

## The Effects of Landfill Temperature on the Contaminant Transport Through a Composite Liner

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**ABSTRACT:** Considering a reasonable distribution of wrinkles in a geomembrane forming part of a composite liner, the effect of temperature on contaminant transport to an underlying aquifer by advective and diffusive transport is examined. The majority of the cases considered were selected based on the conditions that might be expected in southern Ontario (Canada) where the ambient ground water temperature is about 10°C and results given for dichloromethane suggest that for the cases examined the peak impact is very close to that predicted for the usual base case of 20°C. This implies that the simple approach commonly used in Ontario for landfill design which neglects the effect of temperature provides quite good results. However one analysis run for a higher ambient groundwater temperature of 35°C gave a peak impact almost twice that for the other time varying cases suggesting that more investigation is needed to confirm how significant the ambient groundwater temperature may be with respect to contaminant impact.

### 1 Introduction

The temperature on a landfill liner varies with time and for a typical municipal solid waste landfill the temperature may reach 30–40°C and potentially upto about 60°C for a landfill where there is significant moisture addition to accelerate biodegradation of organic waste (Rowe, 2005). The service life of a geomembrane liner used as part of a composite liner in these landfills will primarily depends on temperature (Rowe, 2005). However even before the geomembranes service life is reached, temperature can affect both the hydraulic conductivity and diffusion coefficient of the barrier system (Collins, 1993; Rowe, 1998) and hence has the potential to affect the advective-diffusive transport through the liner system. At present contaminant transport analyses are typically performed using parameters obtained in the laboratory at laboratory temperatures (typically about 20°C) and no studies have been conducted to assess the potential effect of liner temperature on contaminant impact. Thus the objective of this paper is to perform a preliminary analysis of the potential implications of liner temperature for the case of a volatile organic contaminant (dichloromethane, DCM) found in landfill leachate (Rowe et al., 2004) through a composite liner comprised of a 1.5mm thick HDPE geomembrane (GM) over a geosynthetic clay liner (GCL) which rests on a 3.75m thick attenuation layer (AL) which in turn is underlain by a 1 m thick aquifer, as depicted in Fig. 1. Attention will be focussed on the effect of temperature on contaminant transport through the liner system and, in particular, on the calculated peak DCM impact in the aquifer.

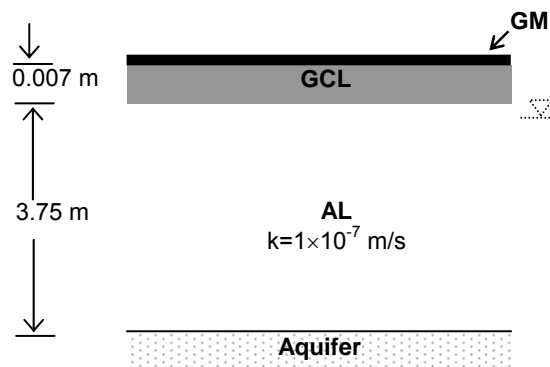


Figure1. Barrier system examined in this study (not to scale)

## 2 Modelling

The modelling of the effect of temperature in this paper was conducted for a landfill cell 200m long in the direction of groundwater flow. The waste mass per unit area was taken as 25 t.m<sup>-2</sup>. The contaminant considered was DCM. The proportion of DCM in the waste and the initial concentration were taken to be 2.3 mg/kg and 3300 µg.l<sup>-1</sup> and the half-life in the leachate of 10 years were all based on Ontario Regulations 232/98 (O. Reg. 232/98). The reference height of leachate (H<sub>r</sub>, Rowe et al., 2004) was hence calculated at 17.4m. The infiltration through the landfill cover and hence leachate generation rate, q<sub>o</sub>, was assumed to be 0.15m/a. The GM was assumed to have interconnected wrinkles with a hole of 125m/ha with wrinkle width of 0.2m. Leakage, Q, through the GM was calculated using the Rowe Equation (Rowe, 1998):

$$Q = 2 L \{k b + (k D \theta)^{0.5}\} h_d / D \quad (1)$$

where L is the length of the holed-wrinkle per hectare; 2b is the width of the wrinkle (0.2m); k is the harmonic mean hydraulic conductivity of the GCL and AL below the GM;  $\theta$  is the transmissivity of the GM-clay liner interface; h<sub>d</sub> is the head loss across the composite liner; and D is the combined thickness of the GCL and AL. The aquifer was assumed to have a potentiometric surface 3.5m above the top of the aquifer, a porosity of 0.3, and a Darcy flux (velocity) at the upward-gradient edge of the landfill of 1 m/a. In cases where a temperature profile is examined, the aquifer was assumed to have a constant temperature of 10°C typical of Ontario Canada.

Since modelling is typically conducted using laboratory parameters at 20°C, this was taken as the “base case” and the reference parameters were based on typical values at this temperature. For the geomembrane the base DCM diffusion and partitioning coefficients were D<sub>g20</sub> = 2.0×10<sup>-5</sup> m<sup>2</sup>/a and S<sub>gf20</sub> = 6 respectively giving a permeation coefficient P<sub>g20</sub> = D<sub>g20</sub> × S<sub>gf20</sub> = 1.2×10<sup>-4</sup> m<sup>2</sup>/a (Rowe, 2005). All analyses were performed using the computer program POLLUTE (Rowe and Booker, 2005) based on the theory published by Rowe and Booker (1995) and diffusion through the GM was modelled by assigning a porosity of 1 to the GM and a coefficient of hydrodynamic dispersion equal to the permeation coefficient P<sub>g</sub>. The GM/GCL transmissivity,  $\theta$ , at 20°C was taken to be 1×10<sup>-10</sup> m<sup>2</sup>/s (Rowe, 1998). The baseline properties of the GCL and AL are presented in Table 1.

Table 1. Properties of the geosynthetic clay liner (GCL) and attenuation layer (AL) at 20°C used in the contaminant transport analysis for DCM

| Property  | GCL                 | AL                 |
|---|---------------------|--------------------|
| Thickness (m)   | 0.007               | 3.75               |
| Hydraulic conductivity to leachate (m/s)                            | 5×10 <sup>-11</sup> | 1×10 <sup>-7</sup> |
| Diffusion coefficient (m <sup>2</sup> /a)                           | 0.009               | 0.022              |
| Sorption (-)  | 0                   | 0                  |
| Porosity (-)  | 0.7                 | 0.3                |
| Transmissivity of geomembrane and GCL interface (m <sup>2</sup> /s) | 1×10 <sup>-10</sup> | -                  |
| Half-life in soil (year)  | 50                  | 50                 |

- Not applicable

The DCM permeation coefficient, P<sub>T</sub>, through the GM at temperature, T, was calculated using a relationship (Eq.2) developed by Chao et al (2007) for chloroform and related to that at 20°C, P<sub>20</sub>, and typical values are presented in Table 2. At temperature, T, the diffusion coefficient, D<sub>T</sub>, in the GCL and AL, hydraulic conductivity of the GCL and AL, and interface transmissivity  $\theta_T$ , were calculated based on Rowe (1998) and typical values are given in Table 2. It is noted that temperature has a significant effect on all parameters.

Table 2. Permeation coefficient, P<sub>T</sub>, diffusion coefficient, D<sub>T</sub>, hydraulic conductivity, k<sub>T</sub>, and interface transmissivity,  $\theta_T$ , at temperature T relative to values at 20°C

| Temperature (°C) | P <sub>T</sub> / P <sub>20</sub><br>GM <sup>#</sup> | D <sub>T</sub> / D <sub>20</sub> <sup>*</sup><br>GCL or AL | k <sub>T</sub> / k <sub>20</sub> <sup>*</sup><br>GCL or AL | $\theta_T$ / $\theta_{20}$ <sup>*</sup> |
|------------------|---|--|--|---|
| 10               | 0.32  | 0.71   | 0.77   | 0.77                                    |
| 20               | 1.0   | 1.0  | 1.0  | 1.0                                     |
| 25               | 1.74  | 1.14   | 1.15   | 1.08                                    |
| 35               | 4.84  | 1.43   | 1.38   | 1.38                                    |
| 50               | 20.1  | 1.93   | 1.85   | 1.84                                    |
| 65               | 73.6  | 2.5  | 2.23   | 2.23                                    |

\* obtained based on Rowe (1998)

# obtained using Eq.2 Chao et al., (2007)

$$P_T = P_0 e^{-E_p/RT} \quad (2)$$

where  $P_0$  represents the pre-exponential factor (back calculated for DCM using its  $P_{20}$  value and it is equals to  $1.21 \times 10^{-10}$  m<sup>2</sup>/a),  $E_p$  is the activation energy and was taken to be the same as for chloroform at 78560 kJ/mol (Chao et al., 2007),  $R$  is the universal gas constant and  $T$  is the absolute temperature.

The leakage through the GM was calculated using Eq. 1 with a design head of 0.3m above the GCL for the service life of the leachate collection systems (which was assumed to be 100 years) and 7m after the leachate was no longer collected from the under drain system. For cases where the temperature varied linearly from that specified at the GM liner to that at the aquifer (assumed to be 10°C), the AL was subdivided into 5 sublayers and hydraulic conductivity and diffusion coefficient were calculated corresponding to the temperature at the midpoint of each sublayer. The hydraulic conductivity values were used to calculate the harmonic mean hydraulic conductivity of the GCL (assumed to be at temperature  $T$ ) and AL and this value was used in Eq. 1. The leakage calculated for a number of liner temperatures is summarized in Table 3. Again it can be seen that temperature can results in a notable increase in leakage rate. Not surprisingly, the build-up of a significant leachate head (i.e., 7m) after failure of the LCS has a significant impact on leakage rate (as depicted in Table3). The contaminant transport analyses (POLLUTE) were performed using downward Darcy velocity corresponding to the leakage for the liner temperature and the diffusion coefficient appropriate to the midpoint of each sublayer.

Table 3. Leakages calculated for different liner (GM) temperatures

| GM Temperature<br>(°C) | Leachate Head<br>(m) | Calculated Leakage |         |
|------------------------|----------------------|--------------------|---------|
|                        |                      | (lphd)             | (m/a)   |
| 10                     | 0.3                  | 12.0               | 0.00044 |
|                        | 7                    | 155                | 0.00566 |
| 20                     | 0.3                  | 15.8               | 0.00058 |
|                        | 7                    | 203                | 0.00742 |
| 30                     | 0.3                  | 19.6               | 0.00071 |
| 40                     | 0.3                  | 23.3               | 0.00085 |
| 50                     | 0.3                  | 27.1               | 0.00099 |

### 3 Results

Analyses were performed for seven cases to assess the effect of temperature on contaminant transport (as shown in Table 4). The first (base) case assumed that the entire barrier system was at 20°C as is usually assumed in impact assessments. As shown in Figure 2, this case gave a peak impact in the aquifer of 18 µg/l at about 109 years (as depicted in Table 4). A change in response can be observed at 100 years when the leakage rate increased due to the assumed failure of the leachate collection system at this time (Table 3). To demonstrate the effect of temperature for a relatively simple case this analysis was repeated (Case 2) for parameters relevant to the entire barrier system being at a 35°C and it can be seen that this 15°C increase in temperature more than doubles the calculated contaminant impact in the aquifer to 42 µg/l and resulted in a reduction in the time to peak impact by almost 35 years to 75 years (Table 4).

It may be argued that Case 2 is too severe since while the GM may reach 35°C, or even higher, this is for a limited time and also the temperature below the liner will be less than that at the liner. To consider these effects five cases were examined where:

- The GM temperature started at a temperature  $T_0$  and remained there until a time  $t_1$  (Figure 3) after which it increased linearly with time to the peak temperature,  $T_p$ , at time  $t_2$ . It remained at the peak temperature until time  $t_3$  after which it reduced linearly with time back to the initial temperature  $T_0$  at time  $t_4$ .
- The temperature decreased linearly with position from the GM temperature defined in (a) above to 10°C at the top of the aquifer.

Cases 3-5 all assumed an ambient aquifer temperature,  $T_0$ , of 10°C and peak temperature,  $T_p$ , of 40°C and differed in terms of the time sequence. Case 6 consider the same change in temperature but with an ambient temperature,  $T_0$ , of 20°C and hence peak temperature,  $T_p$ , of 50°C. Finally Case 7 considered a landfill with an ambient temperature,  $T_0$ , of 10°C and less moisture available for biodegradation so that the peak temperature is only 35°C but it remains at that temperature for 30 years. The results are summarized in Table 4.

Cases 3 and 4 are identical except that the rate of decrease from the peak temperature is much slower in Case 4. The results for the two cases are very similar with a peak impact of 18 and 19 µg/l at 124 and 120 years

respectively. Coincidentally the peak concentration value is essentially identical to that obtained for the base case (Case 1) at 20°C. Case 5 has a 10 year period before the temperature begins to rise but once it peaks it stays there longer than for Cases 3 and 4. This case gave the least impact (14 µg/l at 118 years) because the low temperature at early time reduced contaminant transport at the time when the source concentration was assumed to be greatest (with the source concentration decreasing rapidly with time due to biodegradation with a half-life of 10 years. The variation in concentration with time in the aquifer is shown in Figure 4.

Cases 3 and 6 have the same time history but there is higher ambient and peak temperature for Case 6 which leads to an increase in peak impact from 18 µg/l to 32 µg/l and reduces the time to peak impact by 40 years (Figure 5).

Case 7 explores the effect of a lower peak temperature but where elevated temperature is maintained for a long time (until 100 years). Coincidentally this gave a peak impact of 17 µg/l (at 94 years) that was very close to that for the simple base case (Case 1 in Table 4).

Table 4. DCM peak impact in aquifer for the cases examined (see Figure 3 for definition of  $t_1$ ,  $t_2$ ,  $t_3$ ,  $t_4$ ,  $T_o$  and  $T_p$ )

| Case | $t_1$<br>(years) | $t_2$<br>(years) | $t_3$<br>(years) | $t_4$<br>(years) | $T_o$<br>(°C) | $T_p$<br>(°C) | DCM Peak impact                        |                        |
|------|------------------|------------------|------------------|------------------|---------------|---------------|--|------------------------|
|      |                  |                  |                  |                  |               |               | Concentration<br>(µg.l <sup>-1</sup> ) | Time of peak<br>(year) |
| 1    | -                | -                | -                | -                | 20            | 20            | 18                                     | 109                    |
| 2    | -                | -                | -                | -                | 35            | 35            | 42                                     | 75                     |
| 3    | 0                | 5                | 20               | 35               | 10            | 40            | 18                                     | 124                    |
| 4    | 0                | 5                | 20               | 50               | 10            | 40            | 19                                     | 120                    |
| 5    | 10               | 15               | 40               | 70               | 10            | 40            | 14                                     | 118                    |
| 6    | 0                | 5                | 20               | 35               | 20            | 50            | 32                                     | 83                     |
| 7    | 0                | 10               | 40               | 100              | 10            | 35            | 17                                     | 94                     |

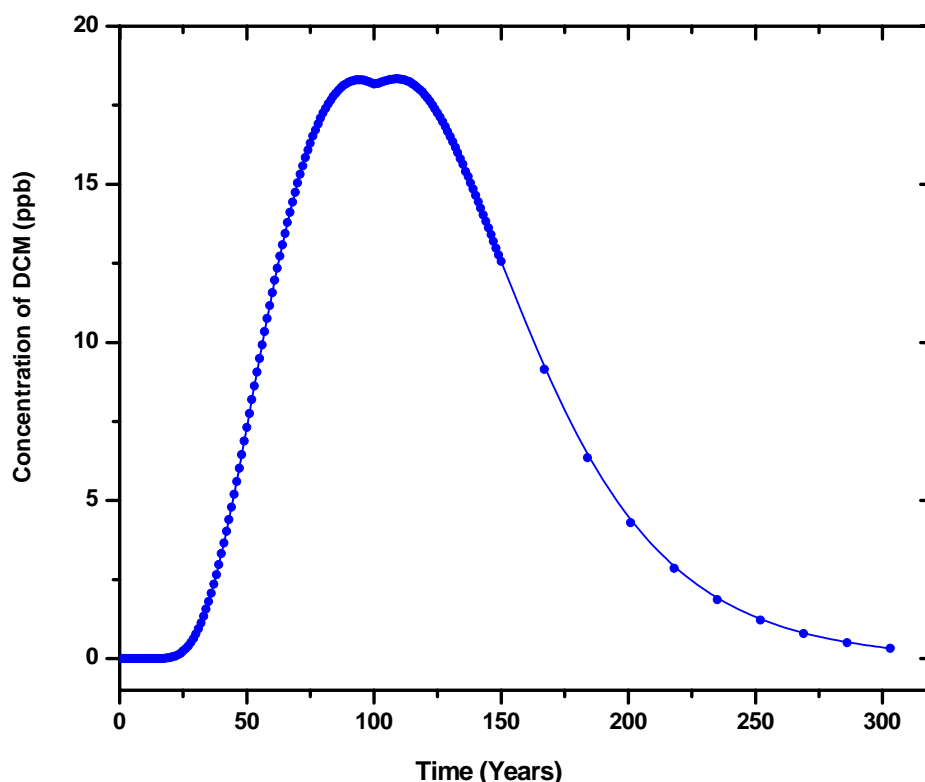


Figure 2. Variation of DCM concentration in aquifer – Case 1  $T=20^{\circ}\text{C}$  (constant throughout)

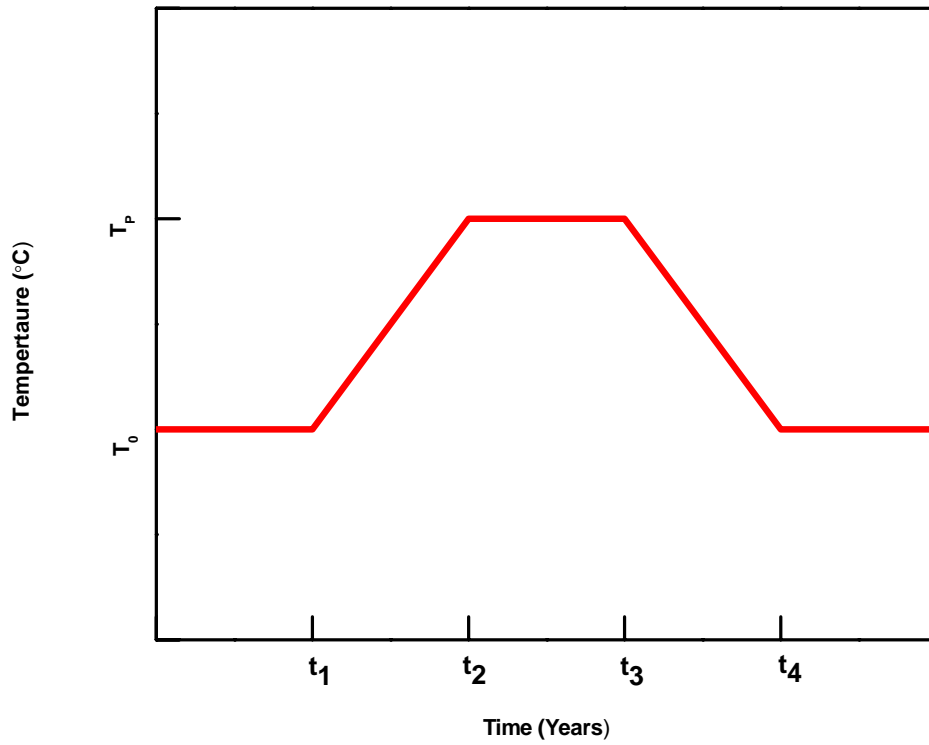


Figure 3. Idealization of variation in landfill liner temperature with time.

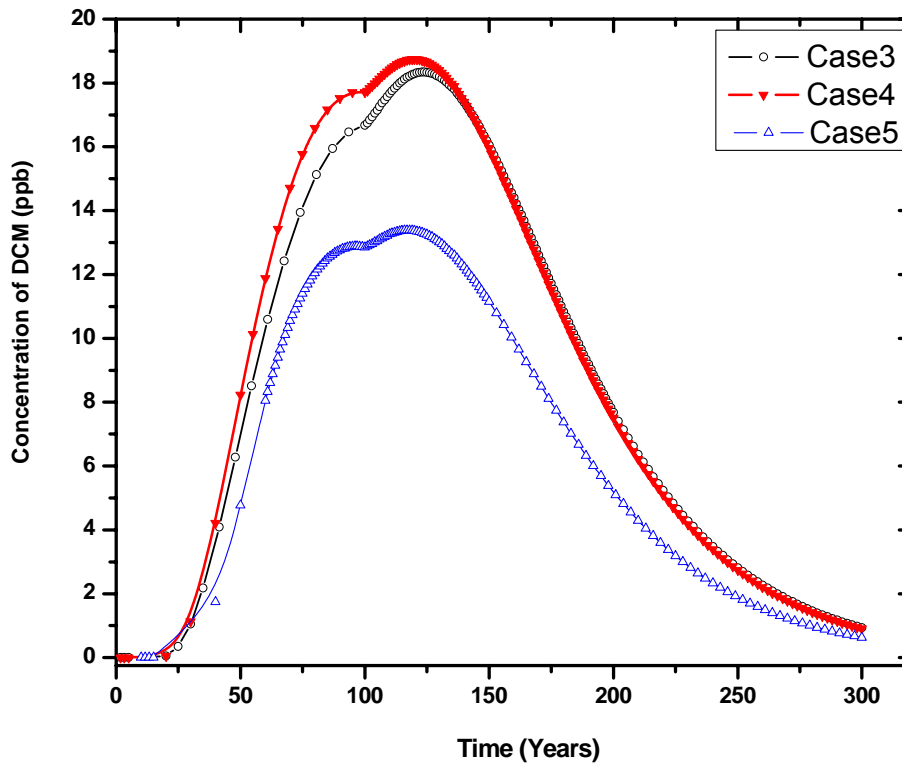


Figure 4. Variation of DCM concentration in aquifer for Cases 3, 4, 5

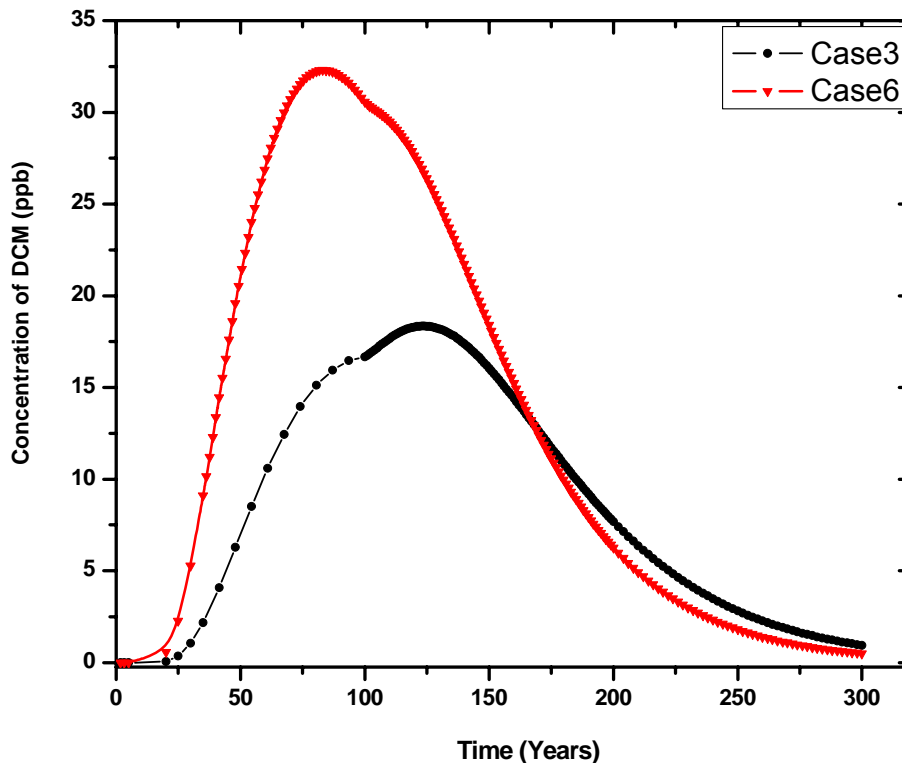


Figure 5. Variation of DCM concentration in aquifer for Case 3 and 6

#### 4 Conclusions

This paper has, for the first time, examined the effect of temperature on the potential impact on an aquifer due to contaminant transport from a municipal solid waste landfill. Most of the cases considered in the present study were selected to correspond to conditions that might be expected in southern Ontario (Canada) where the ambient ground water temperature is about 10°C and the results given herein for DCM suggest that, at least for the cases examined, the peak impact is very close to that predicted for the usual base case of 20°C. If confirmed for other contaminants this is good news since it implies that the simple approach commonly used in Ontario for landfill design which neglects the influence temperature variation gives quite good results. However caution should be adopted in reaching this conclusion until it has been confirmed for other critical contaminants. The one analysis run for a higher ambient groundwater temperature of 20°C gave a peak impact almost twice that for the other time varying cases suggesting that more investigation is needed to confirm how significant the average groundwater temperature may be with respect to contaminant impact.

#### 5 Acknowledgements

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