Fern Phytoremediation Study 2005 – 2007

2013 Study Summary

Tacoma Smelter Plume Project

Toxics Cleanup Program

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This slideshow comprises the final report for the Tacoma Smelter Plume Fern Phytoremediation Study. Based on the 2005 – 2007 results, Ecology decided not to continue the study or attempt to use phytoremediation on a larger scale. Additional resources and a summary of findings from the first year of the study are available online.
http://www.ecy.wa.gov/programs/tcp/sites_brochure/tacoma_smelter/Phyto/index.html

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Purpose of the Fern Study

- To determine if Ecology can use the Chinese brake fern to **clean up contaminated soils** within the Tacoma Smelter Plume.

Study Questions

- Can the brake fern remove arsenic from soil?
- Can **homeowners** use the ferns as a cleanup method?
- How well do the ferns **survive** in this area?
- Are the ferns **invasive**?

Chinese Brake Fern

PHYTOREMEDIATION

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Phytoremediation

- The use of plants to remove contaminants from the environment.

  Phyto = plant Remediation = cleanup

- The Chinese brake fern **hyper-accumulates**– it pulls a large amount of arsenic from soil.

Chinese Brake Fern ***Pteris vitatta***

- From the dawn redwood forest (central China).
- Invasive in Gulf states and southern California.
- Identified as an arsenic bio-concentrator by University of Florida in late 1990's.
- Licensed for phytoremediation use by EdenSpace.

Chinese Brake Fern in the Puget Sound Region

- Requires supplemental watering and fertilization.
- Around 50% over-wintering survival rate at best.
- Best survival when grown in sunny locations.
- Bio-concentration factors of up to 100+ times soil levels.
- High soil arsenic variability confounded results.

Tacoma Smelter Plume Overview

SITE BACKGROUND

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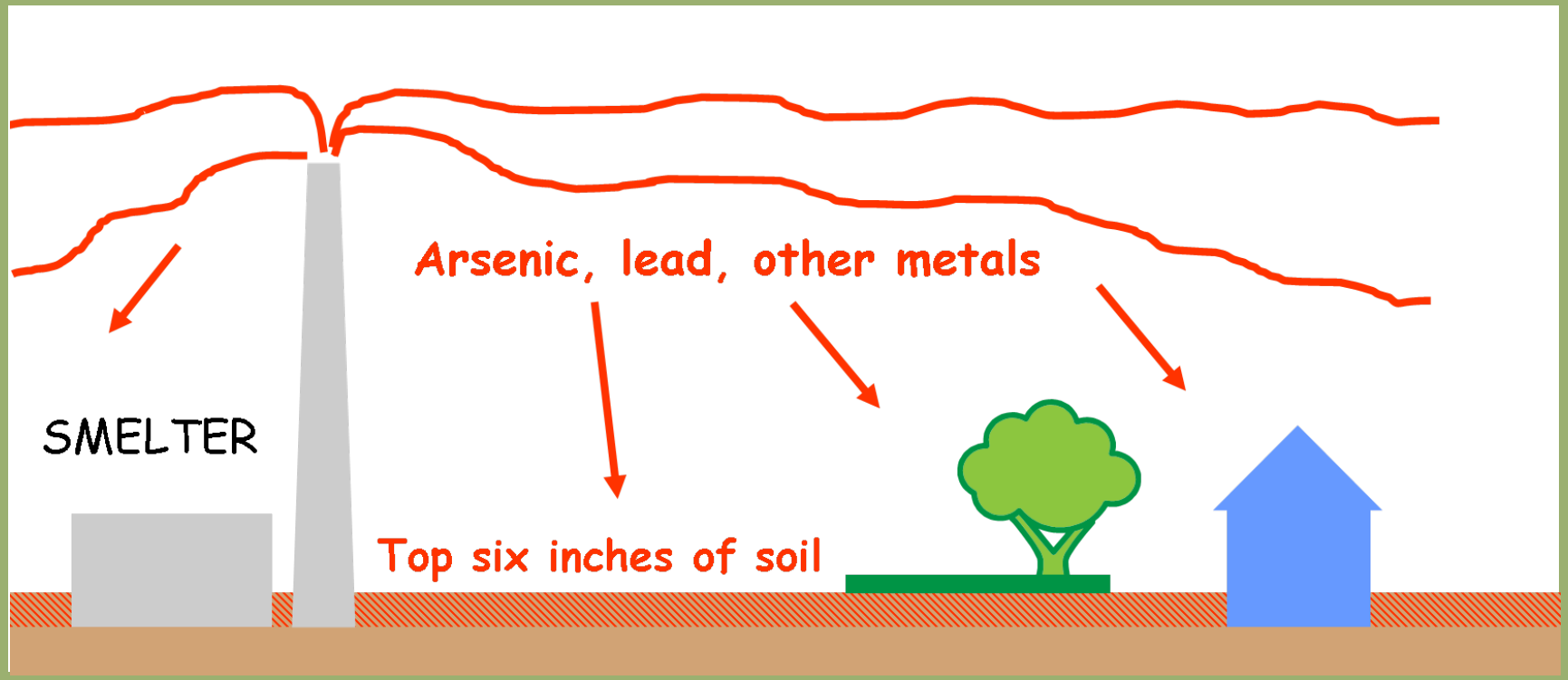
What is the Tacoma Smelter Plume?



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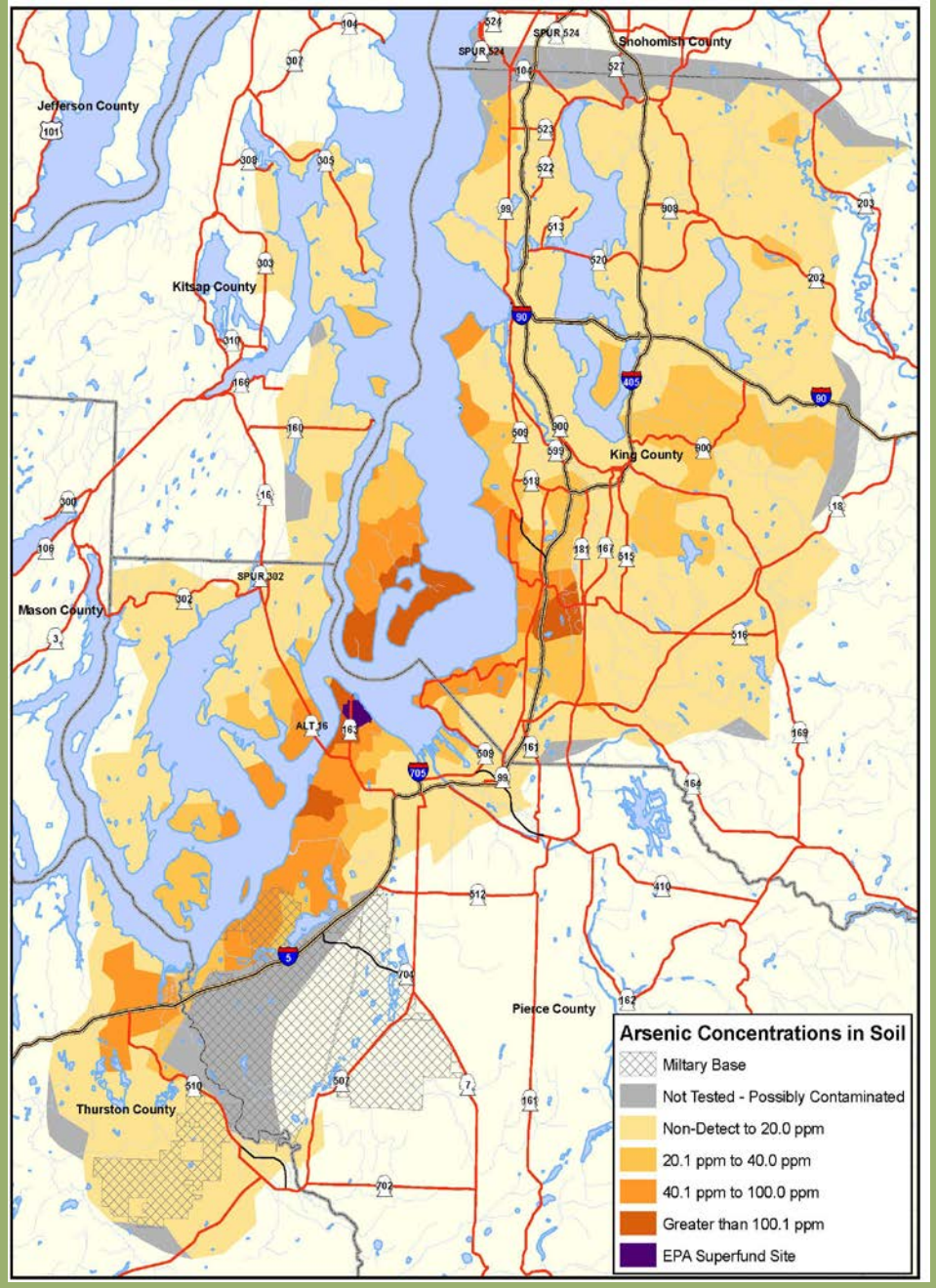
Tacoma Smelter Plume Contamination Patterns

- Within the top 12 – 24 inches of surface soil
- Higher levels closer to the smelter
- Follows wind patterns
- Higher in undisturbed soils
- Levels are highly variable



Tacoma Smelter Plume Extent

- 1,000 square miles
- Four counties

- Max levels found

  Arsenic = 460 ppm

  Lead = 1400 ppm

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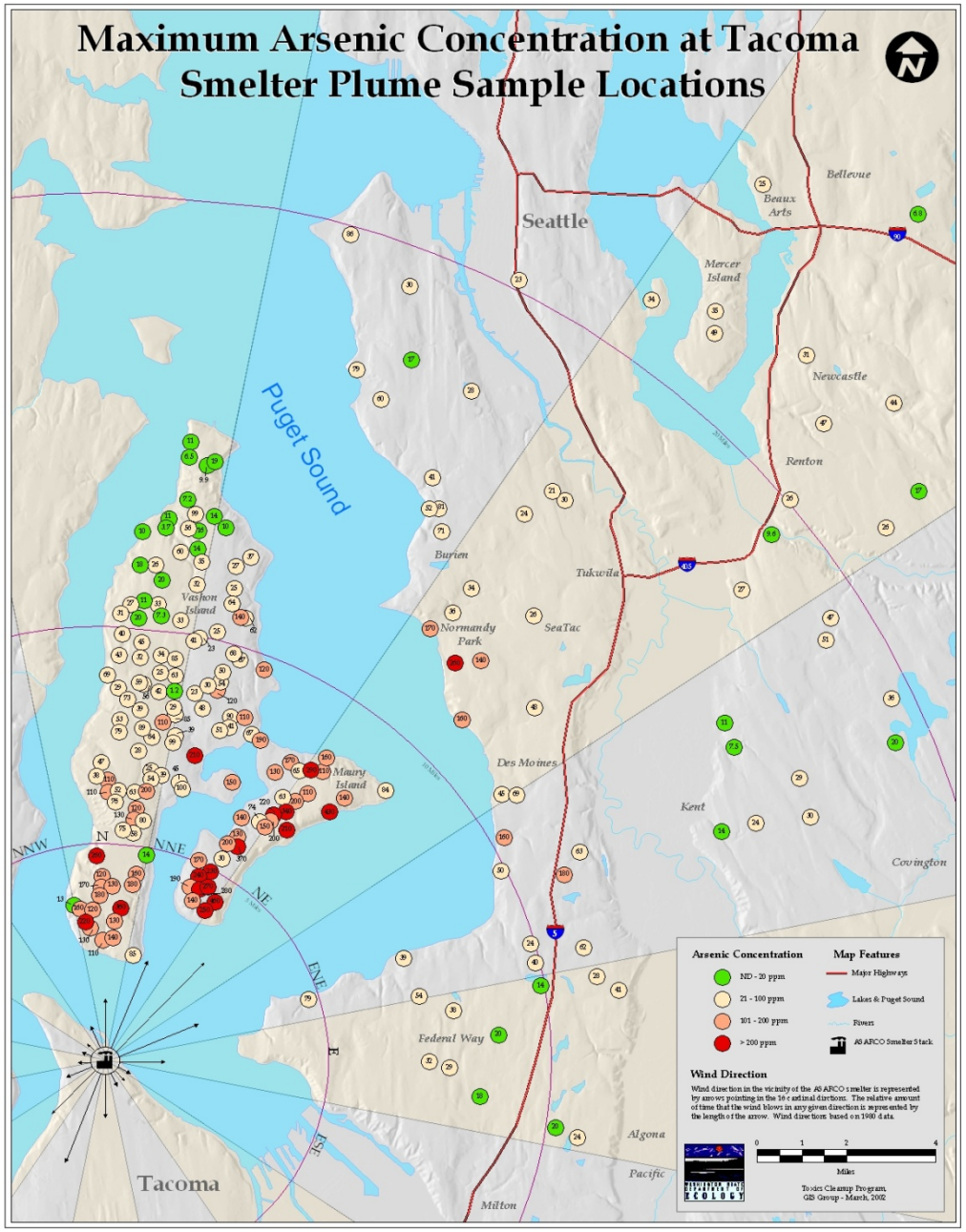
What makes the Tacoma Smelter Plume unique?

- **Size** is very large, in urban area, potentially affecting a very large population.
- **Risk** is relatively low in most areas.
- Large number of **properties.**
- **Long term** cleanup process (decades or more).

→ These factors make cleanup complex!



Arsenic Map

Tacoma Smelter Plume Fern Phytoremediation Study

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STUDY DESIGN

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Vashon Test Plots

Tacoma Smelter Plume Fern Phytoremediation Study

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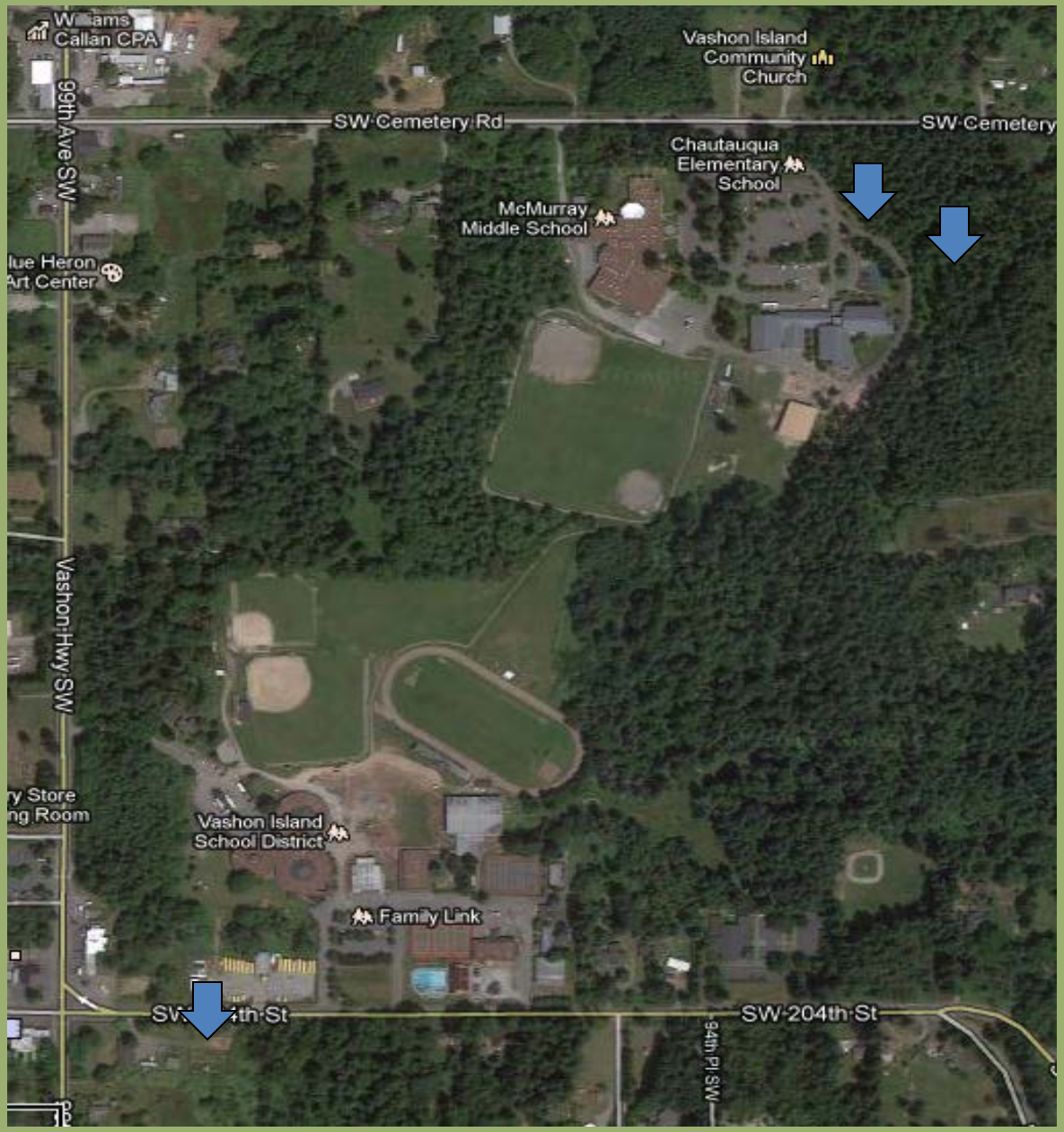
Vashon Test Plot Locations 1

- Vashon Island School District 1 (VISD)
  - VISD 1 = Kindergarten play area
  - VISD 2 = High school garden (southeast corner)
  - VISD 3 = Wooded area east of elementary school*

*Ferns only survived one year.



Vashon School District Test Plots

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Vashon Test Plot Locations 2

- Dockton Park (DP) - One year only
  - DP 1 = Near restroom & play area
  - DP 2 = Near walking path south of Dockton Road

- **Closed after 2005 because most ferns died.**

Dockton Park Test Plots

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Tacoma Test Plot Locations

- Point Defiance (PD)
  - PD 1 = Near park maintenance facility
  - PD 2 = Near ‘Never-Never Land’ log fort child play area

- **Closed after 2005 because most ferns died.**

Photos

RESEARCH PROCESS

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March 2005 VISD1 plot prior to preparation, showing soil survey sample locations where the sample jars sit atop stainless steel bowls.

April 2005 VISD1 Plot with soil tilled and fence posts in place.

April 2005 Plot warning sign

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July 2005 VISD1 Plot mid-season. Fern growth is vigorous. Chicken wire on the lower part of fence is to prevent children from reaching the fronds.

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October 2005 VISD 1 Plot soil sampling by Sid Forman and Doug Jones of Public Health–Seattle & King County just before harvesting fronds. Samples were collected at 0-6” and 6-12” depths using bucket augers. Samplers wear protective gloves to avoid contact with contaminated soil and fern fronds.

October 2005 VISD 1 plot with one area harvested. Fern fronds were cut off at ground level with scissors and placed in plastic bags for weighing and storage pending determination of waste characteristics and proper disposal.

Fern frond height is about 34”. This plot produced slightly over 18 lbs. of fronds.

November 2005 VISD 1 plot completely harvested. Two plants with mature spore formation were left standing to observe potential for invasiveness. In the spring, we looked see if any new ferns developed in or near this plot. No other plots developed mature spores on the fronds this growing season. Plot was left in this condition for about a month before mulching.

November 2005 VISD 1 plot with about 4” of straw mulch for over-wintering.

2007 Fern Harvest

ANALYTICAL RESULTS

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Arsenic in Shallow (0-4”) Soils vs. Fern Fronds

	Soil levels mg/kg				Fern tissue levels mg/kg		
Plot	Pre-Study	2005	2006	2007	2005	2006	2007
VISD 1	25.2	36	31.5	n/a	1732.5	160.4	120
VISD 2	37.3	40.3	38.6	29.3	983.2	46.6	180
VISD 3	40.5	37.9			1846.5		

No clear trend in soil arsenic levels over time.
Fern tissue concentrations were highest in 2005.

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Arsenic in Deep (8-12”) Soils vs. Fern Fronds

	Soil levels mg/kg				Fern tissue levels mg/kg		
Plot	**Pre-Study**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
VISD 1	n/a	31.3	35.7	n/a	1732.5	160.4	120
VISD 2	n/a	27.4	28	30.3	983.2	46.6	180
VISD 3	n/a	10.9			1846.5		

No clear trend in soil arsenic levels over time.
Deeper soils tend to have lower arsenic than shallow soils.

Lead in Shallow (0-4”) Soils vs. Fern Fronds

	Soil levels mg/kg				Fern tissue levels mg/kg		
Plot	Pre-Study	2005	2006	2007	2005	2006	2007
VISD 1	n/a	89.3	104.7	n/a	2.15	6.9	n/a
VISD 2	n/a	104.5	121.8	n/a	2.63	60.5	n/a
VISD 3	n/a	61.4			8.02		

No clear trend in soil lead levels over time.
Fern tissue concentrations were low compared to arsenic.

Lead in Deep (8-12”) Soils vs. Fern Fronds

	Soil levels mg/kg				Fern tissue levels mg/kg		
Plot	Pre-Study	2005	2006	2007	2005	2006	2007
VISD 1	n/a	27.4	95.4	n/a	2.15	6.9	n/a
VISD 2	n/a	72.2	101.8	n/a	2.63	60.5	n/a
VISD 3	n/a	16.5			8.02		

No clear trend in soil lead levels over time.
Deeper soils tend to have lower lead than shallow soils.

Arsenic Leaching vs. Fern Fronds

	Fern tissue levels mg/kg			TCLP mg/L		
Plot	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
VISD 1	1732.5	160.4	120	13.15	3.325	n/a
VISD 2	983.2	46.6	180	8.44	1.98	n/a
VISD 3	1846.5			12.5		

*Toxicity characteristic leaching procedure

Arsenic leaching was roughly proportional to tissue levels.

Lead Leaching vs. Fern Fronds

	Fern tissue levels mg/kg			TCLP* mg/L		
Plot	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
VISD 1	2.15	6.9	n/a	0.001	n/a	n/a
VISD 2	2.63	60.5	n/a	0.004	n/a	n/a
VISD 3	8.02			0.001		

*Toxicity characteristic leaching procedure

Very little lead leached from fern tissues.

Cadmium Results

- Cadmium data from 2005 only:
  - Fern tissue = **0.34 – 0.40 mg/kg**
  - TCLP = **0.001 mg/L**
  - Soils = **0.2 – 0.6 mg/kg**

- Soil levels and uptake were very low compared to arsenic and lead.

Arsenic Data from Plots Closed After 2005

	Soil levels mg/kg				Ferns	
	Shallow (0-4”)		Deep (8-12”)			
Plot	**April**	**October**	**April**	**October**	**Tissue mg/kg**	**TCLP mg/L**
DP 1	46.5	113.4	29.5	91.4	1710	12.3
DP 2	80.1	80.1	38	38	828.5	5.5
PD 1	n/a	147.5	n/a	117.5	16000	132.5
PD 2	n/a	89	n/a	20.3	6975	43.8

Lead Data from Plots Closed After 2005

	Soil levels mg/kg				Ferns	
	Shallow (0-4”)		Deep (8-12”)			
Plot	**April**	**October**	**April**	**October**	**Tissue mg/kg**	**TCLP mg/L**
DP 1	n/a	281.5	n/a	146	10.05	0.013
DP 2	n/a	117.6	n/a	53.9	9.17	0.004
PD 1	n/a	182.5	n/a	162.5	ND	ND
PD 2	n/a	135	n/a	21.75	ND	ND

Cadmium Data from Plots Closed After 2005

	Soil levels mg/kg				Ferns	
	Shallow (0-4”)		Deep (8-12”)			
Plot	**April**	**October**	**April**	**October**	**Tissue mg/kg**	**TCLP mg/L**
DP 1	n/a	2.4	n/a	1.2	0.339	0.001
DP 2	n/a	0.3	n/a	0.0001	0.142	0.0001
PD 1	n/a	1.78	n/a	1.48	ND	ND
PD 2	n/a	1.24	n/a	0.49	ND	ND

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Is fern phytoremediation a good cleanup option?

STUDY FINDINGS

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Fern Winter Survival

- Puget Sound region, with mulch
  - **1%** at Dockton Park plot 2
  - **60%** at Vashon School District plot 2
- Eastern Washington = **0%**

Fern Growth

- Biomass growth 2005 – 2006 = **10-20%**
- Per-plant growth = **5-40%**

- Bio-concentration 2005 – 2006 = **40-60%**
  (how much arsenic the plants took up)

Potential for Invasiveness

- **Ferns reproduce by growing spores.**
  - Only one plot produced mature spores one year.

- **Growth of new plants means the ferns are spreading.**
  - No new plants (gametophyte or sporophyte*) were found near the plots.

*Gametophytes and sporophytes are two different life cycle stages of the fern.

Findings

- Arsenic removal from 2005 to 2006 was **higher** than in eight other studies reviewed.*
- Limited uptake of lead and other metals.
- Estimated time to clean up soils = **8-12 yrs**
- Harvesting means **new plantings** are needed each year.

* Included laboratory and field studies from around the world.

What this means for cleanup...

- **Fern phytoremediation is not a good cleanup option for the Tacoma Smelter Plume.**
- Why?
  - **Climate:** Brake ferns did not grow well in this climate.
  - **Risk:** Arsenic levels in the fronds pose a health risk.
  - **Disposal:** The fronds became dangerous waste.
  - **Metal uptake:** The ferns did not take up lead or other metals.