3.52 E-03	19.90	25.34	6.05
P2-2	55.80	2.19 E-03	11.30	15.70	2.14
P3-1	70.18	2.20 E-03	34.40	57.59	6.54
P3-2	50.20	7.54 E-04	11.70	12.82	0.76
P3-3	45.23	2.64 E-03	26.20	48.12	5.98
P4-1	55.56	1.16 E-03	0.87	1.62	0.09
P4-2	64.90	2.38 E-03	5.73	9.04	1.18
P4-3	81.90	2.70 E-03	1.04	1.68	0.24
P4-4	73.50	2.06 E-03	4.51	8.00	0.80
P4-5	91.73	3.39 E-03	4.20	6.94	1.23

***Fig. 13:* Isochrones and inverted PCE concentration within the aquifer for the three control planes**



the scale of entire industrial areas (megasites) can be used for risk assessment purposes. If applied at multiple control planes (situated at different distances downgradient from a contaminant source zone), results are valid for the quantification of the natural attenuation potential, as well as for the development of priorities for clean-up and/or further investigations and for the design of remediation measures.

Delimitation of potential contamination source zones

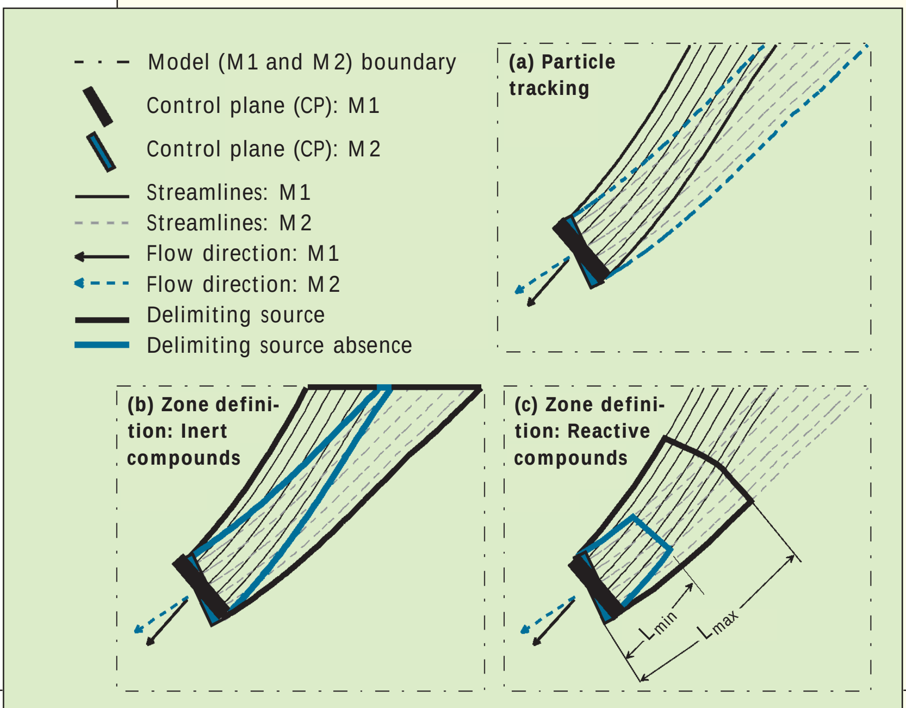
The integral groundwater investigation method can be very effectively introduced into general methodologies for assessing the effects of aquifer parameter uncertainty on estimates of mass flow rates and concentrations, as well as for delimitation of both contaminant source zones and zones not affected by the source (JARSJÖ et al., 2002).

Firstly, possible uncertainties related to undefined boundary condition (BC) values are investigated. For each boundary, a range of variabilities is used to define extreme possible BC values and/or average BC values. The different possible BC values are then combined. The combinations leading to extreme values in terms of hydraulic gradients (flow) and/or flow directions are used in the subsequent uncertainty analysis.

Secondly, the possible uncertainties related to variability in the aquifer properties, e.g. hydraulic conductivity (K) values, are investigated. The starting point is to estimate the statistics of site-specific small-scale hydraulic conductivity values, and to determine the (possible) uncertainties associated with these estimates. These estimates are then used as input for the limiting case analysis and/or for the numerical stochastic simulations described below. Next, a limiting case for aquifer heterogeneity is considered, namely variation of hydraulic conductivity in the vertical direction (z) only (layered anisotropic aquifer geometry). Analytical expressions for the mass flow rate estimation errors have been generally derived, assuming a negligible influence of the natural groundwater flow on the development of pumping well isochrones. If the uncertainty in mass flow rate estimation is shown to be relevant in the limiting case analysis, and if the numerical model indicates aquifer zonations and that the influence of boundary conditions is significantly different from the assumptions of the limiting case problem solutions. Then the mass flow uncertainty is addressed numerically by performing stochastic simulations.

Finally, the combined influence of the uncertainty of the BCs and the uncertainty of the K values can be addressed. The total mass flow rate estimate is linearly related to both the estimated hydraulic gradient (which, in turn is determined by the BCs) and to the estimated value of the hydraulic conductivity. Therefore, the combined uncertainty in

Fig. 14: Principle of using (a) particle tracking results from two models M1 and M2, to delimit the source (or its absence) at the same significance level, for (b) non-reactive and (c) reactive compounds



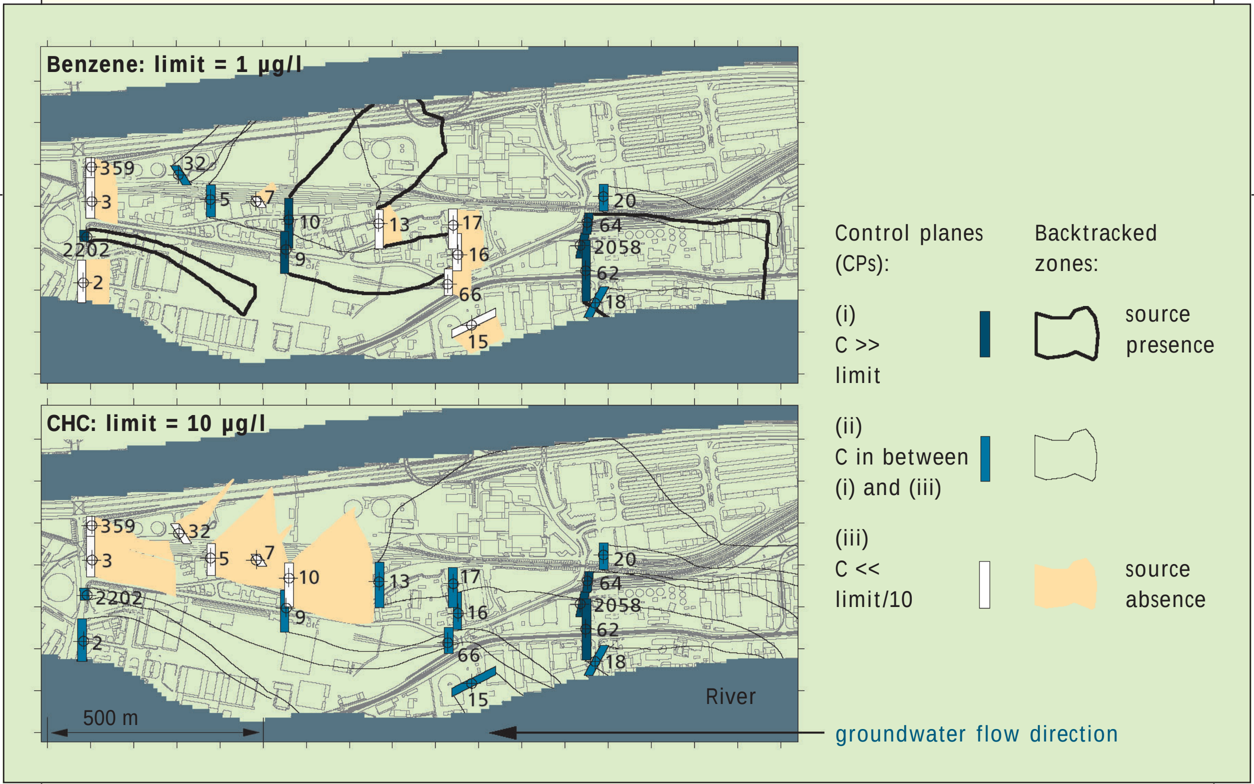


Fig. 15: Delimitation of source zones based on backtracking results in the Neckar Valley, Stuttgart, for benzene and CHC (after JARSJÖ et al., 2002)

the mass flow estimate can be fully determined on the basis of the uncertainty in the hydraulic gradient estimate (caused by the uncertain BCs) and the uncertainty of the K-distribution statistics. The probability of exceeding regulation limits can be estimated by considering the confidence intervals of the mass flow estimates.

The backtracking approach is used in the previously defined worst-case scenarios (Fig. 14) to delimit the position of the source zone. This approach produces a spatial distribution of limits for the source zone extent in the transverse direction. In addition, plume length statistics (e.g. SCHIEDEK et al., 1997) for different contaminants and aquifer conditions (alternatively first order decay rate models or sophisticated multispecies-multiprocess reactive transport models) with a predefined confidence level are used to determine a spatial distribution of limits for the source zone even in the longitudinal direction.

Mapping of contamination levels

A map of the investigation area can be obtained based on **cycle I** and from the application of backtracking methods in **cycle II**. This map shows zones with different levels of contamination impacting on groundwater. Flow weighted concentration averages over the control plane and compound specific concentration trigger values of the State of Baden-Württemberg have been used to delimit the different zones. Maximum concentration values, for example, across a control plane could be used to identify source / source absence zones as well. The decision about which value is used for this modelling work depends on the local regulations. Using the resulting map (Fig. 15), a regulator is able to rank these zones at a predefined level of confidence, and to set priorities for further actions. Focussing at first on zones with high groundwater impact helps to concentrate effort and resources at sites that have the highest groundwater contamination potential. This leads to more efficient decision-making, as well as more effective investigation measures and remediation activities.

The different zones obtained from this integrated investigation give an indication of the location of suspected sites on a large scale. However, a smaller scale identification of local contaminant source zones is needed in order to apply the polluter pays principle. To reach this goal additional source screening tools such as fingerprinting technology can be coupled with integral pumping method.

Cost-effectiveness – costs and level of confidence

To determine the location of the contaminant plumes, their extent and the sources of the groundwater contamination, the INCORE methodology proposes to establish a number of control planes and to perform integral pumping tests (IPT) and on-site analysis. The level of knowledge achieved by this approach is represented by the "level of confidence", which can be estimated by calculating the probability of the plume length for each contaminant based on plume length statistics.

The level of confidence achieved and the size of the area investigated using the INCORE methodology differ from conventional investigation, where groundwater contamination is detected point by point in the source zone, usually without considering the plume. This allows only a limited comparison of the results and the costs of conventional and integrated methodologies.

Table 2: **Integrated preliminary investigation costs**

	[unit]	Stuttgart	Strasbourg	Linz	Milan
integral pumping test costs	EUR	751 400	124 000	162 000	135 260
number of wells		34	2	10	7
total cost/ length of control plane	EUR/m	289,00	354,29	294,55	294,04
total cost/ squaremeter of cross section	EUR/m²	96,33	47,80	32,73	19,60
total cost/ pumped volume	EUR/m³	9,01	3,61	4,42	1,05
total cost/ well	EUR/well	22 100	62 000	16 200	19 300

Fig. 16: **Cost structures for integrated preliminary investigation (in percentage)**

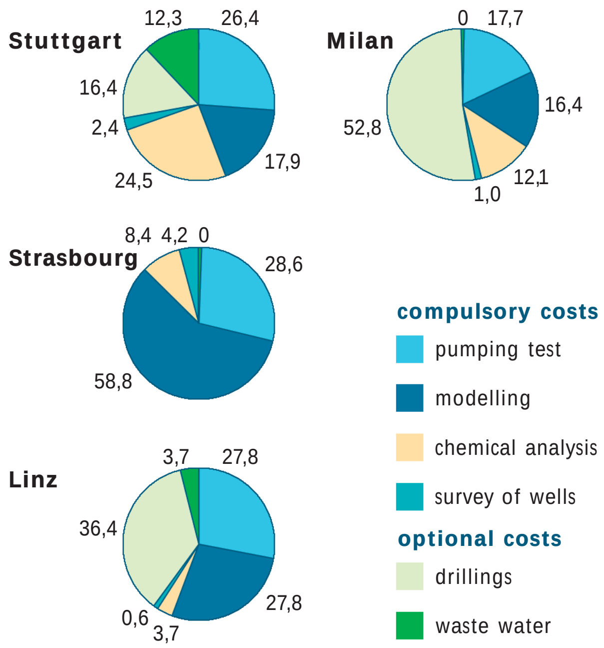
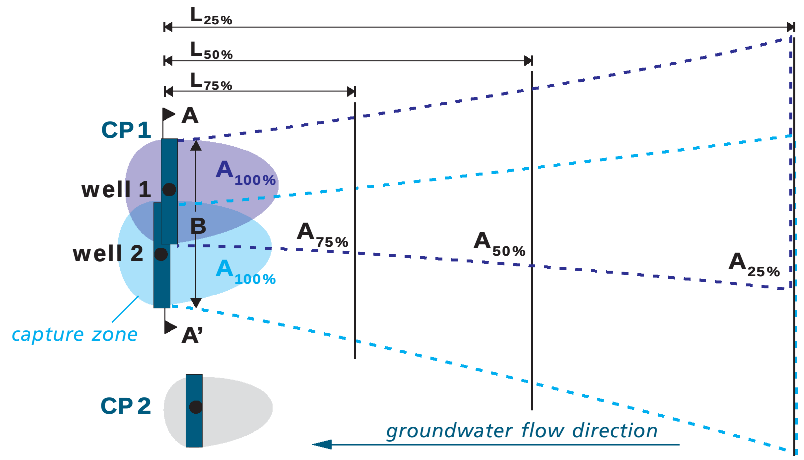


Figure 16 gives the cost structures for IPTs performed in four project areas broken down by the different tasks. This reveals significant differences between the project areas depending on the different contaminants being considered, the possibility to use or partly use existing wells, as well as varying hydrogeological conditions.

Table 2 summarises the costs for integral pumping tests. Although the costs vary quite widely it is obvious that the most influencing factors are the length of the control planes and the number of wells.
The overall costs were highest in Germany where an investigation comprising 34 wells was conducted. The total costs were lowest in France, because no drilling was carried out. However, the costs per well in France are about three times higher than in the other cities, because of relatively high fixed costs for modelling and pumping (because of the high transmissivity of the aquifer).

A 100 % level of confidence was obtained at the control planes by integral investigation. However, the level of confidence decreases with increasing distance up gradient of the control plane (Fig. 17). The distance depends on the nature of the contaminants, the level of confidence to be achieved and the hydrogeological situation. Calculated average values of chlori-

Fig. 17: **Interaction of the level of confidence ($L_{25\%}$-$L_{75\%}$) and the distance between control planes (CP1, CP2)**



nated hydrocarbons and benzene on the basis of plume length statistics are shown in Table 3.

A small distance between two control planes requires a high expenditure. A large distance between two control planes may lead to errors being made, or even the inability to identify source zones. For example, suitable environmental conditions might improve natural attenuation processes and support the degradation of contaminants before they reach the control plane. Therefore positioning the control planes at a 50 % level of confidence as a standard requirement for an integral investigations seems to be a suitable suggestion covering a wide range of site-specific settings.

The decision between conventional and integral investigation should be made on a case-by-case basis. Considering large areas with many potential sources of contamination, the integral INCORE approach leads to significantly reduced costs.

Table 3: **Specific plume lengths**

Site	**Milan** Meton Site	**Stuttgart** Neckar Valley
Contaminant	CHC	Benzene
100 %	**Capture Zone (IPT)**	
75 %	500 m	60 m
50 %	800 m	170 m
25 %	2 200 m	420 m

Source screening

The results of cycle I indicate the areas in which the sources of contamination responsible for the detected plumes are most likely to be found. However, a more precise identification of the contaminant source area is needed. Precise localisation and delimitation is prerequisite for a final risk assessment and any further estimation of remediation activities and related costs. Clear evidence of the source-plume relationship defines the responsibilities and enables the regulator to apply the polluter pays principle with confidence.

INCORE provides several tools for the purpose of localisation and identification of contaminant sources, which have been developed and demonstrated in the project. These are

INCORE tools for localisation and identification of contaminant sources

INCORE tools for localisation:

- local scale integral pumping tests,
- multiple point investigation based on dynamic workplans.

INCORE tools for identification:

- petroleum hydrocarbon fingerprinting,
- isotopic fingerprinting of CHC.

Dynamic workplans

The way back from a detected plume 'somewhere downstream' can be effectively traced by multiple point investigations using a dynamic investigation approach based on the application of adaptive sampling and analysis. This strategy has been described in a manual for application of dynamic investigation programmes (Fig. 18). As well as spatial evidence, finger-

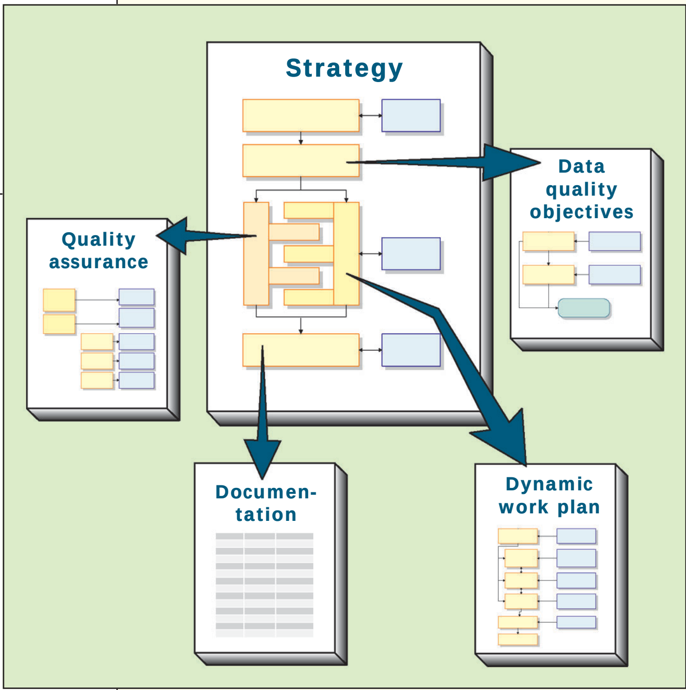


Fig. 18: Strategy for dynamic on-site investigation (LfU, 2001)

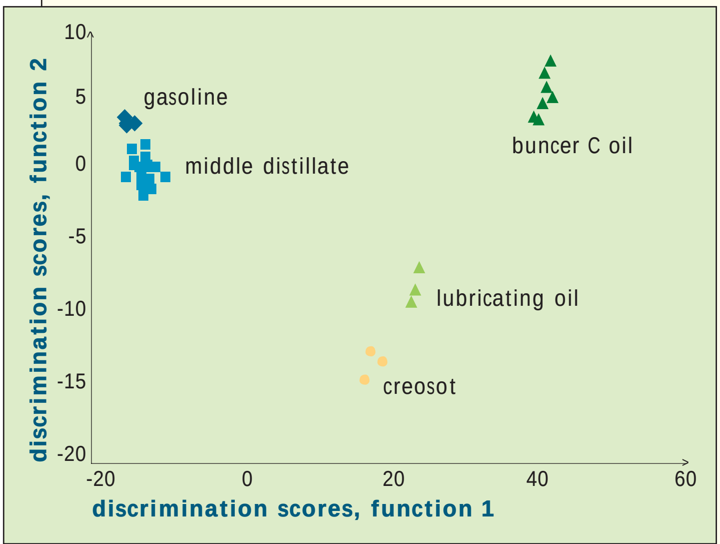


Fig. 19: Calculated discrimination scores for different petroleum derived products

printing technology (based on recognition of characteristic compound distribution patterns or isotopic signatures) can prove source-plume relationships. INCORE has developed a tool based on statistical methods for multi-component analysis evaluation of petroleum hydrocarbon characterisation which can distinguish between different petroleum products as sources of groundwater contamination (Fig. 19).

Two examples for application of the INCORE fingerprinting tool

On June 18th 1997, a tanker truck carrying 13 m³ of lead-free petrol and 17 m³ of diesel fuel overturned near the Petroleum Port in Strasbourg and caught fire. Three control wells were subsequently drilled around the site to check whether pollution had reached the groundwater table which, at 1 to 3 m below ground level, marks the upper surface of the major aquifer in the Rhine valley. No pollution was reported at that time.

To the north west of the site of the accident is an allotment area, equipped with hand-pumps for watering. Garden owners complained that this water smelled of petrol. The INCORE team checked whether some of the residual plume affecting their supplies could be traced to the 1997 accident or to previous events (there have been several accidents involving hydrocarbon fuels in the Petroleum Port area).

Conclusions for accident site: Several wells indicated low concentrations of a contaminant identified as being an old heavy fuel oil. In one of the wells the contamination was overlapped by a younger contaminant identified as being diesel fuel or heating oil, estimated to be about 20 to 25 years old.

Hence, INCORE demonstrated that there was no plume of pollution from the 1997 tanker accident (which involved lead-free gasoline and diesel fuel). Affecting the pollution noticed by its hydrocarbon odour that had led to the complaints from the gardeners, was in fact related to this much older contamination caused by heavy fuel oil.

Example 2, on the Strasbourg site of “Plaine des Bouchers” the plume screening performed in work package 2 (WP2) found high CHC (chlorinated hydrocarbon) concentrations on the western side, and two pumping tests were subsequently carried out. The interpretation of the pumping tests in work package 3 (WP3) could not determine whether there was one single plume (400 m wide) or two parallel CHC plumes. The aim of the fingerprinting therefore was to decide whether or not more than one source has caused the plumes (see Fig. 20).

The $\delta^{13}C$ composition measured for PCE (tetrachloroethene) range from -23‰ to -30‰. PCE from wells 1027 (Prochimest site, a known source), 70, 710 and 933 have similar $\delta^{13}C$ values

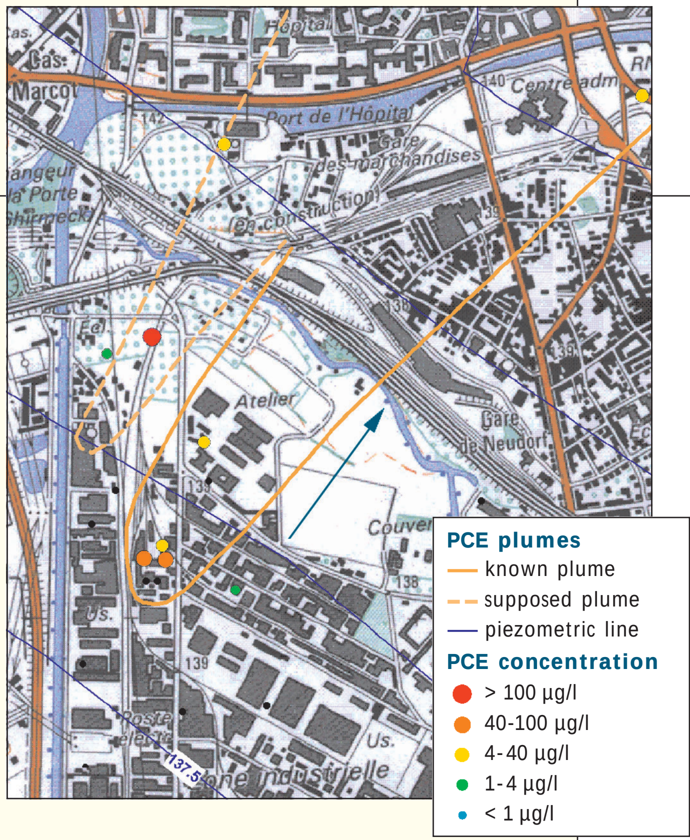


Fig. 20: PCE $\delta^{13}C$ distribution over the "Plaine des Bouchers"

for different concentrations of PCE (about 25‰), whereas wells 1120 and 273 have lower $\delta^{13}C$ compositions (about -30‰).

This indicated the existence of two plumes originating from at least two different PCE sources; one source is located on the Prochimest site, the source of the other plume (responsible for the pollution of the well of the hospital downstream) has not yet been identified.

The results from sites in Milan and Stuttgart additionally reveal clear evidence for ongoing degradation processes by fractionation, which allow basic assumptions for the applicability of monitored natural attenuation as a remediation option.

Risk assessment

The goal of the INCORE work package 5 (WP5) was to assess health risks caused by groundwater contamination. The WP5 INCORE final risk assessment products are:

- Health risk assessments and risk based target concentrations for the investigated test sites;
- "RiskWater" computer software based on typical groundwater exposure scenarios;
- Guidelines for risk-based evaluation and assessment of investigation results and eco-toxicological definition of site-specific remediation targets.

The INCORE project methodology for assessing risks to health was generally based on the US EPA approach to contaminated sites. The health risk assessment (HRA) process comprised two main strands, a baseline human health risk assessment and development of risk-based preliminary remedial goals, also known as risk-based concentrations (RBCs). RBCs are provided as one of the criteria used during analysis of remedial alternatives.

Potential non-cancer risks are evaluated by comparison of the estimated contaminant intakes from each exposure route (oral, dermal, inhalation) using Reference Doses (RfD) to produce the Hazard Quotients (HQ). To assess the overall potential for non-carcinogenic health effects posed by more than one chemical, the HQs calculated for each chemical are summed (assuming additivity of effects) and expressed as a Hazard Index (HI). If the HI exceeds unity (the value of 1), there are potential non-carcinogenic adverse effects.

Cancer risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (i.e., incremental or excess individual lifetime cancer risk). If a site has multiple carcinogenic contaminants, cancer risks for each carcinogen and each exposure route are added (assuming additivity of effects) and compared with the acceptable level. An excess cancer risk value of 1×10^{-6} (one in a million) was used as the acceptable risk level for the INCORE project.

INCORE used deterministic and probabilistic approaches in performing risk assessments. Using the site-specific data already obtained, human health risk assessments were performed for the test sites in Stuttgart, Linz and Milan.

Table 4: Residential groundwater exposure scenario

Summary of risk values, Linz-Heilheim

Well	Hazard index	Cancer risk
P2-1	1.5×10^{-1}	4.1×10^{-5}
P2-2	6×10^{-2}	1.8×10^{-5}
P3-1	2.2×10^{-1}	6.2×10^{-5}
P3-2	6.2×10^{-2}	1.8×10^{-5}
P3-3	1.4×10^{-1}	4.1×10^{-5}
P4-1	4.6×10^{-3}	1.4×10^{-6}
P4-2	3.1×10^{-2}	8.9×10^{-6}
P4-3	5.5×10^{-3}	1.6×10^{-6}
P4-4	2.4×10^{-2}	7×10^{-6}
P4-5	2.2×10^{-2}	6.5×10^{-6}

The same methodology was also used for calculating risk-based contaminant target concentrations at these test sites. The following exposure scenarios were identified and a quantitative risk assessment was performed:

- residential (in Milan – for future groundwater use, Linz – for present and future use) and
- emergency (Stuttgart – for future use).

Application in Linz

The approach and the results for Linz-Heilham are highlighted to illustrate the risk assessment conducted for the INCORE project. The condition of the groundwater in the aquifer was evaluated with regard to the potential risks that it might pose to humans (only adults) in a residential exposure scenario. Exposure pathways considered in this scenario include ingestion of tap water, inhalation of vapour-phase chemicals from water during household use and dermal contact with contaminants while showering or bathing.

The risk assessment is focussed on two contaminants: tetrachloroethene (PCE) and trichloroethene (TCE); they were characterised separately for carcinogenic and non-carcinogenic effects.

WP3 results from a numerical evaluation of concentration-time series data from ten wells were used as input data for the HRA at Linz-Heilham.

The HI values were below 1 for all investigated wells (from 0.0046 for the well P4-1 to 0.22 for the well P3-1; see Table 4). This result indicates that potential non-cancer risks using the residential exposure scenario assumptions are within the acceptable level of risk.

Contribution of exposure routes to total carcinogenic risks

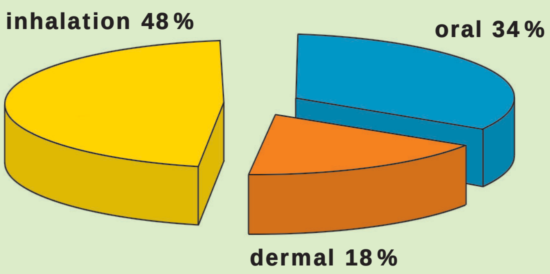


Fig. 21: Carcinogenic risk value, Linz-Heilham, well P2-1

Potential carcinogenic risks from exposure to contaminated groundwater at Linz-Heilham ranged from 1.4×10^{-6} for the well P4-1 to 6.2×10^{-5} for the well P3-1; the acceptable risk of 1×10^{-6} was exceeded at all of the investigated wells (Table 4).

The main contribution to the total cancer risks was from the inhalation exposure where both PCE and TCE occurred together (wells P2-1 and P3-1). When only PCE occurred (the rest of the investigated wells) the main contribution to the risk was from oral exposure.

Figure 21 shows the contribution of exposure routes to total cancer risk for one selected well (P2-1).

The HRA findings indicate that the presence of TCE and PCE in the groundwater in Linz-Heilham may pose a potential cancer risk to consumers of groundwater when used as tap water under the residential exposure scenario.

RBCs, which are target concentration levels for individual chemicals that correspond to a target risk (TR), have been derived under the residential scenario for potential combined exposures by all routes. For non-carcinogenic effects of PCE and TCE, the RBCs were calculated in order to achieve circumstances where the Hazard Index for combined exposures by all routes would not exceed a value of 1 (non-carcinogenic TR). For potential carcinogenic effects, the TR was 1×10^{-6}. Residential RBCs, derived basing on carcinogenic effects, amounted to: PCE – 0.64 µg/l and TCE – 0.03 µg/l.

It should be emphasised that TCE is present in groundwater as a by-product or breakdown product of PCE. Therefore, it would be of utmost importance to locate and remove the sources of the PCE pollution. Only with corrective actions undertaken at source zones will it be possible to reduce the groundwater pollution.

Natural attenuation

Natural attenuation (NA) describes the observed reduction in contaminant concentrations and/or contaminant mass flow rates as contaminants migrate from the source in environmental media. Under favourable conditions monitored natural attenuation (MNA) may be used as a contaminated land management option. However, it has to be demonstrated that the NA processes may efficiently and consistently protect the environment from harmful impacts.

Problems in demonstrating NA arise from the hydraulic and geochemical heterogeneity of the aquifer. Furthermore, the heterogeneous distribution of the pollutants in source zones can cause complex spreading behaviour in the plumes. In these situations a point-scale measurement may lead to a high degree of uncertainty in characterising contaminant plumes.

To overcome these limitations INCORE has developed some new methods for the evaluation of NA at field scale conditions. INCORE's integral method for determination of contaminant mass flow rates may be successfully used for the evaluation of natural attenuation. By combining several integral pumping tests (IPT) along two or more control planes any decrease in contaminant mass flow rates (MFR) with increasing distance from the source can be directly measured under field scale conditions (Fig. 22).

Application in porous aquifer

A field study on NA of BTEX (benzene, toluene, ethylbenzene, xylene) and PAH (polycyclic aromatic hydrocarbons) in porous media was performed at the site "Kraftwerk-Ost" located in a former industrial area (Stuttgart). Former gravel pits had been filled with waste from the nearby gas manufacturing plant. Soil and groundwater are highly contaminated with BTEX, PAH, and other contaminants. NA-specific site investigations were mainly based on measurements of contaminant mass flow rates by IPT at two consecutive control planes. In addition, groundwater samples were taken at a series of points. The preliminary results showed that the mass flow rates between the control planes decrease significantly for the mono-aromatic compounds and naphthalene and by a factor of 2 to 3 for PAH. As this may not be explained by retardation, the most effective NA process at the site is probably biodegradation resulting in steady state plumes. If the results are confirmed by further investigations, NA as a contaminated land management option at the site would be acceptable with respect to the plume length of the mono-aromatic compounds (< 150 m) and probably also for PAH if the remaining mass flow rates at the second control plane are considered to be acceptable.

Use of natural attenuation as contaminated land management option

Application in fractured aquifer

A field study on NA of CHC (chlorinated hydrocarbons) in fractured media was performed at the site "Nesenbachstrasse" (Stuttgart). As fractured rock sites are frequently extremely complex sites and CHC are generally difficult to locate in the subsurface, the characterisation and prediction of the fate and attenuation of these contaminants at such sites is a challenging task. There are numerous local and regional data available from the extensive investigations already undertaken at the "Nesenbachstrasse" site. Low CHC concentrations had been detected in the past in downgradient groundwater monitoring wells so it was assumed that the processes of NA are taking place. Additional site investigations were performed using a step-by-step approach with interim assessments. The first step was the identification of essential migration pathways (lateral and vertical). Then NA specific investigations were performed regarding each pathway. Using a combination of conventional methods, stable isotope measurements and integral pumping tests was found to be an adequate strategy for achieving the objectives.

The results revealed that conventional groundwater sampling by short-term pumping might lead to an essential underestimation of both concentration and contaminant mass flow rates. Because CHC concentrations are still high at approximately 150 m from the source zone-monitored NA is not acceptable as a contaminated land management option at the site.

Based on the sase studies above, the most important **requirements** with respect to NA-specific site investigation and evaluation were identified as:

- Development of an initial conceptual site model is a prerequisite.
- A detailed identification of migration pathways is required.
- In case of quasi homogeneous aquifers the approach of measuring mass flow rates by integral pumping tests at two consecutive control planes may be sufficient for NA quantification.
- A combination of conventional and innovative methods was found to be suitable strategy for a thorough NA evaluation in heterogeneous media.
- At complex sites (e.g. fractured media) the uncertainty in the delineation of the contaminant plume (the quantification of the mass flow rate at consecutive control planes) may be too high to make a firm decision on whether or not MNA is a suitable remedial approach.

INCORE NA flow chart and INCORE NA tool box

NA investigations in contaminated land management programmes should be performed as step-wise (tiered) approach coupled with interim evaluation stages. A possible strategy for the implementation of MNA is given in the INCORE NA flow chart – for each step of the investigation the goals and the resulting NA evaluation criteria are displayed. The INCORE NA tool box shows which methodologies should be used during the respective steps of the NA investigations.

Integral remediation concepts

At present conventional remediation methodologies like excavation, capping and enclosure are common place, whereas use of in situ technologies is still a minor element of the remediation scene in Europe. The integral approach evaluates, at scale of whole areas, the optimal combination of active remediation technologies for source zones with passive systems and monitored natural attenuation. In fact, for large industrial areas, the remediation of the whole areas or a combined remediation of different sources could be a reasonable economic and ecological solution.

In general, three different settings or strategies can be considered (Fig. 23):

- Joint treatment of a whole area by using passive technology or monitored natural attenuation – Plume concept
- Remediation of each single hot spot – Source concept
- Combined remediation of clusters of related hot spots or overlapping plumes – Combined source-plume concept

The evaluation shows that the plume concept and the source concept form the two basic solutions whereas the combined concepts prove to be the optimal solution in many cases indicating no clear preference for the extremes of plume or source concept. Besides the technical aspects and a technology related cost-effectiveness-evaluation, further key questions have to be considered for the decision between the different concepts mentioned above:

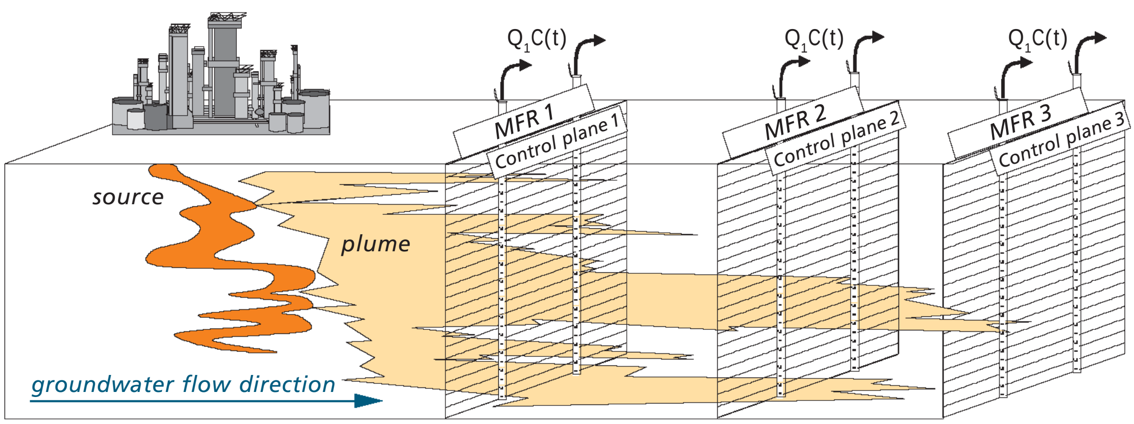


Fig. 22: Control plane approach for the quantification of natural attenuation (HERFORT et al., 2000)

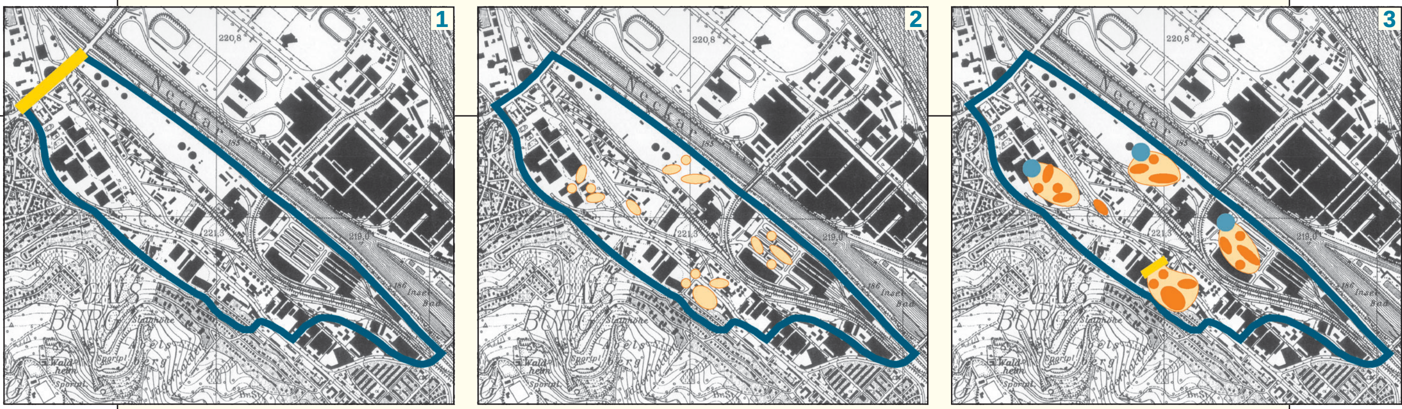


Fig. 23: Principle remediation strategies:
1 *plume concept,*
2 *source concept,*
3 *combined source-plume concept*

- What degree of real estate value can be reached by re-use of land?
- What size of area will be affected by remaining/tolerated concentrations by application of the plume concept and what level of concentrations will be reached?
- Will stakeholder acceptance be obtained for a solution based on the plume concept?
- How many private parties will be involved in a solution based on the plume concept?

Decision support on technical items has been provided by INCORE in a set of data sheets. They form the core input data to the ISIRE software (In Situ Remediation techniques), a computer program implemented in a user-friendly windows interface. The ISIRE program provides an immediate answer to the possible application of the different in situ technologies considering at the same time several parameters, such as chemical compounds and site-specific characteristics. Moreover the program allows the user to check the availability of enhancements and/or combinations of two technologies.

Case study in Stuttgart

The case study in Stuttgart represents a large-scale application of the integral approach on a scale of whole industrial area (mega site). The plume and source screening showed that five different plumes were overlapping. Different remediation scenarios were developed and evaluated, considering technical feasibility, effectiveness and costs for additional investigation, investment, operating and monitoring. The considered scenarios include different settings of pump & treat (close to the sources, along one control plane, or combined with dig & dump), areal scenarios using barriers, in situ removal scenarios and a monitored natural attenuation scenario.

A bioremediation scenario (oxygen enhanced bioremediation, supported by hydrogen releasing compound) turned out to be the most appropriate. Total costs for this scenario were the lowest of all. Although relatively recent to the remediation market, it is a proven technology. A scenario using dig & dump and pump & treat appeared to be preferable only in cases where land was required immediately for a development which included underground construction.

Case study in Milan

The case study in Milan represents an application at a local scale of the integral approach. It started with plume screening at the “Meton” site using IPT at a control plane downgradient of the potential sources. This allowed the identification of areas presumed to be the main areas responsible for the CHC contamination – the “Old Spring” and the “Ex-PzC” sector (Fig. 24). Cycle II source screening was carried out through on-site analyses (Soil Gas Survey) and Isotopic Fingerprinting in a smaller area of about 45,000 m^2. This step allowed the zones contaminated by CHC (see Fig. 24) to be delineated. Basing on this a feasibility study was carried out.

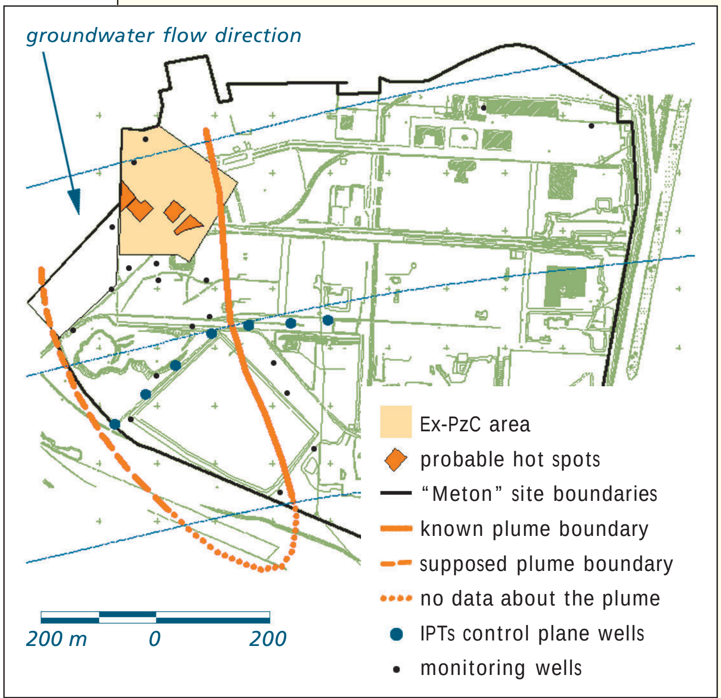
A preliminary evaluation of the possible in situ remediation technologies was carried out using the ISIRE program. Three remediation scenarios were compared: two conventional solutions (excavation and pump & treat) and an in situ source removal scenario (steam injection).

The following conclusions can be drawn from the evaluation of the feasibility study:

(i) Because of its rapid source removal, the excavation scenario has the clear advantage of allowing the planned building activities to commence after one year – although it is very expensive;

(ii) In situ source removal scenario is the least expensive but there is insufficient short-term experience to be able to guarantee the attainment of the desired remediation levels.

Fig. 24: Contaminant sources and related plumes in the project area "Meton" in Milan



Conclusions

Innovative integrated remediation concepts should encompass both effective decontamination techniques, especially for the source zones, to minimise the contaminant potential in an effective way and MNA as a contaminated land management option for plume management. INCORE provides

- a set of tools for evaluation where MNA would be acceptable,
- software for identification of suitable innovative in-situ-technologies (ISIRE),
- general criteria for selection of suitable combination of technologies and NA.

Application of in situ technologies is still impeded because

- some technologies do not yet have proven track records such that a 100 % guarantee can be made of attaining remediation,
- of long time duration of remediation action,
- the presence of low concentrations levels may reduce the effectiveness of the technique.

Administrative concepts

Management of contaminated sites aims at the assessment, safeguarding and restoration of healthy environmental conditions. Special emphasis is placed on the defence of risk or damages for human health. Management of contaminated sites is an important public task; the measures required must be defined and enforced by public authorities.

The INCORE approach for management of contaminated sites is based on the strategy of EU water-framework-directive. The legal requirements of the partner-countries were examined to assess the likely acceptance and implementation of the integrated INCORE approach. Results showed that legislation in most countries is based on the particular, single site of contamination. Very few regulations for the management of complex, overlapping groundwater contamination exist under prevailing law.

The implementation of the INCORE approach will therefore require new administrative concepts. On the other hand this survey of national regulations revealed that there are no significant conflicts exist between the integral INCORE approach and prevailing national law.

Recommendations

The INCORE recommendations should be inserted into each national legal framework, but as the administrations of the EU partner countries are so different specific recommendations cannot be made. However, general recommendations should be made at the European level.

For the improvement of administrative measures private-public-partnership models (PPP models) – e.g. contracts under public law – are included. For successful contractual negotiations a certain amount of information about the relevant sources and respective liabilities is necessary. The willingness of all liable parties to co-operate plays an important role in the success of a project. This could be improved by incentives like public funding or speedy remediation. If the negotiations fail, public authorities need appropriate legislative instruments to be able to enforce remediation.

The recommendations include the application of the polluter pays principle. The proportional contribution of the particular single source to the whole contaminated area as identified by cycle II can be used as a standard for cost allocation.

The practical relevance and applicability of the recommendations have been discussed with representatives of the European Commission, ministries, public authorities, umbrella organisations of industry and liable parties from Austria and Germany.

Private-public-partnership models: their success depends on the willingness for co-operation

Five step approach

The INCORE approach is structured in five different administrative steps (Fig. 25).

Step 1 establishes the area to be considered, based on the results of a historical inventory and hydrogeological conditions.

Step 2 is the core of the integral investigation strategy. It aims to identify the plumes, their sources and the quantification of the their contribution to the groundwater pollution. PPP models can only be used in exceptional cases in this step, because of insufficient information regarding relevant sources and liability. Therefore the public authority should perform this step.

Step 3 is similar to conventional management of contamination at single sites. Therefore the detailed site investigation should be performed in the usual way.

Finally, the integral groundwater remediation is performed in two steps – **step 4** "remediation planning" and **step 5** "remediation activities". Private-public-partnership models are applicable for both steps.

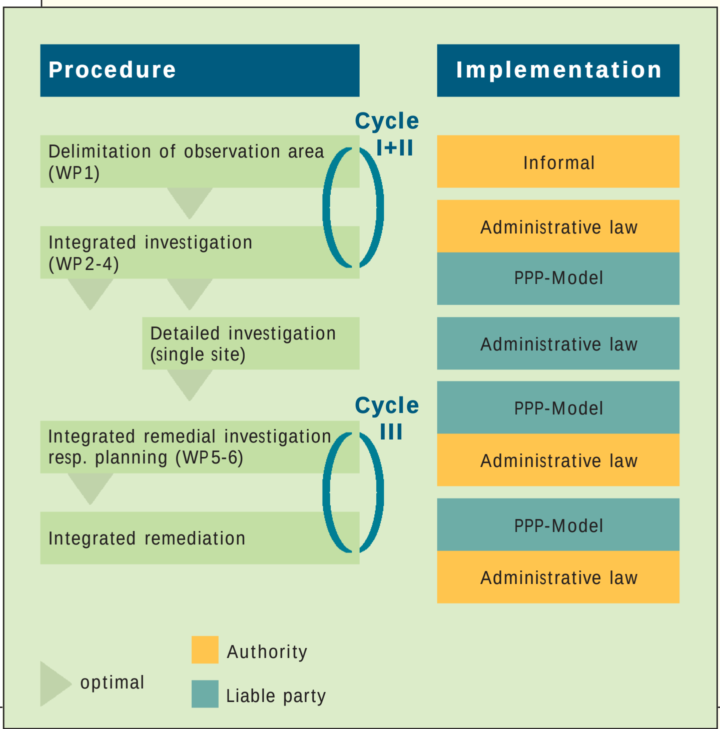


Fig. 25: Five administrative steps to realise the INCORE approach

Application on old gas-works in Bydgoszcz

The old gas-works in Bydgoszcz is located in the middle of the town, on the left bank of the Brda River. The gas-works operated between 1869 and 1973, producing gas for the whole town in the process of dry coal distillation. Since the town switched to the natural gas in 1973 the gas-works operation has been limited only to pumping and distribution of imported natural gas. However, despite a removal of old installation and modernization of most of the buildings, the remains of old technology, such as post-distillation tar and leachates, rich in PAH and BTEX, are still present in soil and groundwater.

Long time of gas-works operation and gaps in partially destroyed during the war archives make nowadays impossible to find out where all the potential pollution sources (tar storage tanks, benzene and naphthalene scrubbers, temporary storages, tailing ponds, etc.) were localized. Moreover in the past the low riverbank area with old riverbeds filled with mud and peat was covered with artificial embankments for leveling purposes. This artificial material, consisted of crushed brick and concrete and furnace slag, included also some quantities of post-distilled tar and other industrial waste, which makes the potential pollution sources identification even more complicated.

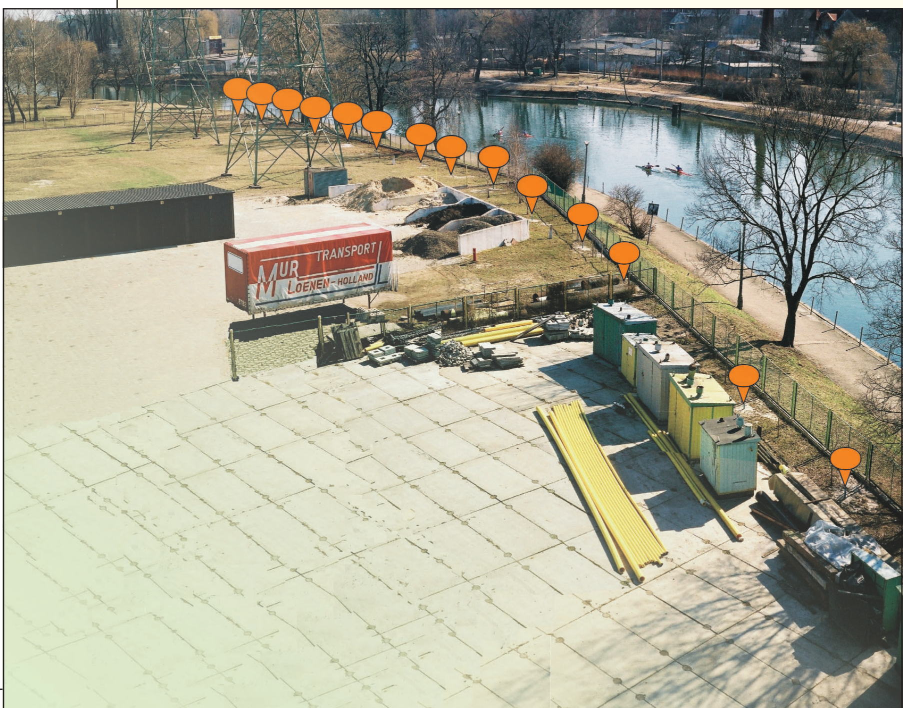
The first, most shallow, generally unconfined groundwater table in the area of gas-works lies on the depth of few meters. The 5 to 7 m thick aquifer is built of layers of post-glacial sands and gravels, locally muds. The Darcy coefficient of this formation k equals to 3 to 8 x 10^{-4} m/s. The hydrophobic character of artificial material in the embankment together with mud and peat layers cause local hydraulic heads of approximately 1.8 m.

Underneath there is a layer of 6.5 m thick Pliocene sediments (clays and silts with lignite), of far lower value of k, which covers the main Bydgoszcz region aquifer in Tertiary sandy sediments.

The INCORE site – a pilot project for Bydgoszcz and Poland

Within the INCORE project one control plane parallel to the river course was constructed. It consists of 21 small diameter boreholes lying within a distance of 10 m from each other. Integral pumping tests and chemical analysis of collected water samples allow for an identification of narrow propagation zones of PAH and BTEX and based on them – sources of these chemicals buried in the area of the gas-works. Further calculations define a degree of human health risk and hazards for the Brda River (influence on water quality, biological life, recreation and sport usage opportunity, etc.). As the final result the most effective scenario of the further area management can be proposed. The contaminated land remediation on the gaswork site is a pilot project for the industrial area in Bydgoszcz which itself is typical for many sites in Poland.

Fig. 26: Control plane constructed parallel to the river



Implementation

INCORE has provided guidance for a structured management approach for dealing with groundwater contamination in large industrialised areas. This approach consists of several technical tools embedded with a concept for related administrative actions.

For practical future implementation of the new approach the administrative acceptance and a complete knowledge transfer should be obtained. The administrative acceptance was objective of a whole work package developing administrative concepts for the INCORE approach. Knowledge transfer will be ensured by a wide distribution of INCORE results on research-, administrative-, and engineering level.

Besides this, the most effective dissemination is the direct practical application of the results by the participants, which will be used as additional model projects. The following projects are already on the way:

Stuttgart

The municipality of Stuttgart has acquired the ownership of an area around the present central railway station from the Deutsche Bahn AG. The station will be relocated underground and the existing infrastructure will be phased out between now and 2013. This area, "Stuttgart 21", covers about 120 ha and is located in the heart of Stuttgart city centre. Over the last 100 years land use closely connected to the railway activities has caused a complex contamination situation in soil and groundwater. The INCORE approach has been applied to this area from 2002. Activities will be completed towards the end of 2003.

In June 2003 the city council will decide on a proposal for an integral groundwater investigation in the district "Feuerbach". This district has had intensive industrial use over many years. Use of the INCORE approach in Feuerbach is planned for 2004-2006.

From 1st April 2003 the state of Baden-Württemberg has been carrying out the integral investigation and remediation of contaminated groundwater in Ravensburg (the seat of county government in the region of Lake Constance). The environmental ministry Traffic in Baden-Württemberg is planning to take up the approach in the rules for public funding contaminated sites management (Förderrichtlinien Altlasten).

Milan

The public administration of Milan has to manage and investigate contamination of soil and groundwater on a large scale, in order to protect the public drinking water supplies (from about 600 wells).

The municipality of Milan is now performing the Groundwater Monitoring Civic System in order to locate the risk areas. This entails covering the whole city area with approximately 50 new monitoring wells (in addition to approximately 50 existing monitoring wells). The Monitoring Civic System will be completed at the end of September and the first groundwater monitoring will begin in October 2003. This first phase of monitoring will identify the most critical areas in Milan using the INCORE methodology to characterise the plumes of contamination and to locate potential sources of groundwater contamination.

By applying the INCORE strategy over the whole city, the municipality intends to be able to prioritise its remediation work, starting with the areas that are a real risk for the human health of the citizens. The application of the INCORE approach is planned for 2004.

Linz

The main sources of the PCE contamination in the test region of Linz-Heilham have been identified. The current intention is to remediate affected public water supply wells in Heilham within the next few years. Remediation projects for at least four contaminated sites are expected to be initiated in the near future. Further investigation projects will use IPTs – for example at a large old municipal landfill, which is today used as a commercial area, and at the industrial area in the south-east of Linz. The general approach will be discussed in the light of the forthcoming European Groundwater Directive and is considered to be an appropriate strategy for investigations of ‘risk management zones’. However, some of the techniques within this strategy will need to be adapted for national conditions.

Strasbourg

The plume at the “Plaine des Bouchers” industrial area described previously will be investigated further and the search for possible sources will continue with the emplacement of new observation wells (cycle II, screening of sources).

The potential of the isotopic fingerprinting method for characterising CHC pollution is going to be put to use in the greater Strasbourg area. A network of observation wells (the “Observatoire de la nappe”) is being regularly monitored in this area, and several areas of CHC contamination have been identified. It is suspected that a large contaminated area to the northwest of the city corresponds to several distinct plumes.

South of the Strasbourg area, a project is underway to remediate a carbon tetrachloride plume (CCl_4, a solvent, belonging to CHC). This plume, several kilometres in length, resulted from a truck accident in 1970. A hydraulic barrier is planned to intercept the plume. The IPT method will be used to determine where the maximum flow rate of the plume can be intercepted, in order to optimise the design of the remediation facility.

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The INCORE guide to integral groundwater remediation [extended final report]

This CD-ROM contains the extendend INCORE final report. For viewing and printing the documents, you need the Adobe Acrobat Reader 6.0 software.

This free software can be downloaded at http://www.adobe.com/products/acrobat/readstep2.html

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