

# **Lead (Pb): Upcoming Implications for Contaminated Site Soil Quality Guidelines**

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# OVERVIEW

- **Background levels (pre- and post-anthropogenic)**
- **Concentrations at contaminated sites**
- **Toxicity and toxicokinetics of Pb**
- **Challenges associated with developing a soil quality guideline for Pb**
- **Options for data collection to provide site-specific guidelines that are more reflective of site-specific conditions**

# BACKGROUND LEVELS

- Pb is a highly useful metal apply by humans since pre-Roman and Greek times
- Concentrations in soil prior to human refinement and use of Pb were < 0.1 ppm
- Elevated levels have been found in various rocks

Table 2-7. Naturally Occurring Lead Concentrations in Major Rock Types

Lithology	Natural Pb Concentration (ppm)
Continental Crust	15.0
Oceanic Crust	0.9
Basalts, Gabbros	3.5
Limestones	5.0
Granulites	9.8
Greywackes	14.0
Gneisses, Mica Schists	22.0
Shales	22.0
Granites	32.0

Source: Reuter and Weiss (2002).

# ANTHROPOGENIC LEVELS

- **Example concentrations at contaminated sites**
  - Smelters 1,500 mg/kg; 1 to 5 ug/L water
  - Refinery sites 1,000 mg/kg
  - Mining (acid mine drainage) > 3,000 ug/L
- **Historical use of Pb in pipes, paint, pipe solder, and gasoline has lead to widespread increases in Pb soil and water concentrations as well as house dust**
- **Older urban cities 1,000 mg/kg**
- **Ottawa – garden soils > 200 mg/kg (95<sup>th</sup> %ile)**
- **Ottawa – house dust 1,300 mg/kg**

## AENV SQG

<b>Agr</b>	<b>70 ppm</b>
<b>Res</b>	<b>140 ppm</b>
<b>Ind</b>	<b>600 ppm</b>
<b>DWG</b>	<b>10 ug/L</b>

# CHALLENGES

- **Guideline Development**
  - typical non-carcinogenic substances involves subtracting background exposure from the threshold reference value
  - What do you do when background exceeds the acceptable limit?
  - Highly published topic – can find 100 new publications per year
- **Toxicity**
  - Current Pb body burdens maybe in adverse effects range
  - No clear threshold where adverse effects do not occur
  - Evidence for non-linear dose-response steeper at low Pb
  - Body burdens dependent on nutrition, hormone status, socioeconomics, behavior, genetics, age, bioavailability
  - Pb get transferred from the mother to developing embryo *in utero* and from the mother to infant via breast milk

# PEER REVIEWED TOXICITY WORK

- **Highly qualified panel**
- **Physicists from McMaster and Mount Allison University**
- **Canadian Medical Doctors in areas of Environmental and Occupational Health**
- **Scientists from Health Canada - Risk Management Bureau, Contaminated Sites Division**
- **Consultants in Canada and the United States (well published in the field)**
- **Center for Disease Control & Prevention in the United States**
- **Federal Biostatisticians**

# LOW DOSE Pb EFFECTS

- 2.5 µg/dL PbB ~ 0.006 µg/dL plasma ~ 0.003 µg/dL cerebrospinal fluid
- Pb can bind > 1000x more tightly to certain calcium receptors

Dose (µg/dL)	Toxicological Endpoint	Reference
0.00015	effects on vitality and prolif. of human peripheral blood mononuclear cells	Hemdan <i>et al.</i> (2005)
0.0021	threshold for calmodulin activation (calcium mimicking)	Fergusson <i>et al.</i> (2000)
0.005	effects on cytokine release	Hemdan <i>et al.</i> (2005)
0.021	11% decrease in dopaminergic neurite length	Schneider <i>et al.</i> (2003)
0.21	38% decrease in dopaminergic neurite length	Schneider <i>et al.</i> (2003)
2.1	44% decrease in dopaminergic neurite length	Schneider <i>et al.</i> (2003)
2.1	inhibited neurite outgrowth	Kern and Audesirk (2000)

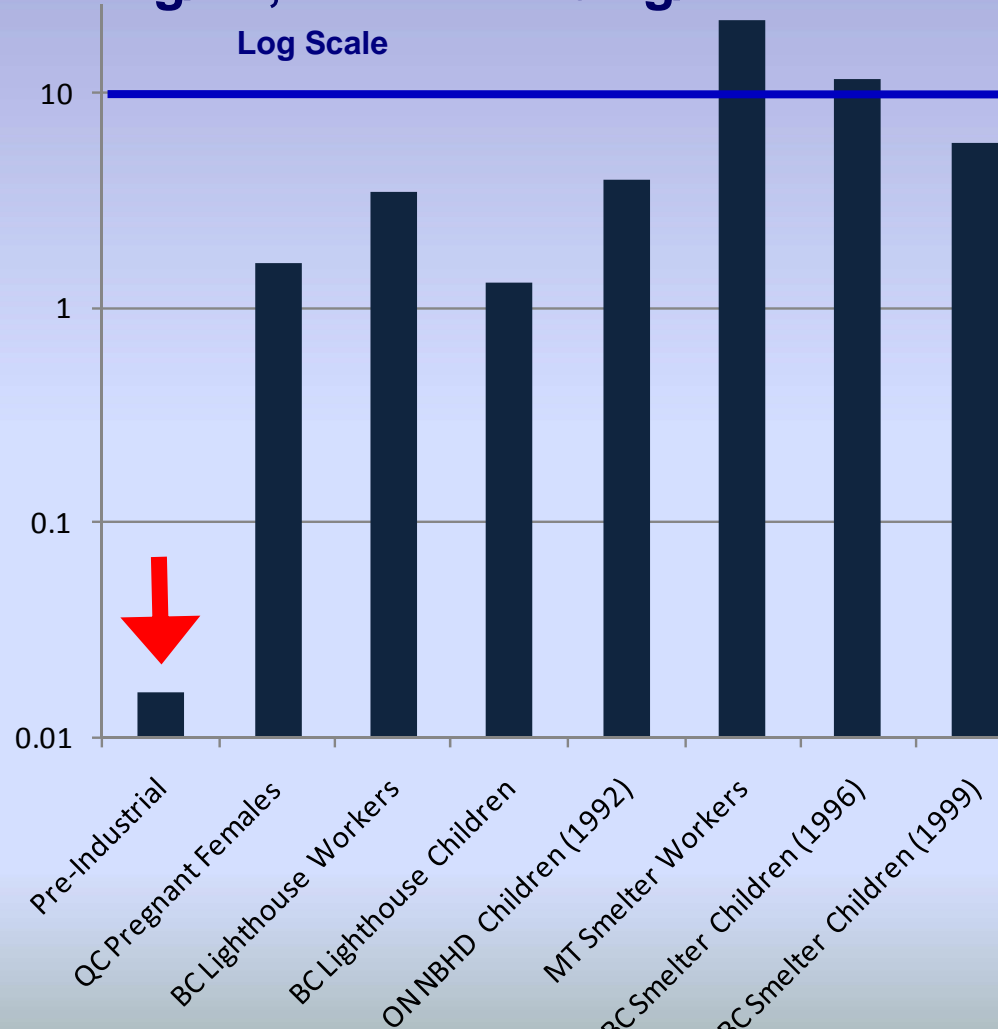
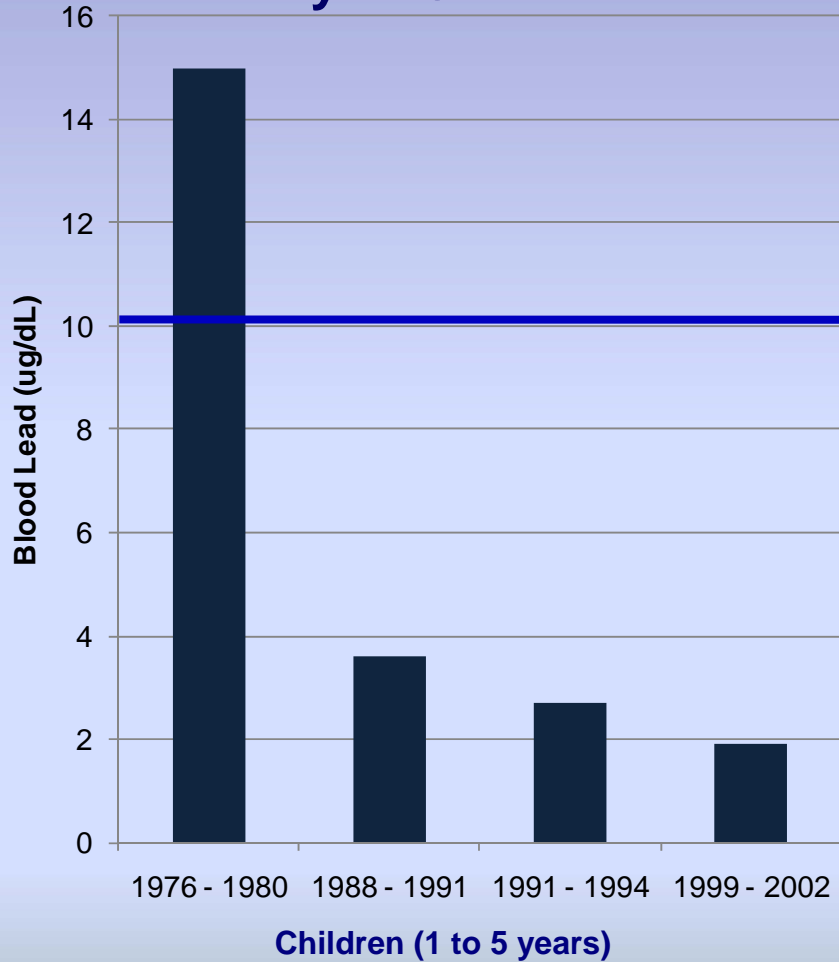
# LOW DOSE EFFECT DATA (< 10 µg/dL)

N	Population	Endpoint	Study
58,518	<u>Adults</u>	<u>increased systolic blood pressure</u>	Nawrot <i>et al.</i> (2002)
2165	Female adults	Hypertension	Nash <i>et al.</i> (2003)
30	Females (preg)	altered placental uptake of calcium	LaFond <i>et al.</i> (2004)
13,946	Adults	Increase cardiovascular disease and mortality	Menke <i>et al.</i> (2006)
325	Female adults	increased risk of neuropsychological effects, reaction time	Muldoon <i>et al.</i> (1996)
707	Adults	Kidney effects	Tsaih <i>et al.</i> (2004)
13,141	Adults	increased risk of kidney disease in hypertensive individuals	Muntner <i>et al.</i> (2003)
2186	Adolescents	delayed sexual maturity	Selevan <i>et al.</i> (2003)
138	Infants	decreased birth weight (measured at 1 month)	Sanin <i>et al.</i> (2001)
290	Children	increased prevalence of dental caries	Gemmel <i>et al.</i> (2002)
1,333 172	<u>Children</u>	<u>decrease in IQ</u>	Lanphear <i>et al.</i> (2005); Canfield <i>et al.</i> (2003a)



# Pb BODY BURDENS

- PbB has dropped since phasing out of lead paint and gasoline
- Levels elevated in Canadian populations well above pre-industrial
- current day in Canada: adults 1 to 4 ug/dL; children < 5 ug/dL



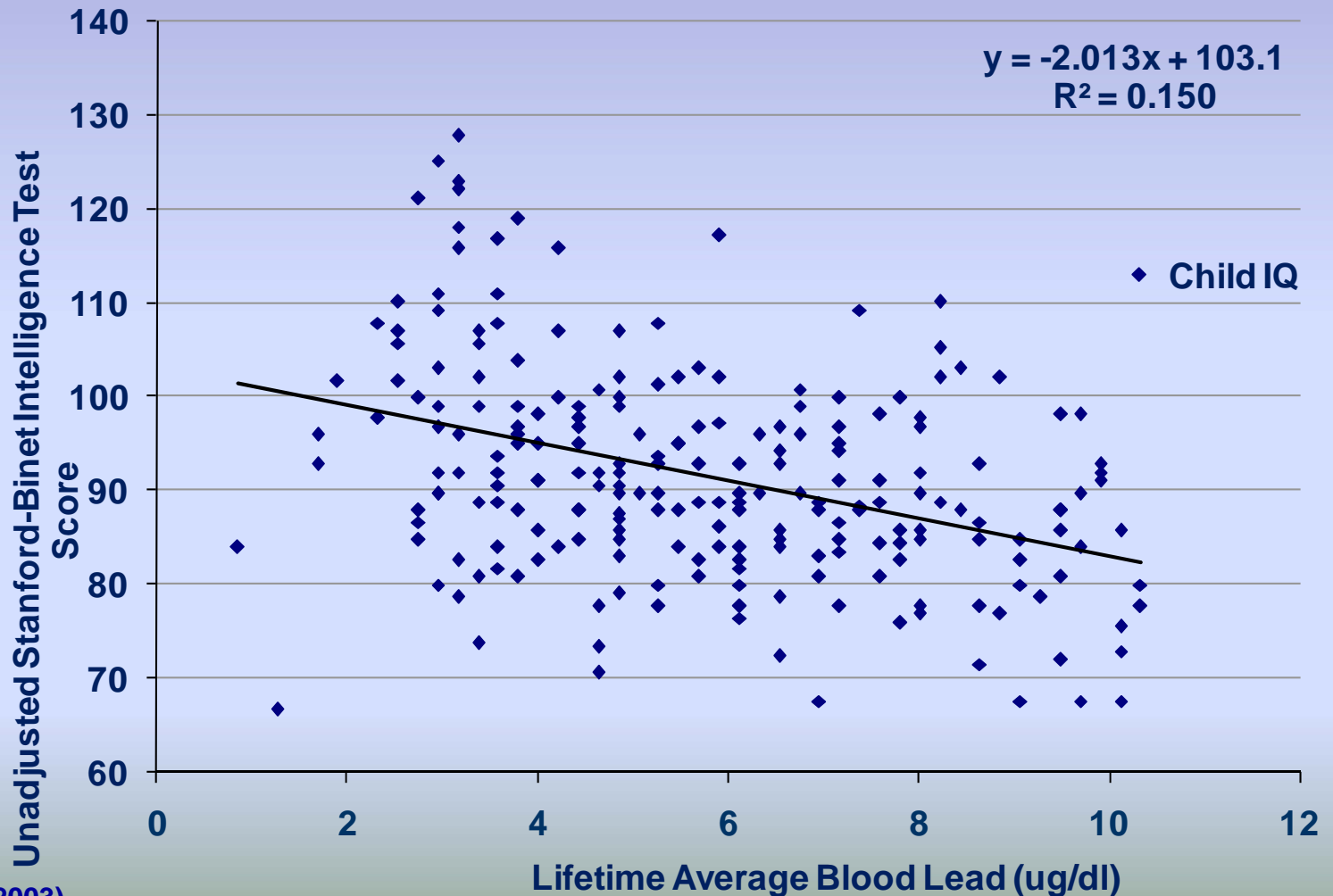
- Centre for Disease Control, in the Agency for Toxic Substances and Disease Registry; children aged 1 to 5 years
- Flegal and Smith, 1992; Lafond *et al.*, 2004; Wilson *et al.*, 2003; Langlois *et al.*, 1996; Fleming *et al.*, 1999; Hilts, 2002

# FACTORS INFLUENCING BODY BURDENS

<b>Age/Gender</b>	<b>Factors Influencing Biokinetics</b>	<b>Percent Increase in PbB</b>
adult females	pregnancy	20 to 33%
adult females	postpartum	65%
adult females	menopause	5 to 60%
adult females	low milk consumption	44%
adult females	low vitamin C intake	48%
adult females	low thiamin intake	47%
adult females	alcohol consumption	55%
adult males	low iron intake	21%
adult males	smoking	10%
Highly exposed children	ALAD 2 carrier	36%
children	low ferritin	22%
children 1 to 3	low vitamin D intake	32%

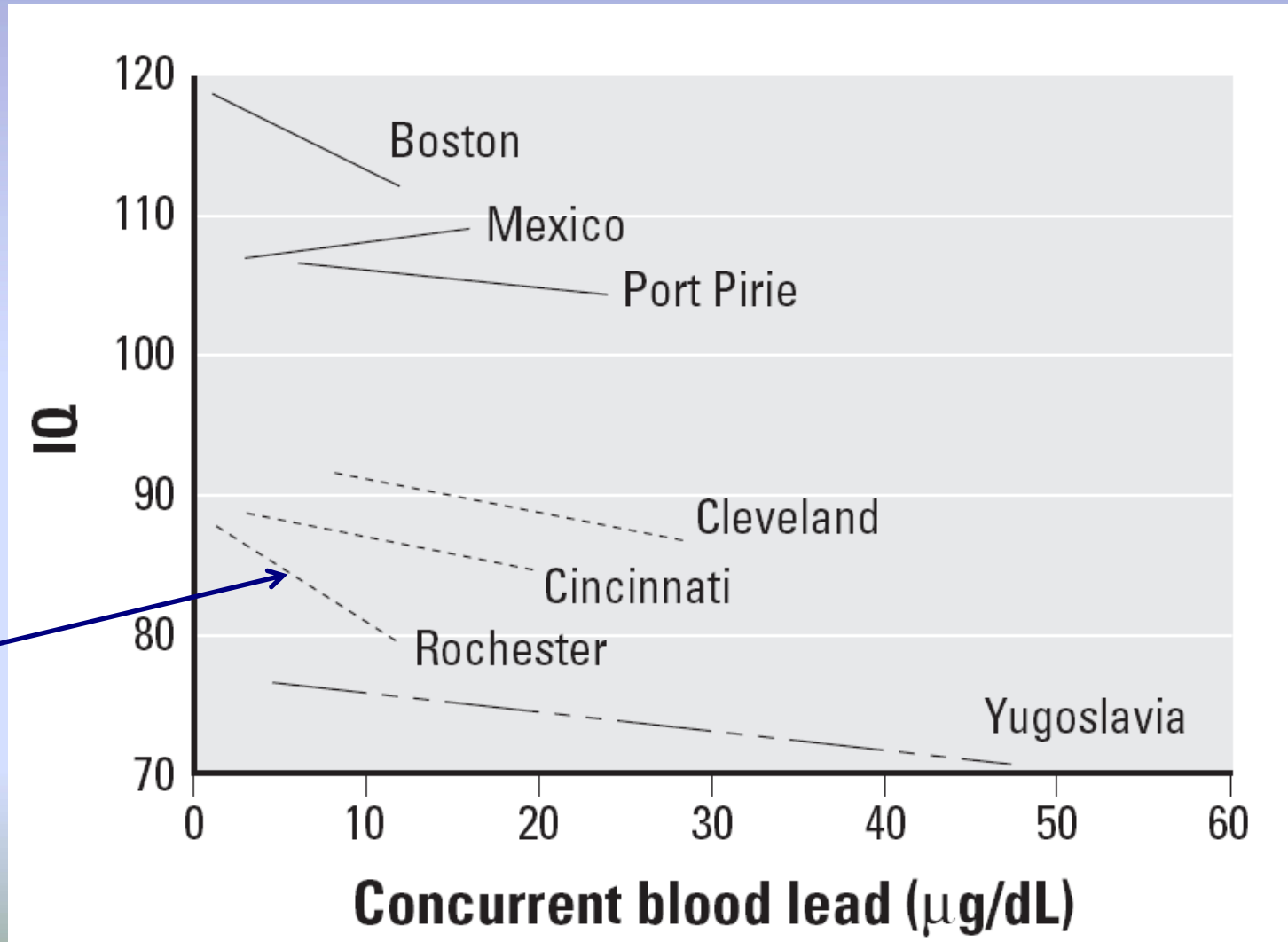
# IQ EFFECTS IN CHILDREN

- Canfield *et al.* IQ of children (n=220), urban area with elevated Pb
- low population IQ & SES; significant decrease in child IQ
- An increase in soil Pb from 250 to 500 mg/kg could be associated with an IQ decrease of 6 points (PbB increase of 3 ug/dL)



# IQ EFFECTS IN CHILDREN

- Recent study confirmed effects with several cohorts
- No threshold identified, although other papers suggest a threshold



- Lanphear *et al.*, 2005

# **IQ EFFECTS IN CHILDREN**

- **Supported by animal data**
- **Monkeys exposed to Pb during infancy (Rice, 1985)**
- **'lowish' PbB (11 or 13  $\mu\text{g}/\text{dL}$ )**
- **impairment in non-spatial discrimination reversal tasks & susceptibility to being distracted by irrelevant clues**
- **Similar results when same monkeys tested at 9 to 10 years**
- **Exposure of pregnant monkeys and offspring to Pb**
- **impairment of IQ at age 6 to 7**
- **maternal transfer plus childhood exposure may be cumulative**
  - **Rice 1990; Rice and Gilbert 1990; Rice and Karpinski, 1988; Rice and Gilbert, 1985**

# IQ EFFECTS IN CHILDREN - CONTEXT

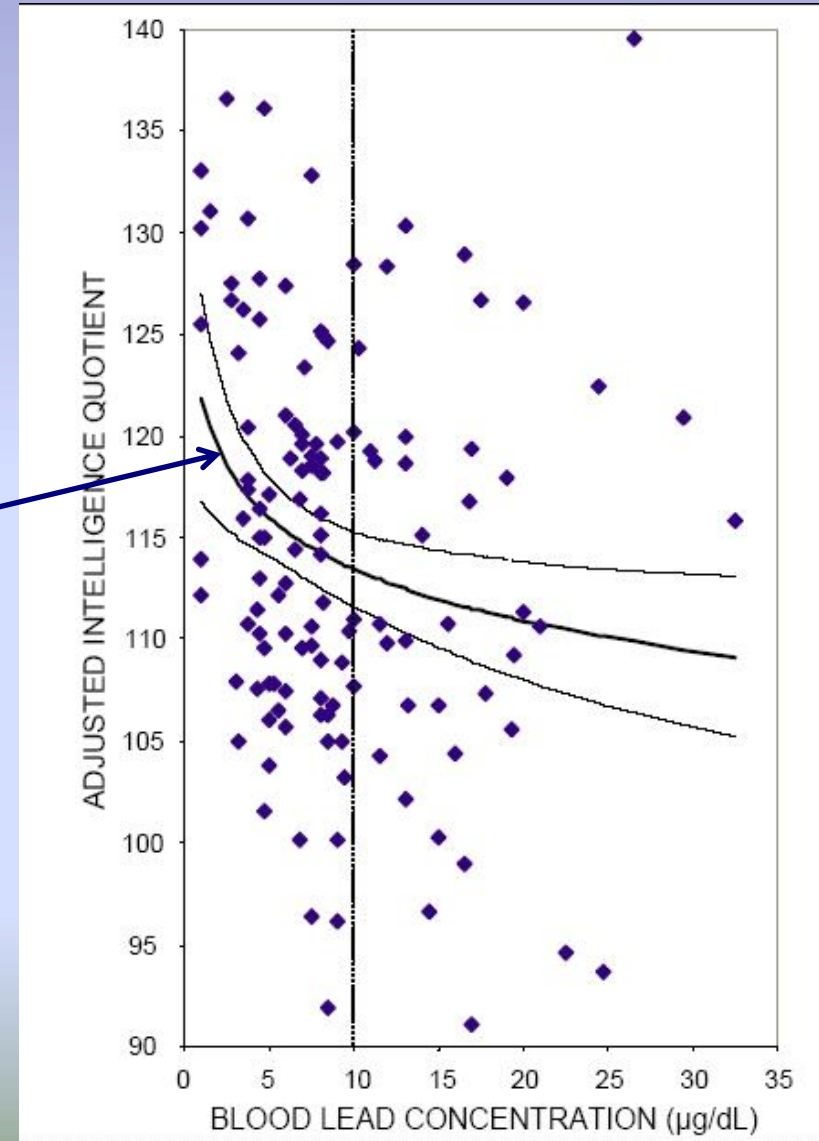
- Guidelines based on a 1 point population mean IQ drop
- How does this compare to other factors?
- Interpret data below cautiously – correlates, not necessarily cause and effect

Environmental Correlates of Children's IQ	Magnitude of Potential Effect on IQ (IQ Points)
Socioeconomic Status (SES)	+ <u>12</u>
Parent's Education	+ 15
Family Size and child's position in family	+ 8
Enriched Pre-school	+ 15

# SOME SUGGEST NON-LINEAR SLOPE

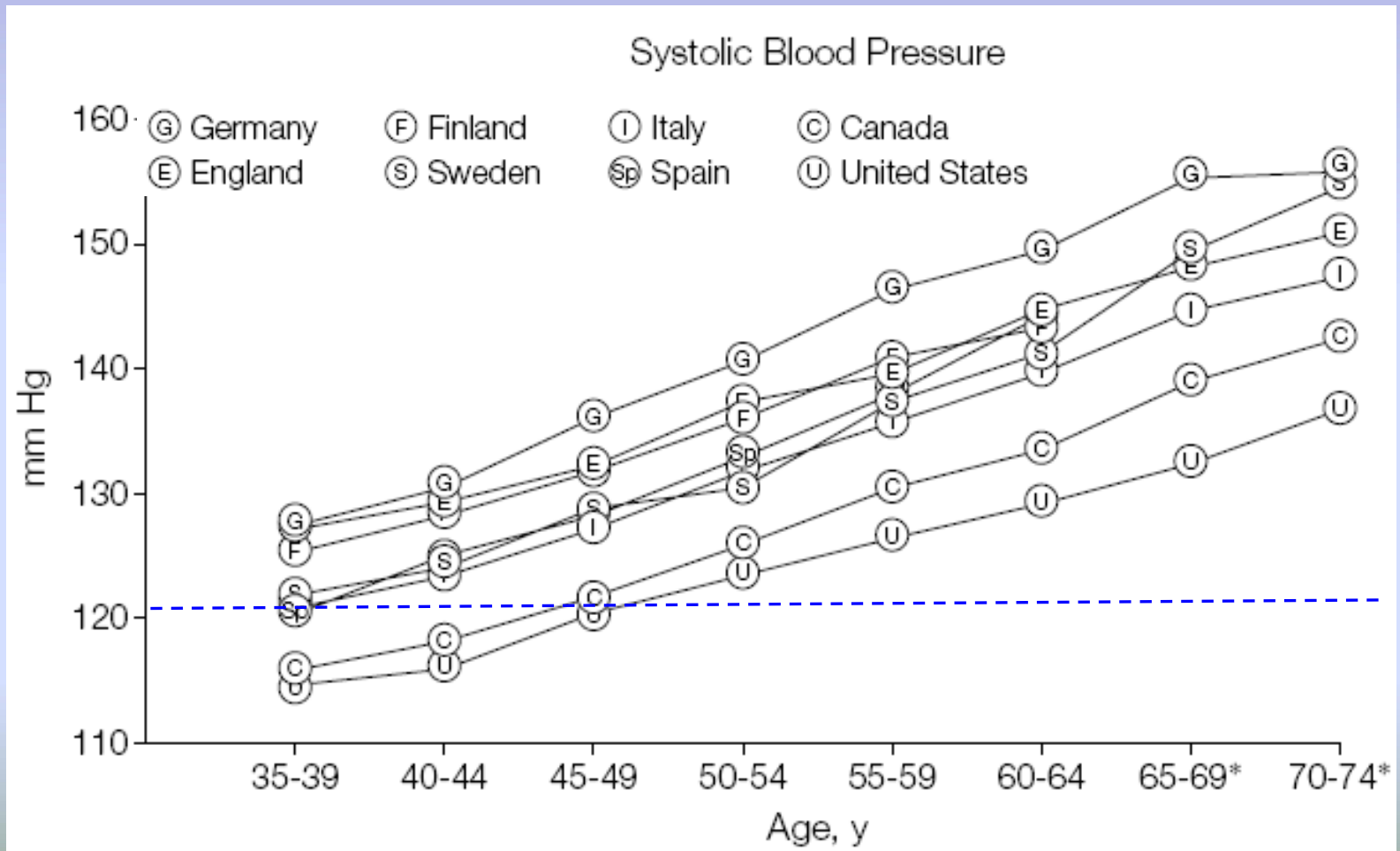
- based on mathematical function slope fitting
- If true, an increase in soil Pb from 5 to 30 ppm could be associated with unacceptable health risks in terms of child IQ

Non-linear dose response at low dose



# ADULTS – SYSTOLIC BLOOD PRESSURE

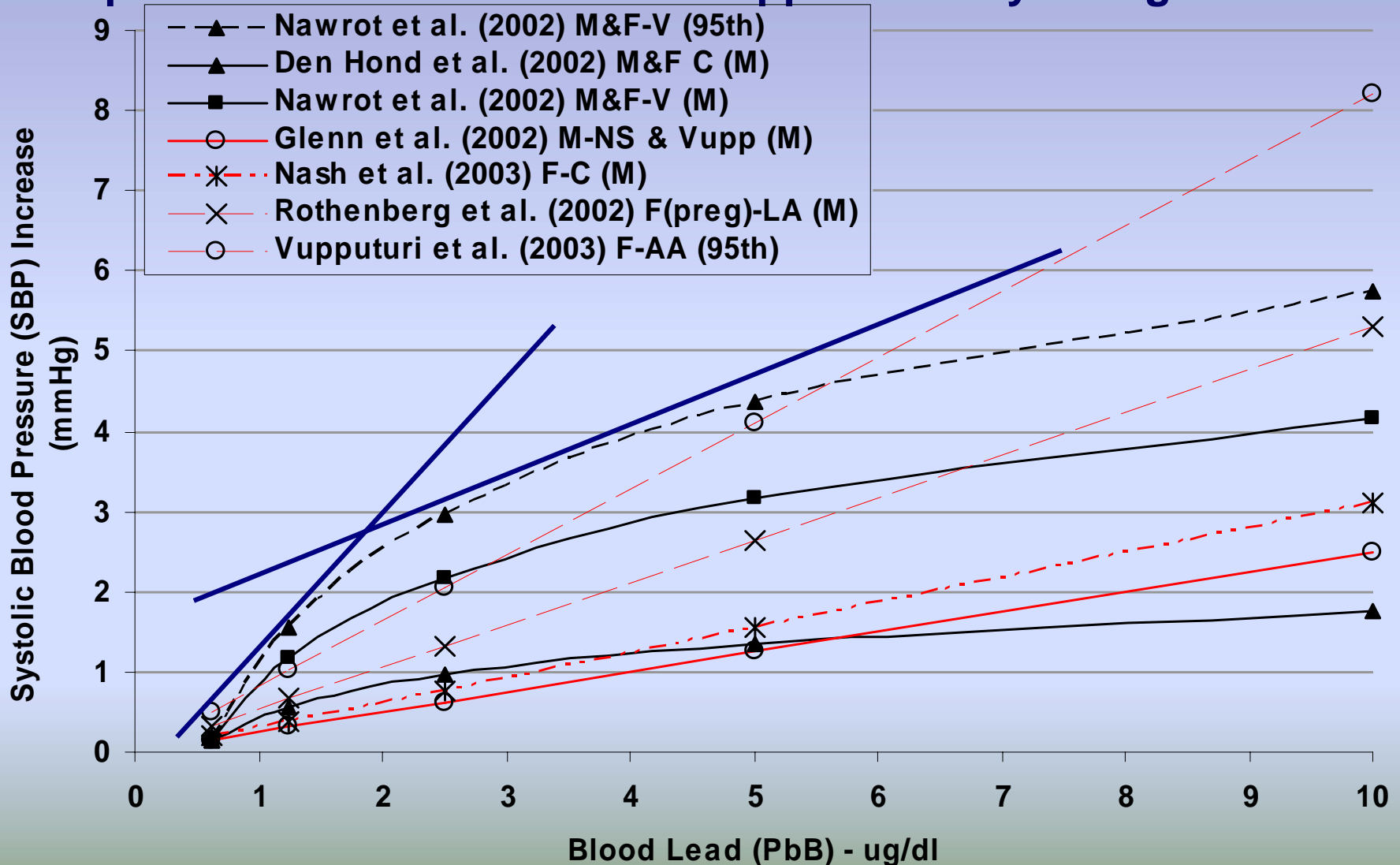
- Elevated SBP and Hypertension is a key factor that contributes to risk
  - Canadians have low SBP compared to other populations
  - USA has lowest SBP particularly in older individuals – disease treatment
- Can impose the increase in SBP cause by Pb onto baseline levels
- ‘Unexposed’ versus ‘Contaminated Site Exposed’ populations





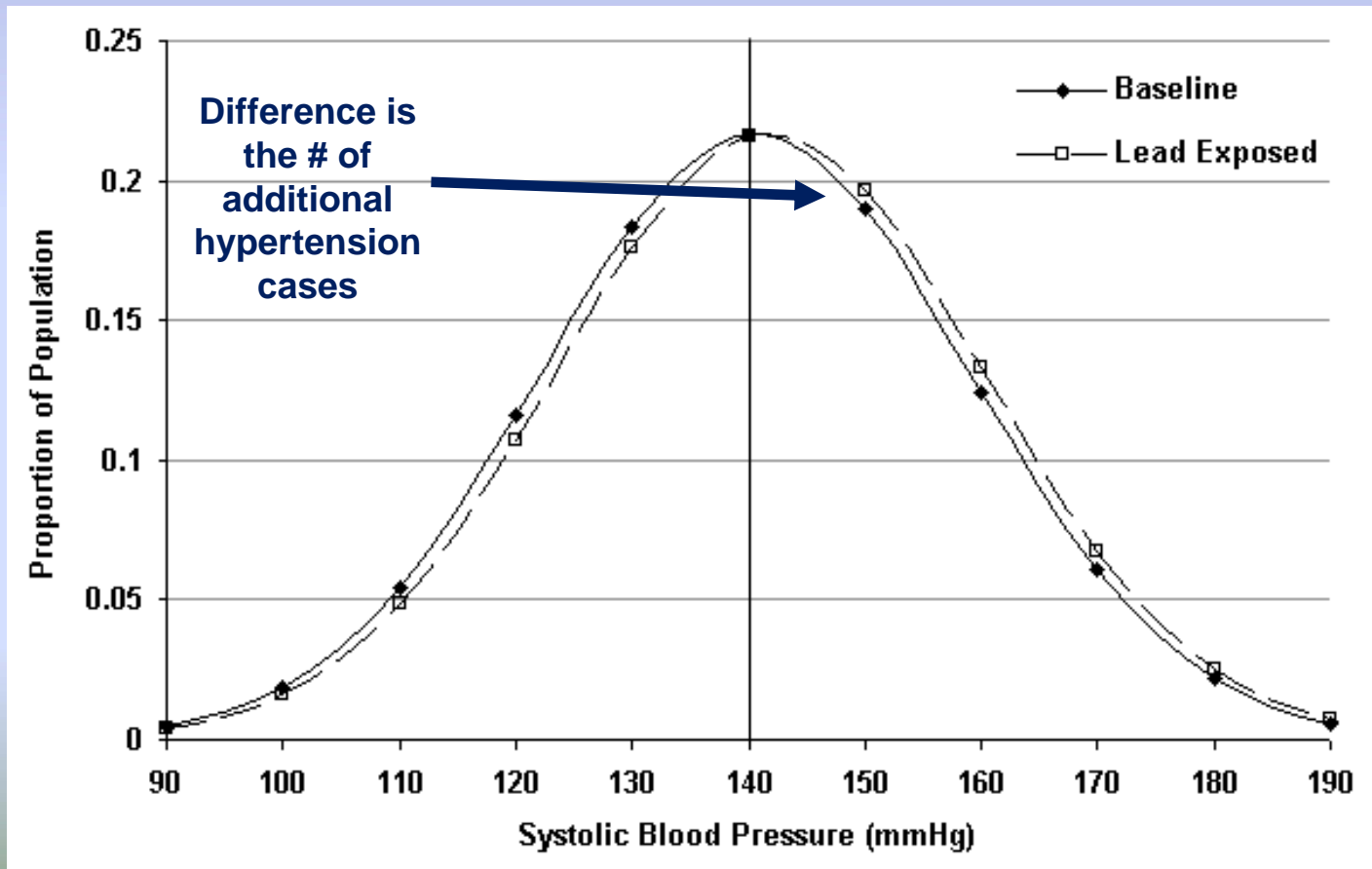
# Pb-RELATED SBP EFFECTS

- Again, no threshold; logarithmic & linear functions
- Suggested guideline based on a 1% increase in mean SBP
- equivalent to a PbB increase of approximately 1.5 ug/dL



# HYPERTENSION RISK

- What does a change in SBP really mean?
- Extra risk of Pre-hypertension, Stage 1, and Stage 2 hypertension prevalence (SBP >120, > 140, > 160 mmHg)
  - Limit of a 1 point increase in mean population SBP
  - Example shown below for males – age bracket 65 to 74 years
  - increase of 4%, 3%, and 2% of the population above hypertension thresholds



# HEART DISEASE MORTALITY

- **Baseline IHD Mortality Rate, impose Pb-related effects on mortality**
  - 1% increase in SBP
  - Increased incidence calculated per gender & decade age bracket  
Summed for adult (34 to 75) lifetime risk
  - shift between stages of hypertension is associated with increase risk of heart disease mortality
  - compare with carcinogen risks of 1 in 100,000

	Extra Risk for Incidence of Coronary Heart Disease Mortality Rate per 100,000 Individuals (% Incidence) by Age Bracket (MALES) (per year data)						TOTAL
CV Disease	35-44	45-54	55-64	65-74	75-84	85+	
Baseline	19	78	267	702	1825	4020	6911
1% inc. in SBP	1.2	5.5	6.9	16.9	n.c.		31

# SocioECONOMICS - ADULTS

- **Economic costs of CVD on Canadian health (1998)**
  - Total approx. \$18.5 billion (11.6% of total of illnesses cost)
    - Direct – approx. 6.8 billion (treatment, care and rehabilitation, etc)
    - Indirect – approx. 11.7 billion (economic output lost due to illness, injury-related work, or premature death)
- **IHD (including AMI) mortality - the single largest source of economic cost associated with CVD (27%)**

Endpoint	Baseline Annual Incidence (age 35 - 84)	Est. Cost/Case	Additional Cases (Increased Incidence) at same PbB Increase	Additional Cost per Endpoint
Hypertension	170631	\$ 5,157	172	\$ 887,060
IHD (Hyp-Related)	11662	\$ 202,024	10	\$ 2,020,237
IHD Mortality	2892	\$ 1,675,773	1	\$ 1,675,773

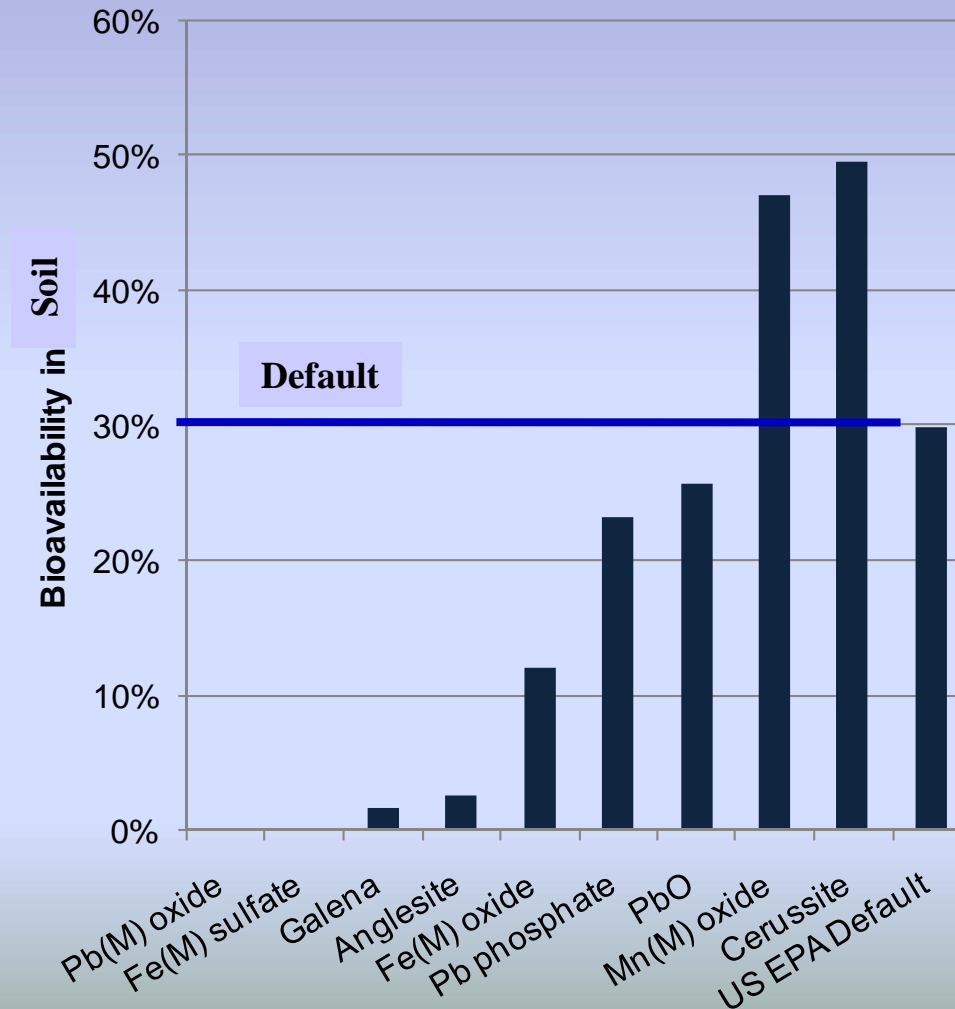
*Costs for IHD (Hyp-Related) excludes mortality cost and includes hospital care, drugs, and long-term disability*

# EXAMPLE EXPOSURE LIMITS

- Population Mean effects, not individuals – very important
- M ADULTS PbB – SBP increase of 1% - 4.9  $\mu\text{g}/\text{dL}$   
6,200 in 100,000 additional Stage 1 Hypertension cases  
increased incidence of 31 in 100,000 for CHD mortality
- F ADULTS PbB – SBP increase of 1% - 2.4  $\mu\text{g}/\text{dL}$   
6,000 in 100,000 additional Stage 1  
Hypertension cases  
increased incidence of 12 in 100,000 for CHD  
mortality
- CHILDREN PbB – IQ decrease of 1% - Both genders – 1.4  $\mu\text{g}/\text{dL}$   
extra risk of 400 in 100,000 with mild mental  
retardation
- These absolute limits are very difficult to apply given current day  
body burdens
- As a result, Equilibrium recommended that the government consider  
an incremental risk approach, similar to carcinogens, although for a  
non-carcinogenic substance – deviates from convention
- Results in risk evaluations and guidelines for contaminated sites that

# What can be done on a site-specific basis? Bioavailability is Key...

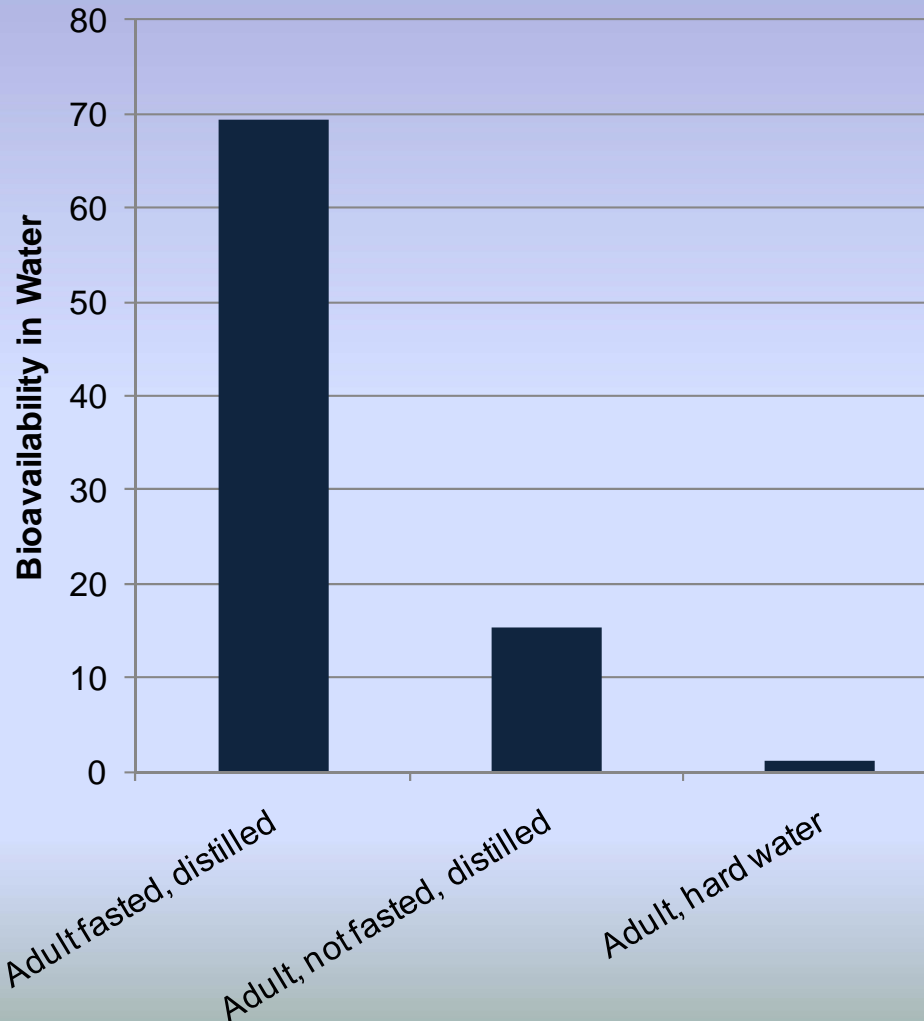
- Bioavailability is highly variable for Pb in the environment
- Consider using a P-BET approach – Physiologically Based Extraction Test



- Blake et al., 1976; Casteel et al. (2006); swine data

# Bioavailability is Key

- Groundwater related risks to Pb may be relatively low
- Absorption of Pb is considerably reduced in mineralized water
- Differences between fasted and non-fasted states – can't be applied site-specific



- *Blake et al., 1976; Casteel et al. (2006); swine data*

# EXAMPLE OF BIOAVAILABILITY EFFECT ON GUIDELINES

- Child PbB limit of 1.4  $\mu\text{g}/\text{dL}$  (1% IQ, 400 additional cases of MMR)
- Equivalent to a Tolerable daily uptake of 0.08  $\text{ug}/\text{kg}\text{-day}$
- Exposure to AENV residential soil quality guideline (140  $\text{mg}/\text{kg}$ )
- Default CCME parameters for body weight and ingestion rate
  
- Risk depends on bioavailability
  
- At 100% bioavailability, 140  $\text{mg}/\text{kg}$  exceeds the guideline by 10-fold
- At 30% bioavailability, 140  $\text{mg}/\text{kg}$  exceeds the guideline by 3-fold
- At 10% bioavailability, 140  $\text{mg}/\text{kg}$  is equivalent to the guideline
  
- A relative-risk approach would allow for increases in these concentrations above background levels
  
- It is likely that risk management may be applied for some populations where background levels are high
  
- The question is – how should Canadian's money be spent?
  - Lower guideline for contaminated sites?
  - Improved child education?
  - Improved nutrition?



# **REGARDLESS OF THE LIMIT**

- **REGARDLESS OF THE LIMIT DEVELOPED,**
- **THERE ARE LIKELY TO BE PEOPLE IN CANADA THAT WILL HAVE PbB CONCENTRATIONS ABOVE THE LIMIT AS A CONSEQUENCE OF HISTORICAL EXPOSURES**
- **POSES CHALLENGES FOR RISK COMMUNICATION**