Landfill Aftercare Forum

9 June 2016, Priory Rooms, 40 Bull Street, Birmingham B4 6AF, UK

Danish initiative to define Final Storage Quality criteria

Development of a methodology for site-specific risk assessment at landfills

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Danish EPA – DepoNet – Dansk Affaldsforening

Development of a methodology for site-specific risk assessment at landfill sites

- The methodology should be based on state-of-the-art knowledge and technology (newest and best available)
- The methodology must be operational
- A gradual increase of complexity should be possible
- The methodology should be widely accepted by all stakeholders – therefore the project requirements have been developed by a partnership of stakeholders

Financed by the Dansk Affaldsforening, the Danish EPA and the Danish Network for Sustainable Landfilling

Budget: 2.5 mio DKK (approx. 260,000 £) – 84 % raised to date

Time schedule:

Start in April 2016,

End mid 2017 (provided all funding is in place) – Source term part ends this year

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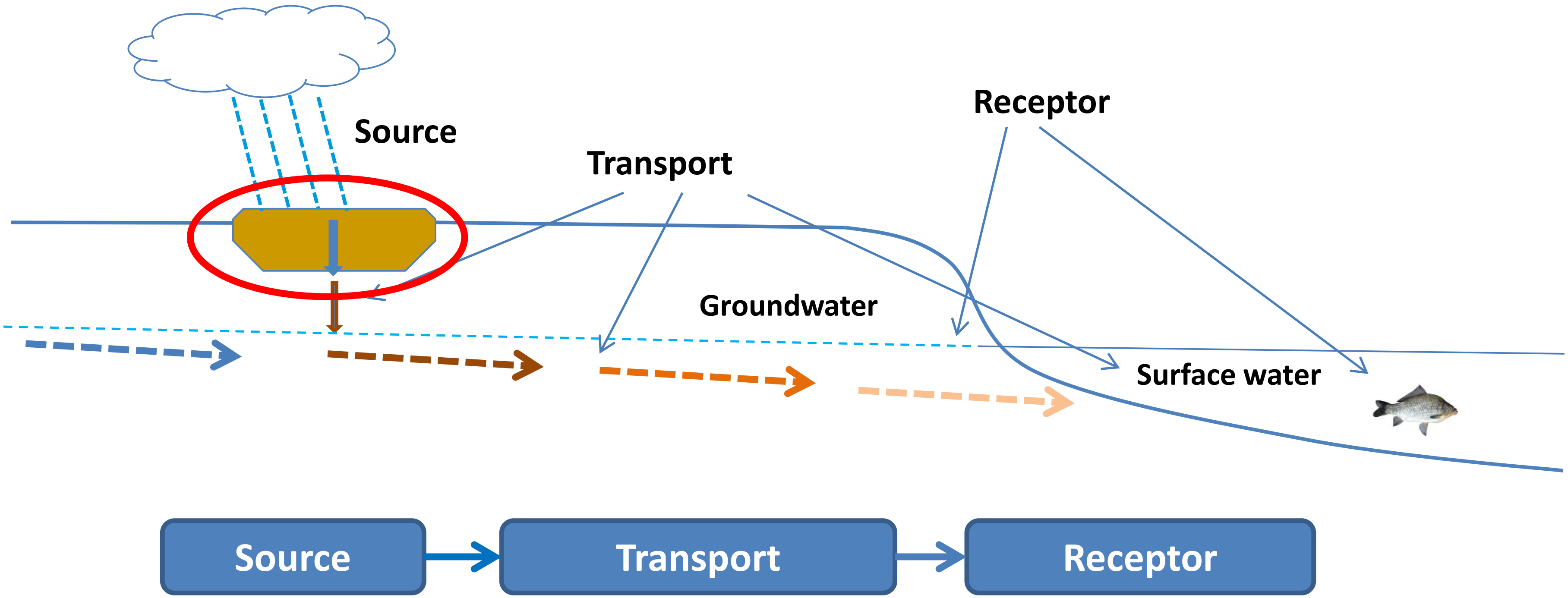
Site-specific risk/impact assessment



Work package 1

Work package 2

Work package 3

Work package 4: Economy

Should be applicable to:

- **Controlled landfills in aftercare**
- **All controlled landfills in operation (near coastal and inland locations)**
- **Extensions of existing landfills and planning of new landfills**
- **Uncontrolled dump sites**

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The source term part
(DanWS & COWI)

Source term model
Transport model
Receptor

Phase 1 (concepts and issues)

- Conceptual (water balance) model
- Time horizon and point of compliance
- Heterogeneous flow through the waste
- Selection of ”critical substances” for the risk assessment

Phase 2 (methodology)

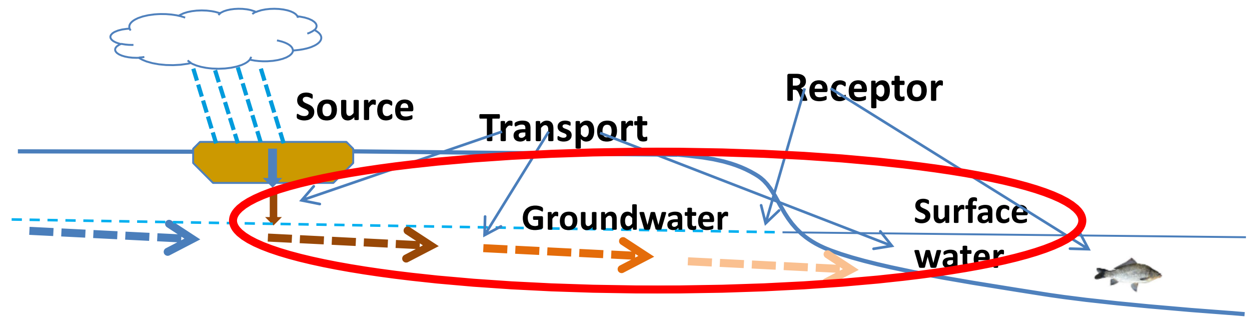
- Basic info required for modelling of the source term
- Formation of leachate
- Release of substances from the waste (into the leachate)
- Release of leachate into the environment (interface with transport model)

Phase 3 (development and completion of source term model/methodology)

- Assessment of data quality
- Proposal for monitoring leachate source development and use of data
- Development of a coherent methodology/model – manual and tools
- Case trials and sensitivity analysis

Transport model part (DTU)

- Source term model
- Transport model
- Receptor

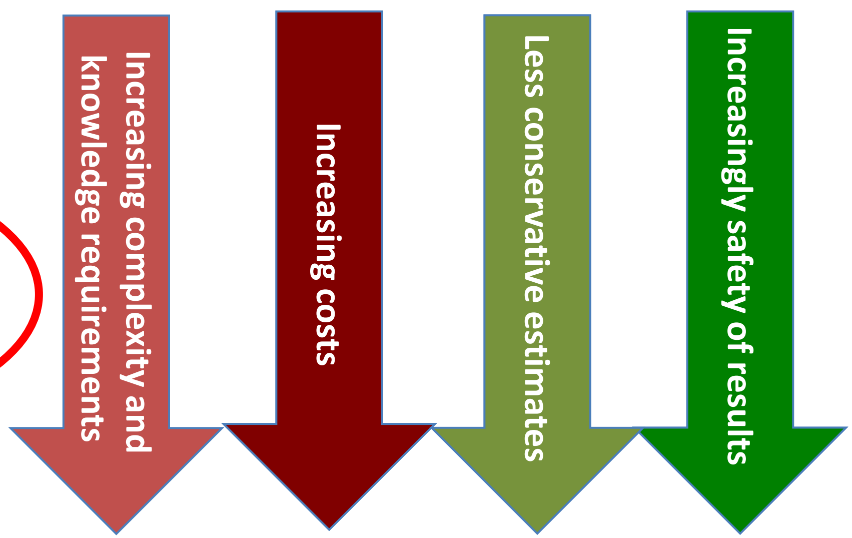


Transport of substances

Step 1: Relatively simple initial considerations

Step 2: Analytical model – possibly including the use of generic parameters

Step 3: Numerical model – with use of site-specific parameters



Product

Step 1: Guidance: Simple flux considerations

Step 2: Analytical model og its application for the purpose

Step 3: Guidance and possibly a framework for application of numerical models

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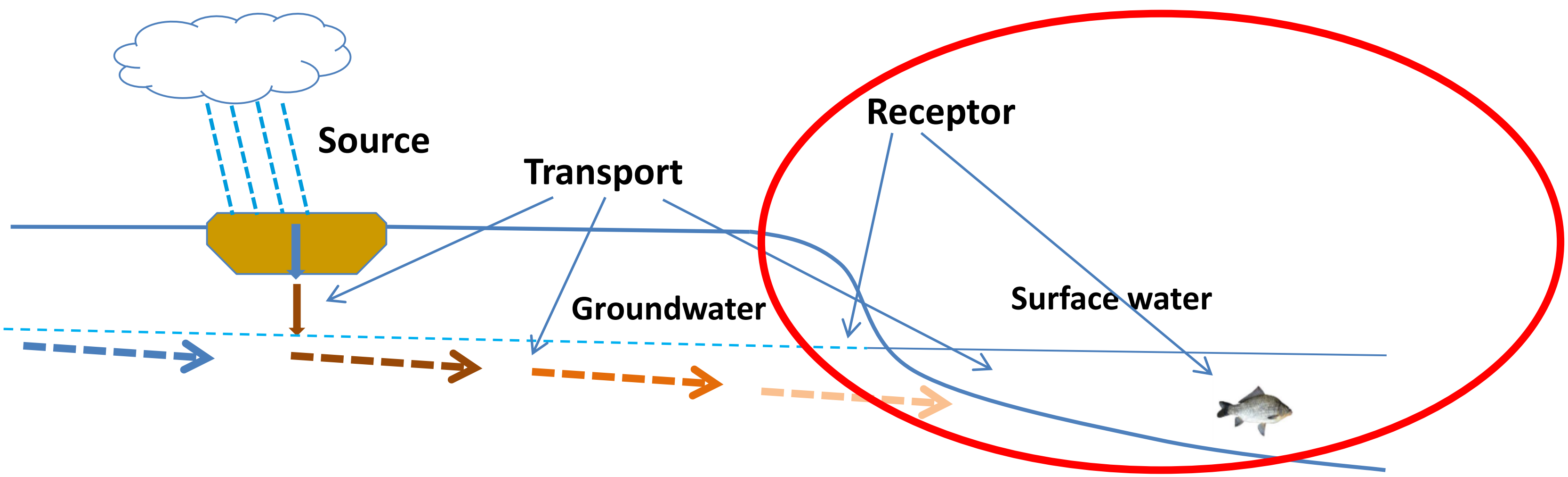
Receptor part

- Source term model
- Transport model
- Receptor

- Placement of POC – distance from landfill, fixed or variable (site-specific)?
- Groundwater and surface water quality criteria to be complied with (substances to be included)
- Special considerations of vulnerability, e.g. NATURA 2000 or the WFD



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Source strength – it is the flux that counts

Source strength = flux (M) = released/discharged amount of substances per time unit (as a function of time)

M(t) = C(t) x Q(t)

C(t) = the concentration of a substance in the lechate – as a function of time

Q(t) = the amount (volume) of leachate – as a function of time

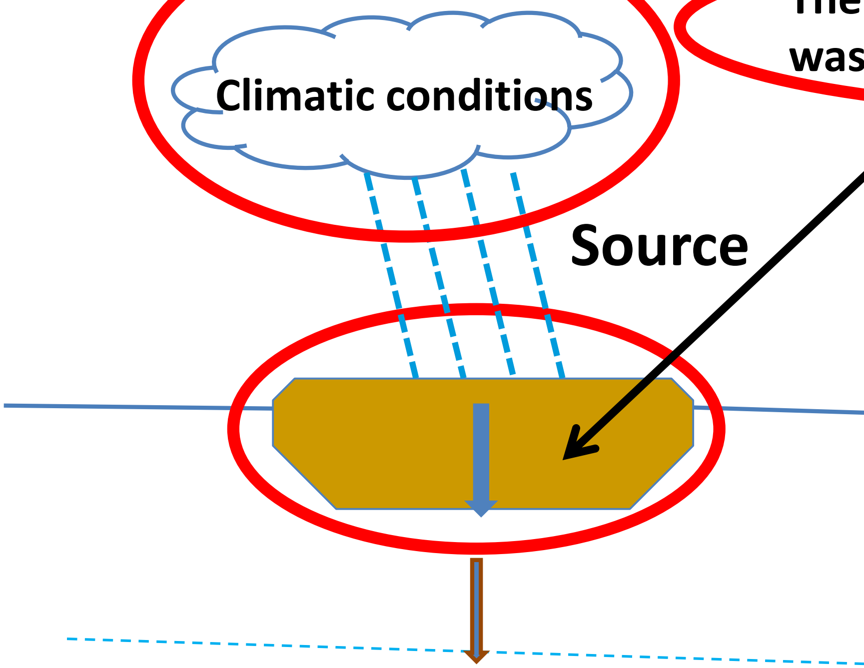
It is expected that C(t) and M(t) decrease with time (and L/S)

Conditions that may influence the source strength

Operation of the landfill

Design and construction of the landfill

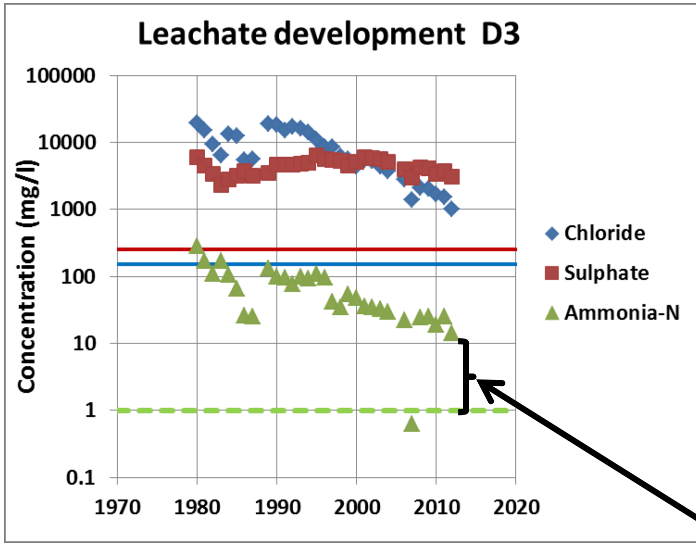
The composition and properties of the waste in the landfill

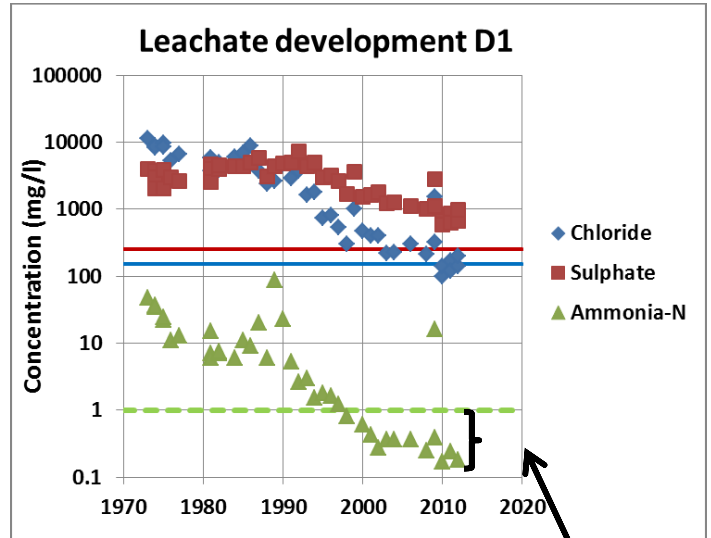


Important factors among many
Physical properties:
Hydraulic conditions (including preferential flow), morphology

Important factors among many
Precipitation rate and intensity
Evapotranspiration (and net infiltration)
Climate changes…….

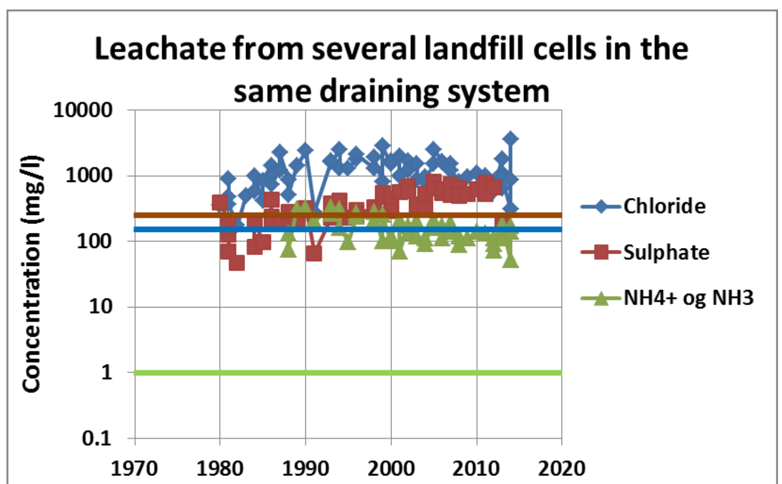
Examples of development of leachate quality over time





Required dilution/attenuation

Cell/Stage	Period in operation
1	1980-1981
2.1	1981-1983
2.1	1983-1985
3	1985-1986
3A	1986-1987
4	1987-1991
4A	
5	1991-2009
6	2009 -



No dilution/atten-uation required

IRL

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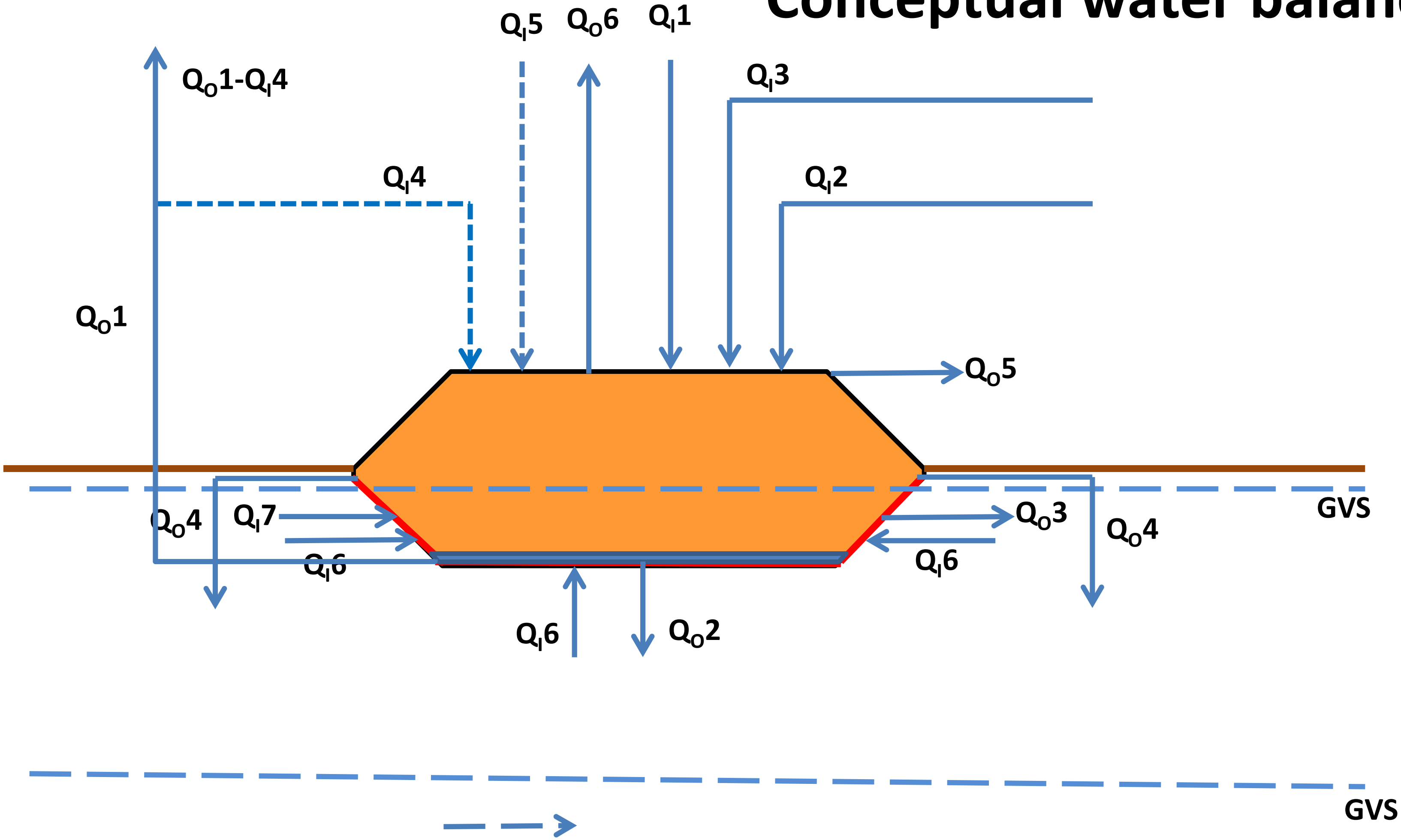
Conceptual water balances



All scenarios in one!

Components of the water balance

Ingoing streams

Q_I1: Infiltration of precipitation

Q_I2: Infiltration of surface water inflow

Q_I3: Infiltration of added clean water

Q_I4: Infiltration of recirculated leachate from the same unit

Q_I5: Infiltration of recirculated leachate from other units

Q_I6: Ingress of groundwater from bottom and sides

Q_I7: Ingress of upstream groundwater which flows through the site

Outgoing streams

Q_O1: Pumped leachate from the draining system

Q_O2: Leachate leaking through the bottom/liner

Q_O3: Downstream leakage/discharge of leachate that has flown horizontally through the unit

Q_O4: Overflow over edge or through holes in side liner after stop pumping of leachate

Q_O5: Surface runoff

Q_O6: Evapotranspiration

The water balances are estimated under the assumption of steady state conditions (no change in water content of the waste)

Different conditions: Scenarios for operation – aftercare - finalised aftercare (possibly a transition period)

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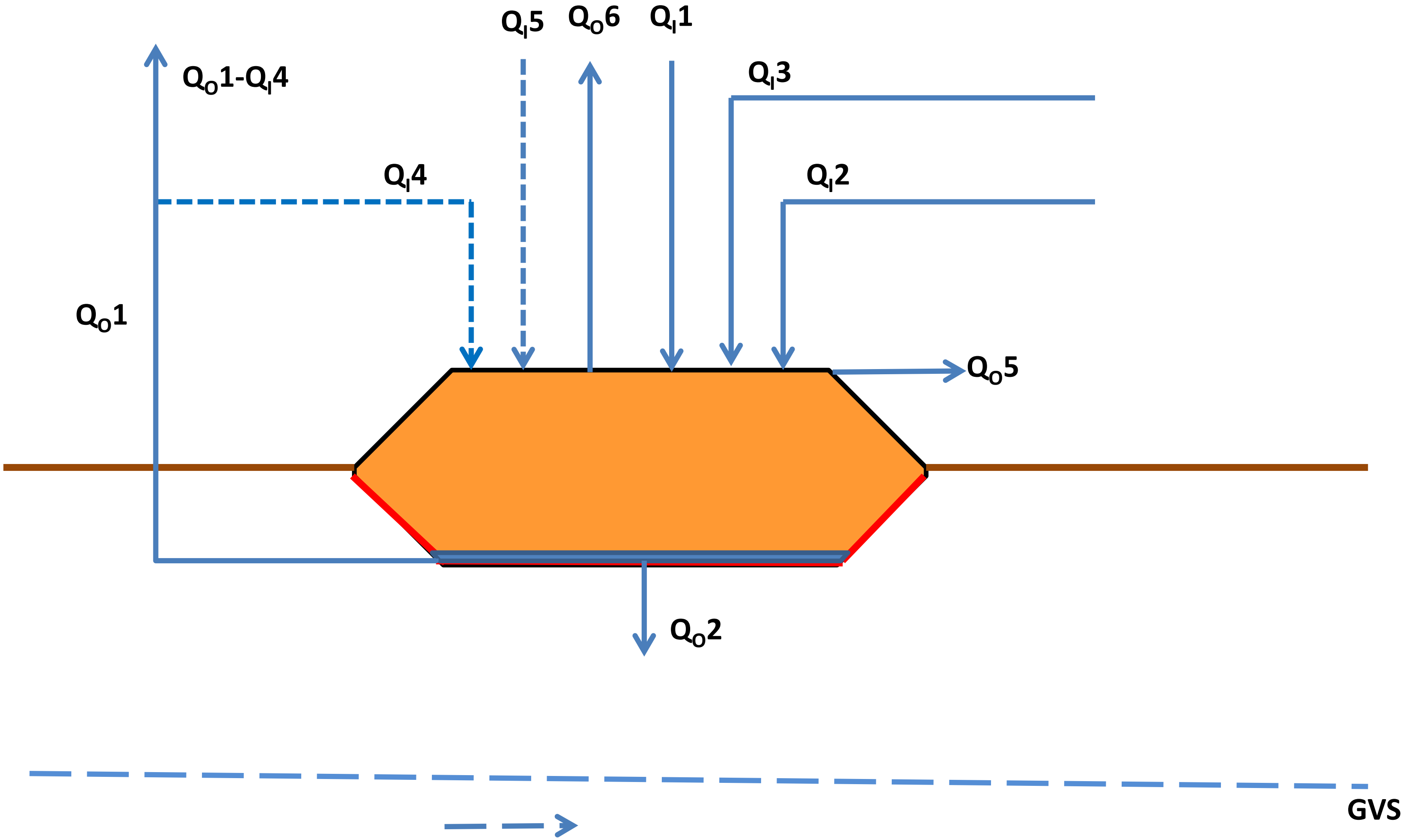
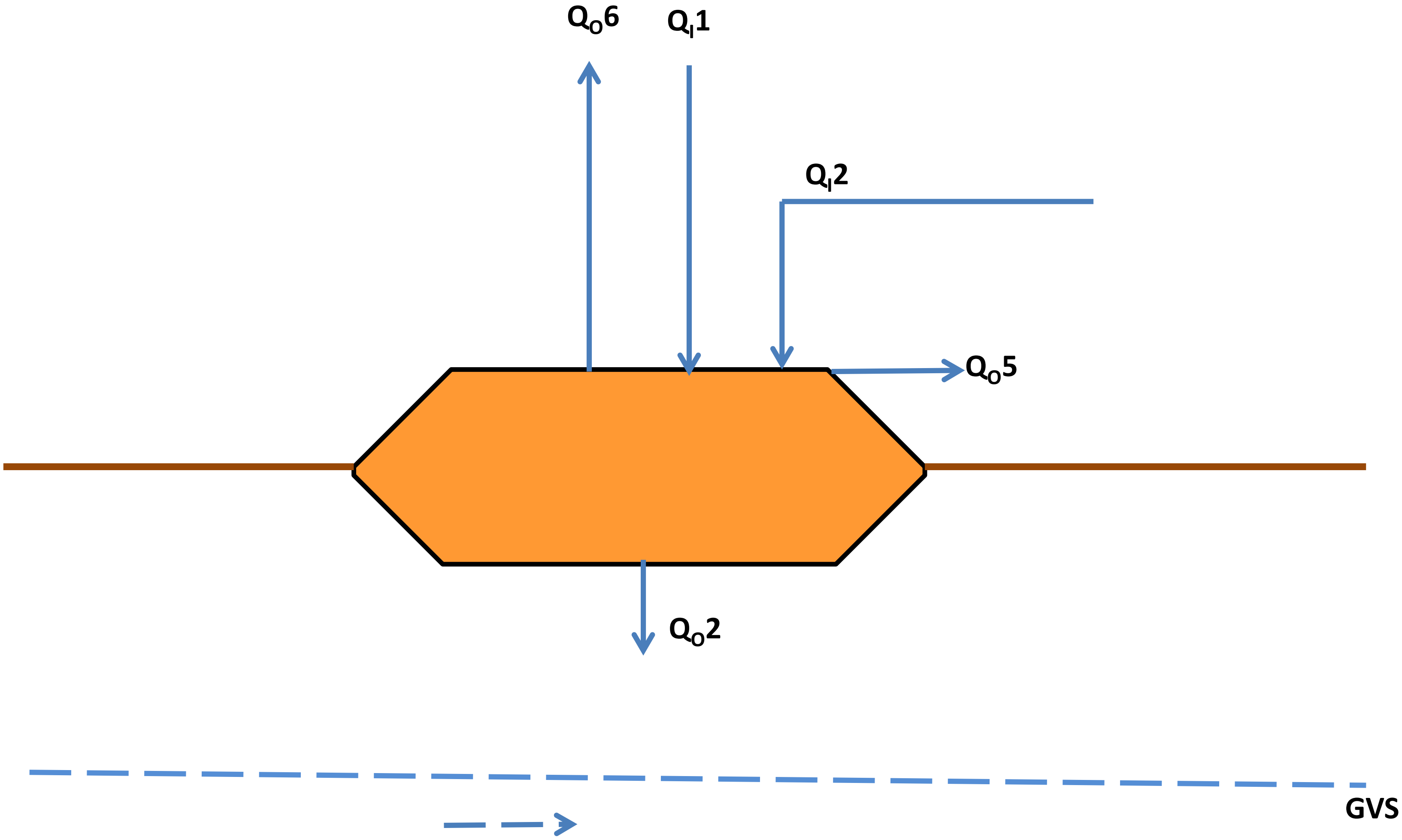
Overview of the various conceptual scenario models for the water balance

Scena-rio	Description	Bottom-liner?	Groundwater level	State	Source volume
1	Controlled landfill	Yes	Below bottom	Aftercare	Q_O2
1a	Uncontrolled dump or controlled landfill with further reduced requirements	No	Below bottom	No active management, vertical flow of infiltrating precipitation	Q_O2
2	Controlled landfill	Yes	Below bottom	Potential bathtub effect after pumping is stopped	$Q_O2 + Q_O4$
3	Controlled landfill	Yes	Above bottom	Aftercare, inwards directed gradient	No source (= 0)
4	Uncontrolled dump	No	Above bottom	Primarily horisontal flow-through of groundwater	$Q_O2 + Q_O3$



Scenario 1: Controlled landfill– aftercare (and operation) – above groundwater - liner

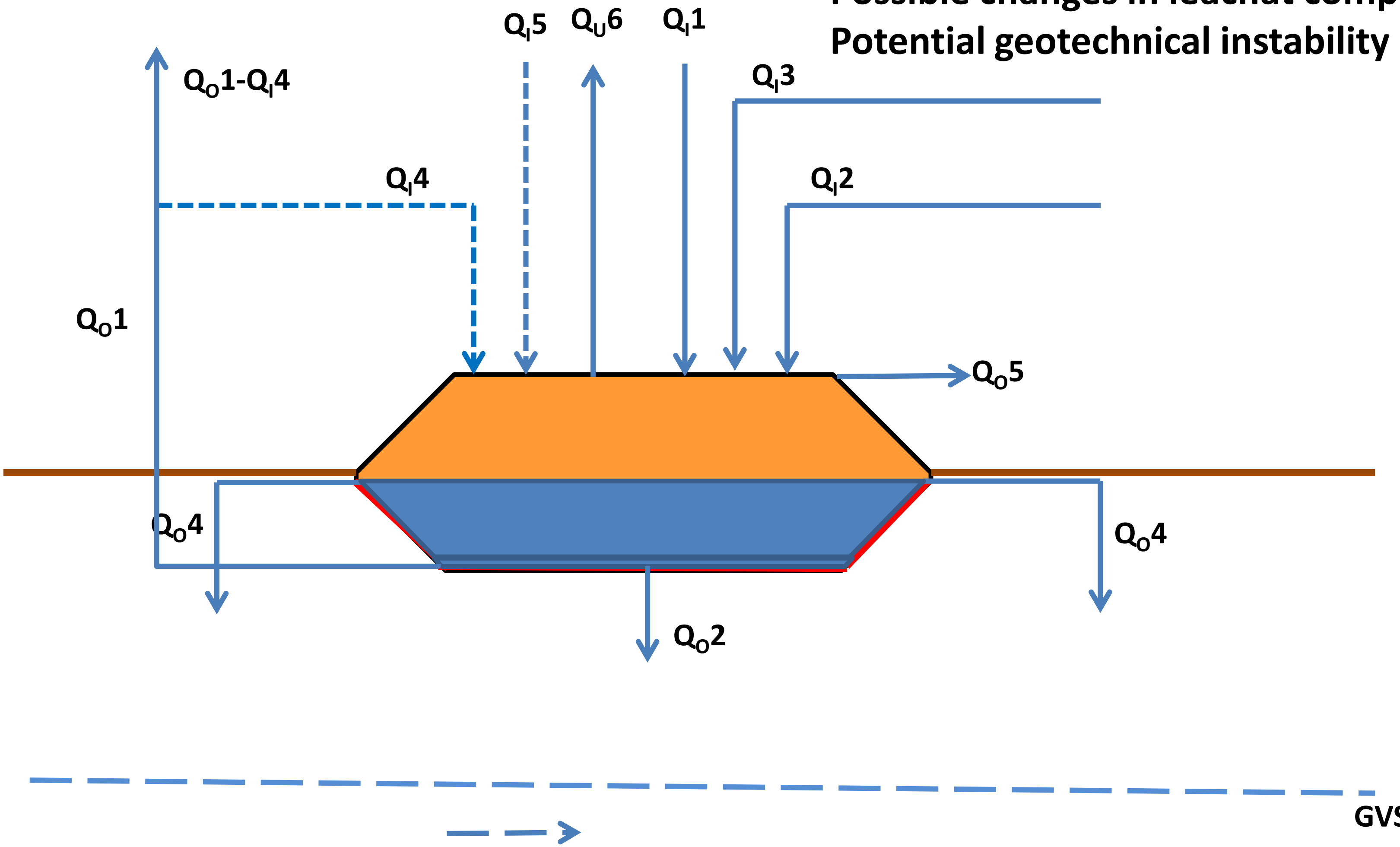
Source term = $Q_O2 = Q_I1 + Q_I2 + Q_I3 + Q_I5 - (Q_O1 - Q_I4) - Q_O5 - Q_O6$



Scenario 1a: Uncontrolled dump – above groundwater level – no liner

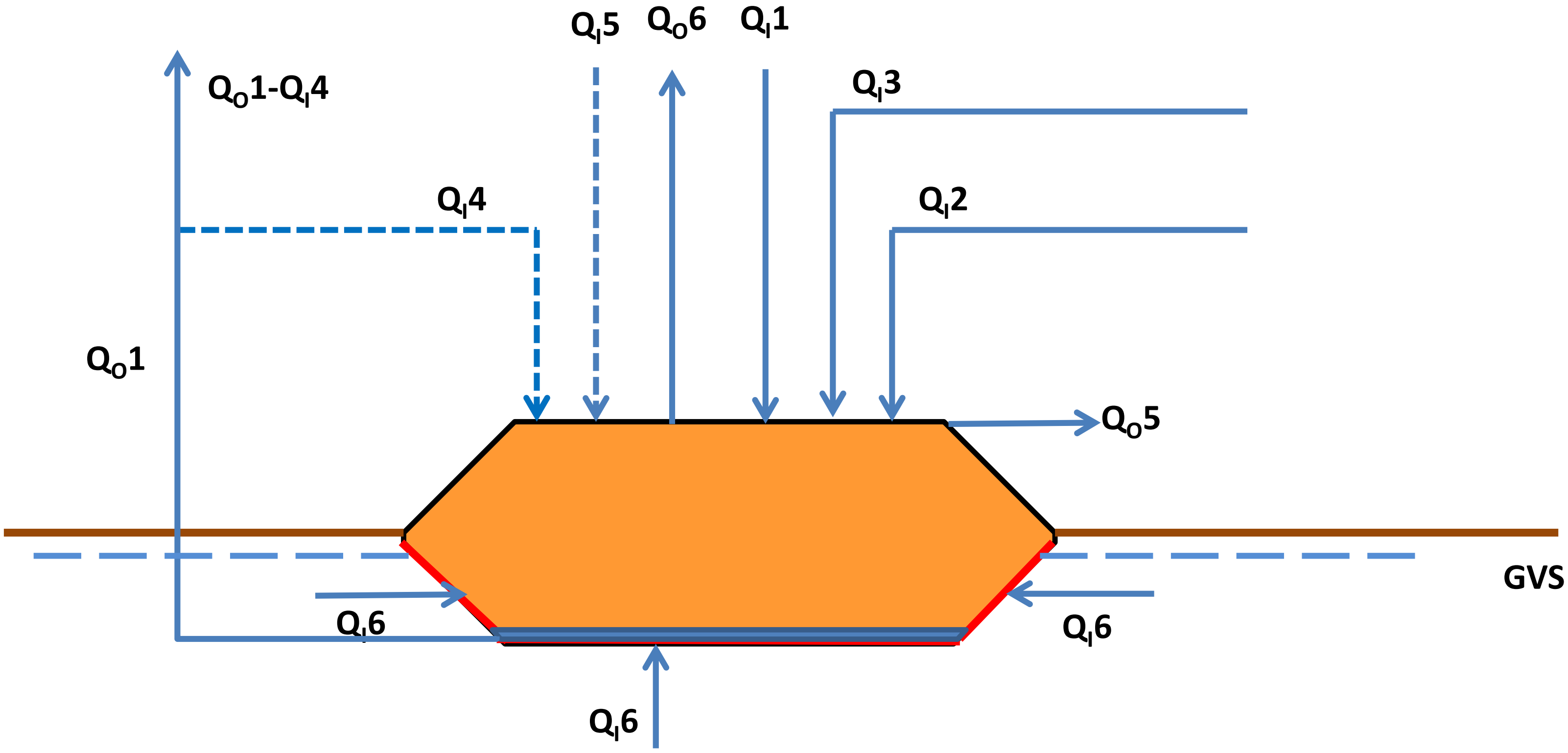
Source term = QO2 = QI1 + QI2 – QO5 - QO6

Possible changes in leachat composition
Potential geotechnical instability



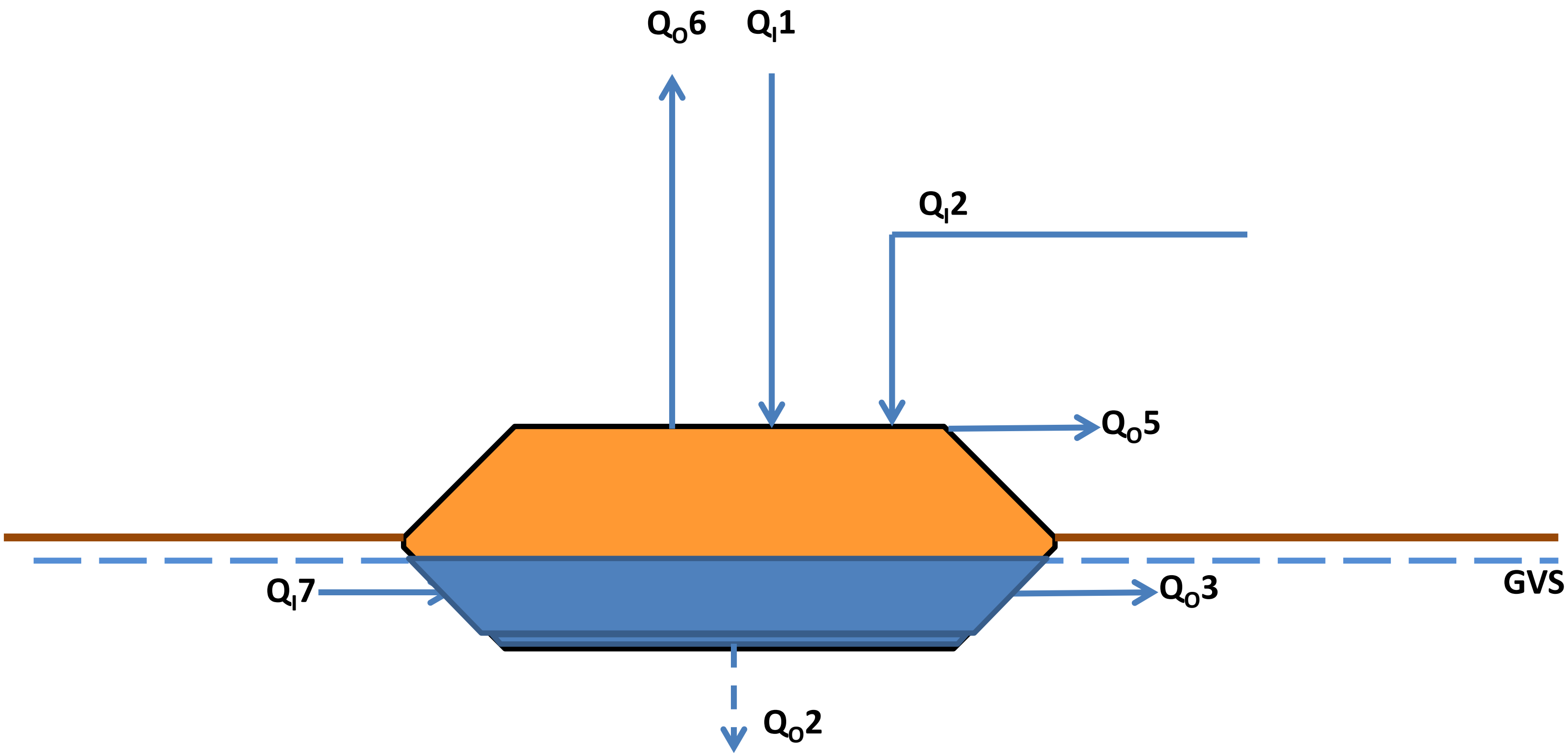
Scenario 2: Controlled landfill – above groundwater level – liner – bathtub-effect after stop of leachate pumping

Source term = QO2 + QO4 = QI1 + QI2 +QI3 + QI5 – (QO1-QI4) – QO5 - QO6



Scenario 3: Controlled landfill – bottom below groundwater level – liner – inwards directed gradient

Source term = 0

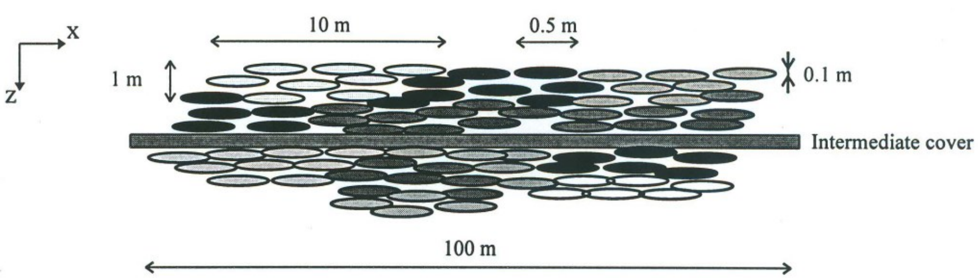


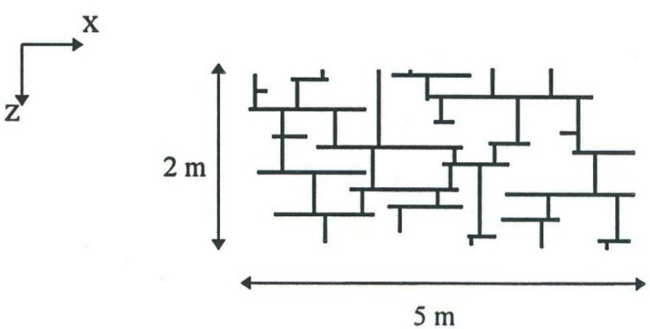
Scenario 4: Uncontrolled dump – bottom below groundwater – no liner - flow through of groundwater

Source term = QO2 + QO3 = QI1 + QI2 +QI7 – QO5 - QO6

Heterogeneous/preferential flow

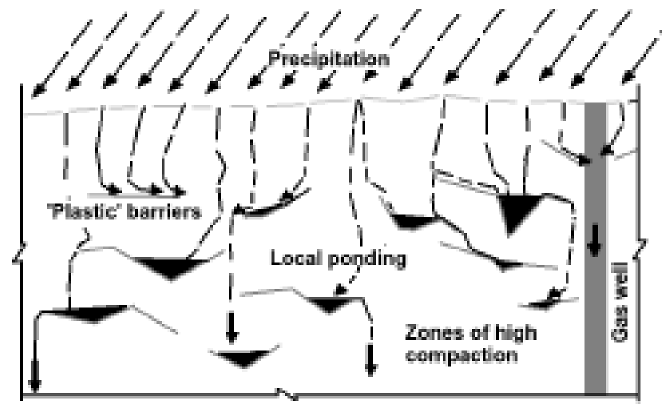
Bendz et al. (1998)

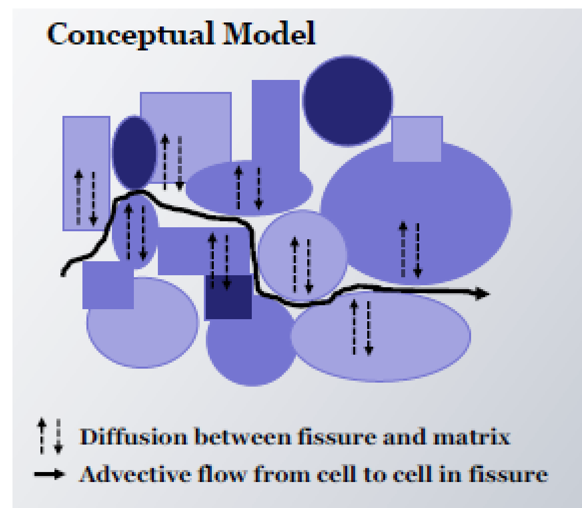




Bendz et al. (1998)

Baviskar & Heimovaara (2011)





Beaven/Rees-White (2014)

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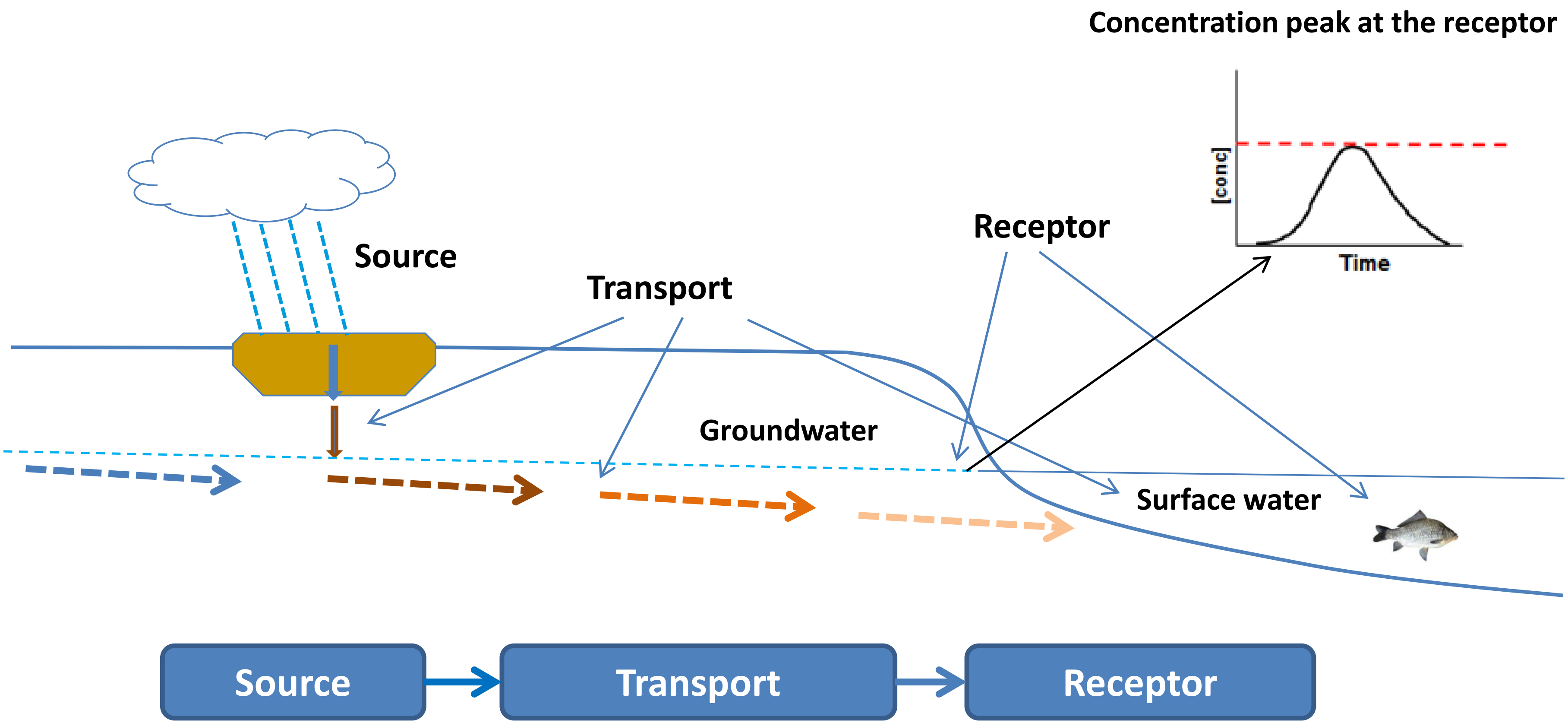
Site-specific risk/impact assessment
Time horizon of modelling



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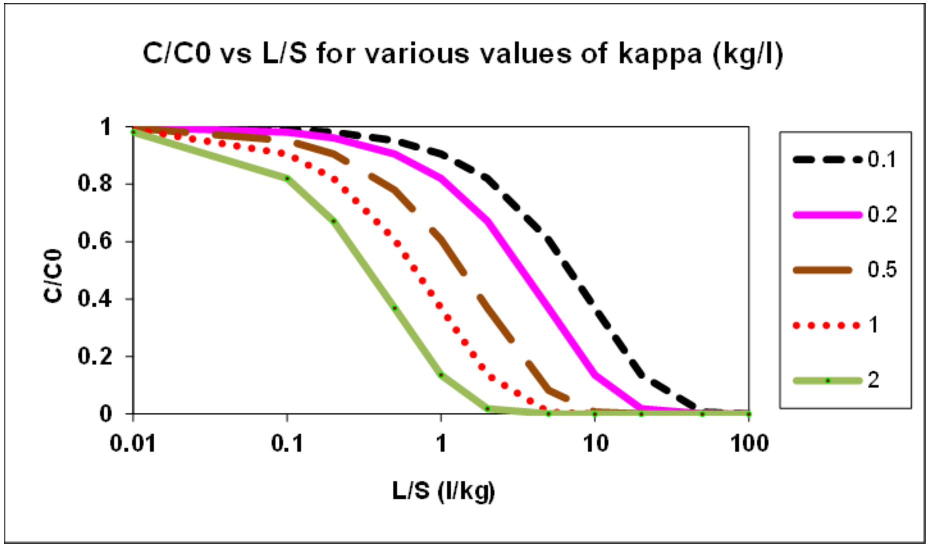
The time horizon of risk assessment modelling

In the risk assessment model, each substance is characterised only by κ and Kd (and relevant water quality criteria)

Substance	κ (kg/l)	Kd (l/kg)
As	0.03	20
Ba	0.15	14
Cd	0.50	20
Cr	0.18	23
Cu	0.28	100
Hg	0.05	20
Mo	0.35	15
Ni	0.29	20
Pb	0.27	100
Sb	0.11	7
Se	0.38	5
Zn	0.28	20
Chloride	0.57	0
Fluoride	0.22	2
Sulphate	0.33	0
DOC	0.17	0



How long does it take for a peak to occur at the POC?

Substance	POC = 6 m	POC = 100 m	POC = 200 m	Extrapolation to POC=1000 m
	Years for peak	Years for peak	Years for peak	Years for peak
As	430	540	633	1470
Ba	147	347	412	1505
Cd	327	436	531	1372
Cr tot	412	540	648	1621
Cu*	1490	2020	2477	6547
Hg	409	519	616	1470
Mo	263	345	415	1042
Ni	348	457	552	1393
Pb	1490	2020	2482	6573
Sb	147	187	220	521
Se	98	126	150	364
Zn	348	457	552	1393
Klorid	2	3	4	12
Fluorid	46	57	67	154
Sulfat	2	3	4	12
DOC	3	4	5	13

First 80 years with 3.5 mm discharge subtracted

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Max concentrations* in the groundwater at POC = 100 m after 100, 300, 500 and 1000 years

Substance	Time to peak	Peak	Cmax	Cmax	Cmax	Cmax
	Years		100 years	300 years	500 years	1000 years
As	540	0.24	0.0000	0.0001	0.14	0.24
Ba	347	0.12	0.0000	0.022	0.12	
Cd	436	0.031	0.0000	0.0001	0.031	
Cr tot	540	0.091	0.0000	0.0000	0.050	0.091
Cu	2020	0.021	0.0000	0.0000	0.000	0.000
Hg	519	0.21	0.0000	0.0001	0.128	0.21
Mo	345	0.059	0.0000	0.0074	0.059	
Ni	457	0.065	0.0000	0.0001	0.060	0.065
Pb	2020	0.022	0.0000	0.0000	0.000	0.000
Sb	187	0.15	0.0000	0.15		
Se	126	0.079	0.0000	0.079		
Zn	457	0.065	0.0000	0.0001	0.060	0.065
Chloride	3	0.17	0.17			
Fliuoride	57	0.13	0.000	0.13		
Sulphate	3	0.13	0.13			
DOC	4	0.088	0.088			

***:Concentrations are relative to a source concentration of 1.0**

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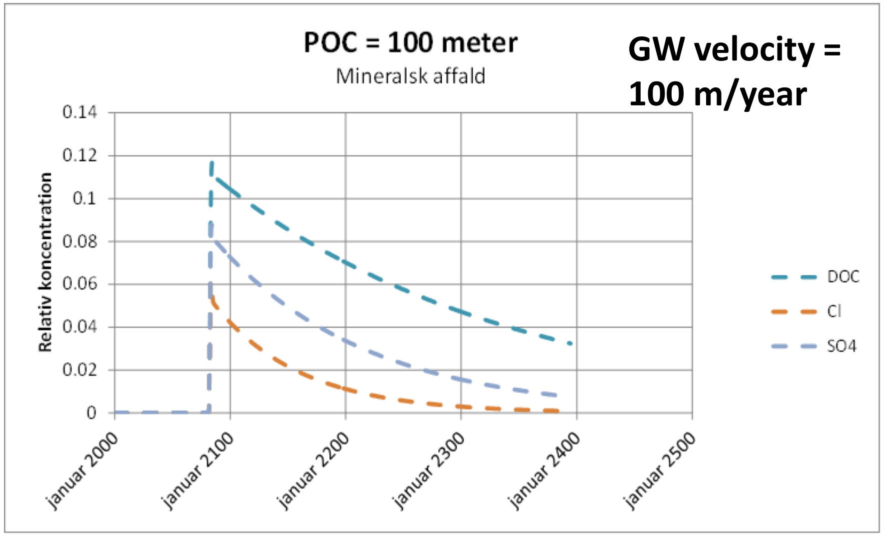
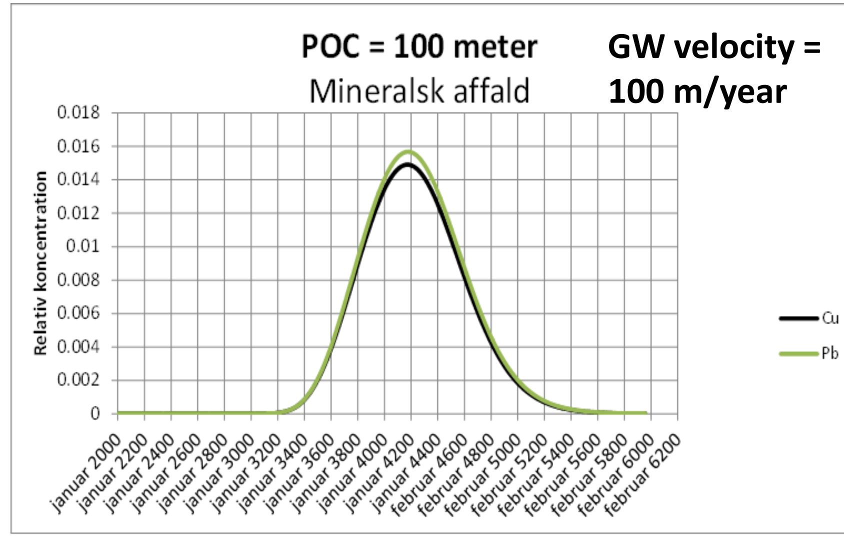
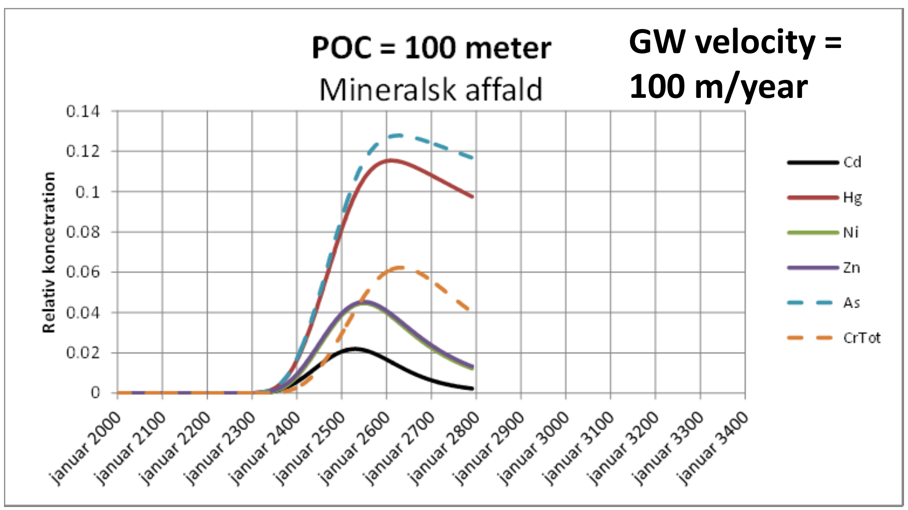
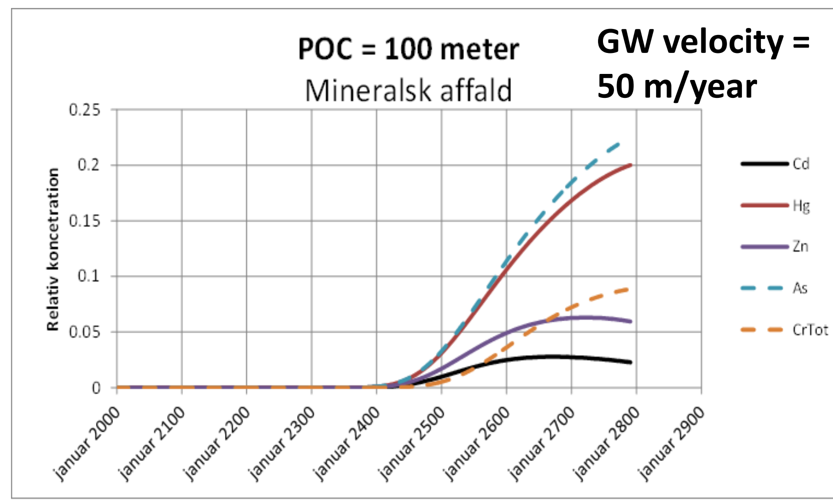
Some examples of break-through curves at POC = 100 m









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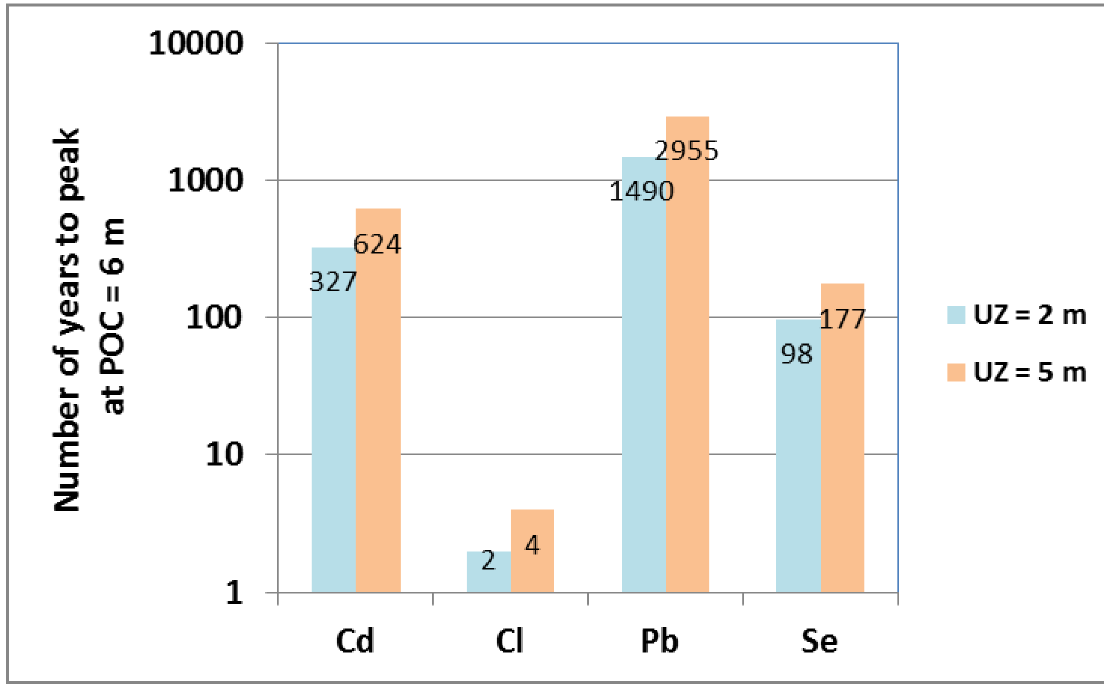
Influence of the thickness of the unsaturated zone (UZ) on the travel time for the concentration peak

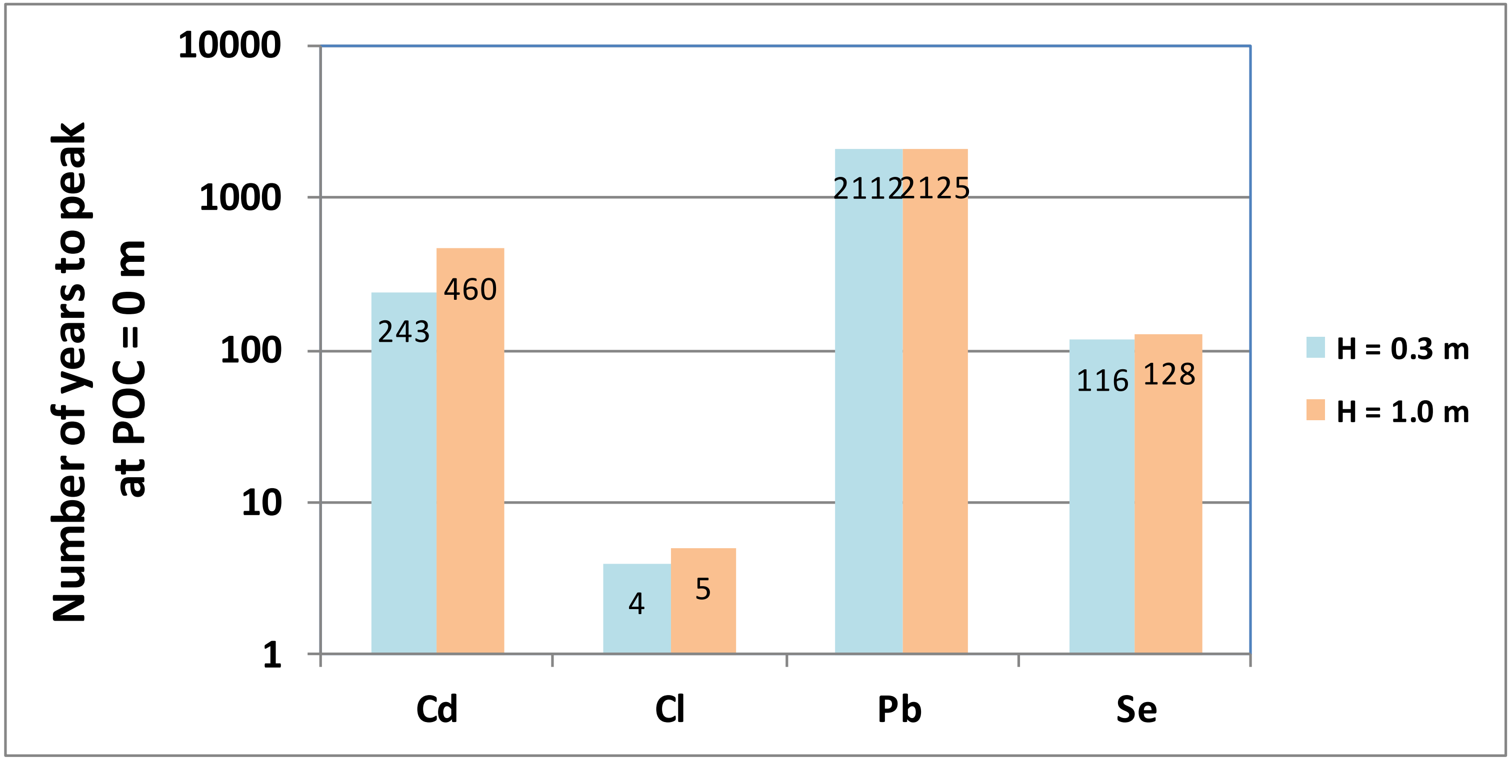
Substance	Kappa	Kd
	kg/l	l/kg
Cd	0.50	20
Cl	0.57	0
Pb	0.27	100
Se	0.38	5



10 m landfill height, 350 mm/year
Period with (almost) non-permable liner deducted

Influence of landfill height on time to peak occurance

Comparison of modelled arrival times for the concentration peak at POC = 0 m for landfill heights of 0.3 m and 1.0 m (from reuse scenario)



1 m UZ, 70 mm/år

POC = 0 m

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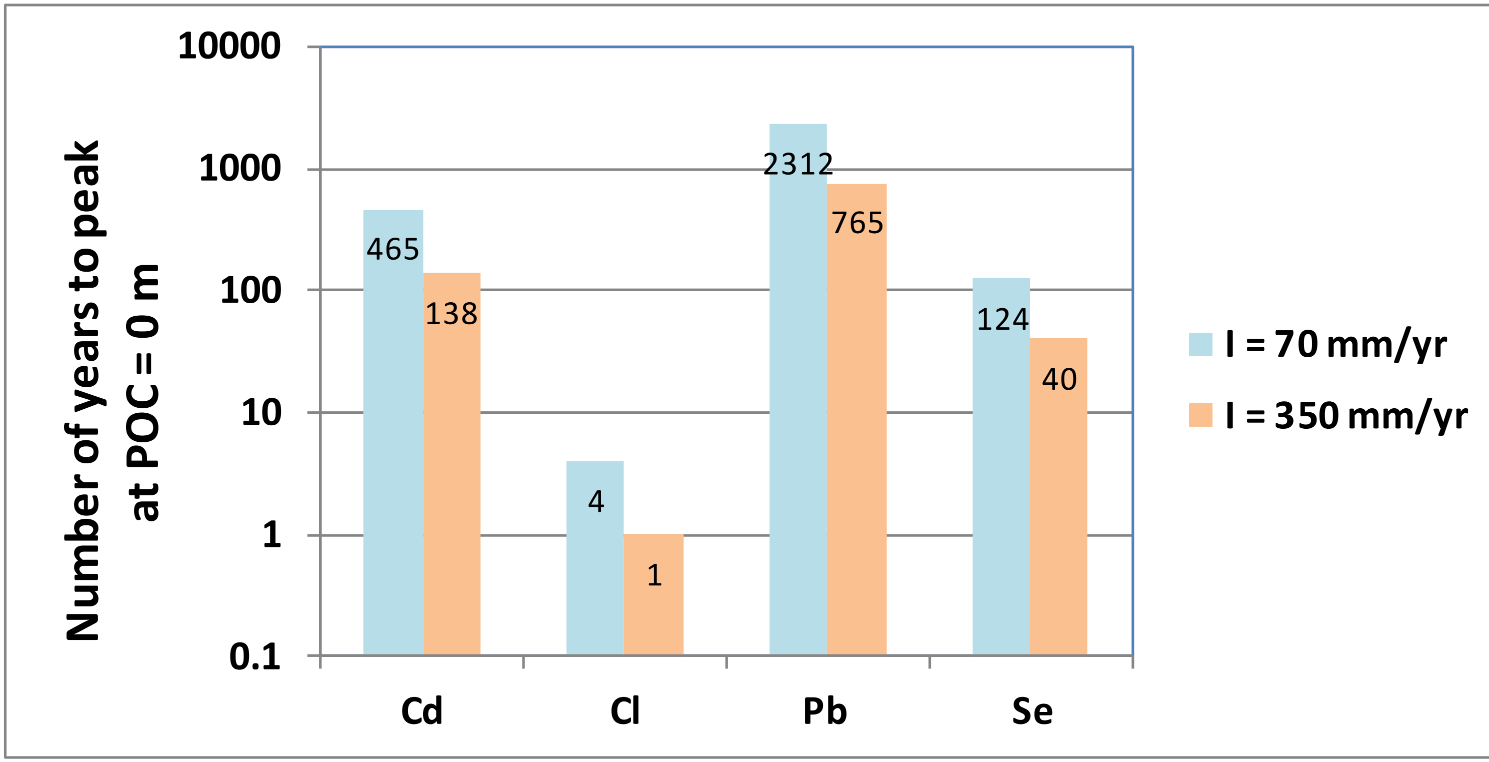
Influence of leachate formation and release rate on time to peak occurance



1 m UZ, H = 0.3 m **Reuse scenario**

POC = 0 m

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To be considered when setting the time frame

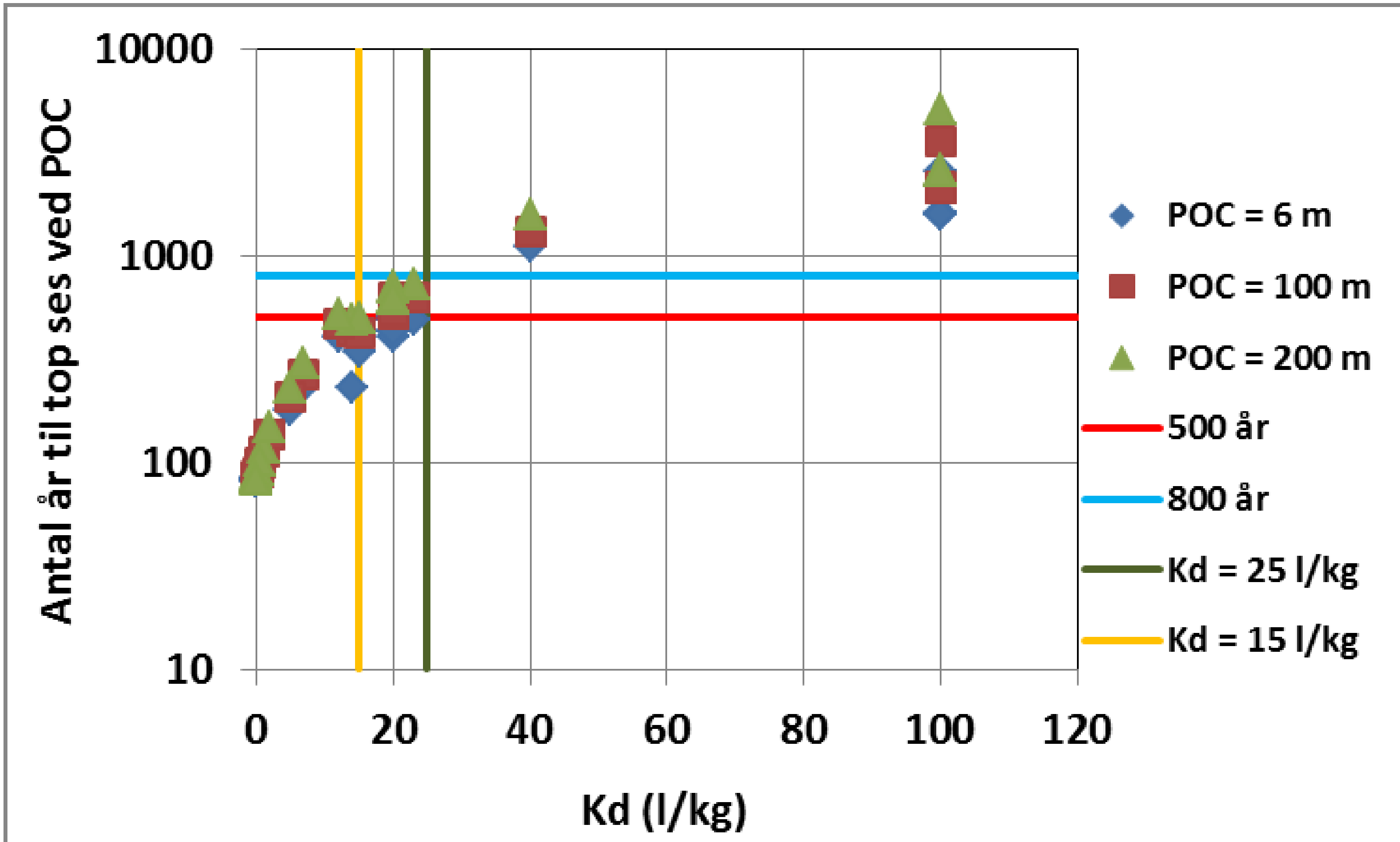
- Strictly speaking, the methodology upon which the risk assessment and subsequent reverse modelling to set criteria is based requires a concentration peak to occur at the relevant POC – if a LV is based on an ascending part of the curve, the LV may be too high (more important for transport modelling than for the source modelling)
- However, depending on the substance in question and the distance to the POC, it may take hundreds to thousands of years for the peak to occur (for organics, degradation may dominate)
- Within several hundred years, geology, climate and society may change rather drastically and make predictions meaningless (a philosophical approach)
- If only ”forward” impact assessments are carried out to assess if the emissions comply with groundwater or surface waste quality criteria, then it may not be necessary to run the model until the peak occurs for all substances – with reference to the previous bullet
- Considering this and the data produced, a time frame for modelling of **500 years** could e.g. constitute a reasonable compromise – if all peaks occur earlier, the modelling can be stopped earlier

How to identify critical substances to be modelled?

Indicators (alone or in combination):

- Substances present in the leachate in relatively high concentration levels over a longer period of time
- Substances for which the GW or SW quality criteria are low
- Substances with a relatively high mobility in soil and groundwater (depends to some extent on the hydro(geology))
- Substances which are not or only to a limit extent biodegradable, even over longer periods of time (this would include inorganic substances)
- Substances that may be transformed/degraded to other substances that are more mobile or more toxic than the original substance
- Substances that are particularly harmful or unwanted in the environment

Kd vs. time until peak occurance at POC for 10 m high landfill unit with 2 m UZ



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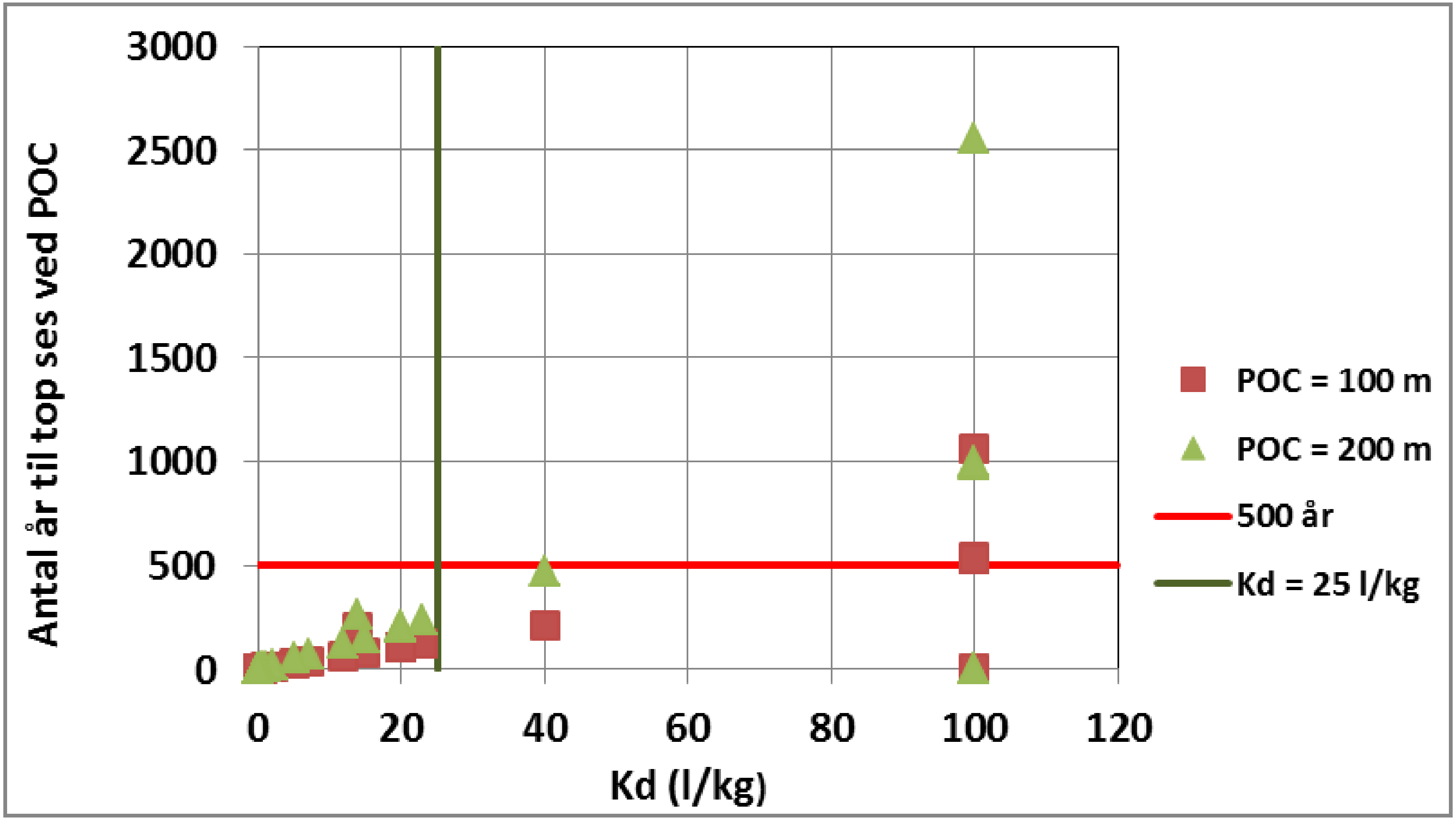
Kd vs. time until peak occurance at POC for 10 m high landfill unit without UZ



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Overview of the relationship between Kd values for discharged substances and estimated maximum transport times for the peak to POC = 100 m and POC = 200 m for a 10 m high landfill unit with 0 m UZ and 2 m UZ, respectively, with a leachate production and release rate of 350 mm/year

Kd (l/kg)	Thickness of UZ (m)	Time for peak to reach POC = 100 m (years)	Time for peak to reach POC = 200 m (years)
≤ 15	0	80	150
≤ 15	2	430	500
15 <Kd ≤ 25	0	200	270
15 <Kd ≤ 25	2	510	710
25 < Kd ≤ 40	0	210	470
25 < Kd ≤ 40	2	1100	1300
40 < Kd ≤ 100	0	1060	2560
40 < Kd ≤ 100	2	2540	5100

Overview of the order of magnitude of Kd for the substances which were modelled to set landfill WAC

≤ 15 l/kg	15 l/kg <Kd ≤ 25 l/kg	25 l/kg < Kd ≤ 40 l/kg	40 l/kg < Kd ≤ 100 l/kg
Chloride, sulphate, DOC, benzene, 2-chlorophenol, phenol, toluene, xylene, naphthalene, Cr(VI), fluoride, Se, Sb, pentachlorophenol, Ba, Mo	As, Cd, Hg, Ni, Zn, Cr(tot)	Fluoranthene***	Cr(III), Cu, Pb, decan*, pentadecan*, PCB28**

***: used as a model substance for hydrocarbons**

****: used as a model substance for PCBs**

*****: used as a model substance for PAHs**

Project plans

- The **source term** methodology/model will be ready by the end of 2016
- The **analytical model** will be ready for use at the end of 2016 and updated with an improved user interface at the end of 2017
- The **receptor impact** part will be ready at the end of 2016
- The **econmomic impact** assessment is planned for 2017

NB: The last 16% of the funding still to be raised

Thank you for your attention!

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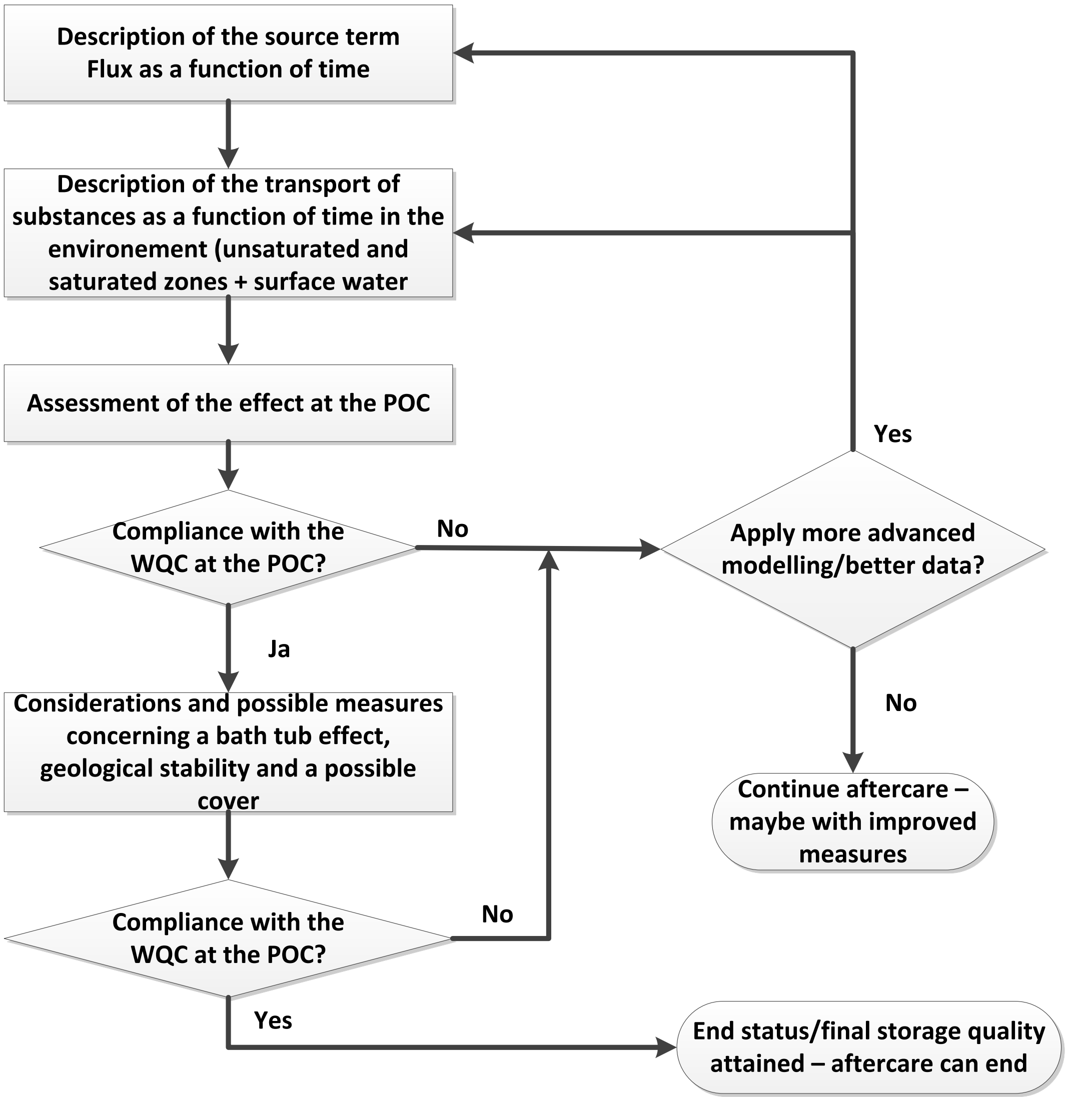
Main considerations when deciding if the aftercare can be ended – based on HHE risks associated with leachate



Main info required:

- Source strength as a function of time (difficult)*
- Transport of substances (state-of-the-art)
- Impact at the receptor (POC) – not very complicated

* Focus on the source/leachate

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