"Capacity Building and Strengthening Institutional Arrangement"

Workshop: "Hazardous Substances and Wastes"

Human Health Risk Assessment of Contaminated Sites Principles and Methodologies

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APAT

Agency for Environmental Protection and Technical Services

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1. Risk assessment

What is risk?

Webster's New World Dictionary of the American Language (1979, Simon & Schuster, New York, NY) defines risk as the chance of injury, damage, or loss. Therefore, to put oneself "at risk" means to participate either voluntarily or involuntarily in activities that could lead to injury, damage, or loss.

- Voluntary risks
  - Voluntary risks are those associated with activities that we decide to undertake (e.g., driving a car, riding a motorcycle, smoking cigarettes).
- Involuntary risks
  - Involuntary risks are those associated with activities that happen to us without our prior consent or knowledge. Acts of nature such as being struck by lightning, fires, floods, etc., and exposure to environmental contaminants are examples of involuntary risks.

1. Risk assessment

Quantitative Risk Assessment **Risk numbers**

Risk [1)]	Risk of Death / Person / Year
Influenza	1 in 5,000
Leukemia	1 in 12,500
Struck by Automobile	1 in 20,000
Floods	1 in 455,000
Tornadoes (Midwest)	1 in 455,000
Earthquakes (California)	1 in 588,000
Nuclear Power Plant	1 in 10 million
Meteorite	1 in 100 billion

[1)] United States

Risk of a particular activity may be expressed as chance/probability of adverse effects per person per year (or lifetime). Risk is expressed as a fraction, without units, from 0 - 1.0, where at 1.0 there is absolute certainty that an adverse effect will occur. Scientific notation is generally used to present quantitative risk information.

1. Risk assessment

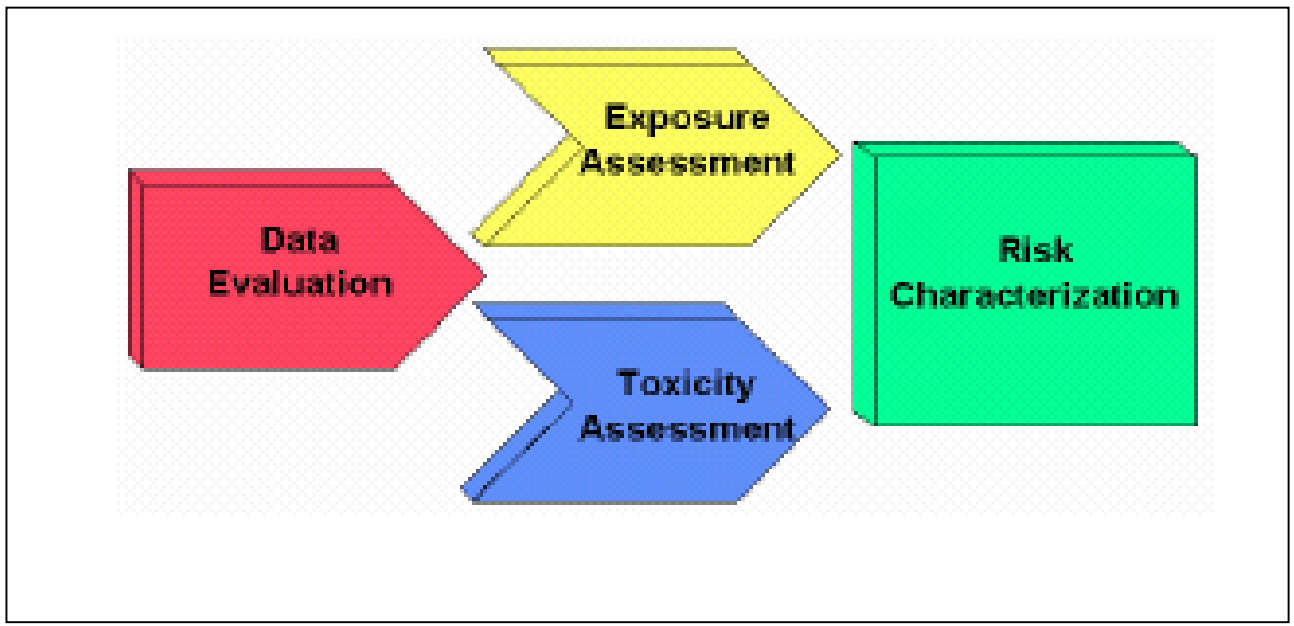
Risk assessment of contaminated sites

- Hazardous substances are (already) present at contaminated sites;
- Chance of exposure (y/n) to these substances is evaluated across the S-P-R pollutant linkage;
- When exposure is envisaged, then toxicological effects are evaluated;
- For cancerogenic substances toxicological effects are evaluated in a probabilistic way.

1. Risk assessment

NAS paradigm (1983)

- Risk assessment is performed in 4 distinct steps:



$$R = E \times T$$

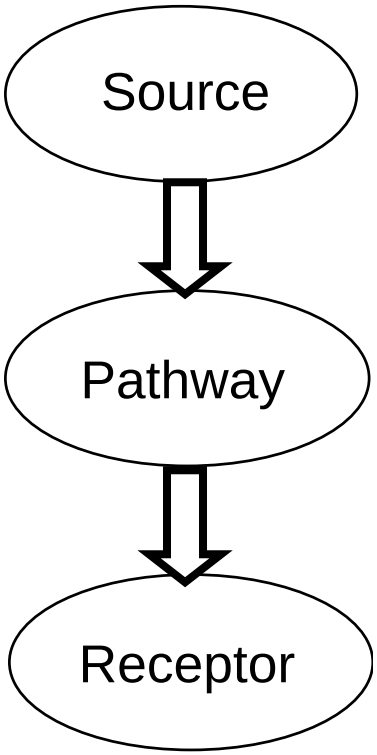
1. Risk assessment

Assessment procedure

- Step 1: Data compilation/evaluation and hazard assessment
  - Verify the location and extent of sources of chemicals of potential concern and verify that the data are appropriate and representative.
- Step 2: Exposure assessment
  - Estimate the type and magnitude of receptor's exposures to chemicals of potential concern that are present at or migrating from the source.
- Step 3: Toxicity assessment
  - Weigh available evidence regarding the potential for a chemical of concern to cause effects in exposed receptors.
- Step 4: Risk characterization and assessment
  - Quantify risks, combine risks across all pathways, present baseline risk assessment characterization results.

2. Conceptual Site Model

Source-Pathway-Receptor



a substance which has the potential to cause harm to human health or the environment

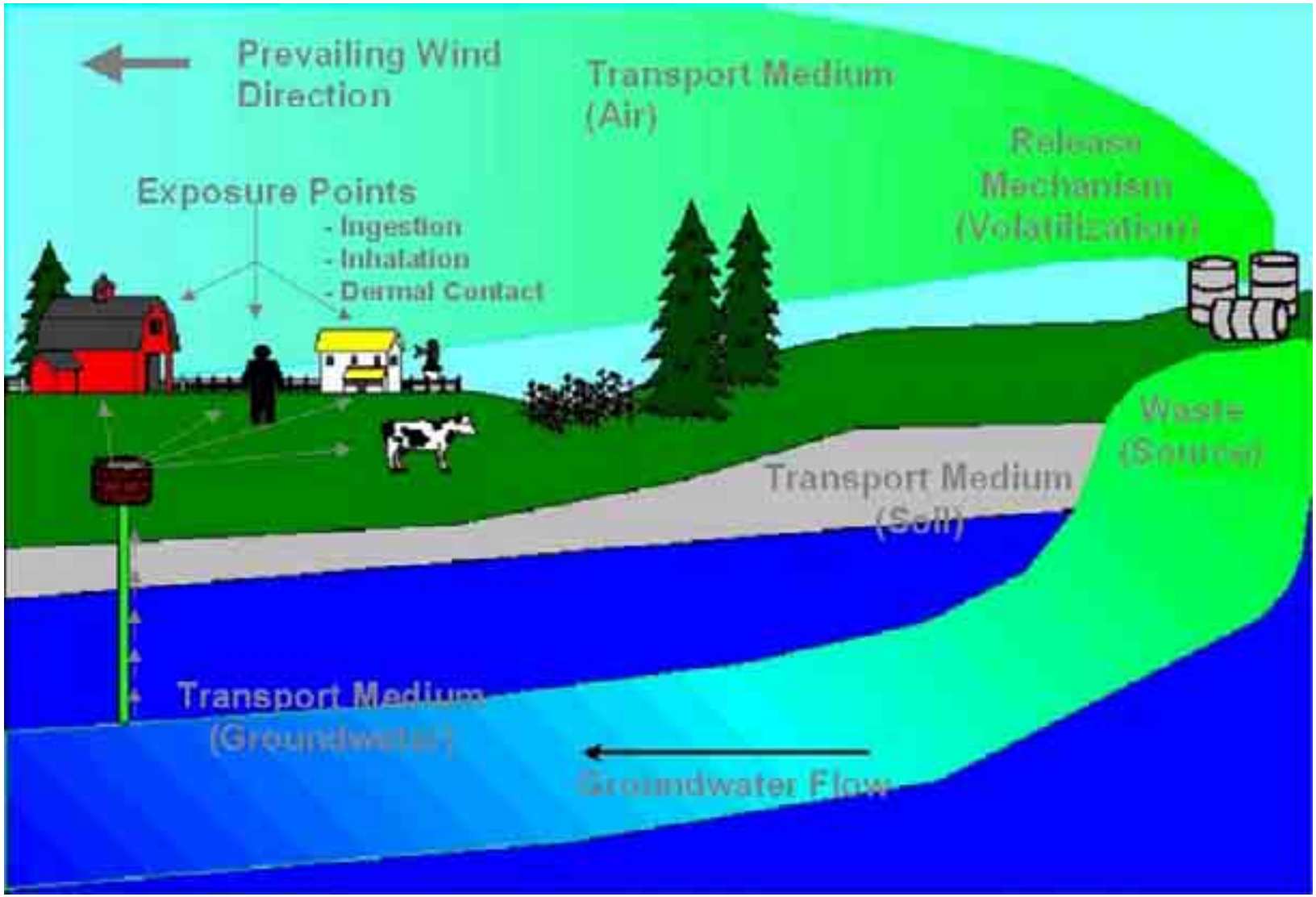
one or more routes or means by, or through, which a receptor is being exposed to, or affected by, a contaminant or could be so exposed or affected

an individual which is being, or could be, harmed by the source

Identify and characterize S - P - R

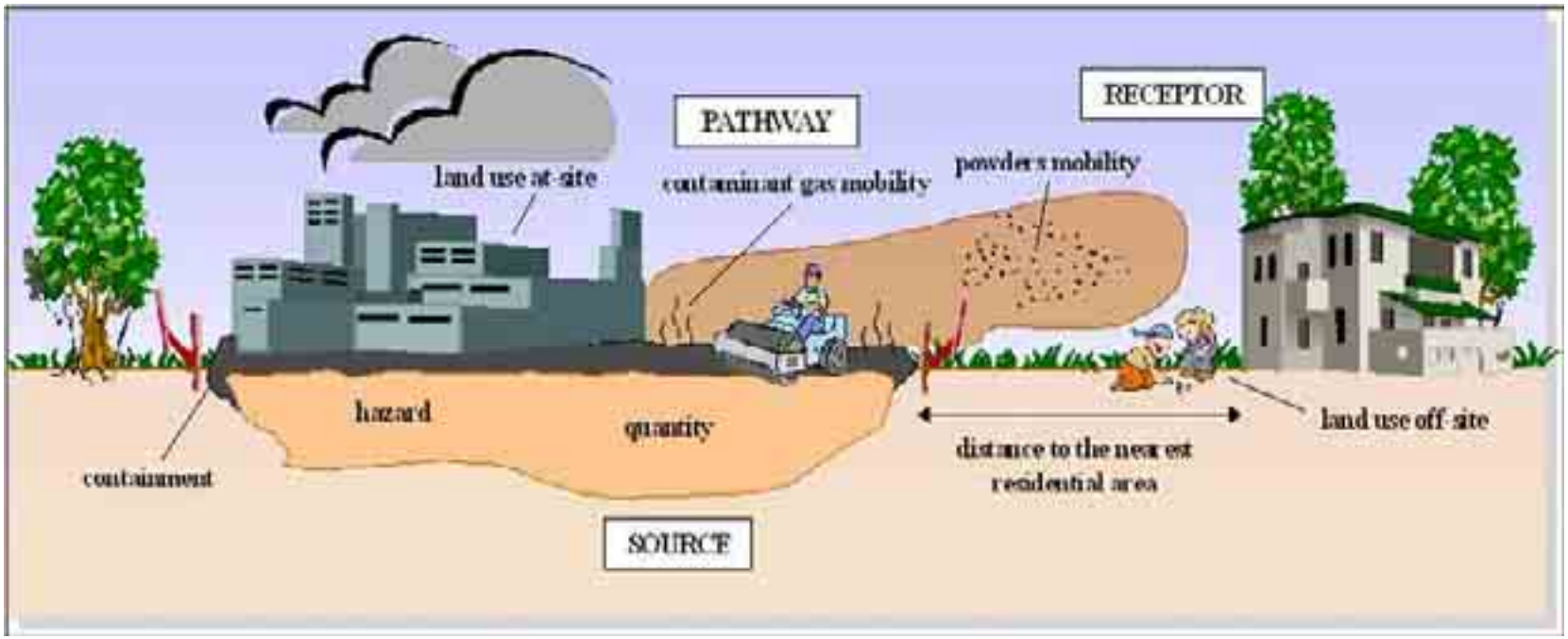
to build the CONCEPTUAL SITE MODEL

2. Conceptual Site Model

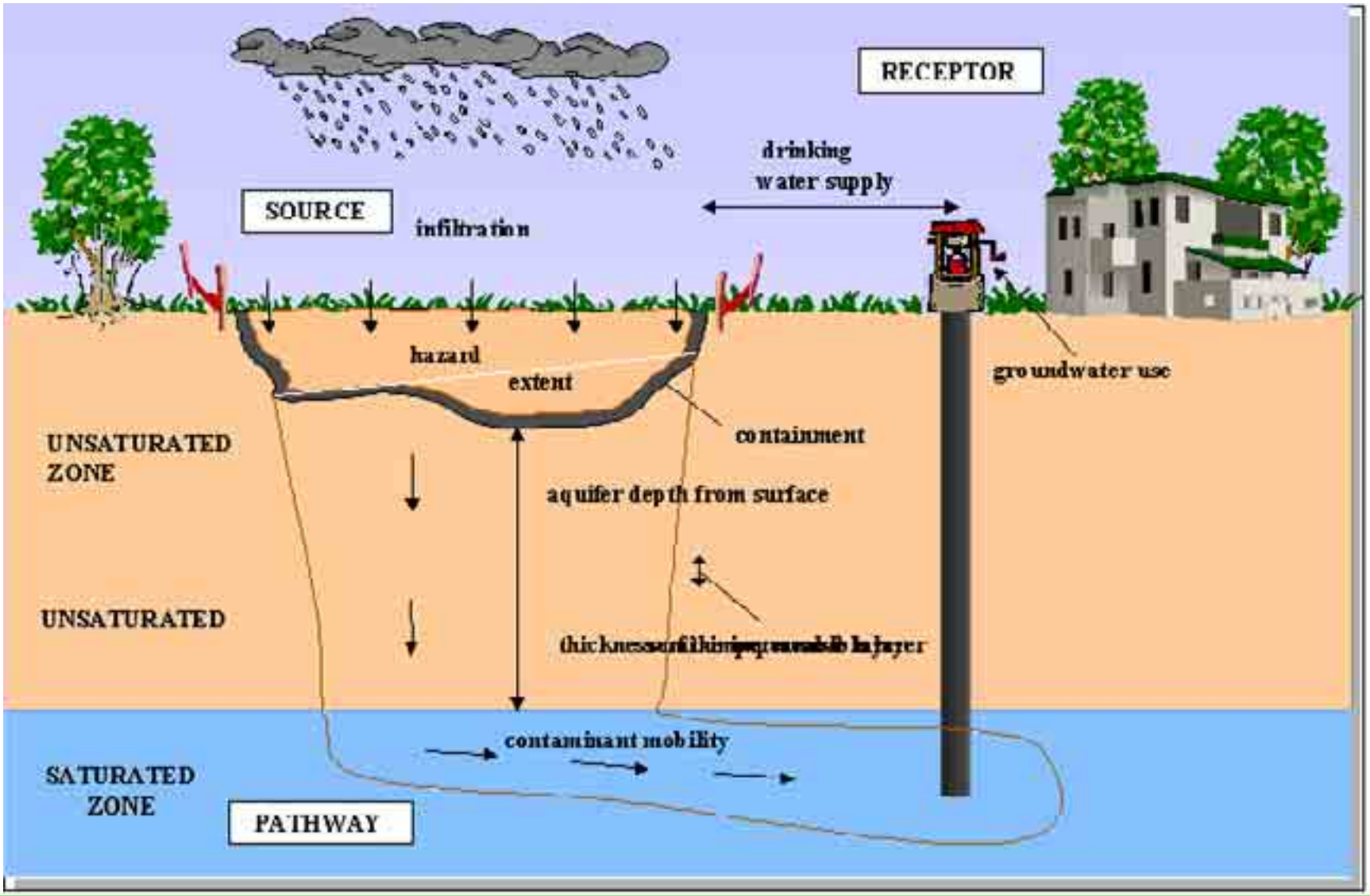


2. Conceptual Site Model

Atmospheric pathway

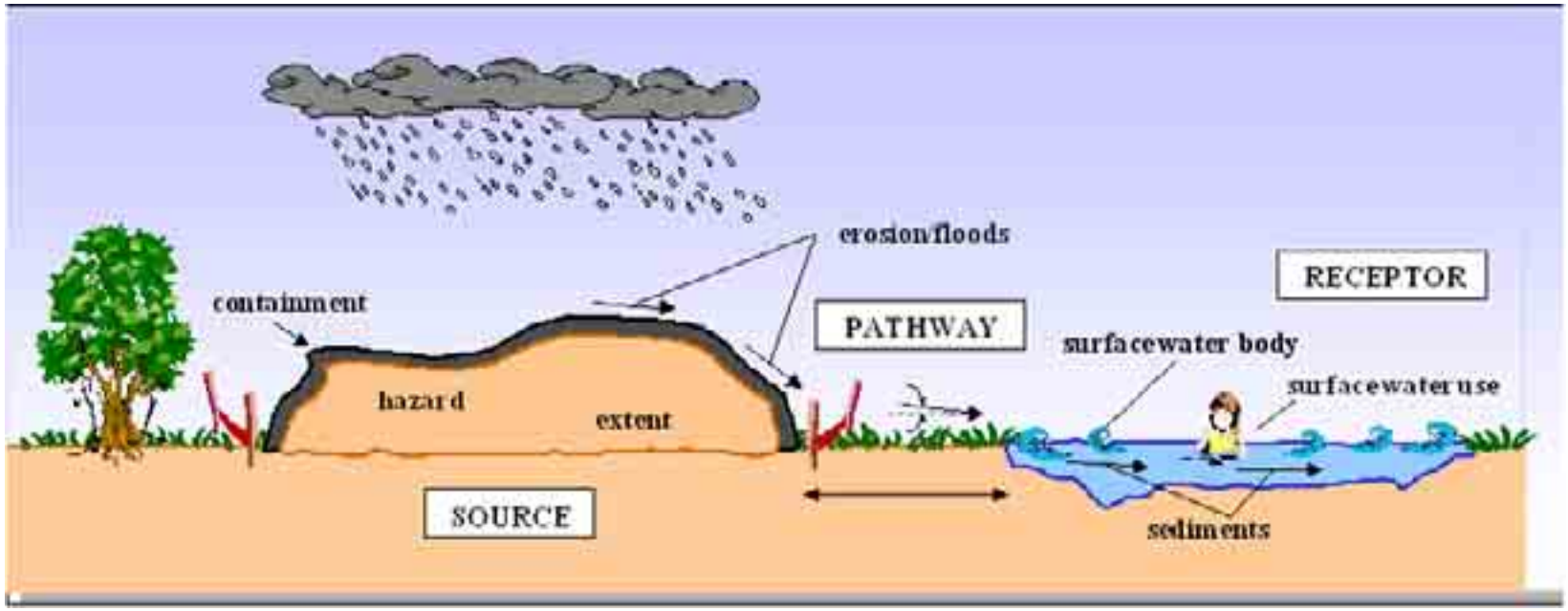


2. Conceptual Site Model



2. Conceptual Site Model

Surface water pathway

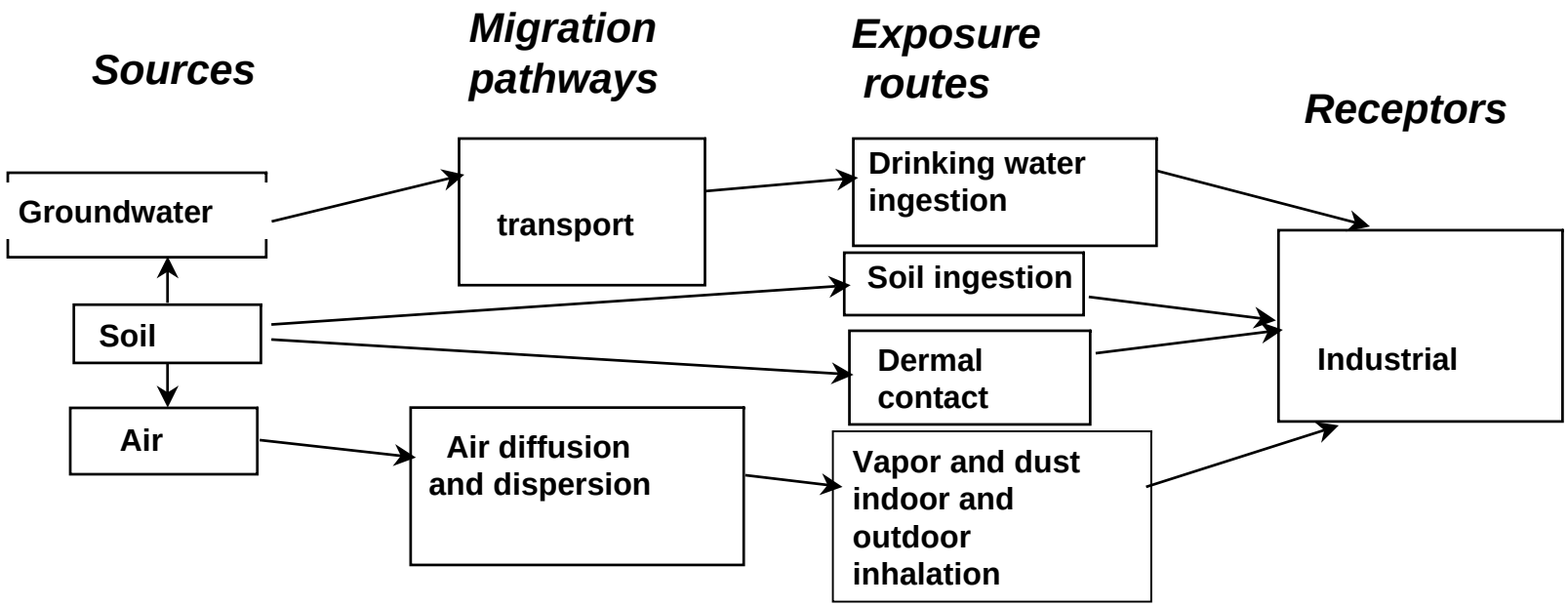


2. Conceptual Site Model

Direct contact pathways

2. Conceptual Site Model

Exposure flowchart

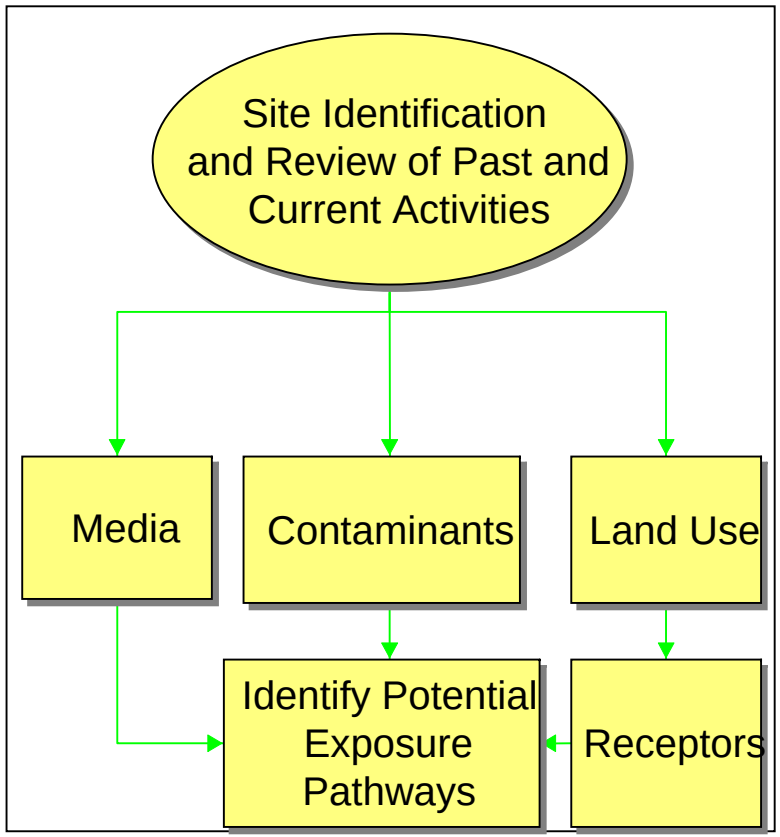


Build the site specific conceptual model and exposure flowchart by including all sources, active pathways, exposure routes and receptors

3. Site characterization objectives

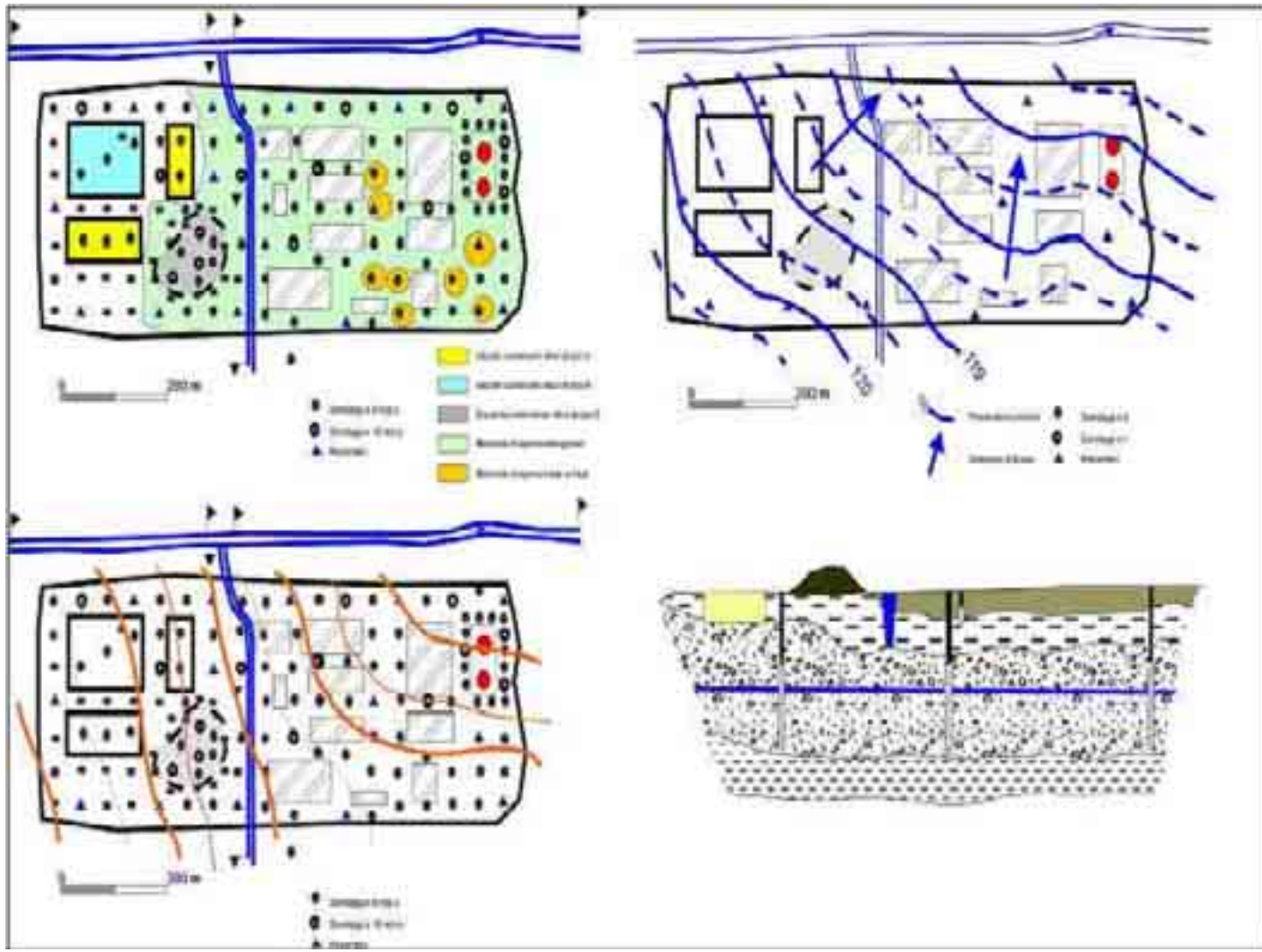
hazard and exposure assessment

- Identify and characterize primary contaminant sources (e.g. wastes, tanks) and secondary sources in soil and groundwater
- Identify and characterize migration pathways by studying environmental media (e.g. hydrogeology)
- Identify and characterize actual and potential receptors (land uses) and exposure routes on-site and off-site



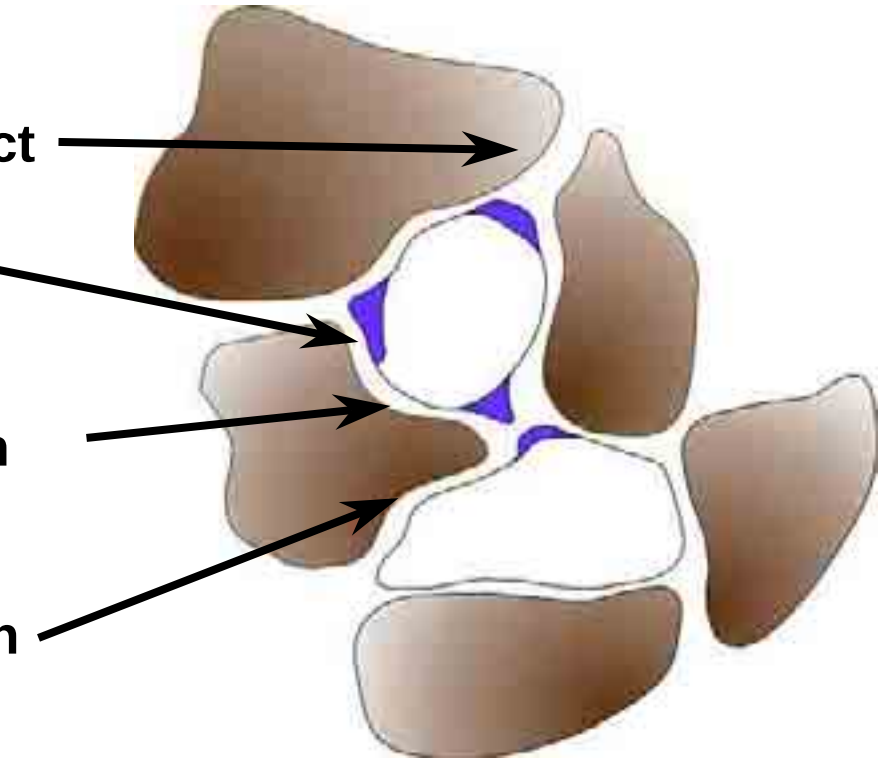
Preliminary Conceptual Site Model (little or no site-specific data available)

Soil and groundwater sampling



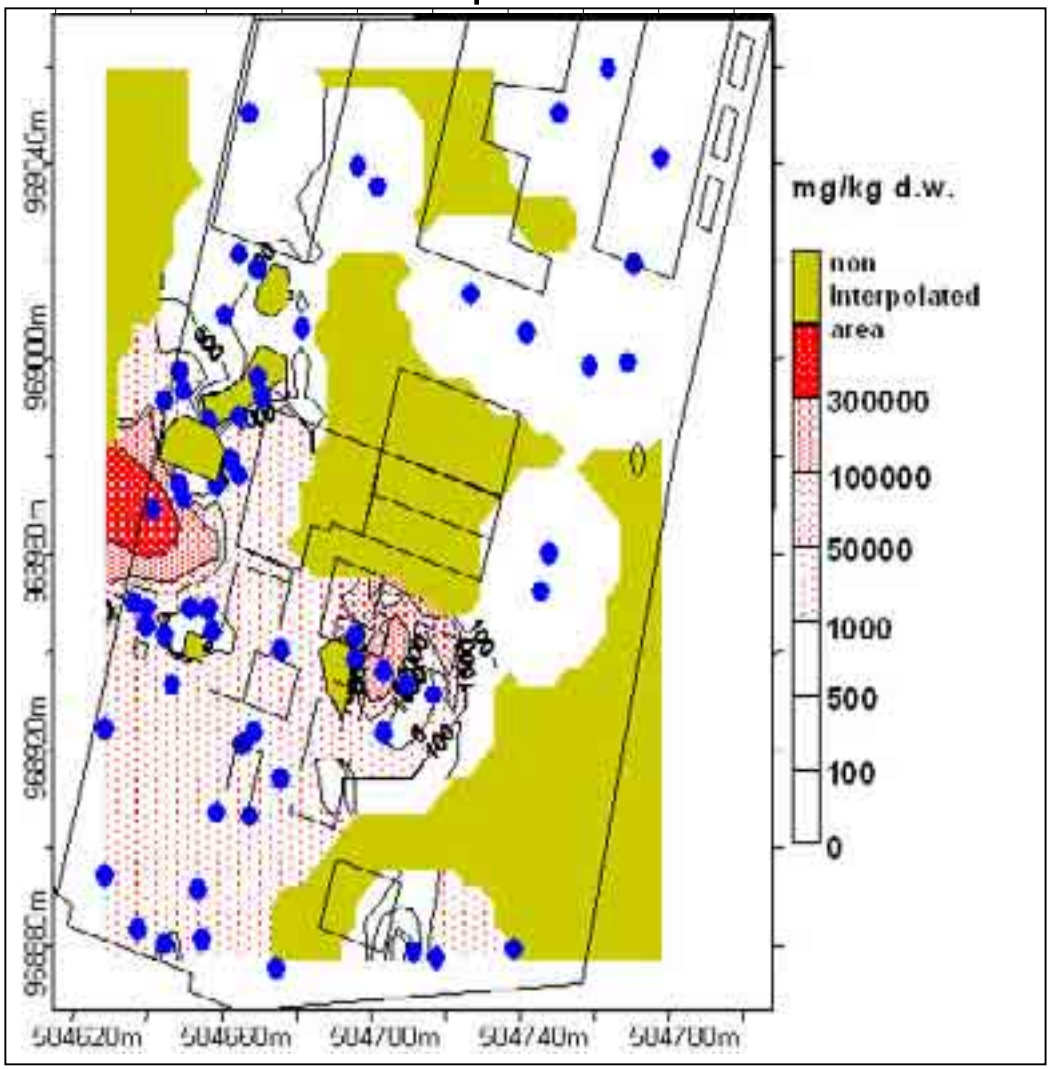
3. Site characterization objectives

Soil sources



3. Site characterization objectives

Hazard Assessment: Spot Contaminants of Concern



Characterize sources:

- Map contaminant concentrations in surface and deep soil
- Define source extent and representative contaminant concentrations

3. Site characterization objectives

CSM: answered questions

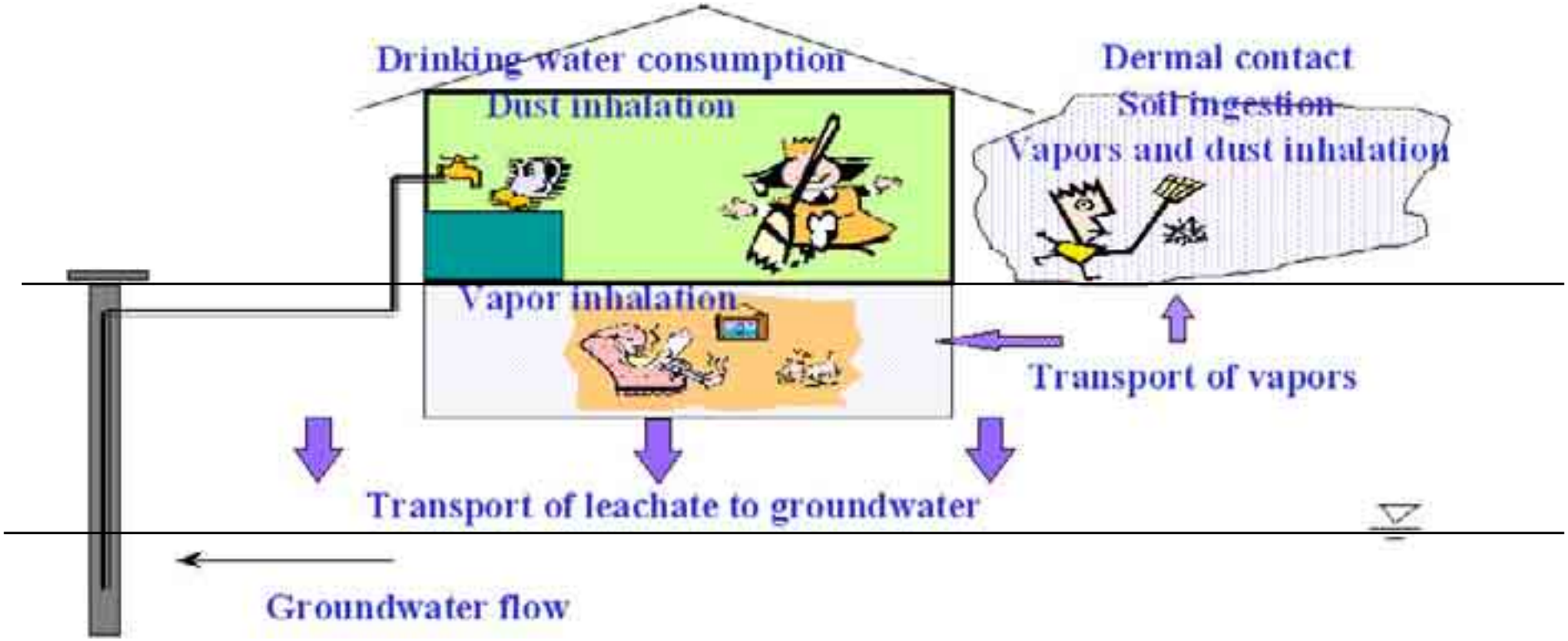
- What is the proposed reuse or current use of the site?
- Is the proposed reuse of the site politically, economically, and socially viable?
- What media are impacted and by what type of contamination?
- Are there any potentially complete source-pathway-receptor pollutant linkages present at the site?
- What exposure point concentration might represent a potential risk?
- Do the exposure assumptions used match the reuse scenario?
- What are the potential human exposure pathways?
- What are the available remedies for the site?

Additional Hints

- a CSM should not be limited to soil and groundwater contamination
- a CSM should consider all potential exposures and receptors, e.g. human health, ecological receptors

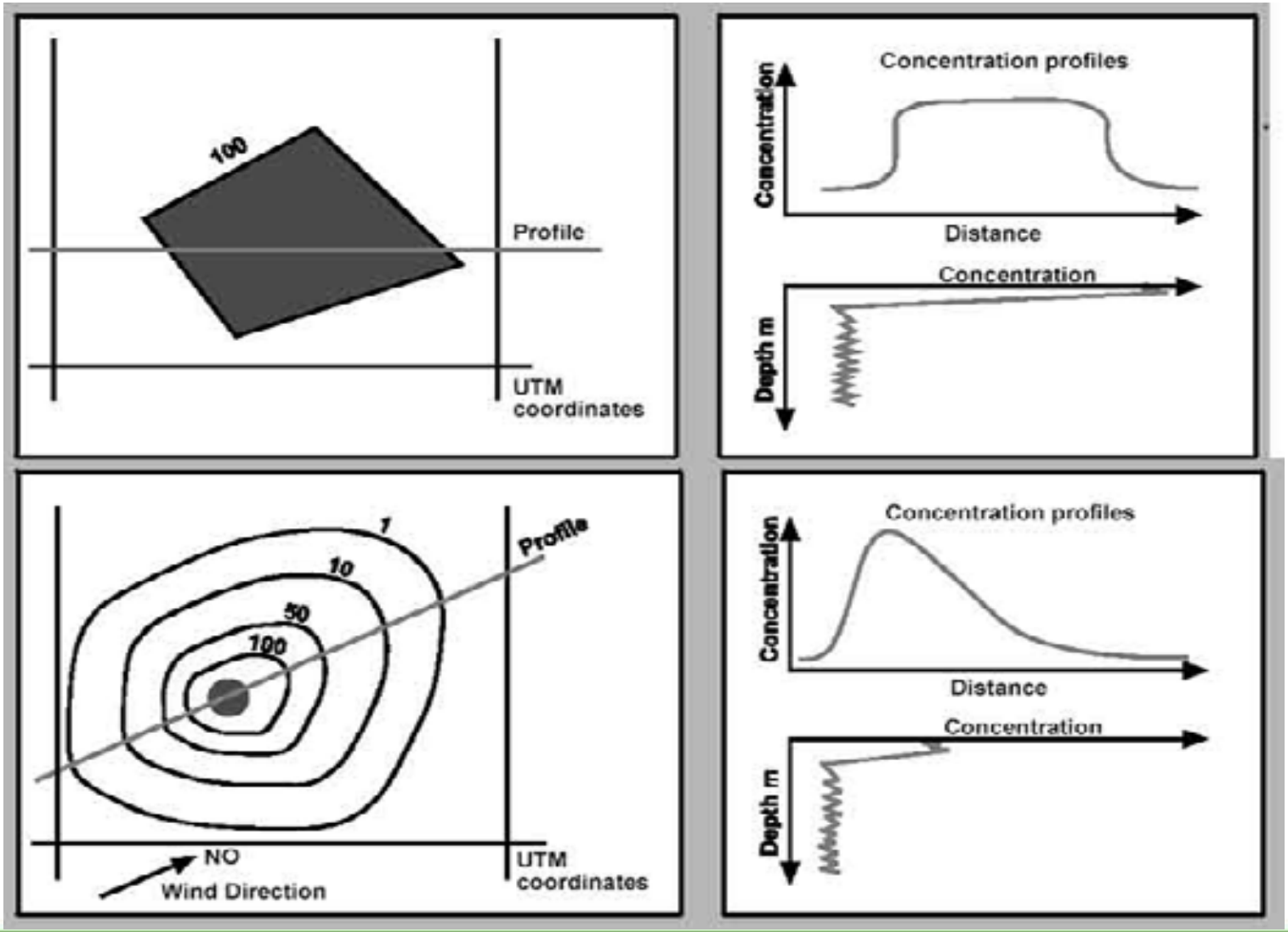
4. Exposure Assessment

Example: exposure scenario for residential use



4. Exposure Assessment

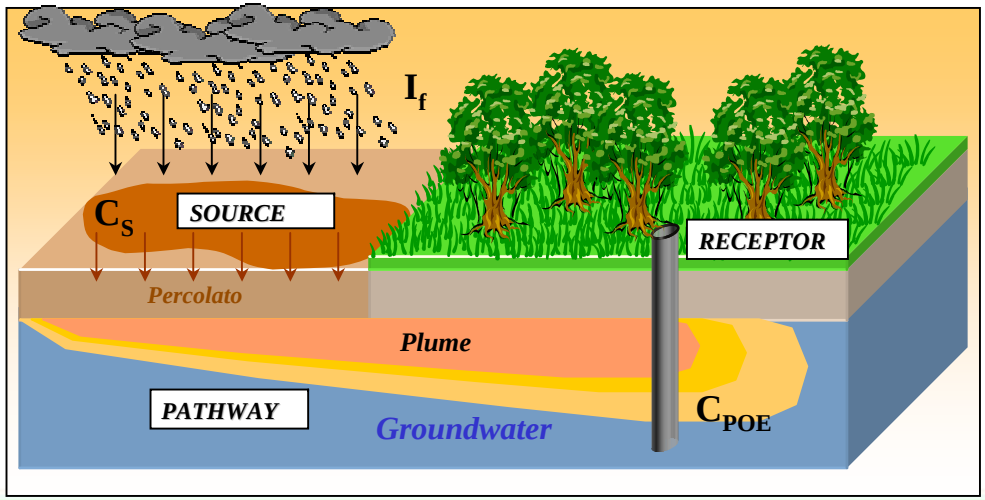
CSM: output examples



4. Exposure Assessment

Concentration profiles

- Concentration profiles from the contaminant source versus distance and versus time are needed in order to estimate expected concentration at the exposure/contact point (C_{POE}) where the receptor is located.
- Simulation *Fate&Transport models* may be needed in order to estimate expected concentrations of contaminants - with distance and time – migrating from the source across different environmental media, eg:
  - groundwater
  - surface water
  - air



4. Exposure Assessment

$$E = \frac{C \times CR \times EF \times ED}{BW \times AT}$$

Example: Exposure to Soil ingestion

E = Exposure [mg/(kg x day)]
CR = Contact (ingestion) rate [mg/day]
EF = Exposure frequency [day/year]
ED = Exposure duration [year]
BW = Body weight [kg]
AT = Averaging time [year]
C = Contaminant concentration in soil at C_{POE}[mg/kg]

Note: long term (chronic) exposure is estimated

4. Exposure Assessment

Data for Exposure Assessment

- **Chemicals:** chemical and physical parameters describing environmental mobility, persistency, volatility, bioaccumulation potential
- **Site/pathways:** physical/chemical parameters describing local soil, air and water resources conditions (from site characterization)
- **Receptors:** data describing land use and receptor exposure characteristics (exp. routes and parameters from site characterization)

  - ***Select contaminants of concern***
  - ***Identify relevant pathways***
  - ***Identify receptors and location***

4. Exposure Assessment

Chemical/physical parameters

Substances	CAS	MW (g/mole)	Ref.	H (-)	Ref.	Koc (*) (ml/g)	Ref.	Sol (mg/l)	Ref.	Dair (cm²/s)	Ref.	Dwat (cm²/s)	Ref.
1,1,1-Trichloroethane	71556	133.4	7	0.705	1	135	1g	1330	1	0.078	1	0.0000088	1
1,1,2,2-Tetrachloroethane	79345	167.9	7	0.0182	7	74.1	7	2960	7	0.071	10	0.0000079	10
1,1,2-Trichloroethane	79005	133.4	7	0.0374	1	75	1g	4420	1	0.078	1	0.0000088	1
1,1-Dichloroethane	75343	99	7	0.23	1	53	1g	5060	1	0.0742	1	0.0000105	1
1,1-Dichloroethene	75354	96.9	7	1.07	1	65	1g	2250	1	0.09	1	0.0000104	1
1,2,3-Trichloropropane	96184	14.4	7	0.0155	7	97.2	13	1900	7	0.0701	9	0.0000079	9
1,2,4,5-Tetrachlorobenzene	95943	215.9	7	0.0494	7	1780	7	1.27	7	0.0521	14	0.00000622	15
1,2,4-Trichlorobenzene	120821	181.5	7	0.0582	1	1660	1g	300	1	0.03	1	0.00000823	1
1,2-Ethylene dibromide	106934	187.9	7	0.0266	7	44	7	4150	7	0.0762	14	0.00000871	15
1,2-Dichlorobenzene	95501	147	8	0.0779	1	379	1g	156	1	0.069	1	0.0000079	1
1,2-Ethylene chloride	107062	99	7	0.0401	1	38	1g	8520	1	0.104	1	0.0000099	1
1,2-Dichloroethylene	540590	96.9	7	0.166	7	49	7	3500	7	0.0736	10	0.0000113	10
1,2-Dichloropropane	78875	113	7	0.115	10	47	10	2800	10	0.0782	10	0.00000873	10
1,2-Dinitrobenzene	528290	168.11	16	0.000902	9	94.3	7	1070	9	0.279	9	0.00000764	9
1,3-Dichlorobenzene	541731	147	8	0.151	2	1700	2c	123	1	0.069	s	0.0000079	s
1,3-Dinitrobenzene	99650	168.11	16	0.000902	9	94.3	7	1070	9	0.279	9	0.00000764	9
1,4-Dichlorobenzene	106467	147	8	0.0996	1	616	1g	73.8	1	0.069	1	0.0000079	1
2,3,4,6-Tetrachlorophenol	58902	213.9	7	0.000105	5	1580	5	1000	2	0.1	s	0.00001	s
2,4,6-Trichlorophenol	88062	197.5	7	0.000319	1	2000	2	800	1	0.0318	1	0.0000625	1
2,4-Dichlorophenol	120832	162.9	7	0.00013	1	380	2	4500	1	0.0346	1	0.00000877	1
2-Chlorophenol	95578	128.6	8	0.016	1	363	c	22000	1	0.0501	1	0.00000946	1
Acenaphthene	83329	154.2	7	0.00636	1	4900	1g	4.24	1	0.0421	1	0.00000769	1

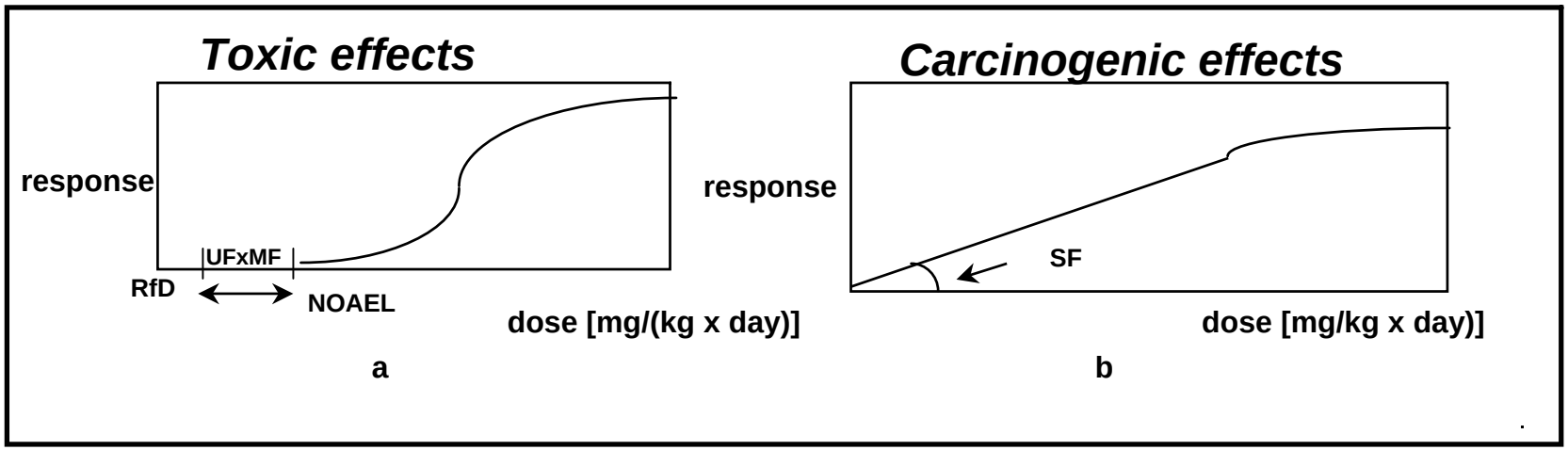
4. Exposure Assessment

Exposure parameters

Exposure parameters	Res/ recr	Ind/comm
	children	adults
Soil ingestion rate (mg/day)	200	50
Body weight (kg)	15	70
Exposure frequency (days/year)	350	240
Exposure duration (years)	6	25
Lifetime (years)	70	70
Dermal surface (cm^2)	6381	17938
Soil skin adh. factor (mg/ cm^2)	1	1
Exposed skin fraction (%)	50	20
Bioavailanility (%)	1	1
Outdoor inhalation rate (m^3/day)	3	2
Indoor inhalation rate(m^3/day)	6	8
Dermal adsorption factor (%)	1-10	1-10

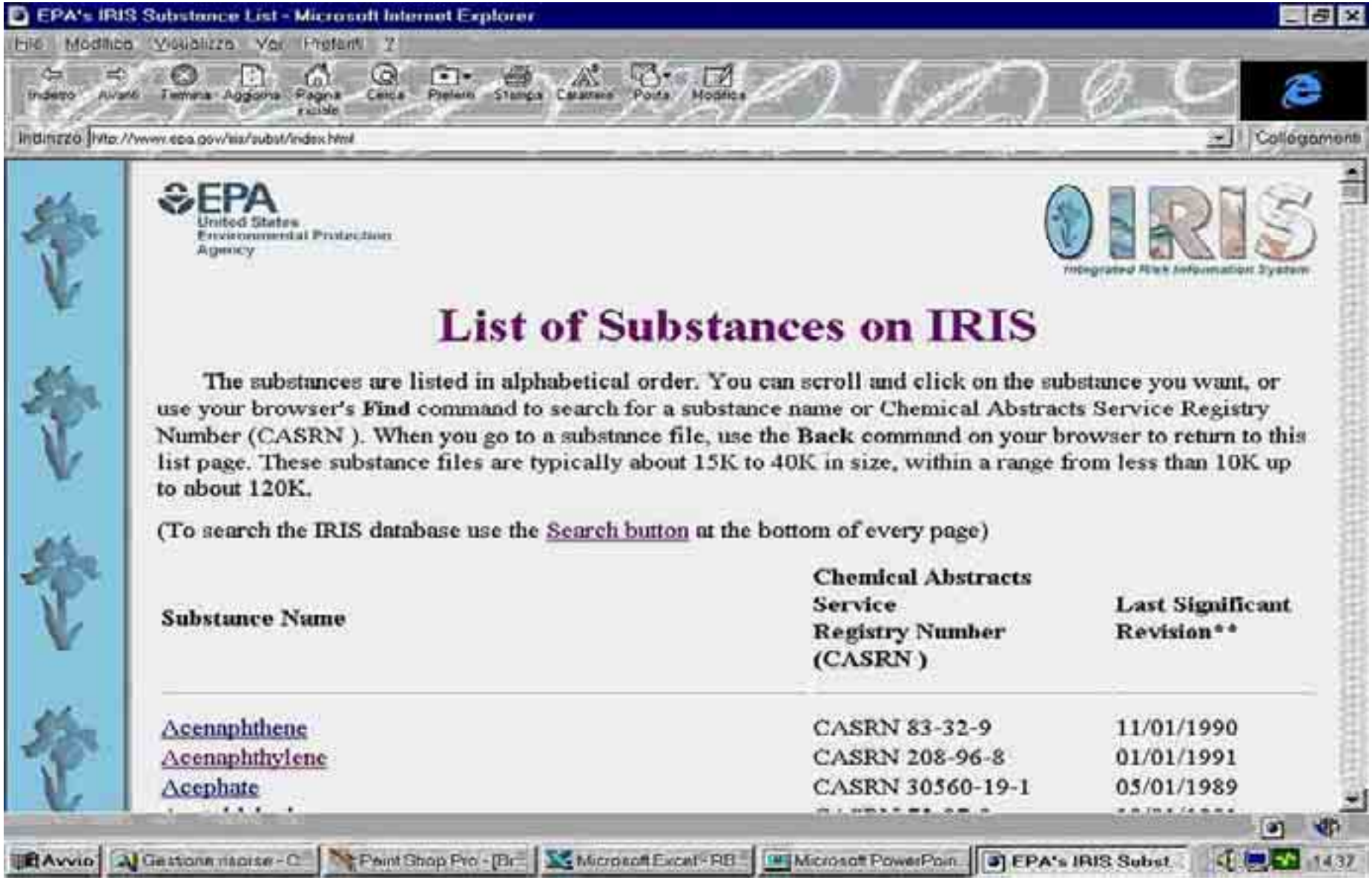
4. Exposure Assessment

Toxicity (Dose/Response) Assessment



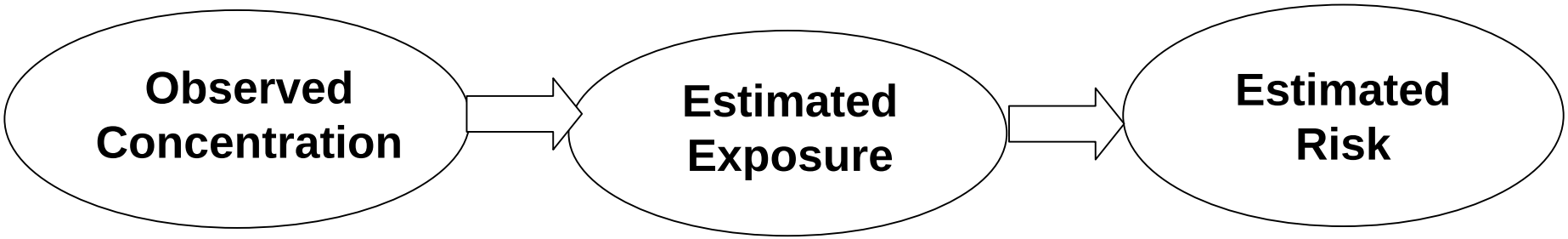
RfD = Reference Dose (or TDI) for threshold substances **[mg/(kg x day)]**

SF = Slope Factor (or CPS) for non-threshold substances **[1/(mg/(kg x day))]**


EPA's IRIS Substance List - Microsoft Internet Explorer
EPA
United States
Environmental Protection
Agency
IRIS
Integrated Risk Information System
List of Substances on IRIS
The substances are listed in alphabetical order. You can scroll and click on the substance you want, or use your browser's Find command to search for a substance name or Chemical Abstracts Service Registry Number (CASRN). When you go to a substance file, use the Back command on your browser to return to this list page. These substance files are typically about 15K to 40K in size, within a range from less than 10K up to about 120K.
(To search the IRIS database use the Search button at the bottom of every page)
Substance Name
Chemical Abstracts Service Registry Number (CASRN)
Last Significant Revision**
Acenaphthene CASRN 83-32-9 11/01/1990
Acenaphthylene CASRN 208-96-8 01/01/1991
Acephate CASRN 30560-19-1 05/01/1989

5. Risk Assessment procedure

Risk Assessment forward procedure



*Assess site risks (*baseline *risk assessment)*

5. Risk Assessment procedure

RISK = EXPOSURE x TOXICITY

Threshold non-cancer substances :

$$HI = \frac{E}{TDI}$$

HI = Hazard Index
E = Chronic Exposure [mg/kg x day]
TDI = Toxicity [mg/kg x day]

Non-threshold cancer substances:

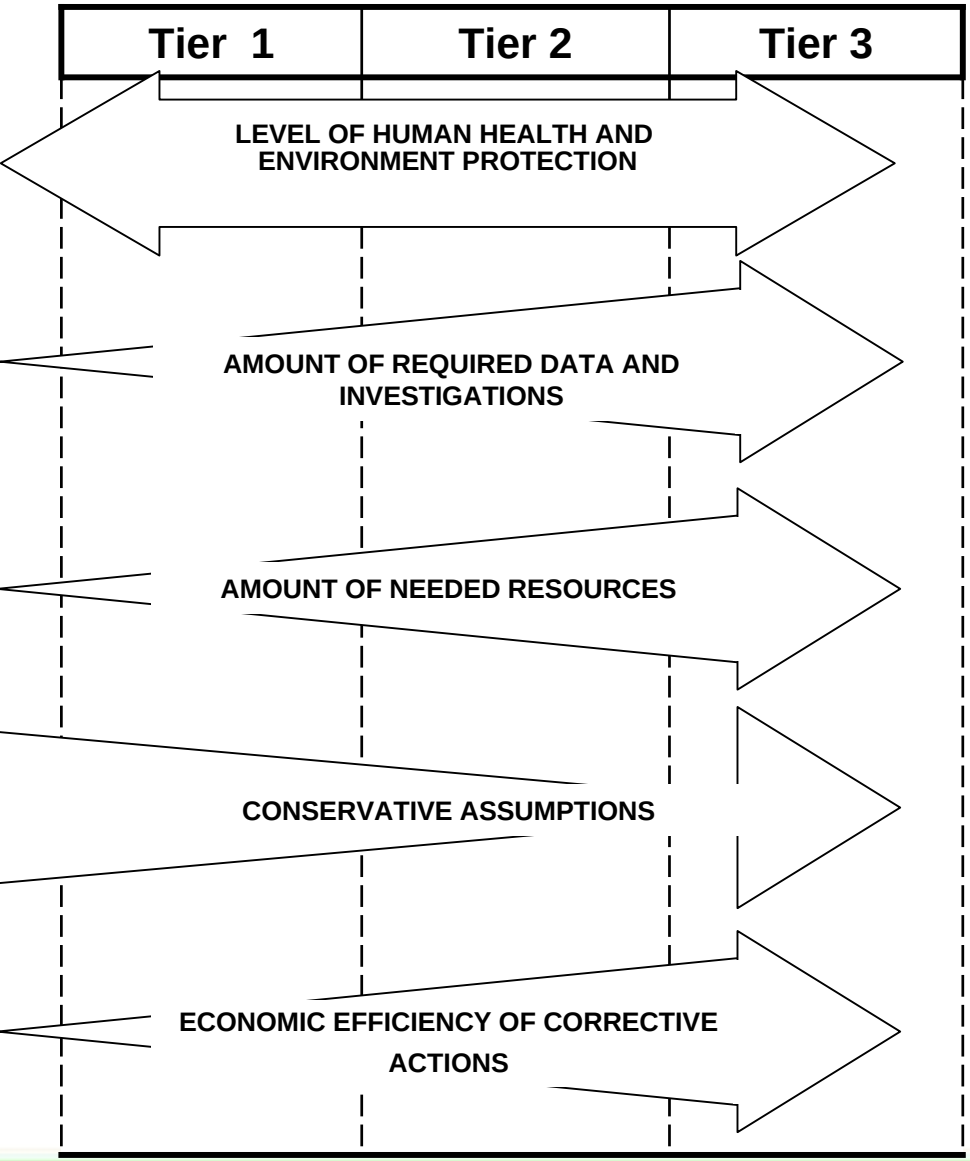
$$R = E \times SF$$

R = incremental lifetime cancer risk
E = Chronic Lifetime Exposure [mg/kg x day], SF = Toxicity [1/(mg/kg x day)]

Acceptable Risk Criteria:

HI = 1
R = 1E-6 ÷ 1E-4

5. Risk Assessment procedure



Risk assessment Tiers

*<u>*NOTE*</u>:

Tier 3 is seldom performed

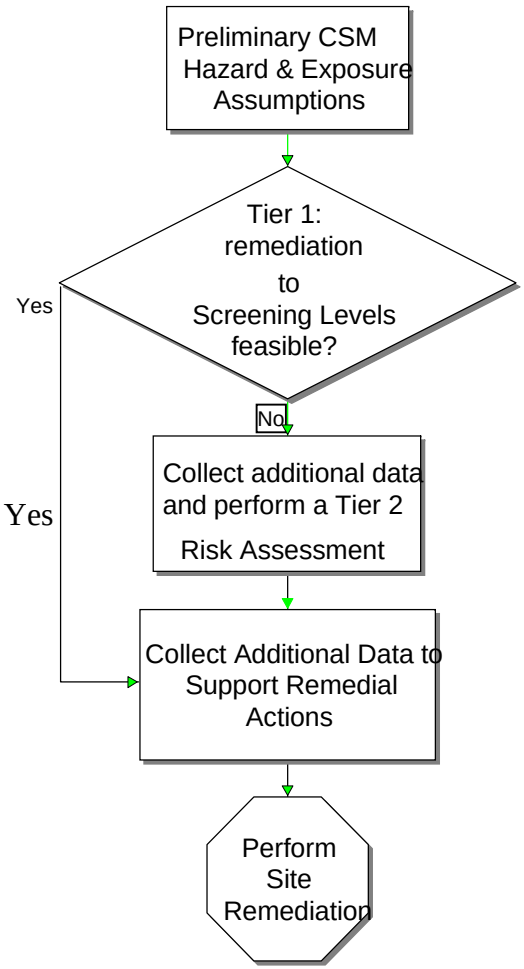
5. Risk Assessment procedure

Risk Assessment tiered procedure

Tier 1: Risk Assessment based on preliminary CSM. Check observed contaminant concentrations against screening values

Design and implement a dynamic work plan to verify/define the preliminary CSM

Tier 2: Risk Assessment based on a mature CSM. Assess site-specific risks. Define site specific cleanup goals.



5. Risk Assessment procedure

Tier 1

- A preliminary evaluation of risks is performed by comparing observed representative contaminant concentrations - in soil and groundwater – against pre-defined screening values. The Conceptual Site Model is a preliminary one.
- Screening values for soil and groundwater concentrations are generally established by law for different soil (and gw) uses.
- If screening values are exceeded, then:
  - the site (soil and gw) is remediated (cleaned up) down to screening values or
  - an in depth site characterization and Tier II risk assessment is performed by refyning the Conceptual Site Model.

5. Risk Assessment procedure

Ex.: Dutch intervention values

SUBSTANCES	SOIL (mg/kg) Intervention values	GROUND WATER (µg/l) Intervention values
I. METALS		
arsenic	55	60
barium	625	625
cadmium	12	6
chromium	380	30
cobalt	240	100
copper	190	75
mercury	10	0.3
lead	530	75
molybdenum	200	300
nickel	210	75
zinc	720	800
II. INORGANIC COMPOUNDS		
cyanides (free)	20	1500
cyanides (complex. pH<5)	650	1500
cyanides (complex. pH?5)	50	1500
thiocyanates	20	1500
III. AROMATIC COMPOUNDS		
benzene	1	30
ethylbenzene	50	150
phenol	40	2000

5. Risk Assessment procedure

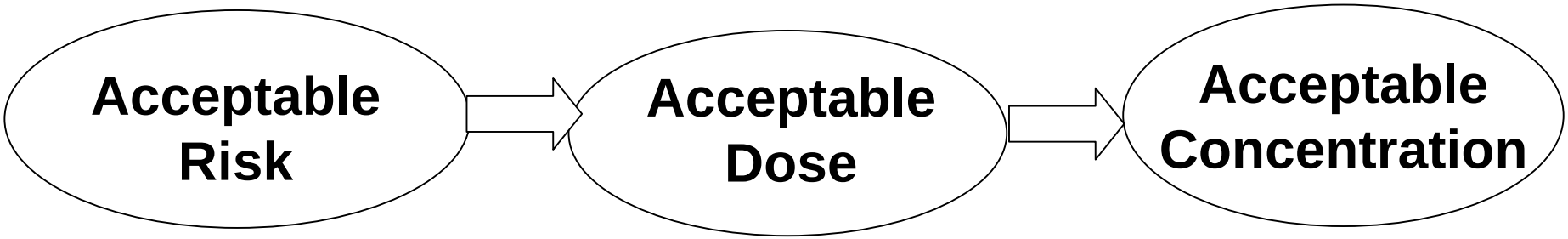
Tier 2

CSM required information

- Historical use of the site
- Climate
  - hydrologic budget, fauna, flora, and land use, precipitation rates
  - temperature, prevailing wind speed and direction
- Pedology/Geology
  - types of soil and geologic materials, structural geologic features, depositional environments, geomorphology
- Hydrogeology
  - Aquifer characteristics
    a. Type (unconfined, confined, or semi-confined)
    b. Characteristics (hydraulic conductivity, transmissivity)
    c. Geology (materials and structure)
  - Hydrologic budget
    a. Recharge/discharge rates (precipitation, artificial recharge, pumping)
  - Groundwater flow
    a. Hydraulic gradient (groundwater elevations, flow direction)
    b. Flow velocity (travel time)

5. Risk Assessment procedure

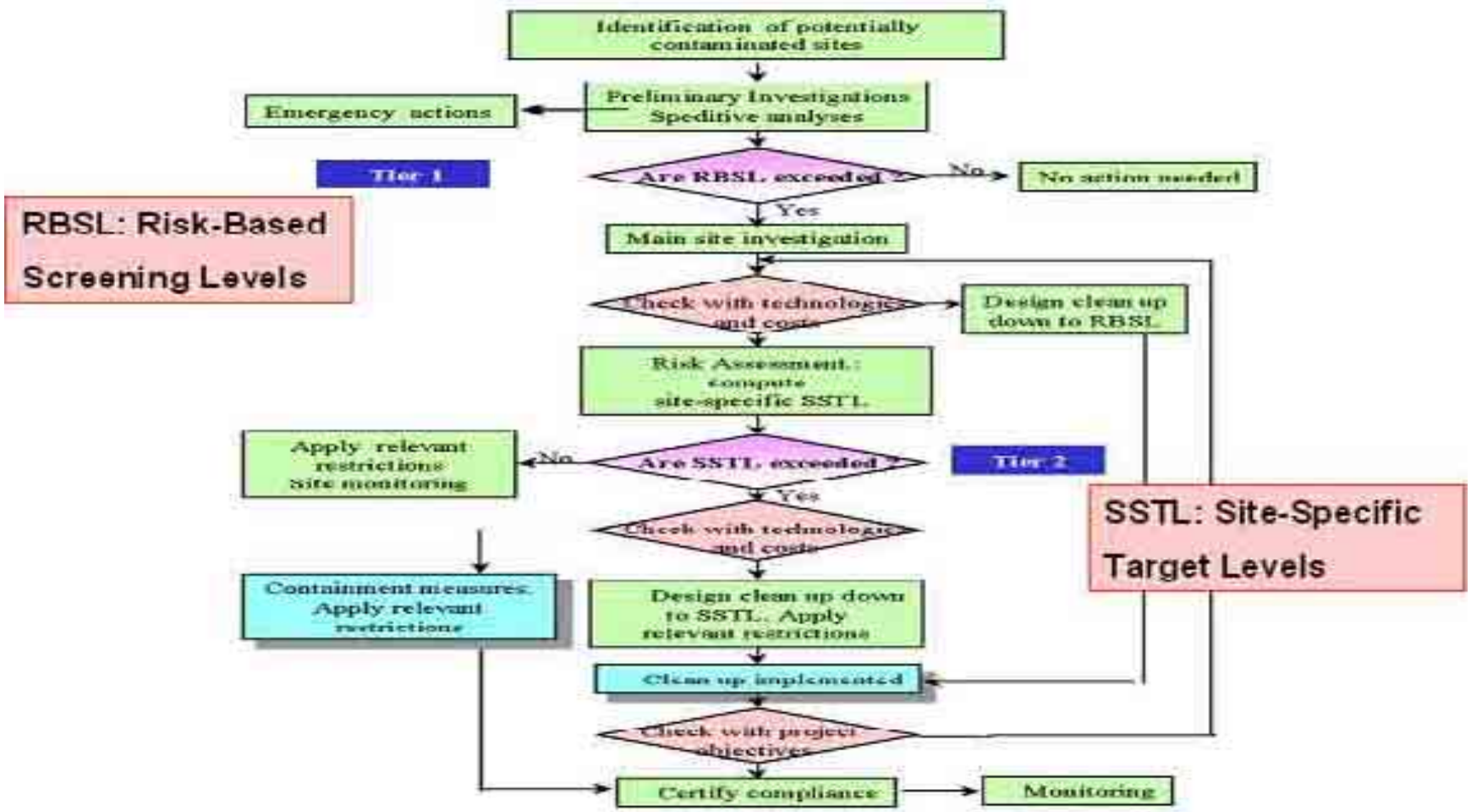
Risk Assessment backward procedure



Assess site specific cleanup goals

5. Risk Assessment procedure

ASTM/RBCA Tiered procedure



5. Risk Assessment procedure

ASTM/RBCA Risk-Based Corrective Actions

- Standard ASTM E1739/95 and PS104/98 for risk-based corrective actions on contaminated sites
- Streamlined tiered procedure for decision making
- Tier 1 develops RBSLs (Risk-Based Screening Levels) look-up tables for each pathway against which site concentrations are compared, according to conservative exposure scenarios and default assumptions
- Tier 2 develops SSTLs (Site specific Target Levels) as site-specific cleanup objectives
- Risk, Exposure and Fate&Transport models (equations) are included in the Standard
- Default Tier 1 parameter values are also included in the Standard

5. Risk Assessment procedure

Main features of RBCA

- Risk protection level is the same at each Tier
- As data from investigation increase more focused quality objectives are defined according to site-specific conditions and exposure scenarios
- Tier 1 receptor location is on site on top or below source area according to a conservative default assumption
- Tier 2 receptor position may be at actual site-specific location (compliance point)

5. Risk Assessment procedure

Groundwater protection: Tier 2 compliance point

compliance point (receptor) might be located at some distance from the source