Overview of Iowa RBCA for Petroleum LUST's

Produced by: LaDon Jones
Associate Professor
Civil Engineering
Iowa State University
Ames, Iowa

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Risk-Based Corrective Action (RBCA)

Definition: A streamlined approach in which exposure and risk assessment practices are integrated with traditional components of the corrective action process to ensure that appropriate and cost-effective remedies are selected, and that limited resources are properly allocated.

Goals:

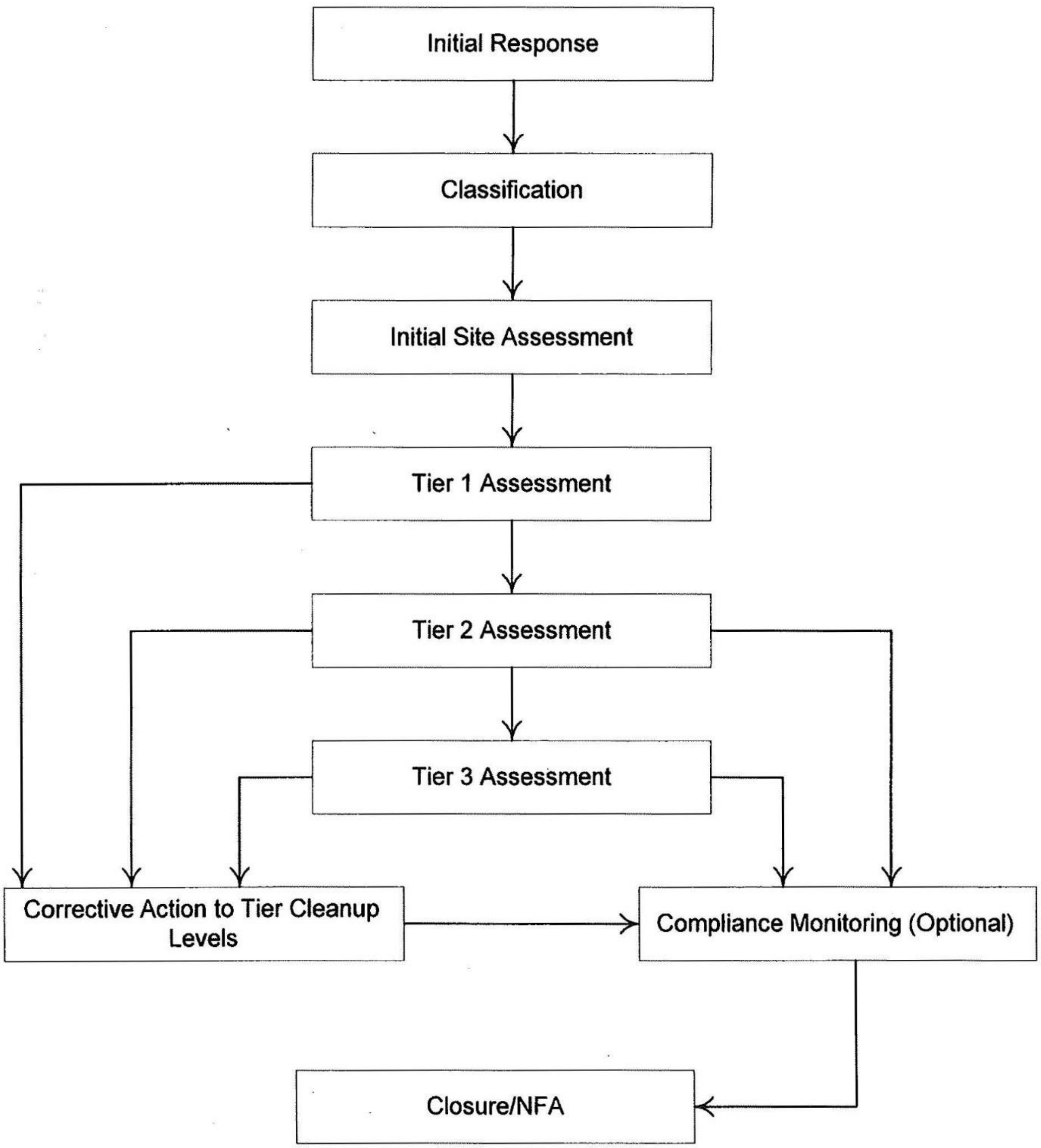
1. Protection of human health and environment
2. Consistent and technically-defensible Outcome: Practical and cost-effective approach.

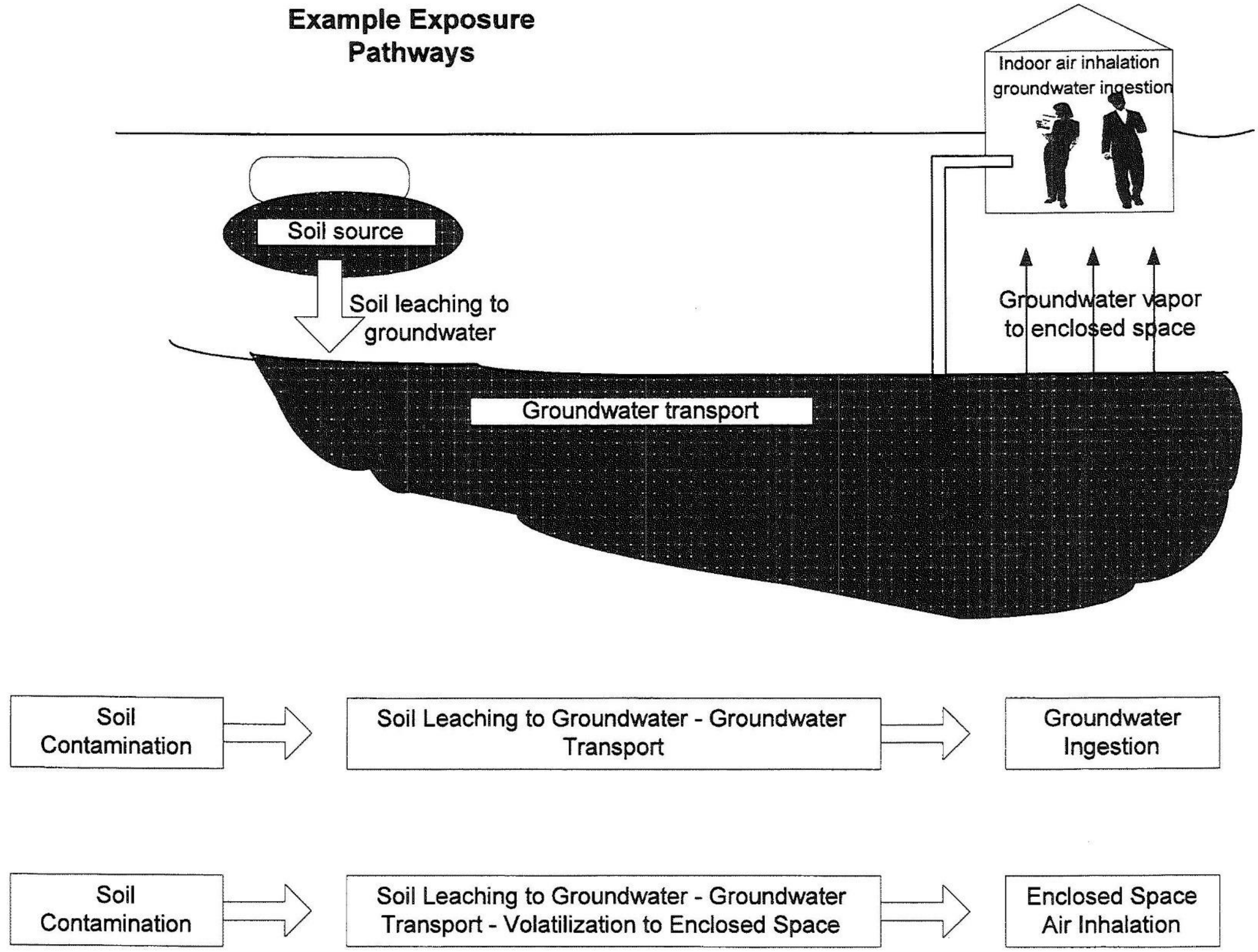
ASTM E 1739-95

"Guide to Risk-Based Corrective Action at Petroleum Release Sites"

E 1739 describes a framework or philosophy upon which regulatory agencies can build their own risk-based guidance.

Tiered Approach





Exposure Assessment

Potential Exposure Pathways
Only complete exposure pathways are quantified in the exposure assessment process.

A complete exposure pathway requires:

1. A source and mechanism for release into the environment.
2. A transport medium (air, soil, groundwater) for the chemical to move from the source to the receptor.
3. A point of potential contact of the receptor with the medium (points of exposure)
4. An uptake route or means for taking the chemical into the body (ingestion, inhalation, dermal contact)

Potentially Exposed Populations (receptors)

- residents (adult, child)
- workers (commercial, industrial, construction, utility)
- visitors
- reasonable potential future population groups

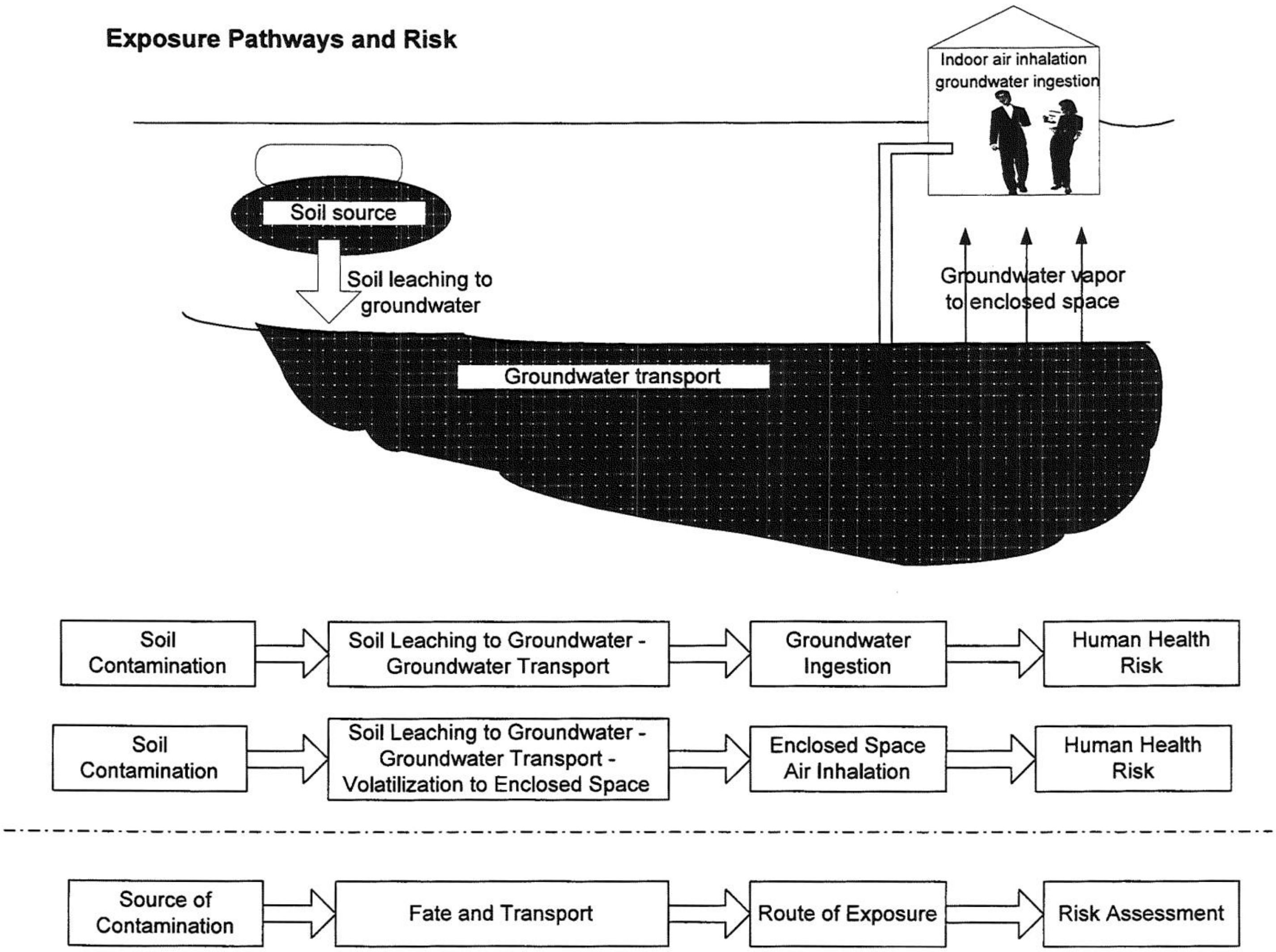
Tier 1: The point of exposure is assumed to be the source.
Tier 2: Site-specific. Accounts for dilution and attenuation between the source and the receptor.

Risk Assessment

- A process based on science that estimates human health and environmental risks associated with chemicals of concern present in the environment.
- Adverse effects/risk depend on **Toxicity** and **Exposure.**
- Risk = Toxicity & Exposure

Exposure:

1. Concentration at the point of exposure
2. Rate of Intake.



Iowa RBCA

Two human health exposure pathways

- Groundwater Ingestion (Drinking)
- Inhalation of Vapors in Enclosed Spaces (Breathing).

Has one ecological exposure pathway

- Surface Water - Designated Use and Chronic Toxicity for Fish

Tier 1

Objective of Soil and Water Sampling:

Identify the source locations and maximum chemical concentrations in soil and groundwater. Refer to [Tier 1 Guidance] for required Tier 1 soil and groundwater sampling. The point of exposure is the source

Pathways at Tier 1

Source - Fate and Transport - Receptor

Tier 1 Pathways: There are seven (7) Tier 1 Pathways

- Route of Exposure; Groundwater Ingestion (Drinking Contaminated Groundwater)
  1. Groundwater Ingestion Pathway
  2. Soil Leaching to Groundwater Pathway
  3. Groundwater to Water Line Pathway
  4. Soil to Water Line Pathway

- Route of Exposure; Indoor Vapor Inhalation (Breathing Contaminated Air in Enclosed Spaces)
  5. Groundwater Vapor to Enclosed Space Pathway
  6. Soil Vapor to Enclosed Space Pathway

- Route of Exposure: Primarily ecological (protecting beneficial uses of surface water bodies; recreation, fishing). Drinking water use for a few locations.
  7. Surface Water Pathway

Receptors

Each receptor pathway must be evaluated:

Is the receptor present?

Are Tier 1 levels exceeded for the receptor?

Tier 1 (and Tier 2) Levels are receptor specific.
Pathways: a convenient and logical way to organize the receptors.
To receive a no further action for a pathway, you have to have a no further action for each receptor in the pathway.

Pathway	Receptors
Groundwater Ingestion	Drinking Water Well Non-Drinking Water Well Protected Groundwater Source
Soil Leaching to Groundwater	Water Supply Wells (Drinking and Non-Drinking) Protected Groundwater Source
Groundwater to Water Line	Actual Water Lines Potential Water Lines
Soil to Water Line	Actual Water Lines Potential Water Lines
Groundwater Vapor to Enclosed Space	Enclosed Spaces
Soil Vapor to Enclosed Space	Enclosed Spaces
Surface Water	Designated Use Surface Water Bodies General Use Surface Water Bodies

Tier 1 and Tier 2 can be organized based on Receptors.

Tier 1: There are eight (8) possible types of Receptors.

Receptor	Route of Exposure	Pathways
Drinking Water Well	Groundwater Ingestion	Groundwater Ingestion Soil Leaching to GW
Non-Drinking Water Well	Groundwater Ingestion	Groundwater Ingestion Soil Leaching to GW
Protected Groundwater Source	Groundwater Ingestion	Groundwater Ingestion Soil Leaching to GW

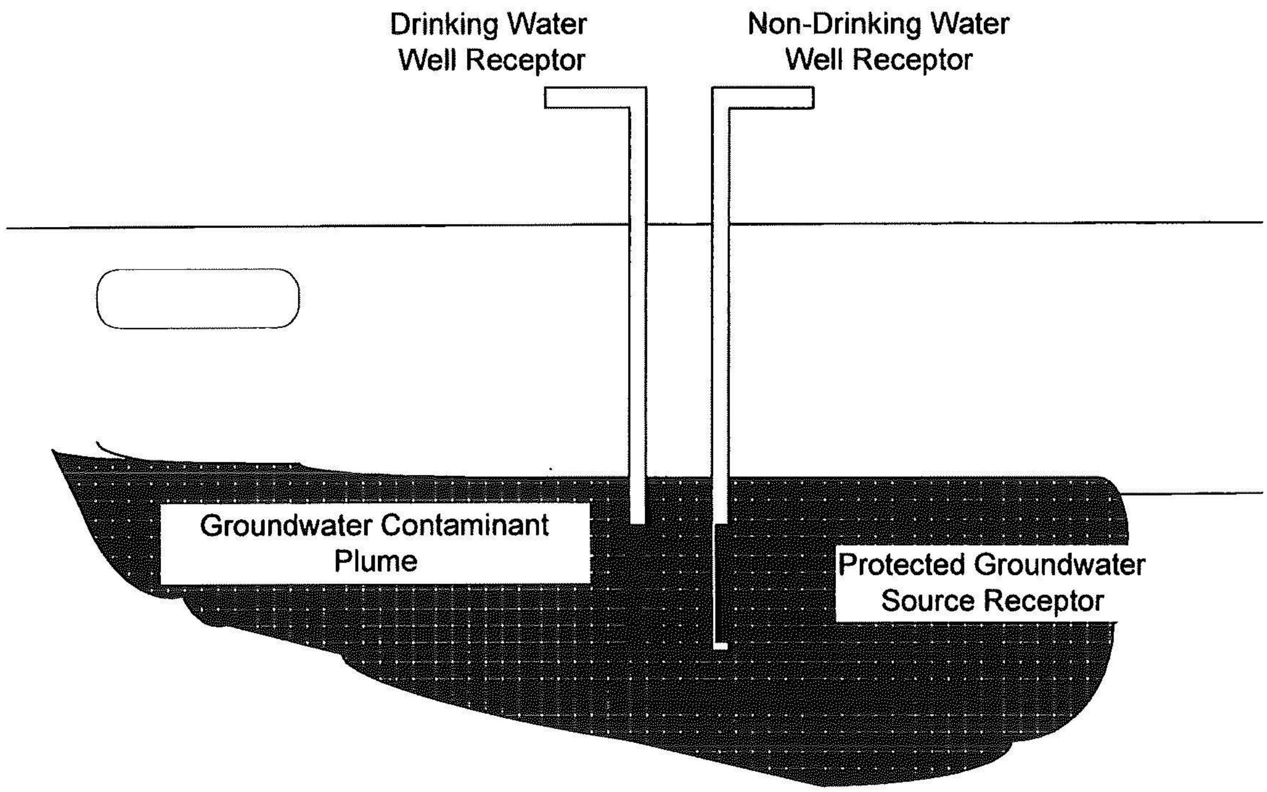
Receptor	Route of Exposure	Pathways
Actual Water Lines	Groundwater Ingestion	GW to WL Soil to WL
Potential Water Lines	Groundwater Ingestion	GW to WL Soil to WL
Enclosed Spaces	Indoor Air Inhalation	GW Vapor Soil Vapor
Designated Use Streams	Ecological, Drinking Water	Surface Water
General Use Streams	Ecological	Surface Water

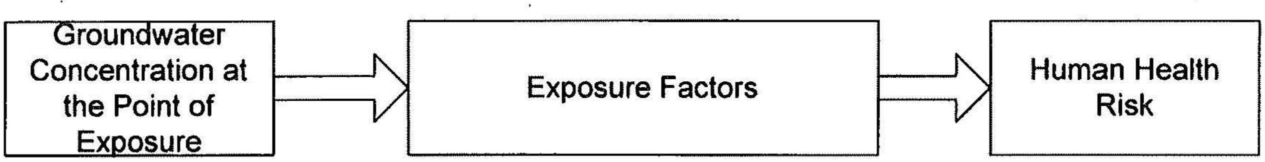
GW: Groundwater
WL: Water Lines

For the same receptor, multiple pathways mean multiple possible sources.

Tier 1: Groundwater Ingestion Pathway
Point of Exposure is the Source: Maximum concentrations for each chemical

3 Receptors: Drinking Water Well
Non-Drinking Water Well
Protected Groundwater Source





Route of Exposure: Ingestion of Water (Drinking contaminated water)

Receptor Types:
- Drinking Water Well (DWW):
- Non-Drinking Water Well (NDWW):
- Protected Groundwater Source (PGWS):

Receptor Definitions:

Receptor Type	Receptor is Present if:
Drinking Water Well	there are drinking water wells within 1,000 feet of the soil or groundwater sources.
Non-drinking Water Well	there are non-drinking water wells within 1,000 feet of the soil or groundwater sources.
Protected Groundwater Source	the first encountered groundwater has a K ≥ 0.44 m/day and TDS < 2,500 mg/1,

Tier 1 Levels: Groundwater Ingestion Pathway; maximum measured concentrations in groundwater (µg/L)

Receptor	Group 1 ppb					Group 2 ppb	
	Type	Benzene	Toluene	Ethylbenzene	Xylenes	TEH Diesel	TEH WO
Drinking Water Well (DWW)	Actual	5	1,000	700	10,000	1,200	400
Non-Drinking Water Well (NDWW)	Actual	290	7,300	3,700	73,000	75,000	40,000
Protected Groundwater Source (PGWS)	Potential	290	7,300	3,700	73,000	75,000	40,000

Must address each receptor in the Pathway:
For each receptor:
1. If the receptor is not present or the Tier 1 Levels are not exceeded;
   No further action is required for the receptor.
2. If the receptor is present and Tier 1 Levels are exceeded:
   Further action is required.

Further Action at Tier 1 can include:
Sever the pathway to the receptor.
Tier 2 Assessment.

Tier 1
Completing information and answering questions on page 2 (Tier 1 Site Data Summary) and page 3 (Tier 1 Pathway Evaluation Summary) of the Tier 1 Report form may be used to complete the initial Tier 1 screening.

A Tier 1 Site Assessment (Tier 1) uses limited site data to determine whether a site poses an unreasonable risk to public health, safety, and the environment. A Tier 1 assessment generally includes: conducting a field investigation to determine the maximum concentrations of chemicals of concern in soil and groundwater associated with the petroleum release, surveying the surrounding area for receptors and comparing maximum contaminant concentrations to the Tier 1 Look-up Table to determine which pathways are complete. The Tier 1 levels are derived from models using conservative assumptions to predict contaminant movement and exposure to receptors.

A Tier 1 Assessment assumes the worst-case scenario, by evaluating whether actual or potential receptors could be exposed to chemicals of concern through soil and groundwater pathways. The location with the maximum concentrations is assumed to be the point of exposure, i.e., the source.

Additional assessment after the Tier 1 assessment is complete depends on maximum concentrations identified. For example, if the maximum concentrations do not exceed the Tier 1 levels for a pathway, further assessment of that pathway may not be required. If a maximum concentration does exceed a Tier 1 level, additional assessment or corrective action may be required, including but not limited to conducting a Tier 2, performing soil excavation, or implementing an institutional or technical control.

Tier 1: Groundwater Ingestion Pathway
Drinking Water Well Receptor

Step 1. Identify whether drinking water wells receptors are present.

Drinking Water Well Receptor: Drinking water well receptors are present if there are drinking water wells within 1,000 feet of the soil or groundwater source(s):

Receptor Type	Receptor is Present if:
Drinking Water Well	there are drinking water wells within 1,000 feet of the soil or groundwater sources.

Step 2. Determine whether the Tier 1 levels are exceeded for the receptor: If the groundwater source concentration for any chemical exceeds the Tier 1 level, the Tier 1 levels are exceeded.

Receptor	Group 1 ppb					Group 2 ppb	
	Type	**Benzene**	**Toluene**	**Ethylbenzene**	**Xylenes**	**TEH Diesel**	**TEH WO**
Drinking Water Well (DWW)	Actual	5	1,000	700	10,000	1,200	400
Non-Drinking Water Well (NDWW)							
Protected Groundwater Source (PGWS)							

Step 3. Determine Possible Corrective Actions

A. If Tier 1 levels for the receptor are not exceeded or the receptor is not present;
   No further action required for the drinking water well receptor.
B. If the receptor is present and Tier 1 levels are exceeded;
   Further action is required, there are two options
   a) Sever the pathway to the receptor:
      Plug all drinking water wells within 1,000 feet of the source.
   b) Tier 2 assessment of the groundwater ingestion pathway.

Step 4. Implement Selected or Required Corrective Action.

Note: Groundwater Remediation is not allowed at Tier 1. The plume has not been defined at Tier 1.

Tier 1: Groundwater Ingestion Pathway
Non-Drinking Water Well Receptor

Step 1. Identify whether non-drinking water wells receptors are present.

Non-Drinking Water Well Receptor: Non-Drinking water well receptors are present if there are non-drinking water wells within 1,000 feet of the soil or groundwater source(s):

Receptor Type	Receptor is Present if:
Non-Drinking Water Well	there are non-drinking water wells within 1,000 feet of the soil or groundwater sources.

Step 2. Determine whether the Tier 1 levels are exceeded for the receptor: If the groundwater source concentration for any chemical exceeds the Tier 1 level, the Tier 1 levels are exceeded.

Tier 1 Levels: Groundwater Ingestion Pathway, Non-Drinking Water Well Receptor

Receptor	Group 1 ppb					Group 2 ppb	
	Type	**Benzene**	**Toluene**	**Ethylbenzene**	**Xylenes**	**TEH Diesel**	**TEH WO**
Non-Drinking Water Well (NDWW)	Actual	290	7,300	3,700	73,000	75,000	40,000
Maximum measured concentration							
Tier 1 Level exceeded:							

Tier 1 Levels are receptor specific.

Step 3. Determine Possible Corrective Actions

A. If Tier 1 levels for the receptor are not exceeded or the receptor is not present; No further action required for the non-drinking water well receptor.

B. If the receptor is present and Tier 1 levels are exceeded; further action is required, there are two options
   a) Sever the pathway to the receptor:
      Plug all non-drinking water wells within 1,000 feet of the source.
   b) Tier 2 assessment of the groundwater ingestion pathway.

Step 4. Implement Selected or Required Corrective Action.

Note: Groundwater Remediation is not allowed at Tier 1. The plume has not been defined at Tier 1.

Tier 1: Groundwater Ingestion Pathway
Protected Groundwater Source Receptor

Step 1. Identify whether a Protected Groundwater Source Receptor is present.

Protected Groundwater Source: the first encountered groundwater is a protected groundwater source if: the hydraulic conductivity (K) is ≥ 0.44 m/day and total dissolved solids (TDS) is < 2,500 mg/L.

Hydraulic conductivity (K): the maximum estimate of hydraulic conductivity at the site (usually found from slug testing).

Total dissolved solids (TDS): the minimum measured value of total dissolved solids from groundwater samples at the site.

Receptor Type	Receptor is Present if:
Protected Groundwater Source	The first encountered groundwater has a K ≥ 0.44 m/day and TDS < 2,500 mg/L

Step 2. Determine whether the Tier 1 levels are exceeded: If the measured concentration for any chemical exceeds the Tier 1 level, the Tier 1 levels are exceeded.

Tier 1 Levels: Groundwater Ingestion Pathway: Protected Groundwater Source

Receptor	Group 1 ppb					Group 2 ppb	
	Type	**Benzene**	**Toluene**	**Ethylbenzene**	**Xylenes**	**TEH Diesel**	**TEH WO**
Drinking Water Well (DWW)	Actual	5	1,000	700	10,000	1,200	400
Protected Groundwater Source (PGWS)	Potential	290	7,300	3,700	73,000	75,000	40,000
Maximum measured concentrations							
Tier I Levels exceeded for Actual Receptor:							
Tier I Levels Exceeded for Potential Receptors							

Note: Two Tier 1 Levels for this Receptor.

Step 3. Determine Possible Corrective Actions.

A. If Tier 1 levels for actual receptors (Drinking Water Well Levels) are not exceeded **or** the receptor is not present:
   No further action required for the protected groundwater source receptor.
B. If Tier 1 levels for actual receptors (Drinking Water Well Levels) are exceeded **and** Tier I levels for potential receptors (PGWS and NDWW) are not exceeded **and** the receptor is present:
   No further action is required, subject to notification of site conditions*.
C. If Tier 1 levels for potential receptors (PGWS) are exceeded **and** the receptor is present:
   Further action is required, there two options
   a) Sever the pathway to the receptor:

1. Institutional control which must prohibit the use of the protected groundwater source within 1,000 feet of the source area.
2. Notification of site conditions*.

b) Tier 2 assessment of the groundwater ingestion pathway.

*Notification of site conditions: provide notification of site conditions on a department form to the department water supply section, or if a county has delegated authority, then the designated county authority responsible for issuing public water supply construction permits or regulating private water well construction as provided in 567-Chapters 38 ad 49.

Summary Tables: Tier 1, Groundwater Ingestion Pathway

Receptor Definitions

Receptor Type	Receptor is Present if:
	drinking water wells within 1,000 feet of the soil or groundwater sources.
	non-drinking water wells within 1,000 feet of the soil or groundwater sources.
	the first encountered groundwater has a K ≥ 0.44 m/day and TDS < 2,500 mg/L

Tier 1 Levels

Receptor	Group 1 ppb					Group 2 ppb	
	Type	Benzene	Toluene	Ethylbenzene	Xylenes	TEH Diesel	TEH WO
Drinking Water Well	Actual	5	1,000	700	10,000	1,200	400
Non-Drinking Water Well	Actual	290	7,300	3,700	73,000	75,000	40,000
Protected Groundwater Source	Potential	290	7,300	3,700	73,000	75,000	40,000
Maximum concentration							
Exceed Drinking Water Levels							
Exceed Protected Groundwater Source							

Drinking Water Well Receptor Evaluation

Drinking Water Well Receptor Present	Tier 1 Levels Exceeded for Drinking Water Well Receptor	Required Actions or Options
No	Yes or No	No further action required
Yes	No	No further action required
Yes	Yes	a. Plug all drinking water wells, or b. Tier 2 Assessment

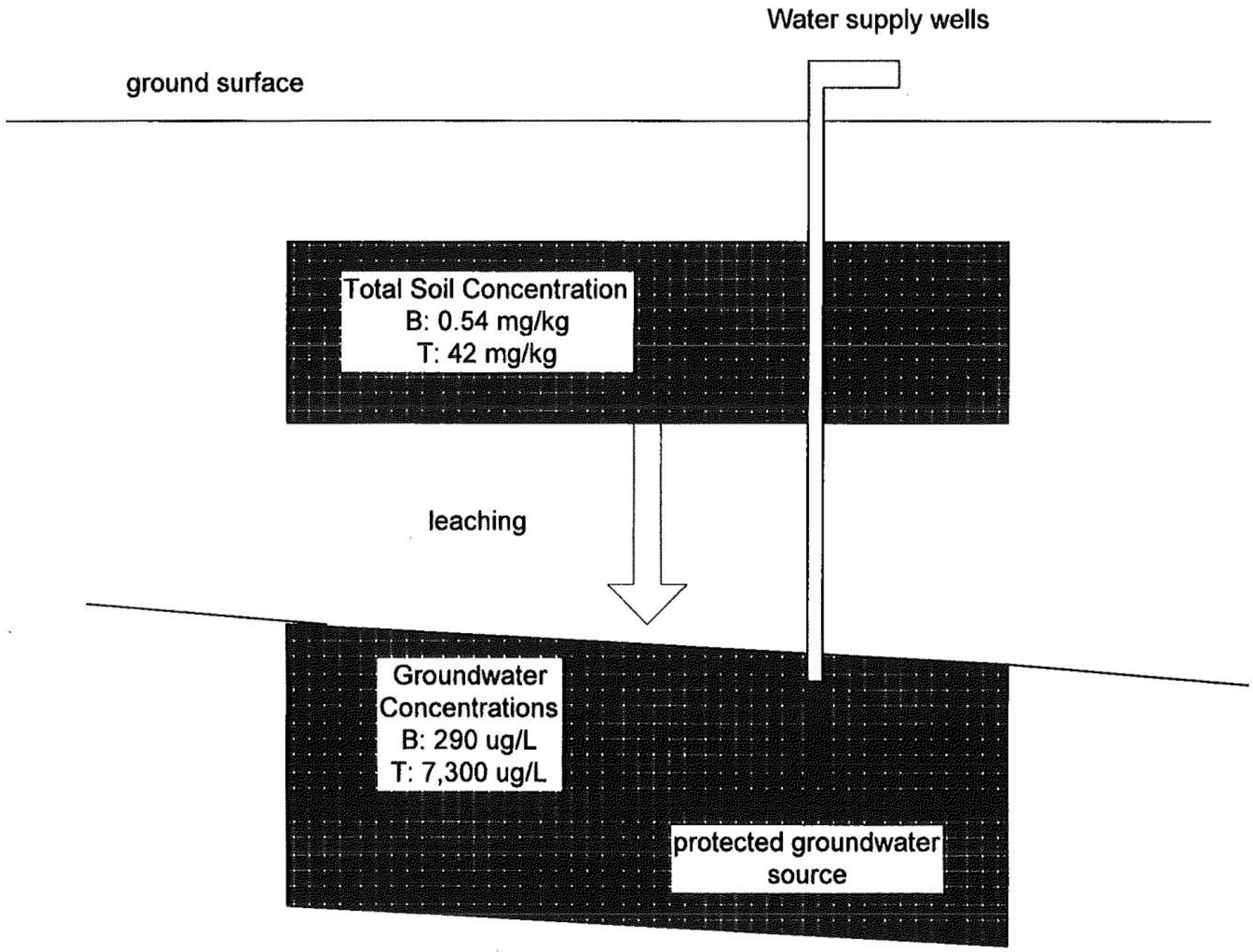
Non-Drinking Water Well Receptor Evaluation

Non-Drinking Water Well Receptor Present	Tier 1 Levels Exceeded for Non-Drinking Water Well Receptor	Required Actions or Options
No	Yes or No	No further action required
Yes	No	No further action required
Yes	Yes	a. Plug all non-drinking water wells, or b. Tier 2 Assessment

Protected Groundwater Source Receptor Evaluation

Protected Groundwater Source Receptor Present	Tier 1 Levels Exceeded for Drinking Water Well Receptors	Tier 1 Levels Exceeded for Protected Groundwater Source	Required Actions or Options
No	Yes or No	Yes or No	No further action required
Yes	No	No	No further action required
Yes	Yes	No	No further action required, subject to notification
Yes	Yes	Yes	a. Institutional control and notification, or b. Tier 2 assessment

Tier 1: Soil Leaching to Groundwater Pathway



Pathway: Source: Soil Contamination
Pathway: Soil Leaching to Groundwater Route of Exposure: Groundwater Ingestion
Receptors: Water Supply Wells, Protected Groundwater Source

Tier 1: The point of exposure is the source. What concentrations can exist in the soil without exceeding the target levels in the groundwater directly beneath the maximum soil contamination.

Receptor Types:

1. Water Supply Wells
2. Protected Groundwater Source

Step 1: Determine which receptors are present (or complete):

Receptor Definitions for Tier 1 Soil Leaching to Groundwater Pathway*

Receptor Type	Receptor is Present if:
Water Supply Well	There are drinking water wells or non-drinking water wells within 1,000 feet of the soil or groundwater sources.
Protected Groundwater Source	The first encountered groundwater has a maximum K≥0.44 m/day and a minimum TDS <2,500 mg/L

*If soil toluene concentrations exceed 3.2 ppm a Tier 2 evaluation of the soil leaching to groundwater to water lines receptor pathway may be required if water line receptors are identified by the Tier 1 receptor survey.

Step 2: Determine whether Tier 1 levels are exceeded for each type of receptor.

Tier 1 Levels for Soil Leaching to Groundwater Pathway (mg/kg in Soil)

Receptor	Group 1 ppm				Group 2 ppm	
	Benzene	Toluene	Ethylbenzene	Xylenes	TEH Diesel	TEH WO
Water Supply Well	0.54	42	15	NA	3,800	NA
Protected Groundwater Source	0.54	42	15	NA	3,800	NA
Maximum concentration						
Tier 1 Levels Exceeded						

Step 3: Determine Possible Corrective Actions for each receptor.

Receptor: Water Supply Wells

A. If water supply wells are not present **or** Tier 1 levels are not exceeded for the receptor;
   No further action is required for the water supply receptor.
B. If water supply wells are present **and** Tier 1 levels are exceeded for the receptor, further action is required and the options are:
   a) Eliminate the Source.
      Soil excavation to Tier 1 Levels for the pathway.
   b) Sever the Pathway.
      Properly plug all water supply wells within 1,000 feet of the soil and groundwater sources.
   c) Tier 2 assessment of the pathway

Receptor: Protected Groundwater Source

A. If the first encountered groundwater is not a protected groundwater source **or** Tier 1 levels are not exceeded for the pathway;
   No further action is required for the soil leaching to protected groundwater source receptor.
B. If the first encountered groundwater is a protected groundwater source **and** Tier 1 levels are exceeded for the receptor, further action is required and the options at Tier 1 are:
   a) Eliminate the source.
      Soil excavation to Tier 1 levels
   b) Sever the pathway to the receptor.
      1. Institutional control to prohibit use the protected groundwater source with 1,000 feet of the soil and groundwater source.
      2. Notification of site conditions*.
   c) Perform a Tier 2 assessment of the pathway.

*Notification of site conditions: provide notification of site conditions on a department form to the department water supply section, or if a county has delegated authority, then the designated county authority responsible for issuing public water supply construction permits or regulating private water well construction as provided in 567-Chapters 38 and 49.

Summary Tables: Tier 1, Soil Leaching to Groundwater

Receptor Definitions

Receptor Type	Receptor is Present if:
Water Supply Well	There are drinking water wells or non-drinking water wells within 1,000 feet of the soil or groundwater sources.
Protected Groundwater Source	the first encountered groundwater has a K $\geq$ 0.44 m/day and TDS < 2,500 mg/L

Tier 1 Levels

Receptor	Group 1 ppm				Group 2 ppm	
	Benzene	Toluene	Ethylbenzene	Xylenes	TEH Diesel	TEH WO
Water Supply Well	0.54	42	15	NA	3,800	NA
Protected Groundwater Source	0.54	42	15	NA	3,800	NA
Maximum concentration						
Tier 1 Levels Exceeded						

Drinking Water Well Receptor Evaluation

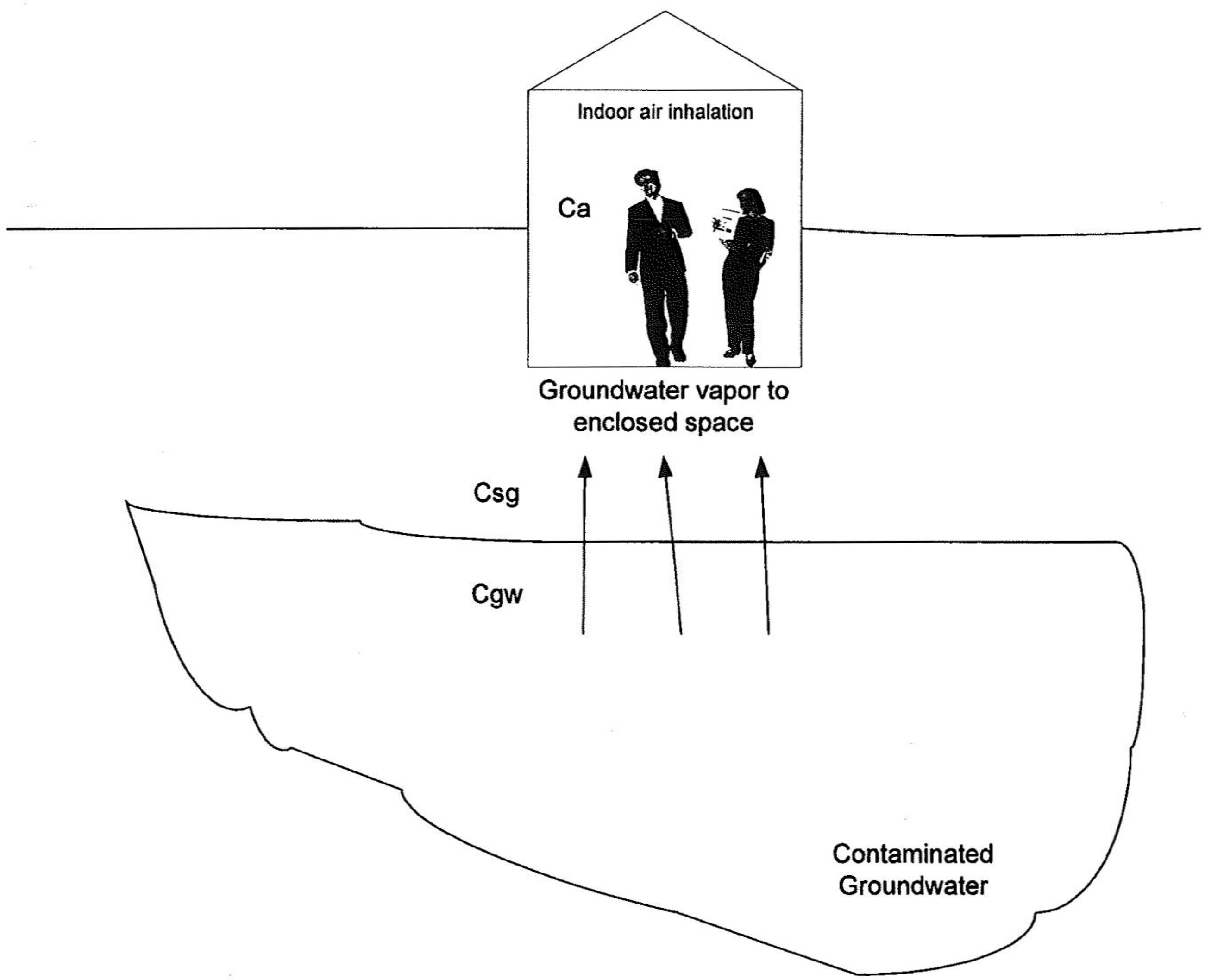
Drinking Water Well Receptor Present	Tier 1 Levels Exceeded for Drinking Water Well Receptor	Required Actions or Options
No	Yes or No	No further action required
Yes	No	No further action required
Yes	Yes	a. Soil excavation to Tier 1 levels, or b. Plug all water supply wells, or c. Tier 2 Assessment

Protected Groundwater Source Receptor Evaluation

Drinking Water Well Receptor Present	Tier 1 Levels Exceeded for Drinking Water Well Receptor	Required Actions or Options
No	Yes or No	No further action required
Yes	No	No further action required
Yes	Yes	a. Soil excavation to Tier 1 levels, or b. Institutional control to prohibit groundwater use, and notification of water supply authority, or c. Tier 2 Assessment

Tier 1: Groundwater Vapor to Enclosed Space

Ca – Contaminated Air
Csg – Contaminated Soil Gas
Cgw – Contaminated Groundwater



Pathway: Source: Contaminated Groundwater
Migration: Vapor migration from Groundwater into an Enclosed Space
Route of Exposure: Inhalation of Vapor (breathing polluted air)

Tier 1: Point of Exposure is the Source. Assumes the enclosed space is over the source (the highest measured concentrations of the chemicals of concern.

First Step

Explosive Vapor Survey: Perform an explosive vapor (>10% LEL) survey. Applies to both vapor pathways (Groundwater and Soil).

A. If potentially explosive vapor levels are not identified;
   continue with Tier 1 assessment of the pathway at Step 1.
B. If potentially explosive vapor levels are identified:

The groundwater professional must notify the owner or operator with instructions to report the conditions in accordance with 567-Chapter 131. The owner or operator must begin immediate response and abatement procedures in accordance with 135.7(455B) and 567-Chapter 133.

If potentially explosive vapor levels are identified; A Tier 2 assessment of the Groundwater Vapor to Enclosed Space and Soil Vapor to Enclosed Space Pathways is required, regardless of the measured groundwater concentrations, soil concentrations, or soil gas concentrations.

Step 1: Determine whether enclosed space receptors are present at Tier 1.

At Tier 1, there is one receptor type and the pathway is always considered complete.

Receptor Definitions for Tier 1 Groundwater Vapor to Enclosed Space Pathway

Receptor Type	**Receptor is Present if:**
Enclosed Space	Always assumed complete at Tier 1

Step 2: Determine whether Tier 1 levels are exceeded for the groundwater vapor to enclosed space pathway.

Tier 1 Levels for Groundwater Vapor to Enclosed Space Pathway (µg/L in Groundwater)

Receptor	**Group 1 ppb**				**Group 2 ppb**	
	Benzene	**Toluene**	**Ethylbenzene**	**Xylenes**	**TEH Diesel**	**TEH WO**
Enclosed Space	1,540	20,190	46,000	NA	2,200,000	NA
Maximum concentration						
Tier 1 Levels Exceeded						

Step 3: Determine possible corrective actions.

There is a single receptor type and the pathway is assumed complete at Tier 1.

Receptor: Enclosed Space.

A. If Tier 1 levels are not exceeded;
   No further action is required for the groundwater vapor to enclosed space pathway.
B. If Tier 1 levels are exceeded, further action is required and there are two options.
   a) Sever the pathway to the receptor.
      Use an institutional control to prohibit the placement of enclosed space receptors within 500 feet of the source area. Note that this would require removal of existing enclosed space receptors.
   b) Perform a Tier 2 assessment of the pathway.

Summary Tables: Tier 1, Groundwater Vapor to Enclosed Space Pathway

Explosive Vapor Survey (Required)

Potentially Explosive Vapor Identified	Response
No	Proceed with Tier 1
Yes	Notify owner/operator with instructions to report, owner/operator must begin abatement, Tier 2 assessment of the pathway is required.

Receptor Definition

Receptor Type	Receptor Definition
Enclosed Space	Always considered complete at Tier 1

Tier 1 Levels (µg/L in Groundwater)

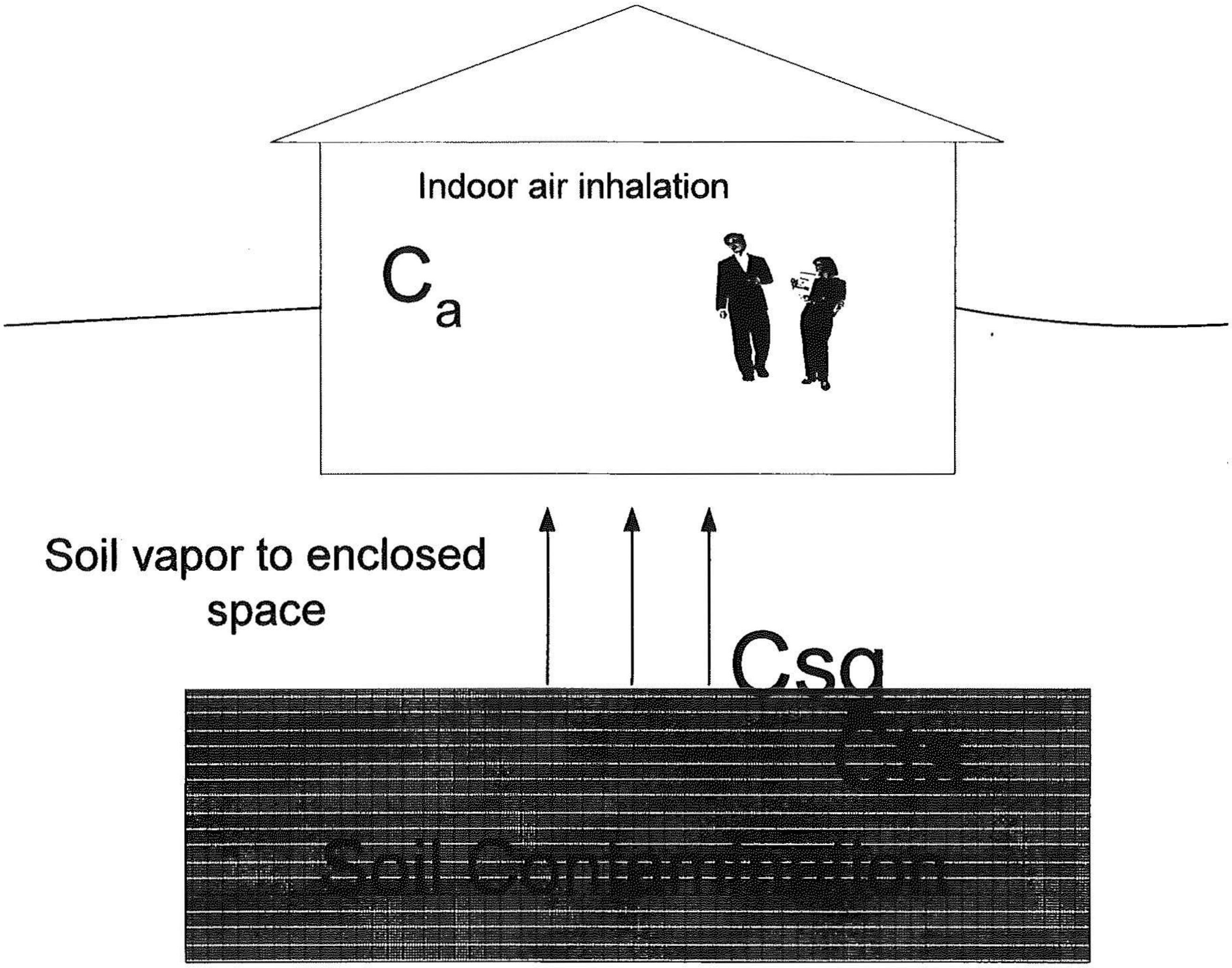
Receptor	Group 1 ppb				Group 2 ppb	
	Benzene	Toluene	Ethylbenzene	Xylenes	TEH Diesel	TEH WO
Enclosed Space	1,540	20,190	46,000	NA	2,200,000	NA
Maximum concentration						
Tier 1 Levels Exceeded						

Enclosed Space Receptor Evaluation

Enclosed Space Present	Tier 1 Levels Exceeded for Enclosed Space Receptor	Required Actions or Options
Yes (Always at Tier 1)	No	No further action required
Yes	Yes	a. Institutional control to prohibit placement of enclosed space receptors within 500 feet of the source area, or b. Tier 2 Assessment of the pathway

Tier 1: Soil Vapor to Enclosed Space Pathway

Ca – Contaminated Air
Csg – Contaminated Soil Gas
Cs – Contaminated Soil



Pathway: Source: Soil Contamination
Pathway: Vapor migration from soil into enclosed spaces
Route of Exposure: Inhalation of Vapors (breathing polluted air)
Receptors: One type, assumed complete at Tier 1.

First Step

Explosive Vapor Survey: Perform an explosive vapor (>10% LEL) survey. Applies to both vapor pathways (Soil and Groundwater).

A. If potentially explosive vapor levels are not identified; continue with Tier 1 assessment of the pathway at Step 1.
B. If potentially explosive vapor levels are identified:

The groundwater professional must notify the owner or operator with instructions to report the conditions in accordance with 567-Chapter 131. The owner or operator must begin immediate response and abatement procedures in accordance with 135.7(455B) and 567-Chapter 133.

If potentially explosive vapor levels are identified a Tier 2 assessment of the Soil Vapor to Enclosed Space Pathways and

Groundwater Vapor to Enclosed Space is required, regardless of the measured groundwater concentrations, soil concentrations, or soil gas concentrations.

Step 1: Determine whether enclosed space receptors are present at Tier 1.

At Tier 1, there is one receptor type and the pathway is always considered complete.

Receptor Definition

Receptor Type	The Receptor is Present if:
Enclosed Space	Always assumed complete at Tier 1

Step 2: Determine whether Tier 1 soil levels are exceeded for the Soil Vapor to Enclosed Space pathway.

Tier 1 Levels (mg/kg in Soil)

Receptor	Group 1 ppm				Group 2 ppm	
	Benzene	**Toluene**	**Ethylbenzene**	**Xylenes**	**TEH Diesel**	**TEH WO**
Enclosed Space	1.16	48	79	NA	47,500	NA
Maximum measured concentration						
Tier 1 Levels Exceeded						

Step 3: Determine possible corrective action options.

There is a single receptor type and the pathway is assumed complete.

There are field measurements that can be used to evaluate the pathway. Soil concentrations and soil gas concentrations.

Receptor: All

A. If Tier 1 soil levels are not exceeded;
   no further action is required for the soil vapor to enclosed space pathway.
B. If Tier 1 soil levels are exceeded, further action is required.
   a) Take soil gas measurements at the source(s).
   b) Eliminate the source.
      Soil excavation to Tier 1 soil levels.
   c) Sever the pathway to the receptor.
      Use an institutional control to prohibit the placement of enclosed space receptors within 500 feet of the source area. Note that this would require removal of existing enclosed space receptors.
   d) Perform a Tier 2 assessment of the pathway.

Soil Gas Measurements

Receptor	Benzene µg/m³	Toluene µg/m³
Enclosed Space	600,000	9,250,000
Soil gas sample 1		
Soil gas sample 2		
Tier 1 Levels Exceeded		

At a minimum, two soil gas samples taken at least 14 days apart are required from the location expected to have the highest soil gas concentrations. This would generally be where the measured soil concentrations are highest.

The following assumes soil gas measurements have been taken.

Case 1. Tier 1 soil levels are exceeded.
If soil gas measurements do not exceed Tier 1 soil gas target levels, no further action is required (this is true, even if Tier 1 soil levels are exceeded).

If soil gas measurements do exceed Tier 1 soil gas target levels, the options are;

a) Soil excavation to Tier 1 soil levels followed by re-evaluation of soil gas levels.
b) Sever the pathway to the receptor.
   Use an institutional control to prohibit the placement of enclosed space receptors within 500 feet of the source area. Note that this would require removal of existing enclosed space receptors.
c) A Tier 2 assessment of the soil vapor and groundwater vapor to enclosed space pathways.

Case 2. Tier 1 soil levels are not exceeded.
It is possible that soil gas measurements have been taken, even though soil concentrations do not exceed Tier 1 levels for the pathway.

The consultant may decide to take soil gas measurements at the same time soil samples are being collected to reduce the cost of field work (one mobilization).

The consultant may have performed soil excavation, followed by resampling of soil gas levels, from Case 1a above.

A. If soil gas measurements do not exceed Tier 1 soil gas target levels, no further action is required.
B. If soil gas measurements do exceed Tier 1 soil gas target levels, there are two options;
   a) Sever the pathway to the receptor.
      Use an institutional control to prohibit the placement of enclosed space receptors within 500 feet of the source area. Note that this would require removal of existing enclosed space receptors.
   b) A Tier 2 assessment of the soil vapor and groundwater vapor to enclosed space pathways.

Summary Tables: Tier 1, Soil Vapor to Enclosed Space Pathway

Explosive Vapor Survey (Required)

Potentially Explosive Vapor Identified	Response
No	Proceed with Tier 1
Yes	Notify owner/operator with instructions to report, owner/operator must begin abatement, Tier 2 assessment of the pathway is required.

Receptor Definition

Receptor Type	Receptor Definition
Enclosed Space	Always considered complete at Tier 1

Tier 1 Soil Levels (mg/kg in Soil)

Receptor	Group 1 ppm				Group 2 ppm	
	Benzene	Toluene	Ethylbenzene	Xylenes	TEH Diesel	TEH WO
Enclosed Space	1.16	48	79	NA	47,500	NA
Maximum concentration						
Tier 1 Levels Exceeded						

Tier 1 Soil Gas Levels (soil gas, $\mu g/m^3$)

Receptor	Benzene $\mu g/m^3$	Toluene $\mu g/m^3$
Enclosed Space	600,000	9,250,000
Soil gas sample 1		
Soil gas sample 2		
Tier 1 Levels Exceeded		

Enclosed Space Receptor Evaluation (Receptor Assumed Present at Tier 1)

Tier 1 Soil Levels Exceeded	Tier 1 Soil Gas Levels Exceeded	Required Actions or Options
No	Not taken	No further action required
Yes	Not taken	a. Soil gas sampling, or b. Soil excavation to Tier 1 soil levels, or c. Institutional control to prohibit the placement of enclosed space receptors within 500 feet, or d. Tier 2 assessment of the pathway
Yes	No	No further action required
Yes	Yes	a. Soil excavation to Tier 1 levels, followed by re-sampling of soil gas. b. Institutional control to prohibit the placement of enclosed space receptors within 500 feet, or c. Tier 2 assessment of the soil vapor and groundwater vapor pathway.
No	Yes	a. Institutional control to prohibit the placement of enclosed space receptors within 500 feet, or b. Tier 2 assessment of the soil vapor and groundwater vapor pathway.

Tier 1: Groundwater to Water Line Pathway

Route of Exposure: Ingestion of Water (Drinking Contaminated Water)
Receptor Types:
Actual Water Line Receptors
Potential Water Line Receptors

Step 1: Determine whether actual or potential water line receptors are present:

Receptor Definitions

Receptor Type	The Receptor is Present if:
Actual Water Line Receptor	There is an existing water line within 200 feet of the soil or groundwater source(s), and the first encountered groundwater is less than 20 feet below ground surface.
Potential Water Line Receptor	The first encountered groundwater is less than 20 feet below ground surface

Step 2: Determine whether Tier 1 levels are exceeded for the groundwater to water line pathway.

Tier 1 Levels for Groundwater to Water Line (µg/L in groundwater)

Receptor	Group 1 ppb				Group 2 ppb	
	Benzene	Toluene	Ethylbenzene	Xylenes	TEH Diesel	TEH WO
PVC or Gasketed Mains	7,500	6,250	40,000	48,000	75,000	40,000
PVC or Gasketed Service Lines	3,750	3,120	20,000	24,000	75,000	40,000
PE/PB/AC Mains or Service Lines	200	3,120	3,400	19,000	75,000	40,000

Assumption Used for Groundwater to Water Line Pathway:

1. The maximum contaminant levels (MCLs) were used for Group 1 chemicals. The target risk for carcinogens for actual receptors is 10^{-6} and for potential receptors is 10^{-4}. A hazard quotient of one, and residential exposure and building parameters are assumed. This pathway uses the same assumptions as the groundwater ingestion pathway for potential receptors, including a target risk for carcinogens of 10^{-4}.

Step 3: Determine Possible Corrective Actions for each receptor type.

Actual Water Line Receptor

A. If an actual water line receptor is not present **or** Tier 1 levels are not exceeded for the receptor;
No further action is required for the actual water line receptor.

B. If an actual water receptor is present **and** Tier 1 levels are exceeded for the receptor, further action is required. The options at Tier 1 are:
   a) Sever the pathway to the receptor.
      1. Replace all water lines within 200 feet of the source(s) with petroleum resistant water lines and gaskets, and/or, relocate all water line receptors to a distance of greater than 200 feet from the source(s).
      2. Utility company notification.
   b) Perform a Tier 2 assessment of the pathway.

*Utility company notification: notification of the utility company which supplies water service to the area of actual or potential water line impacts. Notification may be postponed until completion of Tier 2, if a Tier 2 assessment is required. (At Tier 2 the plume may be defined).

Potential Water Line Receptor:

A. Tier 1 levels are not exceeded for the receptor;
No further action required for the potential water line receptor.

B. Tier 1 levels are exceeded for the receptor;
No further action is required, after utility company notification*.

Summary Tables: Tier 1, Groundwater to Water Line Pathway

Receptor Definition

Receptor Type	Receptor Definition
Actual Water Line Receptor	There is an existing water line within 200 feet of the soil or groundwater source(s), and the depth to groundwater is less than 20 feet below ground surface.
Potential Water Line Receptor	The depth to groundwater is less than 20 feet below ground surface

Tier 1 Levels

Receptor	Group 1				Group 2	
	Benzene	**Toluene**	**Ethylbenzene**	**Xylenes**	**TEH Diesel**	**TEH WO**
PVC or Gasketed Mains	7,500	6,250	40,000	48,000	75,000	40,000
PVC or Gasketed Service Lines	3,750	3,120	20,000	24,000	75,000	40,000
PE/PB/AC Mains or Service Lines	200	3,120	3,400	19,000	75,000	40,000

Assumption Used for Groundwater to Water Line Pathway:

1. The maximum contaminant levels (MCLs) were used for Group 1 chemicals. The target risk for carcinogens for actual receptors is 10^{-6} and for potential receptors is 10^{-4}. A hazard quotient of one, and residential exposure and building parameters are assumed. This pathway uses the same assumptions as the groundwater ingestion pathway for potential receptors, including a target risk for carcinogens of 10^{-4}.

Actual Water Line Receptor

Actual Water Line Present	Tier 1 Levels Exceeded for Actual Water Line	Required Actions or Options
No	Yes or No	No further action required
Yes	No	No further action required
Yes	Yes	a. Replace or relocate all water lines within 200 feet of the source, provide water service utility notification, or b. Tier 2 assessment

*Utility company notification: notification of the utility company which supplies water service to the area of actual or potential water line impacts. Notification may be postponed until completion of Tier 2, if a Tier 2 assessment is required. (At Tier 2 the plume may be defined).

Potential Water Line Receptor

Potential Water Line Present	Tier 1 Levels Exceeded for Potential Water Line	Required Actions or Options
No	Yes or No	No further action required
Yes	No	No further action required
Yes	Yes	No further action, subject to water utility company notification (may be done after Tier 2)

Tier 1: Soil to Water Line Pathway

Pathway: Source: Soil Contamination
Pathway: Soil Contamination Leaching through Water Line
Route of Exposure: Groundwater Ingestion

Receptor Types:
Actual Water Line
Potential Water Line

Step 1: Determine which receptors are present (or complete):

Receptor Type	The Receptor is Present if:
Actual Water Line	There is a water line within 200 feet of the soil or groundwater source(s)
Potential Water Line	Always considered complete for Tier 1

Step 2: Determine whether Tier 1 levels are exceeded for each type of receptor.

Receptor	Group 1 ppm				Group 2 ppm	
	Benzene	Toluene	Ethylbenzene	Xylenes	TEH Diesel	TEH WO
Actual Water Line	2	3.2	45	52	10,500	NA
Potential Water Line	2	3.2	45	52	10,500	NA
Maximum concentration						
Tier 1 Levels Exceeded						

Step 3: Determine possible Corrective Actions for each type of receptor.

Actual Water Lines

A. If actual water line receptors are not present **or** Tier 1 levels are not exceeded for the receptor;
   no further action is required for the actual water line receptor.
B. If actual water receptors are present **and** Tier 1 levels are exceeded for the receptor, further action is required and there are three options:
   a) Eliminate the Source.
      Soil excavation to Tier 1 Levels for the receptor.
   b) Sever the Pathway.
      1. Replace all water lines within 200 feet of the source(s) with water lines constructed with appropriate petroleum resistant materials and/or, relocate all water lines to a distance of greater than 200 feet from the source(s).
      2. Provide water supply utility company notification.
   c) Tier 2 assessment of the pathway.

Potential Water Line Receptors

A. If Tier 1 levels are not exceeded for the potential water line receptor (the receptor is assumed present at Tier 1);
   no further action is required for the potential water line receptor.
B. If Tier 1 levels are exceeded for the potential water line receptor (the receptor is assumed present at Tier 1);
   no further action is required, after utility company notification .

*Utility company notification: notification of the utility company which supplies water service to the area of actual or potential water line impacts. Notification may be postponed until completion of Tier 2, if a Tier 2 assessment is required. (At Tier 2 the plume may be defined).

Summary Tables: Tier 1, Soil to Water Line

Receptor Definition

Receptor Type	Receptor Definition
Actual Water Line	There is an existing water line within 200 feet of the soil or groundwater source(s).
Potential Water Line	Always considered complete for Tier 1.

Tier 1 Levels (mg/kg in Soil)

Receptor	Group 1 ppm				Group 2 ppm	
	Benzene	Toluene	Ethylbenzene	Xylenes	TEH Diesel	TEH WO
Actual Water Line	2	3.2	45	52	10,500	NA
Potential Water Line	2	3.2	45	52	10,500	NA
Maximum concentration						
Tier 1 Levels Exceeded						

Actual Water Line Receptor Evaluation

Actual Water Line Present	Tier 1 Levels Exceeded for Actual Water Line	Required Actions or Options
No	Yes or No	No further action required
Yes	No	No further action required
Yes	Yes	a. Soil excavation to Tier 1 levels, or b. replace or relocate all water lines within 200 feet of the source(s), provide utility company notification (may be done after Tier 2), or c. Tier 2 assessment

Potential Water Line Receptor

Potential Water Line Receptor Present	Tier 1 Levels Exceeded for Potential Water Line	Required Actions or Options
Yes (assumed present at Tier 1)	No	No further action required
Yes	Yes	No further action, after utility company notification (may be done after Tier 2)

Tier 1: Surface Water Pathway

Pathway: Source: Groundwater Contamination
Pathway: Contaminated Groundwater Recharging into Surface Water Bodies
Route of Exposure: Human Ingestion and Chronic Effects on Aquatic Life.

Receptor Types:
Designated use surface water bodies.
General use surface water bodies.

Step 1: Determine whether a designated use or general use surface water bodies are present.

A designated use surface water body is a general use surface water body. A general use surface water body is not a designated use surface water body.

Receptor Type	The Receptor is Present if:
Designated Use Receptor	There are designated use segments of surface water bodies (as provided in 567 subrules 61.3(1) and 61.3(5)) within 200 feet of the soil or groundwater source(s).
General Use Receptor	There are designated use segments or general use segments of surface water bodies (as provided in 567 subrules 61.3(1) and 61.3(5)) within 200 feet of the soil or groundwater source(s).

Step 2: Determine whether Tier 1 levels are exceeded for the Surface Water Pathway.

Surface Water Criteria for Designated Use Streams (µg/l)

Designated Uses for Surface Water Classification	B* (CW1)	B* (CW2)	B* (WW-1)	B* (WW-2)	B* (WW-3)	B* (LW)	C** Drinking Water	State Owned Lakes
	Aquatic Life							
	Cold Water		Warm Water			Lakes & Wetlands		
Benzene	290	290	290	290	290	290	5	2
Ethylbenzene	3,700	3,700	3,700	3,700	3,700	3,700	700	2
Toluene	1,000	1,000	1,000	1,000	1,000	1,000	1,000	2
Xylenes	73,000	73,000	73,000	73,000	73,000	73,000	10,000	5
TEH-Diesel	75,000	75,000	75,000	75,000	75,000	75,000	1,200	500
TEH-Waste Oil	40,000	40,000	40,000	40,000	40,000	40,000	400	400

*Use Tier 1 levels for Surface Water
**Use Tier 1 levels for Groundwater Ingestion Actual

Step 3: Visual inspection requirements.
Based on a visual inspection, determine whether there is a petroleum sheen or residue on all surface water bodies within 200 feet of the source(s) attributable to the site.

Step 4: Determine Corrective Action Options for the receptors.

Receptor: Designated use:

A. If there are no designated use receptors **or** Tier 1 groundwater levels are not exceeded for the designated use receptor:
no further action is required for the designated use receptor.
B. If there are designated use receptors **and** Tier 1 groundwater levels are exceeded for the pathway;

A Tier 2 assessment of the Surface Water Pathway is required.

Receptor: General use (includes designated use receptors for visual inspection requirements).

A. If there are no general use receptors **or** a visual inspection has shown there is no petroleum sheen or residue attributable to the site;

No further action is required for the general use receptor.

B. If there are general use receptors **and** a visual inspection has shown there is a petroleum sheen or residue attributable to the site;

A Tier 2 assessment of the Surface Water Pathway is required.

Visual Inspection Requirements

A) A visual inspection of all surface water bodies within 200 feet of the groundwater source shows evidence of possible petroleum sheen on the water or residue along the bank. (Yes or No).

B) In the opinion of the groundwater professional, the sheen or residue is associated with the underground storage tank site. (Yes or No).

C) In the opinion of the groundwater professional, the sheen or residue is a petroleum regulated substance. (Yes or No).

D) The laboratory sample has shown the sheen or residue to be a petroleum regulated substance. (Yes or No).

Visual Inspection Evaluation

Question A	Question B	Question C	Question D	There is a petroleum sheen or residue attributable to the site
No	-----	----	----	No
Yes	No	----	----	No
Yes	Yes	Yes	----	Yes
Yes	Yes	No	Yes	Yes
Yes	Yes	No	No	No

Summary Tables: Tier 1, Surface Water Pathway

Receptor Definition

Receptor Type	Receptor Definition
Designated Use Receptor	Designated use segments of surface water bodies (as provided in 567 subrules 61.3(1) and 61.3(5)) within 200 feet of the soil or groundwater source(s).
General Use Receptor	Designated use segments and general use segments of surface water bodies (as provided in 567 subrules 61.3(1) and 61.3(5)) within 200 feet of the soil or groundwater source(s).

Surface Water Criteria for Designated Use Streams (µg/l)

Designated Uses for Surface Water Classification	B* (CW1)	B* (CW2)	B* (WW-1)	B* (WW-2)	B* (WW-3)	B* (LW)	C** Drinking Water	State Owned Lakes
	Aquatic Life							
	Cold Water		Warm Water			Lakes & Wetlands		
Benzene	290	290	290	290	290	290	5	2
Ethylbenzene	3,700	3,700	3,700	3,700	3,700	3,700	700	2
Toluene	1,000	1,000	1,000	1,000	1,000	1,000	1,000	2
Xylenes	73,000	73,000	73,000	73,000	73,000	73,000	10,000	5
TEH-Diesel	75,000	75,000	75,000	75,000	75,000	75,000	1,200	500
TEH-Waste Oil	40,000	40,000	40,000	40,000	40,000	40,000	400	400

*Use Tier 1 levels for Surface Water
**Use Tier 1 levels for Groundwater Ingestion Actual

Designated Use Receptor (also a general use receptor for visual inspection)

Designated Use Receptor Present	Tier 1 Levels Exceeded	Required Actions or Options
No	Yes or No	No further action required for designated use receptor
Yes	No	No further action required for designated use receptor
Yes	Yes	Tier 2 assessment of the pathway required

Visual Inspection Evaluation

A) A visual inspection of all surface water bodies within 200 feet of the groundwater source shows evidence of possible petroleum sheen on the water or residue along the bank. (Yes or No).
B) In the opinion of the groundwater professional, the sheen or residue is associated with the underground storage tank site. (Yes or No).
C) In the opinion of the groundwater professional, the sheen or residue is a petroleum regulated substance. (Yes or No).
D) The laboratory sample has shown the sheen or residue to be a petroleum regulated substance. (Yes or No).

Question A	Question B	Question C	Question D	There is a petroleum sheen or residue attributable to the site
No	-----	----	----	No
Yes	No	----	----	No
Yes	Yes	Yes	----	Yes
Yes	Yes	No	Yes	Yes

Question A	Question B	Question C	Question D	There is a petroleum sheen or residue attributable to the site
Yes	Yes	No	No	No

Iowa RBCA Tier 1 and Tier 2 Section II
Risk Assessment at the Point of Exposure

Risk Evaluation at the Point of Exposure

Applies to all Tiers
RBCA Questions:

- Forward Question: What are the risks at the point of exposure for a human receptor?
- Backward Question: What are the acceptable concentrations at the point of exposure?
- ASTM 1739-95; All pathways and Tiers start at the point of exposure and work backwards to the acceptable concentrations at the source of contamination.

Tier 1 Risk-Based Screening Levels and Site-Specific Target Levels at the Point of Exposure.

IA RBCA currently has only two direct routes of exposure for human health:

Direct routes: The contact of the chemical with the human body.

The direct exposure routes for humans for IA RBCA are:

1. Ingestion of Groundwater (drinking contaminated groundwater)
2. Inhalation of vapors (breathing contaminated air in an enclosed space).

Question: How are the allowable direct exposure concentrations determined?

That is:
What concentration of a chemical of concern can be in groundwater used for drinking?
What concentration of chemical of concern can be in air a person might breathe in an enclosed space?

This is the **Risk** of **Risk**-Based Corrective Action:

Risk Assessment
Based on EPA Procedures and Documents.
Based on ASTM 1739.

Risk Assessment

- A process based on science that estimates human health and environmental risks associated with chemicals of concern present in the environment.
- Adverse effects/risk depend on **Toxicity** and **Exposure.**
- Risk= Toxicity & Exposure

Exposure: 1) Concentration at the point of exposure
2) Rate of Intake.

Risk Assessment at the Point of Human Exposure

Routes of Exposure
drinking contaminated water (ingestion)
breathing contaminated air (inhalation)
eating contaminated soil (ingestion)
contact with the skin (dermal)

Risk = Dose x Toxicity

Dose
Concentration
Amount per day
Days per year
years of exposure

Toxicity: Non-Carcinogens

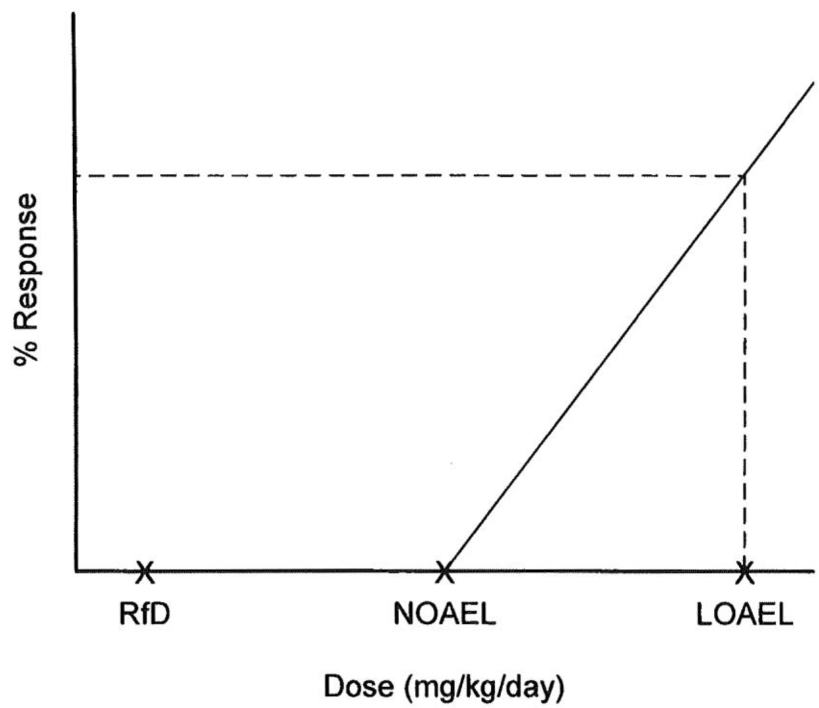
Non-Cancer Effects

- An effect that impacts development, size, or function of the whole body or body specific organs (including the skin and central nervous system), but does not lead to the development of malignant cells.
- There is a toxicity threshold. A dose below which adverse health effects are not expected to occur.
- Potential for adverse effects increase as the dose increases above the toxicity threshold.

Toxicity is estimated by:

- Reference Dose (RrD)
- Reference Concentration (RtC)
- Estimate of the average daily dose or concentration that is not likely to results in any significant adverse health effects (including sensitive subpopulations).

Dose-Response Curve:



- LOAEL: Lowest Observed Effect Level
- NOAEL: No Observable Adverse Effect Level
- R_fD - Reference Dose

$$Reference\ Dose = \frac{NOAEL}{UF1 \times UF2 \times \ldots \times MF}$$

UF: Uncertainty Factors

Oral Reference Dose for Toluene
From: IRIS Database, 1/15/95

Critical Effect, Oral Reference Dose (RrD), Uncertainty Factor (UF), and Modifying Factor (MF) for Toluene

I.A.1 ORAL R_fD Summary

Critical Effect: Changes in Liver and Kidney Weights

Experimental Dose
NOAEL: 312 mg/kg converted to 223 mg/(kg-day) (Dose adjusted for gavage schedule of 5 days/week.)

UF: 1000
MF: 1

$$R_f D_o: 0.2\ \frac{mg}{kg - day}$$

Groundwater Ingestion

- Non-carcinogen: i.e. Toluene
- Forward Question: What is the risk from drinking water with 1000 μg/L toluene?
- Backward Question: Given the acceptable risk, what concentration of toluene can drinking water have without exceeding the risk?
- Risk Evaluation for a Non-carcinogen:

$$Hazard\ Quotient = \frac{Dose\left(\frac{mg}{kg - day}\right)}{Reference\ Dose\left(\frac{mg}{kg - day}\right)}$$

Hazard Quotient = Average Daily Dose / Reference Dose

$$HQ = \frac{Dose}{R_f D}$$

- Usually HQ ≤ 1.0

Risk for Non-carcinogen; non-cancer effects.

$$Dose = \frac{total\ mass\ ingested\ over\ the\ duration\ of\ exposure\ (mg)}{body\ weight\ (kg) \times exposure\ duration\ (days)}$$

$$Dose = \frac{C_w \times IR \times EF \times ED}{BW \times AT_n}$$

Cw = Concentration of the chemical of concern in water (mg/L)
IR = Ingestion Rate of water (L/day)
EF = Exposure Frequency (days/yr)
ED = Exposure Duration (yr)
BW = Body Weight (kg)
AT_n = Averaging time for non-carcinogens (period of exposure) (days) = ED (years) x 365days/year

$$Dose = \frac{C_w \times IR \times EF \times ED}{BW(ED \times 365)}$$

Really: Average daily dose per year

$$Dose = \frac{C_w \times IR \times EF}{BW \times 365} \Leftrightarrow \frac{\left(\frac{mg}{L}\right)\left(\frac{L}{day}\right)\left(\frac{days}{year}\right)}{kg\ \times 365 days} \Leftrightarrow \frac{mg\ ingested\ in\ a\ year}{kg \times 365 days}$$

Dose: Average daily dose in: mg of chemical per day per kg of body weight.

Exposure Assumptions for Iowa RBCA

Groundwater Ingestion

Parameter	Definition	Units	Residential	Non-Residential
BW	Body Weight, Adult	kg	70	70
ATn	Averaging Time (non- cancer)	days	ED x 365 d/yr	ED x 365 d/yr
IR	Drinking water ingestion	L/day	2	1
EF	Exposure frequency	day/yr	350	250
ED	Exposure duration	years	30	25

$$HQ = \frac{Dose\left(\frac{mg}{kg - day}\right)}{Reference\ Dose\left(\frac{mg}{kg - day}\right)}$$

$$HQ = \frac{\left[\frac{C_w \times IR \times EF \times ED}{BW \times AT}\right]}{R_f D_o}$$

Forward

Given: The concentration of the chemical of concern

Given: The exposure factors

Find: The Risk

Example:

Toluene in drinking water at 1000 µg/L (1 mg/L)

Residential Exposure Factors

Oral Reference Dose of 0.2 mg/kg-day

$$HQ = \frac{\left[\frac{C_w \times IR \times EF \times ED}{BW \times AT_n}\right]}{R_f D_o} = \frac{\left[\frac{1 \times 2 \times 350 \times 30}{70 \times (30 \times 365)}\right]}{R_f D_o} = \frac{\left[0.027\left(\frac{mg}{kg - day}\right)\right]}{0.2\left(\frac{mg}{kg - day}\right)}$$

HQ= 0.135 ≤ 1.0

Backward

Given: The Risk

Given: The exposure factors

Find: The Concentration of the Chemical of Concern

Example:

Toluene in drinking water

Residential Exposure Factors

Oral Reference Dose of 0.2 mg/kg-day

$$HQ = \frac{\left[\frac{C_w \times IR \times EF \times ED}{BW \times AT}\right]}{R_f D_o}$$

Solve for C_w

$$C_w = \frac{HQ \times R_f D_o \times BW \times AT}{IR \times EF \times ED} = \frac{1.0 \times 0.2 \times 70 \times (30 \times 365)}{2 \times 350 \times 30}$$

C_w= 7.3 mg/L = 7,300 µg/L

Direct Exposure Concentrations for Groundwater Ingestion for Iowa RBCA: Non-cancer effects

Exposure Factors

Parameter	Definition	Units	Residential	Non-Residential
BW	Body Weight, Adult	kg	70	70
ATn	Averaging Time (non- cancer)	days	ED x 365 d/yr	ED x 365 d/yr
IR	Drinking water ingestion	L/day	2	I
EF	Exposure frequency	day/yr	350	250
ED	Exposure duration	years	30	25

Toxicity: Hazard Quotient and Reference Doses

Chemical	HQ	RrDo (mg/(kg-day))
Benzene	1	
Toluene	1	0.2
Ethylbenzene	1	0.1
Xylenes	1	2.0
Naphthalene	1	0.004
Benzo(a)pyrene	1	
Benz(a)anthracene	1	
Chrysene	1	

Risk Assessment Equations

C_w: concentration in water in mg/L

$$HQ = \frac{\left[\frac{C_w \times IR \times EF \times ED}{BW \times AT}\right]}{R_f D_o} = \frac{C_w \times IR \times EF}{BW \times 365 \times R_f D_o}$$

$$C_w = \frac{HQ \times R_f D_o \times BW \times AT}{IR \times EF \times ED} = \frac{HQ \times R_f D_o \times BW \times 365}{IR \times EF}$$

Iowa RBCA: The direct exposure concentrations used for groundwater ingestion for Iowa RBCA Tier 1 and Tier 2: non-cancer effects.

Chemical	Solubility (µg/L)	Residential (µg/L)	Non-Residential (µg/L)
Toluene	535,000	7,300	20,440
Ethylbenzene	152,000	3,650	10,220
Xylenes	198,000	73,000	204,400
Naphthalene	31,000	146	409

Non-residential concentrations are 2.8 times higher than residential. Same risk, different exposure assumptions.

These concentrations are explicit or implicit in the following Tier 1 Pathways

Pathway - Receptor	Groundwater Ingestion: Non-Cancer
Groundwater Ingestion-potential	Residential Exposure
Groundwater to Water Line	Residential Exposure
Soil Leaching to Groundwater	Residential Exposure
Soil to Water Line	Non-residential Exposure

Toxicity: Carcinogens

Cancer Effects

- An effect that leads to the development of malignant cells.

Incremental Cancer Risk= Dose x Toxicity

Group	Description	Examples
A	Human carcinogen, with sufficient evidence from epidemiological studies	Benzene
B1 or B2	Probable human carcinogen B1 - with limited evidence from epidemiological studies B2 - with sufficient evidence from animal studies and inadequate or no data from epidemiological studies	Benzo(a)pyrene
C	Possible human carcinogen, with limited evidence from animal studies in absence of human data	PCE
D	Not classifiable as to human carcinogenicity, owing to inadequate human and animal evidence	Ethylbenzene Toluene Xylenes
E	Evidence of non-carcinogenicity for humans, with no evidence of carcinogenicity in at least two adequate animal tests in different species or in both adequate animal and epidemiological studies	

Generic Cancer Model

- Positive animal studies taken as presumptive evidence that a chemical has cancer causing potential in humans.
- Use of the most sensitive animal study to extrapolate to humans.
- "No-threshold" dose for carcinogens.
- Use of linear multi-stage model, 95% upper confidence limits, linear response at low doses.

Excess Cancer Risk: Risk in Addition to Background Cancer Risk

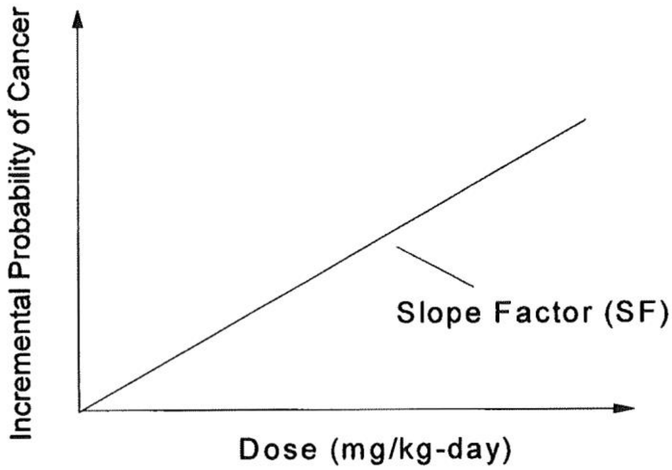
Background Cancer Risk	Target Excess Risk	Total Risk
0.25	1 in 1,000,000 ($1x10^{-6}$)	0.250001
0.25	1 in 100,000 ($1x10^{-5}$)	0.25001
025	1 in 10,000 ($1x10^{-4}$)	0.2501

Annual Risk of Death from Selected Common Human Activities

Activity	Lifetime Risk
Motor Vehicle Accident	1 in 65
Home Accidents	1 in 1190
Coal Mining Accident	1 in 17

Cancer Risk

- Risk= Dose x Toxicity
- Incremental Probability of Cancer = Lifetime Average Daily Dose (LADD) x Cancer Slope Factor (SF)
- Risk= LADD x SF



- Risk (unitless) = LADD (mg/kg-day) x SF

$$SF = \frac{Risk(unitless)}{LADD\left(\frac{mg}{kg - day}\right)} \Rightarrow SF\left(\frac{kg - day}{mg}\right) or \left(\frac{mg}{kg - day}\right)^{-1}$$

Calculating Risk:
Risk= Dose x Toxicity
or
Risk = Dose(LADD, mg/(kg-day)) x Slope Factor ((kg-day)/mg))

Exposure Assessment (Dose) for Carcinogens

What lifetime average daily dose will the person be exposed to?

$$Dose = \frac{total\ mass\ ingested\ over\ the\ duration\ of\ exposure\ (mg)}{body\ weight\ (kg) \times lifetime\ exposure\ duration\ (days)}$$

Groundwater Ingestion:

$$Dose = \frac{C_w \times IR \times EF \times ED}{BW \times AT_c}$$

C_w = Concentration of the chemical of concern in water (mg/L)
IR = Ingestion Rate of water (L/day)
EF = Exposure Frequency (days/yr)
ED = Exposure Duration (yr)
BW = Body Weight (kg)
AT_c = Averaging Time for Cancer (lifetime) (days)

Differences in Dose Calculation for Carcinogens and Non-carcinogens

Non-carcinogens: average daily dose during exposure AT_n = ED

Carcinogens: Lifetime Average Daily Dose (LADD)

AT_c = Lifetime: 70 years

(70 years x 365 days/year= 25,550 days).

Dose Calculation Differences for Carcinogens and Non-Carcinogens

Example: Toluene - Noncarcinogen
C_w= 0.5 mg/L
IR = 2 L/day
EF = 350 days/yr
ED = 20 yr BW=70kg
AT_n = ED x 365 = 20 x 365 = 7300 days

$$Dose = \frac{C_w \times IR \times EF \times ED}{BW \times (ED \times 365)} = \frac{0.5 \times 2 \times 350 \times 20}{70 \times (20 \times 365)} = 0.0137 \frac{mg}{kg - day}$$

Example: Benzene - Carcinogen
C_w = 0.5 mg/L
IR = 2 L/day
EF = 350 days/yr
ED = 20 yr
BW= 70kg
AT_c = 70 years= 70 x 365 = 25,550 days

$$Dose = \frac{C_w \times IR \times EF \times ED}{BW \times AT_c} = \frac{0.5 \times 2 \times 350 \times 20}{70 \times (70 \times 365)} = 0.0039 \frac{mg}{kg - day}$$

Calculating Cancer Risk:

$$Risk = Dose \left(\frac{mg}{kg - day}\right) \times Slope\ Factor \left(\frac{kg - day}{mg}\right)$$

Choosing Notation and Assumptions:
Forward:

$$Risk = \frac{C_w \times IR \times EF \times ED}{BW \times AT_c} \times SF_o$$

$$TR = \frac{C_w \times IR \times EF \times ED \times SF_o}{BW \times AT_c}$$

Backward:

$$C_w = \frac{TR \times BW \times AT}{IR \times EF \times ED \times SF_o}$$

TR = target cancer risk
C_w = Concentration of the chemical of concern in water (mg/L)
IR = Ingestion Rate of water (L/day)
EF = Exposure Frequency (days/yr)
ED = Exposure Duration (yr)
BW = Body Weight (kg)
AT_c = Averaging time for cancer (period of exposure) (days)
SF_o = Oral Cancer Slope Factor (kg-day)/mg

Example: Benzene, groundwater ingestion

Forward Calculation

C_w= 0.5 mg/L
IR = 2 L/day

EF = 350 days/yr
ED = 20 yr BW=70 kg
AT_c = 70 years= 70 x 365 = 25,550 days
SF_o = 0.029 (kg-day)/ ma

$$Risk = Dose \times Slope\ Factor$$

$$Risk = \frac{C_w \times IR \times EF \times ED}{BW \times AT_c} \times SF_o$$

$$Risk = \frac{0.5 \times 2 \times 350 \times 20}{70 \times (70 \times 365)} \times SF_o = 0.0039 \left(\frac{mg}{kg - day}\right) \times SF_o$$

$$Risk = 0.0039 \left(\frac{mg}{kg - day}\right) \times 0.029 \left(\frac{kg - day}{mg}\right) = 0.000113 = 1.13 \times 10^{-4}$$

Incremental Lifetime Cancer Risk: about 1 in 10,000

Backward calculation:

$$Risk(TR) = \frac{C_w \times IR \times EF \times ED \times SF_o}{BW \times AT_c}$$

Solve for: C_w

$$C_w = \frac{TR \times BW \times AT_c}{IR \times EF \times ED \times SF_o}$$

C_w = Concentration of the chemical of concern in water (mg/L)
IR = Ingestion Rate of water (L/day)
EF = Exposure Frequency (days/yr)
ED = Exposure Duration (yr)
BW = Body Weight (kg)
AT_c = Averaging time for cancer (lifetime, days)
TR= target risk (fraction of 1, i.e. $1x10^{-4}$ = 0.0001 = 1 in 10,000)

Assume:
TR = $1x10^{-4}$
IR= 2 L/day
EF = 350 days/year
ED= 30 years BW=70kg
AT_c = 25,550 days
SF_o = 0.029 ((kg-day)/mg)

$$C_w = \frac{TR \times BW \times AT}{IR \times EF \times ED \times SF_o} = \frac{(1 \times 10^{-4}) \times 70 \times 25{,}550}{2 \times 350 \times 30 \times 0.029} = 2.94 \times 10^{-1} \frac{mg}{L} = 294 \frac{\mu g}{L}$$

Direct Exposure Concentrations for Groundwater Ingestion for Iowa RBCA Tier 1 and Tier 2: Cancer effects

Exposure Fact

Parameter	Definition	Units	Residential	Non-Residential
BW	Body Weight, Adult	kg	70	70
AT_c	Averaging time (cancer)	days	25,550	25,550
IR	Drinking water ingestion	L/day	2	1
EF	Exposure frequency	day/yr	350	250
ED	Exposure duration	years	30	25
TR	target cancer risk			

Toxicity: Oral Slope Fact

Chemical	SF_o ((kg-day)/mg)
Benzene	0.029
Toluene	
Ethylbenzene	
Xylenes	
Naphthalene	
Benzo(a)pyrene	7.3
Benz(a)anthracene	0.73
Chrysene	0.073

Risk Assessment Equations for Cancer: Groundwater Ingestion

C_w: concentration in water in mg/L

$$TR = \frac{C_w \times IR \times EF \times ED \times SF_o}{BW \times AT_c}$$

$$C_w = \frac{TR \times BW \times AT_c}{IR \times EF \times ED \times SF_o}$$

Iowa RBCA Concentrations at the Point of Exposure for Groundwater Ingestion: Cancer Risk (Tier 1 and Tier 2)

All the direct exposure concentrations used for groundwater ingestion for Iowa RBCA Tier 1 and Tier 2, for Cancer Risk

Chemical	Solubility (µg/L)	TR	Residential (µg/L)	Non-Residential (µg/L)
Benzene	1,750,000	$1x10^{-4}$	294	987
Benzo(a)pyrene	1.2	$1x10^{-6}$	0.0117	0.0392
		$1x10^{-4}$	1.17	3.92
Benz(a)anthracene	14	$1x10^{-6}$	0.117	0.392
		$1x10^{-4}$	11.7	39.2
Chrysene	2.8	$1x10^{-6}$	1.17	3.92
		$1x10^{-4}$	117.0	392.0

Non-residential concentrations for cancer risk are 3.36 times higher than residential. Same risk, different exposure assumptions.

These concentrations are explicit or implicit in the following Tier 1 Path

Pathway Receptor	Groundwater Ingestion: Cancer
Groundwater Ingestion - actual	MCL or TR = $1x10^{-6}$, Residential Exposure
Groundwater Ingestion - potential	TR = $1x10^{-4}$, Residential Exposure
Groundwater to Water Line	TR = $1x10^{-4}$, Residential Exposure
Soil Leaching to Groundwater	TR = $1x10^{-4}$, Residential Exposure
Soil to Water Line	TR = $1x10^{-4}$, Non-Residential Exposure

Direct Exposure Concentrations for Groundwater Ingestion

Cancer Risks

Chemical	Solubility (µg/L)	TR	Residential (µg/L)	Non-Residential (µg/L)
Benzene	1,750,000	$1x10^{-4}$	294	987
Benzo(a)pyrene	1.2	$1x10^{-6}$	0.0117	0.0392
		$1x10^{-4}$	1.17	3.92
Benz(a)anthracene	14	$1x10^{-6}$	0.117	0.392
		$1x10^{-4}$	11.7	39.2
Chrysene	2.8	$1x10^{-6}$	1.17	3.92
		$1x10^{-4}$	117.0	392.0

Non-Cancer Effects

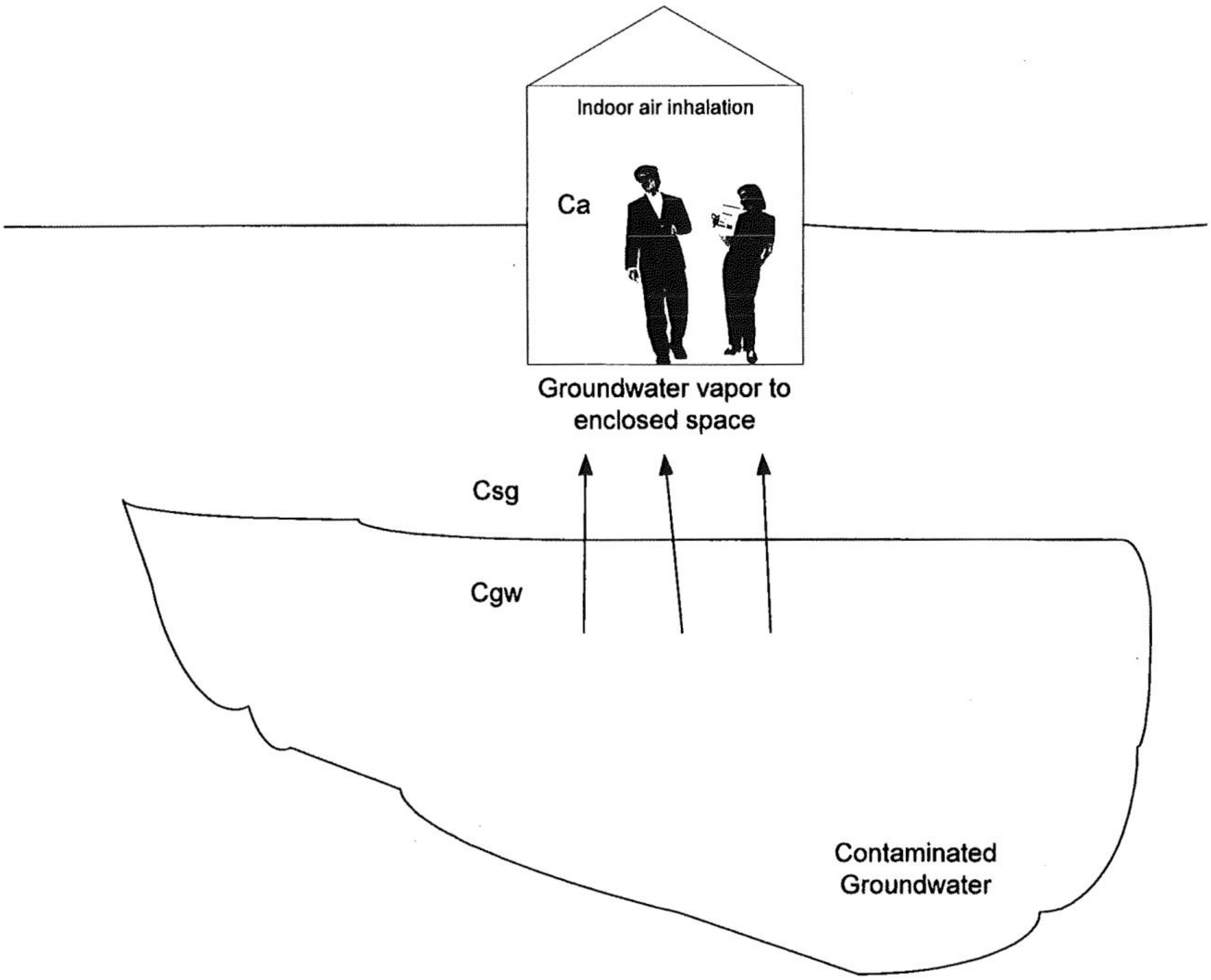
Chemical	Solubility (µg/L)	HQ	Residential (µg/L)	Non-Residential (µg/L)
Toluene	535,000	1	7,300	20,440
Ethylbenzene	152,000	1	3,650	10,220
Xylenes	198,000	1	73,000	204,400
Naphthalene	31,000	1	146	409

Summary of Direct Exposure Assumptions and Concentrations for Groundwater Ingestion

Pathway	Exposure, TR/HQ	Benzene	Toluene	Ethylbenzene	Xylenes	Naphthalene	B(a)P	B(a)A	Chrysene
Groundwater Ingestion - Actual	Res. MCL, HQ = 1, TR = $1x10^{-6}$	5	1,000	700	10,000	146	0.0117	0.117	117
Groundwater Ingestion - Potential	Res, HQ = 1, TR = $1x10^{-4}$	294	7,300	3,650	73,000	146	1.17	11.7	117
Groundwater to Water Line	Res, HQ = 1, TR = $1x10^{-4}$	294	7,300	3,650	73,000	146	1.17	11.7	117
Soil Leaching to Groundwater	Res, HQ = 1, TR = $1x10^{-4}$	294	7,300	3,650	73,000	146	1.17	11.7	117
Soil to Water Line	Non-Res, HQ = 1, TR = $1x10^{-4}$	987	20,440	10,220	204,400	409	3.92	39.2	392.0
Surface Water	Res, HQ = 1, TR = $1x10^{-4}$	294	1,000*	3,650	73,00	149	1.17	11.7	117
Solubility		1,750,000	535,000	152,000	198,000	31,000	1.2	14	2.8

*chronic level for aquatic life from 567-135.2.

Direct Exposure Indoor Air Inhalation
Ca – contaminated air
Csg – contaminated soil gas
Cgw – contaminated groundwater



Direct Exposure Risk Assessment for Iowa RBCA
Route of Exposure: Indoor Air Inhalation
Applies to Tier 1 and Tier 2 Vapor Pathways

Question: What concentration of a chemical is it “acceptable” for a person to breath in indoor air?

Answer: Depends on how much chemical the person breaths in and what chronic health risk is acceptable.

Revised Question: Given the acceptable risk and assumed exposure factors, what concentration of a chemical is acceptable in indoor air?

Risk for Non-carcinogen; non-cancer effects.
Route of Exposure: Inhalation

$$Dose = \frac{total\ mass\ ingested\ over\ the\ duration\ of\ exposure\ (mg)}{body\ weight\ (kg) \times lifetime\ exposure\ duration\ (days)}$$

$$Dose = \frac{C_a \times IR_a \times EF \times ED}{BW \times AT_n}$$

C_a = Concentration of the chemical of concern in air (mg/m^3)
IR_a = Inhalation rate of air (m^3/day)
EF = Exposure Frequency (days/yr)
ED = Exposure Duration (yr)
BW = Body Weight (kg)
AT_n = Averaging time for non-carcinogens (period of exposure) (days) = ED (years) x 365days/year

$$Dose = \frac{C_a \times IR_a \times EF \times ED}{BW \times (ED \times 365)}$$

Really: Average daily dose per year

$$Dose = \frac{C_a \times IR \times EF}{BW \times 365} \Leftrightarrow \frac{\left(\frac{mg}{L}\right)\left(\frac{L}{day}\right)\left(\frac{days}{year}\right)}{kg \ \times 365 days} \Leftrightarrow \frac{mg\ ingested\ in\ a\ year}{kg \times 365 days}$$

Dose: Average daily dose in: mg of chemical per day per kg of body weight.

$$HQ = \frac{\left[\frac{C_a \times IR \times EF \times ED}{BW \times AT}\right]}{R_f D_i} = \frac{C_a \times IR \times EF}{BW \times 365 \times R_f D_i}$$

$R_f D_i$: Inhalation Reference Dose

Backward
Given: The Risk
Given: The exposure factors
Find: The Concentration of the Chemical of Concern

Example: Toluene in air
Residential Exposure Factors
Inhalation Reference Dose of 0.114 mg/kg-day

$$HQ = \frac{\left[\frac{C_a \times IR \times EF \times ED}{BW \times AT}\right]}{R_f D_i}$$

Solve for C_a

$$C_a = \frac{HQ \times R_f D_i \times BW \times 365}{IR \times EF} = \frac{1.0 \times 0.114 \times 70 \times 365}{15 \times 350}$$

$$C_a = 0.555 \frac{mg}{m^3} = 555 \frac{\mu g}{m^3}$$

Direct Exposure Concentrations for Indoor Air Inhalation for Iowa RBCA: Non-cancer effects

Exposure Fact

Parameter	Definition	Units	Residential	Non-Residential
BW	Body Weight, Adult	kg	70	70
AT_n	Averaging time (non-cancer)	days	ED x 365d/yr	ED x 365d/yr
IR	Indoor air inhalation	m3/day	15	20
EF	Exposure frequency	day/yr	350	250
ED	Exposure duration	years	30	25

Toxicity: Hazard Quotient and Reference Doses

Chemical	HQ	R_fD_i (mg/(kg-day))
Benzene	1	
Toluene	1	0.114
Ethylbenzene	1	0.286
Xylenes	1	2.0
Naphthalene	1	0.004
Benzo(a)pyrene	1	
Benz(a)anthracene	1	
Chrysene	1	

Risk Assessment Equations

C_a: Concentration in air in mg/m^3.

$$HQ = \frac{\left[\frac{C_a \times IR \times EF \times ED}{BW \times AT}\right]}{R_f D_i} = \frac{C_a \times IR \times EF}{BW \times 365 \times R_f D_i}$$

$$C_a\left(\frac{mg}{m^3}\right) = \frac{HQ \times R_f D_i \times BW \times AT_n}{IR \times EF \times ED} = \frac{HQ \times R_f D_i \times BW \times 365}{IR \times EF}$$

Iowa RBCA: Indoor Air Inhalation, Tier 1 and Tier 2

The direct exposure concentrations used for indoor air inhalation for Iowa RBCA Tier 1 and Tier 2, for non-cancer effects.

Chemical	Residential (µg/m^3)	Non-Residential (µg/m^3)
Toluene	555	583
Ethylbenzene	1392	1462
Xylenes	9733	10,220
Naphthalene	19.5	20.4

Non-residential concentrations are 1.05 times higher than residential.
Same risk, different exposure assumptions. Change in exposure duration is offset by assuming more air breathed.

These concentrations are explicit or implicit in the following Tier 1 Pathways

Pathway Receptor	Groundwater Ingestion: Cancer
Groundwater Vapor to Enclosed Space	Residential Exposure
Soil Vapor to Enclosed Space	Residential Exposure

Carcinogens

Calculating Risk:

$$Risk = Dose \times Toxicity$$

or

$$Risk = Dose\left(LADD, \frac{mg}{kg - day}\right) \times Slope\ Factor\left(\frac{kg - day}{mg}\right)$$

Exposure Assessment (Dose): Inhalation

What lifetime average daily dose will the person be exposed to?

$$Dose = \frac{total\ mass\ ingested\ over\ the\ duration\ of\ exposure\ (mg)}{body\ weight\ (kg) \times lifetime\ exposure\ duration\ (days)}$$

Inhalation of Air:

$$Dose\left(\frac{mg}{kg-day}\right) = \frac{C_a \times IR \times EF \times ED}{BW \times AT_c}$$

C_a = Concentration of the chemical of concern in air (mg/m^3)
IR = Inhalation rate of air (m^3/day)
EF = Exposure Frequency (days/yr)
ED = Exposure Duration (yr)
BW = Body Weight (kg)
AT_c = Averaging Time for Cancer (lifetime) (days)

Calculating Cancer Risk: Inhalation

$$Risk = Dose\left(\frac{mg}{kg-day}\right) \times Slope\ Factor\left(\frac{kg-day}{mg}\right)$$

Choosing Notation and Assumptions:

Forward:

$$Risk = \frac{C_a \times IR \times EF \times ED}{BW \times AT_c} \times SF_i$$

$$TR = \frac{C_a \times IR \times EF \times ED \times SF_i}{BW \times AT_c}$$

Backward

$$C_a\left(\frac{mg}{m^3}\right) = \frac{TR \times BW \times AT}{IR \times EF \times ED \times SF_o}$$

TR = target cancer risk
C_a = Concentration of the chemical of concern in air (mg/m^3
IR = Inhalation Rate of air (m^3/day)
EF = Exposure Frequency (days/yr)
ED = Exposure Duration (yr)
BW = Body Weight (kg)
AT_c = Averaging time for cancer (period of exposure) (days)
SF_i = Inhalation Cancer Slope Factor ((kg-day)/mg)

Backward calculation:

Inhalation of Benzene, Cancer Effects Assume:
TR = $1x10^{-4}$
IR = 15 m^3/day
EF = 350 days/year
ED= 30 years
BW = 70 kg
AT_c = 25,550 days
SF_i = 0.029 ((kg-day)/mg)

$$C_w = \frac{TR \times BW \times AT_c}{IR \times EF \times ED \times SF_i} = \frac{(1 \times 10^{-4}) \times 70 \times 25{,}550}{15 \times 350 \times 30 \times 0.029} = 3.92 \times 10^{-2}\frac{mg}{m^3} = 39.2\frac{\mu g}{m^3}$$

Direct Exposure Concentrations for Inhalation of Air for Iowa RBCA Tier 1 and Tier 2: Cancer effects

Exposure Fact

Parameter	Definition	Units	Residential	Non-Residential
BW	Body Weight, Adult	kg	70	70
AT_n	Averaging time (cancer)	days	25,550	25,550
IR	Indoor air inhalation	m3/day	15	20
EF	Exposure frequency	day/yr	350	250
ED	Exposure duration	years	30	25
TR	Target risk			

Toxicity: Hazard Quotient and Reference Doses

Chemical	SF_i ((kg-day)/mg)
Benzene	0.029
Toluene	
Ethylbenzene	
Xylenes	
Naphthalene	
Benzo(a)pyrene	6.1
Benz(a)anthracene	0.61
Chrysene	0.061

Risk Assessment Equations for Cancer

C_a: Concentration in air in mg/m^3

$$Risk(TR) = \frac{C_a \times IR \times EF \times ED}{BW \times AT_c} \times SF_i$$

Solve for: C_a

$$C_a\left(\frac{mg}{m^3}\right) = \frac{TR \times BW \times AT_c}{IR \times EF \times ED \times SF_i}$$

Iowa RBCA, Indoor Air Inhalation: Cancer Risk (Tier 1 and Tier 2)

The direct exposure concentrations used for indoor air inhalation for Iowa RBCA Tier 1 and Tier 2, for Cancer Risk

Chemical	TR	Residential ($\mu g/m^3$)	Non-Residential ($\mu g/m^3$)
Benzene	1×10^{-4}	39.2	49.3
Benzo(a)pyrene	1×10^{-4}	0.186	0.235
Benz(a)anthracene	1×10^{-4}	1.86	2.35
Chrysene	1×10^{-4}	18.6	23.5

Non-residential concentrations for cancer risk are 1.25 times higher than residential. Same risk, different exposure assumptions. Exposure duration is the major factor (25 years versus 30 years).

These concentrations are explicit or implicit in the following Tier 1 Path

Pathway Receptor	Groundwater Ingestion: Cancer
Groundwater Vapor to Enclosed Space	TR = $1x10^{-4}$, Residential Exposure
Soil Vapor to Enclosed Space	TR = $1x10^{-4}$, Residential Exposure

However, the PAHs do not appear in the Tier 1 table, because their volatility is very low.

Iowa RBCA, Indoor Air Inhalation (Tier 1 and Tier 2)

All of the direct exposure concentrations used for indoor air inhalation for Iowa RBCA Tier 1 and Tier 2. (Except for sanitary sewers, where concentrations are double, TR = $2x10^{-4}$, HQ = 2)

Chemical	HR/TR	Residential (µg/m^3)	Non-Residential (µg/m^3)
Benzene	TR = $1x10^{-4}$	39.2	49.3
Toluene	HQ = 1	555	583
Ethylbenzene	HQ = 1	1392	1462
Xylenes	HQ = 1	9733	10,220
Naphthalene	HQ = 1	19.5	20.4
Benzo(a)pyrene	$1x10^{-4}$	0.186	0.235
Benz(a)anthracene	$1x10^{-4}$	1.86	2.35
Chrysene	$1x10^{-4}$	18.6	23.5

These concentrations are explicit or implicit in the following Tier 1 Path

Pathway Receptor	Groundwater Ingestion: Cancer
Groundwater Vapor to Enclosed Space	Residential Exposure
Soil Vapor to Enclosed Space	Residential Exposure

However, the PAHs do not appear in the Tier 1 table, because their volatility is very low.

Iowa RBCA, Groundwater Ingestion

All of the direct exposure concentrations for groundwater ingestion for IA RBCA Tier 1 and Tier 2

MCLs

Chemical	Solubility (µg/L)	MCL (µg/L)
Benzene	1,750,000	5
Toluene	535,000	1,000
Ethylbenzene	152,000	700
Xylenes	198,000	10,000

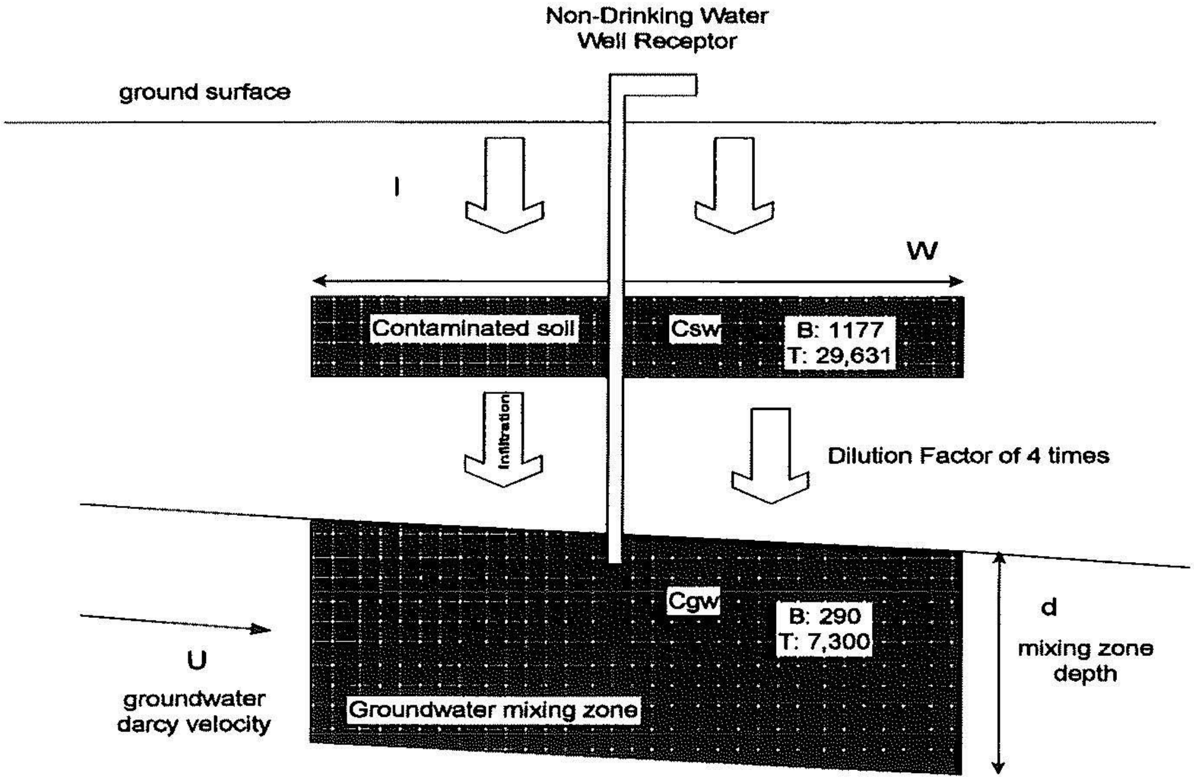
Cancer Risks

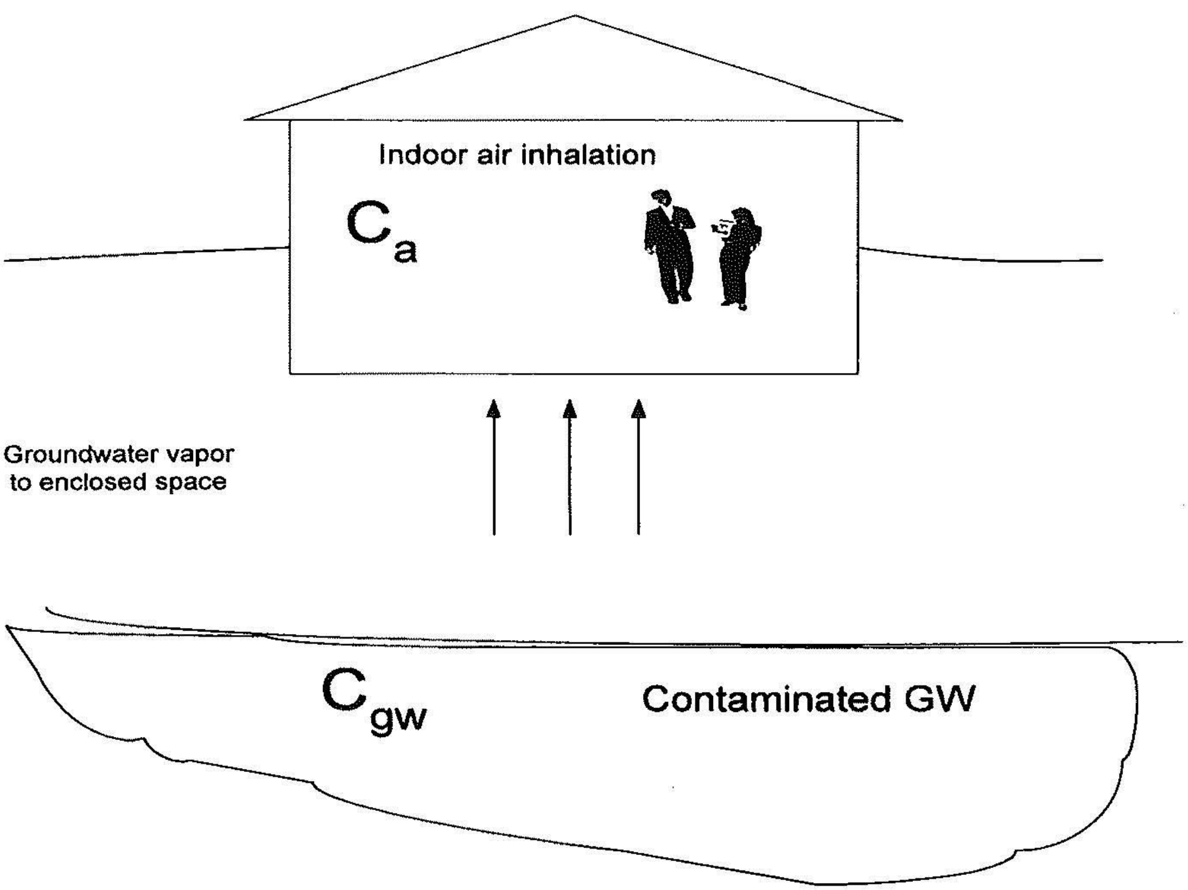
Chemical	Solubility (μg/L)	TR	Residential (μg/L)	Non-Residential (μg/L)
Benzene	1,750,000	$1x10^{-4}$	294	987
Benzo(a)pyrene	1.2	$1x10^{-6}$	0.0117	0.0392
		$1x10^{-4}$	1.17	3.92
Benz(a)anthracene	14	$1x10^{-6}$	0.117	0.392
		$1x10^{-4}$	11.7	39.2
Chrysene	2.8	$1x10^{-6}$	1.17	3.92
		$1x10^{-4}$	117.0	392.0

Non-Cancer Effects

Chemical	Solubility (μg/L)	HQ	Residential (μg/L)	Non-Residential (μg/L)
Toluene	535,000	1	7,300	20,440
Ethylbenzene	152,000	1	3,650	10,220
Xylenes	198,000	1	73,000	204,400
Naphthalene	31,000	1	146	409

Indirect Exposure in Iowa RBCA





Occurs when the source of contamination is not at the point of exposure.

Used for both Tier 1 and Tier 2.

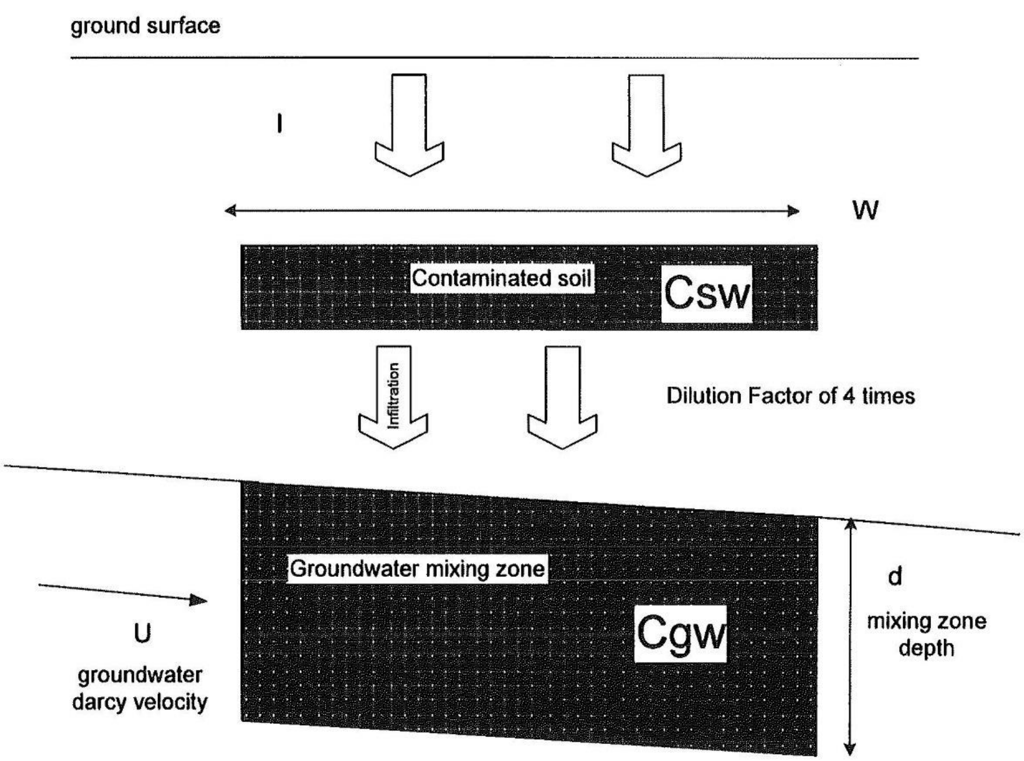
Given the direct exposure concentration (i.e. groundwater ingestion, indoor air inhalation), what concentration can be present at the source without exceeding the direct exposure concentration.

Modeling
Direct exposure concentrations are specified for every receptor type at Tier 1 and Tier 2.

Direct Exposure Concentrations are specified by:
- MCL (only for drinking water wells)
- TR or HQ
- Exposure Factors (Residential or Non-residential)

Find: Source Concentrations

Soil Leaching to Groundwater Pathway
Fate and Transport Model
Used at Tier 1 and Tier 2.
Model: Relates Soil Concentrations to Groundwater Concentrations.
Two Components to the Model:
1) Leaching from Soil Water to Groundwater.
2) Estimate the total soil concentration from the soil water concentration.



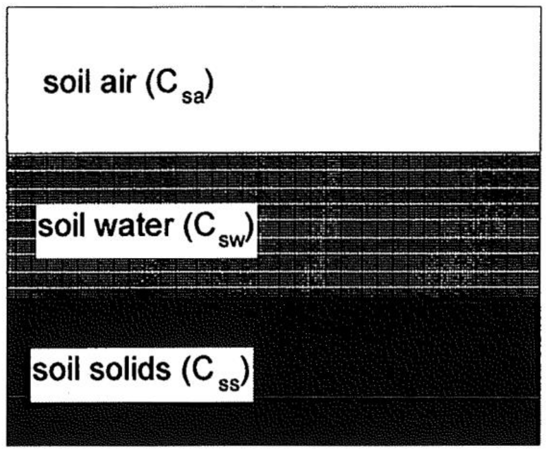
Csw: concentration in the soil water
Cgw: concentration in the groundwater
I: infiltration rate
d: groundwater mixing zone depth
W: width of soil contamination parallel to GW flow direction
U: Groundwater Velocity, U=Ki

Mass Balance Model
One-Dimensional, vertical, Steady-State, Plug Flow
No dispersion or mass loss (bioremediation)

$$Dilution = \frac{Csw}{Cgw}$$

$$Dilution = 1 + \frac{Ud}{IW}$$

Second Step: Given a soil water concentration, find the total soil concentration.

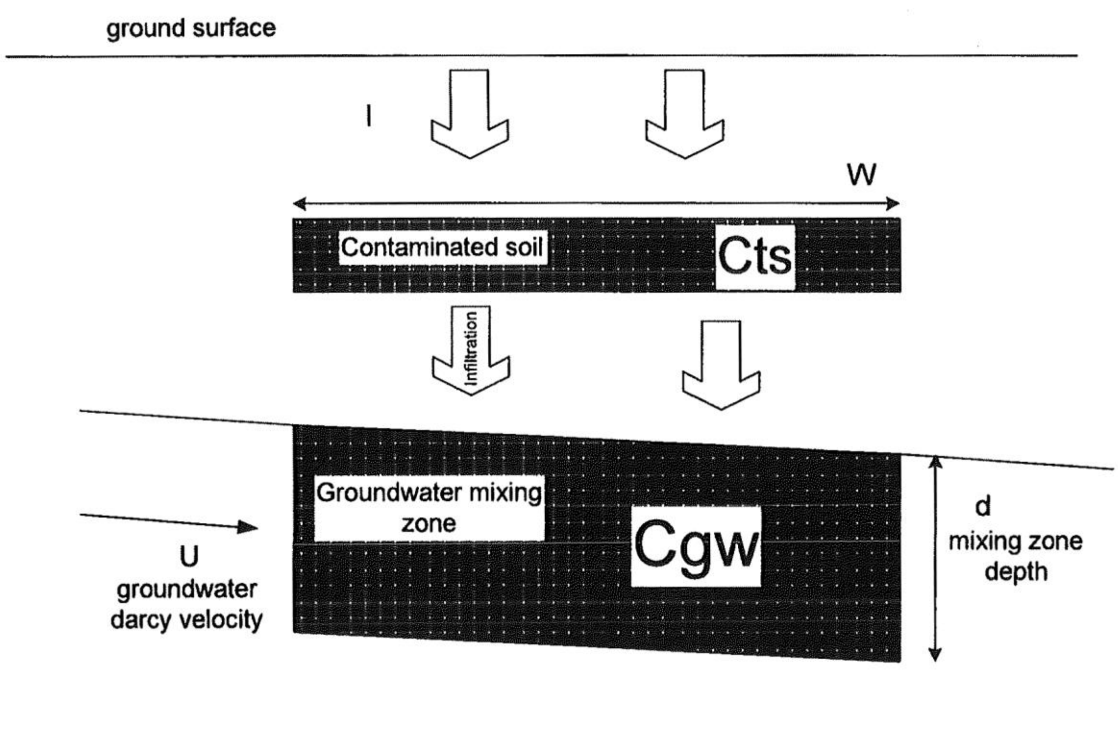


$$Henry's\ Law: C_{sa} = H \times C_{sw}$$

$$Linear\ Equilibrium\ Absorption: C_{ss} = K_s \times C_{sw}$$

Total up the mass of chemical:
Convert to: mg/kg of soil. C_{ts}

Put the two models together:



Model to relate: Cgw to Cts

Cts: Concentration of chemical in the soil

Cgw: Concentration in the Groundwater beneath the soil contamination

What value is used for Cgw at Tier 1?
Direct exposure concentrations:
Cgw will depend on the receptor.

Soil Leaching to Groundwater Model
Used at Tier 1 and Tier 2

$$RBSL_w\left(\frac{mg}{kg-soil}\right) = \frac{RBSL_w\left(\frac{mg}{L-H_2O}\right)}{LF}$$

$$LF\left(\frac{mg/L-H_2O}{mg/kg-soil}\right) = \frac{\rho_s}{(\theta_{ws}+k_s\rho_s+H\theta_{as})\left(1+\frac{U\delta}{IW}\right)}$$

$RBSL_w = C_{gw}$ (concentration in groundwater beneath the soil)

$RBSL_{sl} = C_{ts}$ (concentration in the soil which, using the model, will give C_{gw})

Variable Definitions:

$RBSL_w$	Risk-Based Screening Level for groundwater ingestion (mg/L)
$RBSL_{sl}$	Risk-Based Screening Level for soil leaching to groundwater (mg/kg-soil)
LF	leaching factor from soil to groundwater ((mg/L-H_2O)/(mg/kg-soil))
U	groundwater Darcy velocity (cm/year), U=Ki
K	hydraulic conductivity (cm/year)
i	ground water head gradient (cm/cm)
W	width of soil source area parallel to groundwater flow direction (cm)
I	infiltration rate of water through soil (cm/year)
δ	ground water mixing zone thickness (cm)
H	henry's law constant (L-H_20)/(L-air)
ρ_s	soil bulk density (g/cm^3)
θ_{as}	volumetric air content in vadose zone (cm^3-air/cm^3-soil)
θ_{ws}	volumetric water content in vadose zone (cm^3-H_2O/cm^3-soil)
θ_T	total soil porosity (cm^3-voids/cm^3-soil)
K_s	soil-water sorption coefficient (L-H_2O/kg-soil), f_{oc} x K_{oc}
f_{oc}	fraction organic carbon in the soil (kg-C/kg-soil)
K_{oc}	carbon-water sorption coefficient (L-H_2O/kg-C)

Soil and groundwater parameter Values Used for Iowa Tier 1 Table Generation

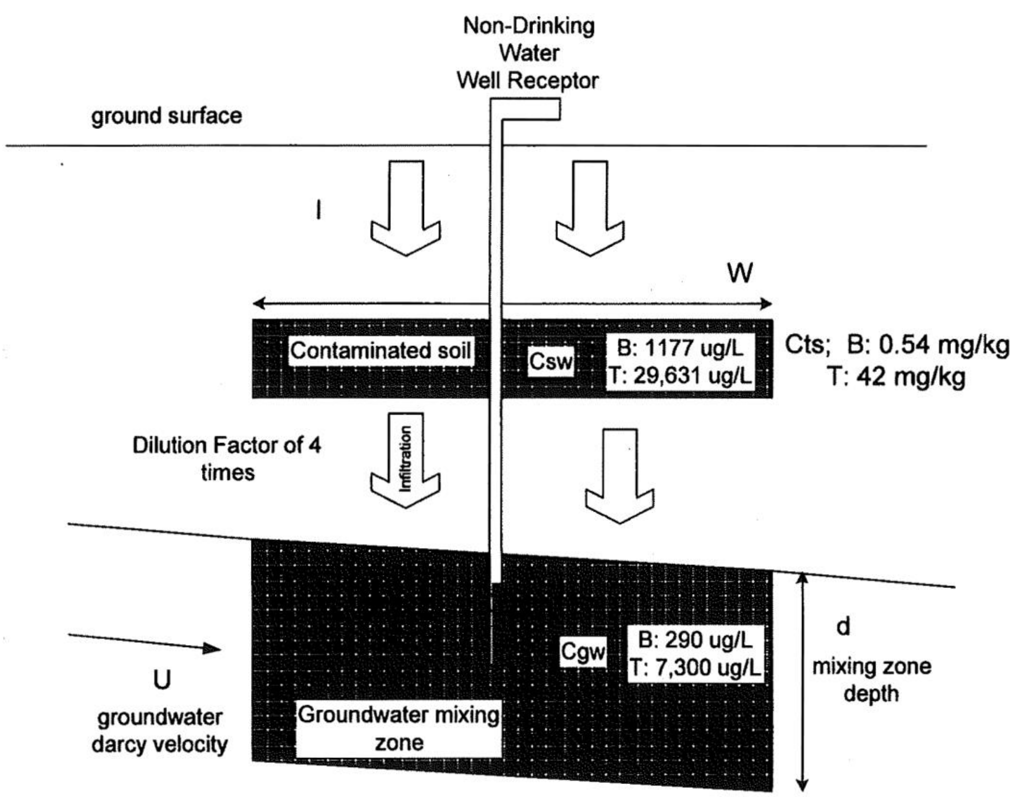
Parameter	Iowa Tier 1 Table Value
K	16060 cm/year
i	0.01 cm/cm
W	1500 cm
I	7 cm/year
δ	200cm
ρ_s	1.86 g/cm^3
θ_{as}	0.2 cm^3-air/cm^3-soil
θ_{ws}	0.1 cm^3-H_2O/cm^3-soil
θ_T	0.3 cm^3-voids/cm^3-soil
f_{oc}	0.01 kg-C/kg-soil

Chemical Spec fic parameter values used for Iowa RBCA

Chemical	H (L-air/L-water)	Koc, (L/kR)
Benzene	0.22	38
Toluene	0.26	135
Ethylbenzene	0.32	96
Xylenes	0.29	240
Naphthalene	0.049	1288
Benzo(a)pyrene	5.8e-8	389045

Dilution Factor for all Chemicals is about 4 times (Using parameters values selected for Tier 1)

Total Soil concentration is chemical and soil parameter specific.



Effect of Organic Carbon on Soil Leaching to Groundwater Pathway

Chemical	Cgw (mfVL)	Csw (mfVL)	Foc	Cts (mg/Kg)
Benzene	0.290	1.16	0.01	0.54
Benzene	0.290	1.16	0.001	0.14
Toluene	7.3	29.6	0.01	42
Toluene	7.3	29.6	0.001	6.42
Xylenes	73.0	296	0.01	736
Xylenes	73.0	296	0.001	96

Tier 1 Soil Leaching to Groundwater Pathway

Route of Exposure: Groundwater Ingestion

Direct Exposure Concentrations in the Groundwater
TR = $1x10^{-4}$, HQ = 1, Residential Exposure Factors

Risk Based Target Levels in Groundwater

Chemical	Solubility (µg/L)	TR/HQ	Residential (µg/L)
Benzene	1,750,000	$1x10^{-4}$	294
Toluene	535,000	1	7,300
Ethylbenzene	152,000	1	3,650
Xylenes	198,000	1	73,000
Naphthalene	31,000	1	146
Benzo(a)pyrene	1.2	$1x10^{-4}$	1.17
Benz(a)anthracene	14	$1x10^{-4}$	11.7
Chrysene	2.8	$1x10^{-4}$	117.0

Corresponding Soil Concentrations for 3 Chemicals

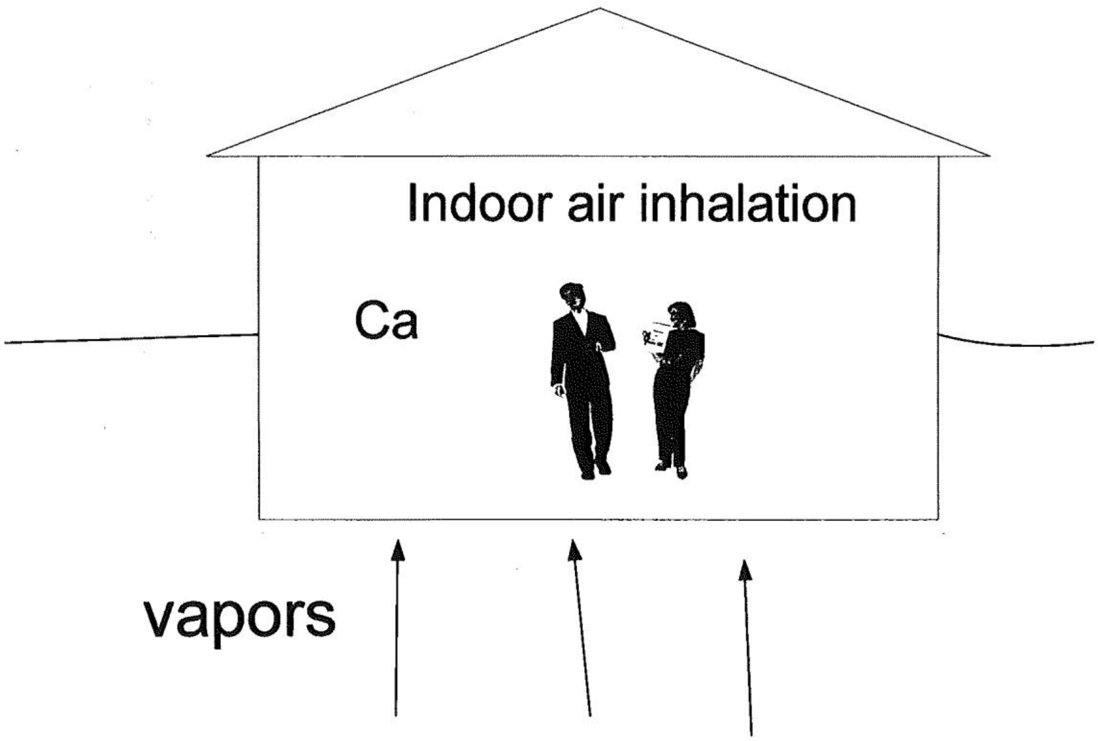
Chemical	Cgw (µg/L)	Csw (µg/L)	Cts (mg/Kg)
Benzene	290	1,177	0.54
Toluene	7,300	29,631	42
Xylenes	73,000	296,000	736

If Csw for a chemical is above the solubility for the pure chemical in water, NA is displayed in the Tier 1 Table.

Enclosed Space Vapor Inhalation for RBCA

Applies to Tier 1 and Tier 2

Route of Exposure: Breathing Contaminated Air in Enclosed Spaces
Two Sources: Groundwater Contamination
Soil Contamination

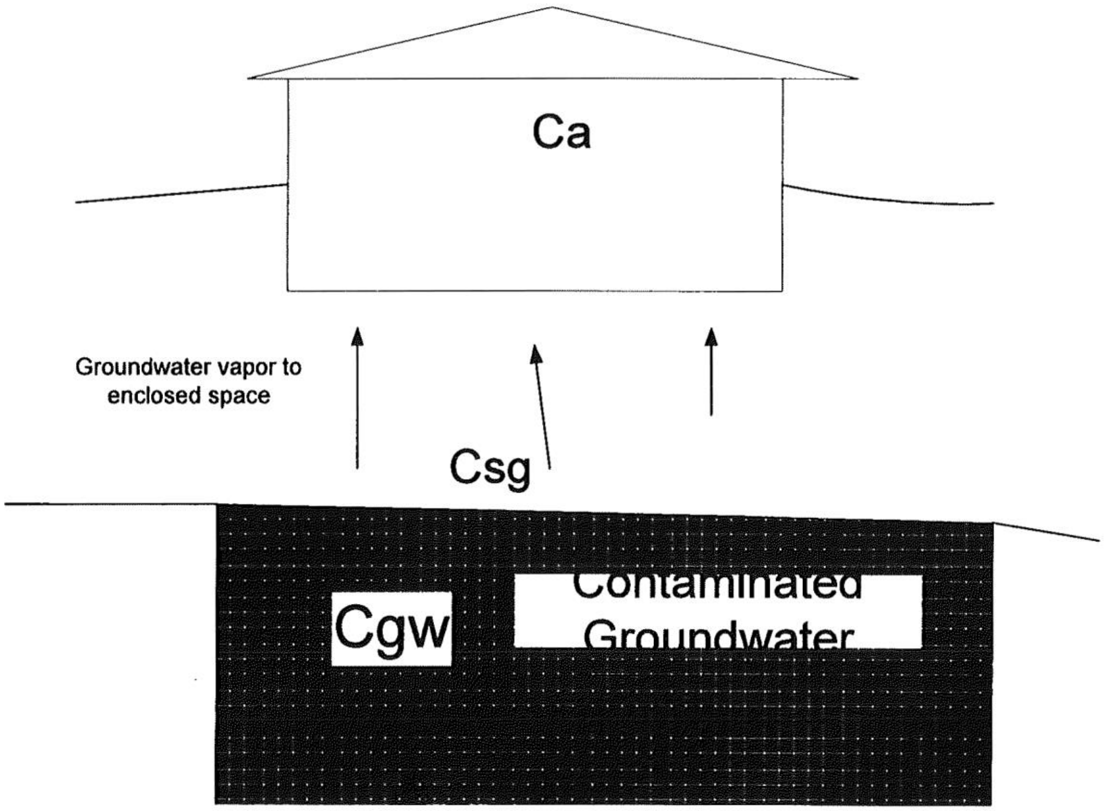


Direct Exposure: Indoor Air Inhalation (Ca)

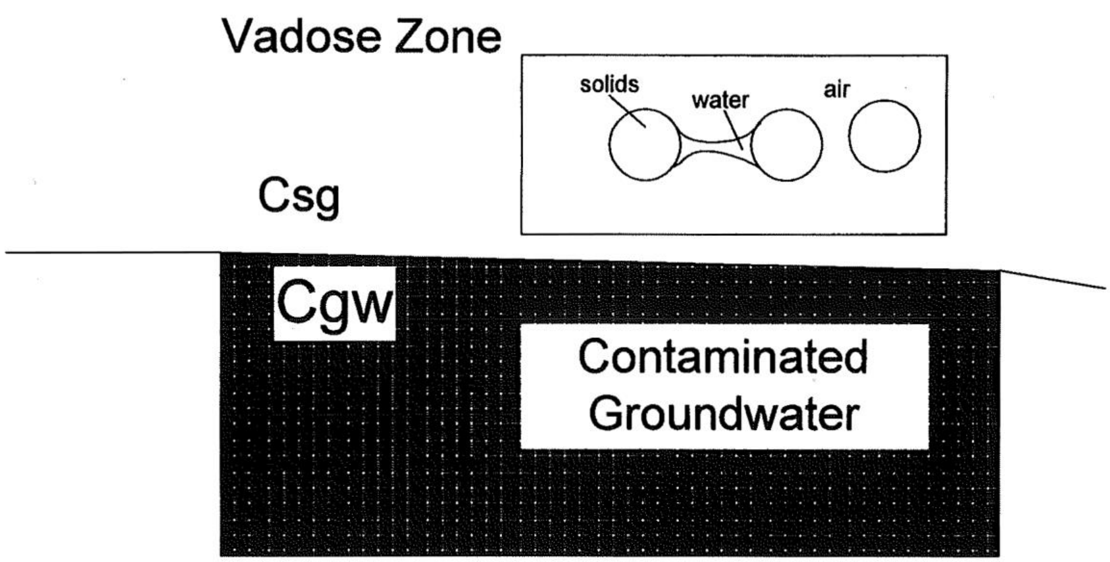
Chemical	TR/HQ	Residential (µg/L)	Non-Residential (µg/L)
Benzene	$1x10^{-4}$	39.2	49.3
Toluene	1	555	583
Ethylbenzene	1	1,392	1,462
Xylenes	1	9,733	10,220
Naphthalene	1	19.5	20.4
Benzo(a)pyrene	$1x10^{-4}$	0.186	0.235
Benz(a)anthracene	$1x10^{-4}$	1.86	2.35
Chrysene	$1x10^{-4}$	18.6	23.5

Groundwater Vapor to Enclosed Space
Model: What is the relationship between the concentration in the air in the enclosed space and the concentration in the groundwater beneath the enclosed space.

Three Processes:
1. Relationship between groundwater concentrations and soil gas concentrations just above the groundwater.
2. Diffusion as a vapor from just above the groundwater to the building foundation.
3. Diffusion into the enclosed space, and mixing.



1. Given the Groundwater Concentration, what is the concentration in the Soil Gas at the groundwater-vadose zone interface.

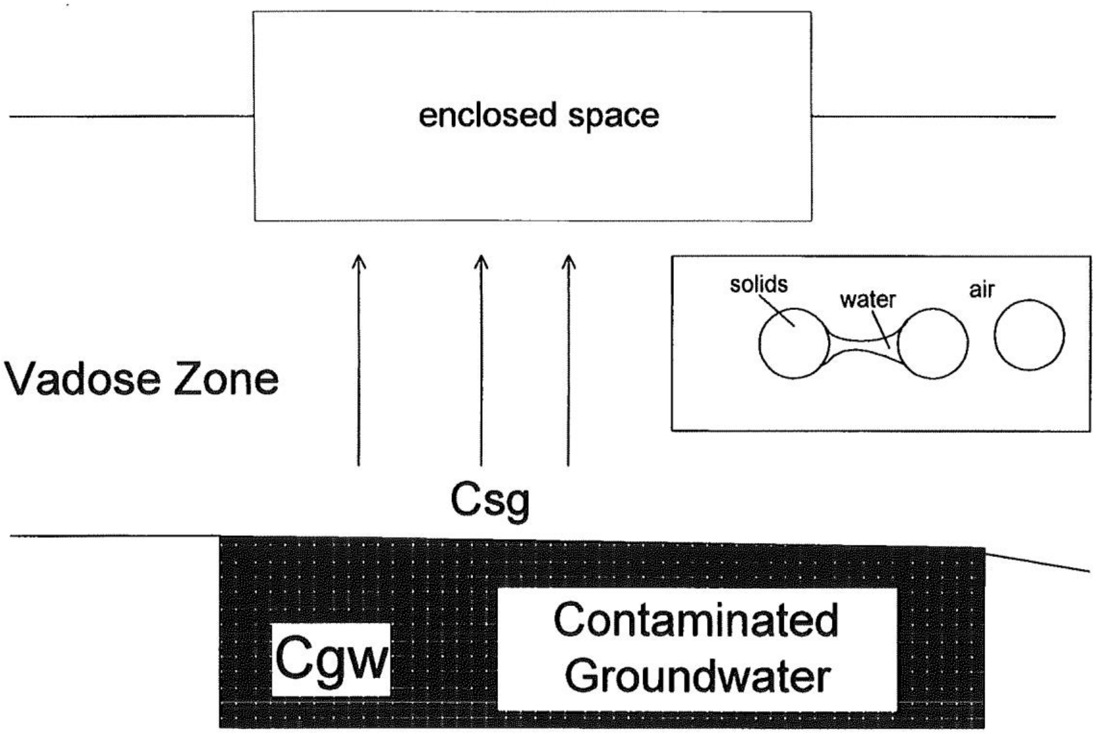


$$Henry's\ Law: C_{sg} = H \times C_{gw}$$

For benzene: H = 0.22

i.e. Cgw = 1000, Csg = 220

Diffusion from the Groundwater to the Enclosed Space



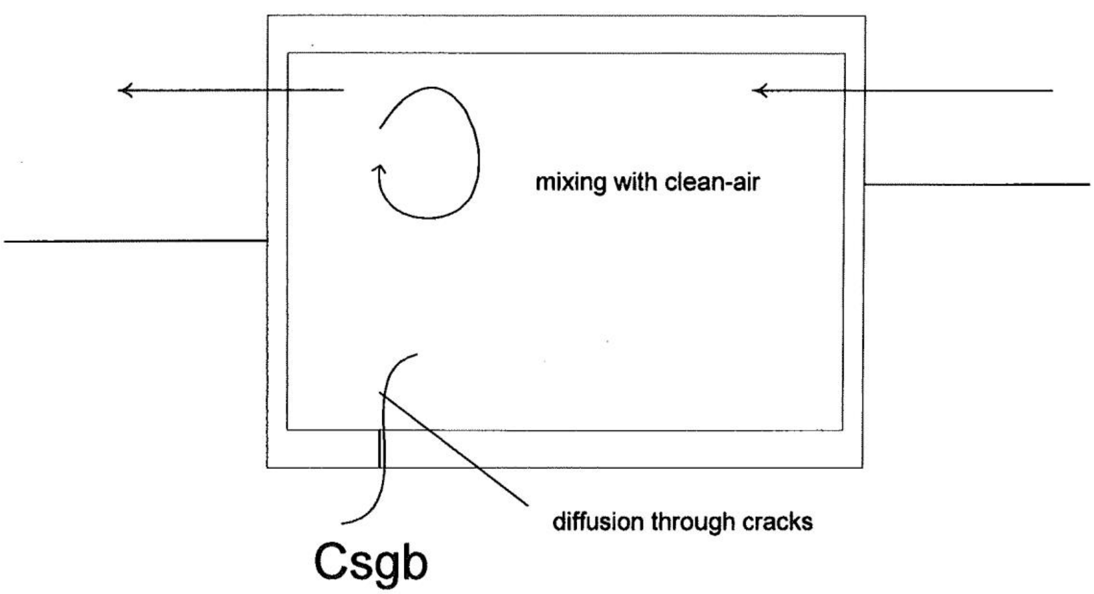
Steady-State, One Dimensional, Vertical Diffusion

Mainly controlled by air content and water content of the soil:

θ_{as} volumetric air content in vadose zone (cm^3-air/cm^3-soil)
θ_{ws} volumetric water content in vadose zone (cm^3-H_2O/cm^3-soil)
θ_T total soil porosity (cm^3-voids/cm^3-soil)

Diffusion rate is much faster in air than in water.

Diffusion into the enclosed space and mixing:

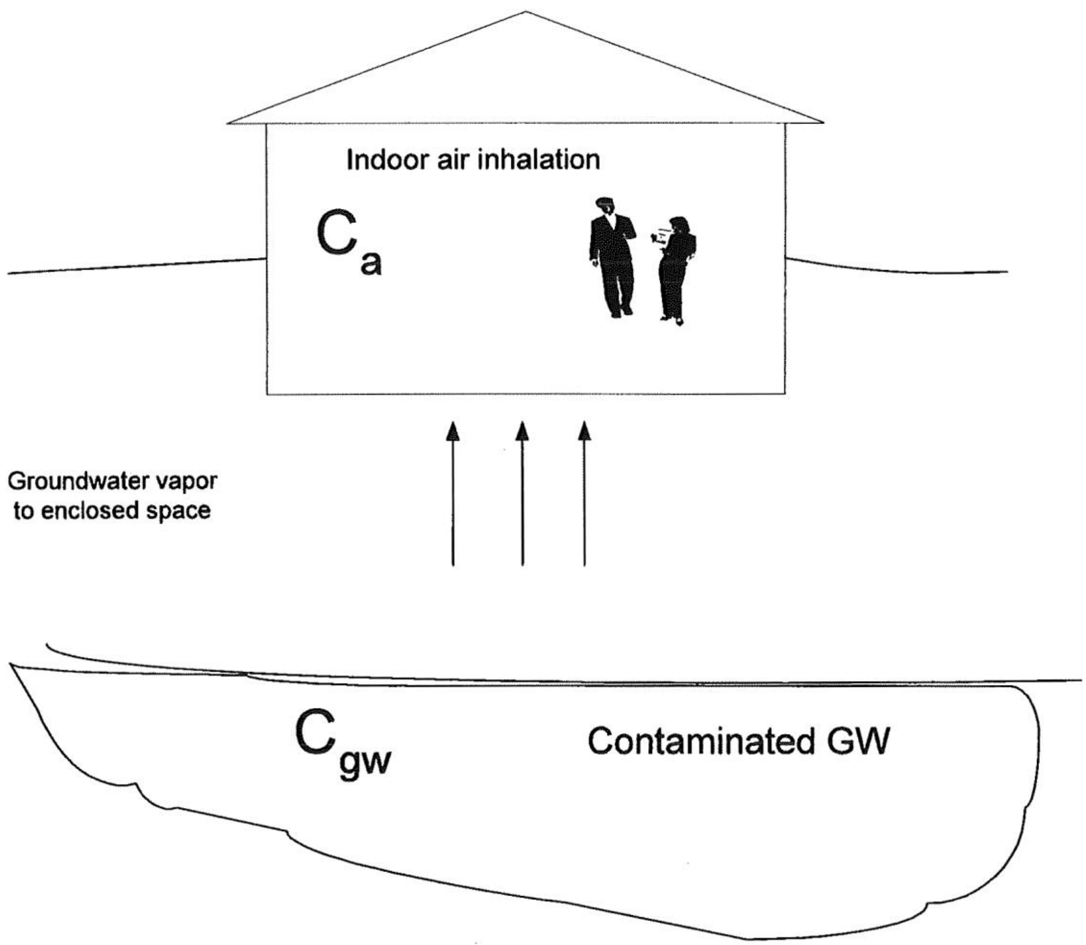


L_{crack} enclosed space foundation or wall thickness (cm)
ER enclosed space air exchange rate (s^{-1})
η areal fraction of cracks in foundation/wall (cm^2-cracks/cm^2-area)
θ_{acrack} volumetric air content in foundation/wall cracks (cm^3-air/cm^3-soil)
θ_{wcrack} volumetric water content in foundation/wall cracks (cm^3-H_2O/cm^3-soil)
L_B enclosed space volume/infiltration area ratio (cm)

TO= 1/ER, TO: turn over rate (time) of the air in the building.

L_B: Volume of the enclosed space - divided by - area of walls and floor below ground.

Combine the Models: Relate Ca and Cgw
Ca: Direct Exposure Concentration for Indoor Air Inhalation
Cgw: Concentration in the groundwater which will result in Ca in the enclosed space.



Example: OW Vapor to Enclosed Space
Risk Based Concentration in the Air at your nose:

Assume: Residential Exposure
Based on: HQ=1, TR=$1x10^{-4}$,
BW=70kg
IR=20 m^3/day
EF=350 days/year

ED=30 years

Ca:

Benzene: 39.2 µg/m^3 OHSA: 3,200 µg/m^3

Toluene: 555 µg/m^3 OHSA: 435,000 µg/m^3

Modeling: What concentration in the soil gas above the groundwater table will result in the indoor are concentrations shown.

Model: Steady -State, diffusion driven

Air turnover rate in the building: 2 hours

Csg:

Benzene: 338,800 µg/m^3 Dilution factor of 8,643 times

Toluene: 5,240,940 µg/m^3 Dilution factor of 9,443 times

What concentration in groundwater will result in the above soil gas concentrations.

Assume equilibrium and use Henry's Law

Cgw:

Benzene: 1,540 µg/L 1,540,000 µg/m^3

Toluene: 20,190 µg/L 20,190,000 µg/m^3

Dilution from Soil Gas (Csg) to Enclosed Space (Ca)

Chemical	Residential Building Parameters	Non-Residential Building Parameters
Benzene	8650	21330
Toluene	9460	23,300
Naphthalene	11,160	27,516

Residential Exposure Factors and Building Parameters, TR=1x10^{-4}, HQ=1

Chemical	Indoor Air (µg/m^3)	Soil Gas (µg/m^3)	GW (µg/L)
Benzene	39.2	339,000	1,541
Toluene	555	5,250,030	20,194
Naphthalene	19.5	217,620	4,441

Non-Residential Exposure Factors and Building Parameters, TR=1x10^{-4}, HQ=1

Chemical	Indoor Air (µg/m^3)	Soil Gas (µg/m^3)	GW (µg/L)
Benzene	49.2	1,049,440	4,770
Toluene	583	13,583,900	52,246
Naphthalene	20.4	561,326	11,456

Soil Gas to Groundwater

$$Henry's\ Law: Csg = H \times Cgw$$

$$Cgw = \frac{Csg}{H}$$

Benzene

$$Cgw = \frac{339{,}000\,\frac{\mu g}{m^3}}{0.22} = 1.54 \times 10^6\,\frac{\mu g}{m^3} \times \frac{m^3}{100L} = 1541\,\frac{\mu g}{L}$$

The Model

$RBSL_{air}$ = C_a, Direct exposure concentration for indoor air inhalation
$RBSL_{gw}$ = C_{gw}, Concentration in groundwater beneath the enclosed space which will results in Ca in the enclosed space.

Note: The equations as presented here are based on specified units.

$$RBSL_{gw}\left[\frac{mg}{L - H_2O}\right] = \frac{RBSL_{air}\left[\frac{\mu g}{m^3 - air}\right]}{VF_{gw}}\left(\frac{mg}{1{,}000\mu g}\right)$$

$$VF_{gw}\left[\frac{(mg/m^3 - air)}{(mg/L - H_2O)}\right] = \frac{H\left[\frac{D_S^{eff}/L_{gw}}{ERL_B}\right]}{1 + \left[\frac{D_S^{eff}/L_{gw}}{ERL_B}\right] + \left[\frac{D_S^{eff}/L_{gw}}{(D_{crack}^{eff}/L_{crack})\eta}\right]}\left(\frac{10^3 L}{m^3}\right)$$

$$D_{crack}^{eff}\left[\frac{cm^2}{s}\right] = D^{air}\frac{\theta_{acrack}^{3.33}}{\theta_T^2} + D^{wat}\frac{1}{H}\frac{\theta_{wcrack}^{3.33}}{\theta_T^2}$$

$$D_{crack}^{eff}\left[\frac{cm^2}{s}\right] = D^{air}\frac{\theta_{as}^{3.33}}{\theta_T^2} + D^{wat}\frac{1}{H}\frac{\theta_{ws}^{3.33}}{\theta_T^2}$$

Variable Definitions:

$RBSL_{air}$	Risk-Based Screening Level for indoor air ($\mu g/m^3$-air)
$RBSL_{gw}$	Risk-Based Screening Level for vapor from groundwater to enclosed space air inhalation (mg/L-H_2O)
VF_{gw}	volatilization factor for vapors from ground water to enclosed space ((mg/m^3-air)/(mg/L-H_2O))
D^{air}	chemical diffusion coefficient in air (cm^2/s)
D^{wat}	chemical diffusion coefficient in water (cm^2/s)
D_S^{eff}	effective diffusion coefficient in soil based on vapor-phase concentration (cm^2/s)
D_{crack}^{eff}	effective diffusion coefficient through foundation cracks (cm^2/s)
H	henry's law constant (L-H_2O)/(L-air)
θ_{as}	volumetric air content in vadose zone (cm^3-air/cm^3-soil)
θ_{ws}	volumetric water content in vadose zone (cm^3-H_2O/cm^3-soil)
θ_{acrack}	volumetric air content in foundation/wall cracks (cm^3-air/cm^3-soil)
θ_{wcrack}	volumetric water content in foundation/wall cracks (cm^3-H_2O/cm^3-soil)
θ_T	total soil porosity (cm^3-voids/cm^3-soil)
L_{crack}	enclosed space foundation or wall thickness (cm)
L_{gw}	depth to groundwater from the enclosed space foundation (cm)
LB	enclosed space volume/infiltration area ratio (cm)
ER	enclosed space air exchange rate (s^{-1})
η	areal fraction of cracks in foundation/wall (cm^2-cracks/cm^2-area)

Soil and groundwater parameter Values Used for Iowa Tier 1 Table Generation

Parameter	Iowa RBCA
θ_{as}	0.2 cm^3-air/cm^3-soil
θ_{ws}	0.1 cm^3-H_2O/cm^3-soil
θ_{acrack}	0.2 cm^3-air/cm^3-soil
θ_{wcrack}	0.1 cm^3-H_2O/cm^3-soil
θ_T	0.3 cm^3-voids/cm^3-soil
L_{gw}	1 cm

Building Parameters Used in Iowa RBCA

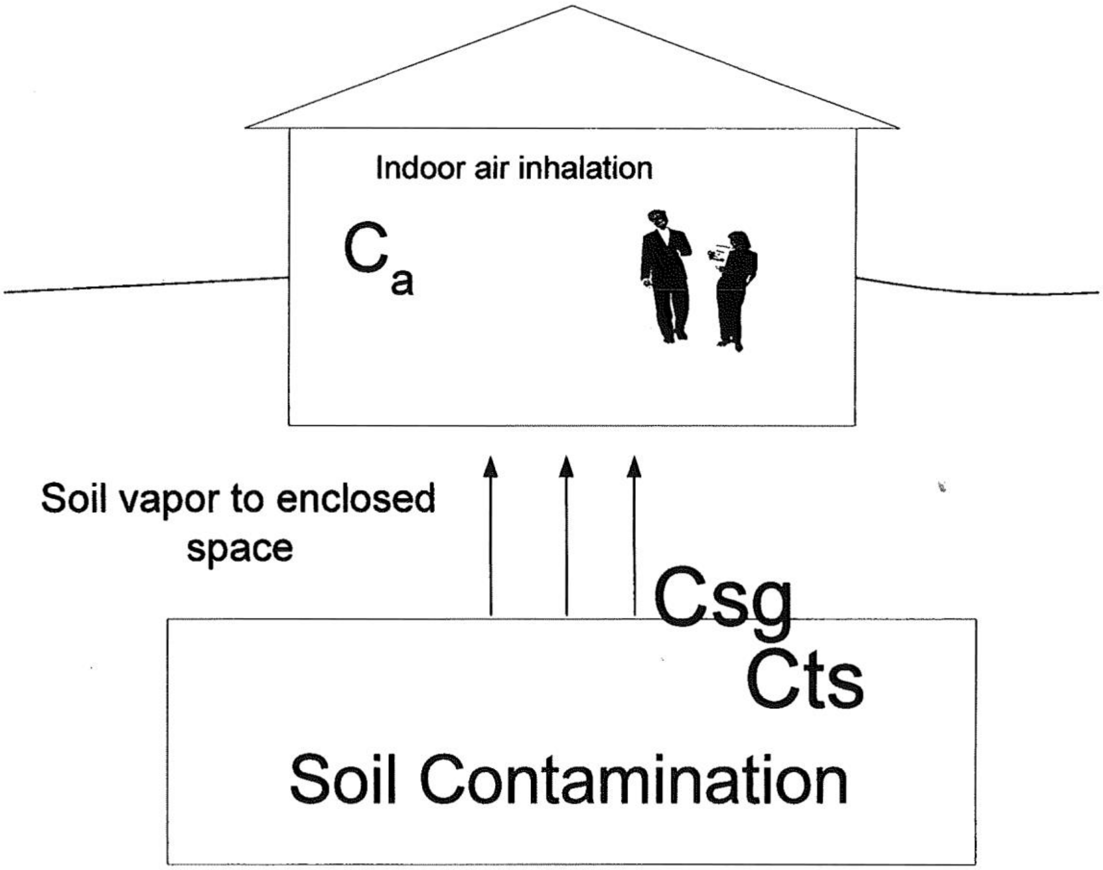
Parameter	Residential	Non-Residential
ER (s^{-1})	0.00014	0.00023
L_B (cm)	200	300
L_{crack} (cm)	15	15
η	0.01	0.01

Chemical Specific parameter values used for Iowa RBCA (Soil Vapor, GW Vapor and Soil Leaching

Chemical	D^{air} (cm^2/s)	D^{wat} (cm^2/s)	H (L-air/L-water)	K_{oc} (L/kg)
Benzene	0.093	1.1e^{-5}	0.22	38
Toluene	0.085	9.4e^{-6}	0.26	135
Ethylbenzene	0.076	8.5e^{-6}	0.32	96
Xylenes	0.072	8.5e^{-6}	0.29	240
Naphthalene	0.072	9.4e^{-6}	0.049	1,288
Benzo(a)pyrene	0.050	5.8e^{-6}	5.8e^{-8}	389,045

Indirect Exposure: Soil Vapor to Enclosed Space Pathway
Used at Tier 1 and Tier 2

Essentially the same model as for groundwater vapor to enclosed space.



C_a: Direct exposure concentration for indoor vapor inhalation
C_{sg}: Concentration in the soil gas (From C_a to C_{sg}, same model as GW vapor)
C_{ts}: total soil concentration (relate C_{sg} to C_{ts})
Model relates C_a to C_{ts}

Given a soil gas concentration (C_{sg}), find the total soil concentration (C_{ts}),

soil air (C_{sg})
soil water (C_{sw})
soil solids (C_{SS})

$$Henry's\ Law: C_{sg} = H \times C_{sw}$$

Linear Equilibrium Adsorption: $C_{ss} = K_s \times C_{sw}$
Total up the mass of chemical:
Convert to: mg/kg of soil. C_{ts}

Soil Vapor to Enclosed Space

At Tier 1: TAC decided to use the average of residential and non-residential building parameters.

Dilution from Soil Gas (Csg) to Enclosed Space (Ca)

Chemical	Average of Residential and Non-Residential Building; Parameters
Benzene	14,282
Toluene	15,627
Naphthalene	18,444

Residential Exposure Factors and Average of Residential and Non-Residential Building Parameters, TR=1x10^{-4}, HQ=1

Chemical	Indoor air (µg/m3)	Soil Gas (µg/m3)	Total Soil (mg/kg)
Benzene	39.2	559,854	1.16
Toluene	555	8,673,000	48
Naphthalene	19.5	359,658	95

Original Model used a depth to soil contamination of 100 cm, giving a soil gas for benzene of 600,000 µg/m^3

Effect of fraction organic carbon on Soil Vapor to Enclosed Space

Chemical	C_a (µg/m^3)	C_{sg} (µg/m^3)	F_{oc}	C_{ts} (mg/Kg)
Benzene	39.2	559,854	0.01	1.16
Benzene	39.2	559,854	0.001	0.29
Toluene	555	8,673,000	0.01	48
Toluene	555	8,673,000	0.001	7.22
Naphthalene	19.5	359,658	0.01	95
Naphthalene	19.5	359,658	0.001	9.9

Used for both Tier 1 and Tier 2 The Model:
$RBSL_{air}$ = C_a, Direct exposure concentration for indoor air inhalation
$RBSL_{sv}$ = C_{ts}, total soil concentration of chemical which will result in C_a.

Again: The model as presented has specific units.

$$RBSL_{sv}\left[\frac{mg}{kg-soil}\right]=\frac{RBSL_{air}\left[\frac{\mu g}{m^3-air}\right]}{VF_{sv}}\left(\frac{mg}{1{,}000\mu g}\right)$$

$$VF_{sv}\left[\frac{(mg/m^3-air)}{(mg/kg-soil)}\right]=\frac{\frac{H\rho_s}{(\theta_{ws}+k_s\rho_s+H\theta_{as})}\left[\frac{D_S^{eff}/L_s}{ERL_B}\right]}{1+\left[\frac{D_S^{eff}/L_s}{ERL_B}\right]+\left[\frac{D_S^{eff}/L_{gw}}{(D_{crack}^{eff}/L_{crack})\eta}\right]}\left(10\frac{cm^3-kg}{m^3-g}\right)$$

$$D_{crack}^{eff}\left[\frac{cm^2}{s}\right]=D^{air}\frac{\theta_{acrack}^{3.33}}{\theta_T^2}+D^{wat}\frac{1}{H}\frac{\theta_{wcrack}^{3.33}}{\theta_T^2}$$

$$D_{crack}^{eff}\left[\frac{cm^2}{s}\right]=D^{air}\frac{\theta_{as}^{3.33}}{\theta_T^2}+D^{wat}\frac{1}{H}\frac{\theta_{ws}^{3.33}}{\theta_T^2}$$

Variable Definitions:

$RBSL_{air}$	Risk-Based Screening Level for indoor air ($\mu g/m^3$-air)
$RBSL_{sv}$	Risk-Based Screening Level for vapor from soil to enclosed space air inhalation (mg/kg-soil)
VF_{sv}	volatilization factor for vapors from soil to enclosed space ((mg/m^3-air)/(mg/kg-soil))
D^{air}	chemical diffusion coefficient in air (cm^2/s)
D^{wat}	chemical diffusion coefficient in water (cm^2/s)
D_S^{eff}	effective diffusion coefficient in soil based on vapor-phase concentration (cm^2/s)
D_{crack}^{eff}	effective diffusion coefficient through foundation cracks (cm^2/s)
H	henry's law constant (L-H_2O)/(L-air)
ρ_s	soil bulk density (g/cm^3)
θ_{as}	volumetric air content in vadose zone (cm^3-air/cm^3-soil)
θ_{ws}	volumetric water content in vadose zone (cm^3-H_2O/cm^3-soil)
θ_{acrack}	volumetric air content in foundation/wall cracks (cm^3-air/cm^3-soil)
θ_{wcrack}	volumetric water content in foundation/wall cracks (cm^3-H_2O/cm^3-soil)
θ_T	total soil porosity (cm^3-voids/cm^3-soil)
k_s	soil-water sorption coefficient (L-H_2O/kg-soil), f_{oc} x k_{oc}
f_{oc}	Fraction organic carbon in the soil (kg-C/kg-soil)
k_{oc}	carbon-water sorption coefficient (L-H_2O/kg-C)
L_{crack}	enclosed space foundation or wall thickness (cm)
L_s	depth to subsurface soil sources from the enclosed space foundation (cm)
LB	enclosed space volume/infiltration area ratio (cm)
ER	enclosed space air exchange rate (s^{-1})
η	areal fraction of cracks in foundation/wall (cm^2-cracks/cm^2-area)

Soil and groundwater parameter Values Used for Iowa Tier 1 Table Generation

Parameter	Iowa RBCA
ρ_s	1.86 g/cm^3
θ_{as}	0.2 cm^3-air/cm^3-soil
θ_{ws}	0.1 cm^3-H_2O/cm^3-soil
θ_{acrack}	0.2 cm^3-air/cm^3-soil
θ_{wcrack}	0.1 cm^3-H_2O/cm^3-soil
θ_T	0.3 cm^3-voids/cm^3-soil
f_{oc}	0.01 kg-c/kg-soil
L_s	1 cm

Building Parameters Used in Iowa RBCA

Parameter	Residential	Non-Residential
ER (s^{-1})	0.00014	0.00023
L_B (cm)	200	300
L_{crack} (cm)	15	15
η	0.01	0.01

Tier 1 Summary

1. The Point of Exposure is the Source.
2. Objective of sampling is to identify the maximum soil and groundwater concentrations. Defining the plume is not required.
3. Divided into Pathways

Receptors: Risk Assessment has been applied for each receptor to determine the acceptable chemical concentrations at the point (route) of exposure (drinking the water or breathing the air).

For each Receptor:

Is the receptor present?
Are Tier 1 Levels exceeded for the receptor?
Corrective Action (Risk Management)
If the receptor is not present or Tier 1 levels are not exceeded, No further action is required.
If the receptor is present and Tier 1 levels are exceeded:

a) Eliminate the source (only allowed for soil at Tier 1)
b) Sever the pathway from the source to the receptor. Institutional controls only at Tier 1
c) Tier "Upgrade", do a Tier 2 assessment for the pathway.

Iowa RBCA Tier 2

A Tier 2 site assessment must be conducted and a Tier 2 Report submitted for all sites when any of the following conditions are present:

- Free phase petroleum product.
- The responsible party decides to bypass the Tier 1 assessment and go directly to the Tier 2 site assessment.
- Failure of a Tier 1 pathway.
- Bedrock is encountered above groundwater.
- Explosive vapor levels are documented.

Goal is the same for all Tiers: To not exceed the risk-based direct exposure concentrations at the receptor.

Tier 1: Point of Exposure is always the source. Default assumptions used for exposure factors and site specific parameters.

Tier 2: Initially the point of exposure is still the source.

However, at Tier 2, the site-specific target levels (SSTLs) between the source and receptor take into account:

institutional controls
location of actual and potential receptors; type of receptor, residential or non-residential
dilution and attenuation (modeling of horizontal contaminant transport in groundwater)
site specific data (groundwater flow direction, depth to groundwater, etc.)

At Tier 2 three principles are critical:

Receptors
Receptors
Receptors

Receptors: <u>You must evaluate every receptor for each chemical of concern.</u>

- Identify all possible receptors (actual and potential).
- Determine the direct exposure risk-based target levels for each receptor.
- Determine the site-specific target level concentrations and simulated concentrations between the source and the receptor.
- Compare measured concentrations to SSTL and simulated concentrations between the source and receptor.

- Determine whether each receptor is high risk, low risk or no further action.
- Implement appropriate corrective action for each high risk and low risk receptor. (institutional control, active remediation, monitoring)
- Monitor until corrective action goals are meet for each receptor; i.e. each receptor is no further action.

Pathways:
A convenient and logical way to group receptors.

Pathways at Tier 2:
Organized by receptor type:

<u>Pathways which using lateral groundwater transport modeling</u>
- Groundwater Ingestion
- Groundwater to Water Line
- Groundwater Vapor to Enclosed Space
- Surface Water Pathway

<u>Pathways which do not use lateral transport modeling</u>
- Soil Vapor to Enclosed Space
- Soil to Water Line

Actually, eight modeled pathways at Tier 2, but four pathways with regard to receptors:

Groundwater Source: Current groundwater contamination is the source. Modeled using measured groundwater concentrations.

Pathways
- Groundwater Ingestion
- Groundwater to Water Line
- Groundwater Vapor to Enclosed Space
- Surface Water

Soil Source: Current soil contamination is the source. Model from a soil source using measured soil contamination. Soil leaching to groundwater, followed by groundwater transport.

Pathways
- Groundwater Ingestion
- Groundwater to Water Line
- Groundwater Vapor to Enclosed Space
- Surface Water

Groundwater Source and Soil Source share common receptor types. Because the soil source and groundwater source locations and concentrations maybe different, the possible receptors may be different.

Receptor Types at Tier 2
For both Groundwater Source and Soil Source

<u>Groundwater Ingestion Pathway</u> (3 receptors types)
- Drinking Water Well (5 μg/L)
- Non-Drinking Water Well (290 μg/L)
- Protected Groundwater Source (290 μg/L)

Groundwater to Water Line Pathway (2 receptor types)

- Actual Water Line (290 µg/L)
- Potential Water Line (290 µg/L)

Groundwater Vapor to Enclosed Space Pathway (8 receptor types)
(Receptor and Site Specific, defaults target levels are shown).

- Actual Confined Space Residential (1540 µg/L)
- Potential Confined Space Residential (1540 µg/L)

- Actual Confined Space Non-residential (4780 µg/L)
- Potential Confined Space Non-residential (4780 µg/L)

- Actual Sanitary Sewer Residential (3080 µg/L)
- Potential Sanitary Sewer Residential (3080 µg/L)

- Actual Sanitary Sewer Non-residential (9550 µg/L)
- Potential Sanitary Sewer Non-residential (9550 µg/L)

Surface Water Pathway

Surface Water Criteria for Designated Use Streams (µg/l)

Designated Uses for Surface Water Classification	B* (CW1)	B* (CW2)	B* (WW-1)	B* (WW-2)	B* (WW-3)	B* (LW)	C** Drinking Water	State Owned Lakes
	Aquatic Life							
	Cold Water		Warm Water			Lakes & Wetlands		
Benzene	290	290	290	290	290	290	5	2
Ethylbenzene	3,700	3,700	3,700	3,700	3,700	3,700	700	2
Toluene	1,000	1,000	1,000	1,000	1,000	1,000	1,000	2
Xylenes	73,000	73,000	73,000	73,000	73,000	73,000	10,000	5
TEH-Diesel	75,000	75,000	75,000	75,000	75,000	75,000	1,200	500
TEH-Waste Oil	40,000	40,000	40,000	40,000	40,000	40,000	400	400

*Use Tier 1 levels for Surface Water
**Use Tier 1 levels for Groundwater Ingestion Actual

Acutely Toxic Levels* for General Water Quality (µg/l)

Species:	Fathead Minnows	Bluegill
Apply Level to:	All Surface Water	Ponds & Lakes
Benzene:	16,500	11,000
Ethylbenzene:	22,650	16,000
Toluene:	19,050	8,750
Xylenes:	---	---
TEH-Diesel**	1,650,000	50,000,000
TEH-Waste Oil**	NA	5,000,000
Naphthalene	3,300	---
Benz(a)anthracene	---	500

*DNR Water Quality staff use half the LC50 values for the standard for acutely toxic levels. These standards are shown in the table above.

---No LC_{50} data available. Also, not available for Benzo(a)pyrene, or Chrysene

**TEH values are based on the values for naphthalene and benz(a)anthracene as shown in the table. They were calculated using the default percentages listed in Appendix B of IAC 567-135.

Pathways without lateral transport modeling:

Soil Vapor to Enclosed Space Pathway (8 receptor types)
(Receptor and Site Specific, defaults target levels are shown for Benzene).

- Actual Confined Space Residential (1.16 mg/kg)
- Potential Confined Space Residential (1.16 mg/kg)

- Actual Confined Space Non-residential (2.19 mg/kg)
- Potential Confined Space Non-residential (2.19 mg/kg)

- Actual Sanitary Sewer Residential (2.32 mg/kg)
- Potential Sanitary Sewer Residential (2.32 mg/kg)

- Actual Sanitary Sewer Non-residential (4.38 mg/kg)
- Potential Sanitary Sewer Non-residential (4.38 mg/kg)

Soil to Water Line (2 receptor types)

- Actual Water Lines (2 mg/kg)
- Potential Water Lines (2 mg/kg)

Groundwater Modeling at Tier 2: In Iowa the Tier 2 application or bedrock software must be used for modeling.

Parameters Needed for Groundwater Modeling
Transport

- Hydraulic Conductivity
- Head gradient (magnitude)
- Main Plume/Groundwater Migration Direction
- Range in Plume/Groundwater Migration Direction

Source

- Source Width (from measured data), single value for all chemicals
- Source Location (X,Y), Chemical Specific
- Source Concentration, Chemical Specific

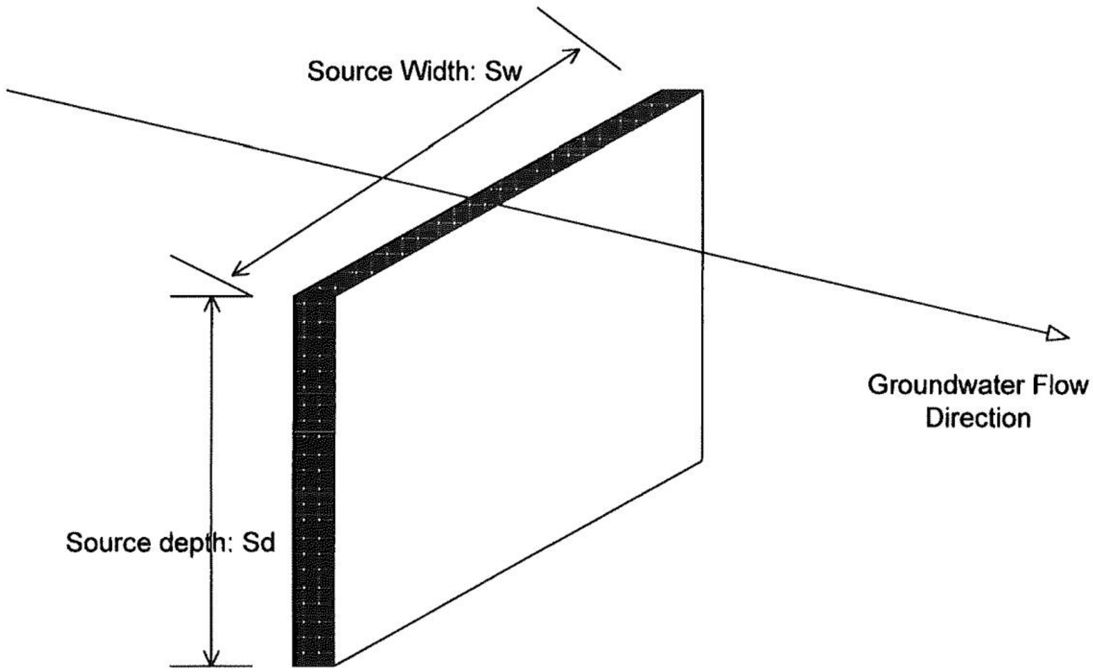
Receptors:

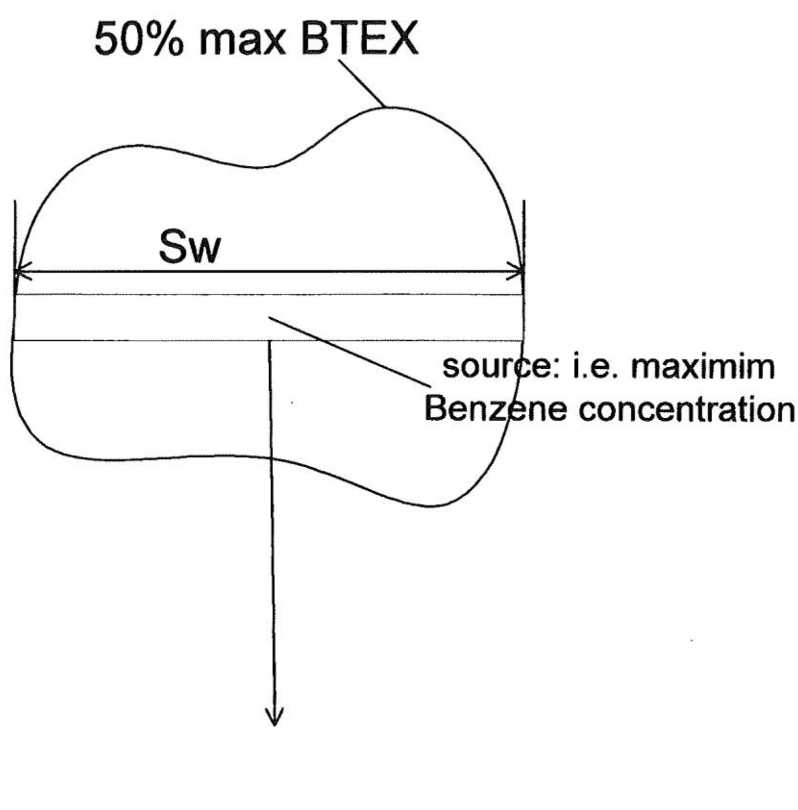
- Receptor Location (X,Y)
- Receptor Type

Monitoring Well

- Well Location (X,Y)
- Measured Concentrations

Defining the Source Width for Groundwater Modeling: Ideally, perpendicular to the groundwater flow direction.



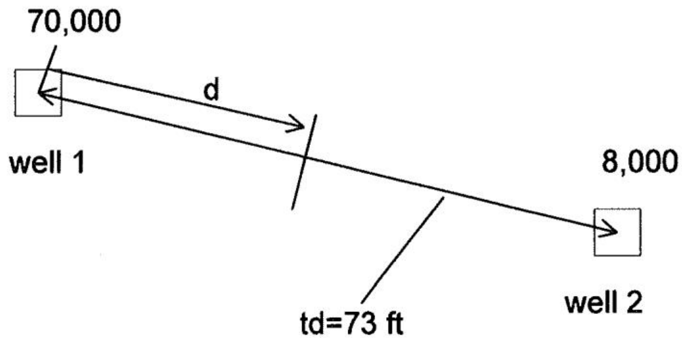


Defining the Source Width: Groundwater Source

Should represent the area continuing to supply contamination long-term.

1. Sum BTEX in each monitoring well. Find the maximum sum of BTEX. Contour the 50% of the maximum contour. i.e. ΣBTEX maximum = 70,000 µg/L

Using ΣBTEX for each well, contour the 35,000 µg/L level, using linear interpolation between wells.



Distance to the target level (TL) along the line from well 1 to well 2 (measured from well 1).

$$C(d) = \frac{C_{w2} - C_{w1}}{td} d + C_{w1}$$

Set C(d)=TL, solve for d

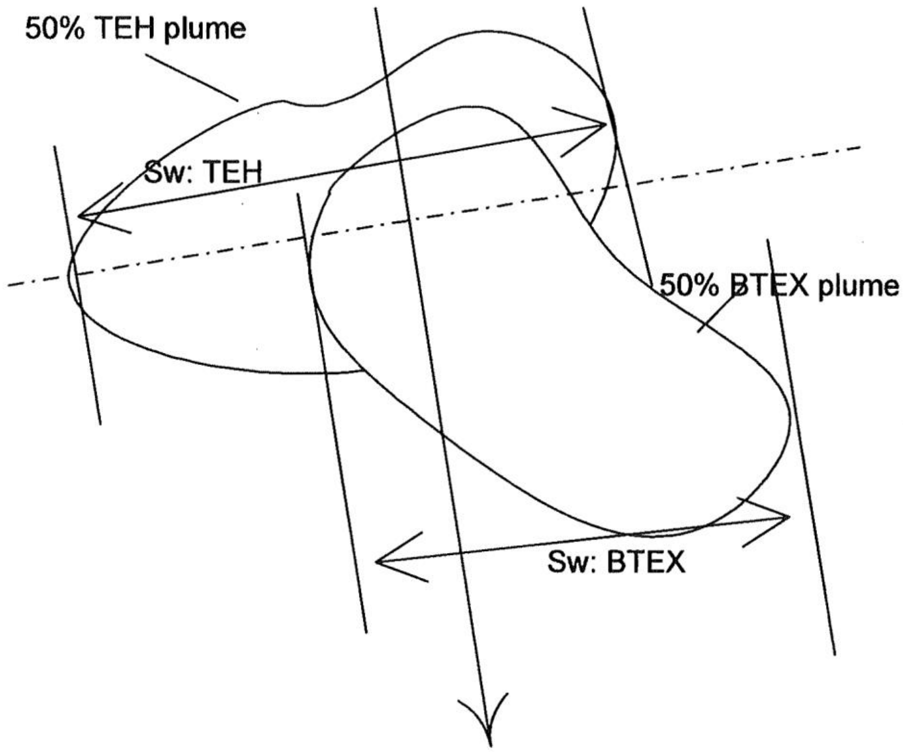
$$d = \frac{(TL - C_{w1})td}{(C_{w2} - C_{w1})}$$

C_{w1}: Concentration at well 1
C_{w2}: Concentration at well 2
td: distance from well 1 to well 2

for the example; d = 41.2 ft

2. Use the same procedure using TEH

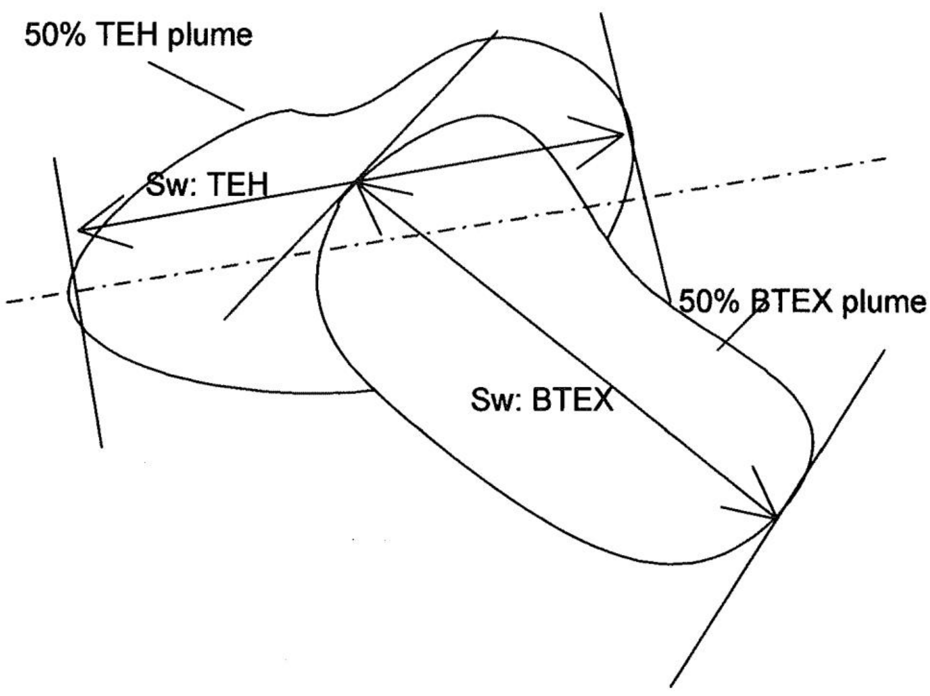
Source Width: Estimate the widths of the ΣBTEX and TEH 50% contours perpendicular to the estimated groundwater flow direction. Use the larger of the two for source width, Sw.



Groundwater Source Width: Special Cases:

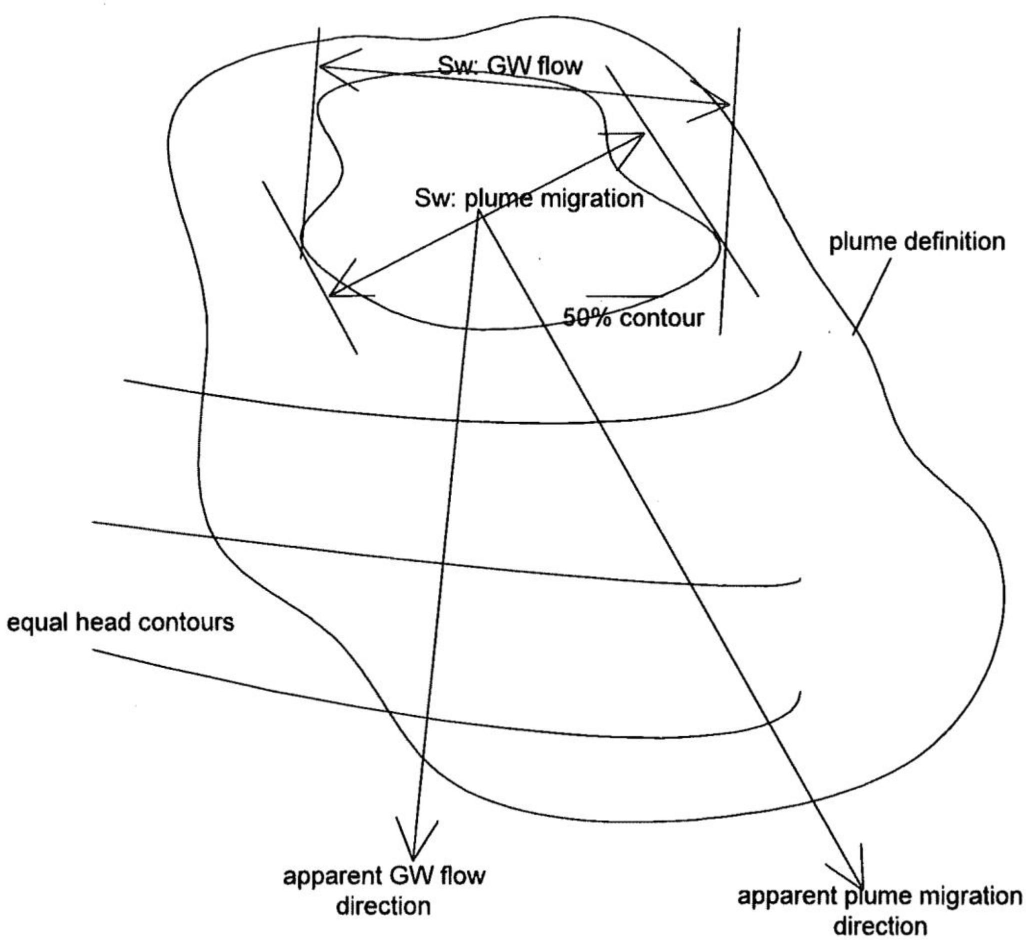
1. groundwater gradient is less than 0.005, contaminant plume shows no definitive direction or shows directional reversals.

Use the largest dimension of the 50% BTEX or 50% TEH plume.



Groundwater Source Width:

Special Cases:
2. If the direction of plume migration is significantly different from the calculated groundwater flow direction, use Sw measured perpendicular to plume movement.



Groundwater Source Width:

Special Cases:
3. Free Product

Take water samples for BTEX and TEH from beneath the free product, and follow the usual procedure using BTEX and TEH

For sites with groundwater data from wells with free product:

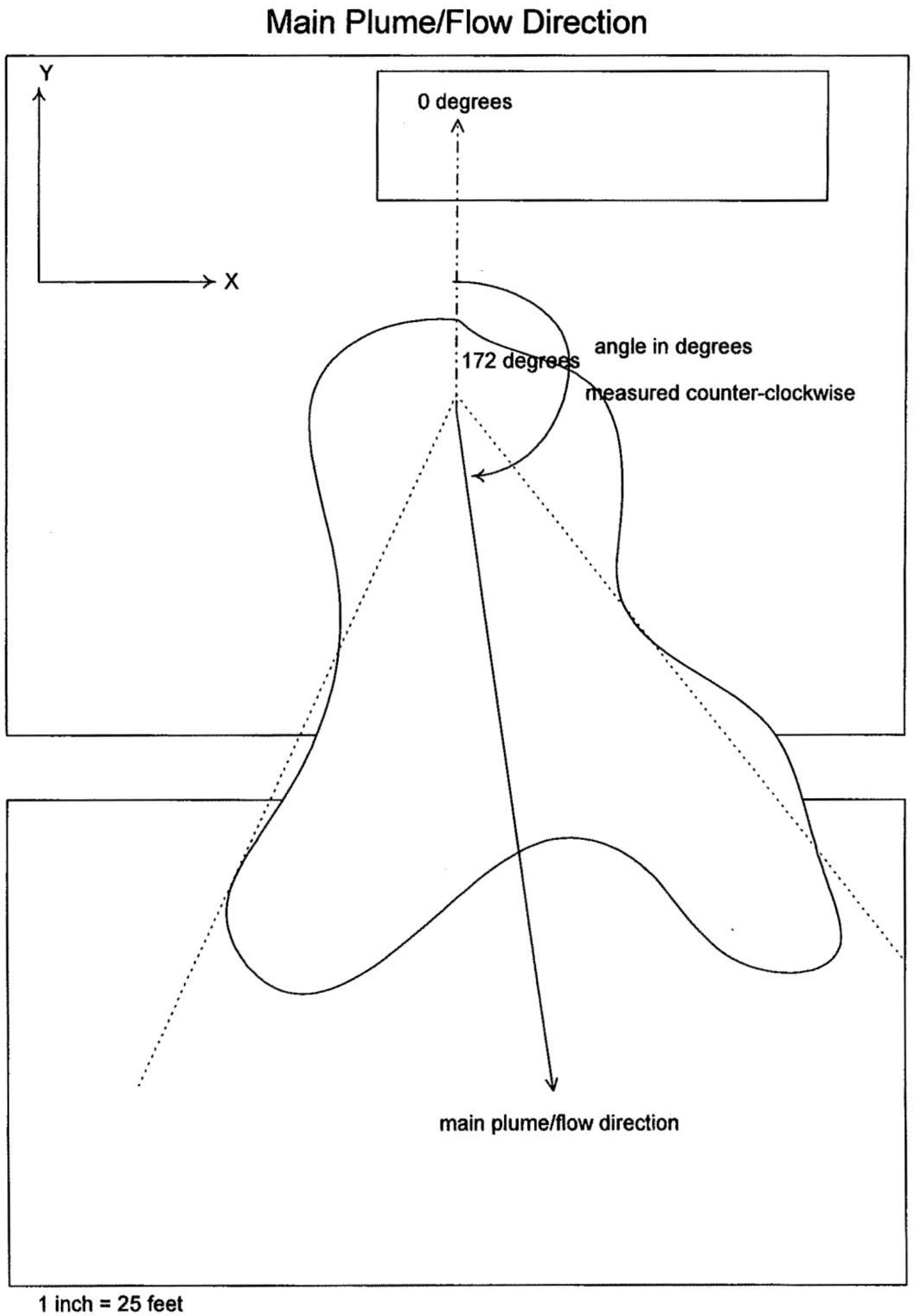
Assume the free product is present ½ the distance between a well with free product and a well without free product. Use the estimated free product contour to estimate Sw.

Groundwater Modeling at Tier 2
Main Plume/Groundwater Flow Direction
Range of Plume/Flow

Main Plume/Groundwater Flow Direction

Estimate the main direction of the expected migration direction of the plume.
This is a judgment call.

Use all available data, including previous plume migration and head contours.
Use measured concentrations when the plume has already migrated some distance.
The direction should be in the middle of the plume.



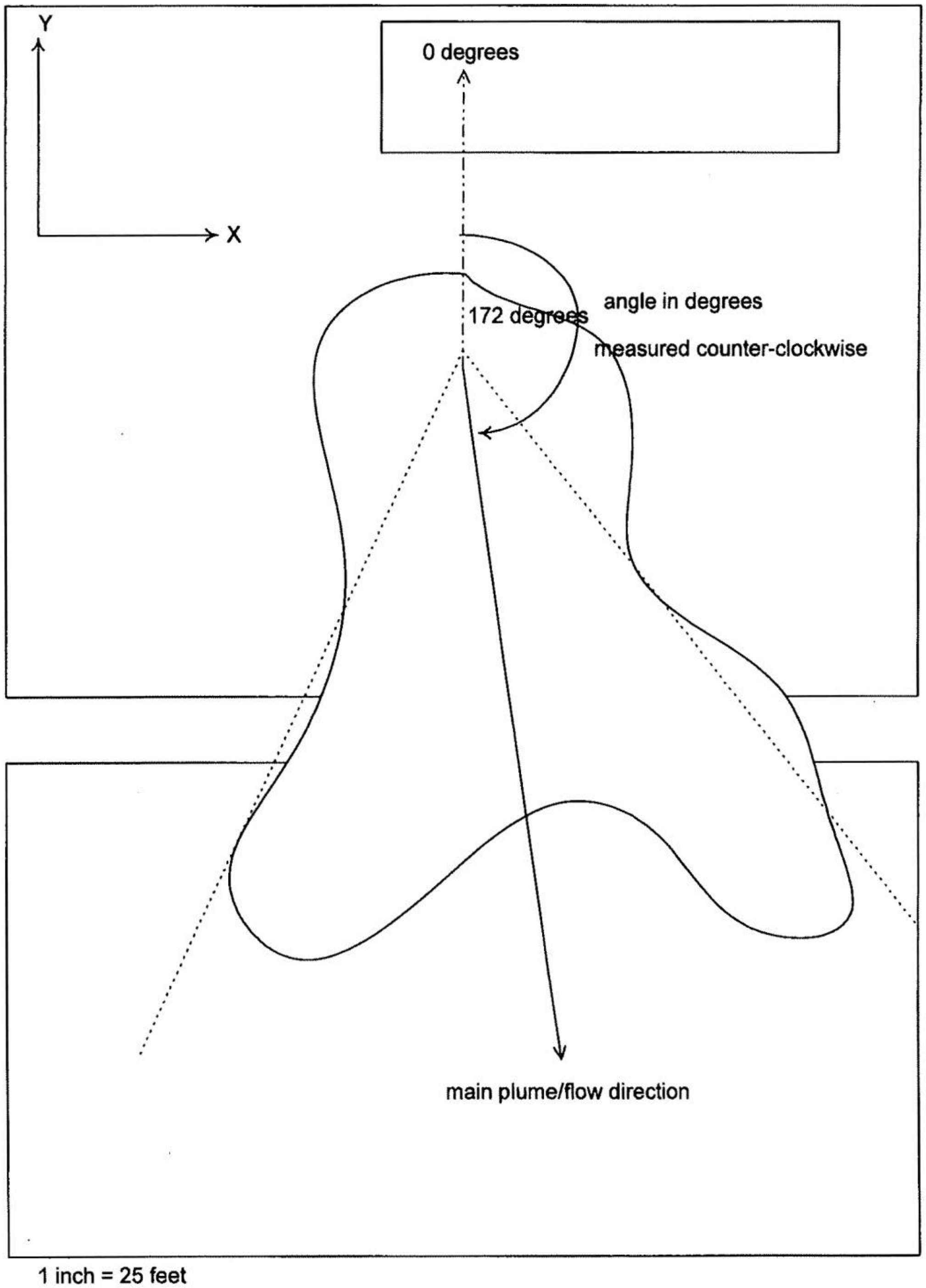
Range of Plume Migration Direction

Used to account for the spread in plume migration, or plumes with multiple lobes or flow directions. If the flow direction is uncertain, the range can be used to help account for future uncertainty.

Range of 100% concentrations:

On each side of the main plume flow direction:
range (in degrees)
plus 30 degrees (default, 30 degrees is always added).

Main Plume/Flow Direction, Range, 30 degree rule



Plume Migration Direction:
Main Plume/Flow Direction: From the source, using measured concentrations and heads, estimate the main direction of the previous or expected further migration of the contamination. This direction should be down the centerline of the plume.

The main plume/flow direction is measured in degrees, counter-clockwise with vertical upward being O degrees.

Concentrations are calculated using Domenico solution for directly downgradient.

Range of Plume/Flow: The range of plume/flow is to account for spread of the plume lateral to the main downgradient direction of migration. The range is measured in degrees relative to the Main Plume/Flow Direction. For example, if the Range of Plume/Flow is 10 degrees, the concentrations are assumed to be 100% of the downgradient concentration for 10 degrees to each side of the Main Plume/Flow Direction.

30 Degree Rule: 30 degrees is added the Range of Plume/Flow on each side of the Main Plume/Flow Direction. For example:

If the Range of Plume/Flow is 10 degrees, it is assumed 100 percent of the downgradient concentrations are present 40 degrees of each side of the Main Plume/Flow Direction.

If the Range of Plume/Flow is 0 degrees, it is assumed that 100 percent of the downgradient concentrations are present 30 degrees of each side of the Main Plume Flow Direction.

If short, the 100 percent concentration range is Range of Plume/Flow + 30 degrees; on each side of the Main Plume/Flow Direction.

The Ground Water Transport Model
The groundwater transport model predicts the concentrations directly downgradient from the source. That is the line of maximum concentration as you move away from the source.

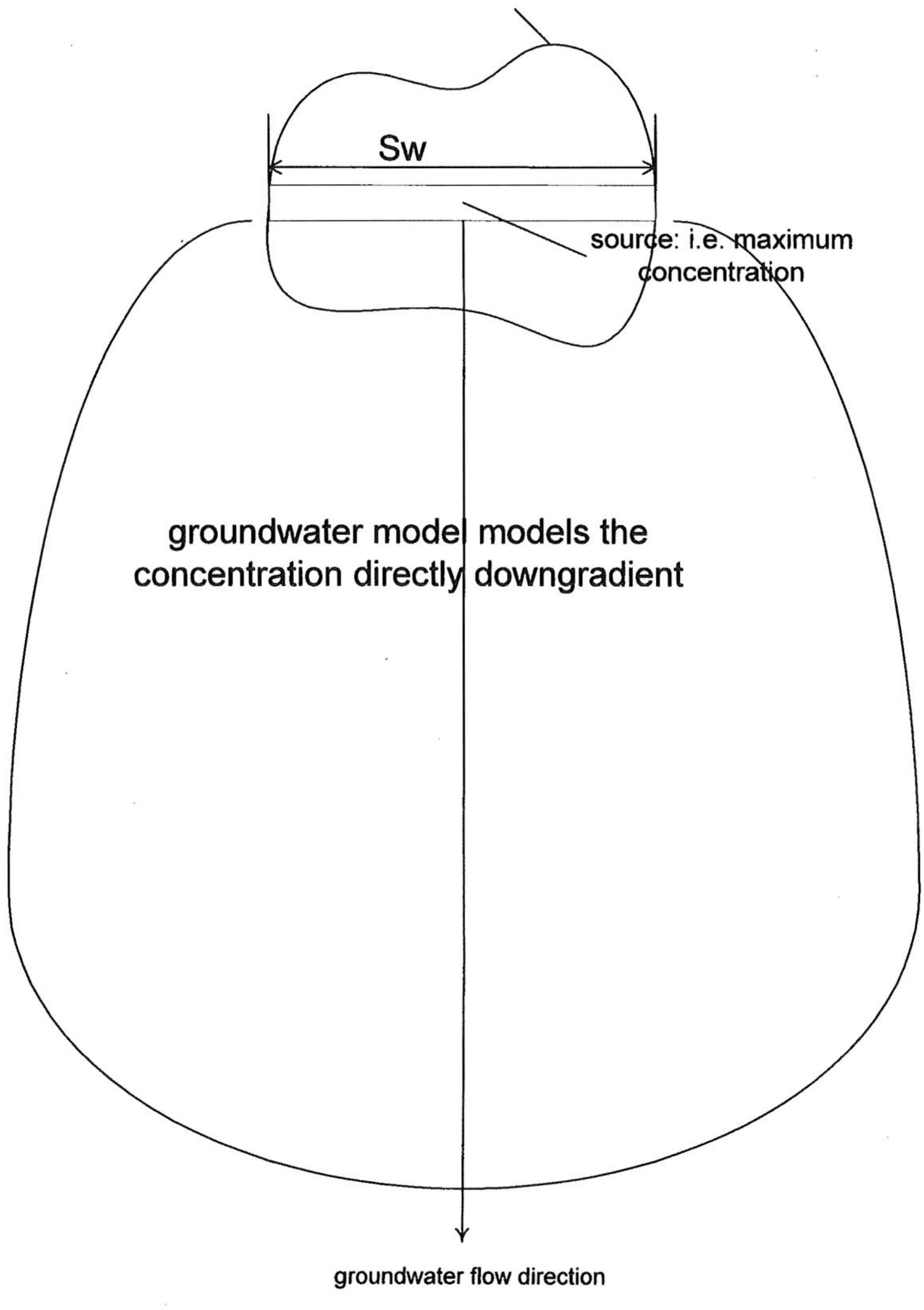
$$C(x) = C_s \exp\left(\frac{x}{2\alpha_x}\left[1 - \sqrt{1 + \frac{4\lambda\alpha_x}{u}}\right]\right) \operatorname{erf}\left(\frac{S_w}{4\sqrt{\alpha_y x}}\right) \operatorname{erf}\left(\frac{S_d}{4\sqrt{\alpha_z x}}\right)$$

Predicts concentration directly downgradient,

x: distance downgradient
C(x): concentration at x
Cs: Source concentration
Sw: width of source
Sd: vertical thickness of source
u: average groundwater pore water velocity,
λ: first order decay coefficient
α_x, α_y, α_z: dispersivities

To use the model, need to know or estimate then:
x: distance downgradient to point of exposure/point of compliance.
C(x): target concentration at the point of exposure/point of compliance.
Cs: Source concentration
Sw: width of source

Sd: vertical thickness of source
u: groundwater pore water velocity, u=Ki/ne; ne is effective porosity
λ: first order decay coefficient
α_x, α_y, α_z: dispersivities



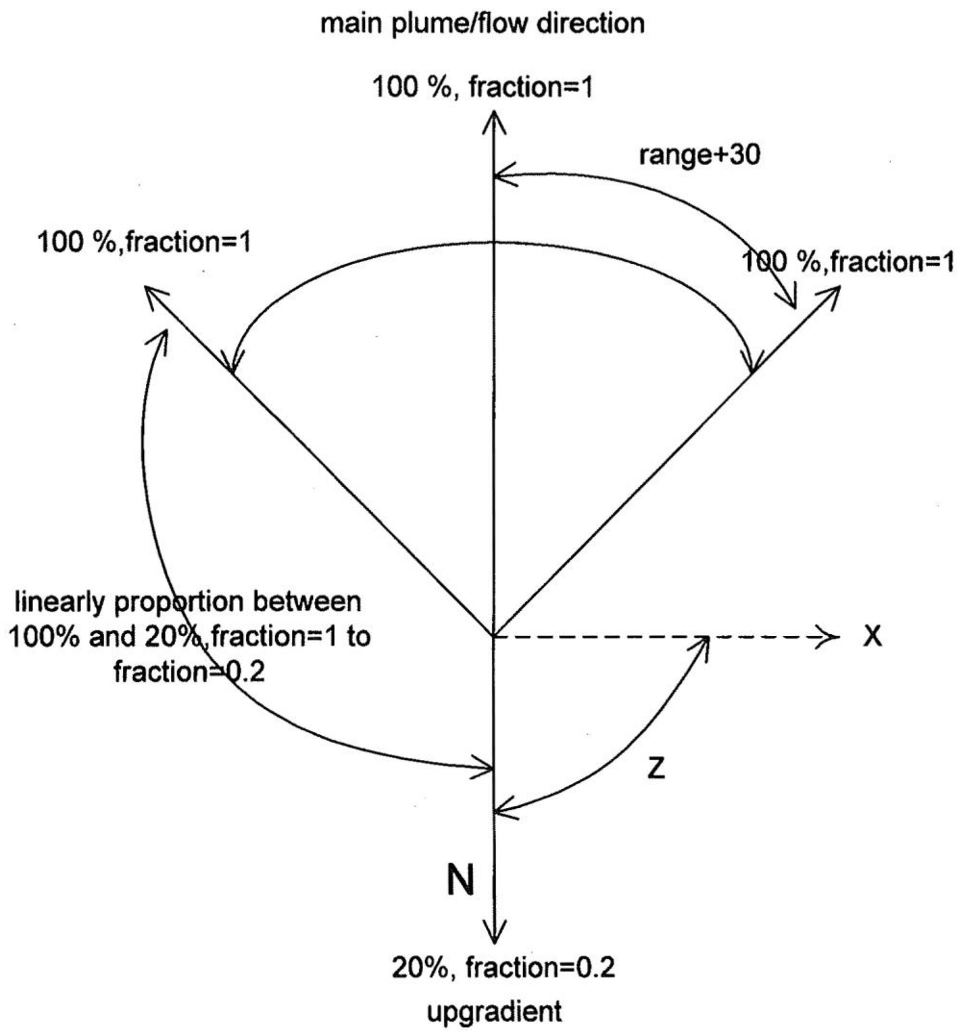
Example: Assume we are modeling directly downgradient.

K = 0.1 m/day, i(m/m) = 0.01, Sw = 45 m

Source Concentration: 10,000 µg/L Benzene

Receptor Target Level (i.e. Non-drinking water well); 290 µg/L at 100 ft.

Off-Gradient Modeling: How directions at less than 100% are handled.
Finding the percent (fraction of downgradient)



Point X, at angle Z from upgradient;

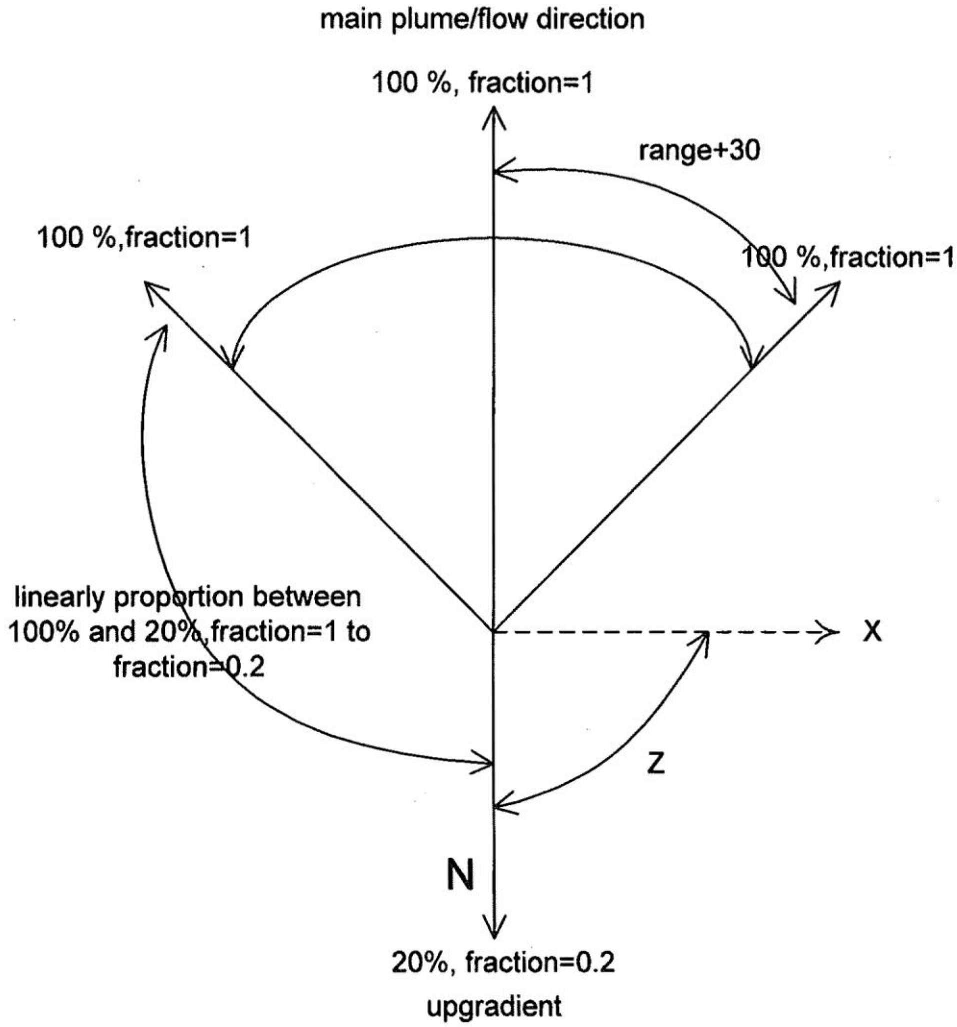
$$fraction(Z) = 0.2 + \left(\frac{0.8}{180 - range - 30}\right) Z$$

Z ≥ (180- range- 30), fraction(Z) = 1

Pick a point: Modeling results depend on:

1. fraction of downgradient
2. Distance from source

Consider a point N, which is directly upgradient at a distance from the source of 20 feet, fraction=0.2.



Case: Simulated concentration at N

First compute adjusted distance for N:

$$Adjusted\ Distance\ (N) = \frac{Actual\ Distance\ (N)}{fraction\ (N)}$$

$$Adjusted\ Distance\ (N) = \frac{20}{0.2} = 100ft$$

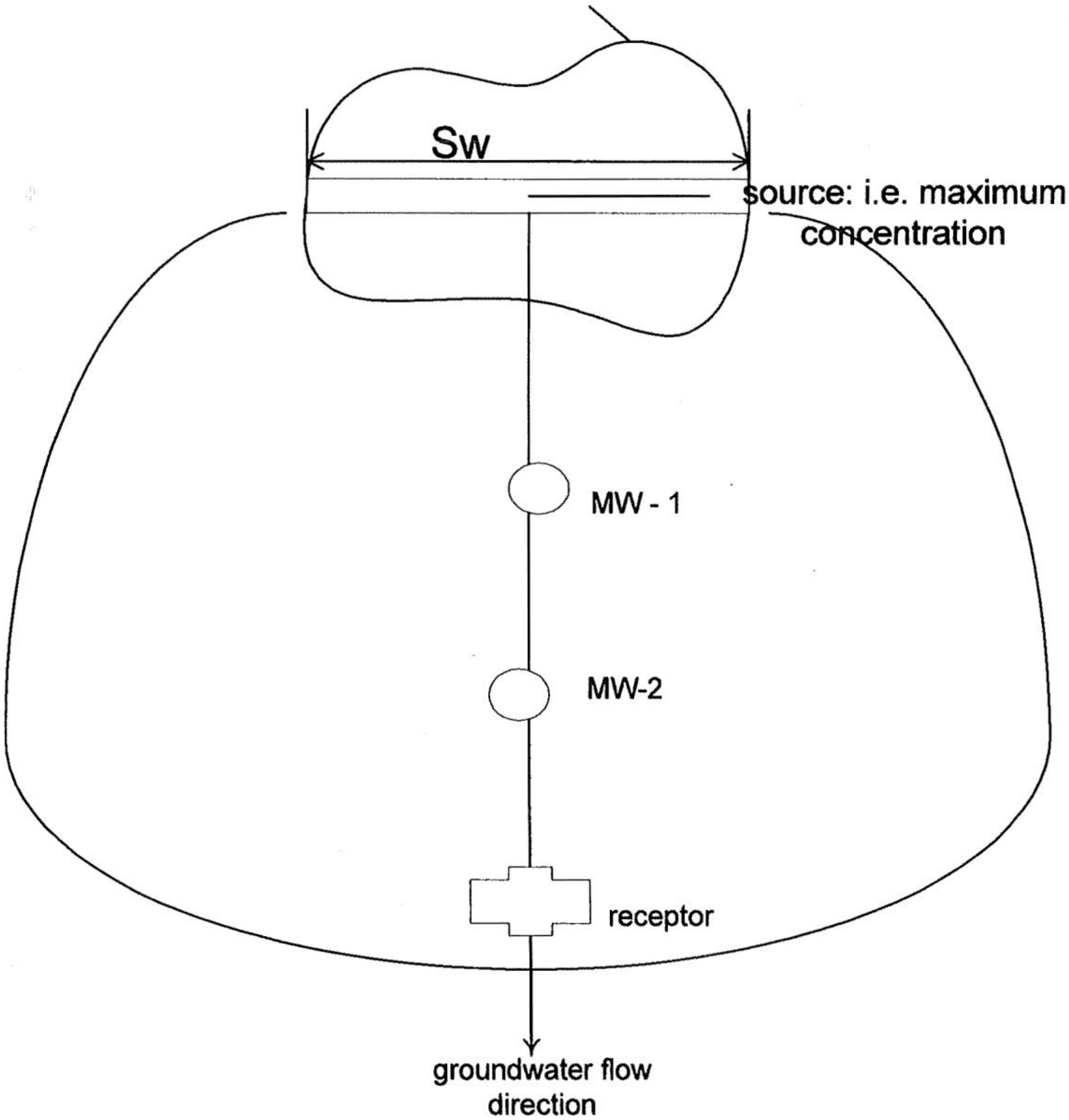
Simulated concentration at 20 feet upgradient is same as simulated concentration 100 feet downgradient. For example, if simulated benzene concentration is 290 µg/L at 100 feet downgradient, simulated benzene concentration is 290 µg/L at 20 feet upgradient. Plume does not travel as far upgradient.

When plotting Simulation Line and SSTL, concentrations are computed based on adjusted distance, but plotted against actual distance.

Groundwater Source and Modeling
Examples of High Risk, Low Risk and No Further Action

Must plot Simulation Line, SSTL Line and Measured Concentrations between the source and the receptor.

Example below: Assume ideal situation, monitoring wells on-line between source and receptor.



High Risk:
An actual receptor is high risk if any actual field data exceeds the site specific target level line at any point for the actual receptor.

Low Risk:
A potential receptor is low risk if any actual field data exceeds the site-specific target level line at any point.

A potential receptor is low risk if the modeled data and actual field data are less than the site-specific target level line, and any of the field data is greater than the simulation line.

An actual receptor is low risk if the modeled data and actual field data are less than the site-specific target level line, and any of the field data is greater than the simulation line.

No Action Required:
Initial Classification: A receptor shall be classified as no action required of the field data is below the site-specific target level line and all field data is at or less than the simulation line, and confirmation monitoring has been completed successfully.

Reclassification from high or low risk: a receptor shall be classified as no action required if all field data is below the site-specific target level line and if exit monitoring criteria has been met.

Note: In all cases, to clear a receptor measured concentrations must be less than the site specific target level line between the source and receptor.

Examples:

For the following, determine whether the receptor is high risk, low risk, or NFA if it is:
A. An actual receptor
B. A potential receptor

Example: Groundwater Ingestion Pathway at Tier 2

Assume: There are no water supply wells with 1,000 feet.
The first encountered groundwater is a protected groundwater source.

Single Receptor Type: Protected Groundwater Source (potential receptor).
Chemical of Concern: Benzene
Target level for benzene in groundwater: 290 µg/L

Procedures:
1. Define the groundwater plume to 290 µg/L benzene.
2. Determine site-specific parameters from measured data (used for modeling):
   Hydraulic conductivity
   Head gradient and plume migration direction Source Width
   Source concentration and location for Benzene (maximum concentration)
3. Identify **possible** receptor locations.
   Based on where modeled or measured concentrations exceed the target level (290µg/L Benzene).
   Will usually include the source.
   Graphical: Overlay modeled concentrations over site map with measured concentrations.
   Locate area where target level is exceeded.

Site-Specific Target Levels (SSTL):
The SSTL line is the simulated concentrations between the source and the receptor, using a source concentration (SSTL source concentration) such that the target level is met at the point of exposure.

Corrective Action Criteria: To achieve no further action for the receptor, the measured concentrations (including the source concentration) must be below the SSTL line between the source and the receptor.

Determine whether receptor is:
- High Risk: Generally actual receptors are high risk; monitoring only is not an acceptable corrective action.
- Low Risk: Generally potential receptors are low risk; monitoring only is an acceptable corrective action. For our example, monitoring would be required until concentrations meet the SSTL concentrations
- No further action: When measured concentrations are below SSTL concentrations.

Generally; Three Options

1. Reduce concentrations below SSTL concentrations (Active remediation for an actual receptor, active remediation or monitoring for a potential receptor).
2. Sever the pathway to the receptor

   For a Protected Groundwater Source, use an institutional control to prohibit groundwater use where the modeled or measured concentrations exceed the Target Level (290 µg/L Benzene).

   For a drinking or non-drinking water well, plug the well.

   Technological control.
3. "Tier Upgrade". Tier 3 Assessment. Requires a work-plan be submitted and approved by DNR.

Tier 2 Example: Groundwater Vapor to Enclosed Space.

At Tier 2, both residential and non-residential receptors are included. Both potential and actual receptors are included.

Also, some site specific information can be used to determine site specific target levels at the point of exposure.

Consider:

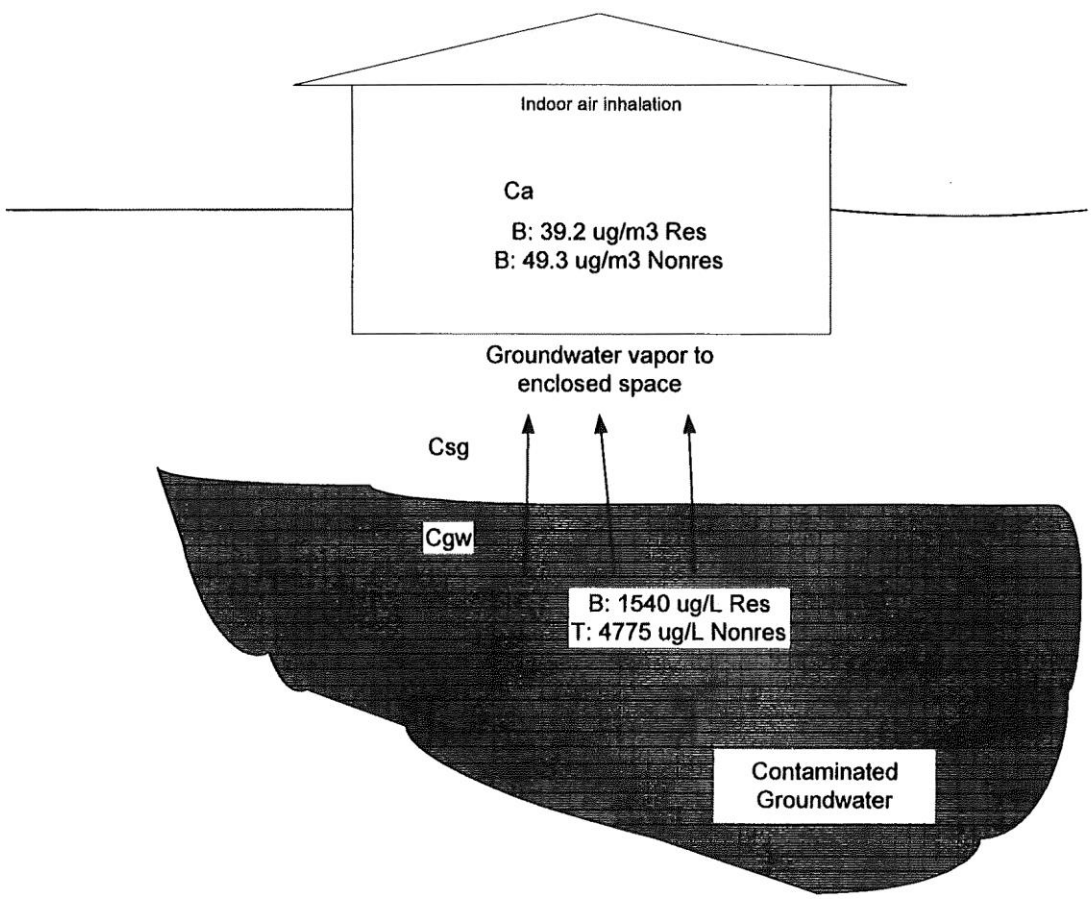
Depth to Groundwater: 20 feet

Depth to foundation: 9.84 feet

Possible Receptors:

Residential and Non-residential

Calculate site specific target levels for groundwater beneath the foundation.



Using the site specific depth to groundwater:
B: 1858 µg/L Res
B: 5757 µg/L Res

Simulate plume to 5757 µg/L and 1858 µg/L
Determine possible non-residential receptor locations
Determine possible residential receptor locations
Determine SSTLs for possible receptors.

For LUST Site:
  Assumed Non-residential
  Nonresidential receptors are: actual or potential? High risk, low risk, NFA?

Options are:
  Soil Gas
  Active Remediation
  Institutional control
  Monitoring

For Down gradient:
  Assumed residential
  Residential receptors are: actual or potential?

For the Actual Receptor
  High risk, low risk, NFA?

Options are:
  Indoor Air Sampling
  Soil Gas Sampling
  Active Remediation
  Institutional control
  Monitoring

For the Potential Receptor
  Low risk or NFA?

Options are:
  Soil Gas Sampling
  Active Remediation
  Institutional Control
  Monitoring

Four Pathways are Modeled at Tier 2

Groundwater Ingestion
Groundwater Vapor
Groundwater to Water Line
Groundwater to Surface Water

There are two sources:
  Groundwater Contamination
  Soil Contamination (Soil Leaching)

Soil Leaching: Based on soil contamination
Soil SSTL
Not compared to monitoring wells

Summary: Tier 2
Based on Receptors: There are target levels at the point of exposure based on direct exposure Risk (and sometimes modeling).

Identify possible receptors: Based on modeled and measured data

Determine SSTLs for each possible receptor.

Corrective Action Response:

Actual Receptors: Generally monitoring only is not an option.
Potential Receptors: monitoring is an option.

Corrective Action Goals:
Meet the SSTL line between the source and receptor; i.e. meet the target risk at the receptor.

Possible Corrective Actions:

Eliminate the Source
Active or Passive Remediation

Sever the Pathway to the Receptor
Eliminate the receptor itself
Institutional Control
Technological Control

Tier 3

Groundwater Modeling at Tier 2

Source(s): Location and Concentrations
Source Width: How to define
Plume Migration Direction

Soil Vapor to Enclosed Space
Soil to Water Line

Risk Classification: High, Low, NFA

Monitoring Requirements
Selecting Wells to Monitor
Interim
Remediation
Exit

Corrective Action

Pathways Which Use Modeling
Groundwater Ingestion

Groundwater Vapor to Enclosed Space
Groundwater to Water Line
Groundwater to Surface Water

Soil Leaching:

Pathway: Groundwater Ingestion
Source: Groundwater Contamination
Migration: Transport in Groundwater from source to the receptor
Receptor Types:
Drinking Water Well
Non-drinking Water Well
Protected Groundwater Source

Target Levels at Tier 2

For information completing a Tier 2 assessment, Tier 2 Site Cleanup Report, post Tier 2 Site Monitoring Reports please see the following:

- Tier 2 Site Cleanup Report Guidance March 2022
- RBCA online application user's manual coming soon. Note for site which are not granular or nongranular bedrock sites. For now please see the Tier 2 – SMR Software, Version 2.51 Manual
- Site Monitoring Report Guidance revision coming soon
- Tier 2 bedrock software version 1.2
- Corrective Action Design Report Guidance Guidance