



National Institute for Public Health  
and the Environment  
*Ministry of Health, Welfare and Sport*

After 25 year  
exposure  
modeling:  
similar model  
structures,  
different exposures

*Frank A. Swartjes*

**International Conference  
Contaminated Sites 2015,  
Bratislava**

28 Mai 2015



# OUTLINE

- Introduction
- Exposure models
- Major exposure pathways
- Exposure comparison
- Good practice



# CHEMICAL BODY LOAD

- ❑ Chemical footprint of past exposure
- ❑ Environment, diet, water, air, indoors
- ❑ Lead from geological sources in tooth enamel of 77 UK individuals from the Neolithic Era (circa 5000 years ago) until 16<sup>th</sup> century  
*(Budd et al., 2004)*




# WHAT'S THE PROBLEM?

Health damage from contaminants from soil and groundwater:

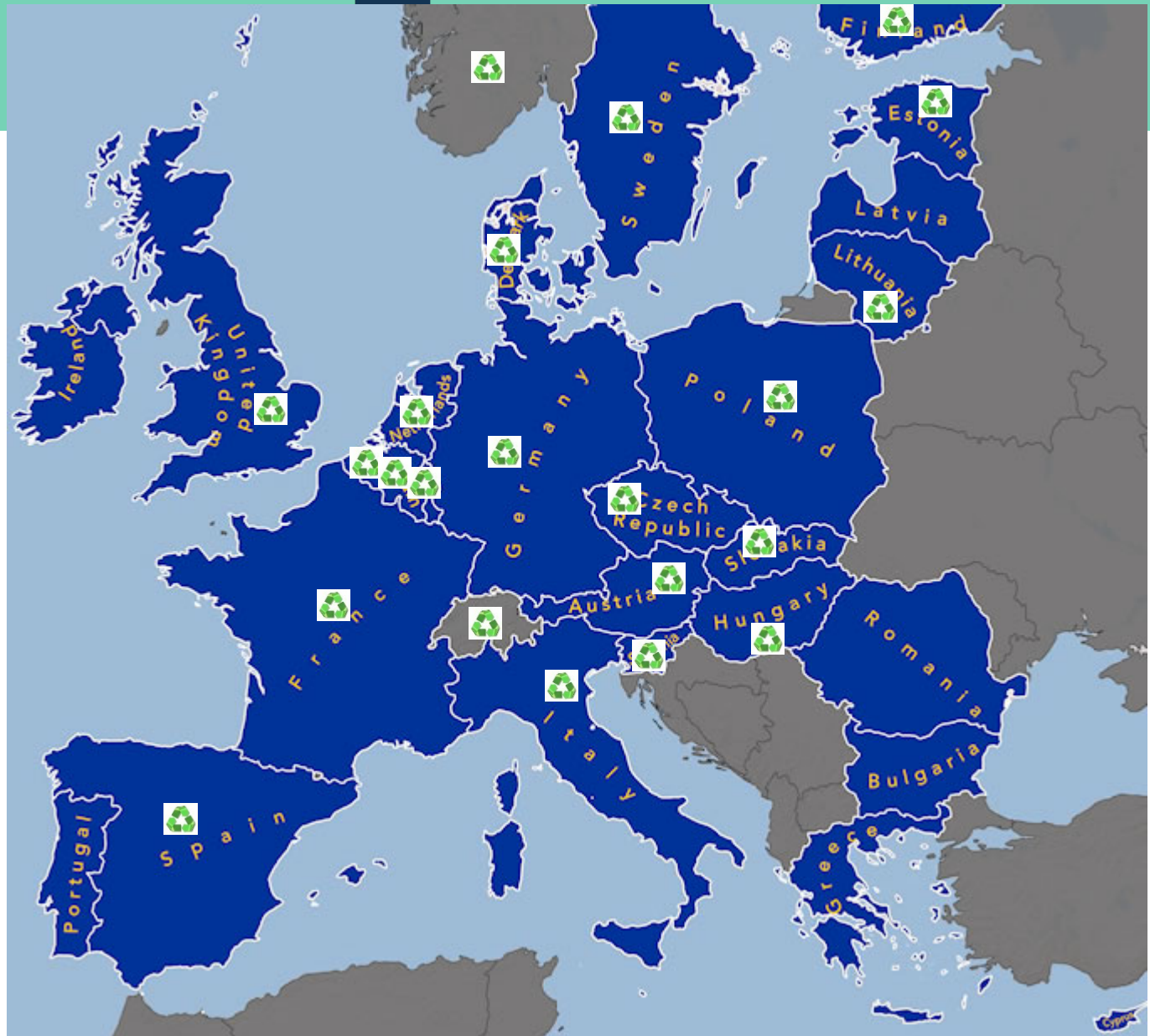
- ❑ From relatively innocent symptoms (e.g. skin eruption or nausea)
- ❑ Up to increased risk for cancer or even death





 = Risk-based SSVs

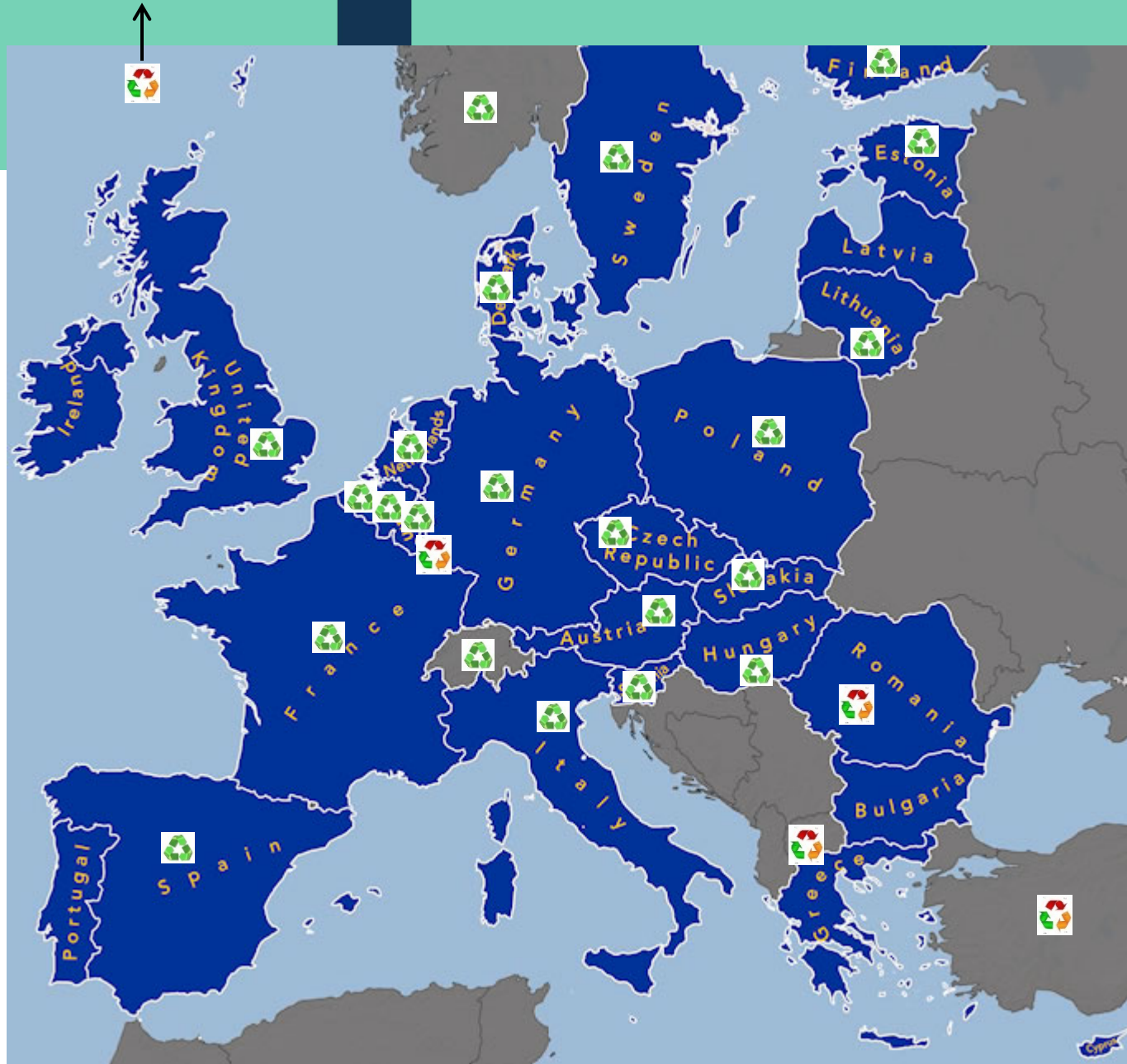
18 out of 28  
EU Member  
States:  
risk-based  
SSVs, incl.  
H Health





= SSVs in development

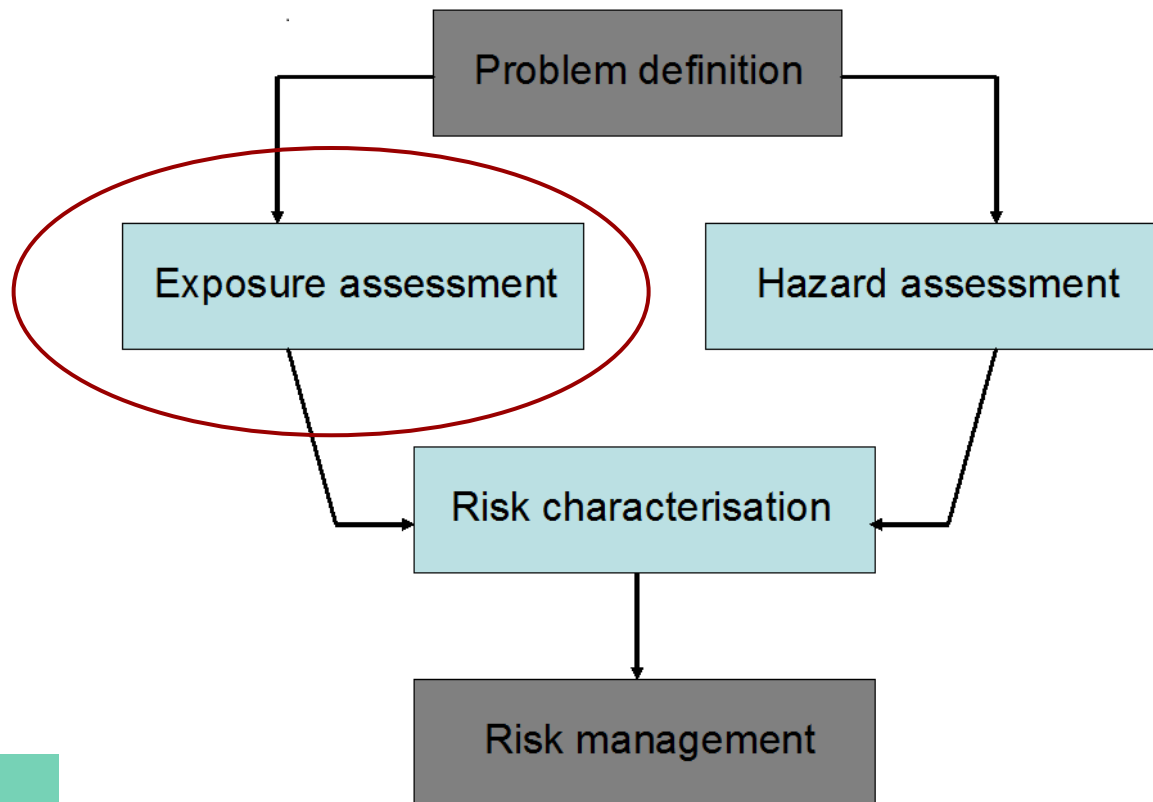
5 (2 EU) in development  
(20 out of 28 EU Member States)





# ASSESSMENT FRAMEWORK

*(US National Research Council 1983)*





# OUTLINE

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- Conclusions





# EXPOSURE CALCULATIONS

- ❑ Worldwide several exposure models available
- ❑ Basically same structure
- ❑ Different boundary conditions and **input parameters**



# NoName Sweden

JAGG  
NMF

CLEA

CSOIL

S-Risk

UMS

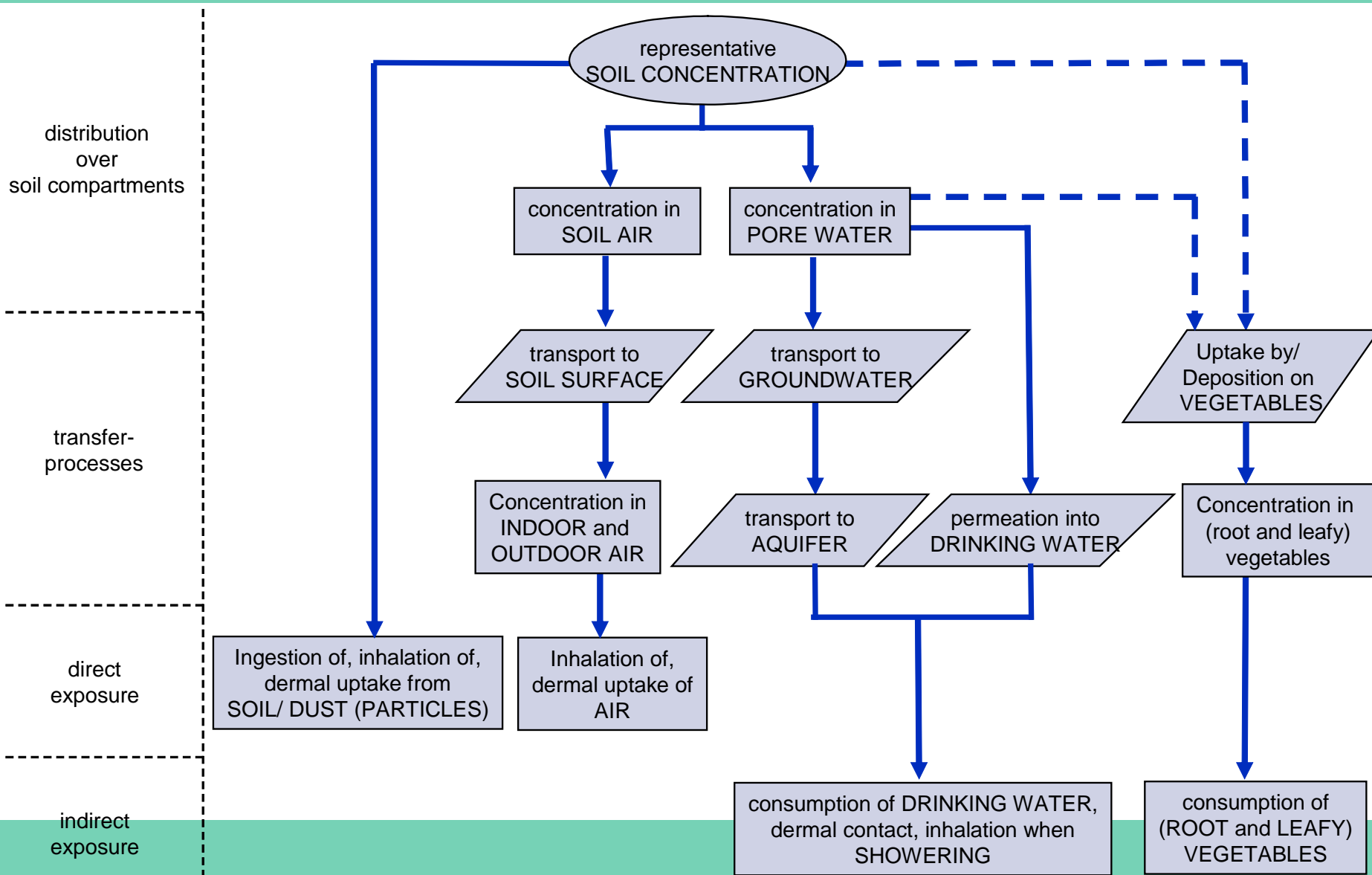
NoName France



LUR

Risk-net

# DUTCH CSOIL EXPOSURE MODEL





# DIFFERENCES EXPOSURE MODELS

## structure

- < compound-specific properties
    - < human characteristics
      - < physical-chemical processes
        - < human behaviour
          - < geological factors (soil/water)
            - < climatic/ cultural factors
- < policy decisions



# OUTLINE

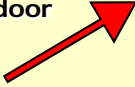
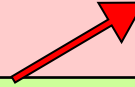

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# EXPOSURE PATHWAYS

*(Carlton and Swartjes 2007)*

Pathways	Routes of exposure
Soil > Outdoor 	<b>Outdoor: soil ingestion</b>
	Outdoor: dermal exposure to soil
	Outdoor: inhalation of soil vapors
	Outdoor: inhalation of soil derived dust
	Outdoor: inhalation of volatilized irrigation water
Soil > Indoor 	Indoor: dust ingestion
	Indoor: dermal exposure to soil derived dust
	<b>Indoor: inhalation of soil originated vapors</b>
	Indoor: inhalation of volatilized domestic water
Soil > Diet 	<b>Res. diet: uptake of homegrown vegetables</b>
	Res. diet: Ingestion of soil attached to vegetables
	Res. diet: uptake of homegrown fruits
	Res. diet: ingestion of soil attached to fruits
	Res. diet: consumption of meat
	Res. diet: consumption of diary products
Groundwater	Resident diet: consumption of groundwater
	<b>Indoor: inhalation of groundwater vapors</b>
	Showering
	Irrigation
Surface water	dermal contact surface water (swimming)
	ingestion surface water (swimming)
	ingestion suspended matter (swimming)
	Surface water consumption of fish and shellfish



# EXPOSURE THROUGH SOIL INGESTION

- Soil and dust ingestion rates
- Soil and dust concentrations
- Body weight
- Relative bioavailability correction



# SOIL AND DUST INGESTION RATES

- ❑ **Tracer studies** (e.g. Al, Si, Ti, Y in faeces (and urine))
- ❑ Hand-loading studies (video, real-time observation)
- ❑ (Biokinetic models)
- ❑ (Lead isotope methodology)

*(Bierkens et al., 2011)*



# SOIL INGESTION RATES

☐ Children: consensus



☐ Adults: debate





# SOIL AND DUST INGESTION RATES

*Soil and dust combined, children:*

☐ Tracer studies: 31 – 195 mg/day  
(*e.g., Stanek et al 2001; Sedman and Mahmood 1994*)

☐ **100 mg/day** (soil and dust combined)







# SOIL AND DUST INGESTION RATES

*Soil and dust combined, adults:*

- ❑ Tracer studies: 23 - 92 mg/day  
(e.g., *Davis and Mirick 2006*)
- ❑ 0 – 50 mg/day





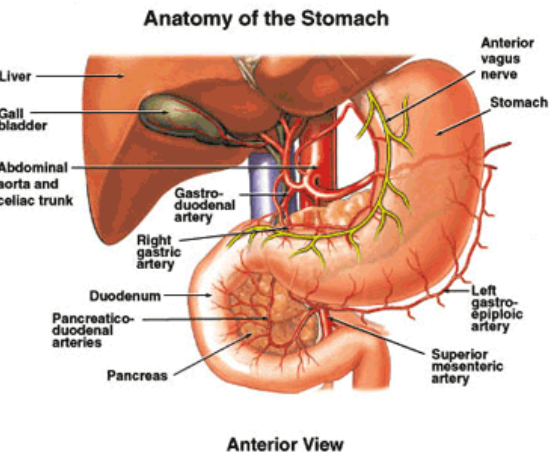
# (SOIL-BORNE) DUST EXPOSURE



- ❑ Crawling children
- ❑ Enrichment in fine particles
- ❑ Settled house dust principle exposure medium for lead of children *(Lanphear 2003)*



# BIO-AVAILABILITY IN THE HUMAN BODY



## *Controlling factors:*

- ❑ Concentration is soil, pH in stomach (hence: **feeding conditions**), soil matrix
- ❑ (Speciation, soil type, soil properties)

*(Oomen en et al., 2002)*



# BIO-AVAILABILITY IN THE HUMAN BODY

- ❑ The Bioaccessibility Research Group of Europe  
[www.bgs.ac.uk/barge](http://www.bgs.ac.uk/barge)
- ❑ Unified BARGE method (UBM)  
(Wragg 2009; Denys et al., 2012; Bakker et al., in press)



# EXPOSURE THROUGH VEGETABLE CONSUMPTION

- Vegetable consumption rates
- Contribution from own garden
- Concentration in crops
- Body weight
- Relative bioavailability correction





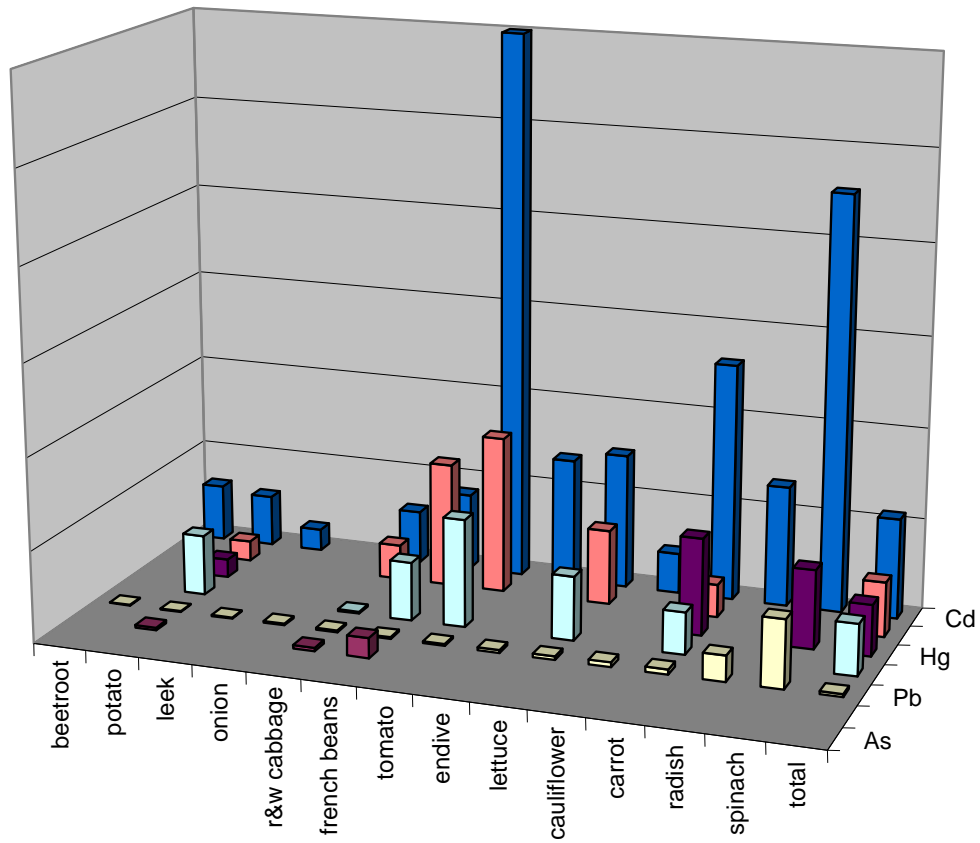
# CONTRIBUTION FROM OWN GARDEN

- No decent statistics
- Policy decision:  $x\%$  *should* be possible
- Depending on land use



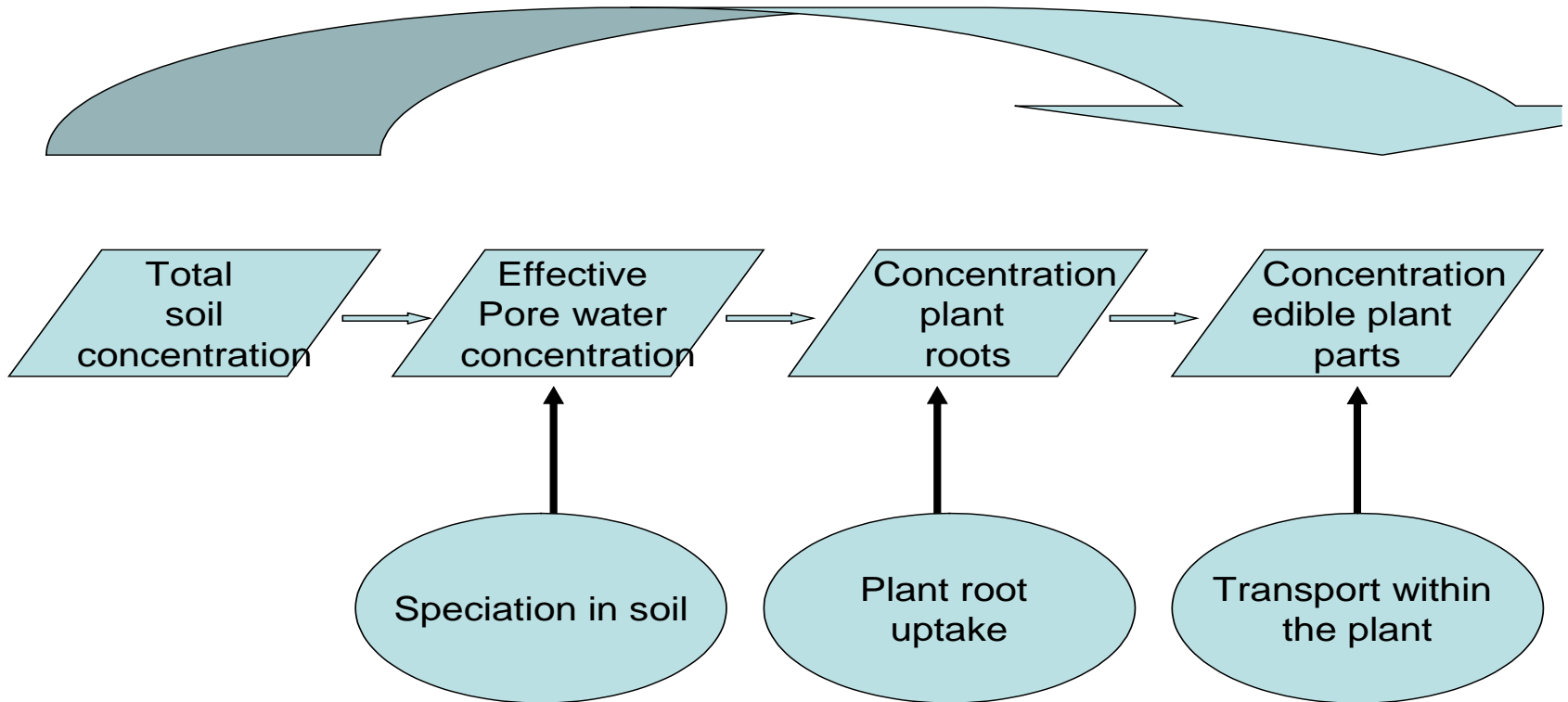


# ACCUMULATION CROPS: METALS





# THREE STEP PROCEDURE





# CALCULATION METALS

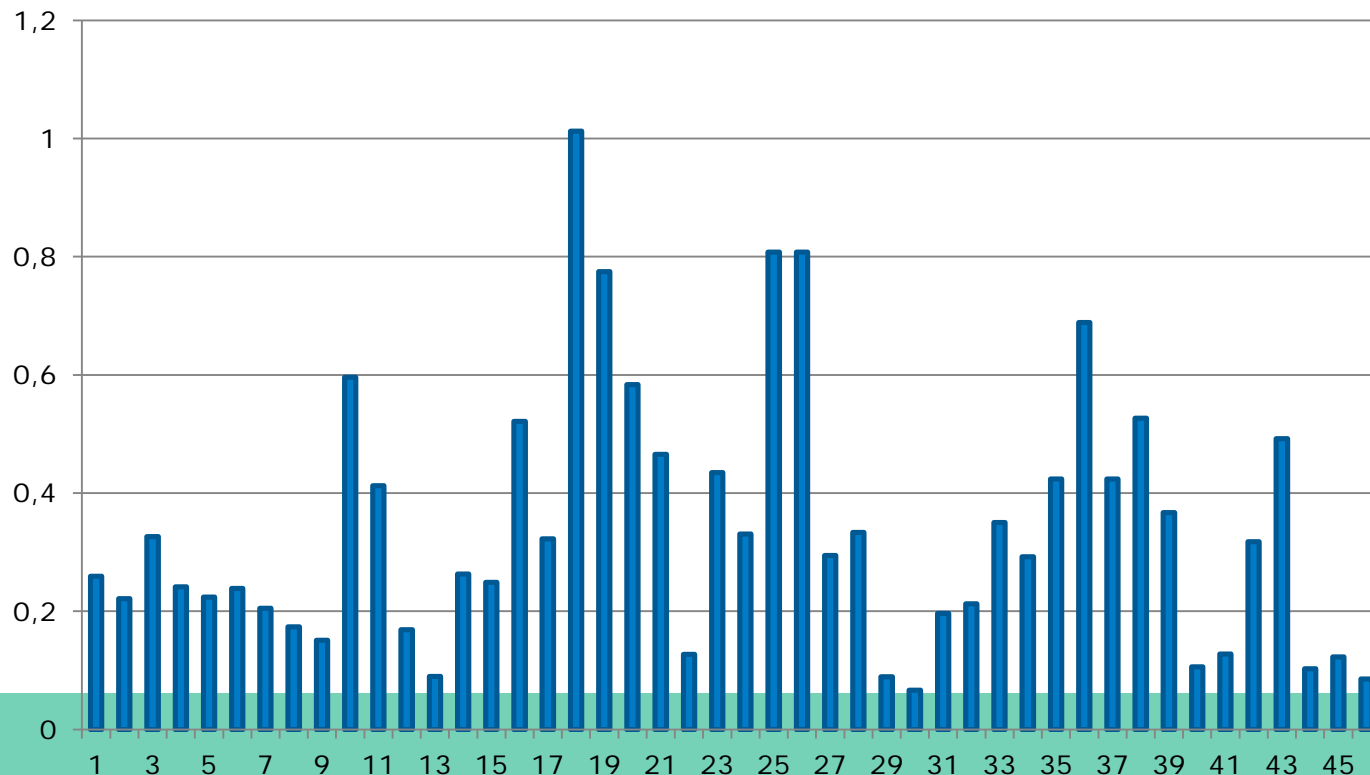
- ❑ Commonly used: constant BCF for a specific metal
- ❑ For all crops
- ❑ Independent of concentration in soil





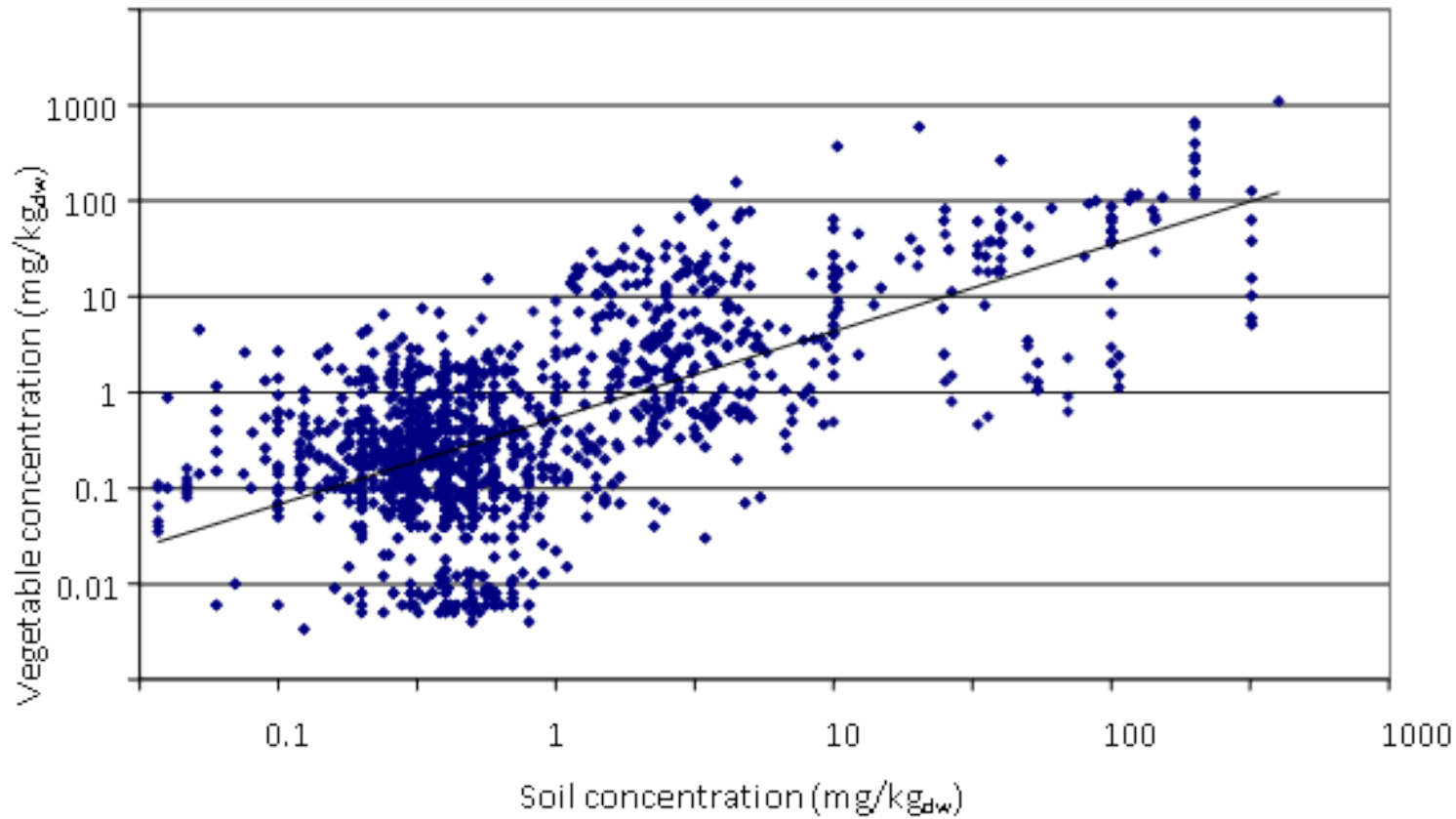
# RIVM DATASET Cu (n = 46)

- Potatoes, cauliflower, cabbage, carrot, lettuce, beans
- pH = 4.9 – 8.4;                      %OM = 0.19-0.57





# SOIL – PLANT RELATIONS Cd



$$R^2 = 0.43 \quad (\text{Swartjes et al. 2007})$$



# CALCULATION METALS

*(Swartjes et al 2013)*

- ❑ Concentration for each vegetable =  
 $f(\text{Concentration}_{\text{soil}}, \text{pH}, \% \text{OM}, \% \text{clay})$
- ❑ For each vegetable
- ❑ Consumption-rate-weighted-BCF



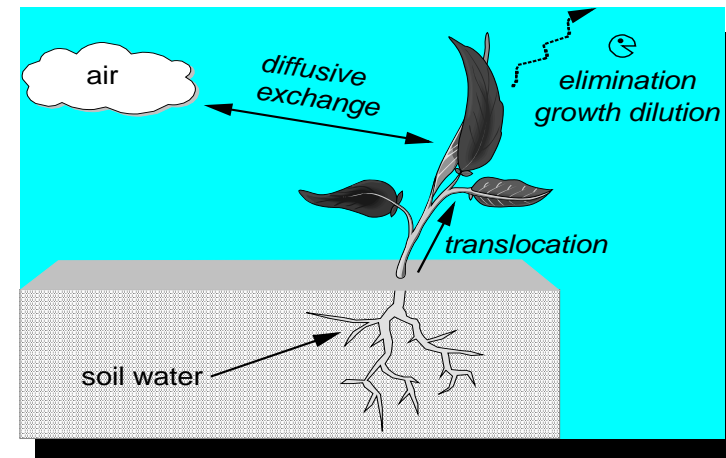


# CALCULATION ORGANIC CONTAMINANTS

*(Trapp and Legind 2011)*

□ Concentration in roots =  
 $f(\text{BCF}_{\text{crop-water}}, C_{\text{pore water}})$

□ Concentration in leafy vegetables =  
 $f(\text{transpiration stream}, C_{\text{pore water}})$





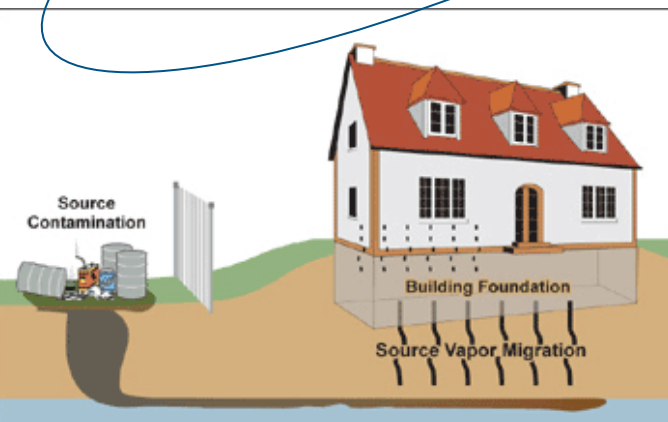
# EXPOSURE DUE TO INHALATION INDOOR AIR

Problem child

- Convection and diffusion in groundwater and soil
- Intrusion into buildings
- Ventilation
- Degradation



Complicated/ Relatively unreliable





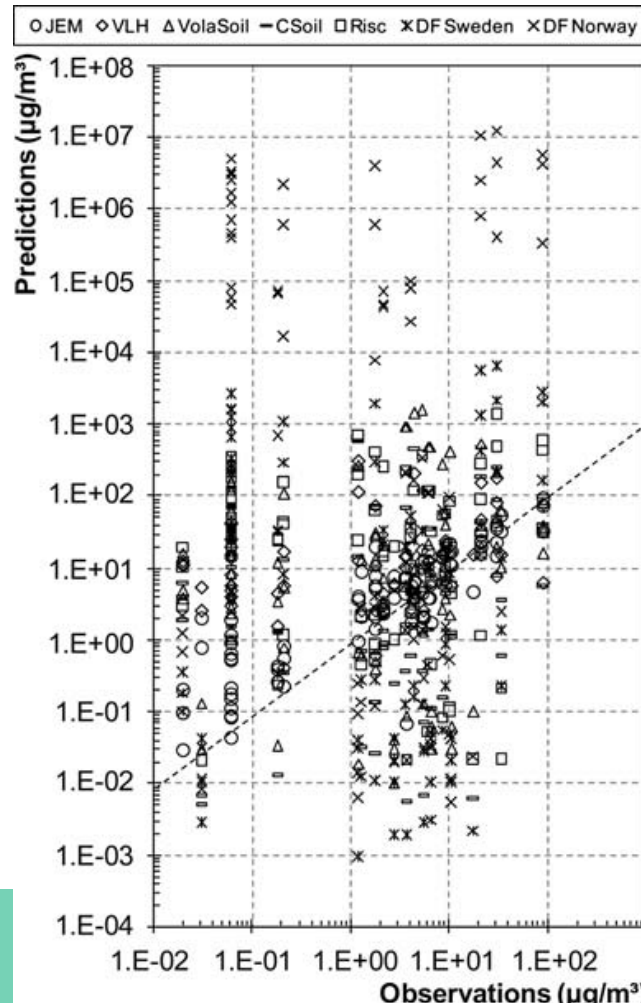
# LIMITATIONS

- ❑ *Abreu & Johnson (2005/2006):* position of groundwater plume/ diffusion obstacles/ preferential flow ( *$\alpha$  2-5 OoM 20 m shift*)
- ❑ *Picone (2012).* Distribution of water in soil profile (oxygen supply)/ degradation (*several OoM*)
- ❑ *Provoost (2013).* Henry coefficient/ overestimation





# VALIDATION STUDY 7 VAPOR INTRUSION MODELS – INDOOR AIR



*(Provoost et al. 2009)*



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# EXPOSURE MODEL COMPARISON STUDY

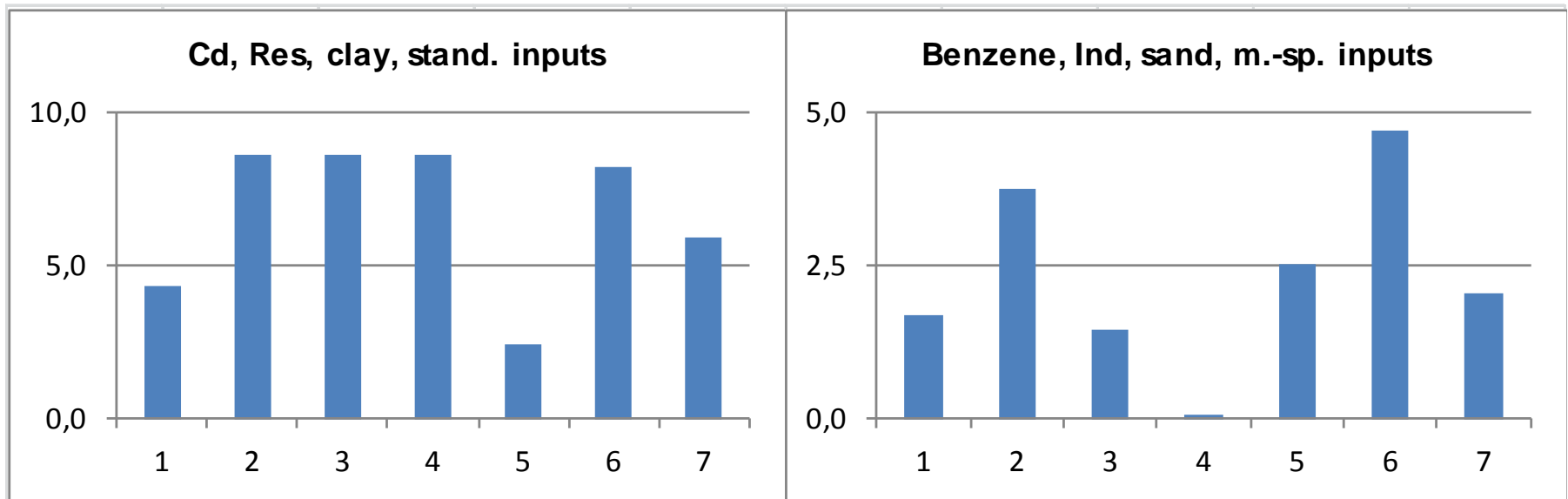
(Swartjes 2009)

- 7 exposure models
  
- 40 hypothetical exposure scenario's:
  - compounds (atrazine, benzene, Cd, B(a)P, TCE)
  - soil types
  - land use
  - Standardised IP/ 'Model specific' IP



# SOIL INGESTION

Exposure adults (mg/ kg<sub>BW</sub>/day):



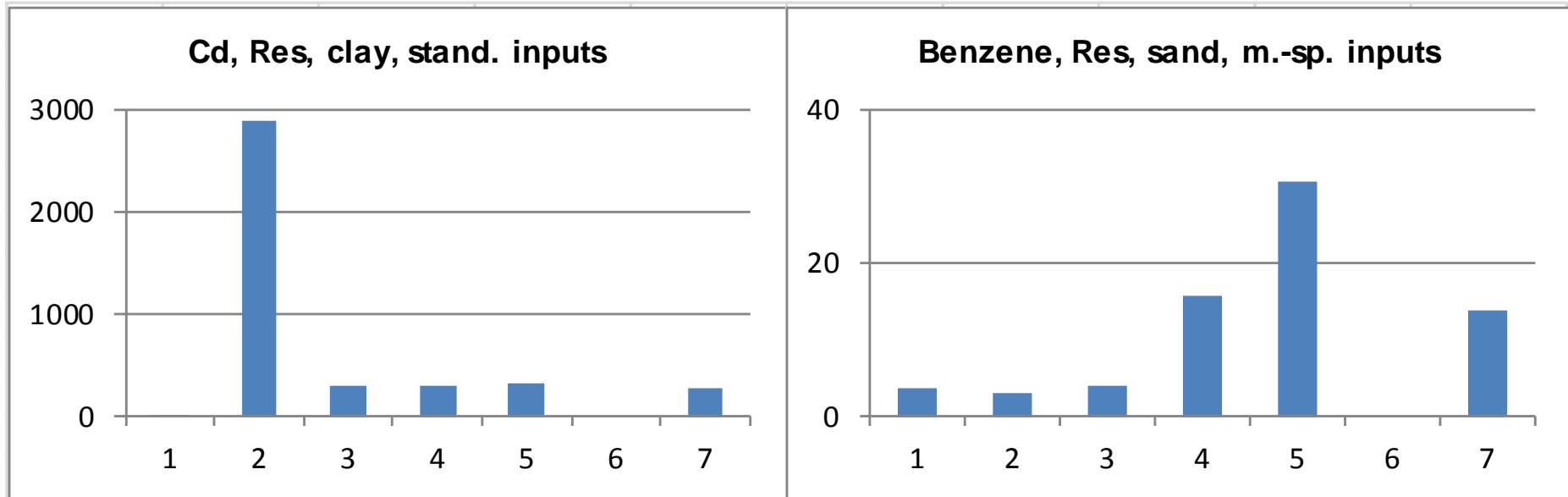
*x 10<sup>6</sup> (left) / x 10<sup>7</sup> (right)*





# VEGETBALE CONSUMPTION

Exposure adults (mg/ kg<sub>BW</sub>/day):



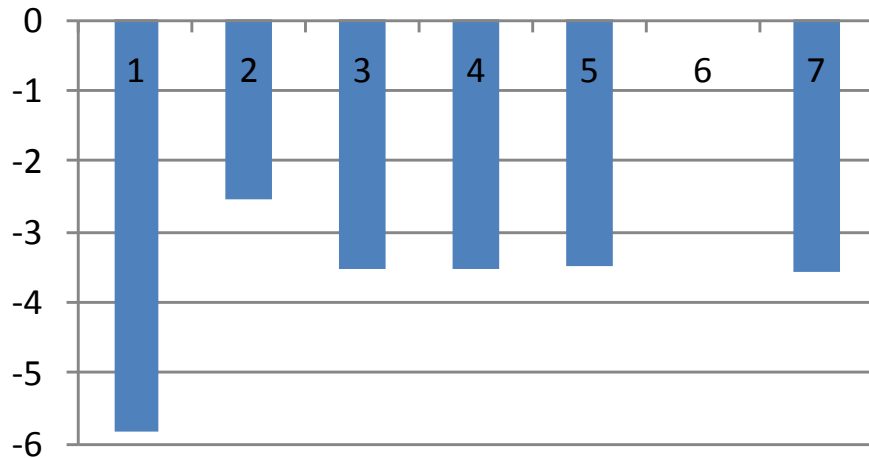
*x 10<sup>6</sup> (left) / x 10<sup>4</sup>(right)*



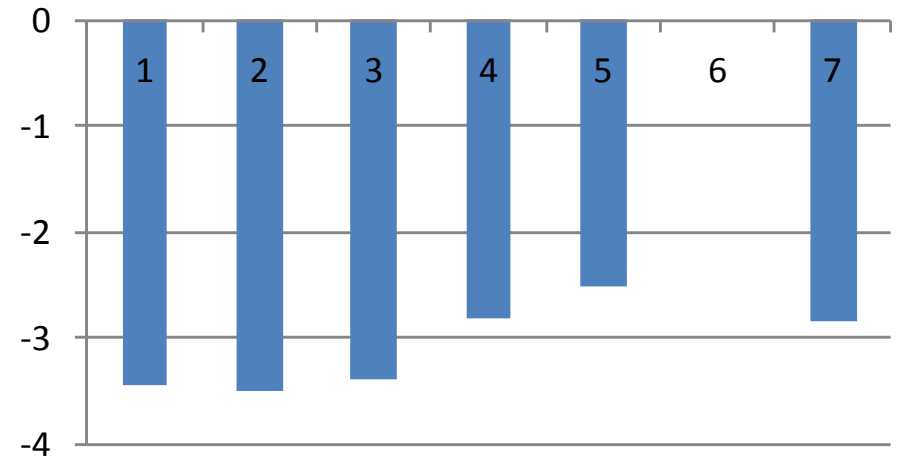
# VEGETBALE CONSUMPTION

Exposure adults (mg/ kg<sub>BW</sub>/day):

Cd, Res, clay, stand. inputs



Benzene, Res, sand, m.-sp. inputs

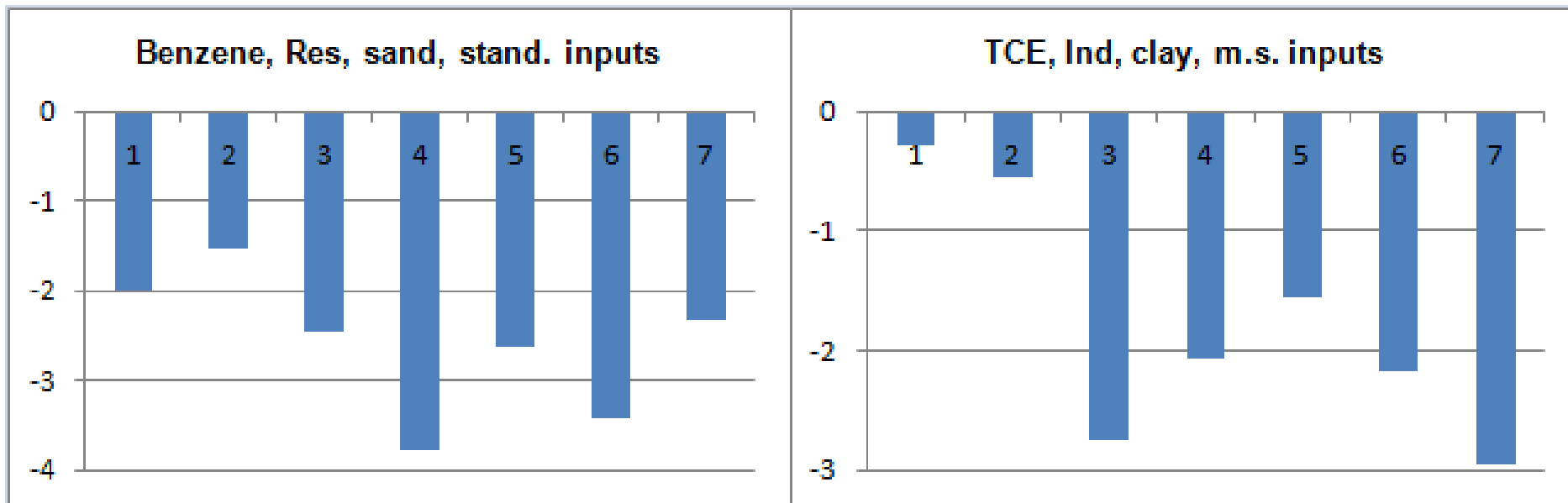


*Log transformed*



# INDOOR AIR INHALATION

Exposure adults (mg/ kg<sub>BW</sub>/day):



*Log transformed*

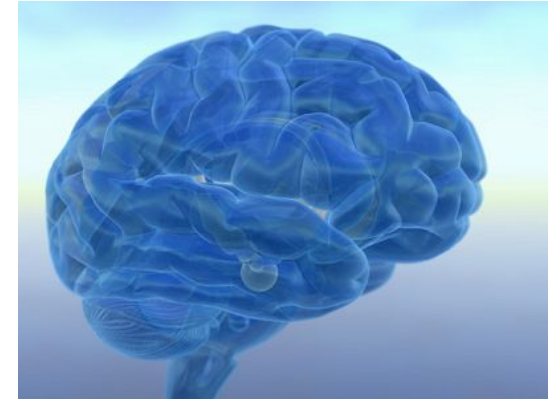


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# ACTING SMART



- ❑ Multiple lines of evidence
- ❑ Combination between **calculations and measurements** (contact media)
- ❑ **Tiered approaches**
- ❑ Experience & **creativity**



# TIME FRAME

- ❑ Biomonitoring: exposure *history*
- ❑ Measurements in contact media: *actual* values only
- ❑ Exposure modelling: *future* conditions



# ACKNOWLEDGEMENT OF LOCAL CONDITIONS

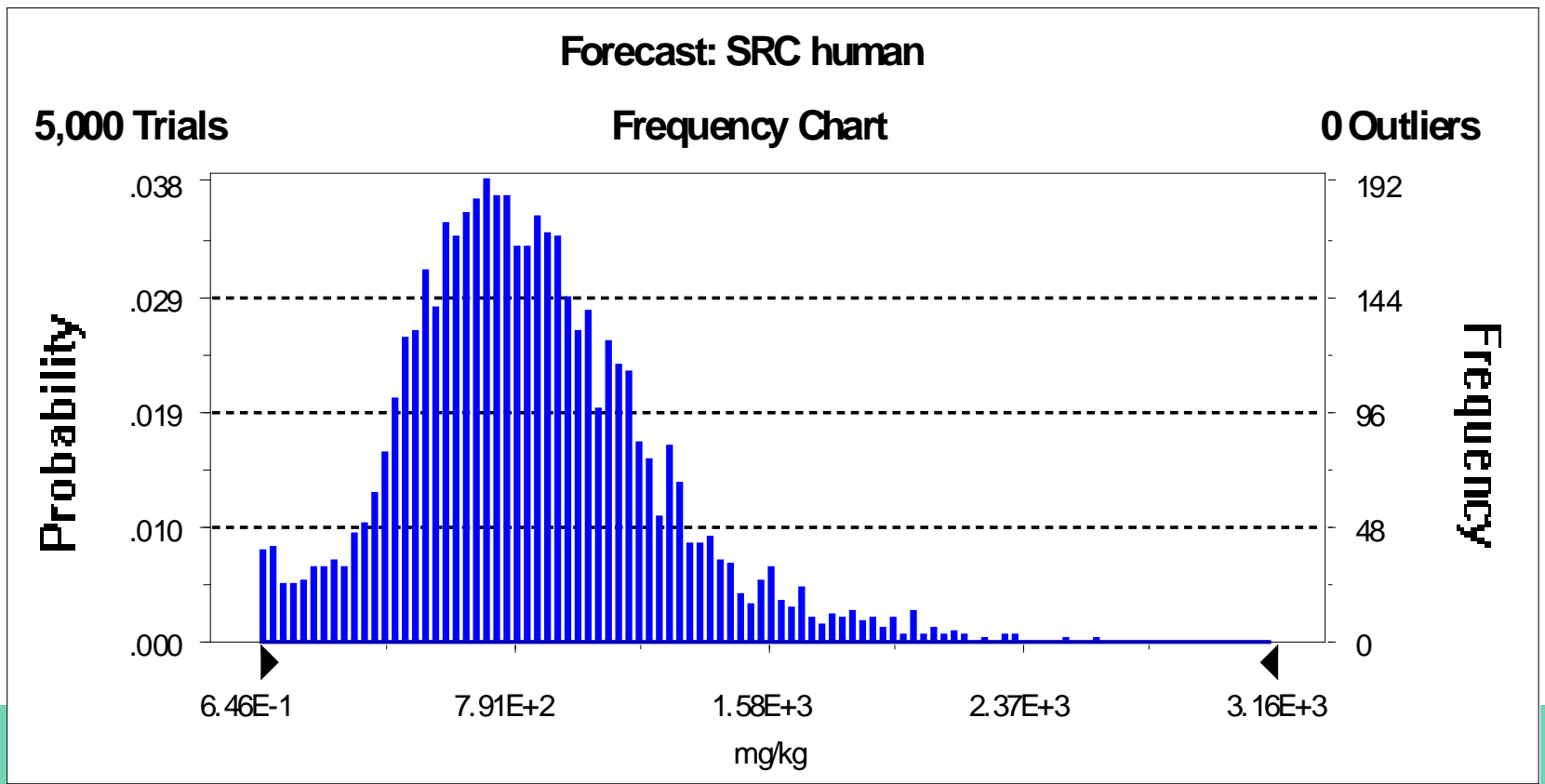
- ❑ Groundwater tables/ design houses VERSUS risk of indoor air inhalation
  
- ❑ Vegetable uptake under tropical conditions  
(Dos Santos et al., in press; Sao Paulo)  
(Jing et al., in press; SW China)
  
- ❑ Geophagy in South Africa  
(*e.g., Eijsackers et al., 2014*)





# PDF HH SCREENING VALUE LEAD

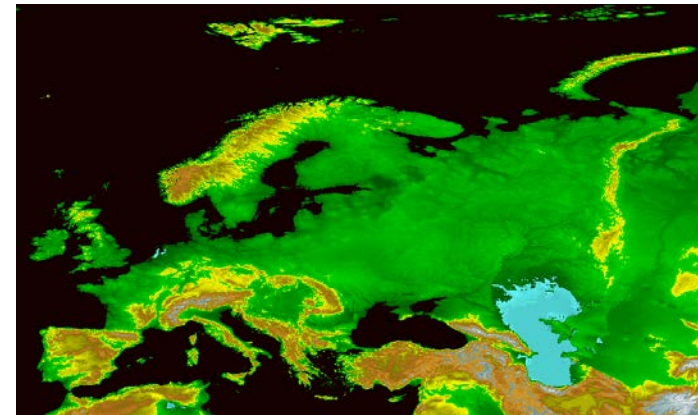
variation due to contaminant characteristics





# HARMONIZATION

- ❑ One set of SSVs? No!!
- ❑ The same blueprint? No!
- ❑ → Toolbox, including
  - standardised tools
  - flexible tools

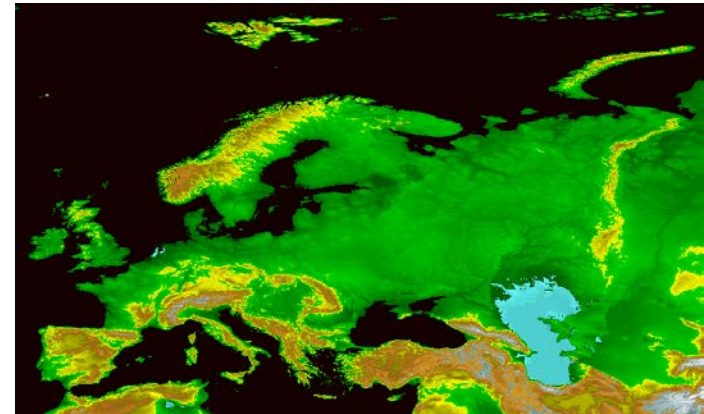




# FLEXIBLE TOOLS

*Accounting for differences in:*

- ❑ Geography
- ❑ Culture/ social aspects
- ❑ Policy decision making

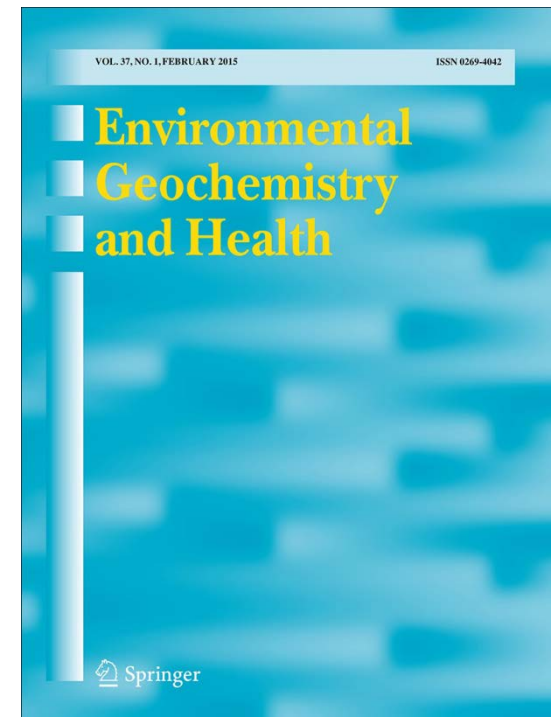




# NOT ENOUGH?

(Swartjes 2015)

*Human health risk assessment  
related to contaminated land:  
State of the art*





*Dear colleagues:*

THANKS  
for  
the  
ATTENTION !



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[www.RIVM.NL](http://www.RIVM.NL)