Groundwater impact simulations for establishing criteria for the recycling of alternative materials in road construction

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1. Introduction

The recent European Waste Framework Directive (OJEU, 2008) promotes a waste hierarchy which places recycling above elimination in landfills in terms of community preference. In view of increasing difficulties with respect to the access to natural granular materials (e.g. sand and gravel), there is an incentive in France to promote the use of alternative granular materials such as those derived from certain types of waste, for applications in road construction for example (MEEDDAT, 2009). The suitability and acceptability of such alternative materials derived from waste is established primarily on the basis of geotechnical and environmental criteria. From a geotechnical standpoint, the alternative materials must provide a “service” in terms of geotechnical properties, such that it may be substituted for natural materials without loss of road structure functionality and durability. From an environmental standpoint, the material must not generate unacceptable risks for the environment and/or human health.

In this context, an important issue is the potential for contamination of groundwater located below or down-gradient from a roadwork. This potential is typically assessed using models that simulate the migration of substances emitted from the alternative material once it is used in a roadwork as defined by a specific utilization scenario (CEN, 2006). Such assessments are generally performed backwards: given a certain objective of groundwater quality at a certain distance from the roadwork (called a “point of compliance” or POC), what characteristics of the source (the alternative material) guarantee that this quality objective will be respected at all times? Such an approach was adopted for the definition of the waste admission criteria in landfill that appear in Decision 2003/33/EC (OJEC, 2003; Hjelmar et al., 2001).

As part of the drafting of the French guidance document (MEEDDAT, 2009), a similar approach was used (consistent with CEN, 2006) to establish acceptance criteria for alternative materials, including those recovered from waste, in road works. This paper presents the methodology used and the results of numerical transport simulations which led to the calculation of attenuation factors (AF) used for establishing the criteria.

2. Methodology

Calculations were performed using commercially-available versions of the groundwater flow model ModFlow (Harbaugh et al., 2000) and contaminant transport model MT3DMS (Zheng and Wang, 1999). Four generic roadwork scenarios were defined:

- The first scenario (noted S1) considers alternative materials used in road-base (layer between the surface course and the sub-grade) in a road with a bituminous surface course, of 1000 m length and positioned parallel to the direction of groundwater flow.

- Scenario 2 (S2) considers alternative materials used in road-base in a parking lot with a bituminous surface, 150 m long and 150 m wide.
- Scenario 3 (S3) considers a 5 metre-deep embankment, without bituminous capping layer, 1000 m long and 25 m wide.
- Scenario 4 (S4) considers two parallel sections of road, 1000 m long with bituminous surface course.

For each scenario, sub-scenarios were defined whereby certain model parameters were varied: net infiltration (300 mm/yr versus 100 mm/yr), dispersion coefficients or road width. With respect to hydrogeological parameters (aquifer hydraulic conductivity, porosity, hydraulic gradient, etc.), parameter selection was performed in accordance with hypotheses adopted by the TAC-Landfill Modelling Group (Hjelmar et al., 2001) for the definition of the waste acceptance criteria in landfills (OJEU, 2003). These parameters were considered as being "reasonably conservative" hypotheses, as they did not lead to excessive dilution/dispersion in the groundwater down-gradient of the contamination source. For example, the TAC-Landfill hypothesis for the pore-water velocity in the groundwater below the source was on the order of 16 m/yr. Considering a cinematic porosity of 10% and an average hydraulic gradient of 0.5%, this velocity implies a hydraulic conductivity of approximately 10^{-5} m/s, which is low compared to values typical of potentially exploitable aquifers (i.e. transmissivities on the order of at least 0.015 m^2/s; Freeze and Cherry, 1979). Aquifer dispersivities were selected in accordance with Mills et al. (1985) and Hjelmar et al. (2001), which are more conservative than those recommended by Neuman (1990), and in coherence with numerical grid constraints. Worth noting also is the fact that unlike what was assumed by the TAC-Landfill, recharge is considered here to occur in the source area but also outside the source area.

Groundwater flow and transport simulations were used to estimate attenuation factors (AF), i.e., ratios between the source concentration and the concentration calculated at a certain distance from the source. Consistent with the approach adopted by the TAC-Landfill, AFs were calculated at two different distances (called points of compliance; POC): 20 m and 200 m. Knowing the AF values, and considering groundwater quality objectives at the points of compliance, maximum source concentrations can be defined at the source such that the concentration at the points of compliance always remain below the quality objectives. These objectives were taken from OJEC (1998). Once the AF values are obtained from the flow and transport modelling, they are multiplied by the element's concentration limit in water destined to the production of drinking water (OJEC, 1998) to yield a maximum tolerable source concentration (C_{max}). This implies that so long as the source concentration does not exceed C_{max}, the groundwater quality objective should be respected.

A constant emission concentration was considered and therefore equilibrium partitioning between the liquid and solid phase (using values of Kd) was not taken into account because it delays contaminant breakthrough but does not change the long-term concentration plateau. Given the hypotheses of a constant source concentration, cumulative emission limits at a liquid-solid ratio of LS = 10 L/Kg were obtained by multiplying C_{max} by 10, to obtain maximum emissions; E_{max}. However, because it was not judged acceptable to charge the groundwater between the source and the POCs up to C_{max}, values of E_{max} were divided by a safety factor. The resulting emission limits can be used as a basis of comparison with the results of leaching tests performed according to standard CEN (2005).

3. Simulation results

An example of a simulation result is presented in Figure 1 for scenario 3. Figure 2 shows the concentration breakthrough curves at the two points of compliance (POC). For the calculation of the attenuation factors, we consider the long term plateau concentrations, taken as the maximum concentrations calculated at the vertical of the points of compliance.

Because the source concentration was taken as 100, the attenuation factors are obtained by dividing 100 by the plateau concentration.

The calculated attenuation factors are presented in Table 1. As the thickness of the road base layer increases from 0.35 to 0.8 m, the attenuation factors decrease by 23% at 20 m and 25% at 200 m. As the width of the road increases (by 150%; 10 to 25 m), the attenuation factors decrease by 55% at 20 m and 200 m. The attenuation factors at 20 m for the car park scenarios are much lower than for the road scenarios, due to car park width. As could be expected, the embankment scenario presents the lowest attenuation factors, due to the absence of bituminous surface course and hence the higher recharge in the source area.

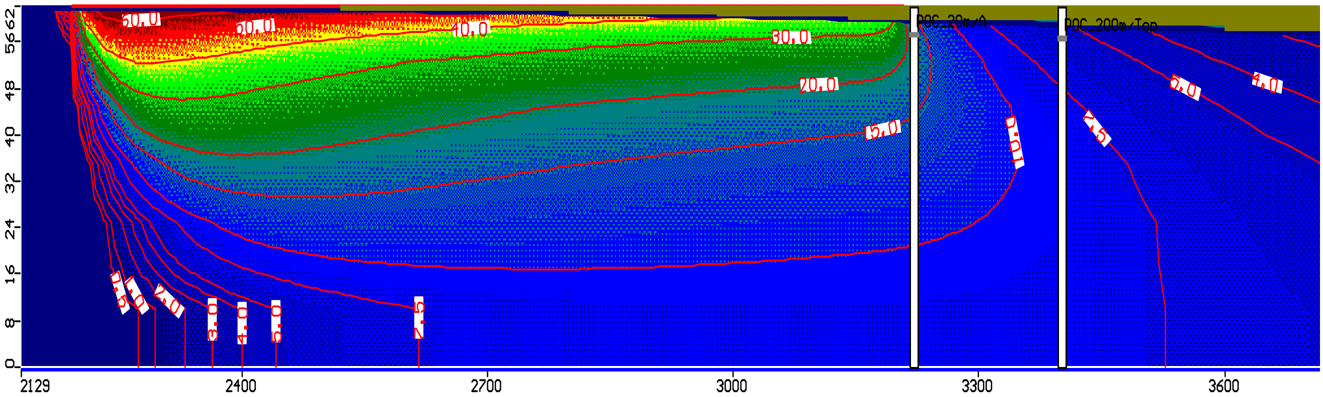

Figure 1 – Iso-concentrations calculated at time t = 200 years for scenario 3 (fill without bituminous surface).

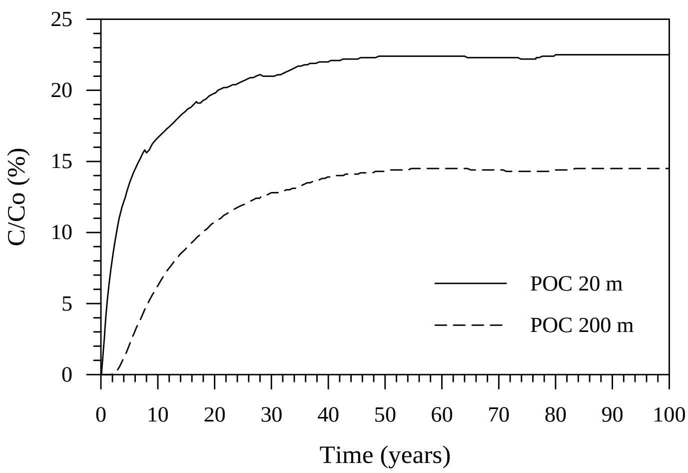

Figure 2 – Example of solute breakthrough curves calculated for scenario S3Ab at two points of compliance (POC) located 20 and 200 metres from the down-gradient edge of the source

4. Discussion and conclusions

The approach presented herein is considered to be conservative because it neglects certain important attenuation mechanisms and in particular co-precipitation of metallic elements with neo-formed mineral phases. For example it is well known that lead will tend to precipitate, over a wide range of pH values, as a carbonate (Cerrusite) in oxidizing conditions, or as a sulphide (Galena) under reducing conditions. But accounting for such attenuation mechanisms would require a far greater level of model complexity (using for example the PHAST model of Parkhurst et al., 2004), and also a considerable number of hypotheses regarding in particular geochemical conditions in the aquifer.

It was preferred therefore, to retain an approach similar to that used by the TAC-Landfill for the waste admission criteria. The calculated attenuation factors are generally greater than those calculated by the TAC-Landfill, due to the different flow scenarios which lead to lower levels of infiltration as it is limited by the presence of the bituminous surface course. The resulting limit values in terms of cumulative emissions are therefore less restrictive than those for inert waste in OJEC (2003). The cumulative emission limit values resulting from the work presented herein are not shown, however, as they are still under discussion at the time of drafting of this paper. Less restrictive, yet environmentally relevant, criteria on leaching characteristics are expected to help lift regulatory barriers on recycling of certain types of waste in France (in particular construction and demolition waste), as is the case in particular in the Netherlands, where the proposed leaching criteria of the Building Materials Decree (Verschoor et al., 2008) are generally higher than the inert waste criteria of the Landfill Directive. The latter are particularly stringent with respect to soluble salts and in particular sulphate. As a result, certain geological materials in the Paris Basin (certain sands and marls), without any human influence, are found not to comply with the inert waste criteria due to the diffuse presence of natural gypsum in the material. It is expected that the criteria derived from the work presented herein will contribute to avoid sending to landfills materials that could be usefully locally reused in geotechnical works, thereby avoiding impacts related to the exploitation of natural resources.

Table 1 – Attenuation factors calculated for the different scenarios

						Attenuation Factor at point of compliance	
Scenario N°	**Type**	**Length (m)**	**Width (m)**	**Height (m)**	**Infiltration (mm)**	**20 m (dispersivities αx/αy/αz = 8 / 3 / 0.4 m)**	**200 m (dispersivities αx/αy/αz = 20 / 7 / 1 m)**
S1_A	Road	1000	10	0.35	300 / 100	**14.8**	**63.1**
S1_B	Road	1000	10	0.8	300 / 100	**11.8**	**47.2**
S1_C	Road	1000	25	0.35	300 / 100	**6.7**	**28.4**
S1_D	Road	1000	25	0.8	300 / 100	**5.9**	**24.8**
S2_A	Parking	150	150	0.35	300 / 100	**3.4**	**20.4**
S2_B	Parking	150	150	0.8	300 / 100	**3.4**	**20.3**
S3_A	Embankment	1000	10	5	300	**3.1**	**11.2**
S3_Ab	Embankment	1000	10	5	300	**4.4**	**11.4**
S2 A et B	Parking	150	150	0.8	100 / 50	**4.6**	**22.8**
S2 A et B	Parking	150	150	0.8	100.0	**2.6**	**11.7**
S3_A	Embankment	1000	10	5	100.0	**4.2**	**12.9**
S4_A	2 roads 30 m apart	1000	25 et 10	0.8	300 / 100	**5.7**	**10.4**

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