Groundwater risk assessments for infiltration systems: calculations and examples

You should use the Environment Agency's J5 Infiltration Worksheet to calculate parameters for your infiltration systems groundwater risk assessment.

These calculations and examples are for illustration. You should only use this or other risk assessment tools when you have a good conceptual model and you believe that the worksheet calculations are relevant to it

Calculate the infiltration rate

Work out the infiltration rate using:

$$Inf = \frac{Q}{A}$$

Where:

- *Inf* – infiltration rate through the infiltration system (metres/day (m/d)
- *Q* – discharge rate to the drainage field (m^3/d)
- *A* – area of drainage field (m^2)

Example

For example, for a septic tank serving 12 people (p) discharging to a drainage field (A) within a Vp of 20 sec/mm:

1. Q = 12 x 150 l/d = 1800 l/d or 1.8 m^3/d.
2. A = 0.25 x p x Vp $\Rightarrow$ 0.25 x 12 x 20 = 60m^2.
3. Inf = Q/A = 1.8/60 = 0.03m/d.

Calculate a discharge's impact on groundwater quality and discharge limit values

To work out the values use:

- C_{cp} - concentration at compliance point (milligrams per litre (mg/l)), where concentration should be below the compliance value
- C_c - compliance value set to protect receptor (mg/l) (for example, water quality standard or minimum reporting value)
- C_e - effluent concentration (mg/l)
- AF_u - attenuation factor (unsaturated zone)
- *DF* - dilution factor

- AF_s - attenuation factor (saturated zone)

Concentration at compliance point

Calculate the concentration of a substance at different points along the pollutant pathway:

1. Water table (attenuation in unsaturated zone only).
   $C_{cp} = C_e / AF_u$.

2. Borehole adjacent to infiltration system (attenuation in unsaturated zone and dilution).
   $DCL = C_e /(AF_u.DF)$

3. Attenuation in unsaturated and saturated zone and dilution (non-hazardous pollutants only).
   $DCL = C_e / (AF_u. AF_s DF)$

Discharge limit values

Calculate the discharge limit values (*DCL*):

1. Attenuation in unsaturated zone only.
   $DCL_1 = AF_u. C_c$
2. Attenuation in unsaturated zone and dilution.
   $DCL_2 = AF_u.DF. C_c$
3. Attenuation in unsaturated and saturated zone and dilution (non-hazardous pollutants only)
   $DCL_3 = AF_u. AF_s DF. C_c$

Calculate dilation factor with standard equations

Use:

- *DCL*- discharge limit value
- *DF* - dilution factor
- *Ct* - compliance value (mg/l) (for example, water quality standard or minimum reporting value)
- *Cu* - background concentration (mg/l)
- *Ce* - effluent concentration (mg/l)
- *K* - hydraulic conductivity (m/d)
- *i* - hydraulic gradient
- *wd* - width of disposal field perpendicular to flow direction (m)

Calculate the dilution factor (DF) for groundwater below the drainage field:

1. Calculate DF taking background concentration into account.

$$DF = \frac{(Gw + Ing.A).C1 - (GwCu)}{Inf.A.Ct}$$

2. Calculate DF with no allowance for background concentration.

$$DF = 1 + \frac{Gw}{Inf.A}$$

3. Calculate DF taking background concentration into account and using effluent concentration.

$$DF = \frac{(Gw + Inf.A).Ce}{Gw.Cu + Ing.A.Ce}$$

For shallow aquifers

If $M_Z > d_a$ then $M_Z = d_a$

L - length of site parallel to groundwater flow (m)
d_a - aquifer thickness (m)

Example calculation of dilution factor

A discharge of 5 m^3/day is applied to a drainage field covering 100 m^2 (10 m by 10m). Information on the aquifer thickness, hydraulic gradient and hydraulic conductivity of the underlying aquifer has come from borehole drilling and testing.

You can calculate the dilution factor using the following equation (no allowance made for background concentration):

$$DF = 1 + \frac{K.i.w_d.M_z}{Inf.A}$$

Where:

- K = 15 m/d
- i = 0.01
- w_d = 10 m
- M_z = 4 m (based on saturated thickness of aquifer)
- Inf = 5/100 = 0.05 m/d
- A = 100 m^2

The calculated dilution factor (DF) = 1 + (15 x 0.01 x 10 x 4)/(0.05 x 100) = 2.20

Calculate attenuation factors using standard equations

In the unsaturated zone

You can calculate the attenuation factor (AF) for the unsaturated zone using:

$$AF = 1/\exp\left[\frac{D}{2a} - \left\{\frac{D}{2a}\sqrt{1+\left(4a\lambda/\mathrm{u}\right)}\right\}\right]$$

Where:

- *D* - unsaturated zone thickness (m)
- α - vertical dispersivity in the unsaturated zone (approximately D/10) (m)
- λ - unsaturated zone decay constant (d^{-1}) = ln(2)/half life for degradation
- *u* - retarded contaminant velocity in the unsaturated zone (m/d) where $\mathrm{u} = \frac{Inf}{R.\theta}$
- *R* - retardation factor where $R = 1 + \frac{Kd.\rho}{\theta}$
- *θ* - effective porosity of unsaturated zone
- *Inf* - infiltration rate (m/d)
- *Kd* - partition coefficient (l/kg)
- *P* - soil bulk density

In the saturated zone

You can calculate the attenuation factor (AF) *(with no allowance for vertical or lateral dispersion)*for the saturated zone as*:*

$$AF = 1/\exp\left[\frac{x}{2a} - \sqrt{1+\left(4a\lambda/u\right)}\right].erfc\left[\frac{x}{2\sqrt{a.u.t}} - \left(x - ut\sqrt{1+\left(4a\lambda/u\right)}\right)\right]$$

This equation ignores dispersion in the vertical or lateral direction where:

- *x* - distance to compliance point down-gradient of the disposal field (m)
- α - longitudinal dispersivity in the saturated zone (m)
- λ - saturated zone decay constant (d^{-1}) = ln(2)/half life for degradation
- *u* - retarded contaminant velocity in the saturated zone (m/d) where $u = \frac{Inf}{R.n}$
- *K* - hydraulic conductivity (m/d)
- *i* - hydraulic gradient
- *n* - effective porosity of the saturated zone
- R – retardation factor where $R = 1 + \frac{Kd.\rho}{n}$
- *Kd - partition coefficient (l/kg)*

- *P - aquifer bulk density*

Example calculation of attenuation factor for the unsaturated zone

A discharge of 5 m^3/day is applied to a drainage field covering 100 m^2 (10 m by 10m). Ammonium is present in the discharge and is considered to represent a risk of pollution of groundwater.

The concentration of ammonium in the discharge is 30 mg/l. Information on the unsaturated zone thickness (15m), soil bulk density (1.8 gm/cm^3) and water filled porosity (25%) come from site investigation boreholes.

Evidence for the use of degradation was agreed with the Environment Agency. Literature values have a half life for the degradation of ammonium of 1 to 2 years and a partition coefficient of 2 l/kg.

You can calculate the attenuation factor using:

$$AF = 1/\exp\left[\frac{S}{2a} - \left\{\frac{S}{2a}\sqrt{1+\left(4a\lambda/v\right)}\right\}\right]$$

Where:

- *Inf* = 0.05 m/d
- *S* = 15 m
- α = *D/10 = 1.5 m*
- θ = 0.25
- λ = ln(2)/365 = 0.0019 d^{-1} (assuming a half life of 365 days)
- *Kd* = 2 l/kg
- *P* = 1.8 gm/cm^3

$$R = 1 + \frac{Kd.\rho}{\theta} = 1 + \frac{2\text{x}1.8}{0.25} = 15.4$$

$$v = \frac{Inf}{R.\theta} = \frac{0.05}{15.4 \times 0.25} = 0.013 \text{ m/d}$$

So $AF = 1/\exp\left[\frac{15}{2\times1.5} - \left\{\frac{15}{2\times1.5}\sqrt{1+\left(4\times1.5\times0.0019/0.013\right)}\right\}\right] = 6.4$

The calculated attenuation factor for ammonium for the unsaturated zone is 6.4. For an effluent concentration of 30 mg/l then the calculated concentration at the base of the unsaturated zone = 30/6.4 = 4.7 mg/l.

Calculate dilution and attenuation factors using monitoring data

You can calculate dilution and attenuation factors can be calculated from monitoring data for existing discharge.

Calculate the dilution factor (DF_{cl}) for a conservative contaminant such as chloride from:

$$DFcl = \frac{Ce - Cu}{CB - Cu}$$

Where:

- *CB* - mean concentration in monitoring borehole down-gradient of disposal field (mg/l)
- C_u - up-gradient or background mean concentration (mg/l)
- C_e - mean concentration in effluent (mg/l)

You can calculate the attenuation factor (*AF*) for a non-conservative contaminant from:

$$AF = \frac{(Ce - Cu)}{(Cb - Cu).(DFcl)}$$

The calculation of dilution and attenuation factors depends on having a conservative contaminant, such as chloride, in discharge. The contaminant is present above background in groundwater.

Example calculation

Groundwater monitoring data are available for 2 boreholes, one located up-down-gradient and one located adjacent to a drainage field receiving an effluent discharge.

The effluent has an average chloride concentration of 90 mg/l and an ammonium concentration of 20 mg/l. The observed chloride concentration in groundwater up and down-gradient of the drainage field is 24 mg/l and 60 mg/l respectively. The concentrations of ammonium in the two boreholes are 0.1 and 0.4 mg/l respectively.

Calculate dilution factor as:

$$DF_{cl} = (C_e - C_u) /(CB - C_u)$$

Where:

- CB = 60 mg/l
- C_u = 24 mg/l
- C_e = 90 mg/l

So $DF_{cl} = (90-24)/(60-24) = 1.8$

You can calculate the attenuation factor (*AF*) can be calculated for ammonium from:

$$AF = \frac{(Ce - Cu)}{(Cb - Cu).(DFcl)}$$

Where:

- CB = 0.4 mg/l
- C_u = 0.1 mg/l
- C_e = 20 mg/l
- DF_{cl} = 1.8

So AF = (20-0.1)/((0.4-0.1).(1.8)) = 36.85

Example calculation for determining the impact of a discharge on groundwater quality and for determining discharge limit values

To calculate the impact on groundwater where a discharge of 5 m^3/day is to be applied to a drainage field covering 100 m^2 (10 m by 10m).

Ammonium is present in the discharge and is considered to represent a risk of pollution of groundwater. The concentration of ammonium in the proposed discharge is 30 mg/l (as NH_4^+).

Information from site investigations together with literature values were used to determine an attenuation factor for the unsaturated zone and a dilution factor.

Calculate these factors as:

$DF = 2.2$

$AF_u = 6.4$

Calculate the concentration of ammonium in groundwater immediately down-gradient of the drainage field as:

$$C_{cp} = C_e / (AF_u.DF)$$

$$= 30/(6.4 \times 2.2)$$

$$= 2.13 \text{ mg/l}$$

This calculated concentration exceeds the drinking water standard of 0.5 mg/l so one of the following applies:

- your application will be refused
- you'll be asked to carry out a further assessment on attenuation in the unsaturated zone and also on whether attenuation in the saturated zone is significant
- you'll need to carry out extra treatment of the effluent before discharging

If you need to carry out extra treatment of the effluent before discharging you can calculate it as:

$$DCL = AF_u.DF.\ C_c$$

$$= 6.4 \times 2.2 \times 0.5$$

$$= 7 \text{ mg/l}$$