Air Dispersion Modeling Analysis Remedial Investigation/Feasibility Study Red Devil Mine, Alaska

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Prepared for:

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
Anchorage Field Office
4700 BLM Road
Anchorage, Alaska 99507

Prepared by:

ECOLOGY AND ENVIRONMENT, INC.
720 3rd Avenue, Suite 17
Seattle, Washington 98104-1816

ecology and environment, inc.

Technical Memorandum

Date:	**August 3, 2010**
To:	**Mike McCrum, BLM** **Paul Krabacher, BLM**
From:	**Bill Vasil, E & E**
Through:	**Bill Richards, E & E**
Subject:	**Air Dispersion Modeling Analysis to Determine Mercury Deposition Footprint Resulting from Historical Air Emissions, Red Devil Mine, Red Devil, Alaska**

The Red Devil Mine consists of an abandoned mercury mine and ore-processing facility located on public lands managed by the Department of the Interior Bureau of Land Management (BLM) in the State of Alaska. The Red Devil Mine is the subject of a remedial investigation (RI)/feasibility study (FS) being prepared for BLM by Ecology and Environment, Inc. (E & E)under Delivery Order Number L09PD02160 and General Services Administration Contract Number GS-10F-0160J.

Historical ore-processing activities conducted at the Red Devil Mine included thermal processing of mercury ore, including retorting and furnacing. From 1939 to 1941, a small wood-fired and later oil-fired retort operated at the site. From late 1941 to 1955, a rotary kiln was installed with a stack approximately 65 feet tall (Bureau of Mines 1956). From 1956 until closing a multiple hearth furnace operated at the site (Bureau of Mines 1965). Aerial deposition of emissions from thermal processing at each of these facilities may have resulted in deposition of mercury and other metals in the vicinity of the ore processing facilities. An understanding of the area (“footprint”) that may have been affected by such deposition is needed to guide the selection of appropriate soil sampling sites, both for background ("clean") information and to determine potentially contaminated purposes the RI/FS. E & E developed an air dispersion modeling approach to estimate the likely footprint of mercury emissions from historical ore-processing locations. The air dispersion impact analysis is described below.

Technical Approach

Modeling was performed to approximate locations with a higher likelihood for elevated mercury in soil due to deposition from historical mercury ore processing operations at the Red Devil Mine. Detailed dispersion and deposition modeling requires detailed data on the operation of an emission source in order to produce reliable model output. The reliability of the results of the dispersion and deposition modeling is closely tied to the amount of accuracy of this data. For this project, no site-specific stack/chimney data are available from records or permits for operation of the retort, furnace, and kiln in their historical configurations. Therefore, assumptions were developed and are discussed in this air dispersion modeling study. These assumptions were developed by drawing upon information from similar sources for which data are available or from which data can be scaled to fit the size/capacity of the source being modeled.

Model Input Data Development

Based on available information, mercury ore processing at the Red Devil Mine employed three principal processing methods and configurations over the history of operations. Each of these methods is described below.

1. From 1939 to 1941, a small wood-fired and, later, oil-fired retort operated at the site. The retort was supposed to act as an essentially closed system, with the end of the condenser tube immersed in a tub of water, with the heat source exhausting through two stacks each approximately 15 to 20 feet tall. Since the primary concern is with impacts from mercury emissions, these stacks were not modeled. However, fugitive leaks in the system containing mercury were modeled as a volume source.

2. From late 1941 to 1955, a rotary kiln (assumed to be oil-fired) was installed with a stack approximately 65 feet tall (Bureau of Mines 1956). This stack was used as the source of mercury emissions in this scenario.

3. From 1956 until closing, a multiple hearth furnace (also assumed to be oil-fired), operated at the site (Bureau of Mines 1965). The stack for the furnace was used as the source of mercury emissions in this scenario.

There are no records of mercury losses at the Red Devil plant, but it was estimated that recovery averaged less than 70 percent (Bureau of Mines 1956). The remaining mercury was not extracted from the ore or was emitted as fugitive emission.

Model Selection

Models initially considered for this study were the screening-level model, SCREEN3, and the refined AERMOD model. The SCREEN3 model was rejected because it cannot provide impacts at locations based on wind direction and it cannot model deposition. AERMOD is a Gaussian plume model recommended by the United States Environmental Protection Agency (EPA) for evaluating ambient air quality impacts of stationary sources located on land. AERMOD uses hourly meteorological data to predict impacts at specified distances and directions from an emission source and contains deposition algorithms. It allows for analysis of air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources in both simple and complex terrain.

Model validation studies were performed by the EPA for dispersion over land. The model can calculate impacts for point sources, area sources, and volume sources. Used in conjunction with the structure data pre-processing program, the Building Profile Input Program for Plume Rise Model Enhancements (BPIP-PRM) model, the evaluation of downwash effects utilizes the latest techniques available for regulatory modeling studies (Schulman et al. 2000). Wind-tunnel and field studies have shown that incorporating estimates of wind speed, streamline deflection, and turbulence intensities in the wake, as well as the location of the source, are important factors for improving modeling simulations of the influence of buildings on ground-level concentrations. The PRIME algorithm was designed to incorporate the two fundamental features associated with building downwash: enhanced plume dispersion coefficients due to the turbulent wake and reduced plume rise caused by a combination of the descending streamlines on the leeward side of a building and the increased entrainment in the wake.

The plume from a stack is divided into two portions based on the configuration of the stack and building. A portion is captured in the near-wake region of the building and recirculated; the remainder of the plume is not captured. The PRIME methodology re-emits the captured plume from the cavity region into the far-wake region, where it is merged with the uncaptured plume. The model also has more advanced calculations to determine dispersion within the wake region (EPA 2004).

Given these considerations, the AERMOD model was chosen for use in this analysis. It requires the following general input data.

- Emission rate
- Meteorological data
- Receptor data
- Stack parameters
- Building/structure parameters
- Land use data
- Miscellaneous model options

Emission Rate

Data on source-emission rates at the Red Devil Mine are not available. Therefore, a normalized (1 g/s) emission rate was used in the modeling analysis. This is appropriate for this study because the objective of the modeling is only to estimate where emissions might have deposited rather than estimate their magnitude.

Meteorological Data

The Alaska Department of Environmental Conservation (ADEC) was contacted to determine if any onsite meteorological data was available in the vicinity of the Red Devil Mine (ADEC 2010). The nearest onsite data available through the ADEC is for a site located an unspecified distance north of McGrath. McGrath is approximately 100 miles northeast of the Red Devil Mine. McGrath has an airport with a first order meteorological station that archives meteorological data. The earliest available meteorological data for the site is the period from 1961 through 1965. This five-year period is considered representative of historical meteorological conditions at the Red Devil Mine site. In addition to surface data, McGrath collects upper air data, which was used in the analysis. The meteorological data was processed through AERMET, a meteorological data pre-processor that prepares National Weather Service data for use in AERMOD.

Terrain and Receptor Data

In order to define the sectors around the retort, kiln, and furnace that may have been more frequently impacted by mercury emissions, the model requires receptor locations as an input. Receptors were placed every 50 meters out to 1 kilometer, every 100 meters from 1 kilometer to 2 kilometers, and every 500 meters from 2 kilometers to 5 kilometers to provide sufficient resolution of impacts. Elevations of nearby receptors were obtained by processing United States Geological Survey (USGS) 1-degree Digital Elevation Model (DEM) data using AERMAP. The 1-degree DEM files are digital representations of cartographic information in a raster format. The DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. Each 1-degree DEM is based on the Universal Trans Mercator (UTM) projection. These data have a slightly lower resolution than 7.5-minute DEMs that are typically used for modeling. However, there is generally limited availability of 7.5-minute DEMs in Alaska, and there are no 7.5-minute DEMs available for the Red Devil site.

Stack Parameters

E & E reviewed data and publications regarding historical operation at Red Devil Mine and other pertinent information regarding the emission sources for the site to develop a data set of emission parameters. Based on the data gaps of stack parameters, E & E has reviewed similar facilities whose emission-source information was used as a surrogate for the Red Devil Mine site. Exhaust gas temperature and exit velocity come from *Bulletin Number 4, Quicksilver in Oregon* (Schuette 1938). Base elevation was obtained from topographic maps. All other data, emission height, exit diameter, and length and width of volume source were estimated based on historical Red Devil Mine photographs

Three scenarios were modeled.

- Scenario 1: 1939 to 1941- retort
- Scenario 2 1941 to 1956 - rotary kiln
- Scenario 3: 1956 until closing – hearth furnace

The 1939 to 1941 retort was modeled as a volume source, since leakage from the retorts would exit through building windows and doors. The kiln and furnace in the two succeeding periods of operation were modeled as point sources. Model input parameters include stack height, stack gas temperature, stack exit inside diameter, stack gas exit velocity, and elevation of stack base above the surface (see Table 1).

It is typically expected that a retort does not have mercury emissions because the exit pipe is submerged under water to collect the mercury. Stack emissions would be from the fuel used to fire the retort and would not be expected to contain mercury under normal operating conditions. However, retorting at the Red Devil Mine was found to be "expensive and hazardous." Antimony and arsenic glassy material in the ore would vaporize and condense in the head of the retort and in the condenser pipes, sealing them. When this occurred, mercury vapors would build up under high pressure in the retort, and leakage would occur (Bureau of Mines 1962). Therefore, mercury emissions for Scenario 1 were modeled as a volume source, assuming the mercury vapor leaked out of windows and doors of the retort building.

For mercury ore processing with a rotary kiln or furnace, the ore is mixed with the fuel. Therefore, mercury would exit through the stack. Scenarios 2 and 3 were, therefore, only modeled as point sources for the deposition of particles, since it is assumed any mercury emitted from the stacks would be attached to particles. Therefore, mercury vapor concentrations were not modeled. The particle size distribution is shown in Table 2.

Table 1 Summary of Emission Parameters

Source Description	Emission Height (m)	Exit Diameter (m)	Length and Width of Volume Source (m)	Base Elevation (m)	Exhaust Gas Temp. (K)	Stack Exit Velocity (m/s)
Scenario 1 – Retorts 1 and 2	4.6	NA	15, 22	70.1	Ambient	NA
Scenario 2 – Rotary Kiln	19.8	0.3	NA	75.0	313	16.59
Scenario 3 – Hearth Furnace	1.83	0.46	NA	75.0	313	7.06

Notes: NA – Not applicable for type of source. The retorts were modeled as a volume source; the kiln and furnace were modeled as point sources.
m – meter
m/s – meter per second
K – degrees Kelvin

Source: Exhaust gas temperature and exit velocity come from *Bulletin Number 4, Quicksilver in Oregon*, 1938. Base elevation is from topographic maps. All other data, emission height, exit diameter, and length and width of volume source were estimated based on historical Red Devil Mine photographs.

Table 2 Surface Area Weighting of Mass Fractions for Particle-Bound Mercury Modeling

Mean Particle Diameter (µm)	Mean Particle Radius (µm)	Surface Area / Volume	Fraction of Total Mass	Proportion Available Surface Area	Fraction of Total Surface Area
23.304	11.65	0.257	0.03	0.0077	0.0018
12.664	6.33	0.474	0.05	0.0237	0.0054
8.163	4.08	0.735	0.15	0.1102	0.0251
4.478	2.24	1.34	0.24	0.322	0.0732
1.942	0.97	3.09	0.22	0.68	0.1547
1.13	0.56	5.312	0.06	0.319	0.0725
0.827	0.41	7.258	0.11	0.798	0.1817
0.394	0.2	15.239	0.14	2.133	0.4856

[1] Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities (Section 3.2.3). USEPA Office of Solid Waste and Emergency Response. EPA530-R-05-006, September 2005.

Building and Structure Parameters

Structure data is included as model input to account for potential building wake effects (downwash) on emission plumes and cavity trapping of emissions. Building dimensions were estimated from historical photographs since buildings no longer exist on the site. The BPIP-PRM model processes building dimension data to calculate projected structure dimensions by wind angle for input to AERMOD. Estimated building dimensions are shown in Table 3.

Table 3 Estimated Building Dimensions

Building	Length (m)	Width (m)	Height (m)
Retort	22	15	4.6
Rotary Kiln	30	13	11
Furnace	30	13	11
Shop Pad A	14	13	6
Shop Pad	14	13	6

m = meters

Land Use

AERMOD incorporates land use parameters for the processing of boundary layer parameters used for the dispersion prior to deposition. AERSURFACE is a tool that processes land cover data to determine the surface characteristics (surface roughness, albedo, and Bowen ratio) for use in AERMET. AERSURFACE use National Land Cover Data (NLCD 1992) to determine land use data around a meteorological data site. However, there is no NLCD 1992 data available for Alaska. Alaska does have NLCD 2001 data, but a beta version of AERSURFACE to process this data has been found to contain errors. Therefore, aerial photographs were used to manually determine local land use. Land use within 10 kilometers of the meteorological data site is shown in Table 4. These surface characteristic result in a surface roughness of 0.0052, an albedo of 0.67, and a Bowen ratio of 0.05

Table 4 Land Use Fractions within 10 Kilometers of the Monitoring Site

Land Use Description	Ground Cover Type	Fraction of Area
Deciduous Forest Land	Heavily Wooded	0.4
Strip Mines, Quarries, Gravel Pits	Minimal Vegetation	--
Residential/Transportation & Utilities	Suburban/Flat Few Trees	0.2
Transitional Areas	Grass, Weeds	0.2
Water	NA	0.2

Miscellaneous Model Option

The AERMOD model has several options that can be selected by the user. The following regulatory options recommended by the EPA were used in the modeling analysis:

- Elevated terrain;
- Stack tip downwash; and
- No optimized meander implementation for point and volume sources.

Analysis of Model Output

The three mercury processing configurations were modeled in three separate model runs. The results of the air quality impact analysis are presented as isopleth maps of mercury dispersion for Scenario 1 and deposition for Scenario 2 and 3. Each of the source configurations (1939 to 1941 retort, 1941 to 1956 rotary kiln, and 1956 to closing furnace) produced different dispersion and deposition patterns due to the differences in stack heights and the location of emission sources on the site. The 1939 to 1941 retort configuration resulted in dispersion and deposition of mercury close to the source structure. The stacks used in the subsequent facility configuration resulted in deposition impacts farther from the emission sources, as would be expected given the elevated emission points.

The modeling analysis addressed the annual averaging period for deposition impacts. The five years of meteorological data were concatenated so that the isopleth maps could show the dispersion and deposition impacts for the entire five-year period. For presentation purposes, Figure 1 shows the buildings for the three scenarios overlaid on a USGS topographic chart; not all buildings were present during each scenario. Figure 2 shows the dispersion impacts for Scenario 1, where mercury was processed by the retort. Maximum impacts appear to occur to the southeast. Figure 3 shows the deposition impacts for Scenario 2, where mercury was processed by the rotary kiln. Deposition from the rotary kiln appears to occur largely to the southeast, east northeast, and northwest. Figure 4 shows the deposition impacts for Scenario 3, where mercury was processed by a multiple hearth furnace. Deposition from the furnace during this scenario occurs most frequently to the southeast and east.

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Figure 1 Building/Source Locations at the Red Devil Mine

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Figure 2 Dispersion of Mercury from the Red Devil Mine Retorts

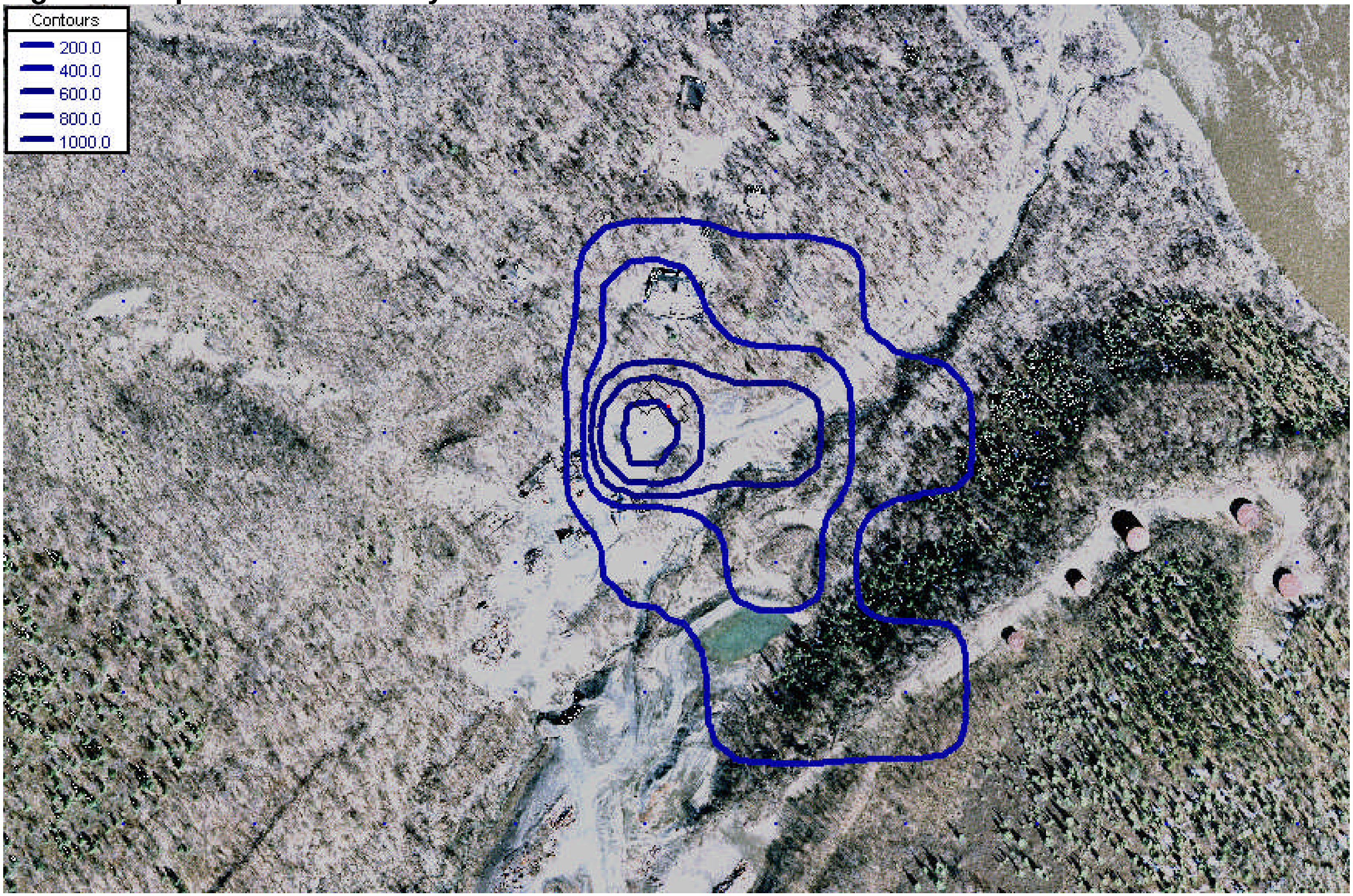

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Figure 3 Deposition of Mercury from the Red Devil Mine Rotary Kiln

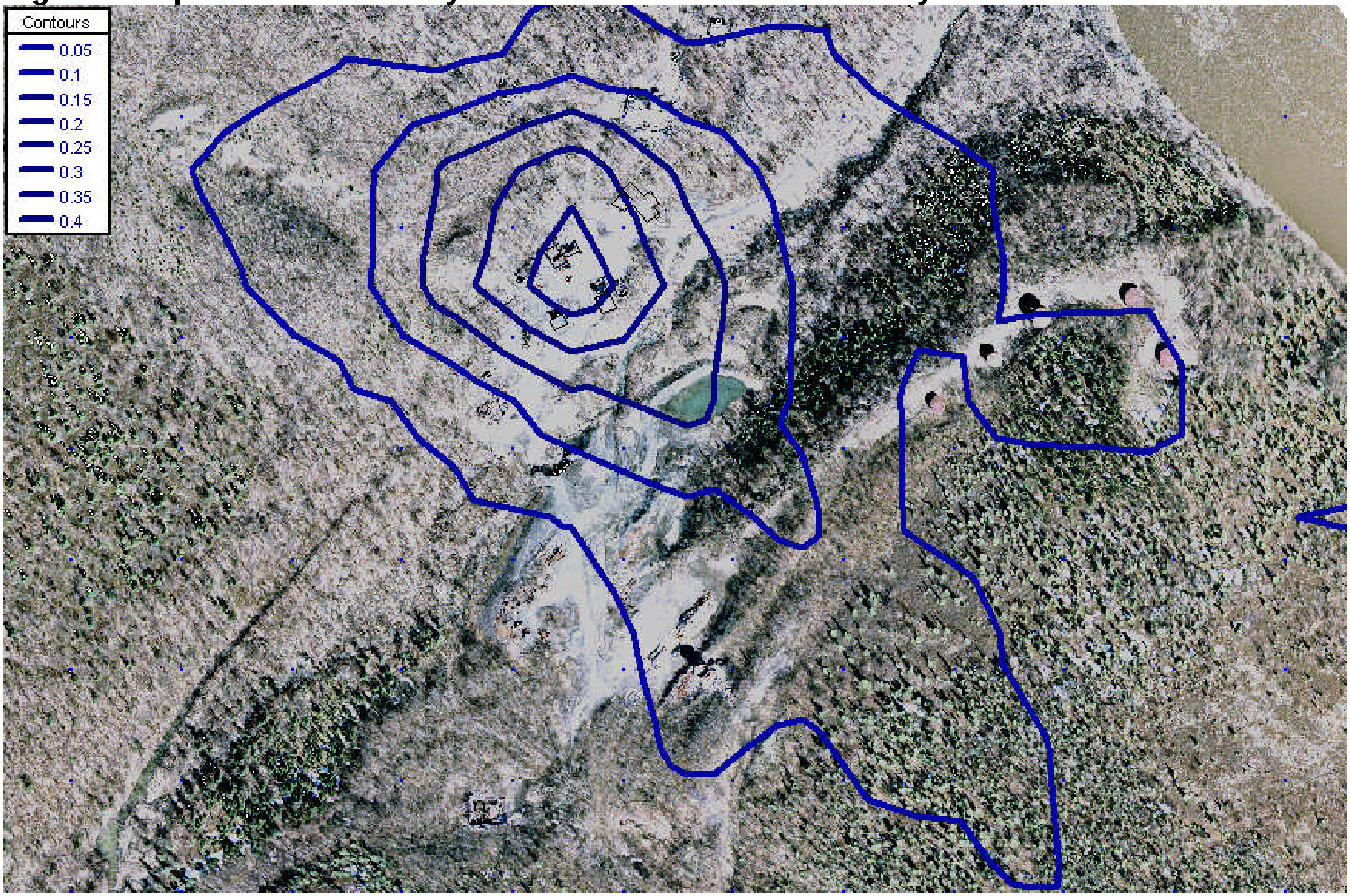

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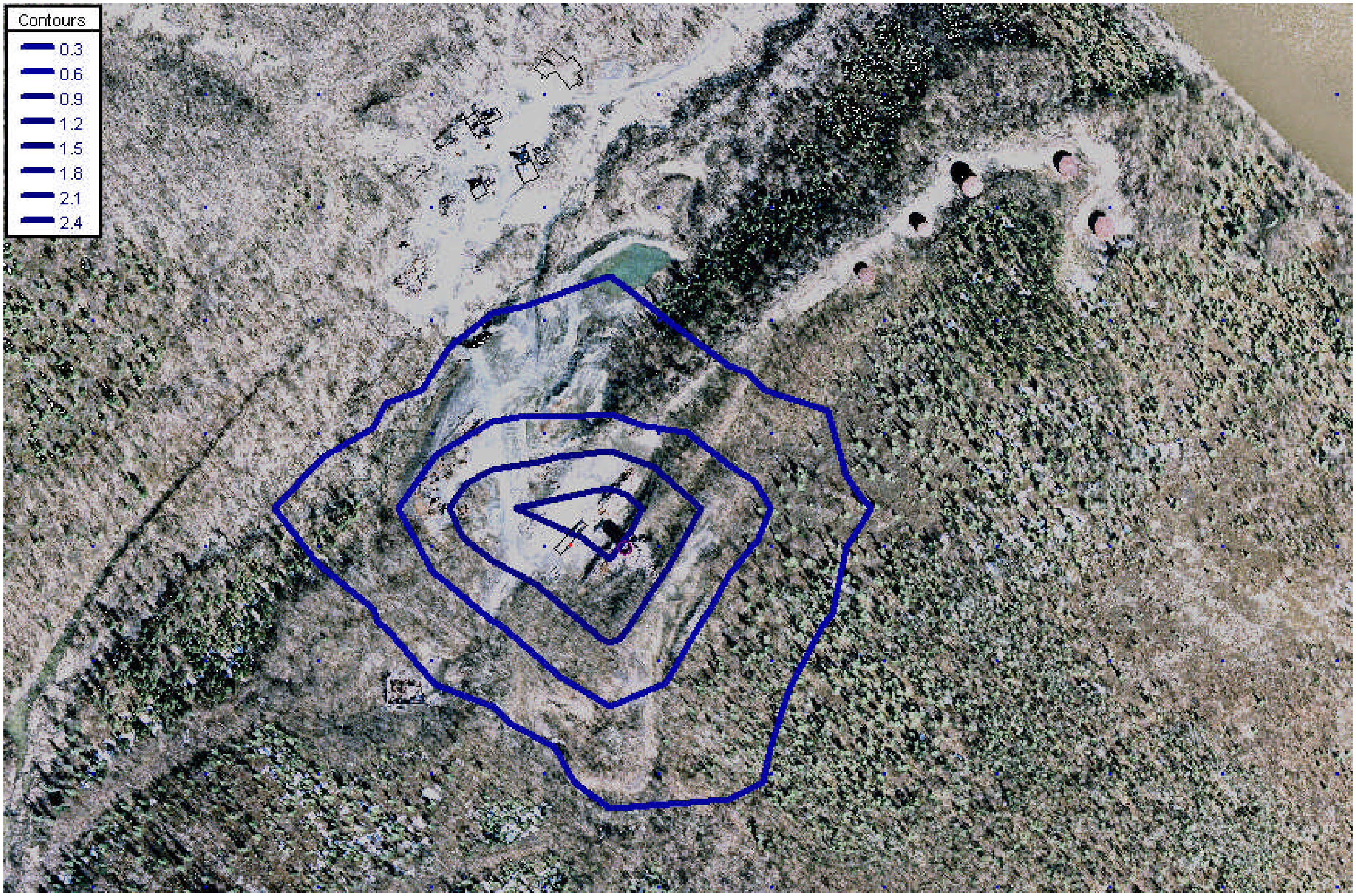
Figure 4 Deposition of Mercury from the Red Devil Mine Multiple Hearth Furnace



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