MANAGEMENT PLAN FOR STUTTGART-FEUERBACH

D.T3.1.3 | Pilot Stuttgart-Feuerbach

Version 2
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SUMMARY

The project AMIIGA has been initiated due a significant contamination of groundwater caused by the long-term and widespread use of contaminants in Central European urban areas. The goal of the project is to develop a strategic transnational management tool to manage groundwater contamination.

The focus of the AMIIGA is to establish a groundwater management plan for each of the seven AMIIGA partner pilot sites, considering technical, financial and legal aspects. The Department for Environmental Protection of the City of Stuttgart has developed a groundwater management plan for the city district Feuerbach.

Introduction

The city district Feuerbach (Fig. 1) 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. Thus, 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 mobile in the underground, (ii) spread over a large area and (iii) endanger the quality of groundwater i.e. Stuttgart’s mineral springs. The integral investigation of CHC contamination in soil and groundwater of Feuerbach has been also previously supported by EU-funded projects MAGIC and FOKS.

Figure 1 City district Feuerbach.

The integral groundwater investigations for Feuerbach performed in AMIIGA 2017 and 2018 indicated that the reference values (CHC concentration < 10 µg/l and load < 20 g/d) at some sites in Feuerbach could not be fully achieved with reasonable efforts and budget. Still it was unclear whether and how the CHC contamination of Feuerbach affects the regional mineral water aquifer Muschelkalk. Unreached reference values as well as the potential influence on the mineral springs were addressed in the management plan for Stuttgart-Feuerbach. The management plan has (i) summarized the results of the integral investigation, (ii) evaluated remediation effects, (iii) developed an action plan required to ensure the good groundwater status in Stuttgart-Feuerbach and (iv) defined an integral monitoring network for controlling the remediation effect.

Project area

Feuerbach is a city district in Northern part of Stuttgart. The long-term industrial and commercial use have caused considerable soil and groundwater contamination in certain areas. This contamination hinders the necessary conversion of industrial sites into new residential areas.

The geology of Feuerbach is characterized by a multi-layered groundwater aquifer system, which is divided into the (i) Quaternary aquifer, (ii) several Gipskeuper aquifers, (iii) Lower Keuper aquifer and (iv) mineral water aquifer Muschelkalk, see Fig 2.

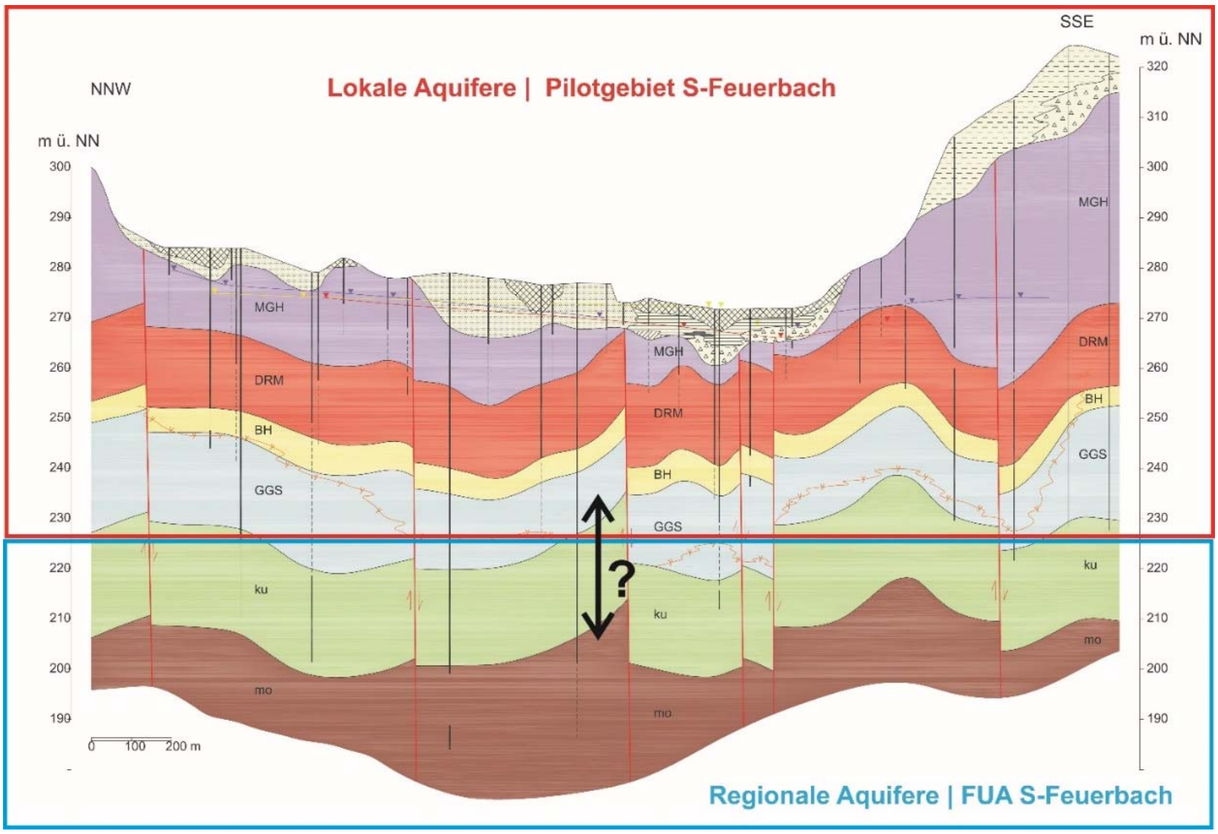

Figure 2 Geological build-up.

In the Gipskeuper, four aquifers are distinguished: Mittlerer Gipshorizont (MGH), Dunkelrote Mergel (DRM), Bochinger Horizont (BH) and Grundgipsschichten/Grenzdolomit (GGS/GD). In the Gipskeuper, the permeability and therefore the groundwater flow are heavily dependent on the lithological structure and the gypsum leaching (subrosion). A vertical groundwater or mass transfer can occur depending on pressure conditions and along tectonic faults.

Based on described hydrogeological conditions, in the project area Stuttgart-Feuerbach, two major types of areas are distinguished, dependent from the expected influence of contamination in the underground:

- Working area is the area, where the former and present industry of Feuerbach is allocated. The working area of the pilot Stuttgart-Feuerbach has in total 530 ha and was hydrogeologically delineated in the previous project MAGIC (see Fig. 3, blue area). In total there are more than 140 known abandoned industrial sites located in the working area that are suspected and/or confirmed to emit CHCs in the groundwater of shallow aquifers. CHC inputs, which can cause a large-scale groundwater contamination and extend over several aquifers, have been detected at several sites.
- Functional urban area (FUA) Stuttgart-Feuerbach is the area, which extends beyond the city administrative borders. Contaminated sites with CHC inputs exist both in the city and in the surrounding area. Contaminants that are localized in the city can influence the groundwater quality in the surrounding area and vice versa no matter from the administrative boarders. Consequently, groundwater flow and contaminant transport in a large-scale aquifer system have to be considered also at the regional level (FUA). FUA Stuttgart-Feuerbach was delineated based on the groundwater flow in the Muschelkalk aquifer. FUA extends to an area over 4,810 ha (Fig. 3, red line).

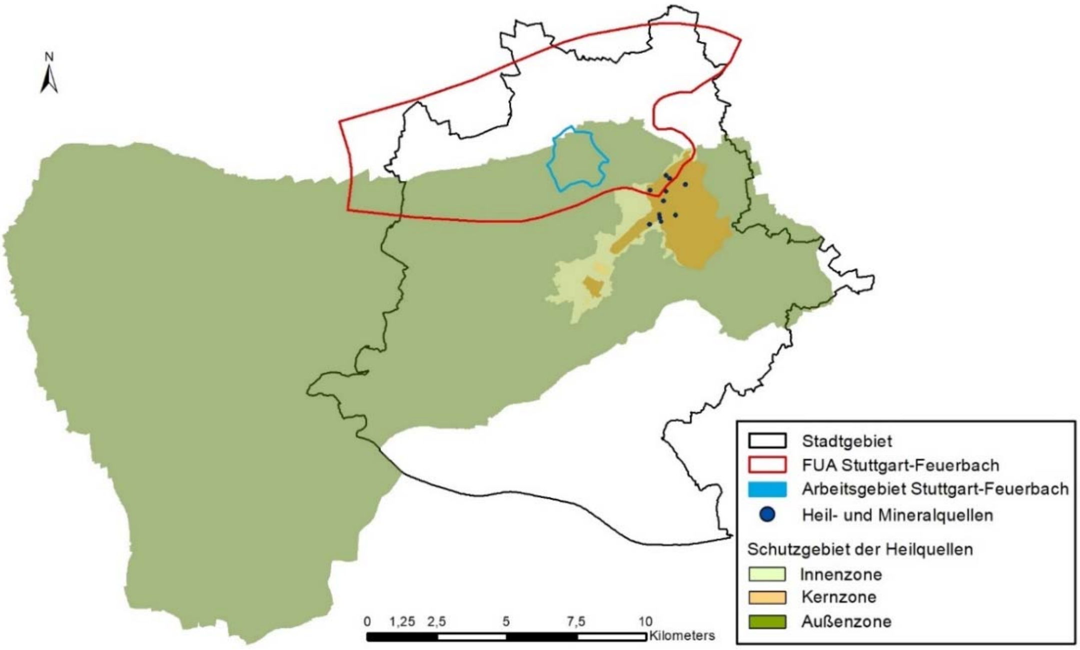

Figure 3 Project areas (working area and FUA) with mineral spring's protection zones.

Working area (blue line), FUA (red line), administrative city border (black line), mineral springs (blue dots) and mineral spring's protection zones are shown in Fig. 4.

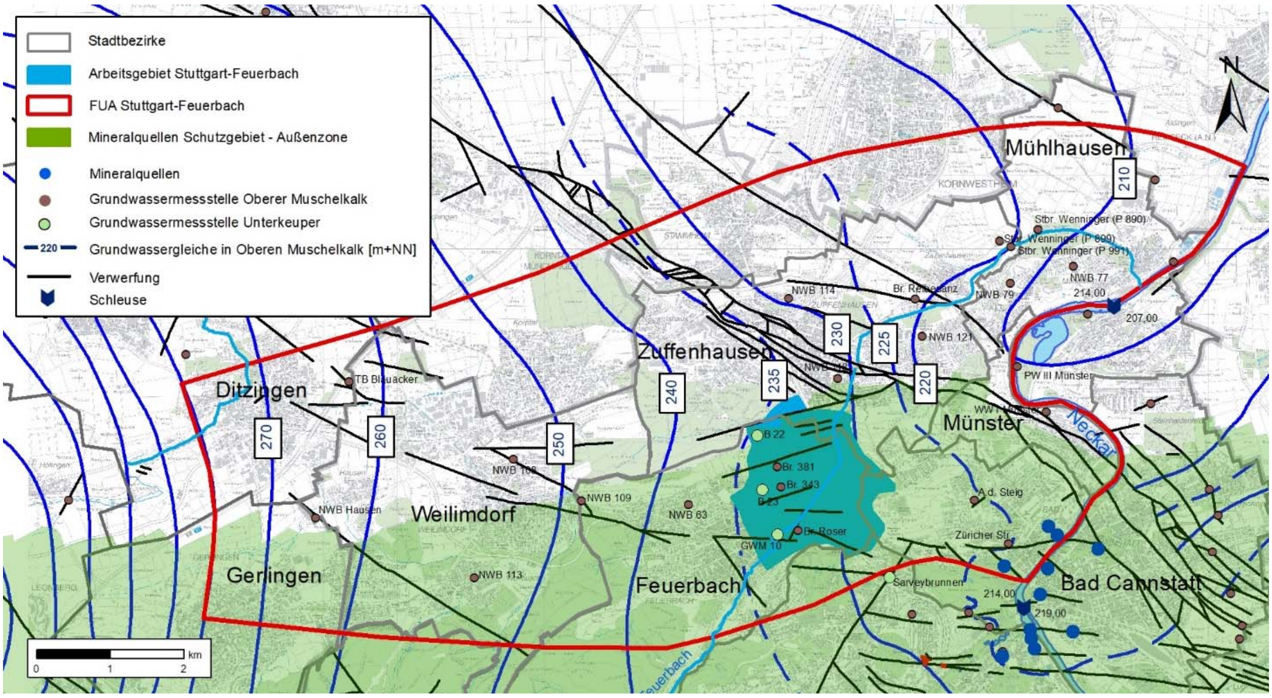

Figure 4 Project areas Stuttgart-Feuerbach: working area und FUA including the flow situation in deep aquifers.

In order to investigate the groundwater flow and contaminant situation as well as to design an integral monitoring network, three new groundwater wells were drilled:

- AMIIGA 1, screened in Bochinger Horizont (BH), 21.3 m deep
- AMIIGA 2, screened in Muschelkalk (mo), 94 m deep
- AMIIGA 3, screened in Bochinger Horizont (BH), 21.1 m deep.

Groundwater Flow

Figures 3 and 4 and the geological build-up (Fig. 2) illustrate the complexity of the groundwater flow due to highly structured geological stratigraphy and numerous faults. Due to those hydraulic properties, the aquifers in the project area were divided into two aquifer units that interact with each other:

- Local shallow aquifers (upper aquifer system) - Quaternary and Gipskeuper were investigated on the local scale of the working area
- Regional deep aquifers (lower aquifer system) - Lower Keuper and Muschelkalk were investigated on the regional FUA scale.

The characterization of the groundwater flow for the period between 2007 and 2017 was conducted by means of (i) existing hydrogeological model, (ii) measurements of groundwater levels in the new drilled wells, (iii) available groundwater level data between

2008 and 2016 and (iv) extraction rates of the operated wells. Based on these data and information, a hydrogeological and a 3D transient flow numerical models were developed.

The main results can be summarized as follows:

- The groundwater levels in shallow aquifers are in the falling trend since 2007. The observed drop was explained by (i) the lower groundwater recharge between 2007 and 2017 that was 15 % lower than in the decade before 2007, (ii) numerous withdrawals of groundwater and (iii) Pump & Treat remediation measures. Quaternary and MGH aquifers were completely dry in some areas. This caused a significant change in groundwater flow directions in shallow aquifers.
- The mean drop of the groundwater level were as follows: Quaternary -3.1 m, MGH -2.7 m, DRM -2.6 m and BH -2.5 m. The major drop of groundwater levels occurred in the BH, where the level drop was more than 8 m in the southwestern part of the working area as compared to the 2007 measurements.
- A depression in the southwest of the working area around AMIIGA 1 was detected, which produced an important effect on vertical exchange processes.
- The aquifer BH is the major aquifer, with hydraulic conductivities of approximately 10^{-3} m/s, fed mainly by the southwest inflow from the Feuerbach valley. In the model, this water (approximately 14 l/s) flows together with the remaining water via aquifers GGS/GD and Unterkeuper (ku) into the underlying Oberer Muschelkalk (mo). This implies that the inflow from the working area in the Muschelkalk aquifer is about 10 % of the total Muschelkalk flow.
- In contrary to the shallow aquifers, groundwater levels in deep aquifers have increased in 2017 compared to the 2007 measurements. The observed increase of the groundwater levels in deep aquifers had no impact on groundwater flow direction.
- The numerical model results indicate that the groundwater in Muschelkalk aquifer originating from the Feuerbach area flows independently of the vertical connection towards the River Neckar.

CHC Contamination

The description of the CHC contamination for 2007 and 2017 was done by means of (i) existing hydrogeological model, (ii) performed groundwater sampling, (iii) available CHC concentration data between 2008 and 2016 from the municipal database and (iv) CHC concentration data gained from new drillings AMIIGA 1-3. Based on these data and information, a 3D transient contaminant transport numerical model was developed.

It was observed that CHCs affect significantly the groundwater quality of shallow aquifers (Quaternary and Gipskeuper aquifers). Due to their mobility, the dominant components of CHC are the tetrachloroethene (PCE) and trichloroethene (TCE). At some locations the degradation products dichloroethene (DCE) and vinyl chloride (VC) occur. For the numerical transport modeling of CHC, the transport of all chloroethene were simulated based on stoichiometric rations, as PCE equivalents.

The main results are:

- The realized remediation measures at relevant contaminated sites were successful. Since 2007, there has been a significant decline in CHC emissions by more than 60 %.
- 75 % of the still emitted CHC loads were taken from the groundwater system through ongoing remediation measures at the main contaminated sites. Therefore, maintaining these measures is of great importance for improvement of groundwater quality. Accordingly, 25 % of the emitted CHC loads reach the groundwater and via geological faults can percolate in the deeper aquifers.
- In addition to applied groundwater remediation measures, a natural degradation and attenuation play a role in a degradation process. Both aerobic and anaerobic degradation processes are taking place in the working area. As a result, only 20 % of the emitted CHC loads that have reached the groundwater are flowing downstream.
- The PCE equivalent concentrations in the shallow aquifers decreased significantly with depth below the ground (from 100 to 1000 µg/l in DRM, from 10 to 100 µg/l generally in BH. In case of deeper Muschelkalk aquifer, the groundwater model simulated a PCE equivalent plume, which spread from Feuerbach towards the river of Neckar. The maximal simulated concentrations for 2017 were 2 to 3 µg/l.
- There was a significant decrease in the CHC pollution from 2007 to 2017, i.e. the CHC concentrations in 2017 were significantly lower than in 2007.
- Based on the results of the new drilled well AMIIGA 1, it was concluded that there are unknown contaminated sites, which emit a significant PCE contamination reaching Bochniger Horizont.
- In the well AMIIGA 2, traces of CHC were found (mostly TCE). During an integral pumping test (IPT), the PCE concentration increased to 2.4 µg/l. By evaluating the IPT results, a maximum of PCE concentrations up to approx. 12 µg/l could be calculated under certain conditions in the center of an assumed plume.
- The results of the integral investigation showed that the vertical CHC migration within shallow aquifers occurs. If CHC contaminations reach BH, there is a high probability that the contamination percolate into the deep aquifers. Approximately 4 g/d of CHCs are percolating from BH and GGS/GD into the Muschelkalk. Therefore, CHC contamination in the working area endangers the groundwater quality of the deep aquifers and Muschelkalk. Nevertheless, the groundwater quality of Muschelkalk is good due to ongoing remediation measures, natural attenuation and dilution by 10 time thicker aquifer.

Goals of the Management Plan

The reference values for groundwater quality are defined in existing regulations. In Germany, legal regulations are primarily included in the Federal Soil Protection and Contamination Ordinance (BBodSchV) that is valid from 12.06.1999. The legal document "Grundwasserverordnung" fully corresponds to the EU Groundwater Directive from 2006. According to these documents a reference value of 10 µg/l for CHC (PCE+TCE) and a maximal CHC load of 20 g/d have been established downstream of contaminated sites (quality targets).

The regulations can be used to derive general quality targets for groundwater:

- Priority 1: Reduction of contamination inputs from the Gipskeuper into the Muschelkalk up to 10 µg/l.
- Priority 2: Reduction of the CHC load in the Quaternary and Gipskeuper aquifers outside contaminant sites, so that CHC concentration of 10 µg/l is not exceeded. This requirement should be applied to the main aquifer BH.
- Priority 3: Reduction of emissions from contaminated sites to achieve the quality targets (CHC concentration <10 µg/l and CHC load <20 g/d downstream of a contaminated site).

Contaminated sites with direct influence on Muschelkalk aquifer have therefore a higher priority than sites, where CHC concentrations have only a local impact on the Quaternary and Gipskeuper aquifers.

Achievement of quality goals should be monitored by suitable "integral monitoring network" (IMN), which was defined for Stuttgart-Feuerbach.

Based on practical experience, in many cases it was not possible to reach the quality target value for CHC concentration with reasonable efforts and costs (principle of proportionality). Even 100 µg/l could often not be reached. Therefore, it is necessary to adjust and redefine a realistic and achievable target values for CHC. This could be defined based on the maximum allowed load of 20 g/d, e.g. the remediation goal was to reach 10 % of required CHC load, i.e., 2 g/d, by taking into account the principle of proportionality.

Taking into account the threat to the Muschelkalk through vertical connections of aquifers and the low observed CHC concentrations in Muschelkalk, the management plan for Stuttgart-Feuerbach primarily considered the areas, in which CHC concentration of 100 µg/l are exceeded. Firstly, it has to be achieved that no CHC concentrations higher than 10 µg/l occur in the Muschelkalk. A good groundwater status shall be ensured, if also in the Bochinger Horizont CHC concentrations of 10 µg/l are not exceeded.

Discussion

The integral investigation for 2017 proved that the remediation measures taken so far were absolutely necessary. They are still effective and necessary in order to prevent vertical percolation of CHCs to the lower aquifer system.

The reduced groundwater recharge in the upper aquifer system, which can also be considered as a consequence of climate change, has a negative effect on the groundwater balance in the Feuerbach work area. Therefore, realized Pump & Treat measures have reached their limits. A further increase of a withdrawal is only possible and reasonable to a limited extent.

The integral investigation also showed that there are still undetected pollutant sources in some areas of Feuerbach, which in some groundwater monitoring wells lead to an increase of CHC concentration compared to 2007. In these cases, investigation and possibly remediation measures are needed. Furthermore, the development of an integral monitoring network (IMN) in the Bochinger Horizont, as the main aquifer of the upper system, is technically and economically reasonable solution.

Fig. 5 and Table 1 show groundwater wells in Quaternary, MGH and DRM with concentrations above 100 µg/l as well as groundwater wells in Bochinger Horizont and GGS/GD above 10 µg/l. Table 1 also shows whether a decrease or an increase in concentration in these wells occurred, compared to 2007. Based on this information, investigation and/or remediation measures are defined for these areas. High concentrations in combination with an increase in CHC concentrations indicated an urgent need and high priority for action.

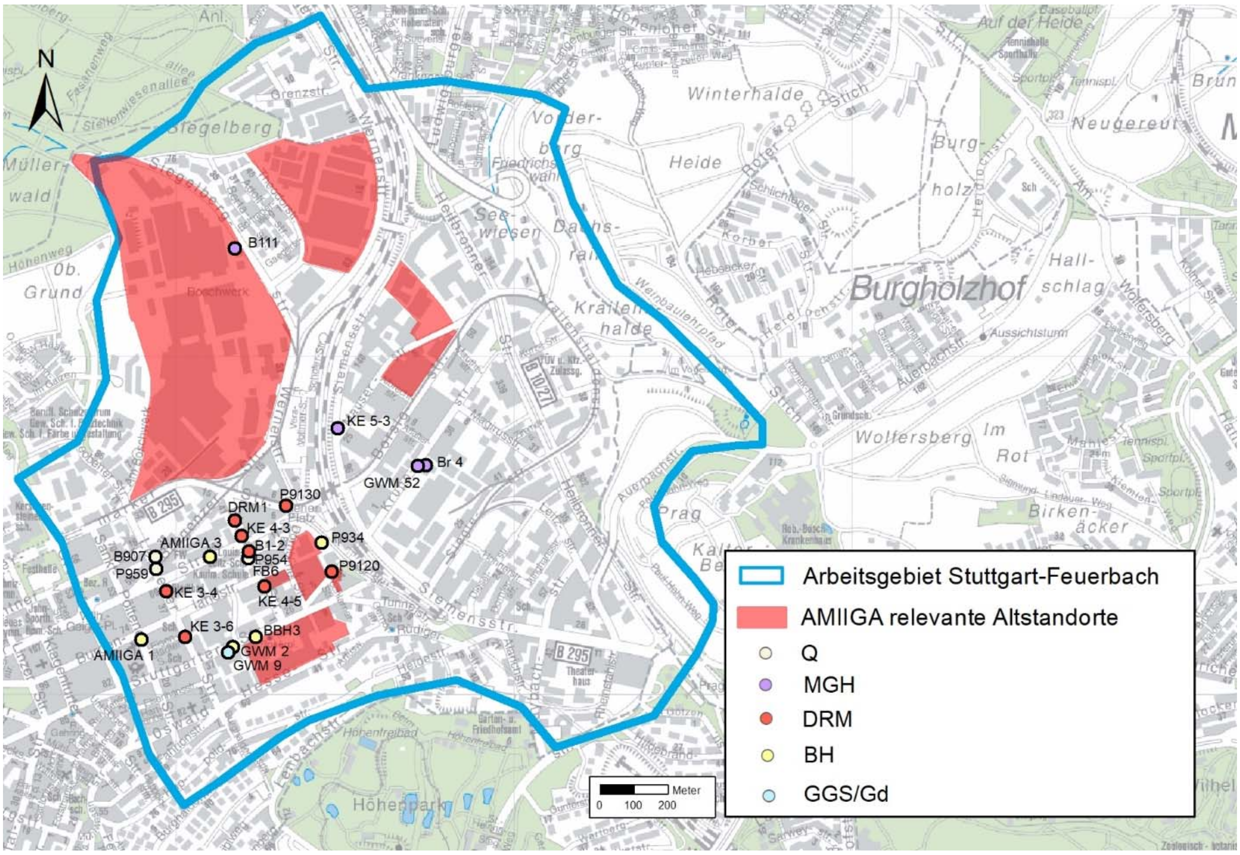

Figure 5 Monitoring wells with CHC concentration in 2017 of more than 100 µg/l in Q, MGH and DRM and more than 10 µg/l in BH und GGS/GD.

Table 1 Monitoring wells with CHC concentration in 2017 of more than 100 µg/l in quaternary (Q), Mittleren Gipshorizont (MGH) or Dunkelroten Mergeln (DRM) and more than 10 µg/l in Bochinger Horizont (BH) and Grundgipsschichten/Grenzdolomit (GGS/GD).

#	GWM	Aquifer	2007	2017	Location
1	P 954	Q	3.755 µg/l	9.440 µg/l	public area, Bludenzer Str.
2	P 959	Q	27 µg/l	105 µg/l	public area, Leobener Str.
3	B 907	Q	k.A.	3.776 µg/l	public area, Leobener Str.
4	FB 6	Q	4.712 µg/l*	2.966 µg/l	public area, Bludenzer Str.
5	Br 4	MGH	68 µg/l	122 µg/l	public area, Kruppstraße
6	B 111	MGH	33 µg/l	1.051 µg/l	downstream of contaminated site 4508
7	GWM 52	MGH	k.A.	137 µg/l	public area, Kruppstraße
8	KE 5-3	MGH	262 µg/l	137 µg/l	public area, Siemensstraße
9	P 9130	DRM	185 µg/l	547 µg/l	public area, Wiener Platz
10	B 9120	DRM	90 µg/l	119 µg/l	public area, Wiener Platz
11	B 1-2	DRM	678 µg/l	1.895 µg/l	public area, Bludenzer Str.
12	DRM 1	DRM	k.A.	112 µg/l	public area, Bludenzer Str.
13	KE 3-4	DRM	450 µg/l	110 µg/l	public area, Leobener Str.
14	KE 3-6	DRM	497 µg/l	346 µg/l	public area, Leobener Str.
15	KE 4-3	DRM	366 µg/l	148 µg/l	public area, Bludenzer Str.
16	KE 4-5	DRM	400 µg/l	210 µg/l	public area, Bludenzer Str.
17	AMIIGA 1	BH	k.A.	210 µg/l	public area, St. Pöltener Str.
	AMIIGA 1	GGS/GD	k.A.	79 µg/l	public area, St. Pöltener Str.
18	AMIIGA 3	BH	k.A.	20 bis 87 µg/l	public area, Wiener Str.
19	P 934	BH	54 µg/l	118 µg/l***	downstream of contaminated site 2430
20	GWM 8/GWM 2	BH	128 µg/l**	33 µg/l***	downstream of contaminated site 4567
21	BBH 3/BBH 4	BH	22/140 µg/l	23 µg/l /k.A.***	downstream of contaminated site 4567
22	GWM 9	GGS/GD	178 µg/l**	140 µg/l	vertical percolation or input at contaminated site 4567

k.A. = no data available
* 2011
**2010
***2019

In order to define the need for action, three levels of consideration are distinguished:

1. Upper shallow aquifers (Quaternary, MGH, DRM)

These are mainly fed by groundwater recharge, almost no lateral CHC inflows. Locally high CHC concentrations reach the underlying BH. High concentrations of CHC show that the remediation measures have not completely prevented percolation into deeper aquifers.

There is a need for action in three areas: (i) wells P 954 and FB 6, (ii) well B 907 and (iii) well B 1-2. The location and CHC concentrations are shown in Table 1 and Fig. 5.

2. Middle aquifers (Bochinger Horizont and Grundgipsschichten/Grenzdolomit)

CHCs that are not removed by remediation measures in the overlying aquifers are gathered in the Bochinger Horizont, as the main aquifer of the upper aquifer system.

Due to a high PCE concentration of 210 µg/l in the well AMIIGA 1, there is an urgent need for investigation in this area. The contamination in BH is caused by an unknown pollutant source upstream of AMIIGA 1, which has to be investigated and remediated. Furthermore, the results of the numerical modelling showed that a vertical percolation of pollutants is possible in this area up to Muschelkalk. Since, hydraulic remediation in the BH and GGS/GD is not very efficient, remediation is needed in upper layers. In BH, the integral monitoring is appropriate measure.

3. Lower deep aquifers (Unterkeuper, Muschelkalk)

The results of the numerical flow model showed that BH and GGS/GD aquifers are at least locally connected to the Muschelkalk and that a vertical percolation of CHC contaminants is possible.

Despite this vertical migration, the investigations carried out in the Mueschelkalk showed no evidence of significant CHC inputs from the working area Feuerbach. This was confirmed by CHC measurements in the downstream groundwater well, also in AMIIGA 2.

Therefore, there are no indications of any conflicts with the general quality goals and priority 1 (maximum CHC concentration of 10 µg/l) in Feuerbach. The CHC inputs at AMIIGA 1 are of local relevance and do not affect the quality of the water in the FUA.

Action Plan for Stuttgart-Feuerbach

The action plan summarizes all necessary measures, see also Annex 1. Those measures have the following development targets:

- Minimisation of CHC inputs in the shallow aquifers by (i) continuation of the ongoing remediation measures, (ii) optimization of the danger prevention in the area of the well B 111, (iii) investigation measures at four areas (P 954 and FB 6, P 907, B 1-2 and AMIIGA 1) and (iv) detailed investigation and remediation of identified sources.
- Integral monitoring of groundwater yeald and quality by (i) integral monitoring network - monitoring in 8 wells of Bochinger Horizont, see Fig. 6; yearly water level measurements and sampling, (ii) monitoring in Muschelkalk; yearly collection of data, since other institutions perform the measurements and sampling and (iii) evaluation of monitoring results.
- Ensuring the implementation of the necessary measures. The results will be summarized and evaluated in reports approximately each 5 years.

The detailed Action Plan with development targets, measures, responsibilities, timetables and additional remarks is given in Annex 1 “Action Plan for Stuttgart-Feuerbach”.

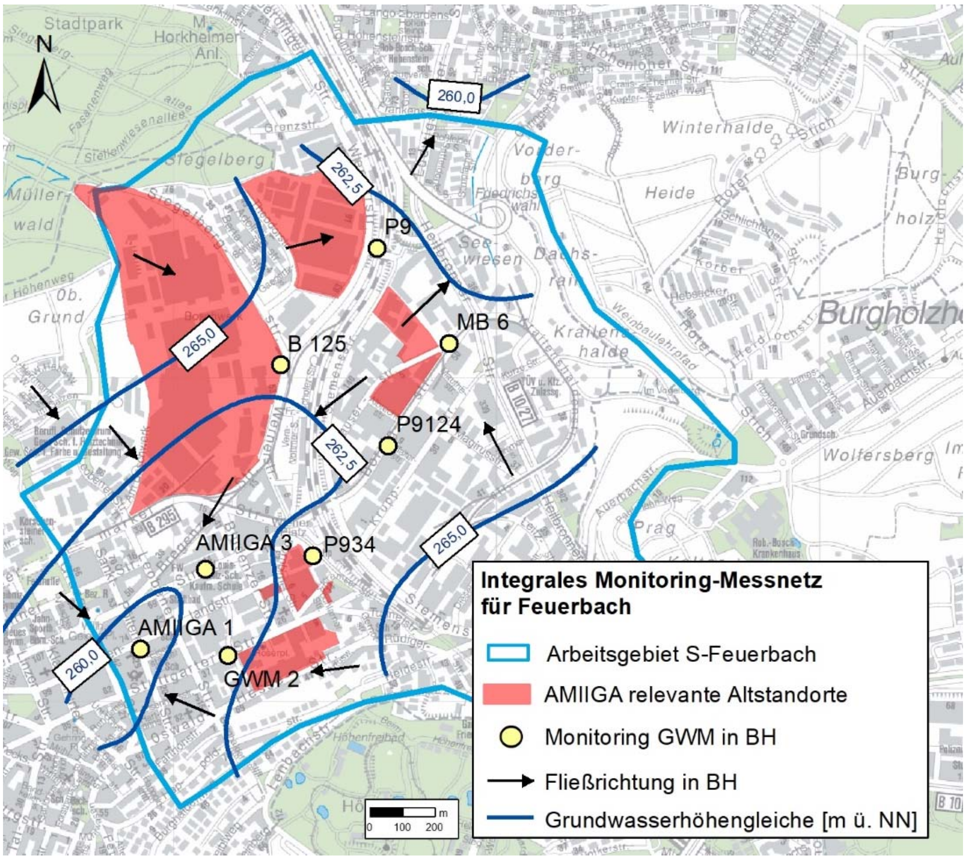

Figure 6 Integral monitoring network for Stuttgart-Feuerbach.

Implementation

The costs of the necessary measures are calculated for 20 years (from 2021 to 2040). Costs of the Measure 1.3 are approximately 560,000 €, costs of the Measure 2 area approximately 240,000 €. Therefore, the total costs of the municipality for 20 years are estimated to approximately 800,000 €, i,e. yearly costs are 40,000 €.