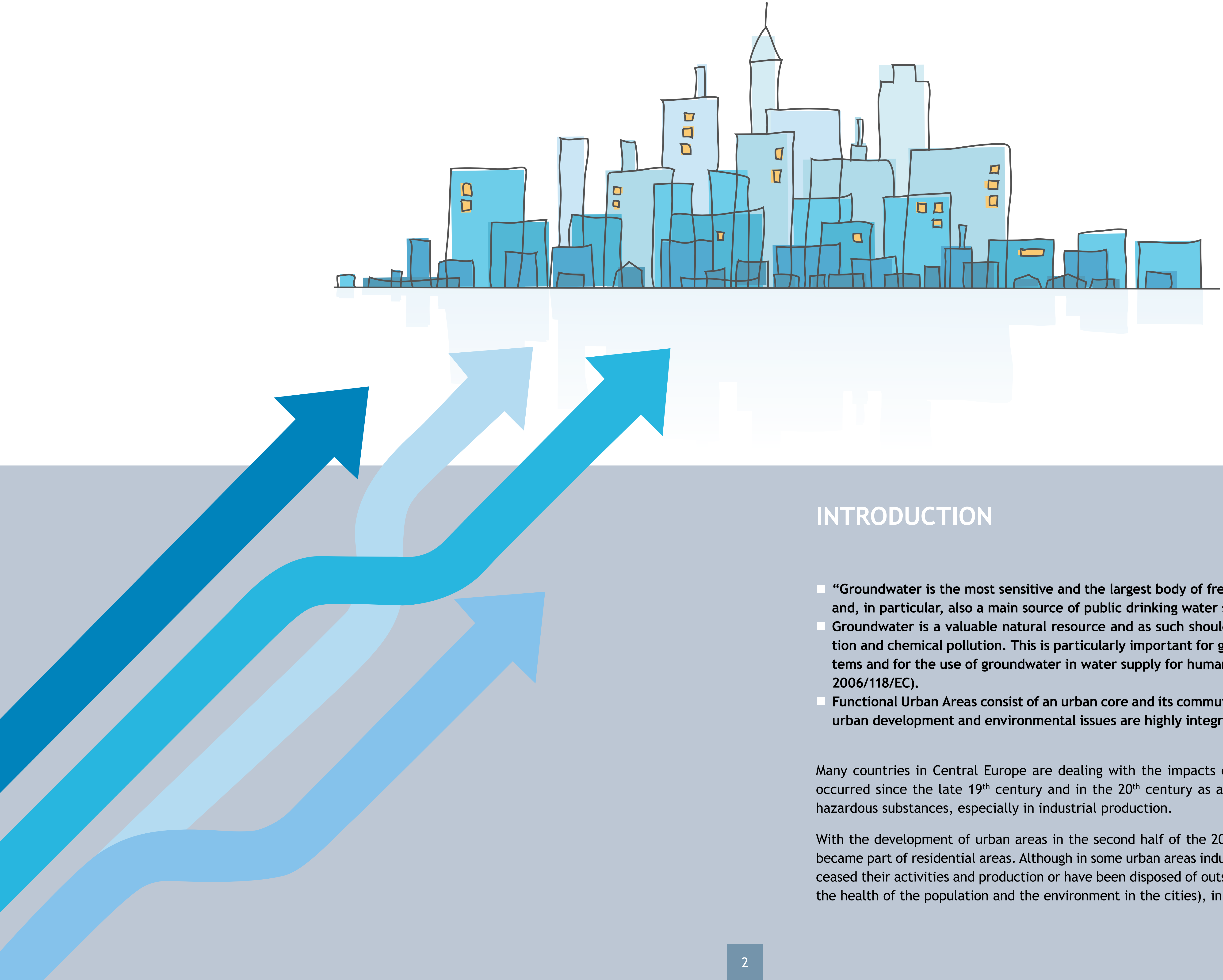
Interreg
CENTRAL EUROPE
European Union
European Regional Development Fund
AMIIGA

AMIIGA

INTEGRATED APPROACH TO MANAGEMENT OF GROUNDWATER QUALITY IN FUNCTIONAL URBAN AREAS



INTRODUCTION

- “Groundwater is the most sensitive and the largest body of freshwater in the European Union and, in particular, also a main source of public drinking water supplies in many regions.
- Groundwater is a valuable natural resource and as such should be protected from deterioration and chemical pollution. This is particularly important for groundwater dependent ecosystems and for the use of groundwater in water supply for human consumption” (from Directive 2006/118/EC).
- Functional Urban Areas consist of an urban core and its commuting zone whose labour market, urban development and environmental issues are highly integrated with the city (OECD, 2012)

Many countries in Central Europe are dealing with the impacts of environmental damages that occurred since the late 19th century and in the 20th century as a result of improper handling of hazardous substances, especially in industrial production.

With the development of urban areas in the second half of the 20th century, many industrial sites became part of residential areas. Although in some urban areas industrial enterprises have gradually ceased their activities and production or have been disposed of outside residential areas (to protect the health of the population and the environment in the cities), in many cases the pollution of the rock environment and groundwater has remained unresolved. As a result, polluted sites are part of the cities in Central Europe. National management approaches developed to reduce the negative effects deal with single sites. Groundwater contamination however is a problem that goes beyond sites and any administrative boundaries. Focusing on single sites does not solve the problems of polluted groundwater and thus even becomes a risk to further development of Functional Urban Areas (FUAs).

The approach of the Groundwater Framework Directive of the European Union (Directive 2006/118/EC) is to identify, to assess and manage pollution in groundwater bodies. This approach however neglects point sources and single sites.

Moreover, the mitigation of groundwater pollution is an extensive, long-term, complex and very expensive process. Even large investments may not provide the expected improvement in groundwater quality, as can be seen in many examples.

In this situation, it is very decisive that the EU Interreg Central Europe program offers a suitable platform for the countries of Central Europe to improve procedures and strategies of groundwater pollution management. The program enables the development of new technical tools and means for refining pollution information on the level of Functional Urban Areas. Their purpose is to prepare and implement appropriate remedial actions that are sustainable in the long term and will address existing risks and threats.

Contamination sources located in “city core” affect the groundwater quality of “hinterlands” downstream and vice versa. It requires effective intervention at this medium (FUA) scale, neglected in the existing legislation. The AMIIGA project is focusing on integrated assessment, remediation and management strategies, as well as on development of tools for characterization/prioritization of groundwater contamination sources. The innovative instrument “groundwater management plan” is a selective further development of the decision-support strategies described in Trzaski et al. 2012. Key elements of this integrated management instrument are characterization, remediation and monitoring plus the management strategy and the plan itself. This involves both technical and process innovation and strengthens water management capacities in the related administrative bodies among a FUA.

Each project partner has an individual problem with groundwater pollution at his FUA (pilot FUA) as in other EU countries. Each pilot FUA represents a serious problem for local or regional authorities they need to address. They differ in the type of pollution, hydrogeological conditions and threats from pollution (e.g. risk of damage to drinking water sources, degradation of mineral springs, threat to the health of the population etc.). In addition, the levels of knowledge about all aspects related to pollution are different: some partners are just beginning with groundwater solutions at FUA, others are already in the phase of preparing the implementation of remediation works.

Each FUA pilot at the beginning of the AMIIGA project faced the challenge of developing a long-term management plan to address groundwater pollution. In order to be prepared, it was necessary to broaden the level of knowledge on the aspects of pollution in specific areas of crucial importance for further decision-making by local or regional authorities.

12 project partners have prepared sets of pilot activities for 7 pilot FUAs, which have helped to clarify specific uncertainties, thus enabling the development of a management strategy and a long-term management plan to address pollution on specific FUAs. In all pilot actions, the new technical tools developed in the AMIIGA project were used (from dealing with data collection and evaluation of all former investigation, through compilation and mapping of all available information in a data base on GIS platform, conceptual hydrogeological modelling, integral pumping tests, delineation of plumes of pollution, numerical modelling of contaminated plumes and CSIA data, backtracking of pollutants, risk assessment for sources and plumes of pollution, identification of natural attenuation processes, development of remediation concepts and realization of remediation by using BMTs), which enabled these innovative resources to be successfully verified in practice.

In the following text, individual FUAs and their solutions are introduced and the achievements that each partner has brought are described in detail.

AMIIGA
(INTEGRATED APPROACH TO MANAGEMENT OF GROUNDWATER QUALITY IN FUNCTIONAL URBAN AREAS)

is a project funded by the EU CENTRAL EUROPE Interreg program 2016-2019 with 6 countries, 12 project partners, 8 regions, 7 pilot actions, 2.9 million euro project budget and 2.4 million euro ERDF. AMIIGA project is building on and capitalizing the results of previous projects especially MAGIC and FOKS (Gzyl and Gzyl 2008; Trzaski et al. 2012; Vasin et al. 2016).

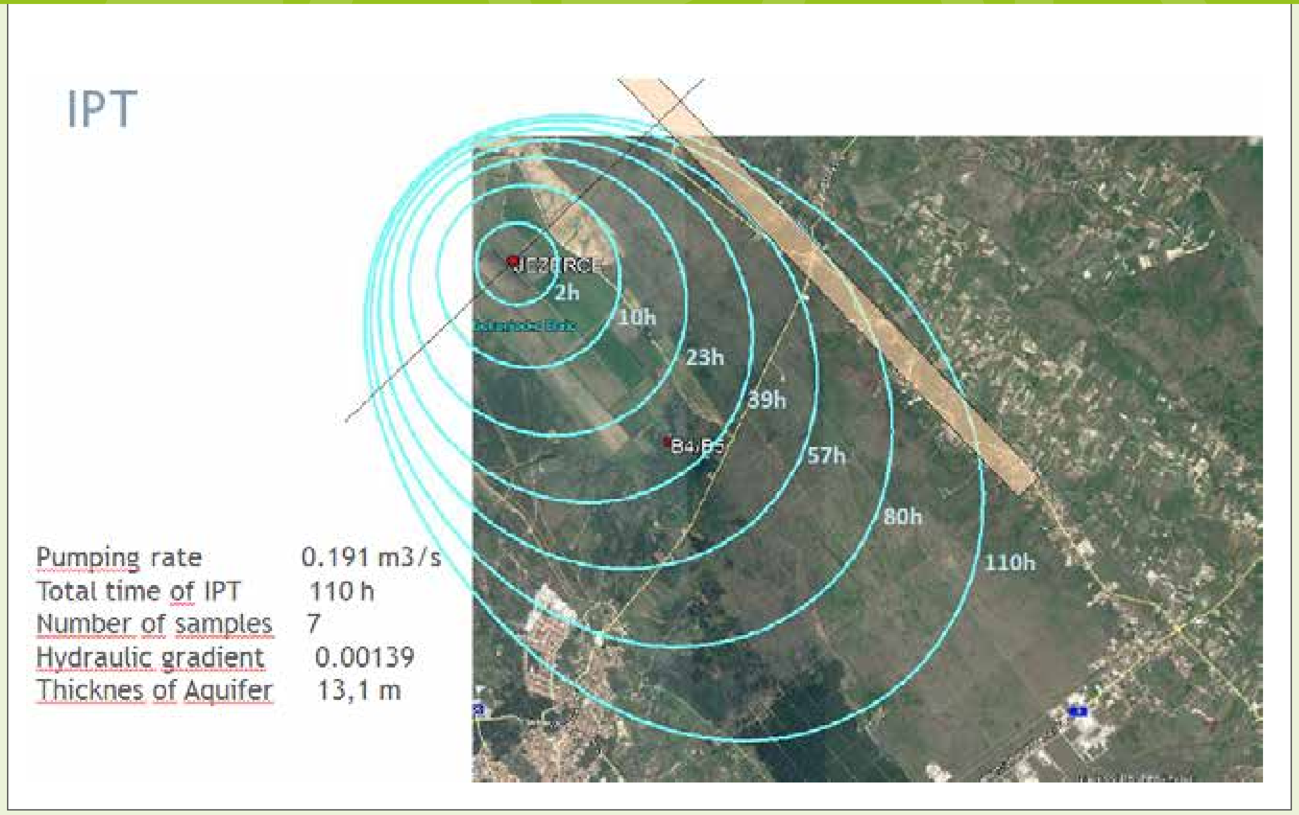
Editors

- **Eugenia Capone**, *Parma Municipality*, Parma, IT
- **Petr Kohout**, *Forsapi s.r.o.*, Prague, CZ

Authors

- **Donata Balzarolo**, *Lombardy Region*, Milan IT
- **Loris Colombo**, *Polytechnic University of Milan*, Milan, IT
- **Marco Ghirardi**, *Parma Municipality*, Parma, IT
- **Marina Bellotti**, *Lombardy Region*, Milan IT
- **Goran Gjetvaj**, *University of Zagreb, Faculty of Civil Engineering*, Zadar, HR
- **Grzegorz Gzyl**, *Central Mining Institute*, Katowice, PL
- **Beata Konczak**, *Central Mining Institute*, Katowice, PL
- **Petr Kohout**, *Forsapi s.r.o.*, Prague, CZ
- **Pawel Labaj**, *Central Mining Institute*, Katowice, PL
- **Malgorzata Markowska**, *Central Mining Institute*, Katowice, PL
- **Justyna Moycho - Jedros**, *Jaworzno Municipality*, Jaworzno, PL
- **Joerg Prestor** , *Geological Survey of Slovenia*, Ljubljana, SI
- **Brigita Jamnik**, *JP Vodovod Kanalizacija Snaga*, SI
- **Marcin Tosza**, *Jaworzno Municipality*, Jaworzno, PL
- **Sandra Vasin** , *State Capital of Stuttgart*, Stuttgart, DE
- **Hermann Josef Kirchholtes**, *State Capital of Stuttgart*, Stuttgart, DE
- **Stanislaw Waclawek**, *Technical University of Liberec*, Liberec, CZ
- **Valentina Caimi**, *Lombardy Region*, Milan IT

Figure No.1 - Zadar peninsular Old Town



IPT

Pumping rate	0.191 m3/s
Total time of IPT	110 h
Number of samples	7
Hydraulic gradient	0.00139
Thicknes of Aquifer	13,1 m

Figure No. 3 - Results of IPT

SOLVING THE INVERSE PROBLEM USING THE FOKS TOOLS IN KARST AQUIFER (ZADAR FUA, CROATIA)

Introduction

Zadar is the oldest continuously inhabited city in Croatia. It is situated on the Adriatic Sea, at the north western part of Ravni Kotari region. Zadar serves as the seat of Zadar Country and the wider northern Dalmatian region. The city covers the area of 25 km^2 with a population of 75,082 in 2011, making it the fifth largest city in Croatia. It is known for the Roman and Venetian ruins of its peninsular Old Town.

Figure No.2 - Zadar and its hinterland

Threat to groundwater in FUA Zadar

Water supply of Zadar is based on groundwater exploitation in the Zadar hinterland. In the hinterland of Zadar there are some villages without sewage system (brown areas in Fig. 2) and only 43 % of the population in this area is connected to the sewage system. Other households use septic tanks that are mostly permeable and leak directly into the karst underground. Pollution from these areas can very fast infiltrate in the groundwater according to absence of confining layer.

Between the villages, there is some agriculture area where farmers use fertilizers and pesticides. So far, there is no significant pollution caused by agricultural activities registered. The pesticide levels in groundwater are below the threshold values due to relatively low use. The level of nitrogen in groundwater is below the threshold values as well (nutrient management plans have been introduced in the EU accession process).

The general direction of groundwater flow is from southeast to northwest and during the rainy season, the pollution can reach pumping wells (yellow dots on Fig. 2) very fast. Results of monitoring from several groundwater wells show microbiological contamination in FUA. The main sources for bacterial contamination are unsuitable disposal of wastewater.

Figure No.4 - Discrete Analyzer-Gallery

Benefits from project AMIIGA to FUA Zadar

Within AMIIGA project, Integral Pumping Tests (IPT), an innovative tool developed within the project FOKS, were conducted in karst aquifer. The results of IPT (Fig. 3) confirmed the previously adopted assumption that the main source of microbiological pollution is inadequate septic tanks that released the effluent in groundwater.

In order to define the groundwater flow and transport of pollution in Bokanjac-Policnik aquifer, the numerical model of groundwater flow was developed within the project AMIIGA. The goal of numerical model was to determine (i) the flow direction, (ii) the amount of infiltrated precipitation and (iii) relationship between the flow through the pores and the flow through the fractures based on the existing data of groundwater levels.

The main goal of AMIIGA project was to ensure good groundwater quality as well as a sustainable water supply system based on its own technological and human potentials. Therefore, the first step in improving the groundwater quality control was made by acquiring new laboratory equipment that increased the laboratory's analytical capabilities: Discrete Analyzer-Gallery (Fig. 4) and Gas chromatograph (Fig. 5). The devises enabled the detection of new potential groundwater pollution, increased the number of analyzes and shortened their implementation time. For this purpose professional training and education of laboratory staff were performed.

Finally, the project AMIIGA helped to develop the Management plan and approve it with the Regional Implementation Group members. In the Management plan for FUA Zadar, the location of new observation wells were suggested, the improvement of groundwater monitoring concept was developed, supplementation of defined accident measures were described and the next upgrade of existing numerical model was suggested.

Figure No.5 - Gas chromatograph (GC-2010Plus)

REMEDIATION CONCEPT FROM DRINKING WATER PERSPECTIVE FOR DIVERSE POLLUTANTS IN TYPICAL SLOVENIAN FUA (SLOVENIA)

Introduction

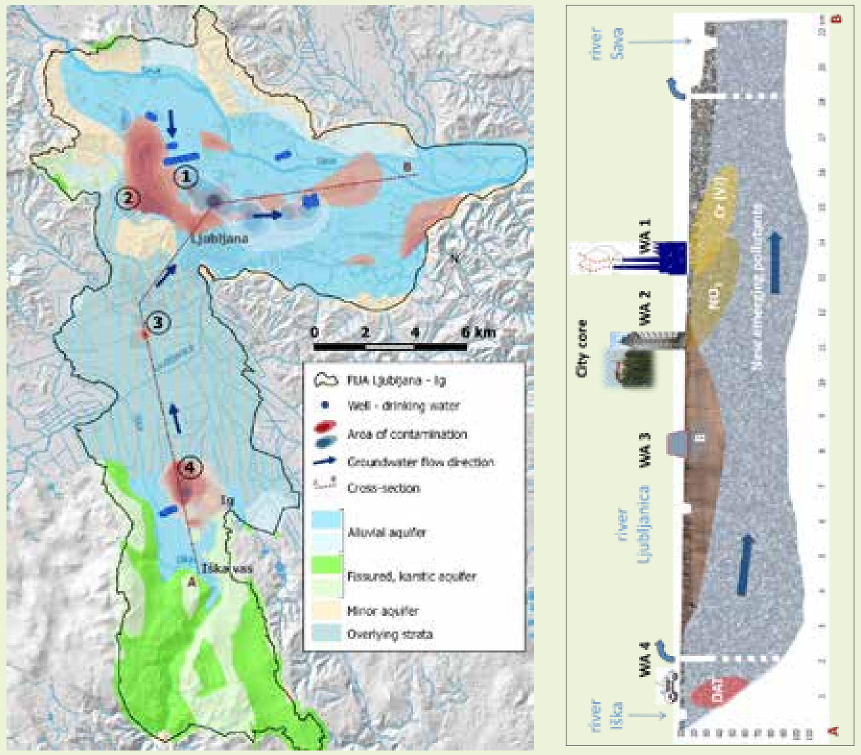
Functional Urban Area (FUA) of Ljubljana – Ig consists of two administrative entities, i.e. Municipality of Ig and Municipality of Ljubljana City. Both municipalities are interconnected by the main common aquifer system, waterworks system and sewage system.

The main common aquifer is composed of alluvial sediments (Fig. 6 – right side), i.e. mostly of highly permeable gravel and sand layers, locally lithified as a conglomerate lenses. Level of groundwater is mainly unconfined, up to 30 m below the surface, but also artesian, covered by low permeable overlaying strata of clayey and silty sediments. Iška River and Sava River are very important recharge and drainage hydraulic boundaries. Groundwater flow velocities range from 0.03 m/day (Barje area) up to about 10 m/day (Stegne-Hrastje and Dravlje-Moste area). The depth of aquifer is around 100 m.

There are numerous contaminants present in the groundwater, originating from past and recent activities. Investigation of groundwater contamination in alluvial aquifers under the highly urbanized area of the City of Ljubljana has been already conducted by the EU-funded project INCOME (2009 - 2012). Comprehensive chemical analyses of groundwater were performed in order to detect and identify variety of contaminants that occur in the subsurface.

In AMIIGA project, we focused our activities on four major contamination sources, working areas FUA Ljubljana – Ig (Fig. 6 – left side). Two of them have characteristics of plumes from point and multipoint pollution, which have highly severe and continuously present risk for the operation of drinking water wells. The aim of the pilot action was to establish the remediation and other measures that will efficiently preserve and improve the quality of the groundwater. The main development goal is drinking water supply without treatment, even from the ground below highly populated city core area and agricultural hinterland, in the next decades.

Figure No. 6 - FUA Ljubljana - Ig with significant contamination working areas (WA 1 Stegne - Hrastje: hexavalent chromium (Cr VI) plumes; WA 2 Dravlje - Moste: nitrate (NO3) and new emerging pollutants contamination; WA 3 Barje: boron (B) contamination; WA 4 Brest: desethyl-atrazine (DAT) plumes)



Threat to groundwater in FUA Ljubljana - Ig

Desethyl-atrazine pollution in Brest area represents the highest risk for water supply among all four working areas (Fig. 7). The risk is high in the present status and potential pollution. The threat of severe contamination of Brest wellfield (exceeding 0.1 µg/l quality standard) is continuously present.

The risk of chromium VI pollution in Stegne - Hrastje area is also high, because of potential severe pollution, which is continuously present. There are multipoint sources, locally exceeding 25 µg/l of chromium VI (Cr VI) in groundwater. Instantaneous releases of Cr VI from not yet identified point sources are possible, for example, during excavating for construction works, or in case of specific hydrological conditions. Such releases could then provoke severe contaminations also in drinking water wells, not only in Hrastje but also in Kleče wellfield.

Nitrate concentrations and new emerging pollutants in Dravlje – Moste area represent the medium risk at present status, but high risk to drinking water wells in the case of potential pollution. The latter is continuously present for some drinking water wells having concentration of nitrate close to 25 mg/l. Some new emerging pollutants have significant increasing trends, which means that the present status is deteriorating in a short-term timeframe.

Contamination from municipal landfill in Barje, most of all by boron, is of low risk for present status of water supply system. Advancement of contamination downstream of the landfill on the flow path towards drinking well is possible, but only of lower severity and longer period of occurrence. However, some measurement points have still significant upward trend or highly oscillating concentrations, so the level of this risk is medium.

Benefits from AMIIGA Project to FUA Ljubljana - Ig

Thanks to the AMIIGA project co-financing and international cooperation, we were able to use and demonstrate beneficial use of FOKS and AMIIGA tools, such as GIS – protocol to establish common database of monitoring data, numerical modelling and backtracking the pollution origins, biomolecular tool (BMT) and compound stable isotope analysis (CSIA) as well as the rich experiences of pollution management in cities of Jaworzno, Milano, Novy Bydzov, Parma, Stuttgart and Zadar.

The groundwater contamination Management plan of Ljubljana – Ig is our key output. Such Management plan is the first in Slovene territory and the ambition is to be also demonstrative case for other functional urban areas. It defines development targets and target values that must be achieved for safe water supply and high-level functionality of urban area in next decades.

The Management plan was elaborated by executing activities in eleven steps for all of four working areas in FUA Ljubljana – Ig.

- **(1) Assessment of actual status and (2) Additional targeted sampling**

Additional sampling campaign enabled us to interpolate data and delineate the Cr (VI) contamination plume in Stegne – Hrastje area for the first time (Fig. 8). At the same time, we identified additional location of excessive Cr (VI). We were also able to observe the changes of DAT contamination plume through 6 years period in Brest area to reveal its progress.

Risk rank	Working Area (WA)	Present status	Potential pollution	Target status
1	Brest WA 4	High risk	High risk	Medium risk
2	Stegne-Hrastje WA 1	Medium risk	High risk	Low risk
3	Dravlje-Moste WA 2	Medium risk	High risk	Low risk
4	Barje WA 3	Low risk	Medium risk	Low risk

Figure No. 7 - Evaluation of risks from waterworks perspective

- **(3) Improved numerical models,**
  (4) Actualized mass balance, and
  (5) Trends and long-term forecasts

We found out that the majority of DAT in wider Brest area most probably originates from two old gravel pits (Fig. 9). The storage of DAT within wider area of Brest was assessed to approximately 25 kg in 2011 (INCOME) and 23 kg in 2017. On the basis of improved numerical model, we simulated possible scenarios for remediation in order to determine feasible measures.

We found out that the downward trend of nitrate in Dravlje-Moste area cannot be expected to continue, because the potential for further decline is lower, hence the long-term forecast is uncertain. In addition, desethyl-terbutilazine concentrations are already above the limit of detection (LOD) at western side of Kleče wellfield with significant upward trend, which makes it necessary to introduce measures to reduce inputs.

- **(6) Assessment of natural attenuation potential**

Organic pollutants in (3) Barje area are identified only in traces, which is confirmed also by the low microbiological activity of degradation of these pollutants. Hence, we focused on dilution and dispersion potential of the boron, as the most significant pollutant.

By fitting calculations on each observation well to measured values, we evaluated, that one of the most

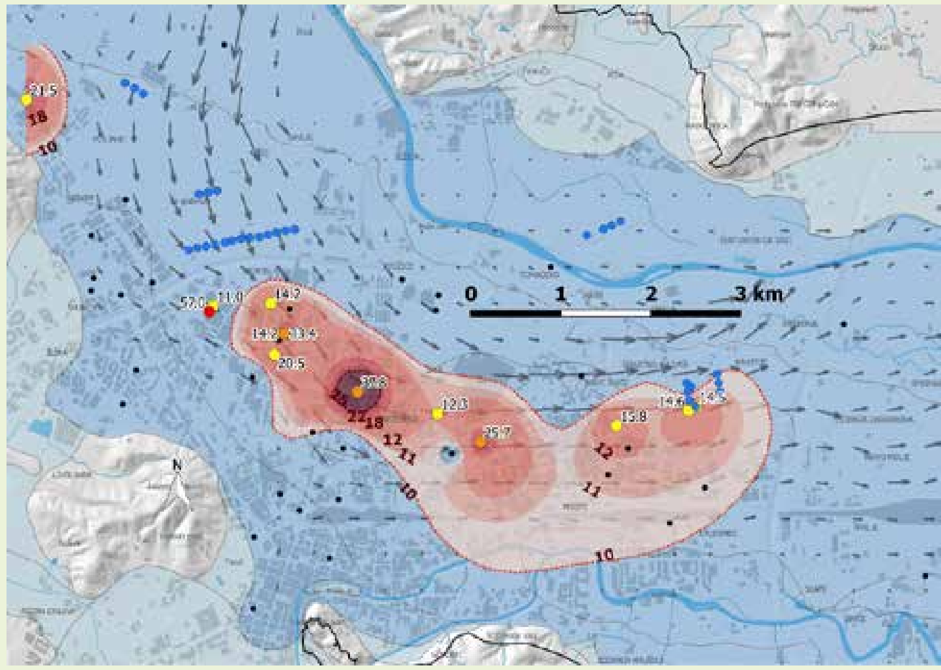
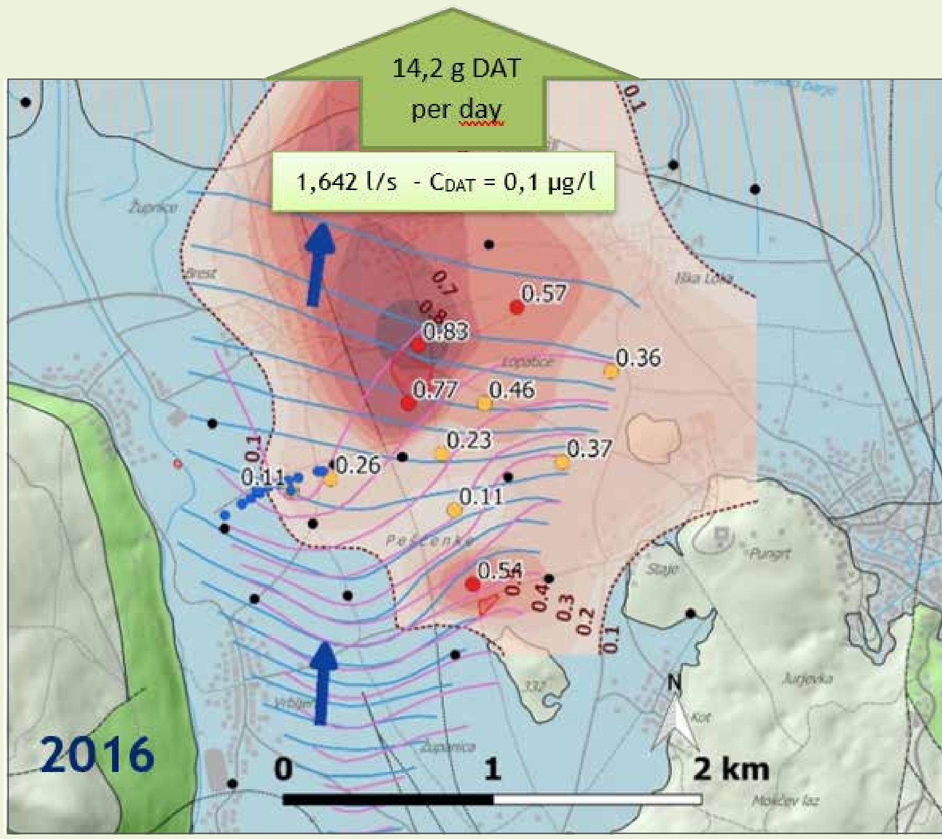


Figure No. 8 - Cr (VI) contamination plume in Stegne-Hrastje area (WA 1)

Figure No. 9 - Evaluated mass balance of DAT in Brest area (WA 4)



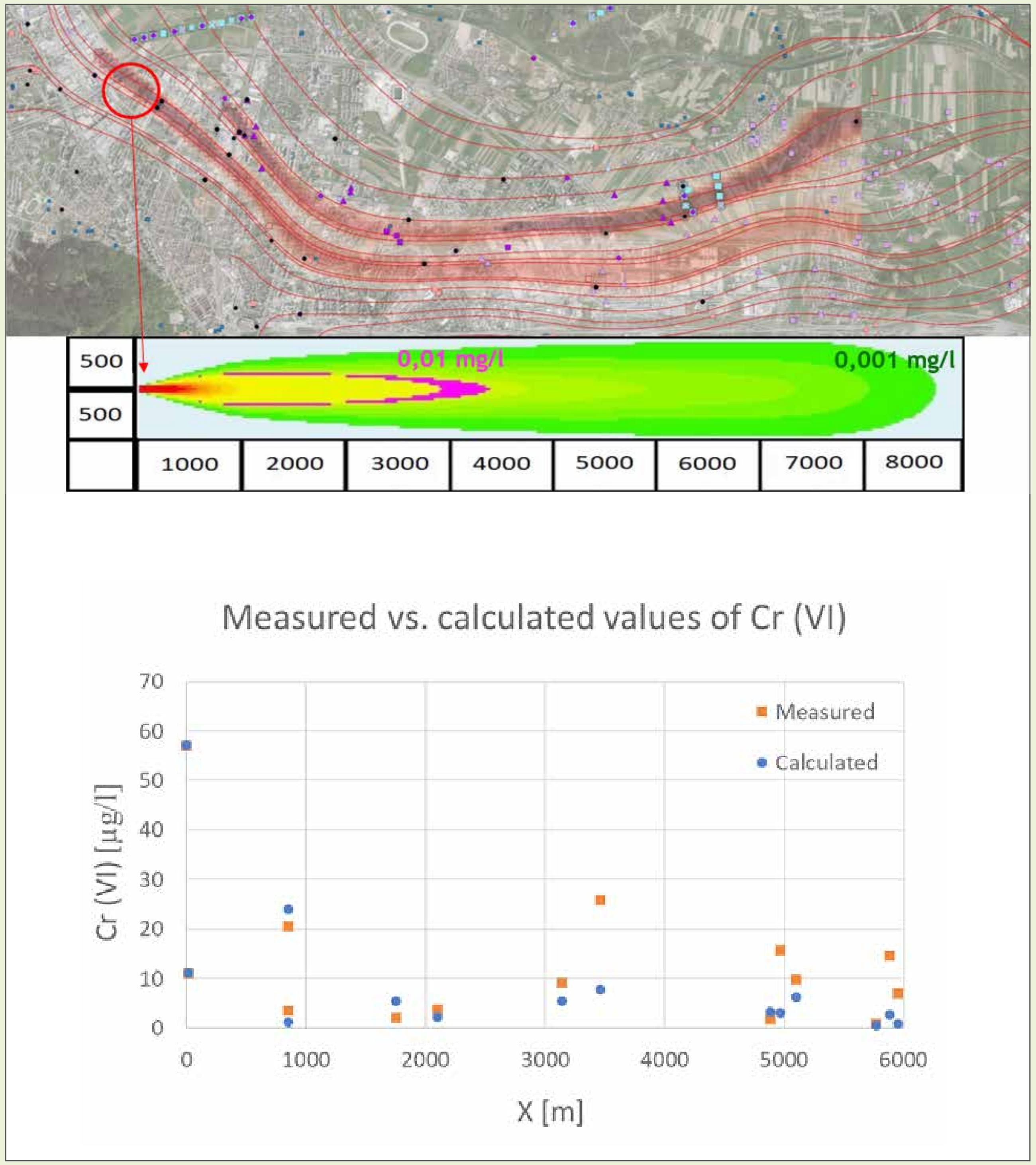


Figure No. 10 - Measured vs. Calculated values of Cr (VI) when the source of pollution is 400 m away from borehole LTH-2/15 (WA 1)

probable sources of Cr (VI) at (1) Stegne-Hrastje area is 400 m upstream from LTH-2/15 observation well (Fig. 10).

- **(7) Most probable scenarios threatening groundwater and (8) Evaluation of risks from waterworks perspective**

Based on analysis of severity and recurrence of contaminations, for present status and for potential pollutions, we ranked the levels of risks of all four working areas from waterworks perspective (Fig. 7). This analysis was crucial for further preparation of program of measures, with emphasis on working areas (4) Brest (desthy-atrazine) and (2) Stegne – Hrastje (Cr VI).

- **(11) Determination of feasible measures, milestones and indicators of progress, via (9) Preinvestment analysis and (10) Feasibility of measures**

For (4) Brest working area of desethyl-atrazine plume we elaborated cost-efficiency for four hydrotechnical remediation measures: redirection of plume, active protection barrier, accelerated abstraction of pollutant and artificial recharge of unpolluted shallow part of aquifer. We also elaborated the procedures for enhanced microbiological degradation. We set up the next steps of investigation measures that will finally enable us to select the most efficient remediation.

At (1) Stegne-Hrastje area of Cr (VI) contamination we delineated three narrower areas of the highest sources of contamination. Further steps are elaborated to localize those point sources and to prepare remediation procedures.

In (2) Dravlje-Moste area we defined reporting protocol to relevant sectors to reduce the input of relevant substances of new emerging pollutants. We also determined critical points to inspect losses from sewerage.

In Barje (3) the main plan is to perform natural attenuation monitoring, additional points of compliance to lower the risk and to identify external sources of boron.

Finally, we set up procedure, tasks and milestones for the implementation of those measures in relevant documents. We are continuing with the activities of cost resources identification and dissemination.

PILOT ACTION 3

SEPARATION OF HOT SPOT & MULTIPLE POINT DIFFUSE CONTAMINATION IN MILAN FUA (ITALY)

Introduction

The northern part of metropolitan area of Milan, Milan FUA, has been historically characterised by a dense agglomeration of industries (automotive, refineries, chemical plants, steel and tires production) that led, over the years, to a significant contamination of soil and groundwater.
In the last decades, Lombardy Region spent many efforts to push polluters to characterize and remediate soil and groundwater in their sites, having important results in terms of water and soil quality at local scale. Moreover, the available dataset highlighted the presence of a contamination not linked directly to a polluter or a restricted area, but to a multiple source clustered in a large area. This kind of contamination, called diffuse pollution, needs to be treated with different tools and procedure.

Lombardy Region has started dealing with diffuse pollution in the metropolitan area of Milan since 2013 with an available data organisation and integration. Based on the results of studies the carried out in 2017, Lombardy Region has delimited the first area affected by diffuse pollution and approved management measures and the penalty for remediation procedures. The area (Fig. 11), which is northeast of Milan (and includes the City of Milan), is affected by diffuse contamination of chlorinated hydrocarbons (CHC).

Furthermore, the performed studies highlighted that several plumes, originating from the north-western part of Milan, have a significant effect on the deterioration of the groundwater quality in Milan and affect some pumping stations used for the water supply services. Moreover, a presence of a contamination was observed, which was characterized by low concentrations and permanence that could be matched to a diffuse nature.

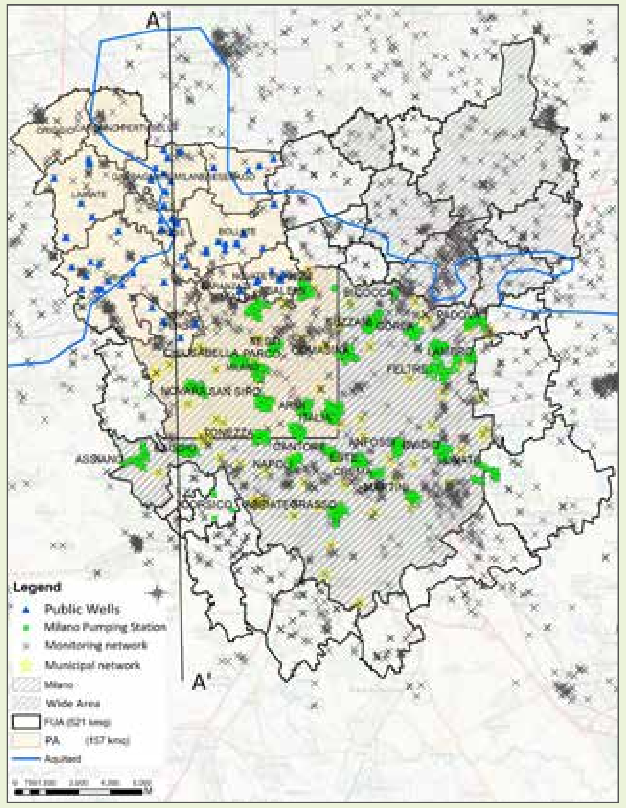


Figure No.11 - Milan FUA (521 kmq, more than 2.2 milion inhabitants) is in black biold, pilot area (PA) is colored in pink. Cross section AA' is represented in Fig. 12.

For this reason, the northwestern part of Milan and some municipalities located at the northern boundary of the city have been selected as the pilot action area for AMIIGA project.

The pilot area (Fig. 11) is covering 12 municipalities in the northwest of the Milan FUA and is about 157 km^2 wide; within the area live more than 600.000 inhabitants.

Threat to groundwater in Milan FUA

Due to the high hydraulic conductivity and high groundwater withdrawal rate, the groundwater contamination reaches the territory of Milan, since it represents the natural drainage area of the groundwater in the north.

From a hydrogeological point of view, the main aquifers relevant for contamination are the shallow aquifer and semi-confined aquifer that are separated in the southern part and connected in the northern part of the studied area (Fig. 12).

The main challenge of AMIIGA project in the pilot area was to define tailored management measures assuring local remediation actions more sustainable. Therefore, the key task of Pilot Action was to distinguish contamination plumes originated from point pollution sources from diffuse pollution in the area of interest.

Benefits from project AMIIGA to Milan FUA

AMIIGA project enabled (i) the implementation of tools aimed at distinguishing point sources of pollution from diffuse contamination and (ii) developing a set of measures, the Management plan, to monitor and manage pollution and prevent further groundwater contamination.

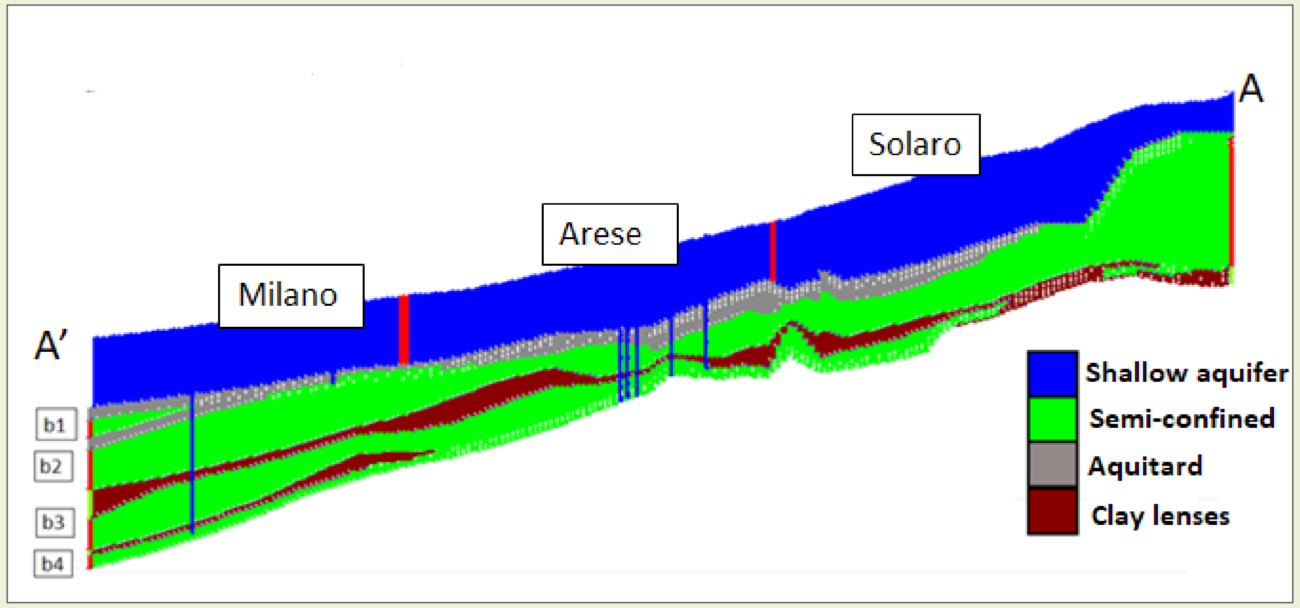
The main goal of the pilot area was the assessment of groundwater contamination, distinguishing diffuse and site-specific contributions, for Perchloroethene (PCE) and Trichloroethene (TCE).

To this aim, the main plumes, their source area, their extension and the characteristics of the contamination outside of them (temporal and spatial distribution) have been investigated and studied within AMIIGA project.

In order to fulfil the goals, the following activities have been carried out:

- ***Hydrogeological and groundwater monitoring data collection***
  - The available dataset from previous studies was integrated and updated for the pilot area and the FUA.
  - The documentation available for the contaminated sites in the pilot area (more than 20 sites in regional registry) was analysed and new data were included in the existing dataset (i.e. hydro-chemical data and hydraulic pumping tests).
  - The data has been implemented in a database and shared among the project partners, through a Web – GIS.
- ***Optimization of existing groundwater network: a new monitoring network***

Figure No. 12 - Cross section N-S of the pilot area, the colors represent the different aquifers (blue and green) and aquitard (grey and brown)



- Analysis of the localization of monitoring wells already existing in the area and their effectiveness in the spatial definition of the phenomena has been performed.
- Six new piezometers have been drilled in order to improve the monitoring network in the pilot area, both for shallow and semi-confined aquifer (Fig. 13).

- ***Realization of three monitoring campaigns***

- Chlorinated solvents (PCE, TCE, TCM, cis-DCE), hydrochemicals and isotopic parameters were monitored in order to survey the extension of plumes and support the calibration of the numerical models.

Figure No. 13 - Realization of deep (left) and shallow piezometers (right)

- ***Hydro-geological and numerical model implementation***

The numerical (Groundwater Vistas 6 interface) groundwater transport (MT3DMS) and flow (MODFLOW2005) model were developed:

- Groundwater flow was calibrated (i.e hydraulic conductivity parameter) based on the observed data (campaign in March 2018) by using automatic inverse calibration (PEST).
- Plume extensions, the mass flow rate released from sources, the spatial evolution of contaminants (from 1954 to 2017) were determined. The plumes contours were used to divide monitoring points linked to point sources from monitoring points linked to diffuse contamination.

- ***Inverse transport model (uncertainty analysis on hydrogeological parameters, i.e. hydraulic conductivity by means of Monte Carlo approach)***

By means of the inverse advection transport model, it was possible to track the particles of the contaminants both (i) forward starting to a suspected sources in order to estimate in a probabilistic way the influence of contamination downgradient, i.e. sensitive receptors like public wells, and (ii) backward starting from contaminated piezometers or wells in order to find, in a probabilistic way, the areas where the pollution takes its origin.

- ***Multivariate analysis and factorial analysis, in association with geostatistical analysis***

The Multivariate and factorial analyses, in association with geostatistical analysis applied on the previous outcomes have allowed to: give a picture of the distribution and to determine the concentrations representative for the diffuse contamination. Maps of diffuse PCE contamination distribution, were provided for the shallow and the semi-confined aquifers, split in three levels associated to ranges of concentrations representative for the diffuse contamination.

All the performed activities, as the modelling tools and elaborations developed on the upgraded groundwater database, have allowed to:

- Depict an extensive profile on the contamination by chlorinated solvents in the pilot area of Milan: the CHC pollution is mainly linked to a diffuse con-

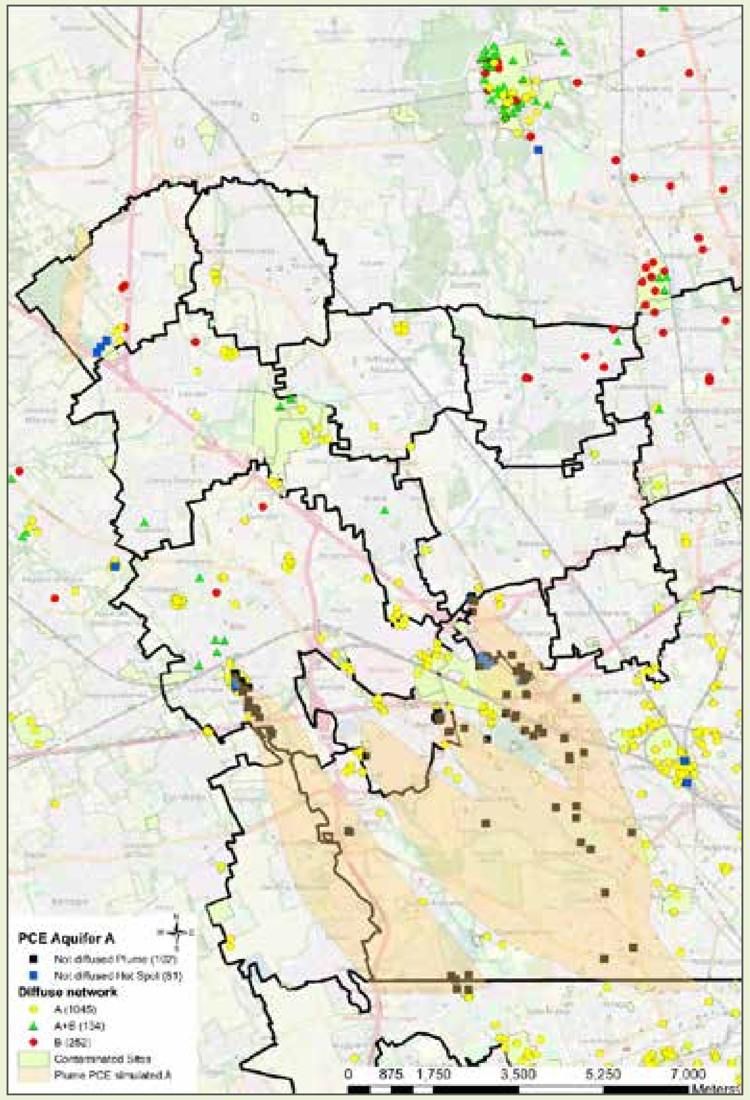


Figure No. 14 - Plumes representation using the modelling results in shallow aquifer

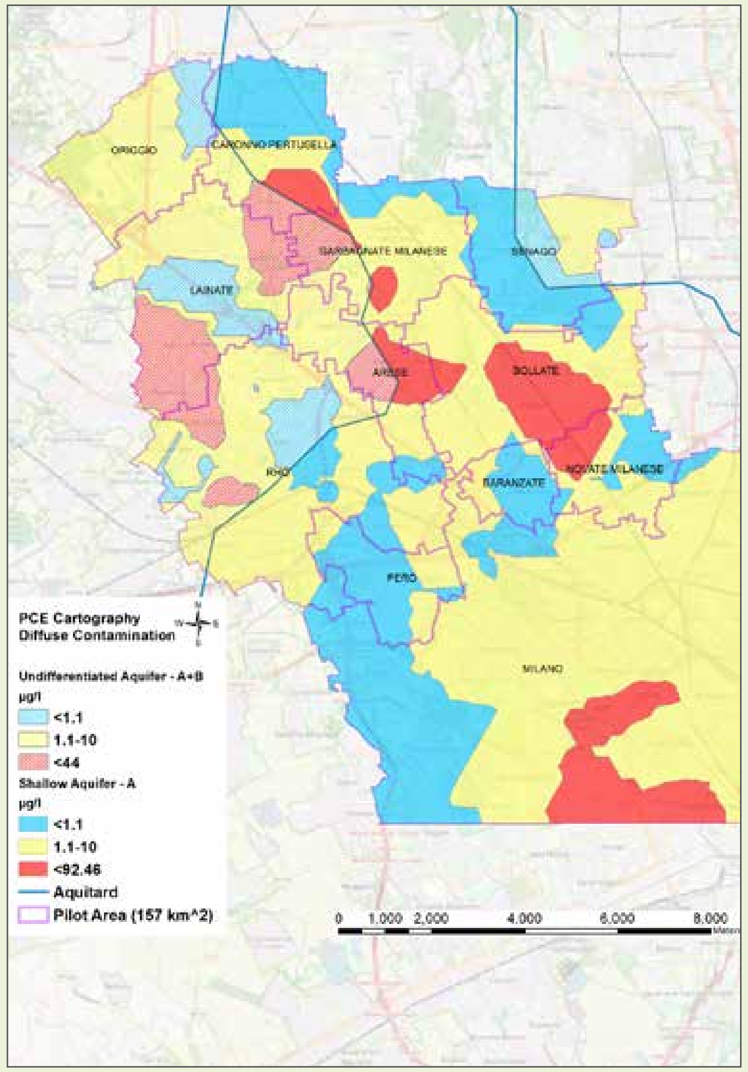


Figure No. 15 - Spatial distribution of the diffuse PCE contamination in the undifferentiated and shallow aquifers

tamination and the monitored values are in general less than 10 µg/l. The median values (2010-2017) show that values in large part of the pilot area are under the threshold values for drinking water, whereas nearby the suspected sources the values are higher than 100 µg/l. The reference standard defines the concentration thresholds for aquifers to guarantee human health are defined by the decree and, among the others, establish the limit values for PCE (1.1 µg/l) and for TCE (1.5 µg/l).

- Detect the six main plumes of contamination, depicting their extension, feature, possible evolution in time and space and the most probable origin/historical potential sources.
- Distinguish both point sources of contamination and relevant plumes from diffuse contamination (Fig. 14).
- Draw the maps of diffuse PCE contamination distribution associated to three ranges of concentrations representative for the diffuse contamination (Fig. 15).

The major critical issues emerged from the above technical outcomes, representing the picture of the groundwater contamination of the pilot area, have been dealt with the Management plan. In the Plan, specific actions for groundwater contamination prevention, monitoring and management have been defined with the aim to protect the public health and increase the awareness of the population on groundwater pollution in north-western Milan pilot area

ASSESSMENT OF NA POTENTIAL AS A REMEDIATION OPTION IN PARMA FUA (ITALY)

Introduction

Study area

Parma is a town in the North of Italy, with a population of about 200.000 inhabitants. The study area is placed in the urbanized territory of the Municipality of Parma (Fig. 16), and includes the historical downtown and recent settlements. The area is subjected by a dense urbanization, with a concentration of residential built up areas, trading and services. Historical gardens (Parco Ducale) are the North boundary of the study area. The mean ground elevation is about 55 m above sea level.

Hydrogeology

The area presents a flat morphology softly sloping to N-NE, following the course of alluvial conoids that have been deposited by the Taro, Parma and Baganza Rivers (all the waterways flow through the municipal territory). The study area is located in hydrographic left of the Parma River (Fig. 18).

The Quaternary drifts present ribbon-like and lens-like structures that lengthen following the stream that laid them down and that are mostly made of

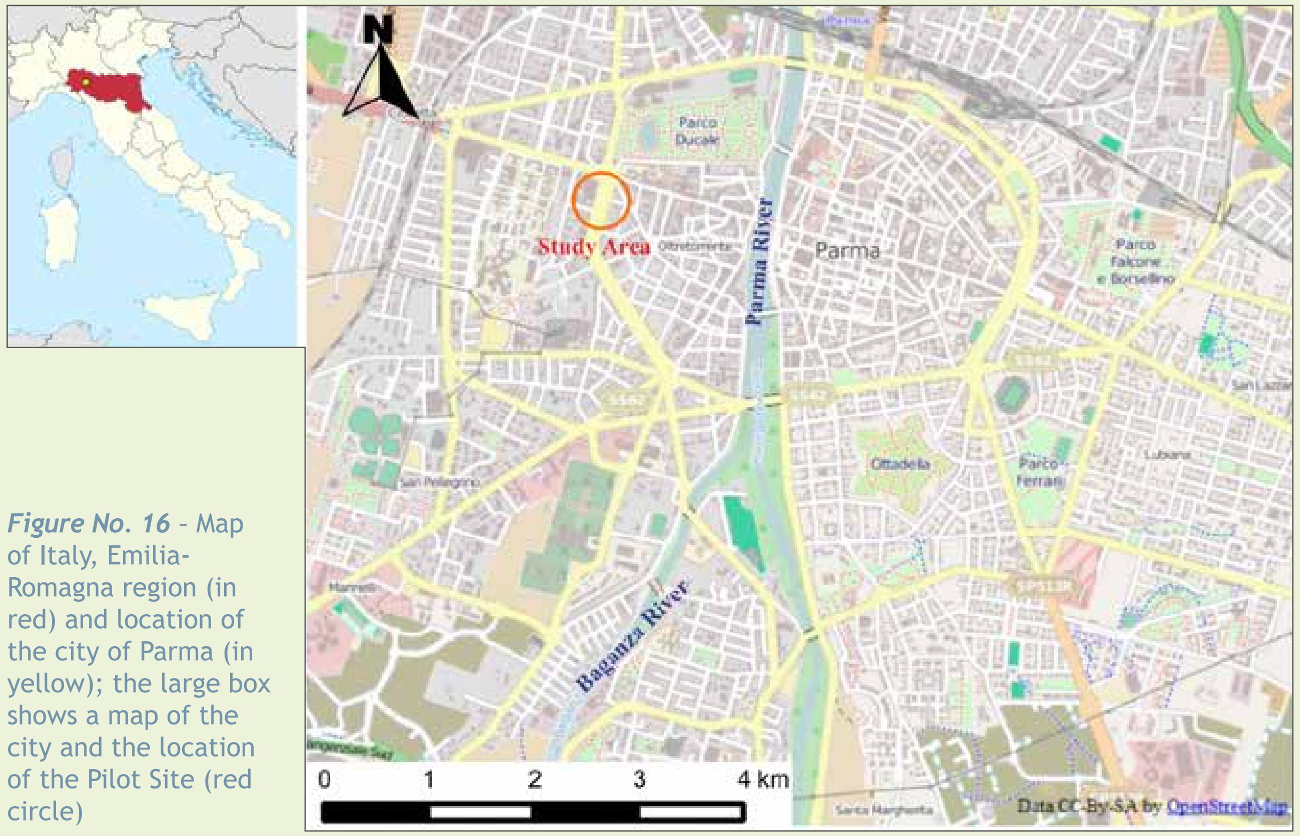


Figure No. 16 - Map of Italy, Emilia-Romagna region (in red) and location of the city of Parma (in yellow); the large box shows a map of the city and the location of the Pilot Site (red circle)

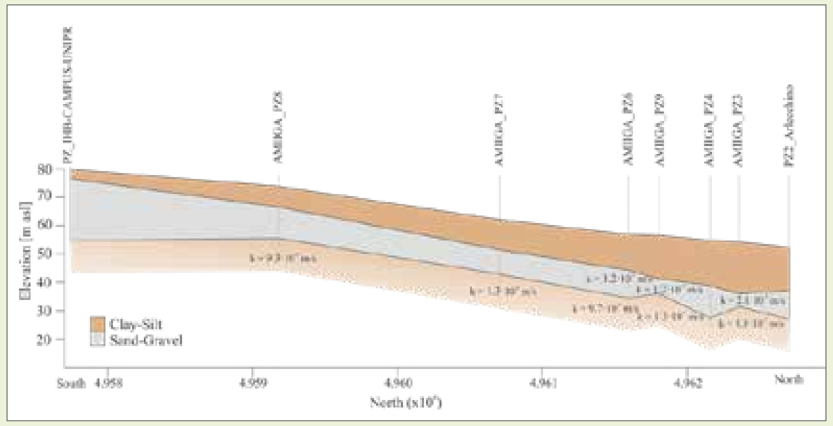


Figure No. 17 - North-South hydrogeological cross section

heterogeneous clastic sediments, from gravelly to clayey (with sudden spatial variations). Fig. 17 shows, as example, the North-South hydrogeological cross section that crosses at the pilot site.

Contamination

The first information about the groundwater pollution (presence of hydrocarbons, Methyl tert-butyl ether - MTBE, Benzene, Toluene, Ethylbenzene, Xylenes - BTEX) was collected in 2002 during a reclamation procedure on an area in which was located a gas station. At the end of the procedure, the sampling analysis showed PCE concentrations in groundwater higher than the law limits, even in piezometers upstream the gas station. From 2005 to 2015 the Perchloroethylene (PCE) concentration presents a positive trend up to 18-24 µg/l.

In February 2013 an historical analysis of the commercial activities, which potentially used PCE and were close to the study area in the 20-25 past years, has been carried out.

The knowledge at the beginning of the AMIIGA project did not allow to identify the source of the pollution and the extent of the plume; for this reason it was necessary to design and improve the environmental investigations.

In order to evaluate the Natural Attenuation as potential remediation method, seven sampling campaigns (from September 2017 to March 2019) were carried out on the designed monitoring network. During the sampling campaigns, water samples were collected for the analysis of the following compounds: Nitrate, Nitrite, Trichloromethane, Vinyl Chloride (VC), Trichloroethylene (TCE), Perchloroethylene (PCE), 1,1-Dichloroethylene (1,1-DCE), 1,2-Dichloroethylene (1,2-DCE), Ethylene, Trichloroacetate and Ethanediol. Moreover, water sample were collected for the evaluation of the bacteria that are present at the pilot site and for isotope analysis.

The sampling campaigns performed by AMIIGA have showed that the main pollutant was PCE. TCE was always below law limits; 1,1 DCE had values above law limits only in the second sampling round (December 2017) and VC was detected only at AMIIGA_PZ5 during the second sampling campaign and at AMIIGA_PZ9 during the third SC, but with very low values.

At the moment, since the responsible of the contamination is unknown, according to Italian laws the Municipality of Parma has to bear the costs of the investigation and remediation. At the present state, the sources of the pollution are still unknown.

Threat to groundwater pollution in Parma FUA

- The hydrostratigraphic system is composed of aquifer reservoirs, juxtapose, overlapping and partially or totally isolated by barriers of permeability made of sedimentary bodies, whose predominant element is fine.

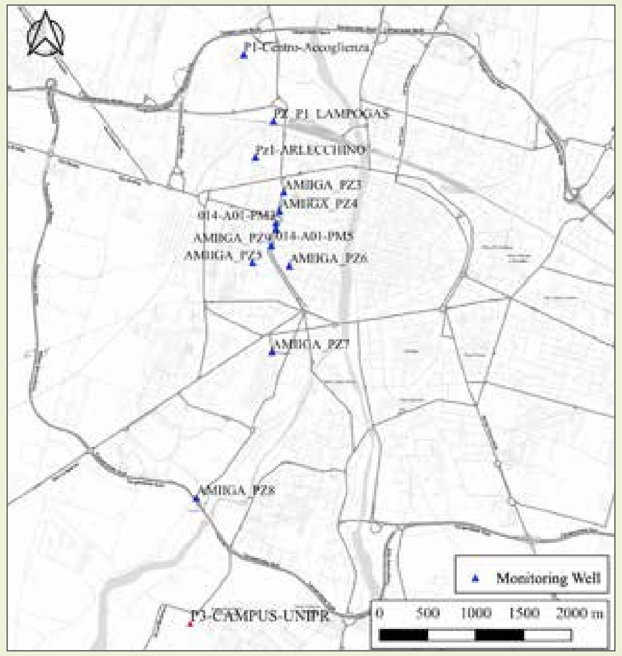


Figure No. 18 - Monitoring network

- The groundwater interested by the pollution is between 9.0 to 18.0 m depth.
- The first aquifer that feeds the city aqueduct is at least 36.00 m deep the ground level.
- The local environmental authorities are aware that the pollution could be drained in the deeper aquifer (feeding the city aqueduct).

Benefits from AMIIGA project to Parma FUA

The application of the AMIIGA project has led us to identify a new situation of contamination of the shallow aquifer around the Arlecchino kindergarten: the adopted consequence is the start of a technical-bureaucratic process that will lead to manage the pollution phenomenon: a risk analysis will be elaborated.

A second action was the development of the groundwater monitoring network within the urbanized area of Parma: seven new piezometers were drilled, that allowed and will allow to control the quality of the groundwater environment in the area of the Oltretorrente (Fig. 18). These infrastructures could also be used for general clean-up operations should the need arise.

The Technical University of Liberec analysed the water samples of two sampling rounds (December 2017 and May 2018) using the innovative Bio-Molecular Techniques. These analyses allowed to identify the presence of denitrifying bacteria, sulfate-reducing bacteria and BTEX degraders and only slightly active organohalide respiration.

These results indicated that there was not an effective degradation of CHCs, which meant that the Natural Attenuation at this stage was not an option in the remediation process of Parma pilot site. On the other hand, the observed concentrations were not very high and presented a variability during the hydrological year.

Nitrite was always close or below the detection limits except in the Galasso Channel, whereas Nitrate was always below law limits. Furthermore, denitrifying bacteria were detected. The Nitrites and Nitrates now do not represent a contamination problem at the pilot site; however a Natural Attenuation of Nitrate is already observed.

The isotope analysis on 18O and 2H performed by University of Parma indicate that surface water and groundwater coming from the Apennines are feeding the shallow aquifers within the Parma plain. Groundwater and surface water have a strict connection upstream the city of Parma. The isotope analysis on 13C performed by Politecnico di Milano, unfortunately, due to the low PCE concentration values did not provide any significant result.

Two groundwater numerical models have been developed. The first was developed at FUA scale in order to evaluate the main groundwater flow direction and to roughly identify the hydraulic parameters of the aquifer, whereas, the second model was developed at pilot site scale and aimed at reproducing with high details the geometry of the shallow investigated aquifer. The local model kept into account all the data collected during the project development. Both numerical models were calibrated in transient conditions, thanks to the available and new data. The model at FUA scale covers an area of about 630 km^2 and spans from Apennines to the Po River, whereas the local model (about 9 km^2) is focused just upstream and downstream the pilot site area. The numerical model at pilot area scale was applied to: identify the mean flow direction at local scale; estimate the mean hydraulic conductivity of the aquifer; reproduce the seasonal variability of the water table; perform transport simulations starting from potential sources.

After the calibration, the numerical model was applied to perform backtracking analysis in order to delimit the potential source areas. Thanks to the work carried out by the Municipality of Parma to list the potential contaminant source sites and the Web-GIS, it was possible to overlap the backtracking results to potential sources, such as: Car Garage, Deposit, electrical Plant, Laundry, Leather works and Mechanical Construction. After an analysis of the potential sources, timing and groundwater velocities, one source was identified as the most probable.

A simplified transport simulation was performed to reproduce the hypothetical contaminant evolution from the identified source. In particular, it was assumed to consider a conservative contaminant and a constant injection (1 mg/L) at a potential source for ten years; then the plume evolution was observed for other 20 years. Fig. 19 shows the plume evolution for 30 years with a time step of 5 years.

Performed Pilot Action A.T2.4 - Implementation of Pilot Action 4: Assessment of NA potential as a remediation option in Parma FUA (IT) has met planned expectation and brought the following achievements:

- collection and organization of all available hydrogeological and chemical data on Web GIS and GIS platform,
- development of a new monitoring network with the drilling of seven new to monitor the development of groundwater pollution,
- development of groundwater numerical model at FUA scale and at local scale,
- chemical, isotope and BMT analyses were performed to evaluate the NA feasibility.

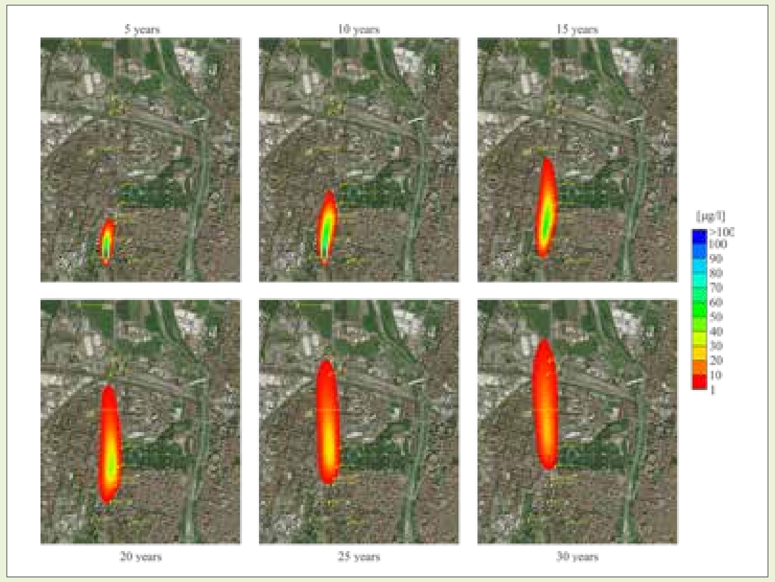


Figure No. 19 - Contamination plume evolution from hypothetical source

PILOT ACTION 5

Figure No. 20 - The aerial photo of the town centre

N-SITU BIOLOGICALLY ENHANCED REMEDIATION IN NOVY BYDZOV FUA (CZECH REPUBLIC)

Introduction

Novy Bydzov (Fig. 20) belongs to the smaller towns in the Czech Republic, with the population of about 7,200 people. It covers the area of 3528 ha. The town was founded in 1305, originally as a royal town, and it was an important administrative centre of the Cidlina Region in the past.

Industry in the city has developed in the 19th and 20th century. Industrial plants, such as machinery plants, metal cutting plants, metal foundry plants, plants for chemical treatment of metals etc., were scattered within the town and a lot of them were situated in the vicinity of residential areas. State owned enterprises were privatized in the 90s of the last century. Some industrial plants were later abandoned or closed as a consequence of bankruptcy or economic inefficiency. The improper handling of hazardous compounds (such as chlorinated hydrocarbons, mineral oils etc.) caused during the communist period uncontrolled contamination of Quaternary aquifer.

A serious health problem of a citizen living beside a ruined and closed KOVOPLAST Plant was discovered in 2007 as a consequence of drinking contaminated water from a private well. The level of groundwater contamination from chlorinated aliphatic hydrocarbons has reached thousands of micrograms per litre.

The City of Novy Bydzov as the responsible authority for groundwater, drinking water and contaminated site management and as land owner has started to initiate measures to protect the public health and has carried out groundwater investigations in the first two decades of 21st century:

- ***Participation in the project FOKS (CE 2008-2013)***
  - Assessment of health risks arising from previously identified contamination of groundwater in the premises of the former KOVOPLAST Plant.

- Identification of other potential hot spots of groundwater contamination in the territory of the City Novy Bydzov, their verification and assessment with regard to possible health impacts on the population, sources of drinking water and other environmental aspects.

- ***Participation in the EU fund Operation Programme – Environment (EU 2012-2015)***
  - Detailed supplementary exploration of the polluted locality for further design of remedial measures.
  - Testing of suitable remedial technologies for removal and reduction of the pollution of groundwater.

Threat of groundwater pollution to FUA Novy Bydžov

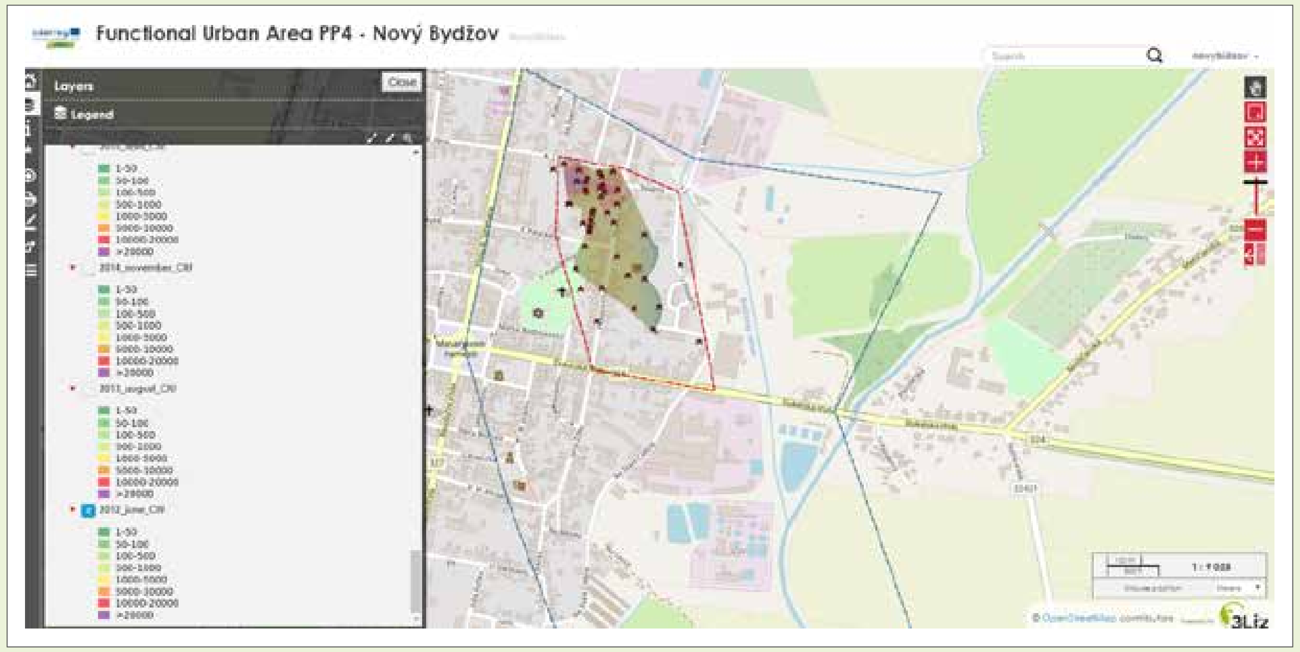
The processed Risk analyses (2010, 2015) have confirmed serious potential risks on human health in residential area surrounding the former plant KOVOPLAST. A numerical model of groundwater flow developed for the city of Novy Bydzov has confirmed that quality of the groundwater body in FUA Novy Bydzov as well as the quality of the surface water body in the Cidlina river basin (covering the area of 176 km²) could be affected from the pollution if no mitigation action is performed.

Environmental burns (Fig. 21) threaten public health, preventing residents use groundwater for drinking and utility water, complicating prepared investment projects in Novy Bydzov area and affecting the quality of surface water of the river Cidlina that represents the main drainage bases of Quaternary aquifer in region.

Benefits from Project AMIIGA to FUA Novy Bydžov

In the project AMIIGA, the innovative remedial technology Biological Enhanced Reductive Dehalogenation (BRD) has been applied for decreasing the contents of chlorinated hydrocarbons in groundwater in the working area in FUA Novy Bydzov. The

Figure No. 21 **-** Concentration of suma chlorinated hydrocarbons in groundwater - FUA Novy Bydzov (June 2012) (webGIS toll developer in AMIIGA)

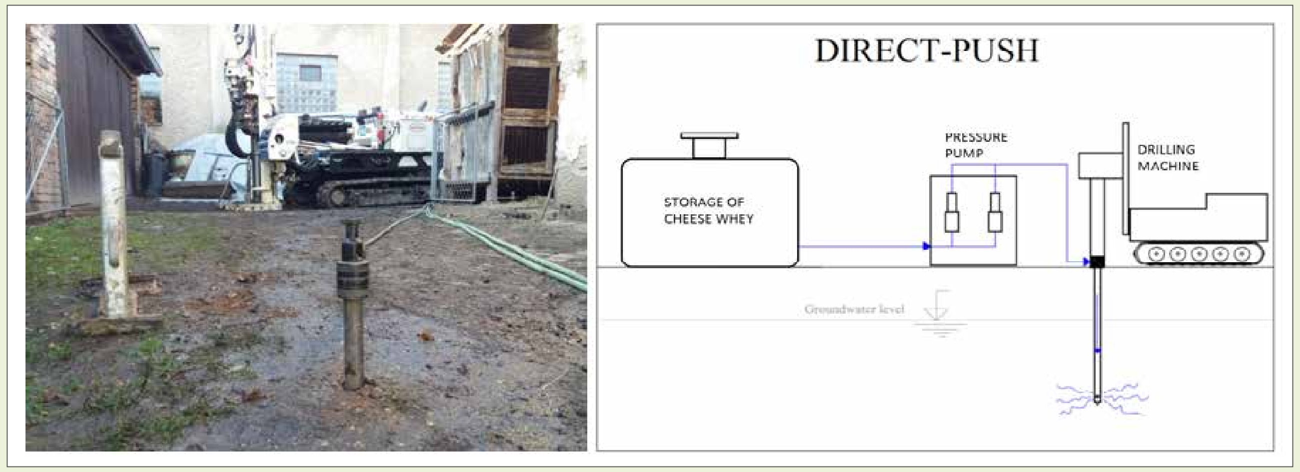


Pilot Action Novy Bydzov demonstrates the exemplary case study of processing the biologically enhanced remediation of groundwater polluted with chlorinated hydrocarbons. Pilot Action in FUA Novy Bydzov performs the key steps assuring the effective and sustainable remediation- testing remedial procedures in laboratory scale, then verifying in the field in pilot scale before the full scale application.

During AMIIGA project the following activities were performed in Pilot Action Novy Bydzov.

- ***Supplementing of monitoring network***
  - The existing system of monitoring wells at the Novy Bydzov built in the years 2012-2015 were supplemented with 5 new monitoring wells.
  - The location of the new wells was based mainly on the possibility to fill in the missing data on the actual extent of groundwater contamination and to improve the planned remediation of the groundwater therein.
- ***Monitoring the development of groundwater pollution in the working area***
  - The monitoring program was carried out twice a year. The initial groundwater monitoring campaign was carried in January 2017. The next campaigns were performed in June 2017, in November 2017, in July 2018 and in December 2018.
- ***Specification of groundwater and dissolved pollution transport pathways***
  - Evaluation of datasets with historical data from remediation works (2012 – 2015).
- ***In-situ biologically enhanced attenuation***
  - Laboratory test of remedial technique was conducted in laboratories of Technical University in Liberec between January and April 2017 Four different carbon sources (lactate, glycerol, cheese whey and PHB (polyhydroxybutyrate)) have been tested and basing on several analyses (BMT, pH, ORP, conductivity) the best one was chosen for application in situ. Further, various oxidants were tested in order to evaluate the removal of contaminants from Novy Bydzov groundwater. The tests helped to specify the parameters of the remediation in the scale of field test.
  - Field Pilot Test of technology BRD (biologically enhanced dehalogenation) was tested in area located eastward from the former plant Kovoplast (the main source of groundwater pollution). Application of cheese whey was performed in three separate rounds via direct-push technique in the inflow area of the monitoring wells. Particular application rounds were conducted in November 2017, December 2017 and May 2018 (Schema of the direct-push application is shown in the Fig. 22).

Figure No. 22 **-** Schema of direct-push injection.



- Groundwater operational monitoring was performed with the objective to evaluate efficiency and progress of remedial technology BRD. Monitoring was conducted once before the first injection of cheese whey in November 2017 and then monthly until nowadays. Bio-molecular tests (BMT) were used to characterize microbial specific degraders according to relevant contamination of CHC.

Performed Pilot Action A.T2.5 - In-situ biologically enhanced remediation has met planned expectation and brought the following achievements:

- Collection and systematization of all available hydrogeological and chemical data on Web GIS and GIS platform,
- Creation of a supplementary network of monitoring wells to monitor the development of groundwater pollution,
- Reduction of CHC groundwater pollution at the testing site (Fig. 23),
- Defining the extent of the contamination plume in the southern part of the area of interest and identifying 2 new sources of pollution,
- Confirmation of suitability of BRD application as the main procedure for removal of CHC contamination in the contamination plume on the site of Novy Bydzov,
- Processing methodology for BMT application in biodegradation method BRD,
- Processing methodology for the removal of groundwater contamination CHC.

The development of groundwater pollution during the testing of innovative technologies is illustrated in the Fig. 23.

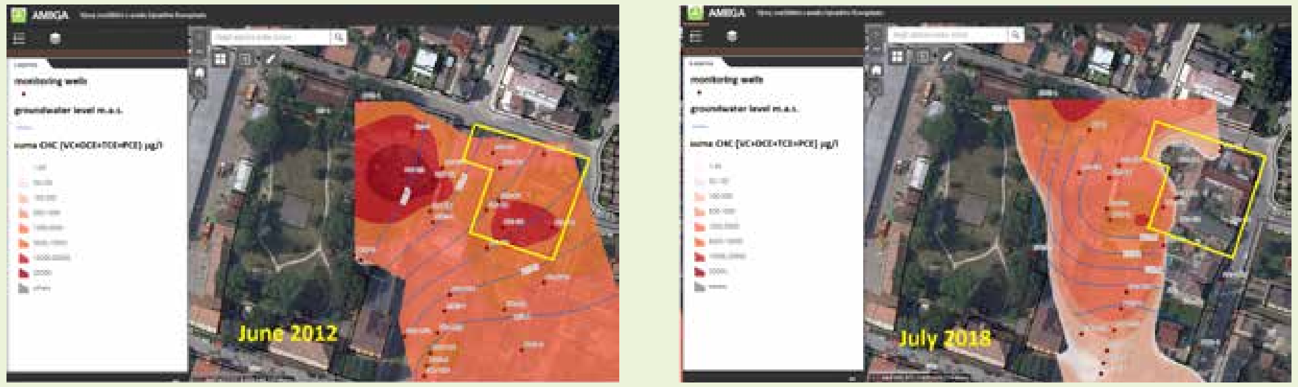


Figure No. 23: Development of concentrations of suma chlorinated hydrocarbons in groundwater - the former plant KOVOPLAST and its vicinity (2012-2018) (webGIS toll developed in AMIIGA)

CONSTRUCTION AND MONITORING OF BIOREACTIVE BARRIER WORKING IN JAWORZNO FUA (POLAND)

Introduction

The city of Jaworzno is located in the southern part of Poland, in the eastern part of the Silesia Province - the most industrialized area in Poland. Jaworzno FUA covers core part of the Jaworzno Municipality and adjacent cities partially located within the boundaries of the groundwater body No. 146 (Fig. 24 and Fig. 25).

Jaworzno is among the largest towns in Poland - its area is 152.7 km^2 with more than 94.000 inhabitants. In 20th century Jaworzno's economy has been based on power engineering connected with the extractive industry, cement and chemical industry which have affected far-reaching transformations of components of the environment. The most significant transformations affected surface water and groundwater. Jaworzno's biggest environmental problem is the impact of pollutants from the chemical industry in the valley of the Wąwolnica stream (Fig. 26).

The valley of the Wąwolnica stream is contaminated as a result of activity of chemical industry dating back to the 1st World War period, with the highest intensity from the 60's to 80's of the 20th century. The site of former Chemical Plant Organika-Azot S.A. plant was recognized by the Helsinki Commission as one of the most important industrial (chemical) "hot spots" in the Vistula River Basin - dangerous sources of potential contamination for the Baltic Sea basin[1]. Up to now more than 195 thousand tons of hazardous wastes have been recorded in this area

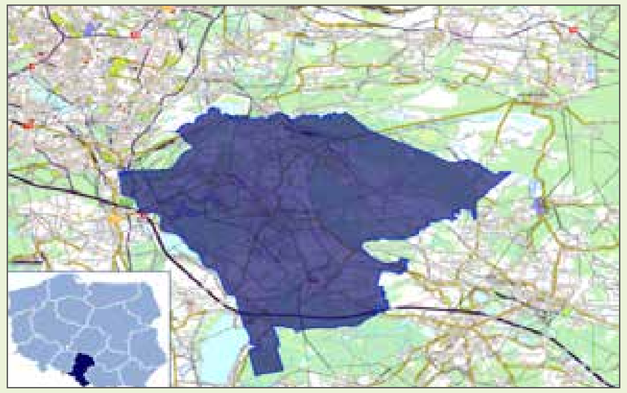


Figure No. 24 - Location of Jaworzno Municipality (source: GIG elaboration based on http://mapy.geoportal.gov.pl and https://commons.wikimedia.org)

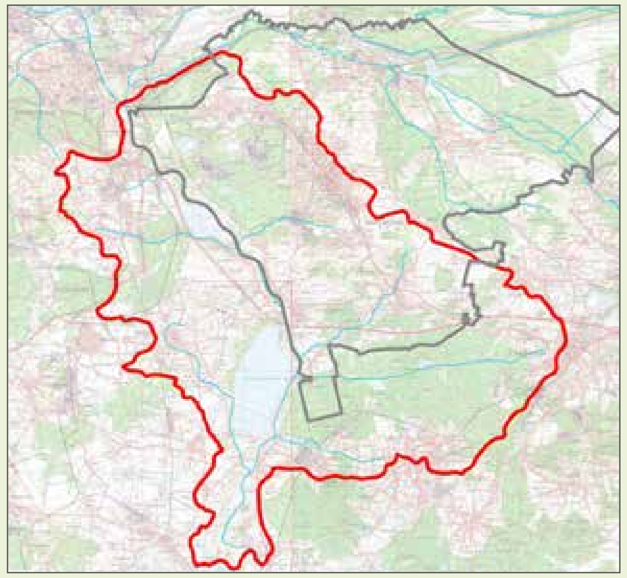


Figure No. 25 - FUA Jaworzno (red colour of boundaries) with indicated boundaries of Jaworzno Municipality (grey colour) (source: GIG elaboration)

---

[1] A list of significant pollution sites around the Baltic Sea – HELCOM Hot Spots – was established in 1992; http://www.helcom.fi/Documents/Action%20areas/Industrial%20releases/List%20of%20hot%20spots%20as%20per%20December%202015.pdf

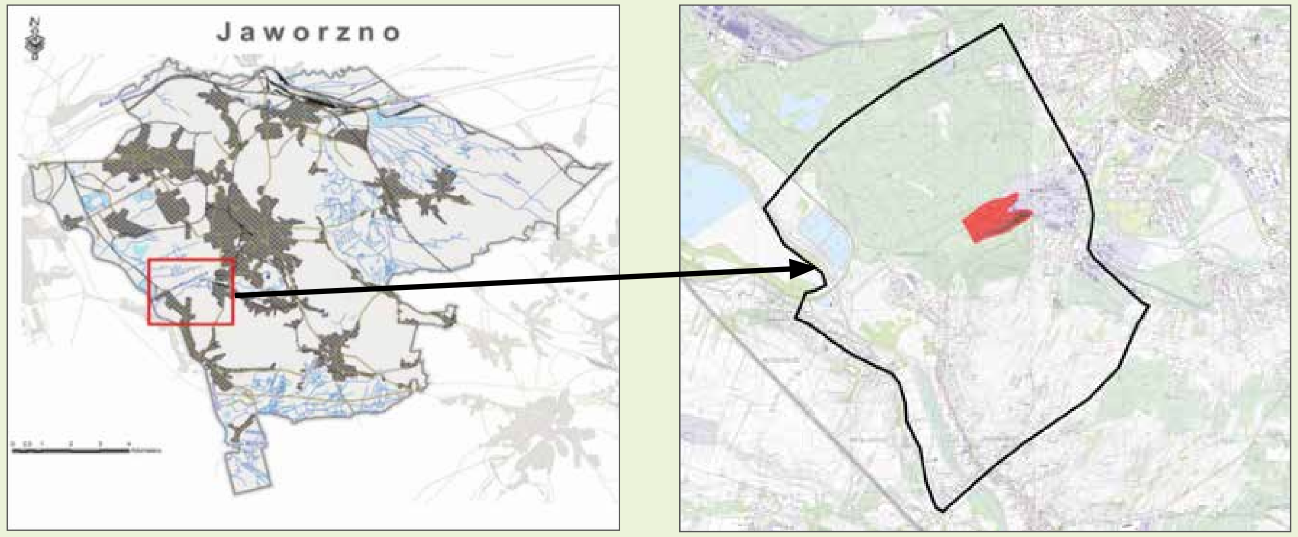


Figure No. 26 - The location of contaminated site in Jaworzno Municipality with indicated plume of contaminants, Trzaski et al. 2012

and their adverse effect on the environment, especially soil, groundwater and surface water has been confirmed[2]. Among the disposed wastes there are hundreds of dangerous, persistent toxic substances, such as: pesticides, their semi-finished products and partial decomposition products. Some of them, like - DDT, DDE, DDD, dieldrin, endrin, alpha-HCH (α-HCH), beta-HCH (β-HCH), gamma-HCH (δ-HCH) are considered as posing particular threat to the environment and are included in the list of persistent organic pollutants (POPs) under the Stockholm Convention.

AMIIGA project, focused on multiple characterization, assessment and management strategies, intended to build and capitalize on the results of former Interreg Central Europe project FOKS (Focus On Key Sources of Environmental Risks), which had been realized in the years 2008-2012 by Central Mining Institute with the City of Jaworzno. The activities implemented within FOKS project concerned the identification of key sources of groundwater contamination in the most contaminated area of Chemical Plant Organika-Azot S.A. and the nearby waste disposal area – Central Landfill (CSO) in the Wąwolnica stream valley (including a former sand pit "Rudna Góra"), as well as selection of best technology to stop the contamination emission and development of general concept of remediation.

The further and more detailed remediation concept for Jaworzno contaminated site was developed in the years 2014-2015 within Multi-variant Technical and Environmental Analysis (WATS[3]) carried out by GIG in 2015 at the request of the City Council of Jaworzno as part of the project titled "Activities aimed at solving the problem of hazardous waste accumulated in the valley of the Wąwolnica stream in Jaworzno - stage 1".

Threat of groundwater pollution to Jaworzno FUA

The main waste collection place in Jaworzno is the former sand pit "Rudna Góra". Although part of the contaminants is being captured through a trench system constructed at the bottom of the former sand pit, the groundwater is still being contaminated. The level of groundwater contamination from HCH is being from several to hundreds of micrograms per liter.

The contaminant plume migrated downstream, along the post-glacial valley of the Wąwolnica stream, according to the general groundwater flow direction. The analyses of risk carried during FOKS project have confirmed serious environmental risk in Jaworzno site. As part of AMIIGA project, a groundwater Management plan has been created, including, among others, concept for the regional monitoring network and specific action plan covering activities to be performed in different periods of time.

Within AMIIGA project also actions reducing the impact of the identified groundwater contamination plume have been carried out, including modernization of the monitoring network in the area of the Wąwolnica stream valley and in the Przemsza river valley for better tracing of the contamination of groundwater pollution. The results of AMIIGA project showed that there are two plumes of contaminants differing in types of HCH isomers and their concentration. The northern plume is mostly contaminated with b-HCH. And the second plume containing α-HCH, β-HCH and δ-HCH with the concentration of sum HCH even above 100 ug/l was noticed on the south of the Wąwolnica stream (Fig. 27).

The one plume with the concentration of HCH between 10-100 µg/l was observed in the north of the Wąwolnica stream (Fig.4).

Benefits from AMIIGA Project to Jaworzno FUA

In the AMIIGA pilot action, the novel technology of passive bioreactive barrier (PRB) has been applied for decreasing the contents of HCH in groundwater in the area of groundwater contamination with pesticides downstream the Chemical Plant Organika-Azot S.A. PRB technology is a novel groundwater remediation method which allows to combine of physical, chemical and bio-

Figure No. 27 - The spatial distribution of HCH: A. The differences in concentration of HCH in the northern and southern plume of contaminations; B. The proporotion between various isomers of HCH in the monitoring points: aHCH (a, grey); bHCH (b, red); dHCH (d, blue); gHCH (g, yellow); eHCH (e, beige) - Jaworzno FUA (June, 2017) (source: results of sampling campaigns during AMIIGA)


A.

B.

---

[2] • For example: in regional documents, such Environmental Protection Program for the Silesian Voivodship until 2019, with a view to the year 2024, https://www.slaskie.pl/download/content/67075

[3] • Wariantowa Analiza Techniczno-Środowiskowa (WATS) pn. „Działania zmierzające do rozwiązania problemu odpadów niebezpiecznych zgromadzonych w dolinie potoku Wąwolnica w Jaworznie - etap 1", Główny Instytut Górnictwa, Katowice 2015

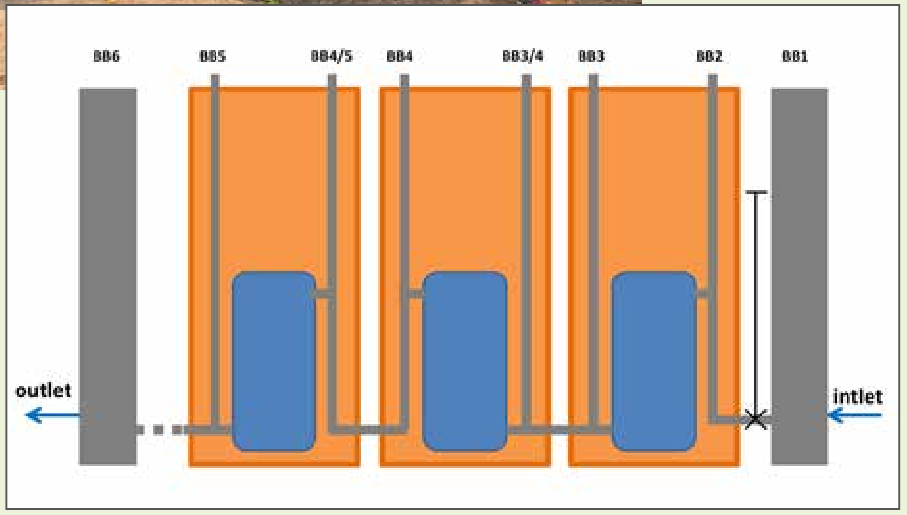


Figure No. 28 - Scheme of the reactive barrier (source: GIG elaboration, AMIIGA)

logical in situ treatment of contaminated groundwater using different reactive materials, such as: iron chips, sand, peat, biochar and bacteria inoculum. The barrier was built in the funnel and gate system with impermeable funnel walls and 3 chambers connected together (gates). (Fig. 28).

The impermeable funnel is used to channel the contaminant plume into chambers 1, 2 and 3 (I stage) or 1 and 2 (II stage) which contains the reactive material. The main goal of investment implementation is to test the effectiveness of the reactive barrier with microbiological deposit (especially prepared for this pilot action), as an appropriate component used for bioremediation of groundwater environment contaminated with persistent organic compounds, to eliminate migration of contaminants, as well as to identify possible difficulties and the potential impact of carried works on the health of residents and the environment.

Within AMIIGA project the following activities were performed in the contaminated sites of Jaworzno FUA.

- ***Supplementing of monitoring network***
  - Upgrading system of monitoring wells which was built in 2010 in the framework of FOKS project, by cleaning existing research points (partially devastated and clogged) and construction of three new monitoring wells.
  - The implementation of new wells was necessary to improve monitoring process of the current state of the environment at the Jaworzno site and to obtain the missing data on the actual extent of groundwater contamination.
- ***Monitoring the development of groundwater pollution in the working area***
  - The monitoring program was carried out once a year. The initial groundwater monitoring campaign was carried in June, 2017. The next campaigns were performed in June, 2018.
- ***Modelling of dissolved pollution transport in a different scenarios***
  - Development of dissolved pollution transport pathway in a 5- and 25- years perspective.
- ***Monitoring the efficiency of groundwater treatment by the bioreactive barrier***
  - Pilot test of bioreactive barrier technology was provided in the area so-called “old heap near the tracks” located nearly the Chemical Plant Organika Azot S.A. in Jaworzno.
  - Implementation of the bioreactive barrier was preceded by the preparing actions:
    - Determination of geotechnical conditions in the place of localization of the barrier.
    - Selection of appropriate sorbent for the barrier.
    - Isolation and preparation of bacteria inoculum to application into the reactive zone of barrier in order to enhanced the treatment of groundwater.
    - Development the concept and then the technical project of the reactive barrier.
    - Acquisition of necessary permissions and the installation.
  - The operational monitoring of the bioreactive barrier was performed with the objective to evaluate efficiency and progress of remedial technology.
  - Monitoring was conducted from May 2018 until nowadays. The samples for physical, chemical and biological analysis were taken twice a month. Laboratory tests were conducted in laboratories of Technical University in Liberec. The isotope analysis of groundwater samples was conducted in laboratory of Polytechnic of Milan.
  - Three different reactive materials (reactive iron, peat&sand and biochar) have been tested separately and in combination in order to evaluate the effectiveness of HCH sorption and reduction. During sampling process, several physicochemical analyses (pH, ORP, conductivity, temperature and oxygen concentration) were measured. The test help to determination of sorption capacity of peat&sand bed, the reduction process effi-

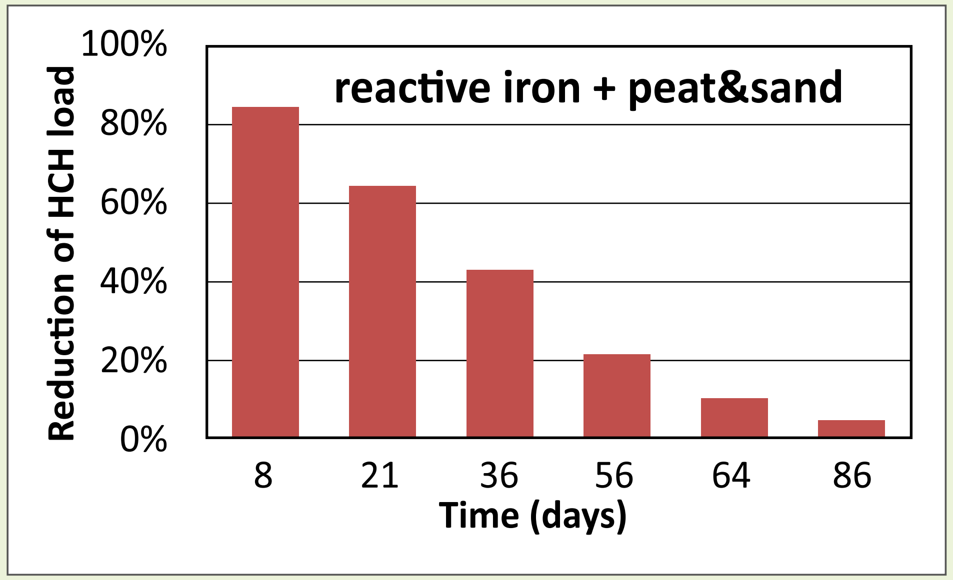


Figure No. 29 - The effectiveness of HCH load reduction by 2 chambers reactive biobarrier contains: cartridge I: (reduction process by reactive iron) and cartridge II: (sorption process with peat&sand bead) (source: GIG elaboration, AMIIGA) ciency by using iron chips, and to specify the parameters of the remediation in the pilot scale.

Performed Pilot Action A.T2.6 - Passive GW treatment by bioreactive wall in Jaworzno FUA (PL) has met planned expectations and brought the following achievements:

- Reduction of HCH groundwater pollution at the testing site (Fig. 29).
- Confirmation the potential of the passive bioreactive barrier technology for groundwater treatment application, especially in the term of HCH pollution removal.
- Indicating the technical guidelines for groundwater treatment by using reactive materials as sorbents in the passive reactive barrier technology.
- Processing methodology for BMT application in monitoring of treatment progress by the passive bioreactive barrier.
- Processing methodology for the removal of groundwater contamination with HCH.

The effectiveness of sum HCH and various HCH isomers reduction by 2 chambers reactive biobarrier is illustrated in the Fig. 29 and Fig. 30.

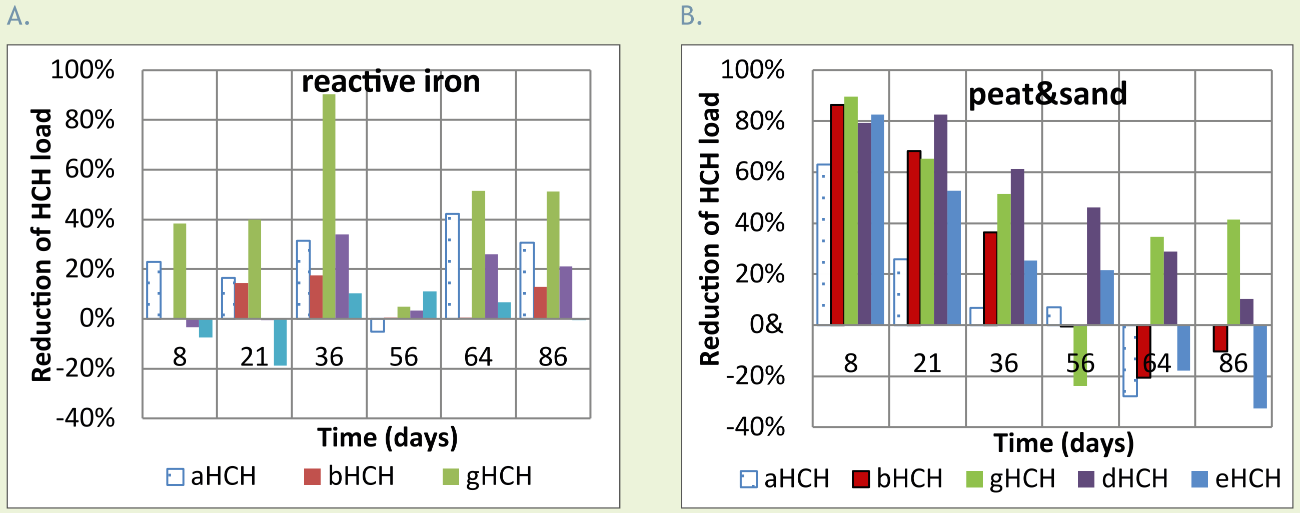


Figure No. 30 - The effectiveness of various HCH isomers reduction by 2 chambers reactive biobarrier: A) The effectivness of HCH isomers reduction via cartridge I: (reduction process by reactive iron); B) The effectivness of HCH isomers reduction via cartridge II: (sorption process with peat&sand bead) (source: GIG elaboration, AMIIGA)

Figure No. 31 City district Feuerbach.

INTEGRAL MONITORING OF REMEDIAL MEASURES EFFICIENCY (STUTTGART-FEUERBACH FUA, GERMANY)

Introduction

The city district Feuerbach (Fig. 31) is historically characterized by many industries and small commercial entities, handling with hazardous substances, which led to severe soil and groundwater contamination generated over the past decades. Since 1983/84, the private responsibles and municipality have investigated and remediated sites in Feuerbach that are contaminated with volatile chlorinated hydrocarbons (CHC). CHCs are of particular interest as pollutants, because they are (i) persistent and easily mobile in the underground, (ii) spread over a large area and (iii) endanger the quality of groundwater i.e. the Stuttgart's mineral springs (Vasin et al., 2016).

The integral investigation of CHC contamination in soil and groundwater in Feuerbach has been also previously supported by the EU-funded projects MAGIC and FOKS. Those projects focused on flow and contaminant description of the shallow aquifers (Fig. 32, working area). AMIIGA broadened the scope on the deep, regional aquifers (Fig. 32, FUA). Those are of particular importance in Stuttgart as they discharge 19 mineral springs, which are used for medical and spa purposes.

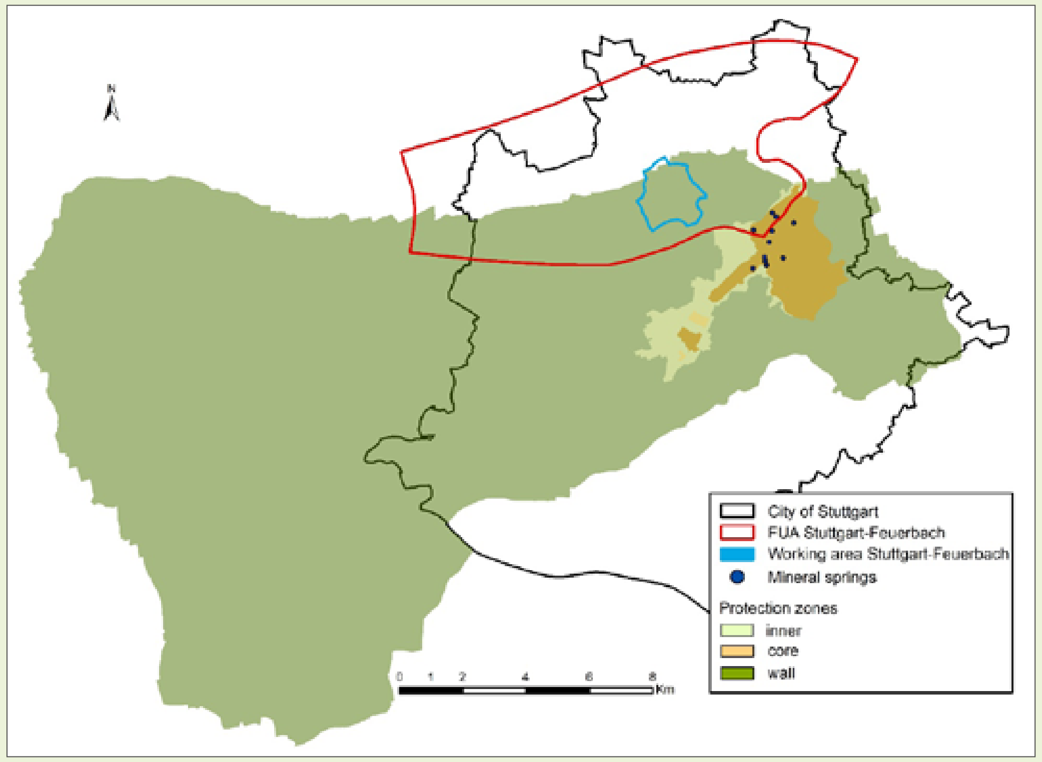


Figure No. 32 - Project areas (working area and FUA with mineral springs and their protection zones).

The goal of the pilot action was (i) to clarify the flow and contaminant situation in both shallow and deep aquifers, (ii) to understand potential pathways of contaminant migration into the deep mineral water aquifer and (iii) to design an efficient monitoring network that captures the integral contaminant situation. The pilot action met the planned expectations and achieved its goals.

Threat to groundwater in FUA Stuttgart-Feuerbach

Despite carried investigation and remediation measures over decades and current practices of environmental management, soil and groundwater are still remaining polluted in Stuttgart-Feuerbach. The integral groundwater investigations indicated that the threshold values (CHC concentration < 10 µg/l and load < 20 g/d) could not be fully achieved at some sites with reasonable efforts and budget. Still it was unclear whether and how the CHC contamination of Feuerbach affects the regional mineral water aquifer (Muschelkalk). A system to monitor the development of groundwater quality is missing.

Benefits from project AMIIGA to FUA Stuttgart-Feuerbach

AMIIGA project enabled the City of Stuttgart to address the issue of the existing mixed CHC-plumes in public areas and their potential threat to deep aquifers. Performed integral investigations in pilot action and investments enabled to update and improve the knowledge about groundwater flow and transport of CHCs in complex hydrogeological conditions. By identifying one major groundwater aquifer (Bochinger Horizont – BH) out of seven, it was possible to design an integral monitoring network (IMN), which was tested and proved to be effective for description of the integral contaminant situation in Stuttgart-Feuerbach. The obtained findings helped establishing a groundwater management plan for the working area Stuttgart-Feuerbach as well, aiming at a reduction of groundwater contamination and ensuring the good groundwater status.

During AMIIGA project, the following activities were performed:

- ***Data assessment***

All available data on flow and contamination were assessed. The origins of data and information were mainly from (i) the municipal database (BOISS/AquaInfo), (ii) the previous projects MAGIC and FOKS and (iii) several investigation reports of contaminated sites. The collected data and data gained in the project were imported into the database and evaluated.

- ***Development of conceptual models***

In order to develop a conceptual model, the following investigations were performed: (i) measurements of groundwater level on 227 monitoring wells, (ii) sampling and analysing CHC concentrations on 55 monitoring wells, (iii) 15 isotopic analysis on 10 monitoring wells, (iv) BMT groundwater analysis on 9 monitoring wells and (v) 10 BMT carrier analysis on 5 monitoring wells. Evaluation of all results enabled the development of the conceptual models for shallow and deep aquifers, describing the flow and contaminant situation in FUA Stuttgart-Feuerbach (Fig. 33).

- ***Development of a numerical model***

A 3D transient groundwater model was developed, based on the conceptual models and previous investigations. The model included seven aquifers from the quaternary to the limestone mineral water aquifer Muschelkalk. The program system MODFLOW with extended functions was used. Flow and transport of CHC were calculated between 2007 and 2017 for each aquifer (Fig. 34). The results were essential for the development of the management plan.

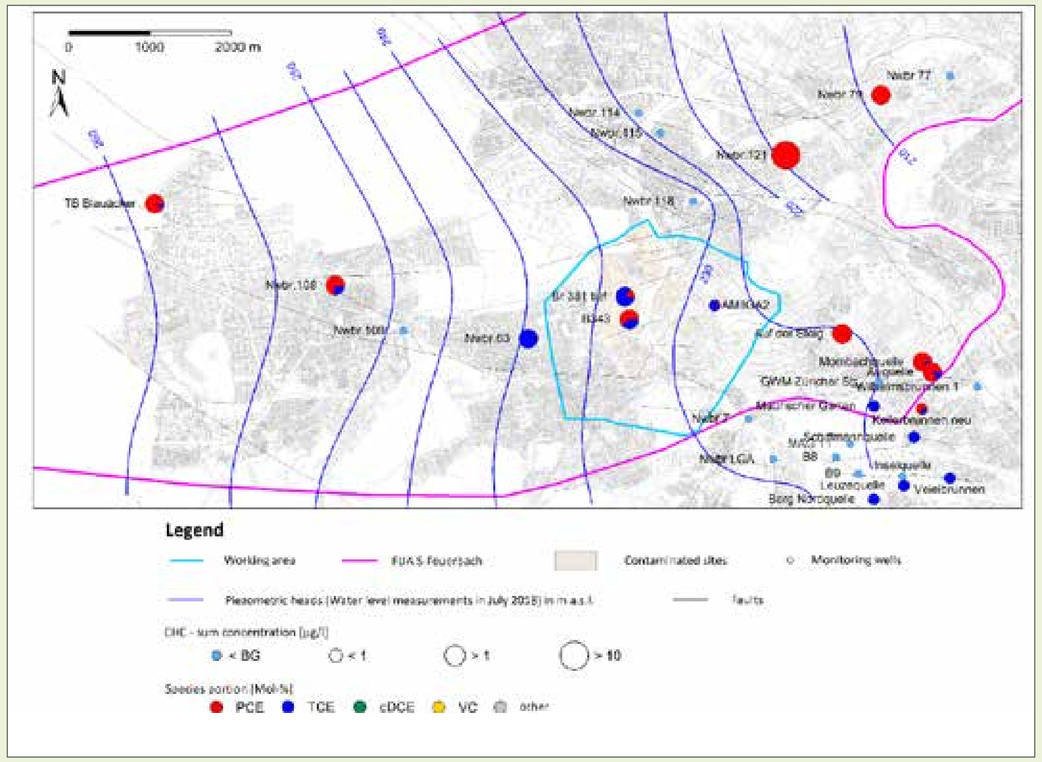


Figure No. 33 - Flow and contaminant situation in the mineral water aquifer Muschelkalk in FUA scale.

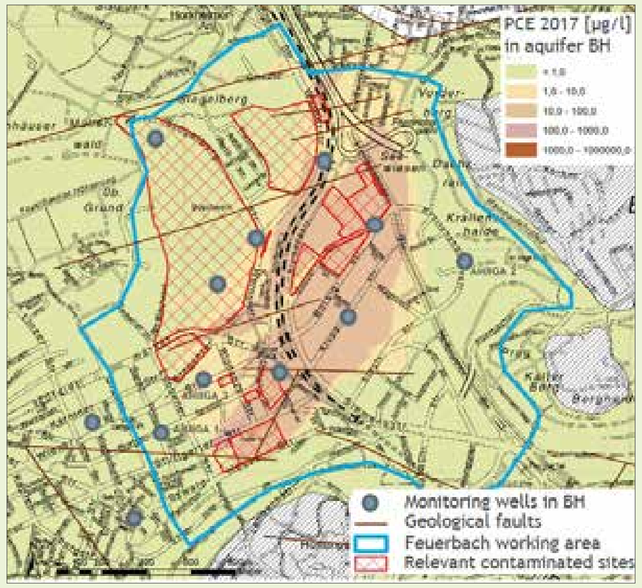


Figure No. 34 - Numerical model results for the CHC contaminant transport in the major groundwater aquifer.

- ***Drilling of new monitoring wells***

Within investment activities, three monitoring wells were constructed (Fig. 35):

(i) AMIIGA 1 with a depth of 32 m in order to check the vertical percolation of CHCs in the area of depression, built in the major groundwater aquifer BH,

(ii) AMIIGA 2 with a depth of 94 m in order to extend the monitoring network in deep mineral water aquifer, built in Muschelkalk and

(iii) AMIIGA 3 with a depth of 21 m to capture the northeastern gradient and to describe, evaluate and quantify a possible vertical transfer of CHCs to deeper aquifers, built in the major groundwater aquifer BH.

Figure No. 35 - Drilling cores of AMIIGA 2 monitoring well.

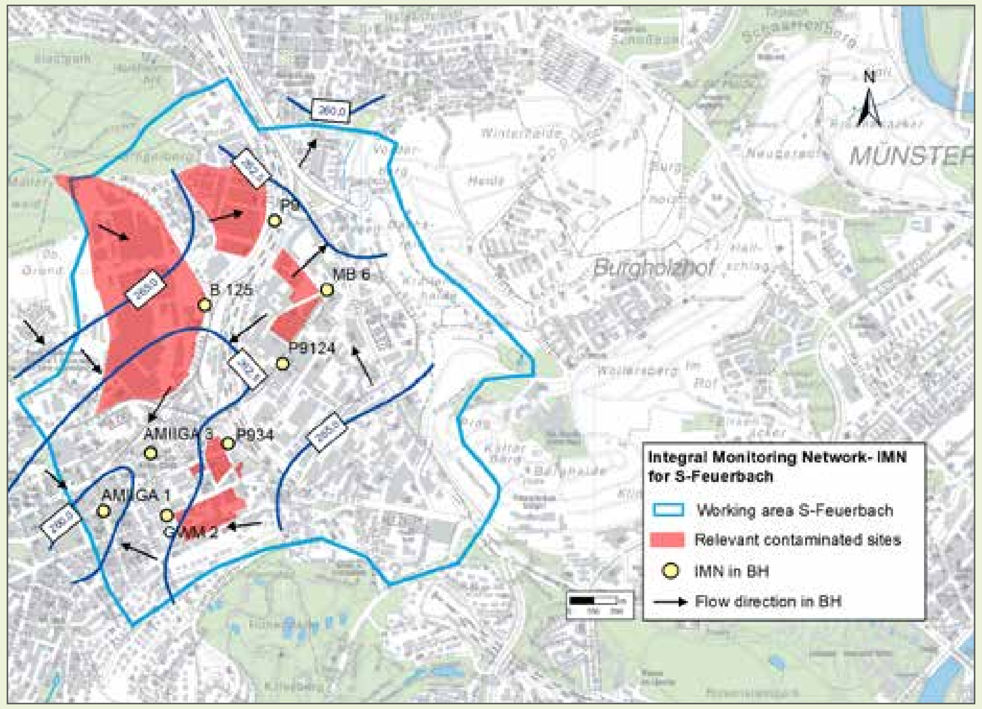


Figure No. 36 - Integral monitoring network in the working area Stuttgart-Feuerbach.

- ***Establishing of the integral monitoring network***

An efficient monitoring network (IMN) for Stuttgart-Feuerbach was designed. The wells of the IMN were selected to capture and describe the integral contaminant situation in the major aquifer BH (Fig. 36). One sampling campaign has been performed, which confirmed that IMN is efficient, enables further reduction of long-term monitoring costs and is easily transferable to other FUAs.

Literature

- **Vasin, S., Carle, A., Lang, U. and Kirchholtes H.J.** (2016): *A management plan for Stuttgart. Science of the total environment.* 704-712.
- **Gzyl, J. and Gzyl, G. eds.** (2008): *MAGIC Management of Groundwater at Industrially Contaminated Areas. INTERREG IIIB CADSES Programme.*
- **Trzaski, L, Gzyl, G. and Gzyl, J. eds.** (2012): *FOKS Transnational Guideline for Implementing Innovative Tools for Remediation. INTERREG IVB CENTRAL EUROPE Programme.*
- **Water Framework Directive** 2000/60/EC
- **OECD**, 2012

www.interreg-central.eu/AMIIGA

GIG

Jaworzno
źródło energii

STUTTGART

VODOVOD
KANALIZACIJA

TECHNICAL UNIVERSITY OF LIBEREC
www.tul.cz

Regione
Lombardia

Vodovod d.o.o.
Zadar

Comune di Parma

GeoZS
Geološki zavod
Slovenije

POLITECNICO
MILANO 1863

UNIVERSITY OF ZAGREB
FACULTY OF CIVIL ENGINEERING
HYDROTECHNICAL ENGINEERING DEPARTMENT