DISPERSAL OF MERCURY-CONTAMINATED SEDIMENTS BY GEOMORPHIC PROCESSES, SIXMILE CANYON, NEVADA, USA: IMPLICATIONS TO SITE CHARACTERIZATION AND REMEDIATION OF FLUVIAL ENVIRONMENTS

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Abstract. The discovery of the Comstock Lode near Virginia City, Nevada, in 1859 resulted in the construction of more than 30 stamp-mills along Sixmile Canyon and its tributaries to process the gold and silver ore. Extraction of the precious metals from the ore was accomplished using a crude mercury (Hg) amalgamation process. As a result, a substantial quantity of Hg was released along with tailings materials to this tributary of the Carson River. During the past 134 years, Hg-contaminated sediments have been eroded from the mill sites and transported downstream by fluvial processes, thereby expanding the influence of Hg pollution. Geomorphic and geochemical data have been combined in this study to document the distribution, quantity, and physical dispersal of Hg-contaminated materials from Sixmile Canyon to the Carson River. These data show that the influx of Hg to the Carson River has varied through time as a function of the erosional and depositional processes operating on the Sixmile Canyon Alluvial Fan located between the canyon and the Carson River channel; relatively high influx rates to the river occurred immediately after mining began and from approximately 1933 to 1948. Hg-polluted sediments are located within discrete areas of the fan and comprise about 21% of the total active and relict fan surface. Mass balance calculations estimate that about 31,500 kg of Hg, 18,200 oz of Au, and 1,205,800 oz of Ag are contained within 710,700 m^3 of contaminated materials. If site remediation is conducted, extraction of Au and Ag, which is worth about \$ 12 million at current market prices, would greatly defray the costs of clean-up activities. The study also illustrates that the effects of Hg may be temporally and spatially displaced from the period and location of milling activities. Thus, we conclude that to accurately assess the site for remediation, an understanding of the spatial and temporal variations in geomorphic dispersal processes is required.

1. Introduction

The discovery of the famous Comstock Lode near Virginia City, Nevada, in 1859 resulted in the construction of more than 30 mills along Sixmile Canyon and its tributaries to process the ore (Figure 1). In general, ore obtained from deep-shaft mines was shipped to the mills where it was pulverized and mixed with mercury (Hg) forming a mercury-silver/gold amalgam. Subsequently, a 'pure' form of the precious metal was produced by roasting the amalgam, a process which released Hg from the complex as a vapor. Although most of the Hg vapor was re-captured by retorting, Smith (1943) estimated that as much as 0.68 kg of Hg was released to the environment with mill tailing fines for every ton of ore that was processed. The estimates vary, but it is generally thought that 6.75×10^6 kg of Hg was lost

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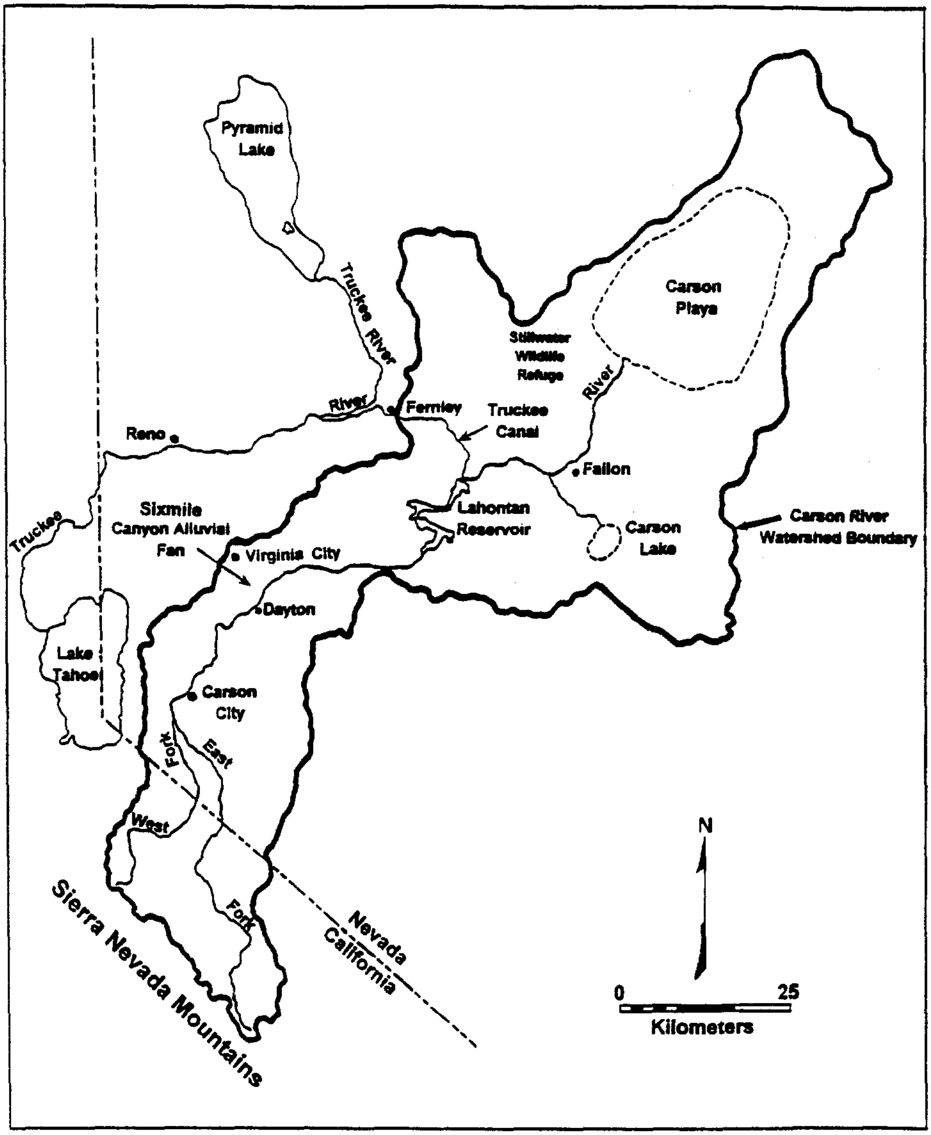

Fig. 1. Map showing the location of the Sixmile Canyon Alluvial Fan in north-central Nevada.

during the 30 year peak of Comstock mining (Smith, 1943), a significant portion by the mills located within Sixmile Canyon. Most of the mining activity and the utilization of Hg ended around the turn of the century, and today the milling facilities such as the one shown in Figure 2 are gone; all that remain are the concrete foundations and the Hg-contaminated mill tailings. A recent sampling and analysis program conducted by the U.S. Environmental Protection Agency found that Hg concentrations as high as 4,600 ppm occur in the fine-grained materials of the

Fig. 2. A stamp mill in Sixmile Canyon. Note the light-colored tailings materials near the drainage on the right side of the photograph.

tailings piles (Hogan, personal communication). During the past 134 years, mill tailings have been redistributed throughout the Carson River valley, in large part by fluvial processes; the tailings are eroded, transported downstream, and re-deposited in specific localities. Recent studies have shown that the dispersal of Hg has been extensive, and concentrations exceeding 100 ppm have been measured along the Carson River more than 60 km downstream of the mining and milling operations (P. Lechler, unpublished data). Moreover, the tissues of fish and other aquatic biota exhibit concentrations in excess of 1 μg/g (Cooper *et al.*, 1985; Richins and Risser, 1975), the action level set by the U.S. Food and Drug Administration. As a result, contaminated areas of the Carson River valley, including Sixmile Canyon, were placed in 1990 on the U.S. National Superfund Priorities List. The effects of Hg on both human health and the environment are now being assessed.

This paper examines the distribution, quantity, and physical dispersal of Hg-contaminated sediments between the mill sites in Sixmile Canyon and the Carson River. In addition, this investigation illustrates that the assessment of sites polluted with heavy metals can benefit significantly from studying surficial geomorphic processes, investigations which are not generally performed in *detail* during site characterization. A detailed discussion of the geochemistry of the contaminated deposits and the chemical mobility of Hg in this semi-arid environment will be presented elsewhere.

2. Recent Geomorphic Evolution of the Sixmile Canyon Alluvial Fan

2.1. CHANGES IN FLUVIAL EROSION AND DEPOSITION

Tailings eroded from milling sites within Sixmile Canyon have been, and continue to be, transported downstream where they are distributed upon an alluvial fan located at the mouth of the canyon. Understanding the dispersal of these tailing materials has been considered an important component of the Carson River Superfund Site Characterization Program because 1) the Sixmile Canyon alluvial fan is an area of past, current, and future urban development, and 2) tailings derived from the canyon must traverse the alluvial fan in order to enter the modern channel of the Carson River where the tailings can potentially be distributed throughout downstream river reaches. The physical dispersal of tailings materials is undoubtedly controlled by fluvial processes operating on the alluvial fan complex. Therefore, a record of the erosional and depositional changes that have occurred in this area during approximately the past 150 years has been documented using stratigraphic, morphologic, and cartographic data.

Stratigraphic data show that prior to mining operations, the alluvial fan was characterized by a well-defined channel in proximal- and medial-fan areas and a shallow depression in distal fan areas. The topographic depression, which was located near the modern channel shown on Figure 3, extended downstream to the floodplain of the Carson River. On the fan, the channel was incised into older materials which were deposited at different times during the past several thousand to tens of thousands of years (Figure 4). These pre-mining materials can be subdivided into three stratigraphic units which, at any given distance from the mountain front, exist at different elevations and can be distinguished on the basis of the degree of weathering and surface micro-relief. All pre-mining units exhibit a zone of weathering (soils) at their surface, clearly distinguishing them from younger post-mining deposits (Figure 5). Alluvial fan units grade downvalley and either interfinger with or bury undifferentiated Carson valley fill deposits (Figure 3).

The initiation of mining activities in 1859 provided an abundance of easily eroded sediment in the form of mine and mill tailings to Sixmile Canyon and its tributaries. The exact amount of tailings released has yet to be quantified, but Smith (1943) noted that more than 5.44×10^5 kg of material were released daily to the surrounding area during some periods of peak milling. There is no doubt that a significant portion of the tailings were delivered to the Sixmile Canyon watershed.

Field observations indicate that in proximal- and medial-fan areas, the pre-mining channel has been filled with tailings material. Similarly, the tailings form a distinct depositional unit inset into, and confined by, pre-mining deposits in distal-fan areas as well as beyond the limits of the fan, adjacent to the Carson River. These relations suggest that immediately after mining began, tailings were transported during storm events from the mouth of Sixmile Canyon, downfan to the Carson

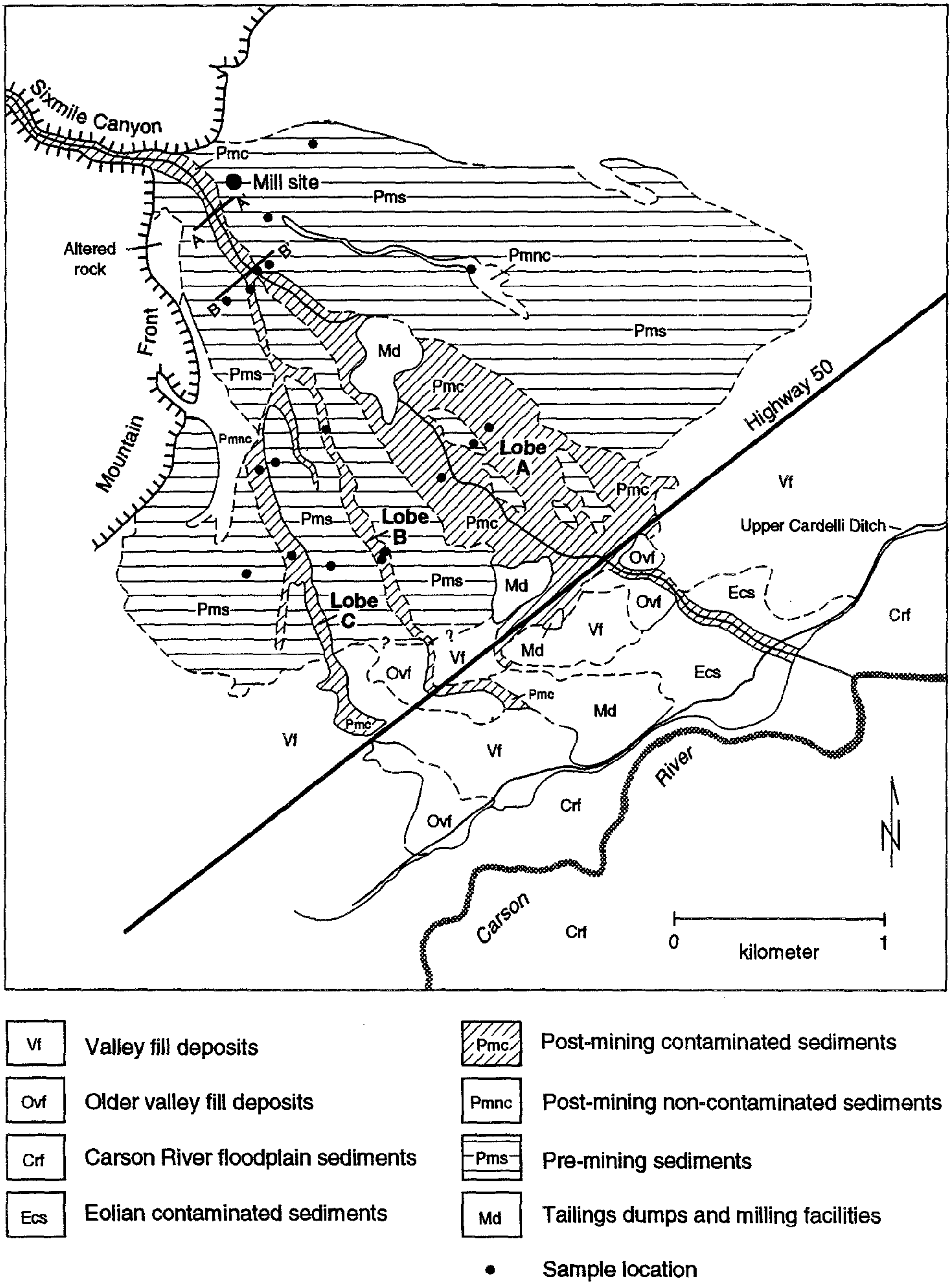

Fig. 3. Surficial geologic map of the Sixmile Canyon Alluvial Fan. Updated from Miller *et al.* (1993).

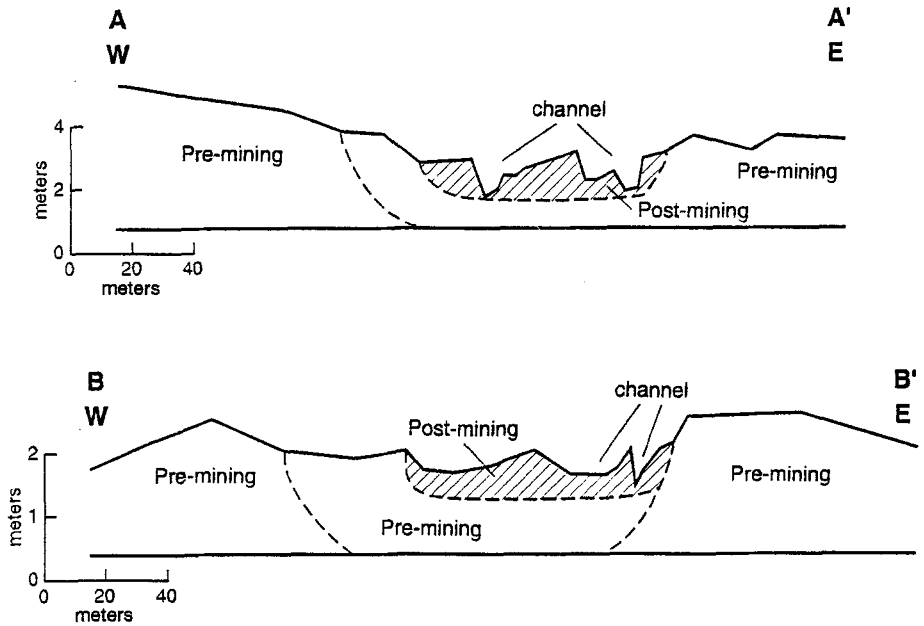

Fig. 4. Cross-sections near fan apex showing the relationships between pre- and post-mining deposits. See figure 3 for cross section locations.

Fig. 5a.

River, an implication supported by an 1877 map (Wheeler, 1877) that shows a 'flow of tailings' occurring in this area. However, the influx of tailings presumably caused channel aggradation, both within Sixmile Canyon and on the alluvial fan;

Fig. 5b.

Fig. 5. Pre-mining deposits are characterized by extensive surface weathering allowing them to be easily distinguished from post-mining units. (A) Pre-mining colluvial materials that bury older fan sediments. Note the well-developed soils on both units. (B) Post-mining Hg-contaminated sediments which overlie pre-mining deposits on the Sixmile Canyon Alluvial Fan.

a process that would increase the gradient of the channel and enhance its ability to transport larger quantities of sediment. The net effect was to completely fill the channel in medial-fan areas and allow Hg-contaminated materials to spread out as a sheet of sediment, designated as lobe A on Figure 3, over the older deposits near the center of the alluvial fan complex. The thickness of the deposits is on the order of 0.8 m in regions of the filled-channel and 0.5 m in adjacent zones. At the end of lobe A deposition, contaminated materials had been distributed over approximately 1.25 km^2, about 17% of the fan area. As mentioned above, post-mining sediment had also been deposited beyond the distal limits of the fan where they were confined to a narrow zone by undifferentiated valley fill deposits (Figure 3).

Continued aggradation of the proximal-fan channel apparently forced a portion of the flow into adjacent low-lying areas. The result was channel avulsion, a phenomenon in which the transport of water and sediment is transferred to a new location on the fan surface. In this case, avulsion occurring at different times, created two primary and several smaller deposits of Hg-contaminated materials. The primary deposits, labeled depositional lobes B and C on Figure 3, traverse the length of the fan west of the original zone of post-mining deposition (Figure 3). The tailings were deposited within linear depressions on the fan surface, depressions which were partially, or in some areas, totally filled to a depth of approximately 0.20 m with tailings and other sediment. The area of the fan impacted by Hg contamination increased to about 1.55 km^2.

Considering that the original depressions were shallow (on the order of 20 cm), it is perhaps surprising that contamination was limited to these rather narrow areas. That is, had large volumes of Hg-contaminated materials been transported from the Sixmile Canyon watershed, they would likely have spread out over the older fan units as a sheet of sediment in a manner similar to that associated with the deposition of lobe A. The explanation probably resides with the timing of deposition for lobes B and C. The downfan movement of water and tailings along lobe C was inhibited by fill placed across the drainage at about 1933 during construction of Highway 50 (NDOT, 1933). In addition, aerial photography of the fan shows that contaminated materials had been deposited in this region by 1948, implying that deposition of lobe C occurred between 1933 and 1948. Deposits of lobe B, Figure 3, pre-date 1933 as Hg-contaminated materials were not ponded upfan of the Highway 50 fill. These materials apparently were, however, impounded by the Upper Cardelli Ditch, an irrigation structure built in approximately 1905. (Note that portions of lobe B located immediately upfan from the Upper Cardelli Ditch have been reprocessed and are labeled mine dumps and milling facilities on Figure 3.) These relations suggest that the avulsion and abandonment of the pre-mining channel near the fan apex occurred between 1905 and 1933. Thus, for all practical purposes, mining and milling operations had ended by the time that lobes B and C had formed by avulsion. The mills were no longer dumping large quantities of tailings into Sixmile Canyon and its tributaries. The quantity of contaminated sediment available for transport had probably declined considerably in comparison to earlier times, limiting the spatial extent of fan deposition.

Currently, a channel system traverses the length of the Sixmile Canyon Alluvial Fan. A topographic survey conducted in 1933 along the course of Highway 50 indicates that this modern channel had already begun to form. Thus, while deposition of Hg-contaminated sediments was occurring along the western portion of the fan (i.e. along lobes B and C), channel cutting and tailings remobilization was taking place in the vicinity of the post-mining deposits formed immediately after the initiation of mining operations (lobe A, Figure 3). Presumably, the expansion of this channel had by 1948 (where it can be identified on aerial photographs) captured the flow from Sixmile Canyon and created the channel that exists today. Comparison of aerial photographs from 1948 to 1990 show that the fan and channel complex have changed little during the past 45 years.

2.2. Movement of Hg-Contaminated Sediment by Eolian (Wind) Processes

The processes acting within one geomorphic system often impact those of another, a phenomenon which Ritter (1986) has referred to as process linkage. In the case of Hg dispersal in the vicinity of Sixmile Canyon, the transport of contaminated sediments by channelized flow has increased the ability of wind to distribute the materials throughout the Carson River Valley. That is, the movement of polluted tailings from the confines of Sixmile Canyon to the open alluvial fan has subjected them to stronger winds as fetch lengths increased by several orders of magnitude. The result has been the movement of Hg-polluted sediments from the areas of fluvial deposition on the fan to the adjacent margins characterized by older deposits. This movement is clearly shown on 1990 and earlier aerial photographs where thin sand streaks can be seen extending from the channel short distances to the east. The image data are supported by chemical analyses. Pre-mining units all exhibit soils in their upper materials. Hg-analysis of integrated (composite) samples collected from soil A-horizons are composed in large part of wind-blown silts. These A-horizon sediments exhibit Hg-levels higher than those observed in samples collected from the underlying B-horizon (Figure 6) (analytical procedures are presented below). Although they were generally low (< 1 ppm), locally the wind-blown materials immediately adjacent to the channels exhibited total-Hg concentrations exceeding 15 ppm. In addition, coppice dune materials (wind blown sand accumulated around vegetation) locally exhibited total-Hg concentrations of up to 16 ppm. The rate of Hg dispersal by eolian processes is not known at this time. Nonetheless, it is clear that wind processes represent a potentially significant mechanism of Hg-dispersal from the fan deposits.

3. Implications for Site Characterization and Remediation

Most investigations of heavy metal contamination have focussed on chemical mobility, atmospheric dispersal, biogeochemical transformations, or metal accumulation in biological systems, even though it is generally recognized that physical processes play a role in trace metal dispersal (Graf, 1990). This study of Sixmile Canyon and its associated alluvial fan clearly illustrates that physical processes significantly control trace metal distribution and dispersal. This is not to say that physical process studies should take precedence over geochemically-related analyses. Rather, geomorphic and geochemical data should be integrated in site assessment programs. In fact, doing so will allow for a more precise determination of a number of parameters required in the development of effective remediation programs including 1) the documentation of the temporal variability in contaminant transport, 2) an estimate of the current distribution, thickness, and absolute quantity of contaminated materials, 3) insights into contaminant residence times,

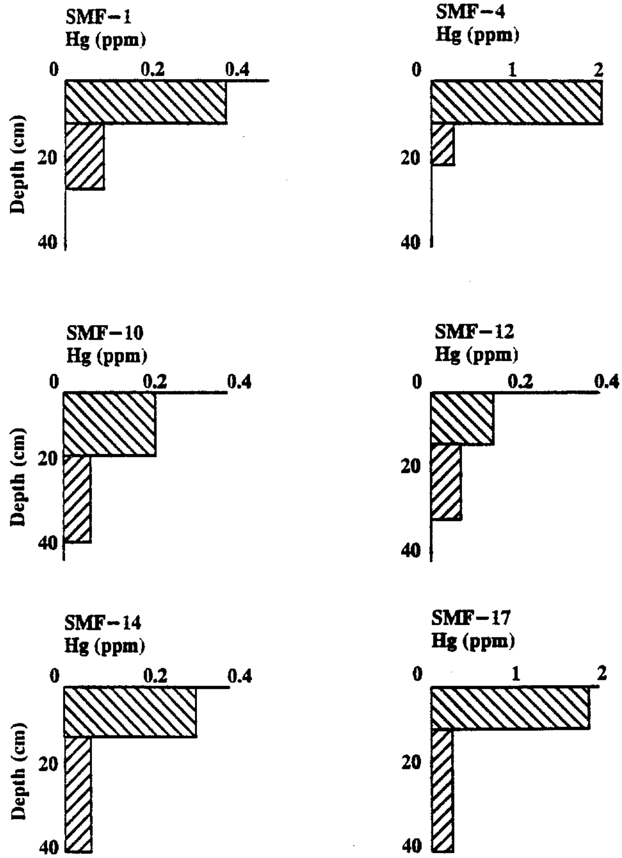

Fig. 6. Hg concentrations as a function of depth at sites located on pre-mining fan deposits. In all cases, total Hg concentrations are elevated in surface A-horizons suggesting that the levels reflect the influx of wind-blown, polluted materials from the adjacent fan channels.

and 4) a detailed framework from which to conduct other studies such as those of geochemical mobility, atmospheric dispersion, bioaccumulation, and health risks. The assessment of these parameters for the area in and adjacent to Sixmile Canyon is illustrated and discussed below. First, however, is a brief discussion of the geochemical data collected from the Sixmile Canyon alluvial fan.

3.1. Trace Metal Concentrations in Pre- and Post-Mining Deposits

Once a basic understanding of the geomorphology/geology of the Sixmile Canyon alluvial fan had been established, a sampling plan was designed with the intent that each of the delineated depositional fan units would be sampled. More than 40 samples were collected from 20 locations (Figure 3). Samples were collected not only from the surface, but at depth with the vertical sampling increment being based on stratigraphic changes.

After collection, the samples were analyzed for Hg, Au, and Ag using atomic absorption techniques following a hot aqua regia digestion; limits of detection were 0.01, 0.001, and 0.2 ppm, respectively. Method development and quality assurance for the determination of Hg were tied to a U.S. NIST Hg standard reference material (# 8407). Methodology for Au-Ag analysis had already been quality-assured in a large Au-Ag standard reference material project previously undertaken by the Nevada Bureau of Mines and Geology (Lechler and Desilets, 1991).

A summary of Hg, Au, and Ag concentrations for pre- and post-mining fan deposits is presented in Table I. Because of the eolian influx of post-mining, contaminated materials to the surface of the pre-mining deposits (described above), the concentrations presented for pre-mining sediments have been limited to samples collected at depth. Table I shows that the trace metal concentrations of the post-mining deposits significantly exceed levels measured in pre-mining units. For example, in contaminated zones, total-Hg concentrations range from a few to more than 350 ppm, values well above the generally assumed background levels of 20–40 ppb for soils in this area. However, adjacent pre-mining fan areas exhibit concentrations on the order of a few parts per billion.

3.2. Temporal Variability of Hg Dispersal

The recent changes in the location and magnitude of erosional and depositional processes on the Sixmile Canyon Fan strongly suggest that the movement of Hg-contaminated, post-mining materials has not been uniform through time (Figure 7). Currently, however, it is not possible to quantify, in absolute terms, the flux of contaminated sediments from Sixmile Canyon to the Carson River for any given period. Nonetheless, the collected geomorphic data allow for a determination of the relative changes in contaminant flux.

Immediately following the onset of mining operations, river processes apparently transported nearly homogeneous tailings directly to the Carson River. Although channel aggradation probably began shortly after the initiation of mining operations, maps prepared in 1877 suggest that tailings may have been transported to the Carson River up to this time. Once the medial-fan channels had filled with sediment, the contaminated materials were deposited and stored upon the fan complex; influx to the Carson River was limited (Figure 7). Nevertheless, the location of contaminant distribution upon the fan itself changed as a result of channel filling and avulsion. Cutting of the modern fan channel in the area of lobe A between about 1933 and 1948 resulted in the transport of Hg-polluted sediments, stored on the fan, to the Carson River. As the channel system grew, the influx of remobilized contaminated materials to the river system is likely to have increased. By 1948, however, the modern fan channel had formed, and the quantity of contaminated sediments eroded from the fan is likely to have decreased significantly. Hg-rich sediments were being transported from the canyon, across the fan, and directly into the Carson River with little erosion of contaminated fan materials. The cur-

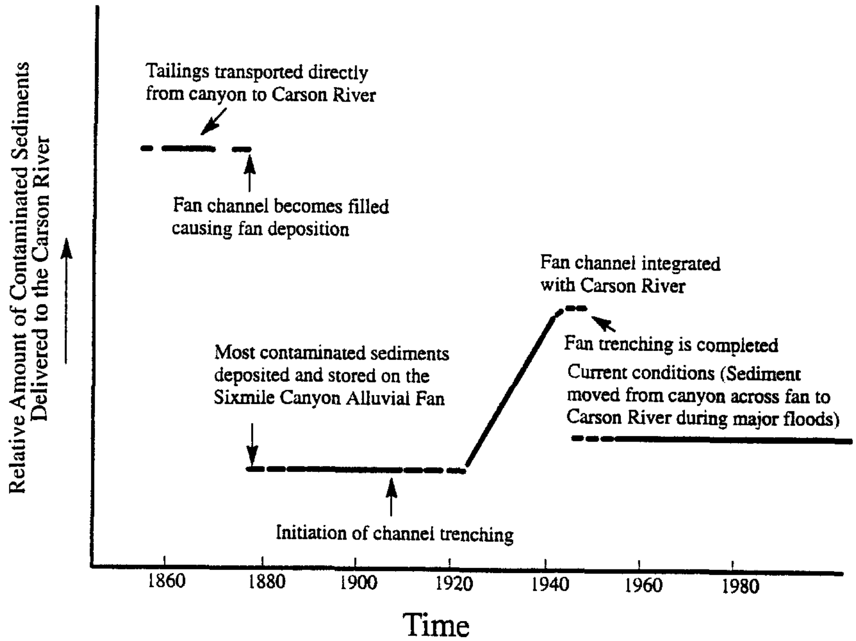

Fig. 7. Schematic diagram illustrating the temporal variations in the influx of Hg-polluted sediments to the Carson River system where the largest populations of biota are generally found. Updated from Miller *et al.* (1993).

rent channel configuration is similar to that which existed at the onset of mining activities. However, mining operations are no longer releasing large quantities of tailings into the drainage system and, therefore, influx is unlikely to reach levels exhibited before the turn of the century (Figure 7).

3.3. The Spatial Distribution of Contaminated Sediments

The distribution of contaminated sediments on the Sixmile Canyon Alluvial Fan was determined by combining geomorphic mapping procedures with geochemical data. The steps involved with this process include 1) a delineation of the stratigraphic units which make up the fan complex, 2) assessment of the relative-age and, when possible, the absolute-age of the defined units, 3) unit mapping on aerial photographs or other remotely sensed images, and 4) geochemical characterization of each of the delineated deposits. The essence of the combined geomorphic/geochemical program is that the defined stratigraphic units, because of their timing of deposition with respect to contaminant influx, exhibit differences in trace metal concentration. Thus, unit mapping allows for the precise delineation of contaminated and non-contaminated areas. For example, the distribution of post-mining deposits on the Sixmile Canyon Fan, delineated on Figure 3 using

TABLE I

Summary of Hg, Au, and Ag concentrations measured in pre- and post-mining deposits comprising the Sixmile Canyon Alluvial Fan

	Mercury (ppm)		Gold (ppb)		Silver (ppm)		
Unit	Mean	Range	Mean	Range	Mean	Range	N
Pre-Mining	0.478	0.075–1.926[a]	13[b]	<5–29[a]	0.4[b]	<0.2–1.3[a]	5
Post-Mining							
Fan Deposits	103.7	1.34 –368	473	80–843	54.8	6.2–117	9
Modern Channel	4.840	1.12 –9.30	166	15–424	5.1	1.4–9.3	8

[a] High values probably result, in large part, from the movement of contaminated wind-blown dust particles downward from the surface into the pre-mining deposits.
[b] Mean calculated using one-half of detection limits when samples exhibit concentrations lower than detection levels. Two-thirds of the samples were below detection limits for both Au and Ag in the pre-mining deposits.

geologic/geomorphic mapping procedures, exhibit significantly higher Hg, Au, and Ag concentrations than the pre-mining deposits (Table I).

Many site characterization programs rely solely on random sampling procedures. However, random sampling programs used in solo will not provide the detailed picture of contaminant distribution that is supplied by combining geomorphic and geochemical data. In fact, it is likely that a solely random sampling methodology will require the analysis of more samples and, therefore, be less cost effective than the combined method while providing less detailed information on contaminant distribution. Thus, we suggest that the current distribution of contaminated sediments be defined by combining geologic and geochemical data. Subsequently, a random sampling program can be utilized to determine the variations in trace metal concentrations within the contaminated zones.

The data presented above illustrate that on the Sixmile Canyon Fan, post-mining sediments are confined to distinct zones extending from the fan apex to the Carson River. Approximately 79% of the fan area remains uncontaminated or has received contaminated sediments only as wind-blown dust. Thus, if remediation programs were to be implemented in this area, it should be possible to focus only on zones characterized by Hg-contaminated sediments deposited by fluvial processes, thereby significantly reducing the cost of clean-up operations. It is important to recognize, however, that at this time there has been no decision concerning site remediation and it is possible that site remediation will be considered too costly or ineffective to be conducted. In this case, the constructed maps showing the distribution of contaminated materials provide extremely important information to local and state officials responsible for land-use or resource planning. For example, zoning agencies can rapidly determine if there is a high probability for a proposed subdivision to be located upon or immediately adjacent to a contaminated area.

TABLE II

Summary of polluted sediment and trace metal mass balance calculations for the Sixmile Canyon Alluvial Fan. Note that the estimates do not include post-mining materials beyond the limits of the fan (i.e. between the fan and the floodplain of the Carson River). See Figure 3 for the locations of depositional Lobes A, B, and C

Depositional Area	Sed. Volume (m^3)	Hg (kg)	Au (oz)	Au (\$)*	Ag (oz)	Ag (\$)**
Lobe A	672,195	25,899	17,455	6,545,625	1,115,606	4,908,666
Lobe B	,275	560	419	157,125	74,725	328,790
Lobe C	22,211	81	295	110,625	15,457	68,011
Totals	710,681	31,540	18,169	6,813,375	1,205,788	5,305,467

Total Au and Ag: $ 12,118,842.
* Au @ $ 375/oz.
** Ag @ $ 4.40/oz.

Care must be taken, however, when utilizing such maps for planning purposes. For instance, in the Sixmile Canyon area we have shown that the distribution of Hg-polluted sediments has increased during the past 90 years, well after mining activities ended. It is likely that the distribution of Hg pollution will increase on the fan in the future as it has in the past. Thus, not only should the current distribution of post-mining materials be determined, but land-use and resource planners should consider the potential for an area to be affected in the future.

3.4. Estimates of Trace Metal Quantities

An understanding of stratigraphic unit thickness, lateral extent, and geochemical nature allows for an estimation of the total quantity of Hg existing within the fan complex. These data are essential to any assessment of the costs involved with clean-up operations. The information is particularly important for the Sixmile Canyon Alluvial Fan in that the analysis cannot only be used to determine the amount of sediment to be processed and the quantity of Hg to be removed, but the amount of Au and Ag present in the tailings-rich fan materials. Preliminary mass balance calculations for the Sixmile Canyon Fan are shown in Table II. Although variations in unit thickness and concentrations exist, the calculations clearly indicate that the extraction of Au and Ag, which amount to about $ 12 million dollars at current market prices, would significantly defray the cost of site remediation.

3.5. Insights to Contaminant Residence Times

In addition to economic insights to site remediation, the geologic data provide some clues as to the persistence of Hg in the area. Only a small fraction of the contaminated materials have been removed from the fan by natural processes during the past 130 years. The removal primarily occurred during the development of the modern fan channel as contaminated sediments in lobe A were eroded and transported to the Carson River. Geomorphic studies also show that most of the fan is composed of pre-mining deposits, the surface materials of which are highly weathered suggesting that they have remained in this area for thousands of years. Thus, we expect that without human intervention, the Hg-contaminated materials will remain at the surface of the fan complex for 100s or, perhaps, 1000s of years into the future. This does not mean that natural processes will cease to remove Hg-contaminated materials from the Sixmile Canyon Alluvial Fan. Both fluvial and eolian processes will continue to operate on this fan complex and introduce an unquantified amount of Hg-contaminated sediment to the Carson River and the surrounding valley. The rate at which the post-mining materials will be removed from the fan is expected, however, to be very slow.

Currently, Hg is being utilized to extract precious metals in a number of countries throughout the world including Brazil, Colombia, Peru, and Venezuela. As was the case for mining of the Comstock Lode, large quantities of Hg are being released in these regions during the precious metal extraction process. For example, it is estimated that more than 100 tons of Hg are being lost to the Amazon basin annually (Lacerda and Salomons, 1992). The persistence of Hg in the vicinity of the Sixmile Canyon Alluvial Fan emphasizes the potential for Hg to impact the environment in these countries for decades to come.

4. Conclusions

The cost-effective, geomorphic/geochemical approach utilized here found that the distribution of Hg-contaminated sediments by fluvial processes has been limited to discrete zones on the Sixmile Canyon Alluvial Fan. However, the movement of contaminated sediments from the confines of the canyon to the open fan has allowed eolian processes to distribute polluted materials over wide areas of the Carson River valley. Fortunately, the measured total-Hg concentrations in wind-blown materials are typically low (< 1 ppm) in comparison to fluvially transported and deposited sediments which locally exhibit total-Hg concentrations exceeding 350 ppm.

Data from the Sixmile Canyon Alluvial Fan also show that trace metal contaminants may be highly persistent in semi-arid environments. Their lateral distribution, however, has changed as sites of erosion and deposition continued to be altered well after mining operations ended. Not only has the spatial distribution of Hg-polluted sediments changed through time, but the influx of Hg to the Carson River has fluctuated since the onset of mining.

The study clearly illustrates that the effects of Hg (and other heavy metals) may be temporally and spatially displaced with Hg potentially impacting areas significant distances from the milling sites and well after mining operations ended. We conclude, therefore, that chemical data collected at an instant in time may lead to an incorrect evaluation of the site. To accurately assess the site for remediation, an understanding of spatial and temporal variations in geomorphic dispersal processes is required.

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