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Predicted Impacts of Heavy Metals in Soils Downwind of the City of Ames Power Plant

Background of City of Ames Power Plant

- City of Ames Power Plant is a 71 MW plant.¹⁴
- The first coal fired plant to open at this location opened in 1901.¹⁴
- In 1975, the plant began to burn a combination of coal and refuse derived fuel (RDF) produced from private and municipal solid waste (refuse).¹
- Until the plant was converted to a natural gas system in early 2016, it burned 164 tons of coal and 26,000 tons of RDF annually.¹
- The fly ash, which escapes the 99.66% efficient air pollution removal system, contains trace elements that were originally present in the fuel sources.¹



Heavy Metals

- Heavy metals have a density >5 g/cm³ and are often toxic to plants and animals at low concentrations.²
- Plants take up and accumulate heavy metals from the soil, which can alter plant metabolism, and reduce growth and biomass production.^{2,3}
- Humans may consume contaminated plants, or animals that have eaten contaminated plants. Heavy metals can persist in organisms after contact, resulting in a bioaccumulation effect (Figure 1).²

Heavy Metal	Soil Toxicity Level (ppm) ^{2,3}	Health Effects ^{2,3,5}
Nickel	75	Eczema and other skin conditions, asthma, carcinogen
Lead	420	Headache, irritability, behavioral disturbances, memory loss, sleeplessness, carcinogen
Mercury	<1	Neurological/psychological disturbances, tremors, personality change, sleeplessness, carcinogen

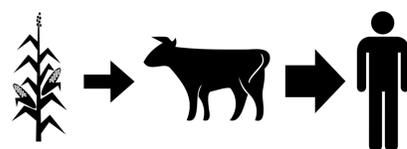


Figure 1: Simple bioaccumulation diagram.

- In wetlands and poorly drained soils, Hg mostly transforms to more bioavailable forms, like methylmercury.^{5,6}
- In agricultural areas, Hg mostly remains adsorbed to the surfaces of sulfides, clay particles, and organic matter as Hg²⁺.³
- Ni and Pb deposits onto soil in bioavailable forms.

Land Use	Contaminated Soil Exposure	Frequency of Contact
Wetland/Riparian	recreational activity, ingestion of contaminated plants or animals	Intermittent
Urban	spending time outdoors, vegetable gardening, children playing in soil	Continuous
Agriculture	occupational activity, ingestion of contaminated plants or animals	Intermittent and Continuous

Objective

The objective of this project is to:

- Predict the areas of highest expected deposition of nickel, lead, and mercury from the City of Ames Power Plant between 2004 and 2015.
- Anticipate the behavior of Ni, Pb, and Hg in the soils where highest deposition is expected.
- Assess land use and associated risks of human exposure in the predicted areas of high deposition.

Methods

- Heavy metals in fly ash are emitted from the smoke stack of the power plant and deposit downwind.
- Manipulation of the advection diffusion equation for concentration⁸ produces the following Gaussian Dispersion equation for the concentration (C) in g/m³ of the effluent in the air at downwind position x, y, z from the smoke stack:

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) \right]$$

Q = Emission rate of pollutant g/s
 u = wind speed (m/s)
 σ_y, σ_z = standard deviations of the plume (m)
 H = effective stack height (m)

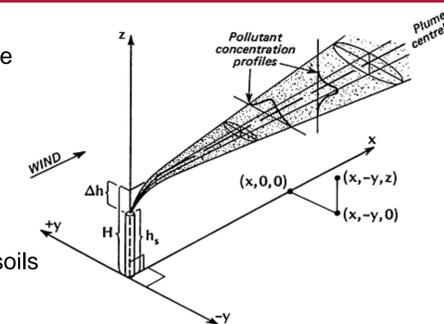
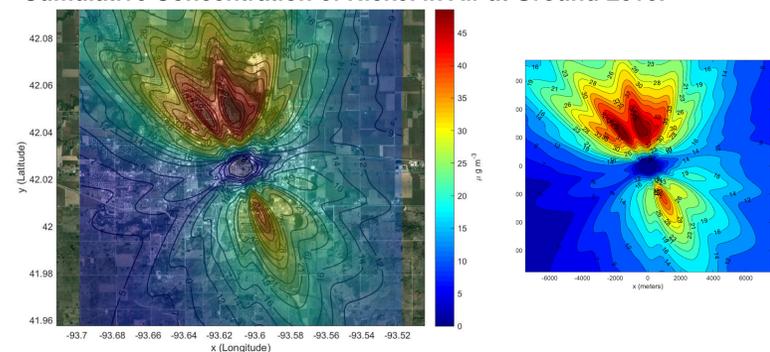


Figure 2: Typical plume from an elevated point source using Gaussian-plume model.⁹

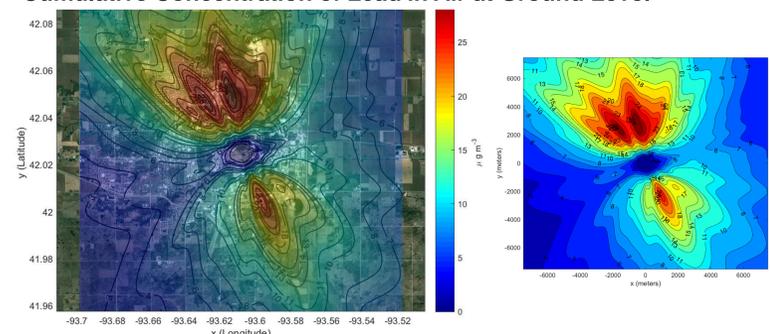
- The EPA uses Gaussian models (Figure 2) to model point source pollution at short distances.¹²
- This equation was used to model cumulative, hourly concentration of heavy metals in air at ground level, to predict the location of soils with the highest concentrations of heavy metal over the 12 year period.
- The model used hourly, local, atmospheric data from the Natural Resources Conservation Service weather station in Ames.¹⁰
- Annual emissions data obtained from the City of Ames was converted to a constant hourly emission rate.

Model Results and Discussion

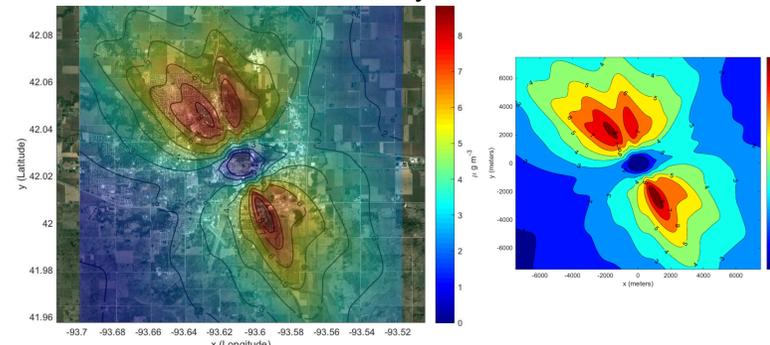
Cumulative Concentration of Nickel in Air at Ground Level



Cumulative Concentration of Lead in Air at Ground Level



Cumulative Concentration of Mercury in Air at Ground Level



- The Gaussian Dispersion model calculated the ground-level concentration of Ni, Pb, and Hg in air, and their position relative to the point source at the center of the plots.
- Areas of high cumulative concentration in the air at ground level are the locations of maximum contact between air and soil, and where most deposition is expected to occur.¹¹
- Because the plume may reflect off the ground and continue to push downwind, the concentrations at these points do not directly translate to soil concentrations.
- Using the model data, primary soil series were identified at the locations of highest concentration (>30 µg Ni/m³, >20 µg Pb/m³, >5 µg Hg/m³) using NRCS soil survey to predict heavy metal behavior in these soils and associated areas of risk (Table 3).

Soil Series	Description	Drainage Class	Landscape Position	Land Use	% Area in Maximum Affected Area
Clarion	Fine-loamy, mixed, superactive, mesic Typic Hapludolls	Moderately Well Drained	1-9%	Predominately urban, some agriculture	16.65%
Webster	Fine-loamy, mixed, superactive, mesic Typic Endoaquolls	Poorly Drained	0-3%	Predominately urban, some agriculture	12.45%
Hayden	Fine-loamy, mixed, superactive, mesic Glossic Hapludalfs	Well Drained	2-40%	Predominately wetland, some agriculture	10.32%
Coland	Fine-loamy, mixed, superactive, mesic Cumulic Endoaquolls	Poorly Drained	0-5%	Predominately wetland, some agriculture	9.01%

- Due to their urban land use in North Ames, the Clarion and Webster soil series have potential for frequent soil exposure to humans. However, more bioavailable forms of Hg are expected to be found in the Webster series than the Clarion series because Webster is poorly drained.
- The Coland and Hayden series in wetland areas may contain more bioavailable forms of Ni, Pb, and Hg, but human contact with soil in these areas may be less frequent than in urban areas.
- Crops grown on agricultural lands (containing all four soil series) may take up heavy metals, especially in poorly drained Webster and Coland series, extending exposure risk beyond contact with contaminated soil.

Conclusions

- The City of Ames Power Plant burned coal for 115 years. Earlier periods of operation did not record heavy metal emission, and had higher emission rates due to less efficient fly ash removal systems.
- Additionally, the plant exclusively burned coal from 1901 until 1975, when RDF was introduced.¹⁴
- Heavy metal concentrations in RDF are not tested, and any contribution to heavy metal from this fuel source was unaccounted for in the model.
- Coal-based heavy metal contamination in Ames is underestimated over these 12 years, since the Iowa State University Power Plant has annually burned 150,000 tons of coal for the past ten years.¹⁵ Heavy metal emissions data was unavailable for this plant.
- Predicted areas of high heavy metal concentrations in the soil may diverge from the actual locations of highest impact, largely due to possible variations in weather patterns since 1901, and the unaccounted inputs from the ISU Power Plant.
- Soil samples are needed to verify the locations of highly impacted areas.