Evaluating Byproducts for Beneficial Use in Soil Applications

Professor Nicholas Basta
Dr. Elizabeth Dayton
Soil and Environmental Chemistry Program

School of Environment and Natural Resources

The Ohio State University

Objectives

- Present key concept essential to risk-based evaluation of byproducts for soil application

- Demonstrate the dire need for beneficial reuse of non-hazardous industrial byproducts

Land Application of Contaminants in Byproducts: Two Philosophies

1. **Do not increase contaminant content in soil regardless of health effects: not risk-based**

2. **Prevent adverse health effects: risk-based**

Risk-based regulation U.S. EPA Part 503
The standards for Use or Disposal of Sewage Sludge Federal Register 1993. 58:9248-9404.

Part 503 is a comprehensive risk-based framework based on high quality scientific research studies for beneficial reuse of a biosolids (a byproduct)

Key Elements in Part 503

Chemicals of Concern: organic and inorganic chemical contaminants present in municipal biosolids

Exposure Assessment: 14 likely exposure pathways
Highly exposed individuals: humans, animals, plants

Risk Characterization for each pathway (individual, general population, sensitive populations)

Risk-based Contaminant Loadings determined from most limiting pathway (with safety factors)

Risk Pathways Considered in Part 503

Table 13.6 Pathway Models for Land Application of Municipal Biosolids

Pathway	Description of Highly Exposed Individual (HEI)
1: Biosolids → soil → plant → human	Individuals with 2.5% of all food produced on amended soils
2: Biosolids → soil → plant → human	Home gardeners with 1000 Mg/ha, 60% garden foods for lifetime
3: Biosolids → soil → human child	Ingested biosolids product, 200 mg/day
4: Biosolids → soil → plant → animal → human	Farms, 45% of home-produced meat
5: Biosolids → soil → animal → human	Farms, 45% of home-produced meat
6: Biosolids → soil → plant → animal	Livestock feeds, 100% on amended land
7: Biosolids → soil → animal	Grazing livestock, 1.5% biosolids in diet
8: Biosolids → soil → plant	Phytotoxicity, strong acidic amended soil but with limestone added to prevent natural aluminum and manganese toxicity
9: Biosolids → soil → soil biota	Earthworms, microbes, in amended soil
10: Biosolids → soil → soil biota → predator	Shrews (*Sorex araneus* L.), 33% earthworms in diet, living on site
11: Biosolids → soil → airborne dust → human	Tractor operator
12: Biosolids → soil → surface water → human	Subsistence fishers
13: Biosolids → soil → air → human	Farm households
14: Biosolids → soil → groundwater → human	Well water on farms, 100% of supply

Source: Chaney, R. L. et al., Soil root interface: ecosystem health and human-food-chain protection, in P. H. Huang et al., Eds., *Soil Chemistry and Ecosystem Health*, SSSA Spec. Pub. No. 52, Soil Science Society of America, Madison, WI, 1998.

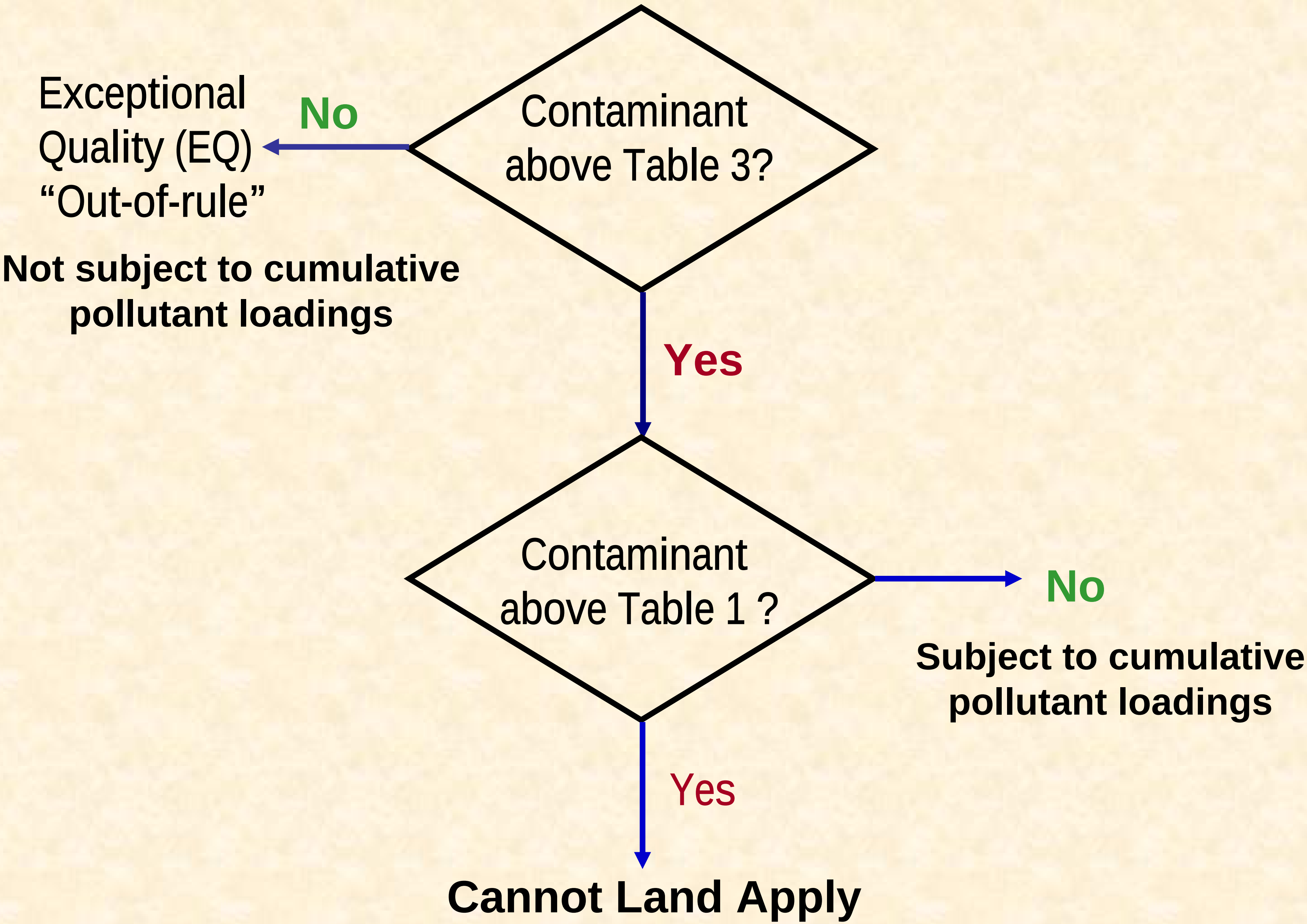
Part 503 Contaminant Tables

Table 1 – Ceiling Contaminant Concentrations for Contaminants in Biosolids

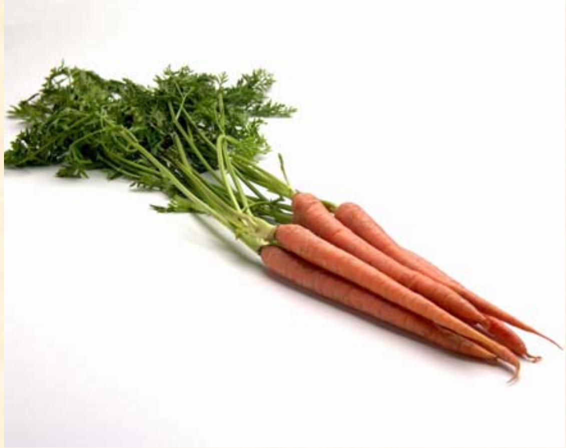
Table 2 – Cumulative Limits for Land Applied Contaminants

Table 3 – Exceptional Quality Contaminant Concentrations in Biosolids

Used to determine "Out of Rule" category


Contaminant
above Table 3?
No
Exceptional
Quality (EQ)
“Out-of-rule”
Not subject to cumulative
pollutant loadings
Yes
Contaminant
above Table 1 ?
No
Subject to cumulative
pollutant loadings
Yes
Cannot Land Apply

“Carrot - Stick” Regulation



Byproduct Generator
“Mule”

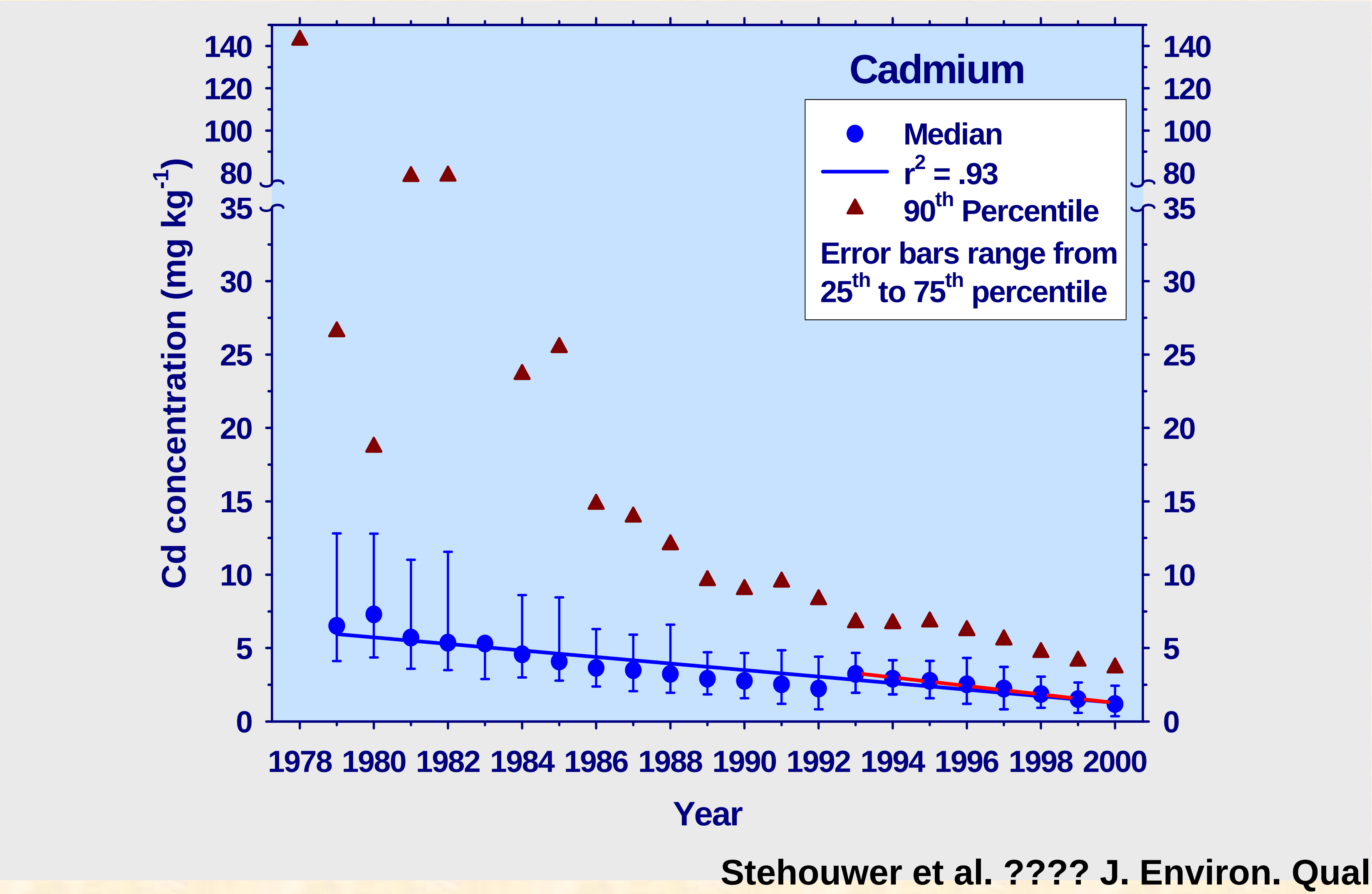
Clean Byproduct
(“EQ” Biosolids)

Get Carrot
Out of Rule
Less Reporting

Not so Clean
Byproduct/Biosolids

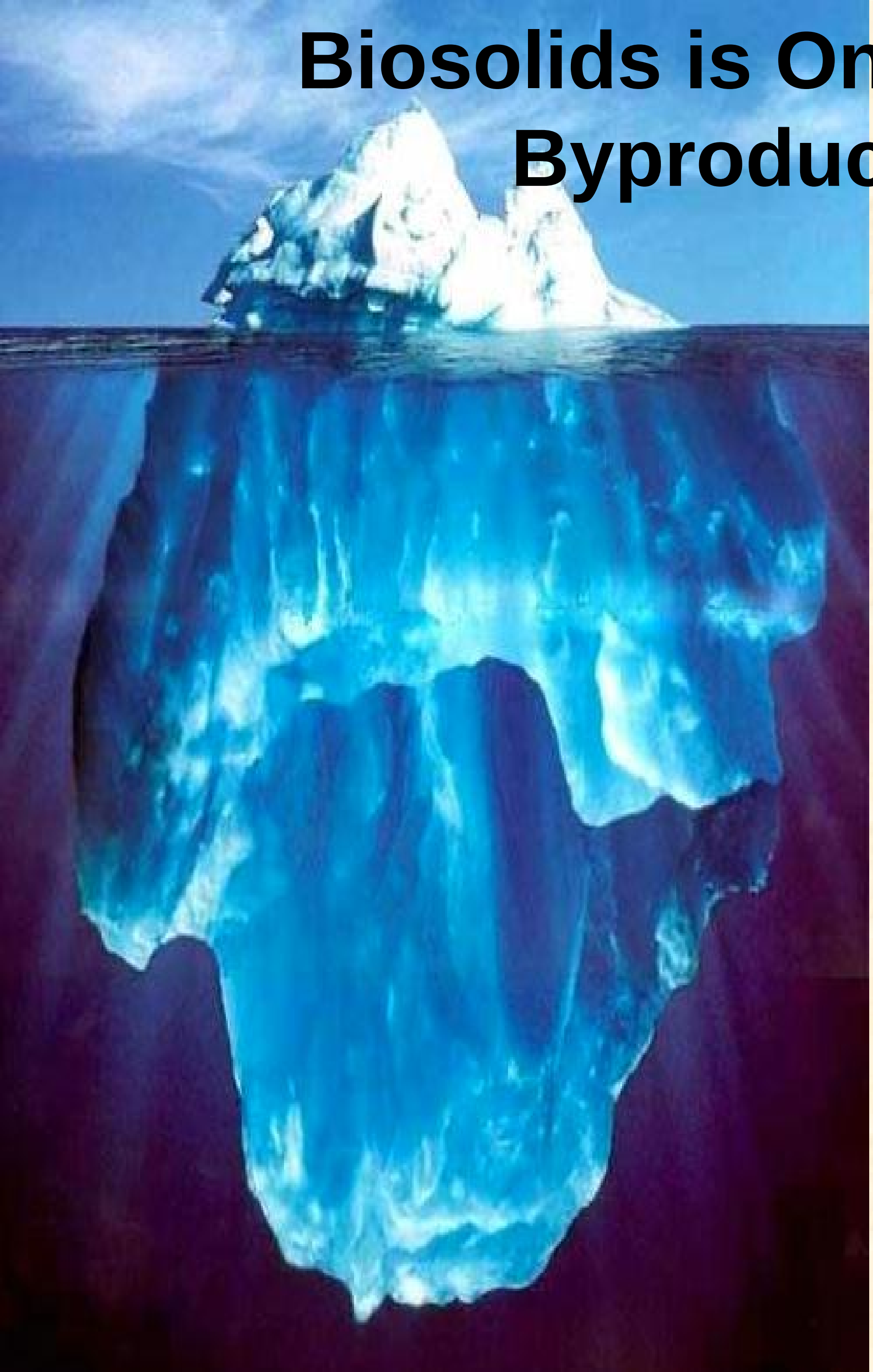
Get Stick
More Restriction
More Reporting

Carrots Work !
Part 503 Reduced Contaminants in Biosolids



Stehouwer et al. ???? J. Environ. Qual.

Biosolids is Only the Tip of the Byproducts Iceberg



Why not 503 limits for everything?

approach is risk-based

byproduct matrix/mineralogy different from biosolids which affects contaminant mobility, bioavailability and risk
different table limits than 503

Potential for non-503 contaminants

Framework for Non-Biosolids Byproducts

Established/Demonstrated Beneficial Use of Byproduct

↓

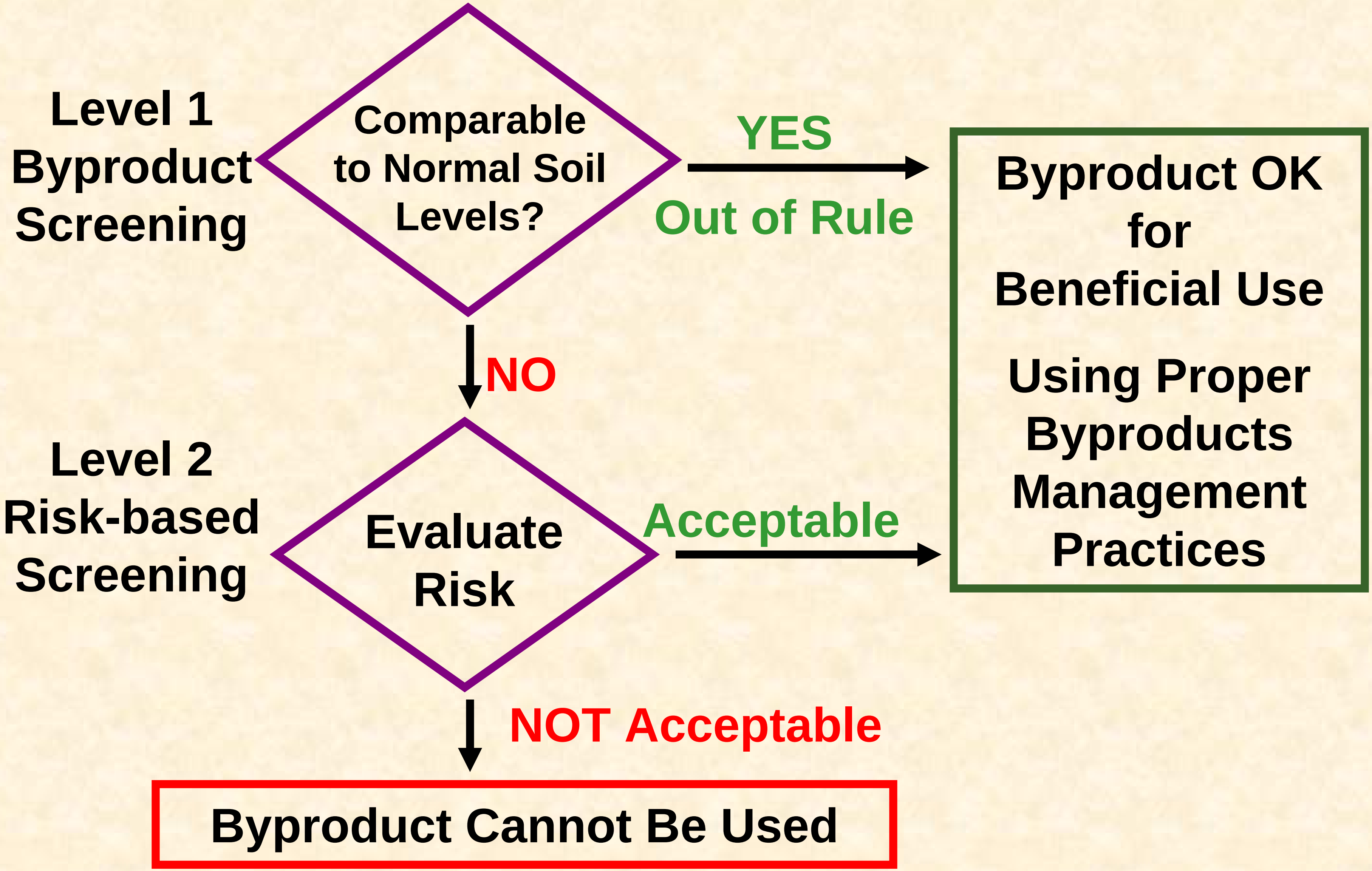
Is the Beneficial Use “safe”?

↓

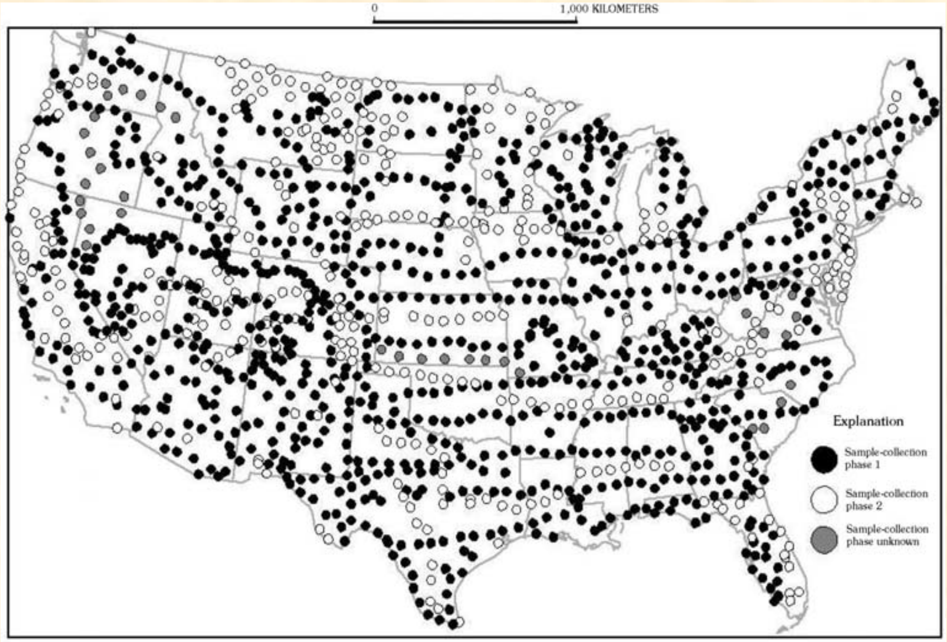
Guidelines for Proper Management for Byproduct Beneficial Use

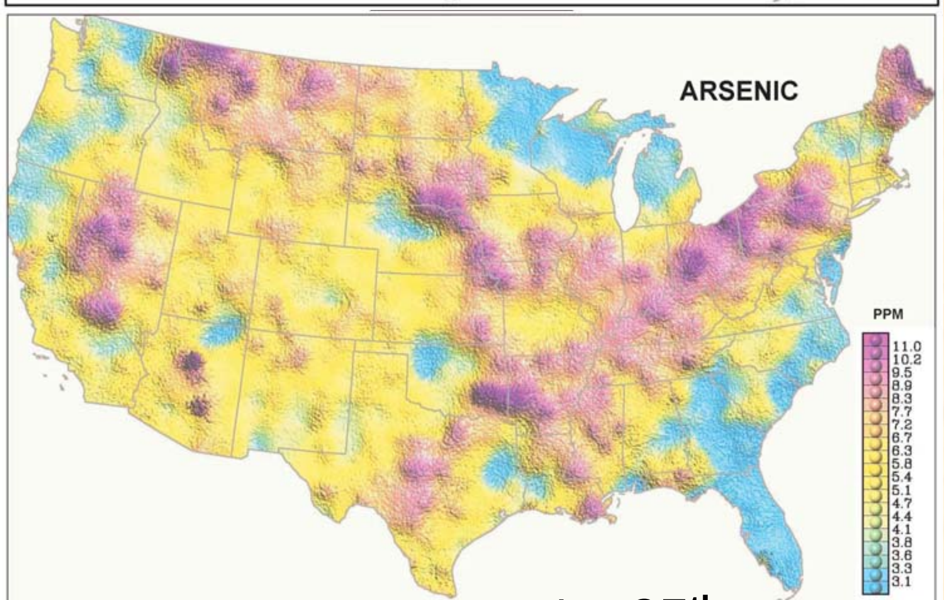
non-contaminant issues: soil science essentials

Framework for Byproduct Evaluation



Level 1: Normal Soil Background Levels





USGS, 2001, (#1648) 10^{th} – 95^{th} Percentile

Al	%	2.1 - 10
As	mg/kg	3.1 - 11
Ba	mg/kg	241 - 945
Ca	%	0.2 – 8.6
Cr	mg/kg	20 - 129
Cu	mg/kg	7.3 - 63
Fe	%	1.0 – 5.7
Hg	mg/kg	0.03 – 0.38
K	%	0.55 – 2.8
Mg	%	0.12 – 1.5
Mn	mg/kg	155 - 881
Ni	mg/kg	6.0 - 47
Pb	mg/kg	10.3 - 30
Se	mg/kg	0.17 – 0.74
Zn	mg/kg	26 - 92

Level 2 Byproducts Evaluation

Risk-Based Screening

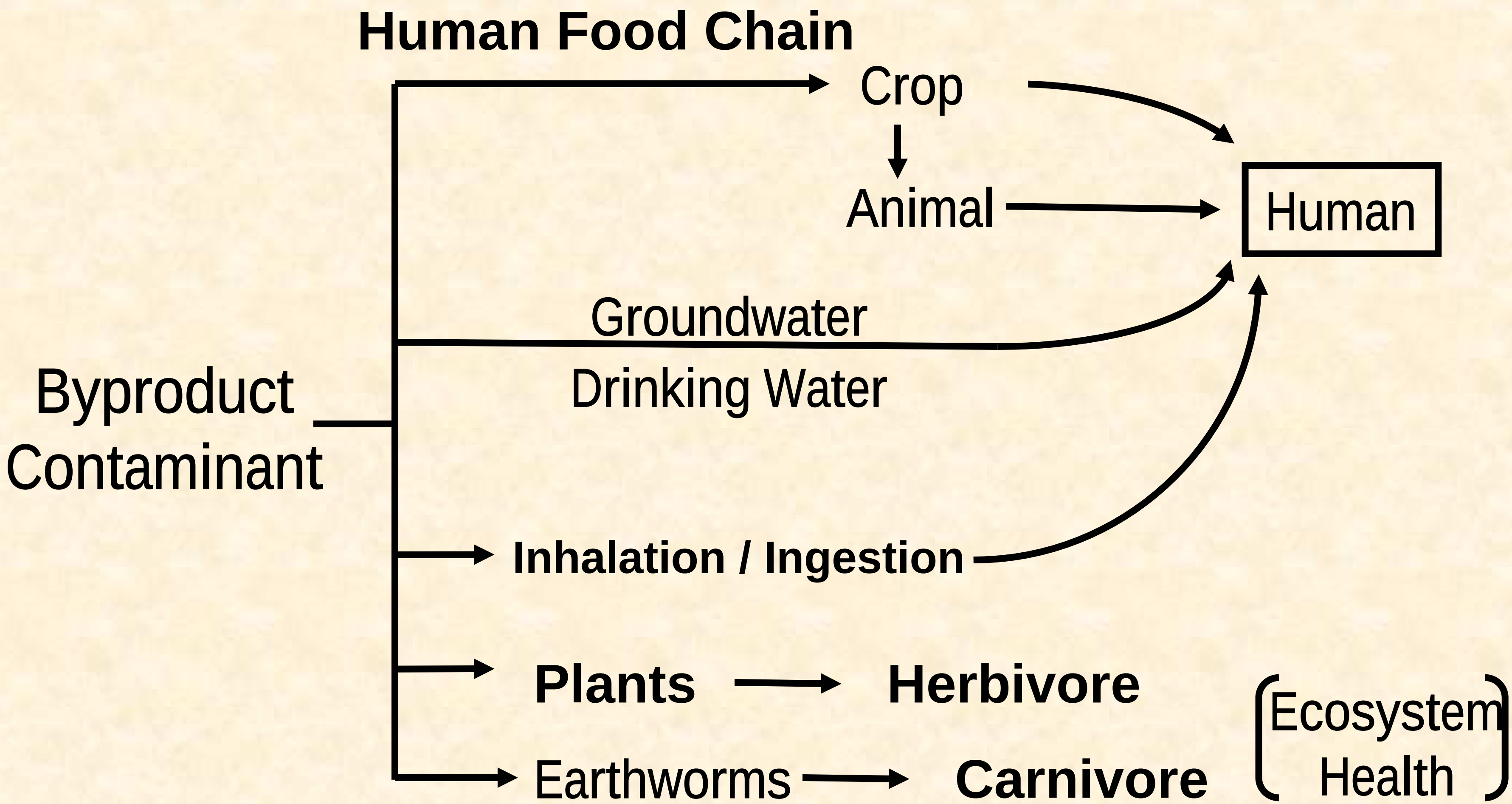
Identify categories of soil uses:
soil amendment, manufactured soil component, sorbent

Identify critical exposure pathways for categories of byproducts and use categories

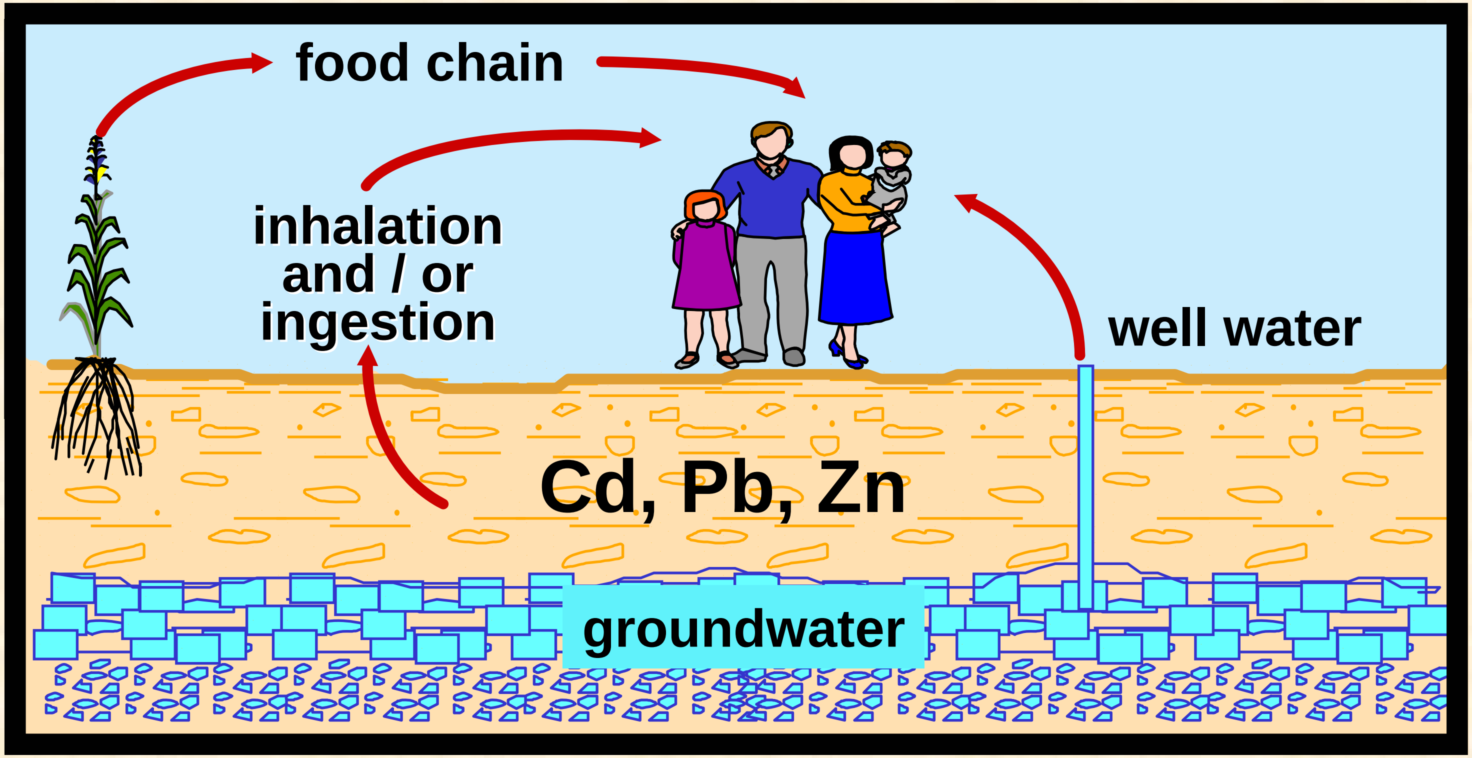
Use pathway-based methods to evaluate categories of byproducts and uses rather than generator by generator

Level 2 Byproducts Evaluation

Possible Exposure Pathways to Consider



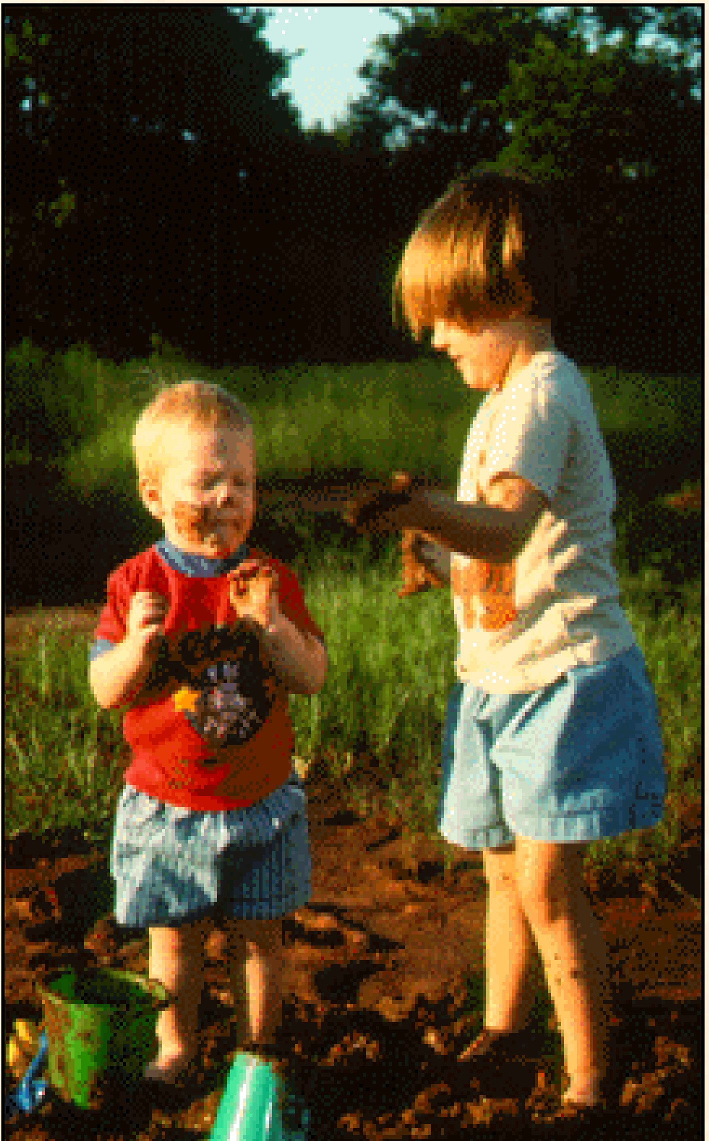
Human Exposure Pathways



Risk depends on contaminant transmission

mobility and bioavailability

Soil Ingestion Pathway and Bioavailability
"Soil Contaminant Oral Bioavailability"



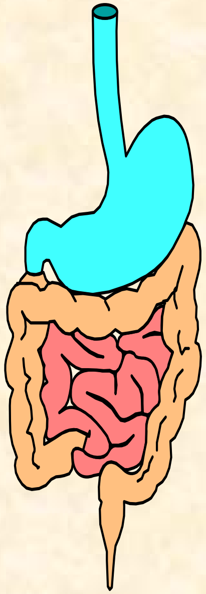
Soil ingestion often "risk driver" for human exposure to contaminated soil

$$\text{Risk} = [\text{Soil}]\frac{(EF)\,(ED)\,(IR)\,(BIO)}{(BW)\,(AT)}$$

[Soil] = Total Soil Contaminant Content
(BIO) = "Oral Bioavailability"

Oral bioavailability drives risk for Pb- and sometimes As-contaminated soils

Ohio State University
In Vitro Gastrointestinal Method (OSU IVG)
An Inexpensive Screening Method



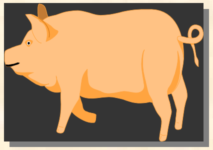
Sequential extraction, $37^{o}C$

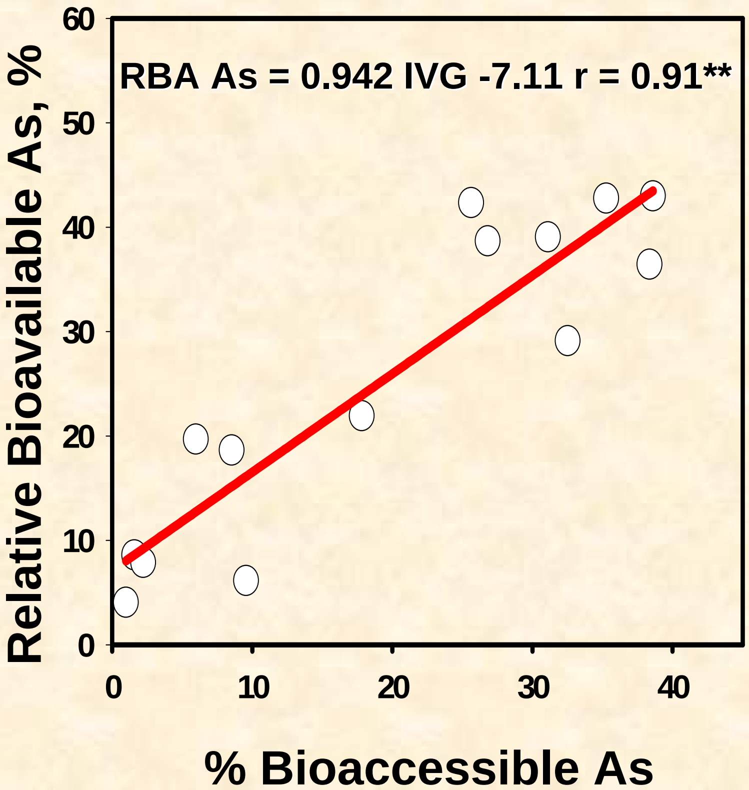
Gastric phase
Intestinal phase

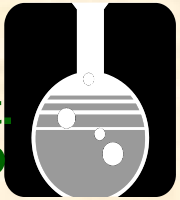
in vitro **"(bio)availability"= dissolved contaminant**
= bioaccessible contaminant

U.S. EPA Guidance for Evaluating the Oral Bioavailability of Metals in Soils for Use in Human Health Risk Assessment OSWER 9285.7-80, May 2007. Criteria for acceptance of IVG methods for Pb

OSU IVG correlated with immature swine model







Basta et al. 2003.
Grant R825410 Final Report.
submitted to U.S. EPA ORD

OSU IVG correlation with in vivo

As with dosing vehicle

Rodriguez et al. 1999. ES&T 33:642-649

As without dosing vehicle

Basta et al., 2007. J. Environ. Health Sci. Part A 42:1275-1181.

Special Publication: Bioaccessibility of Soil Contaminants C. Grøn and J. Wragg (eds.)

Pb with/out dosing vehicle

Schroder et al., 2004
J. Environ. Qual., 33:513-521.

Cd with/out dosing vehicle

Schroder et al., 2003.
ES&T 37:1365-1370.

Research on OSU IVG USEPA Project still continuing after 10 yr

1997

2007

the soil
isn't contaminated

OSU IVG USEPA Project Productivity

Publications: 39

10 refereed publications

27 proceedings / abstracts (11 at international conferences)

2 (book chapter, technical report)

5 Conference Symposia (3 international)

4 Graduate Student Ph.D. dissertation and M.S. Theses

Collaborative research

Soil samples, reports, data (including bioavailability) sent to 13 research groups

many joint publications / proceedings / symposium

U.S. EPA ORD (NERL, NRMRL)

Round robin validation studies

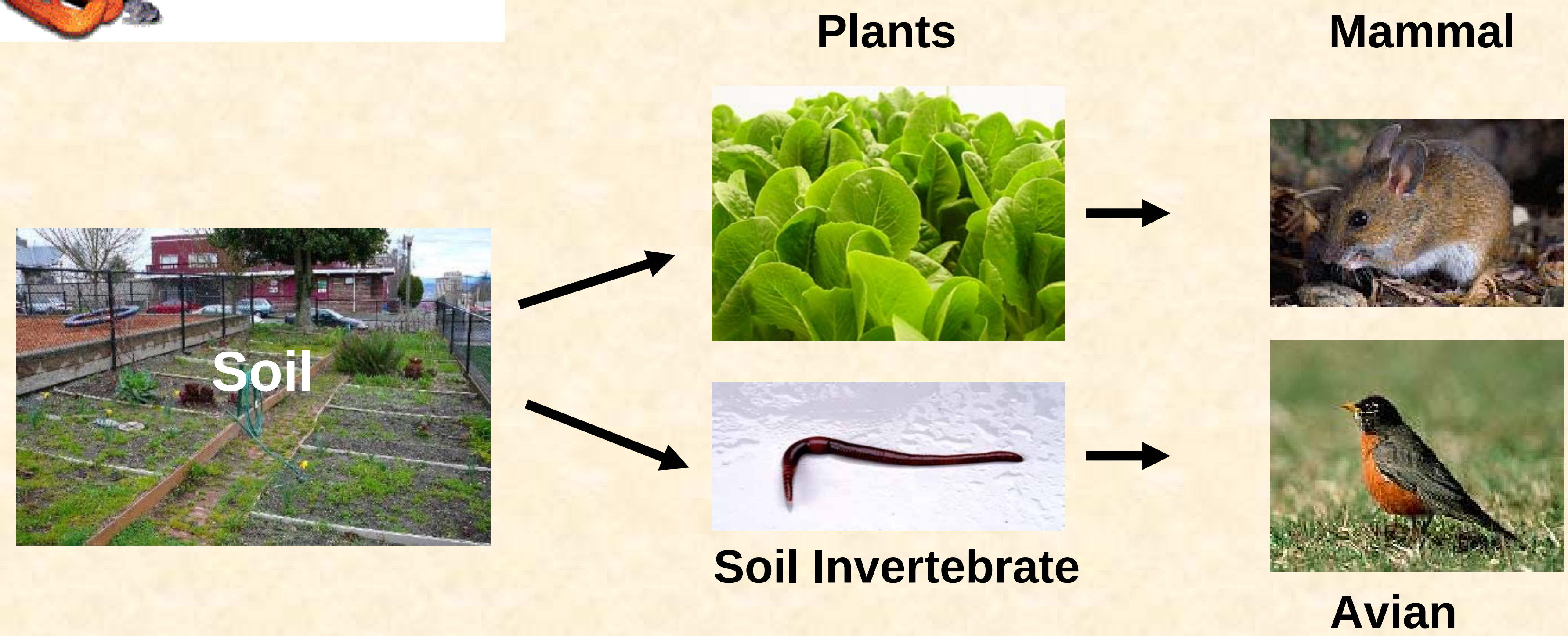
Bioavailability Research Group of Europe (BARGE)

Bioavailability Research Group of Canada (BARC)

Ecosystem Exposure Pathways

Important [Soil Eco-receptor] Contaminant Pathways

USEPA EcoSSL



Risk depends on contaminant transmission / bioavailability

Adjustments for Contaminant Bioavailability

Quantifying the Effect of Soil Properties on Soil Ecotoxicity for Ecological Risk Assessment

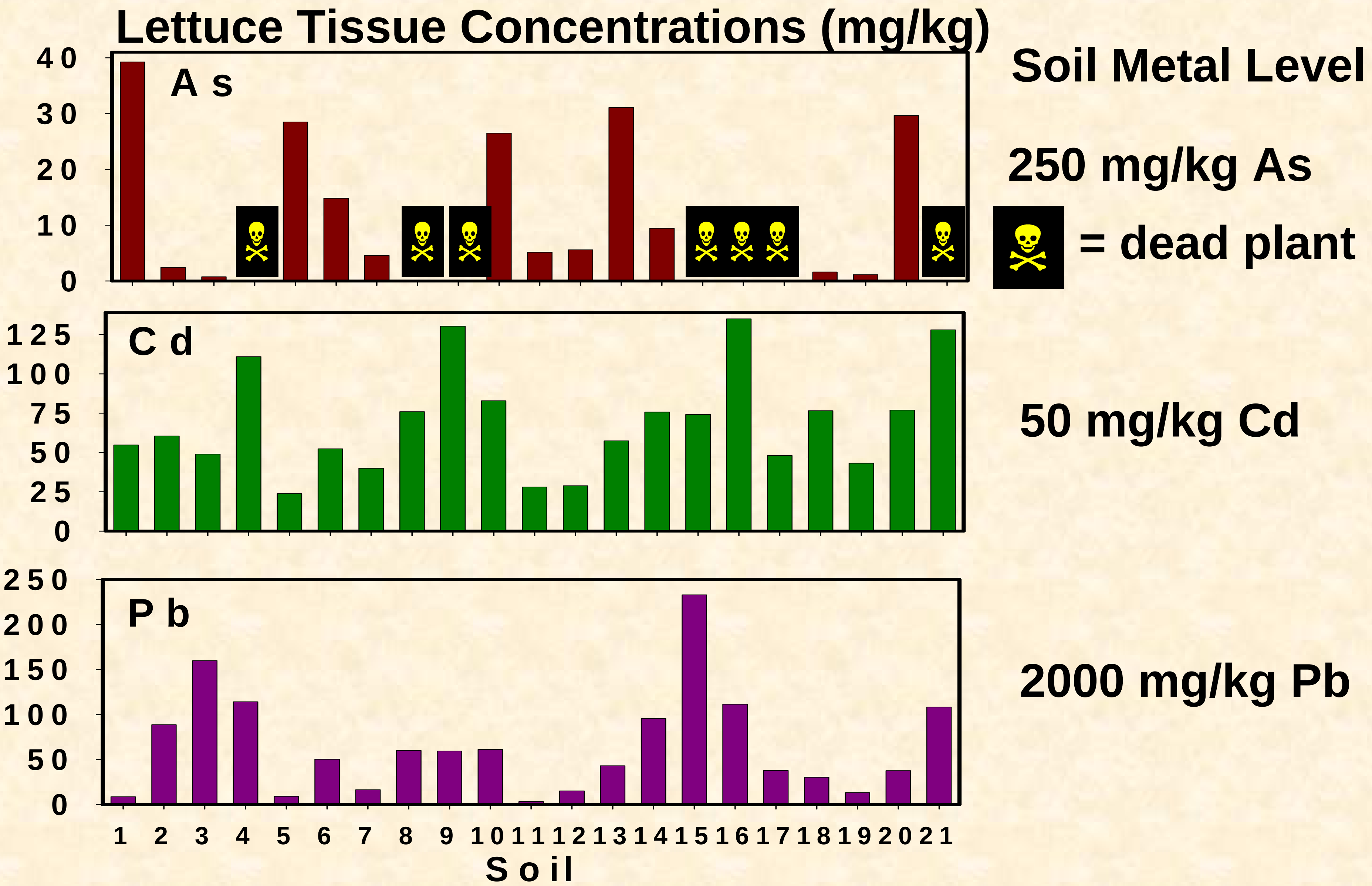
Environmental Security and Technology Demonstration Program (DOD, DOE, USEPA consortium), 2005-2008.

Strategic Environment Resource Development Program SERDP (DOD, DOE, USEPA consortium), 2001-2005.

USEPA National Center for Ecological Assessment 1998-2002.

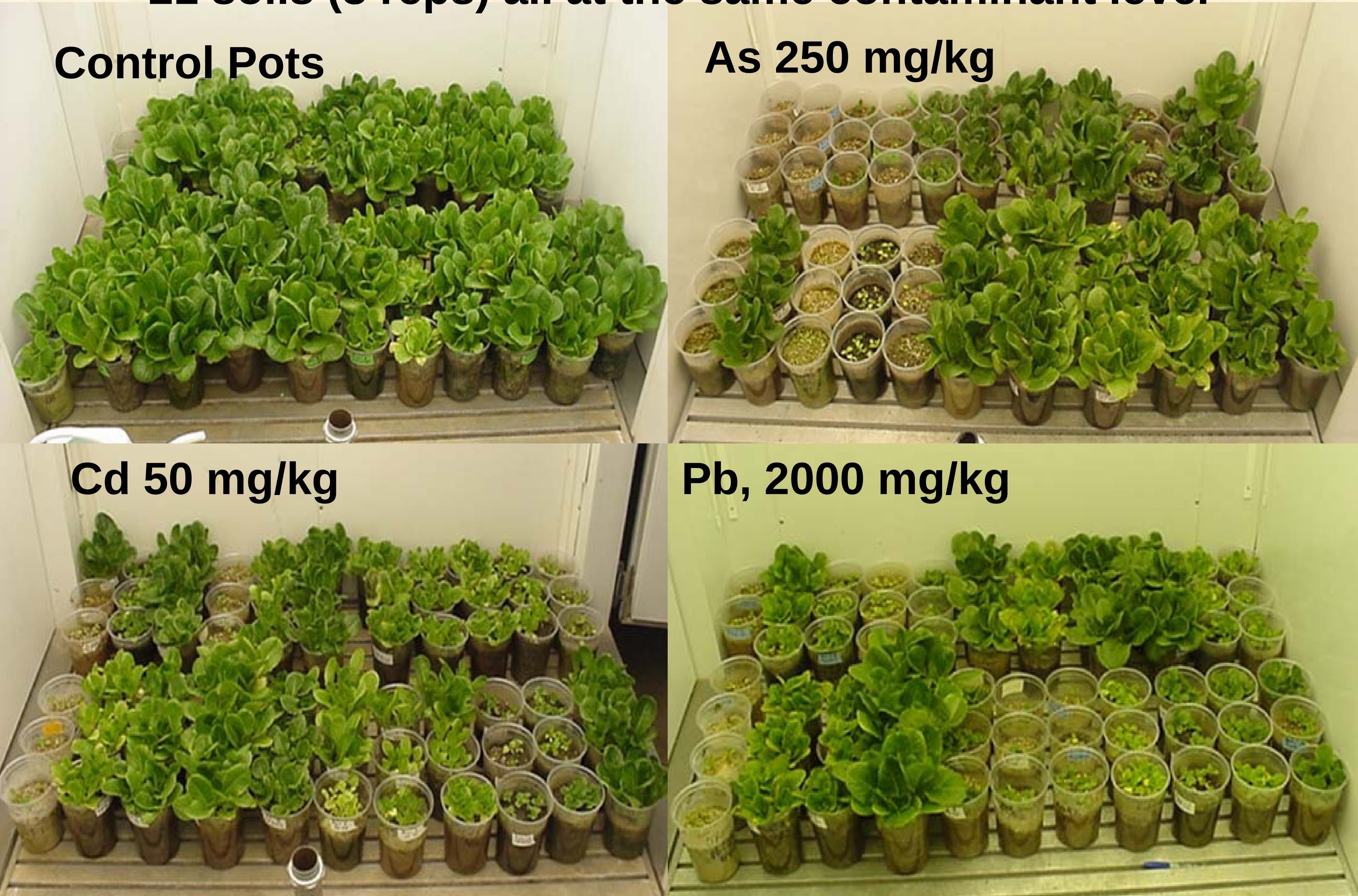
Soil/Byproduct Properties Control Bioavailability

E.A. Dayton et al. 2006. Environmental Toxicology and Chemistry. 25:719 - 725



A Picture is Worth a Thousand Words

21 soils (3 reps) all at the same contaminant level



Conclusions

Beneficial Use of Byproduct must be demonstrated: research studies preferred

The use of clean materials that do not need to be regulated and managed should be "Out of Rule"

Soil Scientists work with industry professionals to engineer out undesirable components to produce a high quality/exceptional product for land application

Demand for Byproducts

Benefits of Byproduct Soil/Land Applications

Crop Production (Fertilizer / Lime / Soil Conditioning)

Lime Substitute

Non-Point Source Agricultural Pollution Sorbent

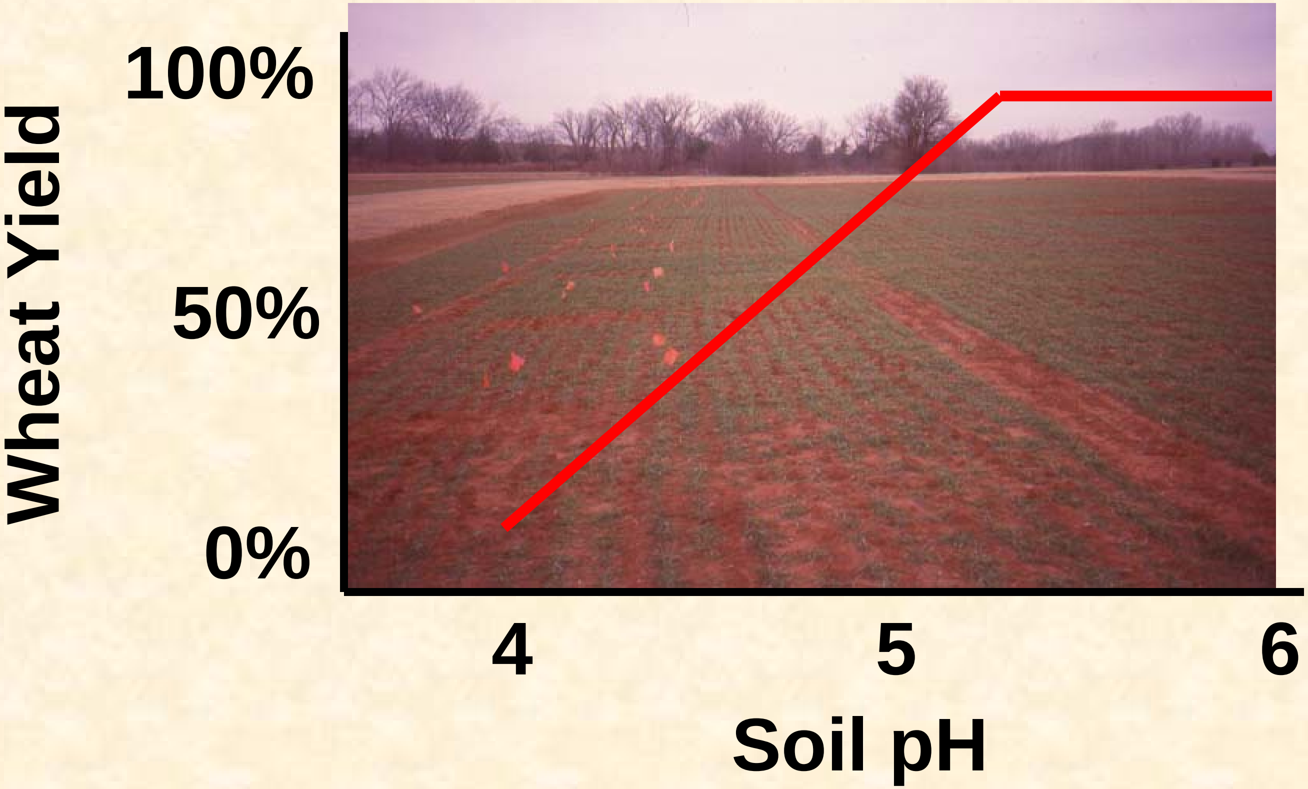
Remediation of Contaminated Sites

Restoration of Disturbed Sites/Manufactured Soil

Byproduct Benefit: Lime Substitute

Soil pH and Crop Production

1/3 of U.S. Cropland is Below Optimum Soil pH for Crop Production (food and energy production)

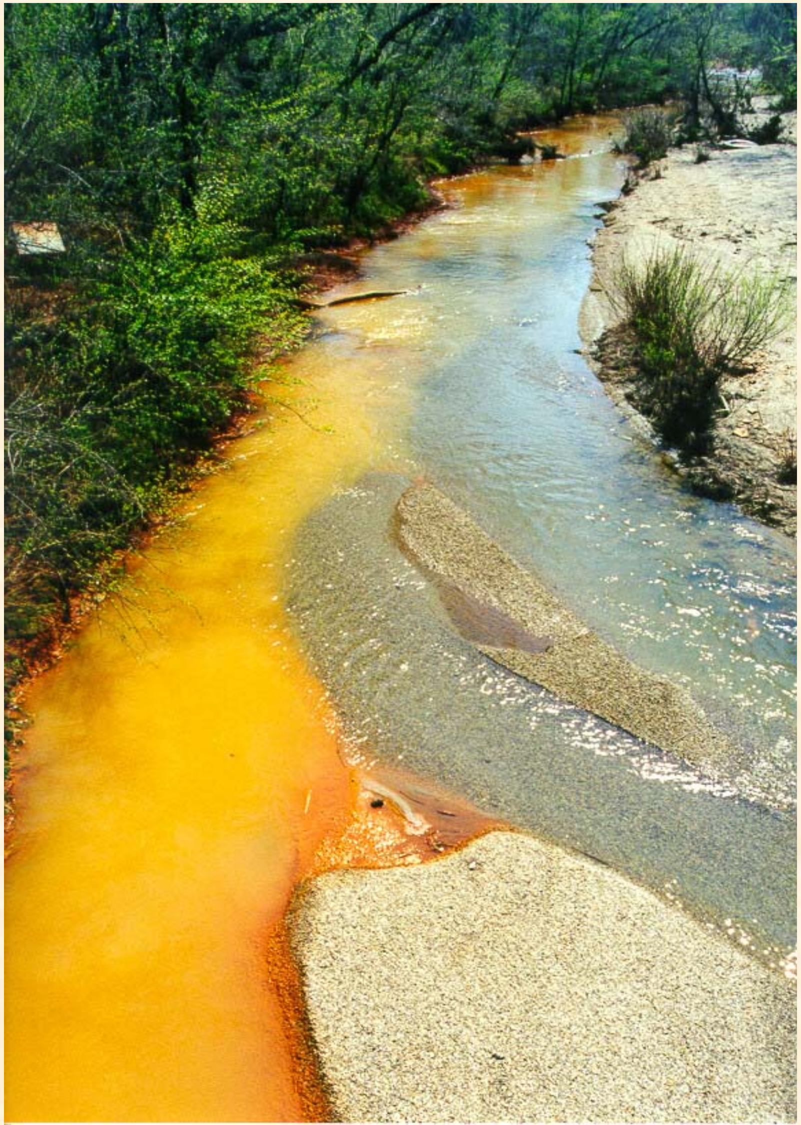


Maximum Yield

Wheat
pH > 5.5

Corn
pH > 6.0

Byproduct Benefit
Neutralize Acid Mine Drainage
Lime Substitute



Impacts:

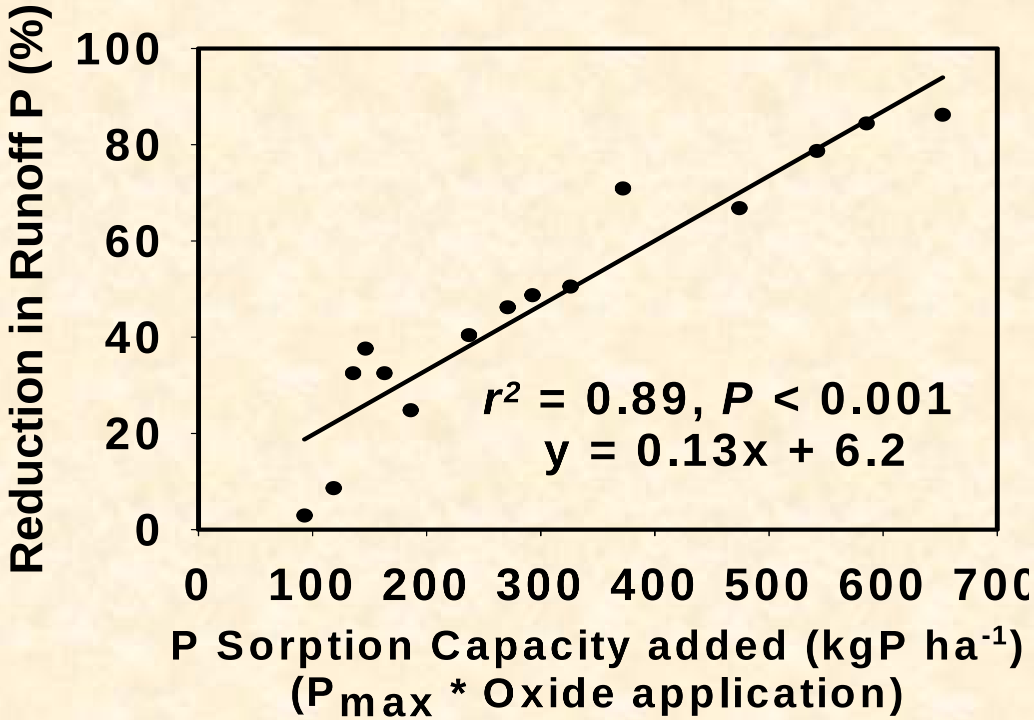
Up to 10,000 mi streams in U.S.

> 50,000 mines generating acid in the U.S.

Non-Point Source Agricultural P Pollution

- P is the nutrient most often implicated in surface water degradation
- There are 290,000 CAFOs (Concentrated Animal Feeding Operations) in the U.S.
- 2.5 Million tons of Manure P is generated annually in the U.S.
- Byproducts can be a rich source of metal oxide surfaces capable of binding agricultural P and preventing its movement into surface and ground water

Using Byproduct Sorbent to Reduce Phosphorous Runoff from Agricultural Land



Dayton & Basta, 2005, J. Environ. Qual. 34:2112-2117

We have conducted 13 yrs of research on use of byproducts as sorbents to reduce nutrient and contaminant (e.g. pesticide) runoff

Restoration of Disturbed Sites
Manufactured Soil

Superfund National Priorities List Sites: 1,498

Brownfields: 450,000

Military Bases: 204 currently undergoing cleanup

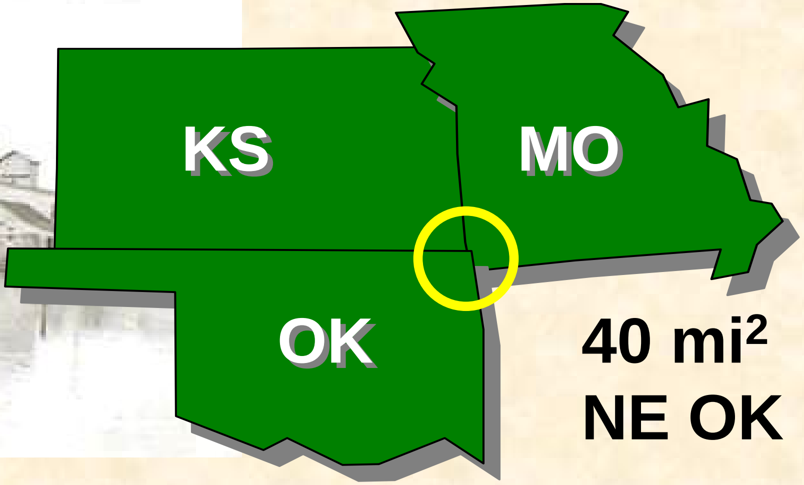
Abandoned Mine Lands: 10,200 BLM sites
> 80,000 total

It takes soil/soil components/soil amendments to reclaim/restore/revitalize disturbed land

Manufactured Soil Needs

Tri-State Mining Region

Extensive Pb, Zn Mining Smelting / Processing



40 mi^2
NE OK

<u>Manufactured Soil Need</u>

Acre Furrow Slice

1 Acre of Soil 6.5 in deep = 1,000 tons

40 mi^2 X 640 A/mi^2 X1,000tons/A =

25.6 Million Tons

Non-Hazardous Byproducts Are Needed for Site Restoration

Inconceivable to use natural soils

"It takes 500 yrs to form 1 inch of natural soil."

The Good News
Plentiful Potential Sources of Byproducts

Industrial Non-Hazardous Waste
7.6 billion tons

Municipal and Industrial Sludge

Dredge
several 100 million $yards^3$

Animal Manure
500 million tons

Beneficial Reuse of Byproducts
New Potential Economic Sectors

Beneficial Reuse / Recycling
is Working!

Thank you for your attention

More information? Please contact:

Nick Basta, SENR OSU

basta.4@osu.edu,

Elizabeth Dayton, SENR OSU

dayton.15@osu.edu

www.snr.osu.edu