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Title: APPLYING GIS IN CHARACTERIZING AND MODELLING TRANSPORT IN SURFACE WATER AT LOS ALAMOS NATIONAL LABORATORY (GEOGRAPHIC INFORMATION SYSTEM (GIS)

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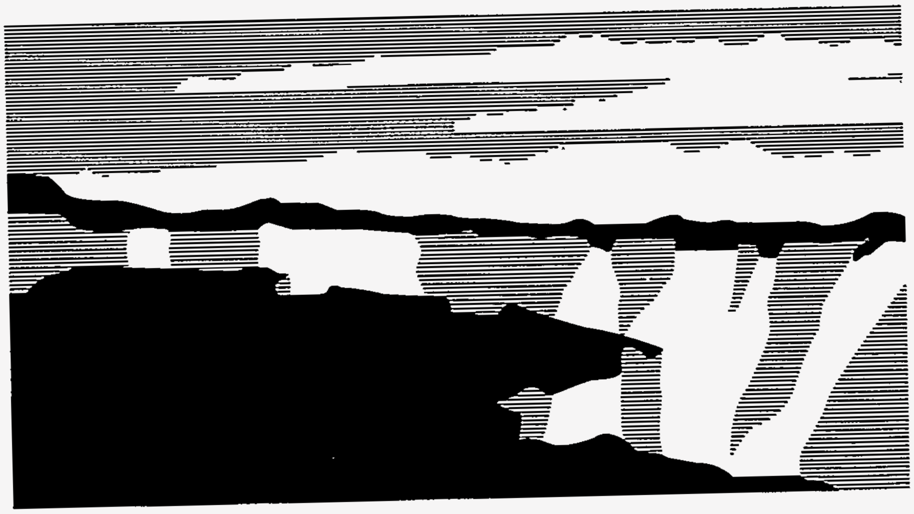

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Applying GIS in Characterizing and Modeling Contaminant Transport in Surface Water at Los Alamos National Laboratory

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Abstract At Los Alamos National Laboratory, transport of uranium and other metals away from firing sites is evaluated through the employment of GIS techniques. These techniques are demonstrated through three hydrologic examples: (1) design of a contaminant sampling scheme in an unknown watershed; (2) characterization of the spatial variability of uranium and copper; and (3) modeling uranium transport away from firing sites.

Introduction

During World War II, Los Alamos, New Mexico was chosen as the site for the secret development of the first atomic bomb (Fig. 1). The remote location in the southwestern United States was ideal for such a project. After the war, research activities continued at the Los Alamos installation, focusing on new nuclear weapons models as well as greater effectiveness and reliability of existing weapons. Due to the emphasis on nuclear and non-nuclear weapons development as well as associated nuclear research, a large inventory of radionuclides and heavy metals have been tested, expended, and disposed of in the local environment, a high plateau of tuffaceous volcanic rocks incised by deep canyons in a semi-arid climate.

In recent years an intensive evaluation of the environmental impact of weapons testing at Los Alamos and elsewhere has been undertaken. GIS system utilization and image processing of past and current data has been an important part of this evaluation. Important problems can be more easily displayed and understood using this methodology. The primary software packages utilized at Los Alamos were TNTmips and ARC/INFO on the SUN, SGI, and Macintosh platforms.

The main objective in this paper is to illustrate how transport of depleted uranium and associated heavy metals (copper in this case) used in dynamic testing of weapons components at open air firing sites can be evaluated and visualized. In our studies, surface water has been found to be the predominant transport mechanism. We have sampled soils, sediments, fallout, runoff water and snowmelt over a number of years in order to understand contaminant transport on- and offsite. Statistical analyses of these data have assisted in our characterization of issues such as contaminant variability, spatially and temporally, as well as in development of transport rates. Together, these data are used in providing model parameter input and validation of selected models.

The following several examples demonstrate the combination of hydrologic data with other data and imagery in a GIS context, thus allowing a clearer understanding of the hydrologic transport of contaminants produced by dynamic weapons testing.

Design of a Contaminant Sampling Scheme in an Unknown Watershed

In this example, the problem is to design a sampling scheme to measure the mean concentration of (depleted) uranium to a known uncertainty and accuracy limit on a watershed scale. In the case of a watershed where little to no data exists, one might choose a random grid, or perhaps biased sampling near the firing sites to address the question. Instead, statistical sampling strategies were developed to reduce the number of samples needed by taking advantage of the known geological and hydrological features of the area.

To determine whether or not stratified sampling could improve accuracy of results, an estimate of the standard deviation in each strata was needed (Cochran, 1984). These were obtained by using a large, high quality contaminant and hydrologic data set from the Potrillo Canyon watershed. Figure 2 shows the location of Potrillo Canyon overlaid on SPOT imagery of Los Alamos. The SPOT image provides geographical information along with the stream channels, firing sites and other features of the watershed. Another watershed, Big Buck Canyon, is shown as well. The Potrillo Canyon watershed was divided into a number of strata where it is expected that there is little variability within the strata, but considerable variability between strata. The 4 selected strata, based on hydrogeologic considerations, were: mesa tops, canyon sides and bottom, firing sites, and a geomorphologic discontinuity known as a discharge sink (Becker and others, 1995). Figure 3 shows how those strata are separated. Strata were delineated quickly through overlay with aerial photography and topography to produce geocoded data and then to code the strata. To determine the number of samples which need to be collected to estimate the mean uranium concentration in soils (and sediments) in the Potrillo Canyon watershed, the standard statistical sampling theory of Cochran (1984) was followed, and a prescribed number of samples were calculated for each strata using the standard deviations shown in Table 1. Note the savings in stratified sampling compared to random sampling.

To apply this to another watershed, Big Buck Canyon, the watershed was overlaid onto an aerial photographic basemap and strata were digitized. In contrast to the large data base at Potrillo Canyon, we had few data points with which to test the initial hypothesis to use a stratified sampling approach: little variability within strata, but large variability between strata. Available data points were recognized in terms of their strata due to their geocoded location. Sample standard deviation for each strata was calculated, and compared to standard deviations for comparable strata which were geolocated in Potrillo Canyon watershed. Standard deviations for comparable strata in Big Buck Canyon watershed were expected to be in similar proportion due to similarity in topography, hydrology, geology, and dynamic testing activities. This was found to be true, and the number of samples derived to compute the mean uranium concentration in Big Buck Canyon watershed soils and sediments, Table 1. The similarity in number of samples between Potrillo and Big Buck Canyons is related to their similarity in area (Becker and David, 1995).

Characteristics of Uranium and Copper Transport in Potrillo Canyon Watershed

We use the notion of strata further to aid in understanding the distribution of uranium and copper in the watershed as distributed during dynamic testing operations, and then transported by hydrologic means. Figure 4 shows the overlay of mean uranium concentration with strata in the Potrillo Canyon watershed for surface soil and sediment samples collected between 1987 and 1989. It may be observed that uranium concentrations are greatest in firing sites and canyon (exclusive of firing sites and the discharge sink) strata, and lower on the mesa tops and in the discharge sink. Examination of the standard deviation of the same data show that the greatest variability exists again in the canyons and at the firing sites. Means and standard deviations for strata were based on 75-125 soil samples each, except at firing sites where there were only 10 samples collected.

Compare these to results for analyses of copper taken from the same samples, Fig. 4. Greatest copper concentrations exist at the firing sites and in the canyons, whereas concentrations decline on mesa tops and in the discharge sink. Similar patterns exist for the standard deviations of these data. These trends reflect a number of concepts on contaminant transport by hydrologic mechanisms in this system. First, uranium and copper concentrations are greatest at the firing sites, 102.6 and 42.3 μg/g (ppm), respectively. This is to be expected, since they are the primary source area for uranium and copper in the watershed. These regions also have the greatest variability in concentration, reflecting a non-uniform initial distribution (at the firing sites) and redistribution in the surface water pathway (canyons). Concentrations of these two elements on mesa tops demonstrate that the primary method of redistribution is by surface water rather than by wind, and that the effect of the firing site is spatially limited. Relatively low concentrations in the discharge sink show that most of the contamination is either still at the firing site, or tied up in the channel sediments. Low variability in both mesa tops and firing sites implies that few samples are needed to accurately characterize the soil concentration in these regions. Larger variability at firing sites and in the canyon necessitates greater sampling density and frequency here. Finally, it may be assumed that uranium and copper have similar transport rates by surface water in this hydrologic system.

Because we had numerous samples which had been analyzed for both uranium and copper, it was possible to calculate the correlation of uranium with copper, Fig. 4. Good correlations between uranium and copper were observed at firing sites and in the canyons, r^2 of 0.89 and 0.84, respectively and 1.00 is a perfect correlation Therefore, in these regions it may be possible to infer uranium concentrations using copper, which is desirable because uranium is a more expensive analyte to detect. In the discharge sink and on mesa tops, the correlation coefficient is poor, 0.26 and 0.10, respectively. In these strata, copper correlates poorly with uranium, and other methods need to be employed to make inferences on the concentration of the other element, if even possible.

A Model for Uranium Transport Away from Firing Sites

In the final example, we sought to evaluate the decline in soil concentration of uranium with increasing distance from a firing site. Concentrations on the firing pad itself are considerable, in the range of thousands of ppm. In a first approximation, soil samples in the vicinity of firing sites were collected, and averaged as a function of their distance from the firing pad, Figure 5. Using one of the firing sites on the mesa as an example, the mean uranium concentration within the closest 125 m on the mesa is expected to be 85.8 µg/g (ppm); from 125 to 300 m distance the mean uranium concentration is expected to be 40.8 ppm, and at distances between 300 and 700 m, the mean uranium concentration in soil is expected to be 6.9 µg/g (ppm) (Becker and others, 1995). These expected soil concentrations were not extended into the canyon strata because we expect there to be a different transport rate down the steep sides of the canyon and through the channel. Such actual data are being used to validate hydrologic transport models.

Conclusions

Several examples are presented to illustrate the benefits gained by GIS techniques in displaying contaminant transport data associated with Los Alamos National Laboratory firing sites and as an aid to understand the dynamics of hydrologic transport of several heavy metals. These representations assist in modeling hydrologic transport of uranium and copper, both in conceptual as well as process/simulation models.

ACKNOWLEDGMENTS

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FIGURE CAPTIONS

Fig 1. Location Map of Los Alamos National Laboratory.

Fig 2. Potrillo Canyon and Big Buck Canyon Watersheds Overlaid on a 1991 SPOT image.

Fig 3. Designated Strata in Potrillo Canyon and Big Buck Canyon Watersheds.

Fig 4. Mean and Standard Deviation of Uranium and Copper Concentrations and Correlation of Uranium with Copper in Soils and Sediments in Potrillo Canyon Watershed.

Fig 5. Mean Uranium Concentration in Soils as a function of distance from one Firing Site in Potrillo Canyon Watershed.

Table 1 Number of Samples Required, by Strata, for Mean Uranium Concentration*

Strata	Uranium Standard Deviation (µg/g)	Potrillo Canyon Stratified Sample	Random Sample	Big Buck Canyon Stratified Sample
Firing Sites	150.8	105	49	60
Mesa Tops	9.0	43	337	35
Canyon	61.1	149	172	212
Discharge Sink	8.1	6	55	1
TOTAL		303	613	308

*Accuracy to ± 4 µg/g 95% of the time.

Notice that a random scheme requires over twice as many samples as the stratified scheme.

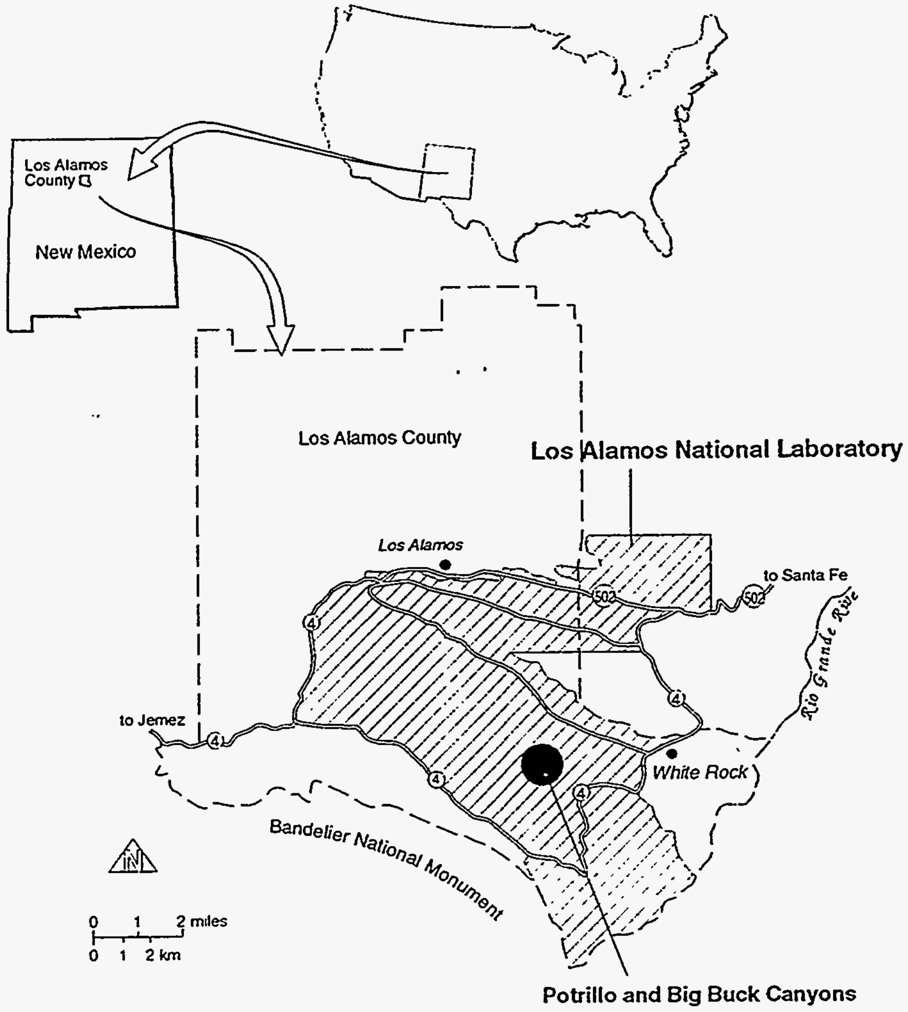

Los Alamos County
New Mexico
Los Alamos County
Los Alamos National Laboratory
Los Alamos
to Santa Fe
502
502
Rio Grande River
4
4
4
4
4
to Jemez
White Rock
Bandelier National Monument
N
0 1 2 miles
0 1 2 km
Potrillo and Big Buck Canyons

FIG 1

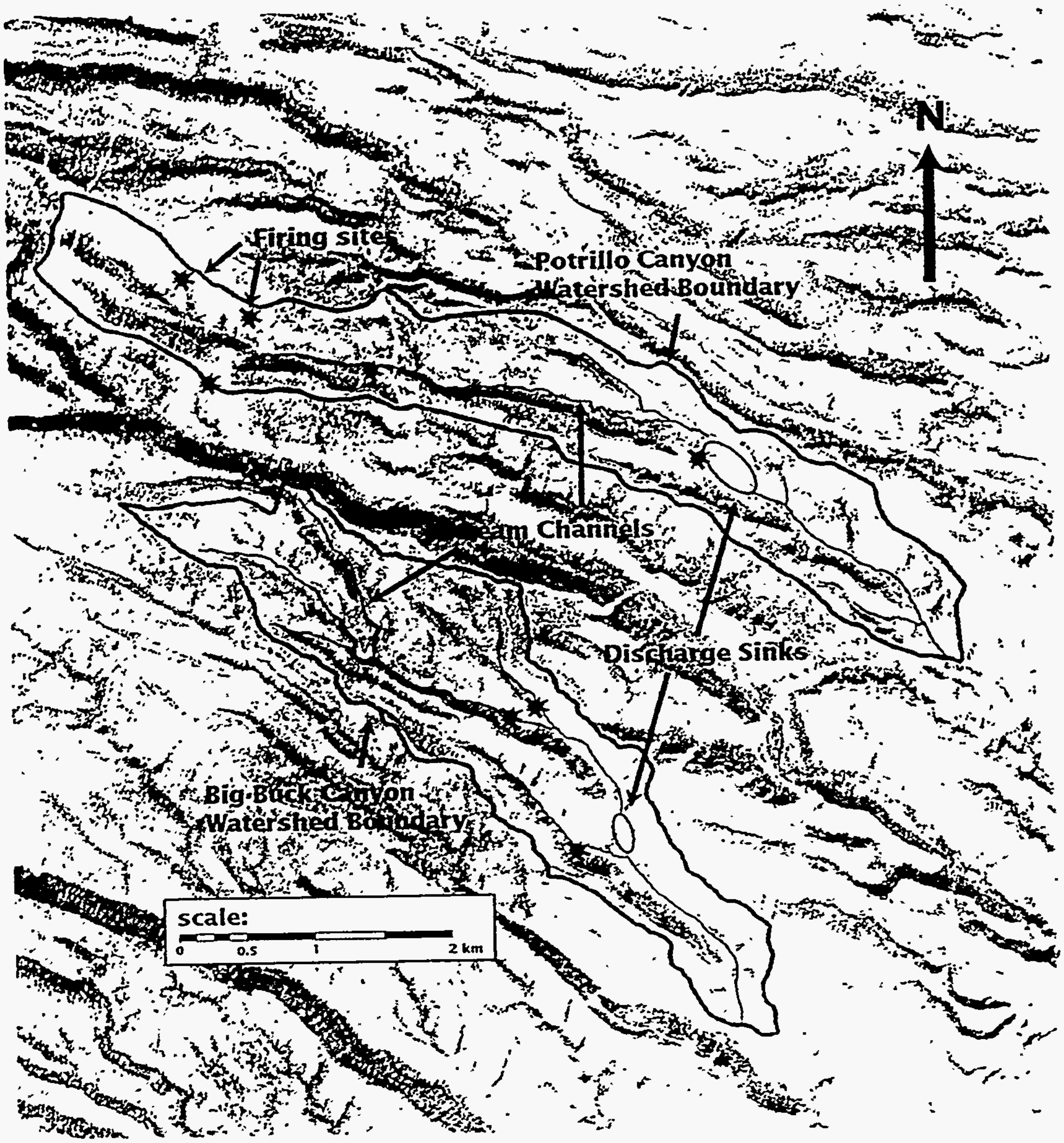

N
Firing site
Potrillo Canyon
Watershed Boundary
Stream Channels
Discharge Sinks
Big Buck Canyon
Watershed Boundary
scale:
0
0.5
1
2 km

FIG 2

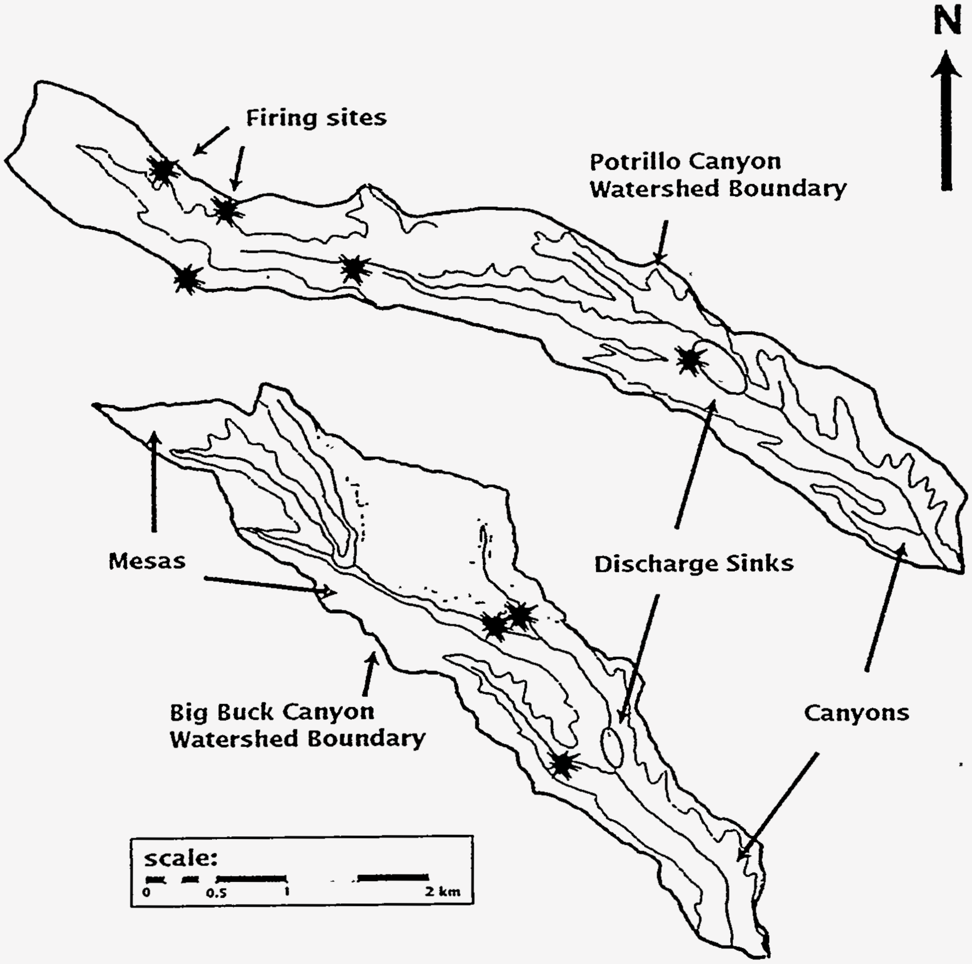
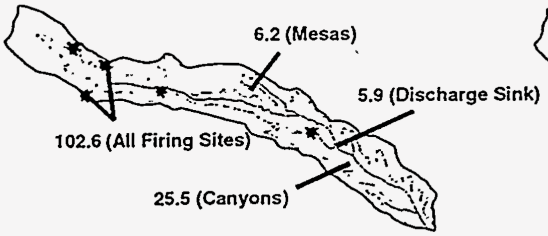
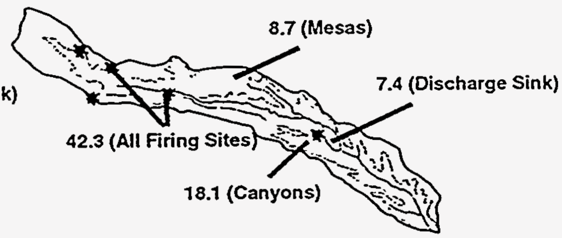

N
Firing sites
Potrillo Canyon
Watershed Boundary
Mesas
Discharge Sinks
Big Buck Canyon
Watershed Boundary
Canyons
scale:
0
0.5
1
2 km

FIG 3

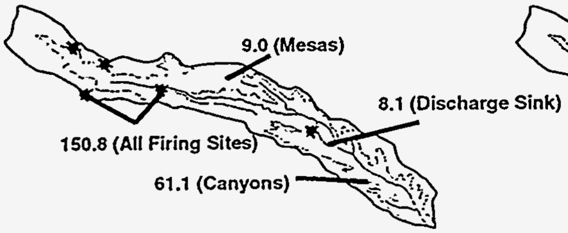
Mean Uranium Concentration (ppm)



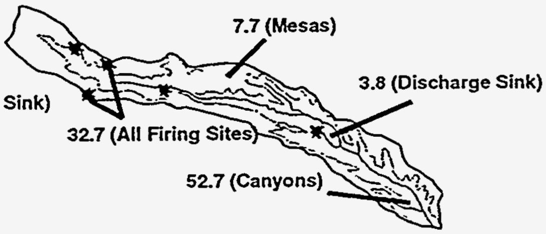
Mean Copper Concentration (ppm)



Standard Deviation



Standard Deviation



Correlation of Uranium with Copper

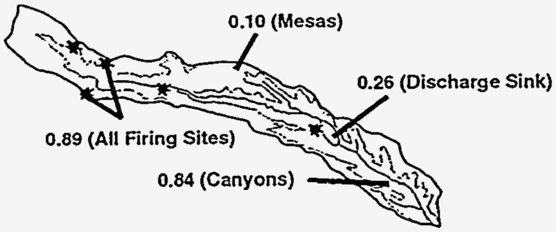


FIG 4

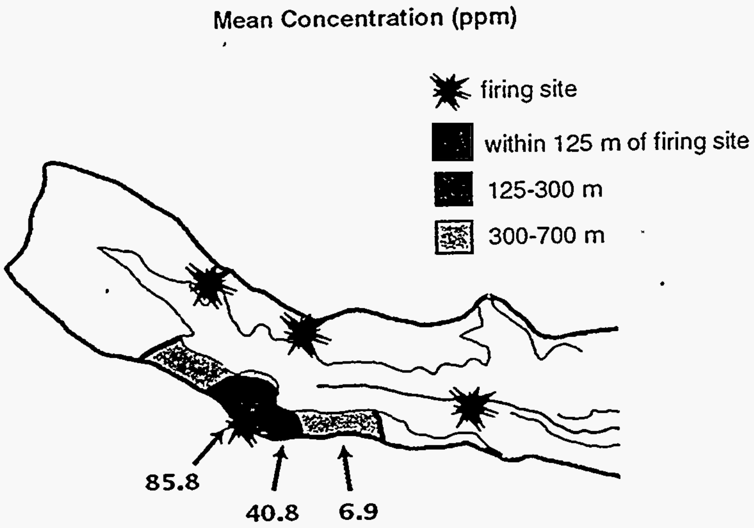

Mean Concentration (ppm)
firing site
within 125 m of firing site
125-300 m
300-700 m
85.8
40.8
6.9

FIG 5