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ENVIRONMENTAL COMPATIBILITY OF BUILDING MATERIALS IN CONTACT TO GROUNDWATER

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ABSTRACT

This paper focuses on the evaluation of the environmental compatibility of concrete, which is used in contact with groundwater. The German regulations for hardened concrete that are used for technical approvals of new raw materials for concrete are explained. The leaching of fresh concrete was investigated in a field test and in laboratory tests. Based on the laboratory tests the groundwater concentrations were calculated using a numerical transport simulation program. A comparison of the real concentration and the calculated values showed that transport modelling is an adequate tool for the evaluation of the leaching of building materials. An evaluation concept should always include a realistic description of the source term, which is usually time-dependent, reasonable assumptions for the transport (e.g. adsorption or decay of organic compounds) and a practice-relevant exposure scenario, for which the concentrations in soil or groundwater are modelled. These concentrations can be compared to national limit values.

Key words: Environmental compatibility, concrete, leaching, transport modeling

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Introduction

There is a growing sensibility towards the use of building materials. As a result of the efforts to put into focus the sustainability of the value chain in the building sector and thus to maintain sufficient living space for future generations, the individual aspects of sustainability play a major role even for building materials. However, building materials exert influence on our environment in quite a different way, in particular by leaching processes of environmentally relevant substances into the soil and groundwater. Each building material contains very small amounts of mobile substances as for instance organic substances, salts or heavy metals. When they get into contact with water, these substances diffuse to the surface of the building element and are then released into the environment. Thus, concrete structures built into the groundwater as well as façades exposed to rain and roofs made of masonry building materials, metals or plastic materials are sources for the elution of environmentally relevant substances. The substances leaching out during the service life of buildings must therefore be assessed very closely. In the past, an assessment model was developed for concrete construction in groundwater which has been incorporated into the national technical approval proceedings of the Deutsches Institut für Bautechnik (DIBt) (German Institute of Construction engineering) [6]. Using this model, it is now possible to calculate the concentrations in the groundwater from the source strength by applying a transport model and to compare them to the currently valid limit values (derived no-effect levels). This model is presented here and afterwards first results of the investigations on the irrigation of mineral building materials are illustrated. Special emphasis should be placed on the fact that the investigations shown in this paper deal with the service life of the building materials in the structure. This is being intensely debated even at the European level of CEN TC 351 in order to enable the approved use of building materials. Depending on scenarios (compact building material or permeable layers) test methods shall be described. On the level of the European Product Standards, the environmental compatibility will have to be verified.

By declaring the building materials for which the environmental compatibility has already been proven, a further verification might become unnecessary (WT – without testing or WFT – without further testing). This could apply for masonry materials. For new raw materials, as e. g. granules made of special lightweight aggregates or concrete additives which develop during the burning of special combustibles, a national technical approval will normally be required. In this case, the environmental compatibility will also need to be verified. The leaching during the service life is completely different from that during the recycling phase because of the state of the building materials. During the service life, a monolithic structure is to be examined which features a considerably smaller surface than crushed material. In the following, using the concept of concrete, it is shortly explained how transport models can be developed which allow to draw conclusions from the test results to the groundwater compatibility of building materials. For further information, please refer to the literature [1], [2], [3].

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Evaluation Concept for Compact Building Materials in Groundwater

All evaluation concepts for the environmental compatibility of building materials in Germany are based on the derived no-effect levels [7]. These were derived from human and eco-toxicological considerations or background values. Using a transport model, the amount eluted from the building material must be converted into the concentration values of the groundwater layer surrounding the building structure. Assuming a diffusion-controlled leaching, which in the first approximation mostly yields conservative results concerning the release of heavy metals, the source strength of the building material can be determined by means of a simple long-term tank test according to [5] which reflects reality very well.

Figure 1 illustrates the tank test; Figure 2 shows the function of the leaching determined in this test. It is assumed that the release into the water-saturated soil is smaller than in the test during the contact with water. Therefore, the release is reduced according to the effective porosity of the soil – in the model, 10 % were applied. Finally, a model area is needed where the building structure and the properties of the soil must fulfill pessimal boundary conditions in order to cover the worst case situation. In the present case, a low flow velocity is chosen as input parameter, shown in Figure 3.

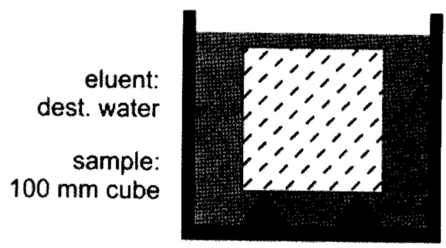

Figure 1 : Tank test to determine the leaching behavior of hardened concrete

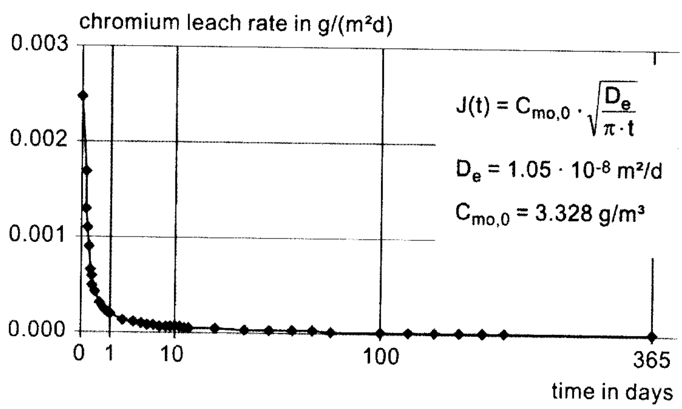

Figure 2 : Leaching function using the example of concrete

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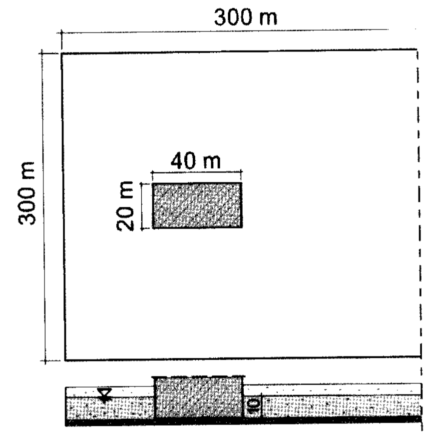

Modelling parameters:

- conductivity: $k_f = 10^{-4}$ m/s
- effective porosity: $n_e = 0.1$
- groundwater gradient: $i = 1 \cdot 10^{-3}$
- temperature: T = 10 °C

(retardation, chemical or biological degradation is neglected)

Figure 3 : Model area to simulate the leaching

Using the function of elution and the parameters of the soil, a calculation of discharge and distribution of the observed pollutant is carried out by means of the commercially available FE program Feflow. Depending on the point of observation in effluent and duration the resulting concentration in groundwater can now be calculated.

Figures 4 and 5 show the result of this calculation after one year in a top view and the development of the groundwater concentration depending on the location as an example for Chromium. To fulfil the criteria of the laws for water management, which only allows small-scale and short-term exceeding of permissible concentrations in groundwater, the short duration and the small area required must now be defined. For real buildings a space surrounding with 2 m thickness (thickness of the layer of ground water in contact) and a period of 6 months (due to the service life) has been considered as appropriate.

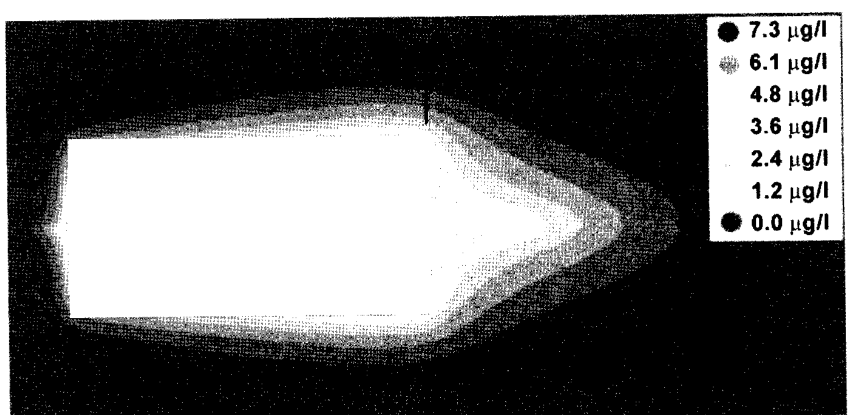

Figure 4 : Spreading of chromium from concrete after one year

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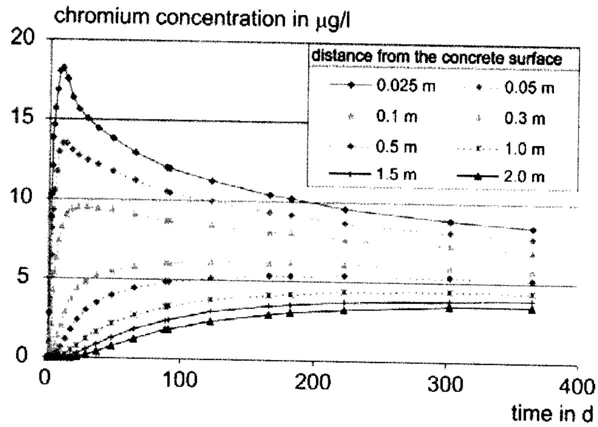

Figure 5 : Development of the chromium concentration at different distances from the structure

The evaluation is carried out at the worst location in the center behind the building. In accordance to the procedure described before, the calculated concentrations are averaged over 2 m and 6 months to determine the mean contact groundwater concentration.

In Figure 6 the contact groundwater concentrations versus the release are shown for different concretes and mortars in the tank leaching test. The result is a straight line with the gradient 0.97 that means that the release in the tank leaching test in mg/m^2 is randomly equivalent to the concentration in µg/l. Choosing the no-effective value as a limit for the contact groundwater concentration, the permissible release could be read or calculated for the tank leaching test.

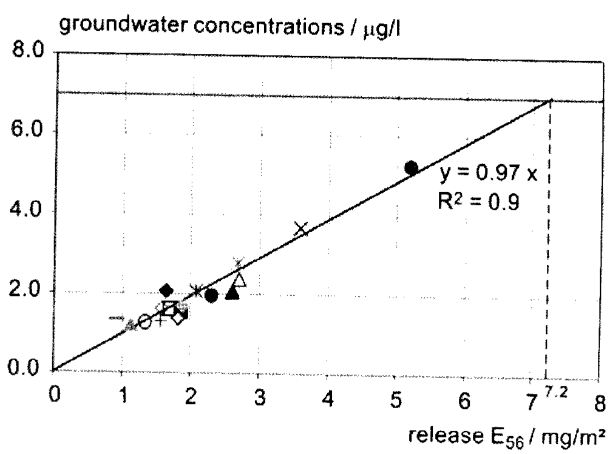

Figure 6 : Derivation of the permissible release

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Experiences with this concept have shown that even the use of conventional additions with higher total contents of heavy metals, e.g. fly ash, concrete usually fulfills the requirements. A possible environmental impact of increased leaching rates is determined in this evaluation. Therefore, it can be prevented with this procedure that waste is disposed in concrete, which are not suitable for achieving a quality building material. Concrete remains a very ecologically friendly building material.

Evaluation Concept for Fresh Concrete

Concept of the Construction Site

The leaching of fresh and, after hardening, of hardened concrete was determined within the framework of measurements of the leaching at a building structure. For this purpose, a building site of the Düsseldorf urban rail line in Germany was examined making the respective measurements. The basic structure work of the underground station is made using the top-down cut-and-cover method with diaphragm walls. This building method is divided into two big steps (Figure 7). In the first step, the diaphragm wall at the northern edge of the construction pit is built. Afterwards, the upper soil layers are removed and bored piles are cast as primary columns which bear the major load of the partial cover. Finally, the first part of the concrete cover is cast directly on the soil. A concrete base layer with PE-foil acts as blinding layer for the flatness of the cover. After finishing the castings, the construction pit is filled again and the carriageway is relocated onto the partial cover. The second step is made with the same method. Both partial covers are then connected to form one cover (Figure 7).

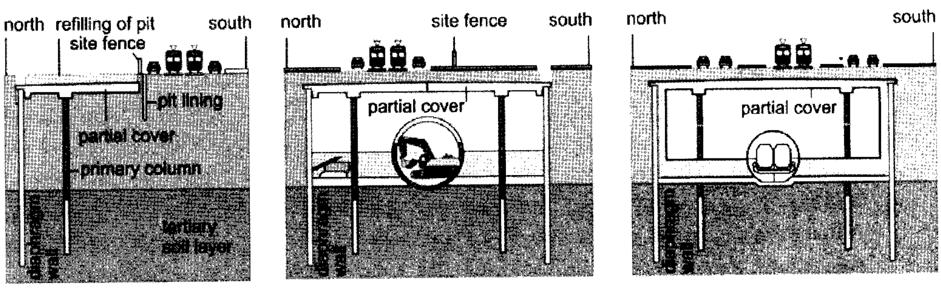

Figure 7 : Illustration of the top-down cut-and-cover method

The underground tunnel is constructed using the shield driving method. In the station area, the soil is excavated between the diaphragm walls and below the concrete cover. When the excavation is finished, the base plate of the station as well as the walls and slabs are cast and the station is completed for operation. Since the diaphragm walls shall be embedded into the tertiary below the relatively permeable sand and gravel layers, they must be driven about 30 m into the ground. This means that, depending on the

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season, the diaphragm walls are covered with groundwater up to 20 m. The in-situ test was conducted during the first construction phase, i.e. when the northern diaphragm wall was constructed. This diaphragm wall was built in 17 segments.

Investigations on Groundwater

Ground water measuring points were installed for the temporal and spatial recording and analysis of the groundwater before, during and after the construction execution. The closest measuring points 9 and 10 are located about 1 m from the diaphragm wall (see Figure 8).

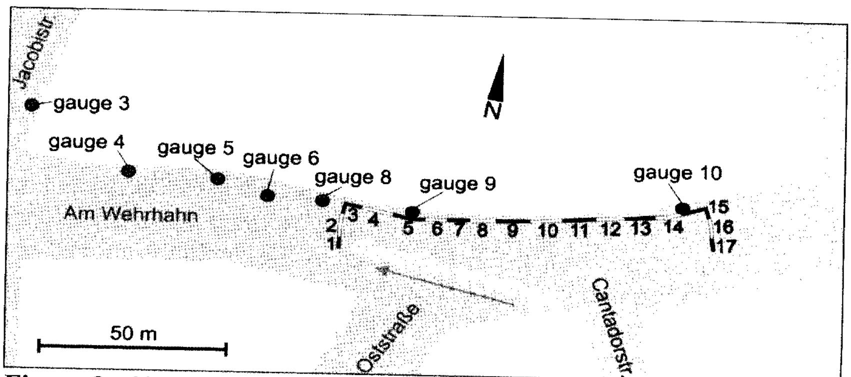

Figure 8 : Site map of the gauges and the segments of the diaphragm wall

It was determined that the concentrations of fluoride, cyanide, antimony, arsenic, lead, cobalt, molybdenum, mercury, selenium and thallium in the groundwater are generally very low and are not increased by the castings. In view of the comparatively low toxicity, the boron concentrations are also to be considered as harmless whereas the derived no-effect limits of the blank values of cadmium and vanadium are partly exceeded. An increase in the concentration because of the construction of the diaphragm wall was also not detected in these three parameters. Copper, nickel and zinc are detectable in the groundwater, however, the values range significantly below the respective derived no-effect limits. The castings do not have any influence even on these parameters. While building the diaphragm wall, there were sporadically increased values of chromium and barium which ranged however below the derived no-effect limits. Besides the trace elements, the concentrations of sodium, potassium, chloride and sulphate as well as the pH-value were measured. A clear increase was only detected regarding sulphate at the measuring gauges 9 and 10 which are located near the diaphragm wall (see Figure 9). At these gauges, the water temperature was increased by about 3 °C.

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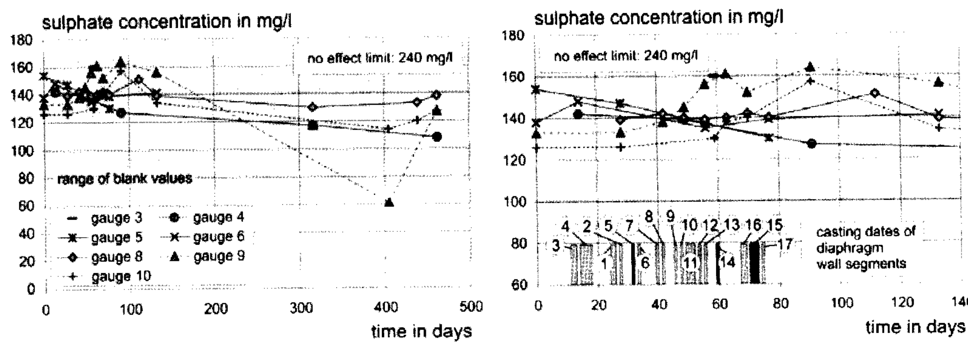

Figure 9 : Development of the sulphate concentration in the groundwater (left: total test period, right: detail of the first 140 days with the casting dates of the diaphragm wall segments)

Laboratory Investigations

For reasons of comparison, laboratory tests were conducted on the used concrete mixes in order to determine the release of environmentally relevant substances. Since fresh concrete gets into contact with the groundwater in this building project, the fresh concrete tank test illustrated in Figure 10 with a subsequent long-term tank test was performed. The mix design complied with the concrete used on site (CEM III/A 32.5 N, c = 270 kg/m³), fly ash (f = 100 kg/m³), water content (w = 190 kg/m³) and also the raw materials were identical.

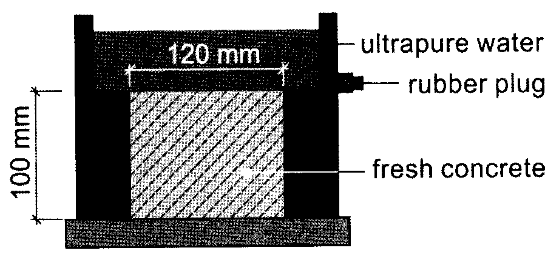

Figure 10 : Schematic diagram of the fresh concrete tank test

The fresh concrete was filled into the lower part of the polyethylene cylinder compacted for 15 seconds. The surplus concrete was carefully removed so that there was no fresh concrete on the edge of the upper part of the cylinder. The upper part of the polyethylene mold was filled with ultrapure water. The ratio of the eluent volume to the concrete surface was chosen in accordance with the DAfStb guideline /Daf05/ to be V/0 = 80 l/m². Within the first 24 hours, 6 eluate changes were conducted, afterwards the changes were performed over a period of 56 days (total duration: 57 days). At every change of the eluent, the rubber plug was removed, the eluate was collected and a sample was

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taken. A repeat determination was performed in the test. Figure 11 illustrates the results for sulphate and chromium. These parameters were used for the modelling.

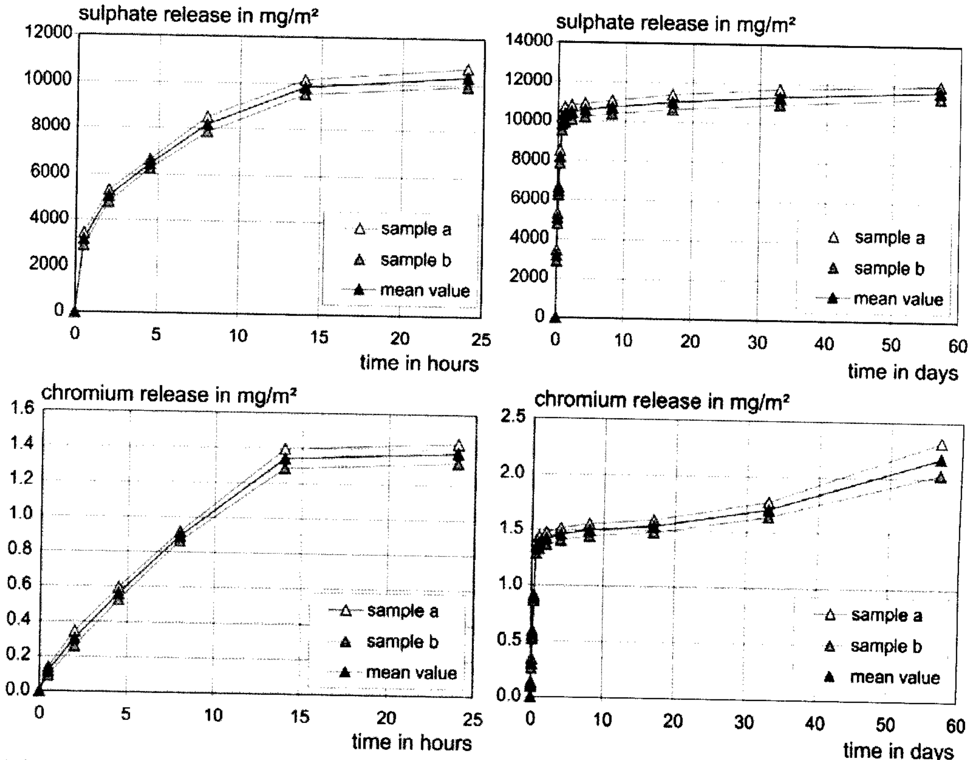

Figure 11 : Cumulative sulphate and chromium release in the fresh concrete tank test (left) and in the entire test with subsequent long-term tank test (right). In the fresh concrete phase, this release determined in the test was used as pollutant ingress for the model calculations. For the hardened concrete phase, an approximation was made applying the law of diffusion (Figure 2)

Model Calculations

In the simulation, the boundary conditions of the construction site were modelled in a slightly simplified way. Firstly, a flow simulation was conducted in order to examine the chosen permeability of the soil (0,004 m/s). Figure 12 shows the comparison between the measured and the calculated groundwater levels at gauge 10. There is a very good correlation. Hence it can be assumed that the model represents the flow conditions in the groundwater.

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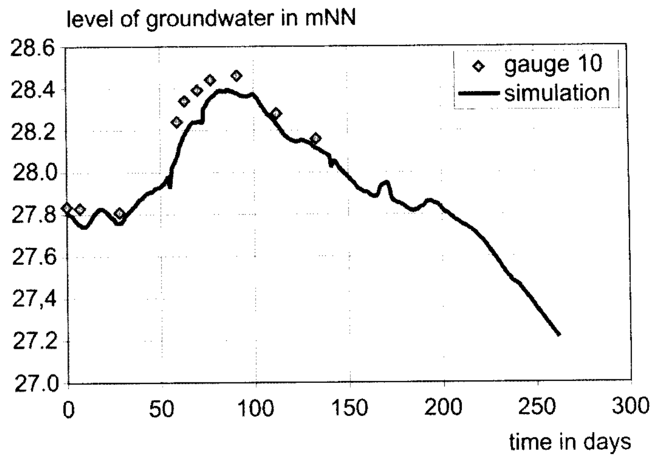

Figure 12 : Comparison of the simulated groundwater hydrographic lines at gauge 10 to the measured values

With the simulation of the transport, adsorption effects and the precipitation were neglected. On this basis, the spreading of the parameters chromium and sulphate in the groundwater was simulated. By means of the parameter sulphate, it was ascertained that the simulation is correct and that it models the concentration gradients in a realistic way (see Figure 13, left). The concentrations were overestimated by about 20 %. Thus, such model calculations are suited to predict the environmental compatibility.

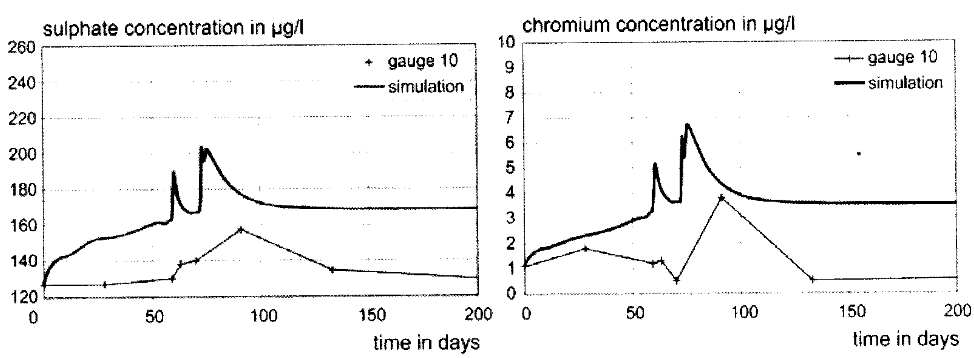

Figure 13 : Comparison of the simulated and the measured sulphate and chromium concentrations at gauge 10

For poorly adsorbing substances like sulphate, the neglect of the retardation is entirely justified. With regards to chromium, the results indicate that an adsorption or precipitation had occurred. There was only one increased measuring value which may possibly also have been an outlier (Figure 13, right). In this case, the simulation overestimates the concentrations.

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Application of the Model to Other Case Studies

In this paper other case studies can only be mentioned referring to the literature. These case studies show that there is a tremendous need for investigating practical scenarios to evaluate the environmental compatibility of building materials.

Renderings, façades, masonry walls where rain in different intensities may leach inorganic hazardous substances and so may in long-term duration influence the quality of the soil and groundwater [8], [9].

Bituminous or other organic water-protecting layers which may be leached by surface groundwater [10].

In-liner repair systems for connectors of sewage pipes [4] Soil injection materials (inorganic and organic) [4].

The experimental work to describe the leaching behavior of building materials to rain or groundwater is separated into two parts: Firstly, measuring the source and modelling the leaching function and secondly, modelling the transport of substances in soil and water. The major problem is that the source and the transport are connected. Therefore, a complete set of the leaching problem has to be described. Test methods to determine the leaching of dangerous substances should take this into account.

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