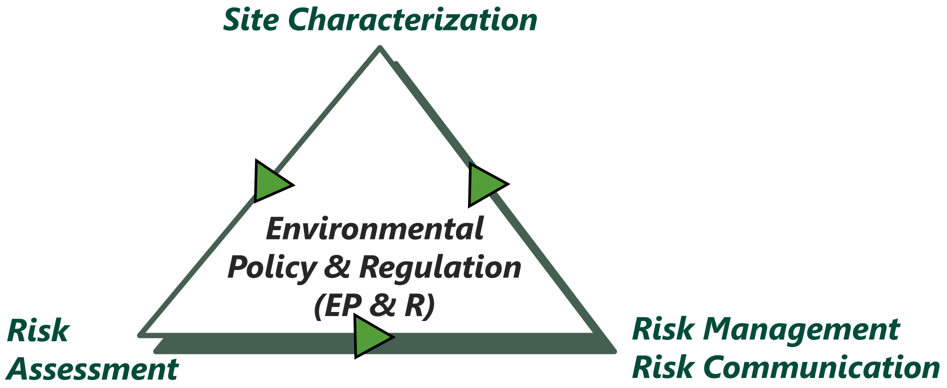
The Risk Based Corrective Action Approach



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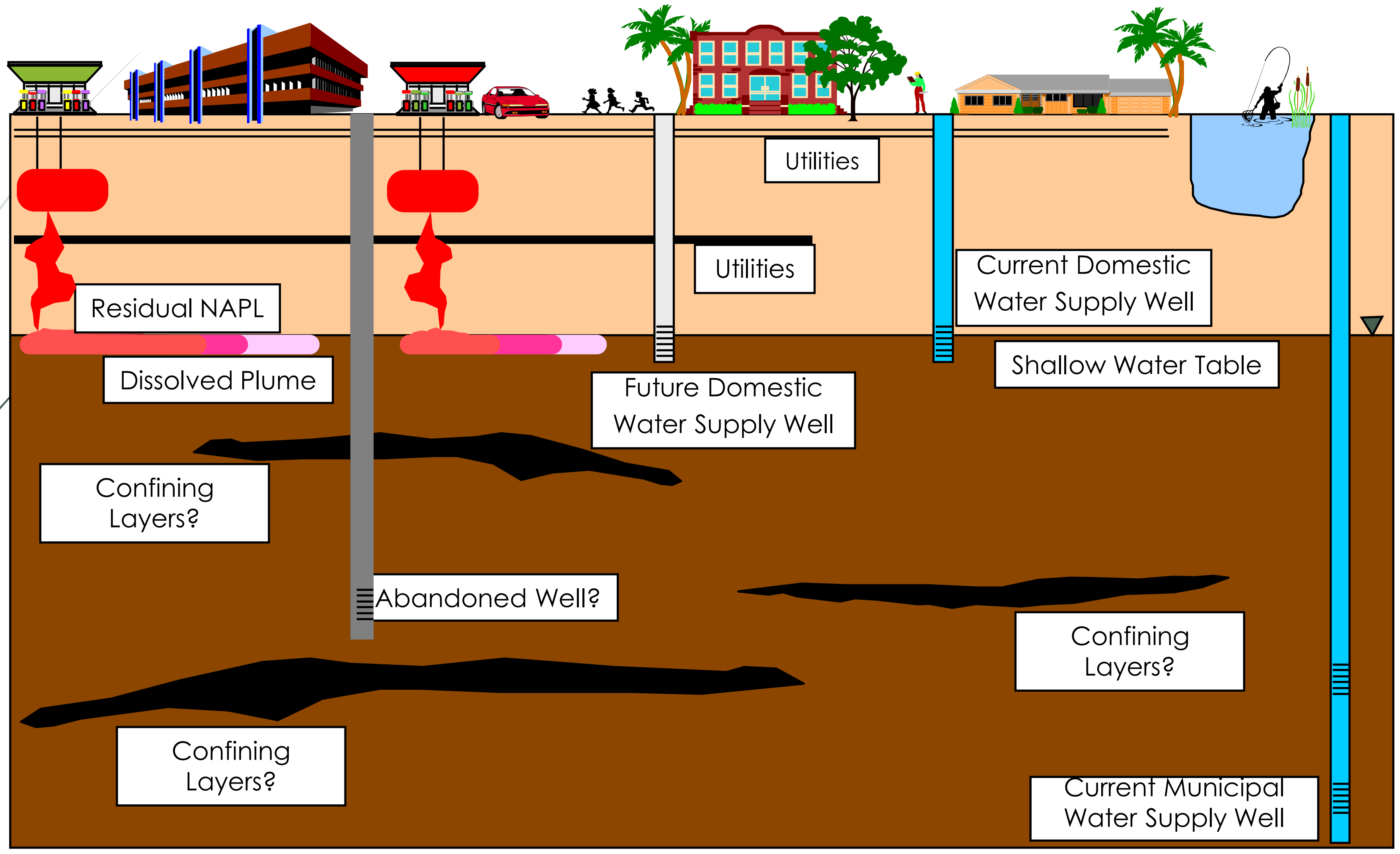
The Challenge

The Problem?

- Thousands of legacy contaminated sites
  - Petrol stations
  - Manufacturing and chemical plants
  - Landfills and mining site
- Residual chemicals exist at these sites
- Chemicals <u>can</u> cause risk to humans, environment, and natural resources
- We do not have resources to eliminate chemicals at these sites

Therefore, we need a decision-making process to manage the risk.

A General Contaminated Site Model



Media of Concern

- Surface and subsurface soil
- Ambient air and Indoor air
- Shallow and deep Groundwater
- Rivers, lakes, estuaries, sea and sediments
- Fish and produce

How clean is clean?
What is "safe concentrations" in each media?

Environmental Receptors of Concern

- Human Beings
  - Children
  - Adults
  - Sensitive subgroups

- Ecological Receptors
  - Terrestrial organisms including plants
  - Aquatic organisms including plants
  - Avian organisms

- Natural resources

What is "safe concentration" for each receptor?

Key Characteristics of PRBCA

- **Follows ASTM's RBCA program developed in early 1992**
- **Primary goal is to protect human health & environment**
- **Scientifically defensible**
- **Allows revisions as science and knowledge evolve**
- **Practical and consistent**
- **Encourages involvement of stakeholders**
- **Focus is on risk reduction not only mass reduction**

Has been implemented in many countries and states

One Possible Solution

PRBCA

Portugal Risk Based Corrective Action Process

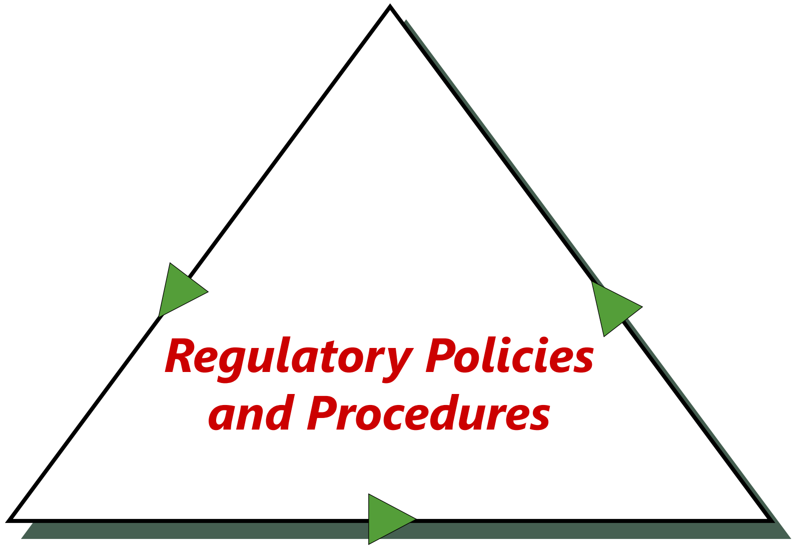
PRBCA Tools

1. A set of policy choices
2. Calculations based on good science
3. Clearly documented
4. Software for calculations
5. Training and education
6. Consensus amongst shareholders

Nobody is happy but all are satisfied!

Activities and Elements of PRBCA

Site Characterization



Risk Assessment
- Explosive Conditions
- Human Health
- Environment
- Nuisance conditions

Risk Management
- Cleanup
- Institutional controls

Steps analogous to a medical checkup!

Objective of Site Characterization (SC)

- Size of problem (delineate impacts)
- Characteristics of media
- Distribution of residual chemicals
- Design of risk management systems
- Understand behavior of chemicals

Collect the right quality and quantity of data

Risk Assessment

- Site-specific data
- Toxicity of chemicals
- Behavior of chemicals in the environment (fate and transport modeling)
- Complete routes of exposure (ingestion, inhalation, and dermal contact)
- Receptor characteristics (residential, non-residential, and construction worker)
- Regulatory program & policies

Requires models and calculations!

Risk Management (RM)

Risk Management (RM) follows RA and is used to:

1. **Decide whether calculated risk is acceptable**
2. **Develop cleanup levels**
3. **Remediate site to cleanup levels or use institutional controls to manage risk**

RM includes technical and non-technical considerations such as (policy choices, cost, stakeholder agreements, risk perception, institutional controls)

Risk Assessment Concepts-1

Calculation of Risk

Risk depends on <u>exposure</u> and <u>toxicity</u>

Given a concentration calculate risk

Exposure Calculation: Ingestion of Water

$$\text{Dose (mg/kg-day)} = \frac{CW \times IR \times EF \times ED}{BW \times AT}$$

CW	=	Representative concentration in water at POE (mg/L)
IR	=	Ingestion rate (L/day)
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (days)

For carcinogenic health effects, AT = 70 years and dose is referred to as the lifetime average daily intake (LADI).

For non-carcinogenic health effects, AT = the exposure duration and dose is referred to as the chronic daily intake (CDI).

Risk Characterization: Non-Carcinogenic Health Effects

$$\text{Hazard Quotient (HQ)} = \frac{\text{Dose}}{\text{Reference Dose}}$$

- **HI is the sum of HQs.**
- **HQ/HI has to be calculated for each chemical and each receptor**

The follow-up question is: What is acceptable HQ?

Risk assessment is followed by risk management.

Risk Calculation: Carcinogenic Health Effects

IELCR* = Dose x Slope Factor

If IELCR > acceptable risk, need for risk management

If IELCR < acceptable risk, no action required from a human health risk perspective.

*Individual Excess Lifetime Cancer Risk

Estimation Of Dose : Ingestion Of Water

Estimate the dose for an adult who ingests water in a residential scenario with a benzene concentration of 0.005 mg/l.

Benzene: Carcinogenic effects (Lifetime average dose)

$$Dose = \frac{CW \times IR \times EF \times ED}{BW \times AT}$$

$$Dose = \frac{0.005 \times 2.0 \times 350 \times 24}{70 \times (70 \times 365)} = 4.70\mathrm{E}-05 \ \mathrm{mg/kg-day}$$

Benzene: Non-Carcinogenic effects (Chronic daily intake)

$$Dose = \frac{0.005 \times 2.0 \times 350 \times 24}{70 \times (24 \times 365)} = 1.37\mathrm{E}-04 \ \mathrm{mg/kg-day}$$

Estimation Of Risk
Ingestion Of Water Example

Benzene: Carcinogenic effects

$$IELCR = Dose \times Slope\ factor$$

$$IELCR = 4.70E-05 \times 0.055 = 2.6E-06$$

Benzene: Non-Carcinogenic effects

$$HQ = \frac{Dose}{RfD}$$

$$HQ = \frac{1.37E-04}{0.004} = 0.034$$

Calculated risk is compared with acceptable risk to make a decision!

Risk Assessment Concepts

Calculation of Risk Based concentrations

Risk depends on exposure and toxicity

Given an acceptable risk, calculate safe concentration

Estimation Of Risk Based Target Level
Ingestion of Water

Estimate the allowable concentration in water for ingestion for an adult for an IELCR of 1E-05.

Benzene: Carcinogenic effects

$$AllowableDose = \frac{IELCR}{Slopefactor}$$

$$Dose = \frac{1E-05}{5.5E-02} = 0.0002\, mg/kg-day$$

Allowable Concentration for Carcinogen

$$CW = \frac{Dose \times BW \times AT_C \times 365}{IR \times EF \times ED}$$

$$CW = \frac{0.0002 \times 70 \times 70 \times 365}{2.0 \times 350 \times 24} = 0.02\ \text{mg/L}$$

Estimation Of Risk Based Target Level Ingestion Of Water

Estimate the allowable concentration in water for ingestion by an adult receptor for a HQ of 1.0

Benzene: Non-Carcinogenic effects

$$AllowableDose = HQ \times RfD_o$$

$$Dose = 1.0 \times 4E-03 = 0.004 \; mg/kg-day$$

Allowable Concentration for Non-Carcinogen

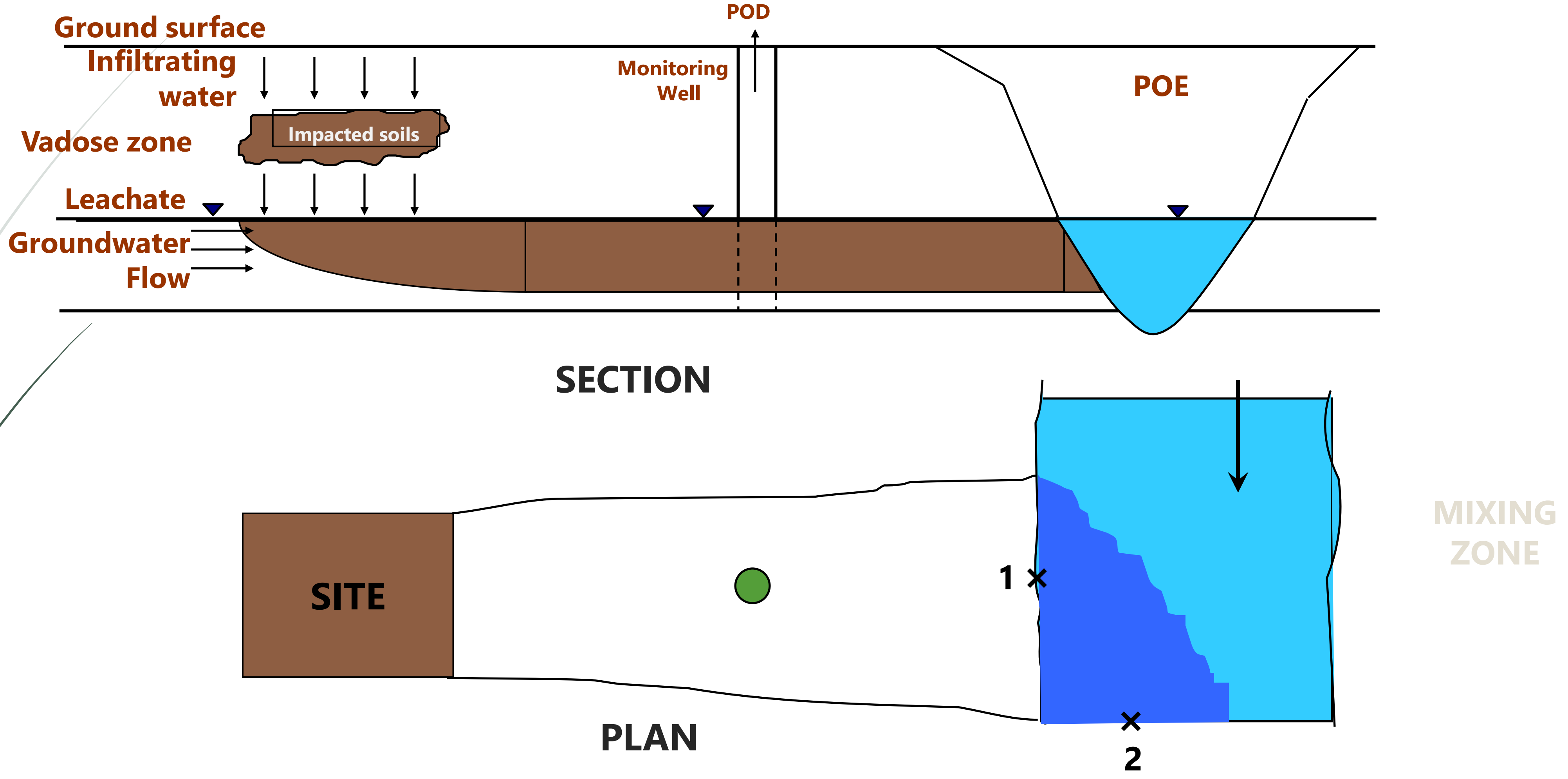
$$CW = \frac{Dose \times BW \times AT_{NC} \times 365}{IR \times EF \times ED}$$

$$CW = \frac{0.004 \times 70 \times 24 \times 365}{2.0 \times 350 \times 24} = 0.15 \, \text{mg/L}$$

Risk Based Groundwater Protection

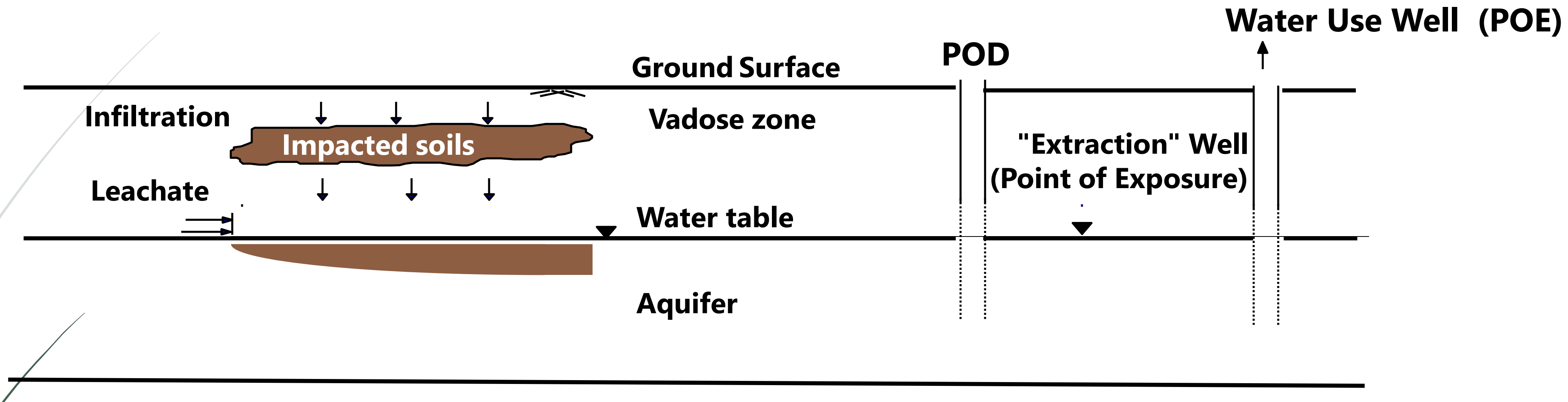
Policy & Science

Migration from Soil to Groundwater to Surface Water



1: Point of seepage; 2: Edge of mixing zone

Leaching from Soil to Groundwater Pathway



POE: Point of Exposure
POD: Point of Demonstration

Two Critical Policy Choices

1. Location of POE
2. Acceptable concentration at POE

Key Policy Choice-1

Examples of location of downgradient POE

- Nearest location of an existing well
- Nearest location of a future well
- Below the source
- Property boundary
- Specified distance from property boundary
- Specified distance from source

Key Policy Choice-2

Examples of Concentration at the POE:

- Drinking water standard
- Tap Water Standard
- Other value

Science: Estimation of Concentration Reduction (CRF) Factor

Estimate CRF between source and POE

Option 1: Use data

Option 2: Use a fate and transport model

Option 3: Use combination of model and data

The only practical approach is Option 3.

Example Calculation

A well is located 200 m downgradient of a soil source.

- **CRF in unsaturated zone = 1**
- **CRF in mixing zone = 5**
- **CRF in saturated zone = 10**
- **Acceptable POE Concentration is 5ug/l**

Estimate

- **Groundwater source concentration**
- **The soil source leachate concentration protective of POE**

Solution

Acceptable concentration at the POE = 5 ug/l

Acceptable concentration at groundwater source

5 X 10 = 50ug/l

Acceptable concentration at the water table

50 X 5 = 250 ug/l

Acceptable concentration at the soil source/leachate concentration:

250 X 1 = 250 ug/l

Using the equilibrium theory to calculate soil concentration.

Forward And Backward Modes Of Risk Assessment (Indirect Routes Of Exposure)

Forward Mode - Is risk below regulatory acceptable level?

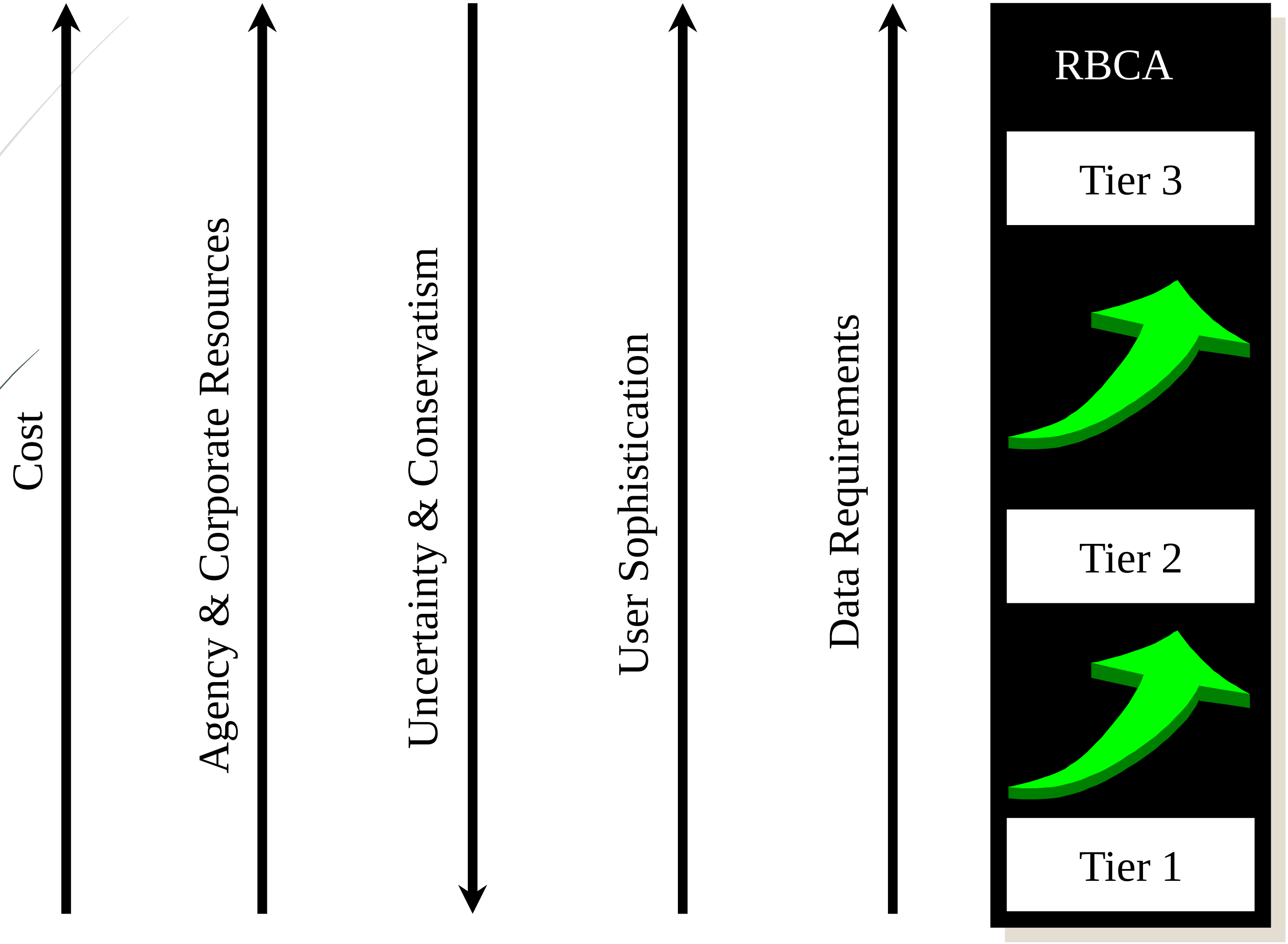
Model/Data		Default or Site-Specific		EPA/State Databases		Default or Site-Specific		EPA/State Databases		?
POD Concentrations	X	Media Parameters	X	Chemical Specific Properties	X	Exposure Factors	X	Toxicity	=	Risk
?		Default or Site-Specific		EPA/State Databases		Default or Site-Specific		EPA/State Databases		Policy

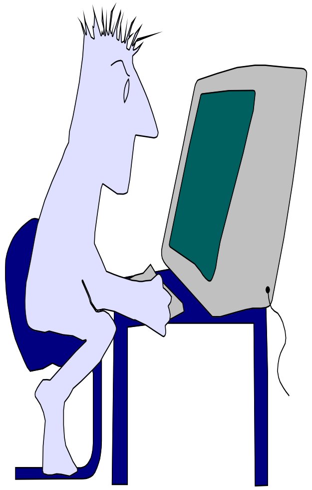
Backward Mode - Are the representative site concentrations below the estimated clean-up levels?

PRBCA is a Tiered Process

- **All tiers provide the same acceptable risk level.**
- **All tiers require similar inputs to develop target levels.**
- **Tier-1 levels are developed using conservative default assumptions and factors.**
- **Tier 2 & 3 allow use of more site-specific data**

Tiered Analysis



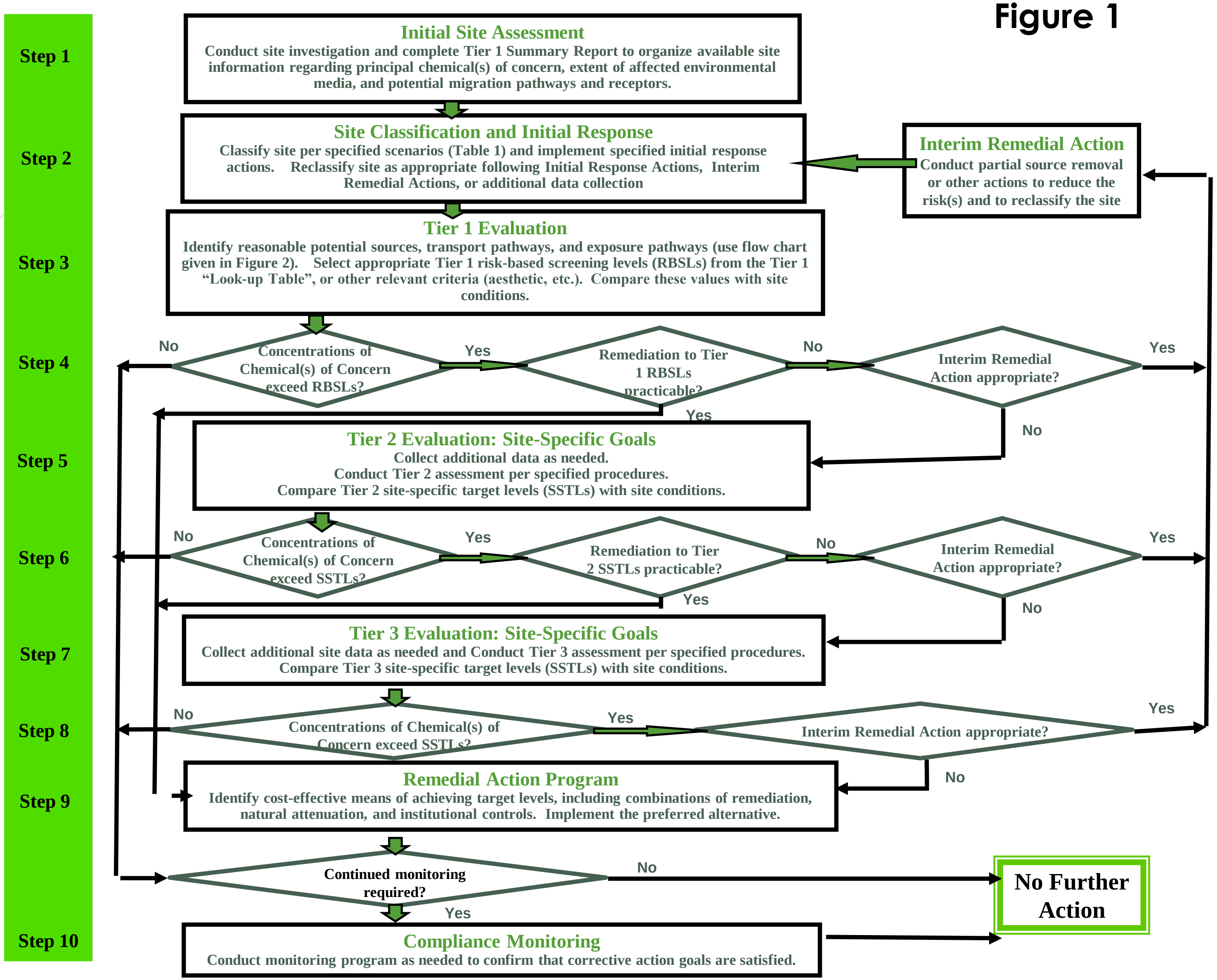


Tiered Analysis: Total Project Cost

Tier	Data Collection	RA	Monitoring	Remediation	Opportunity Loss
Tier 1 1 ppm	Low	Low	High	High	Low
Tier 2 20 ppm	Medium	Medium	Medium	Medium	Low
Tier 3 100 ppm	High	High	Low	Low	High

Total project cost must decrease as the project moves to higher tiers
All tiers meet target risk levels and other requirements

RBCA Flowchart
Figure 1



Comparison of Different PRBCA Tiered Evaluations (PRBCA Process)

Factors	Threshold Level	Tier 1	Tier 2	Tier 3
Exposure Factors	NA	Default	Default	Site-specific
Toxicity Values	NA	Default	Default	Most current
Physical and Chemical Properties	NA	Default	Default	Most current
Fate and Transport Parameters	NA	Default	Site-specific	Site-specific
Unsaturated Zone Attenuation	NA	Depth dependent (refer Appendix A)	Depth dependent (refer Appendix A)	Site-specific
Fate and Transport Models	NA	Default	Default	Alternative
Representative Concentrations	NA	Average	Average	Average
Acceptable Risks for Each COC and Each Exposure Pathway	NA	IELCR = 1×10^{-5} HQ = 1.0	NA	NA
Cumulative Site-wide Carcinogenic Risk	NA	NA	1×10^{-4}	1×10^{-4}
Cumulative Site-wide Non-carcinogenic Risk	NA	NA	HI = 1.0	HI = 1.0
Point of Exposure	NA	Source	Site-specific	Site-specific
Ecological Risk	NA	Level 1, 2, or 3		
Outcome of Evaluation	NA	NFA, Tier 2, RMP	NFA, Tier 3, RMP	NFA, RMP
Land Use Restrictions/AULs	NA	Site-specific		

Outcome of PRBCA Process

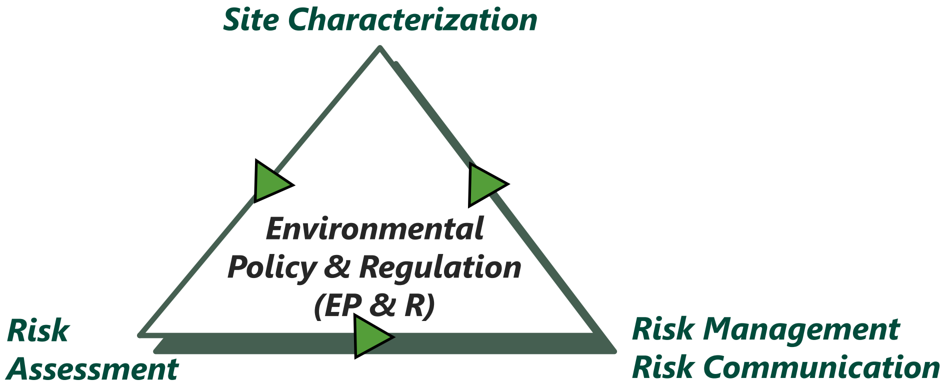
If correctly implemented, PRBCA can provide a clear path forward for the site that may include:

- No further action needed (safe levels achieved & residual impacts are stable)
- Additional data collection to demonstrate (i) plume is stable, and (ii) safe levels have been achieved
- Remediation (passive or active) to meet safe levels

A Fundamental Paradigm Shift

- **Conventional Approach**:
  - How much chemical mass can we remove?
- **RBCA Approach**:
  - How much chemical mass can we safely leave behind?
  - How do we ensure that future generations are aware of the chemicals left behind so there are no surprises?

Thank you



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