PROGRESS REPORT ON THE BIOLOGICAL MONITORING PROGRAM FOR THE MONTICELLO, UTAH, MILL SITE: AUGUST 1996 SAMPLING PERIOD

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Date: March 3, 1997

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for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-96OR22464

1. INTRODUCTION

From 1942 through 1946, the Vanadium Corporation of America operated a vanadium and uranium mill in Monticello, Utah (Rust Geotech 1995a). In 1948, the U. S. Atomic Energy Commission (AEC) purchased the mill site and milled uranium from 1949 until the mill was permanently closed in January 1960. During operation of the mill, associated contaminants entered the surrounding environment through atmospheric releases, effluent discharges into Montezuma Creek which flows through the middle of the mill site, and runoff and soil infiltration from associated tailing piles. In 1961, the AEC stabilized the tailing piles by covering them with soil, and by 1975 the mill structure had been demolished and buried (Rust Geotech 1995a, 1995b). These actions, however, did not eliminate surface water or ground water contamination. In 1989, the mill site was placed on the Comprehensive Environmental Response, Compensation, and Liability Act's (CERCLA) National Priorities List (NPL). Remediation of portions of the properties was initiated in approximately 1992 and completion is anticipated in the late 1990's.

In August 1995, a biological monitoring program was initiated for Montezuma Creek. The primary objectives were to first characterize the extent of contamination in resident biota in Montezuma Creek and determine the condition of the stream's biological communities before completing major remedial actions, and then using these baseline data evaluate the response of the biota to remediation of the mill site. This progress report summarizes the results of the second year of sampling that was conducted in August 1996. Where appropriate, data from August 1995 were also included.

A list of the sites sampled for each task is given in Table 1, and the location of each site except MZUG is shown in Fig. 1. Site MZUG was the upstream most site sampled on Montezuma Creek, and it was located just upstream of the western boundary of the Monticello golf course. This site was used only by the bioaccumulation task as an additional reference site for a one-time evaluation to determine the suitability of using a site upstream of the mill site as an additional reference.

2. STREAM HABITAT EVALUATION

As part of the environmental surveys of Montezuma Creek and Verdure Creek, a qualitative habitat evaluation index (QHEI) was determined for some sampling sites. The QHEI is an index that incorporates information on 20 metrics including gradient, substrate, instream cover, channel morphology, channel stability, riparian zone development, pool quality, and riffle quality. It was originally developed by the Ohio EPA to assist in statewide biological monitoring surveys of water quality (Ohio EPA 1988; Rankin 1989). The QHEI is an effective and efficient tool for comparisons of overall habitat quality because it imposes the same review of various components at each site, has a built-in assessment of the

Table 1. Sample activities at sites in Montezuma Creek and Verdure Creek, August 1996.

	Site[a]					
Task	MZG	MZUG	MZ-2	MZ-3	MZ-9	VD-1
Benthic macroinvertebrate bioaccumulation	X	X	X	X	X	X
Benthic macroinvertebrate community	X		X	X	X	X
Fish community - quantitative						X
Fish community - qualitative[b]			X	X	X	

[a]Montezuma Creek sites = MZ"X" where "X" equals transect number; MZG = Montezuma Creek just downstream of the eastern boundary of the Monticello golf course boundary; MZUG = Montezuma Creek just upstream of the western boundary of the Monticello golf course; VD-1 = transect one in Verdure Creek.

[b]Montezuma Creek downstream of MZ-9 to the confluence of Verdure Creek was also sampled qualitatively.

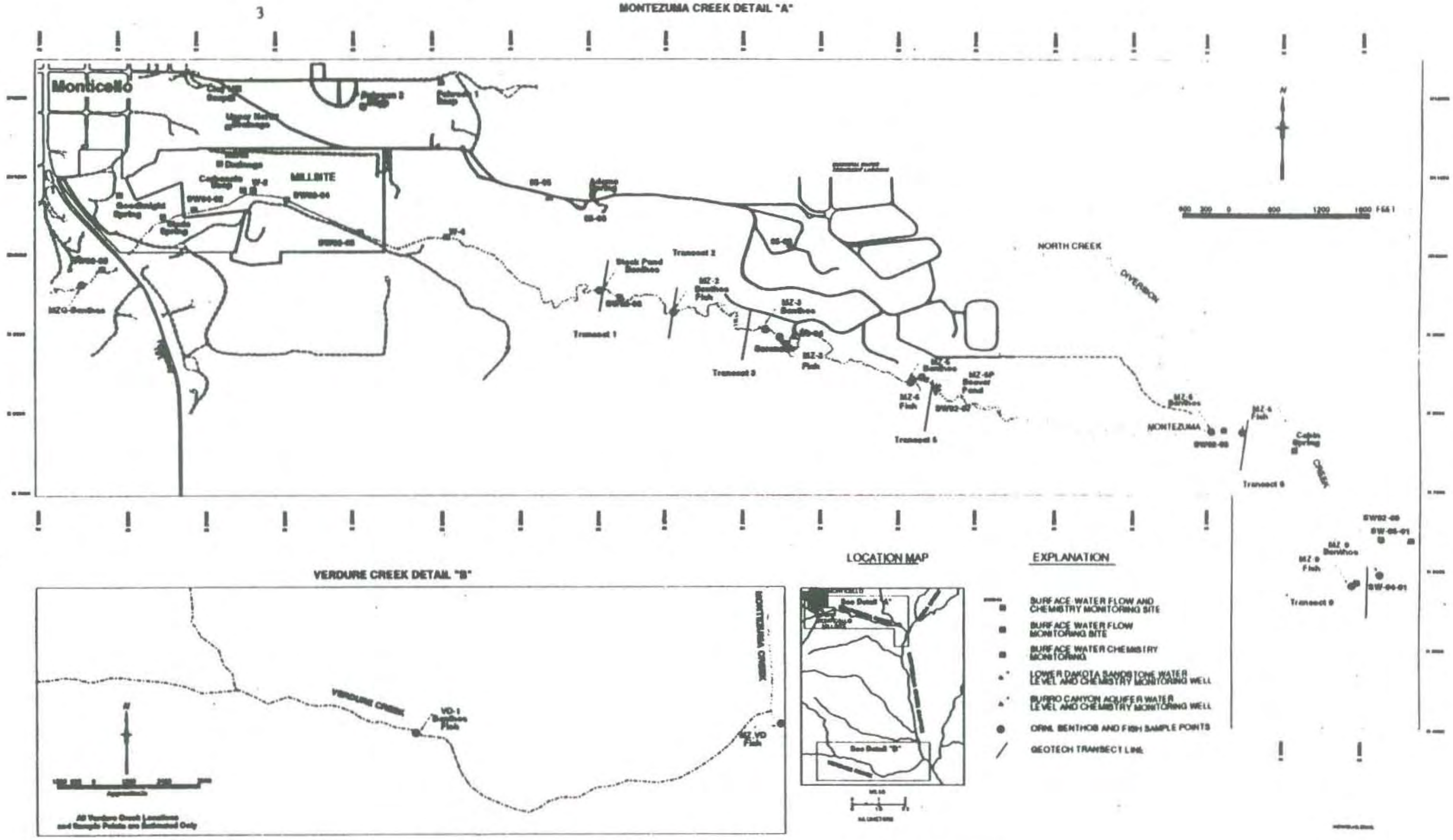


Fig. 1. Montezuma and Verdure Creek Macroinvertebrate and Fish Sample Locations

relative value of each component, and requires few actual measurements of habitat variables. Despite relying on a subjective evaluation by the individual making the survey, the QHEI has been demonstrated to be fairly consistent among surveyors (Rankin 1989), thus, enhancing its use for comparative evaluations. Although originally intended for use in Ohio, the QHEI should develop comparable scores for streams in Utah, with the understanding that total scores may not be directly comparable to scores for other states or regions.

The QHEI ratings were made on August 12, 14, and 15, 1996 at MZ-3, MZ-9, and VD-1 using guidelines and forms provided by Ohio EPA (1989). Stream gradients determined from topographic maps for the 1995 analysis (Smith et al. 1996) were also used in this analysis. The rating scale for stream gradient was modified by a factor of 10 from the rating scale used by Ohio EPA (1989) because of the much greater relief present in Utah compared to Ohio.

The QHEI ratings for the Montezuma Creek sites indicated the presence of high quality habitat (Table 2), although overall the ratings were lower than in 1995. The ratings were in the low 70s at all three sites compared to values of 82.5 to 91.5 in 1995. The lower flows in both creeks, but especially Verdure Creek, had a substantial impact on the ratings. Much of the habitat that was available to fish and benthic communities in 1995 was not covered by water in 1996. This reduction in available habitat was evident by the presence of shallower riffles (some riffles without obvious water in Vedure Creek), lower current velocities, and more extensive siltation. Montezuma Creek, at least downstream as far as MZ-9, was buffered from the impacts of lower regional water flows as a consequence of the minimum flow released from Lloyds Lake upstream. Even with the lower ratings, these streams still had habitat within the exceptional range (Rankin 1989) and with excellent habitat heterogeneity. The individual components indicate that most sites still had a variety of microhabitats and sufficient instream cover. Overall, the QHEI suggests that the physical habitat should support successful benthic macroinvertebrate and fish communities in Montezuma Creek from MZ-9 upstream to the mill site.

3. MACROINVERTEBRATE BIOACCUMULATION

On August 14 and 15, 1996, invertebrates were collected for contaminant analysis from five sites in Montezuma Creek (MZ-2, MZ-3, MZ-9, MZG, and MZUG) and one site in Verdure Creek (VD-1); MZG, MZUG, and VD-1 were reference sites. Sampling of upstream sites on Montezuma Creek (MZG and MZUG) was conducted in 1996 to evaluate metal contributions upstream of the mill site. In contrast to sampling protocols followed in 1995, samples were collected in triplicate from distinct locations within each sampling site. Use of this more sound protocol was possible because of greater availability of the selected taxa. Aside from this protocol exception, all other procedures for sampling, quality assurance,

Table 2. Habitat analysis of Montezuma Creek and Verdure Creek sites in August 1996 based on Qualitative Habitat Evaluation Index (Ohio EPA 1988). QHEI scores are given in parentheses for each parameter.

Parameters	Sites		
	MZ-3	**MZ-9**	**VD-1**
Primary Substrate Type	Cobble-Hardpan (12)	Cobble-Muck (10)	Boulder-Cobble (17)
Number of Substrates	6 (2)	4 (0)	3 (0)
Substrate Quality	Sandstone (0)	Sandstone (0)	Sandstone (0)
Substrate Embeddedness	Heavy-Moderate (-3)	Extensive (-4)	Moderate (-2)
Instream Cover Types	7 (7)	6 (6)	5 (5)
Instream Cover Amount	Extensive (11)	Extensive (11)	Moderate-Sparse (5)
Channel Sinuosity	Moderate (3)	Moderate (3)	Moderate-High (3.5)
Channel Development	Excellent-good (5.5)	Good-Fair (4)	Good-Excellent (6)
Channelization	None (6)	None (6)	None (6)
Channel Stability	Moderate (2)	High (3)	High (3)
Riparian Width	Narrow-Very Narrow (1.5)	Wide (4)	Wide (4)
Riparian Cover	Old field-Fenced Pasture (2)	Pasture-Shrub (2)	Forest-Shrub (6)
Bank Erosion	Moderate (4)	None (6)	Little-Moderate (5)
Pool Depth (m)	0.7-1.0 (4)	0.4-0.7 (2)	0.4-0.7 (2)
Pool-Riffle Width	Pool>riffle (2)	Pool>riffle (2)	Pool>riffle (2)
Current Velocity	4 types (4)	2 types (2)	2 types (0)
Riffle Depth (cm)	5-10 (1)	5-10 (1)	<5 (0)
Riffle Stability	Stable (2)	Stable (2)	Stable (2)
Riffle Embeddedness	Moderate (0)	Low (1)	Moderate (0)
Gradient	Moderate (8)	High (10)	Low-Moderate (6)
TOTAL	**74**	**71**	**70.5**

processing, and contaminant analysis were the same as those used in 1995 (see Smith et al. 1996).

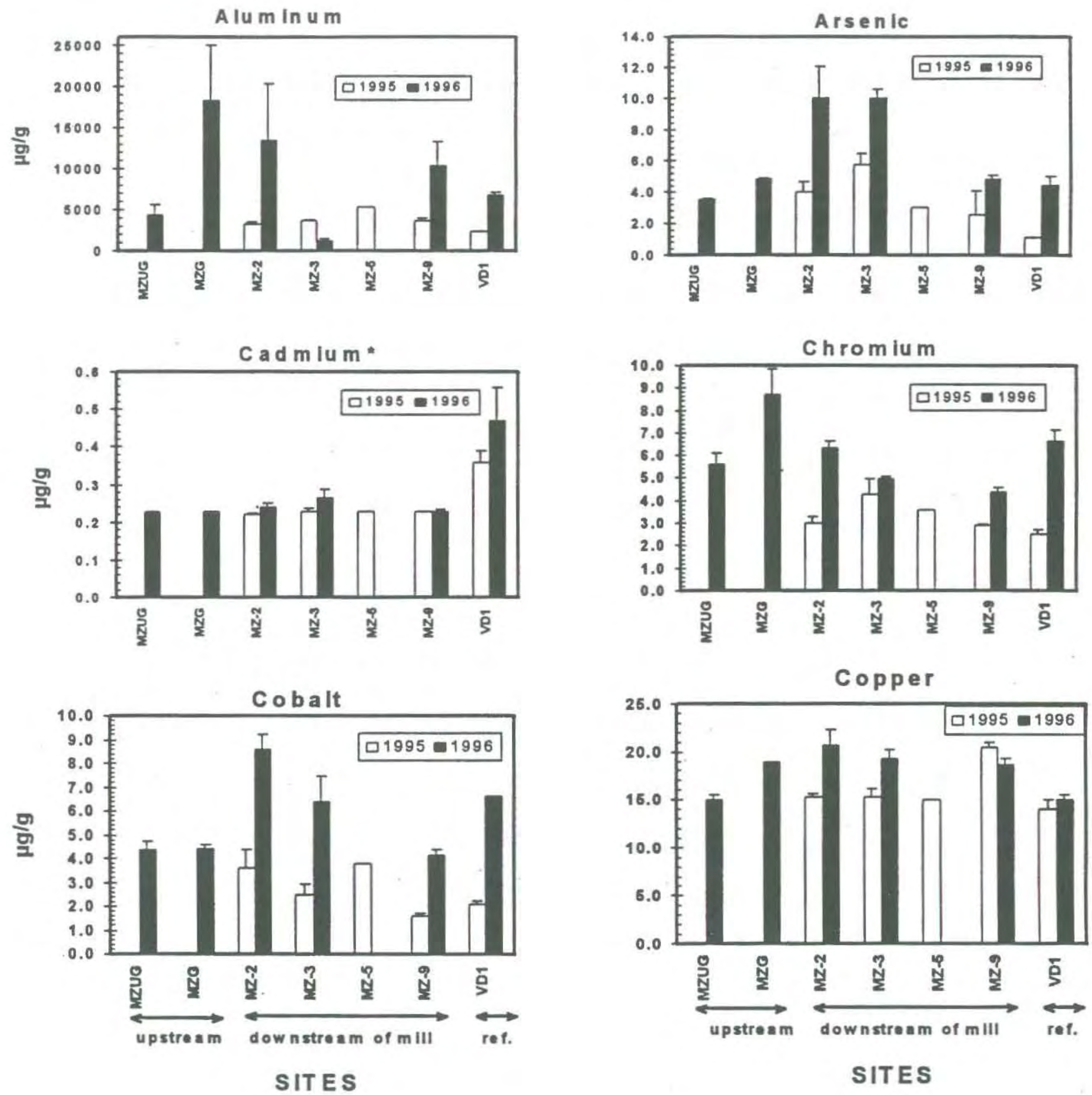
An attempt was made to include a similar biomass of each taxon for each site (Smith et al. 1996), but as in 1995, this was not possible due to differences among sites in species availability. Each replicate from each site included a similar number of each representative taxon, and two to five taxa were included in each sample. Replicates from MZ-2 and MZ-3 included Hydropsychidae, Limnephilidae, *Argia*, *Tipula*, and Dytiscidae larvae; MZ-9 and MZG included Hydropsychidae, Limnephilidae, *Argia*, and *Tipula*; MZUG included Limnephilidae, *Argia*, and *Tipula*; and VD-1 included Limnephilidae and *Argia*. Samples were thus composed of similar contributions of taxa or functional feeding groups. The functional feeding groups represented included detritivores (*Tipula*, Limnephilidae), predators (*Argia*, Dytiscidae), and filter feeders (Hydropsychidae). By including a range of functional feeding groups, it was hoped that the sample would be representative of a wide range of possible exposure routes.

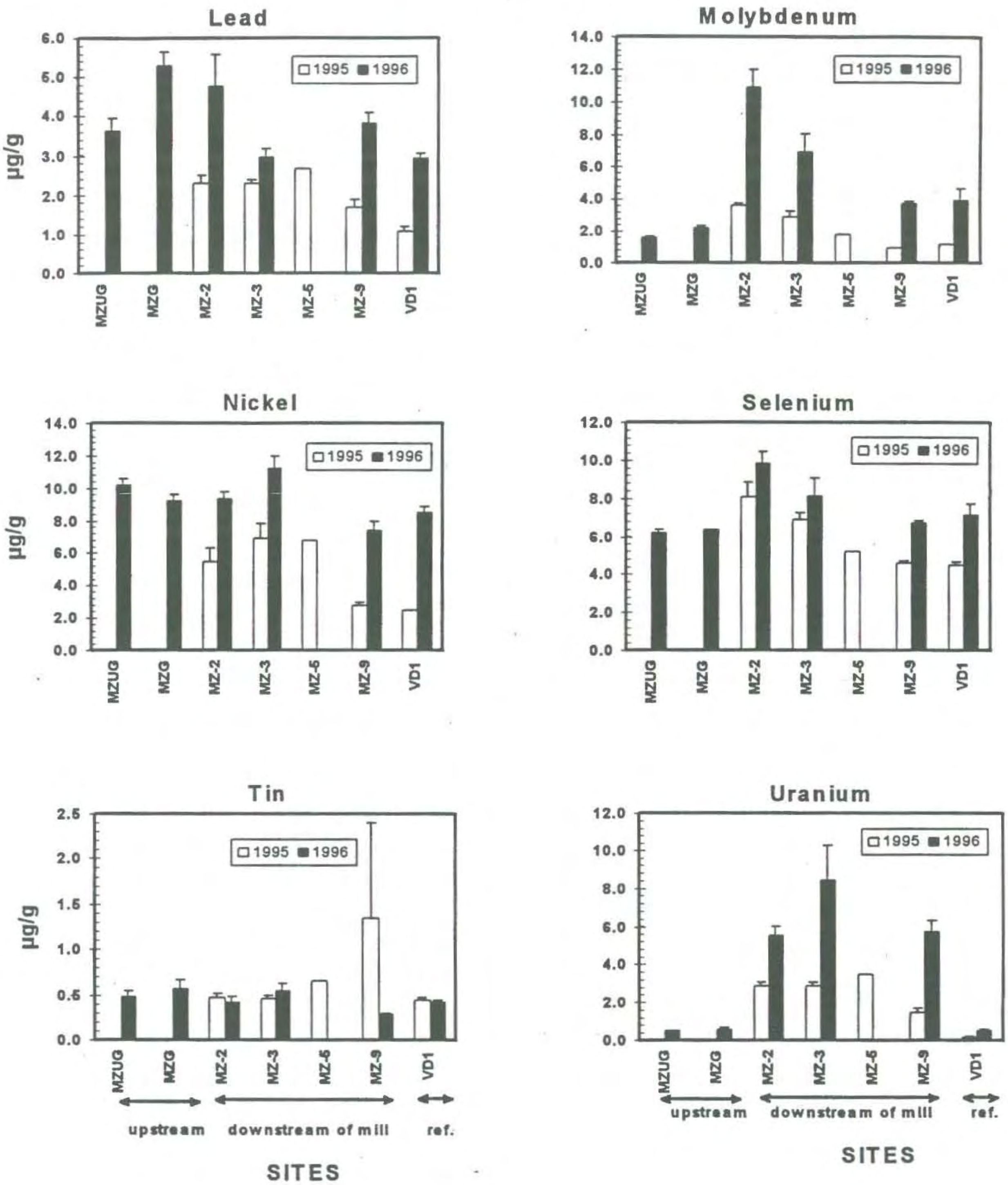
The Analytical Services Organization at the Oak Ridge K-25 Site in Oak Ridge, Tennessee conducted the chemical and radiometric analyses. Results are reported on a dry weight and wet weight basis in Appendix A, Tables A1-A3. Dry weight concentrations are best used to make comparisons between sites and years because of the taxonomic differences among sites and varying water content of each species. Metal concentrations on a wet weight basis are also provided because they provide data necessary for ecological risk assessment.

Compared to Verdure Creek, mean concentrations of aluminum, arsenic, cobalt, lead, molybdenum, nickel, selenium, uranium, and vanadium appeared to be elevated in invertebrates collected from the two Montezuma Creek sites immediately downstream of the mill tailing site (Fig 2). However, three of these metals (aluminum, lead, and nickel) were also elevated at sites upstream of the mill site, suggesting that the higher levels in compared to Verdure Creek may be a consequence of naturally higher levels in this stream or to some upstream source. Aluminum results should be interpreted with caution due to the many dilutions required by the analytical procedure that may have resulted in the highly variable concentrations reported. Concentrations of arsenic, molybdenum and vanadium in invertebrates from sites immediately downstream of the mill (MZ-2 and MZ-3) were generally 2-4 times higher than in invertebrates from all reference sites and the site furthest downstream on Montezuma Creek (MZ-9). Selenium and cobalt showed a similar spatial pattern but the differences between sites were smaller. Mean uranium concentrations in invertebrates downstream of the mill were greater than an order of magnitude higher than reference sites.

The 1996 results more clearly define which metals are most likely to be related to impacts or contributions from the mill site. Arsenic, cobalt, molybdenum, selenium, and vanadium showed a clear spatial pattern of contamination with the highest mean concentrations at MZ-2 and steadily decreasing

Figure 2. Mean metal concentrations (µg/g, dry weight) and gross alpha and beta activity (pCi/g, dry weight) in composite samples of aquatic macroinvertebrates from Montezuma Creek and Verdure Creek, August 1995 and 1996.




Lead
6.0
5.0
4.0
3.0
2.0
1.0
0.0
µg/g
□1995 ■1996
MZUG
MZG
MZ-2
MZ-3
MZ-5
MZ-9
VD1
Molybdenum
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
□1995 ■1996
Nickel
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
µg/g
□1995 ■1996
Selenium
12.0
10.0
8.0
6.0
4.0
2.0
0.0
□1995 ■1996
Tin
2.5
2.0
1.5
1.0
0.5
0.0
µg/g
□1995 ■1996
upstream
downstream of mill
ref.
SITES
Uranium
12.0
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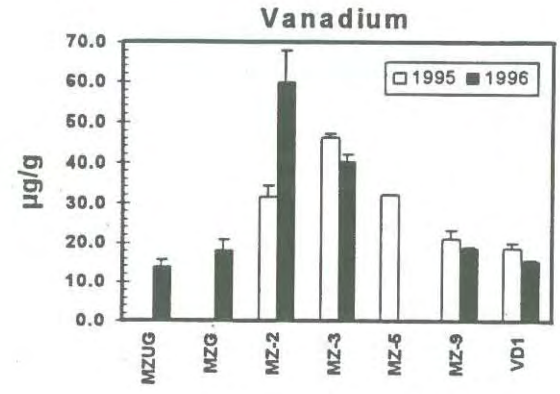

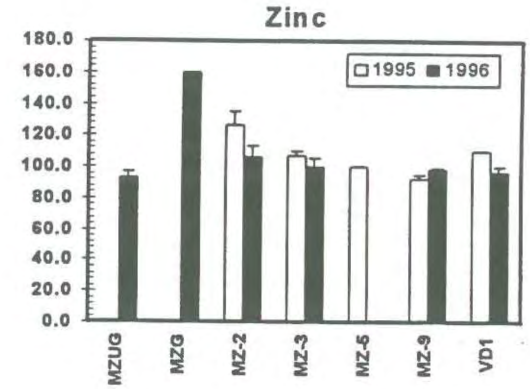

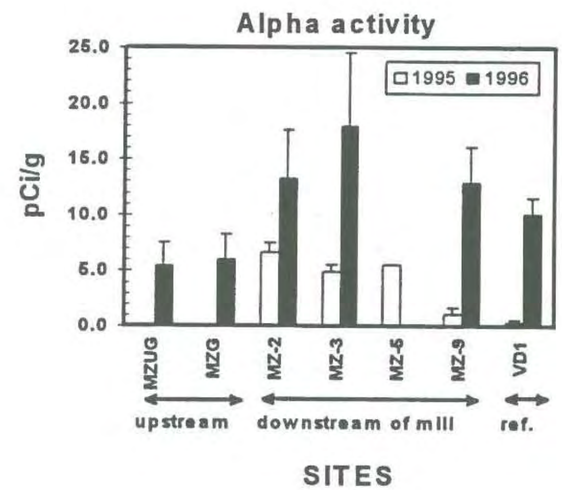

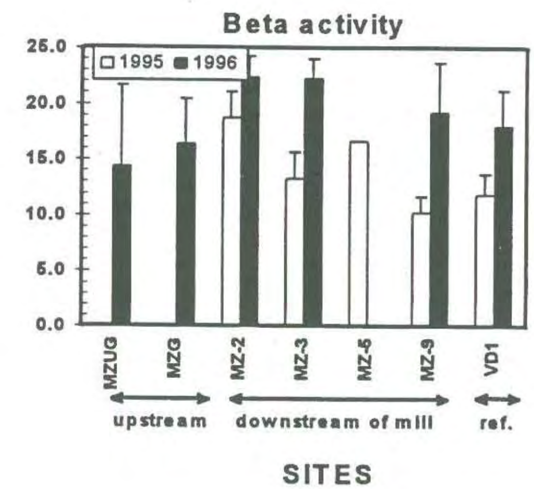

Note:

*Most cadmium concentrations from Motezuma Creek were below the detection limit (typically 0.23 µg/g). Means were calculated using the detection limit value.

Beryllium, antimony, and thallium were not detected in most samples and are not presented.

Error bars illustrate the standard error (±1SE).

concentrations with distance downstream, and low concentrations upstream of the mill site and in Verdure Creek (Fig. 2). As in 1995, elevated concentrations of these metals remained localized within a few kilometers of the mill site; mean concentrations of these metals at MZ-9 were not different from reference site concentrations. Uranium was the only metal that was substantially elevated over background in macroinvertebrates at all sites in Montezuma Creek downstream of the mill site and did not show a pattern of decreasing with distance downstream: Future studies may consider a one-time sampling for uranium in macroinvertebrates at a site or sites further downstream to evaluate the downstream extent of uranium contamination. The following metals in invertebrates from Montezuma Creek showed no conclusive spatial pattern of contamination that appeared to be related to historical mill activities, although there were elevated levels at some sites: aluminum, antimony, beryllium, cadmium, chromium, cobalt, copper, lead, nickel, tin, and zinc (Fig. 2).

In general, the spatial patterns of contamination in 1996 were very similar to 1995 for almost every metal. Uranium, vanadium, molybdenum, selenium, and arsenic were elevated at one or more sites immediately downstream of the mill site in both years. Cadmium was again substantially higher in invertebrates from the reference stream in comparison to all Montezuma Creek sites. Although the spatial patterns of metal contamination in invertebrates were similar, nine of seventeen metal concentrations were higher in 1996 than in 1995. Metals clearly higher in 1996 included aluminum, arsenic, chromium, cobalt, lead, molybdenum, nickel, selenium, and uranium. Vanadium was approximately two times higher at MZ-2 in 1996, but was not higher at the other sites. Concentrations of all other metals were similar between years. Metals that exhibited an increase were higher not only at most Montezuma Creek sites, but at Verdure Creek as well. A plausible explanation for the higher concentrations in macroinvertebrates from both creeks is that the 1996 drought resulted in a greater relative influx of deep groundwater. Low surface water flows would mean less dilution of groundwater sources and greater silt deposition in the remaining pools. This may have been especially important in Verdure Creek where much of the stream was reduced to isolated pools with little or no water in riffles.

Gross alpha activity in invertebrates was higher at sites downstream from the mill site than at the upstream sites (Fig. 2, Table A.4), averaging ($\pm$ SE) 14.8 ± 1.6 pCi/g dry wt. downstream versus 5.7 ± 1.0 pCi/g dry wt. upstream. The higher uranium concentrations in invertebrates at the downstream sites account for much of the difference (0.7 pCi). Alpha activity in invertebrates at the Verdure Creek site were much higher in 1996 than 1995 (Fig. 2), perhaps reflecting differing contributions of deep groundwater as a source of surface flow between the two sampling periods. Concentrations of many naturally occurring radionuclides would be expected to be higher in deep groundwater than in surface runoff or shallow groundwater. Gross beta activity was similar among all sites, with the upstream and

Verdure Creek reference sites bracketing the range of beta activity (Fig. 2, Table A.4). Gross beta activity was higher in invertebrates at all sites in 1996 than 1995, and, as was the case for alpha activity, the year-to-year difference was greatest in Verdure Creek.

Gamma spectroscopy was not able to conclusively detect radioisotopes in invertebrate samples. No radionuclides were consistently above the minimum detectable activity in invertebrate samples. Thorium-234 (a short-lived decay product of uranium-238) and cesium-137 (a fallout component) were reported in about 1/3 of the samples below the mill site and at the reference sites.

4. BENTHIC MACROINVERTEBRATE COMMUNITY STUDIES

Quantitative benthic macroinvertebrate samples were collected from four sites on Montezuma Creek (MZ-2, MZ-3, MZ-9, and MZG) and one site on nearby Verdure Creek (VD-1) on August 12, 1996. The upstream most site on Montezuma Creek (MZG) and Verdure Creek served as reference sites. All procedures used for collecting and processing macroinvertebrate samples were the same as those used for the 1995 sampling effort (Smith et al. 1996), and can be found in even greater detail in Smith (1992) and Wojtowicz and Smith (1992).

Major differences were generally seen in total community density and the combined and individual densities of the pollution sensitive Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) at all sites between 1995 and 1996 (Figs. 3 and 4). This was especially notable at MZ-2, MZ-3, and MZ-9 where total densities were 3.5 to 10 times lower than in 1995. Mayfly densities were about 6X to 27X lower in 1996 than in 1995 at all sites (Fig. 4). Stoneflies were again absent from sites downstream of the mill site, but unlike in 1995, stoneflies were also absent from Verdure Creek samples (Fig. 4). Stonefly density at MZG was more than two times higher in 1996 than in 1995, but they still occurred in very low numbers (< 3 individuals/0.1 m^2). As observed in 1995, most density metrics tended to be higher at sites downstream of the mill site than at the reference sites. This tendency for higher densities downstream of the mill site may indicate, as previously hypothesized (Smith et al. 1996), that nutrient enrichment may be a factor affecting invertebrates downstream of the mill site.

In general, the Epemeroptera, Plecoptera, and Trichoptera (EPT) exhibited the largest differences between years in relative abundance (Fig. 5). Whereas the EPT taxa accounted for a large proportion of the total densities at most sites in 1995, in 1996 the proportion of this group was much lower, particularly at MZG, MZ-9, and VD-1. At MZ-2, there was little difference between years in the relative abundance of the EPT taxa, and as in 1995, the Chironomidae (true midges) and Oligochaeta

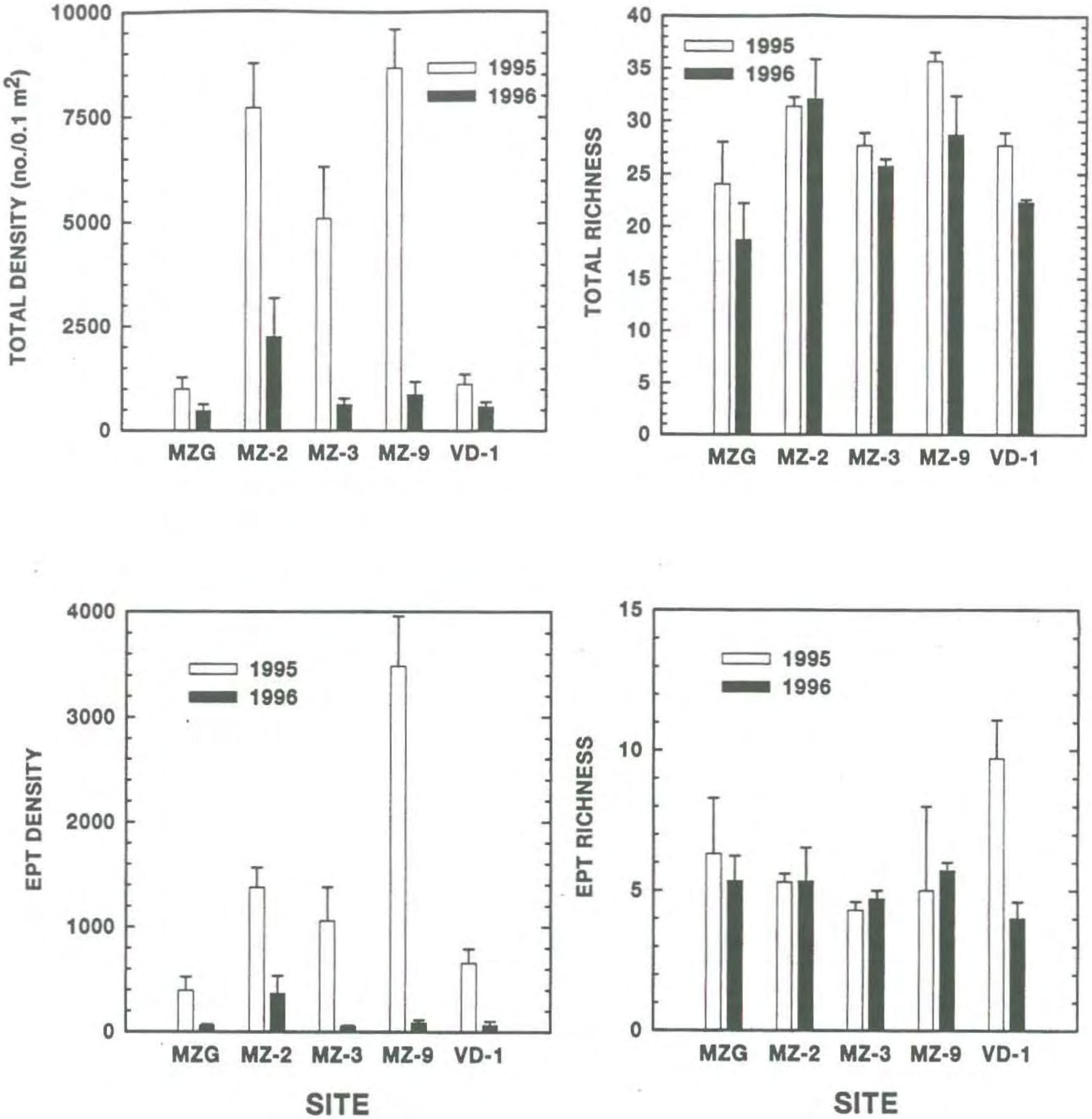

Fig. 3. Total density (number of individuals/0.1 m²), total combined density of the Ephemeroptera, Plecoptera, and Trichoptera (number of EPT individuals/0.1 m²), total taxonomic richness (number of taxa/sample), and total EPT richness (number of EPT taxa/sample), in Montezuma Creek and Verdure Creek, Monticello, Utah, August 1995 and 1996. Values are means ± 1 SE; n=3.

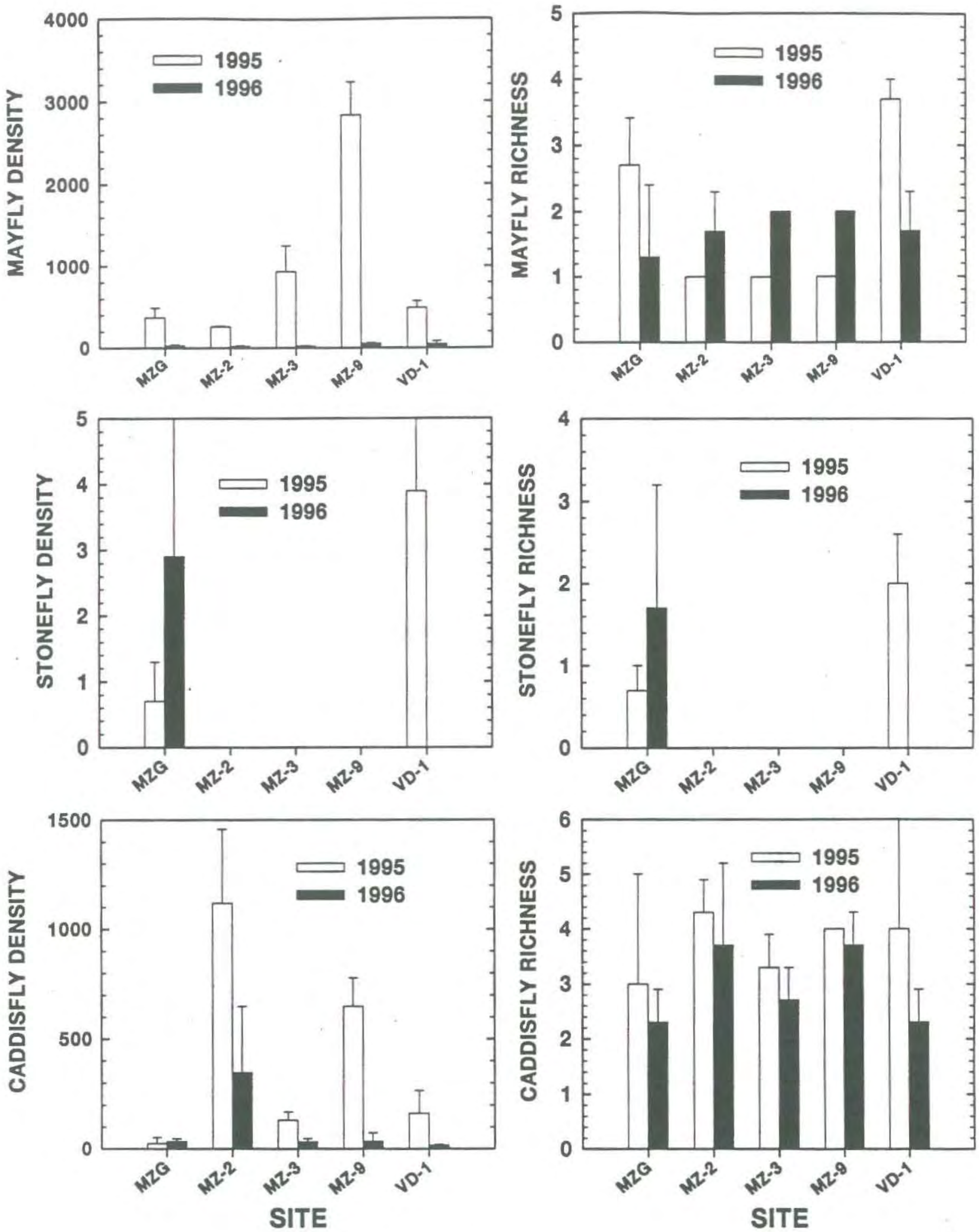

Fig. 4. Total densities (number of individuals/0.1 m^2) and taxonomic richness (number of taxa/sample) of the mayfiles (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) in Montezuma Creek and Verdure Creek, Monticello, Utah, August 1995 and 1996. Values are means ± 1 SE; n=3.

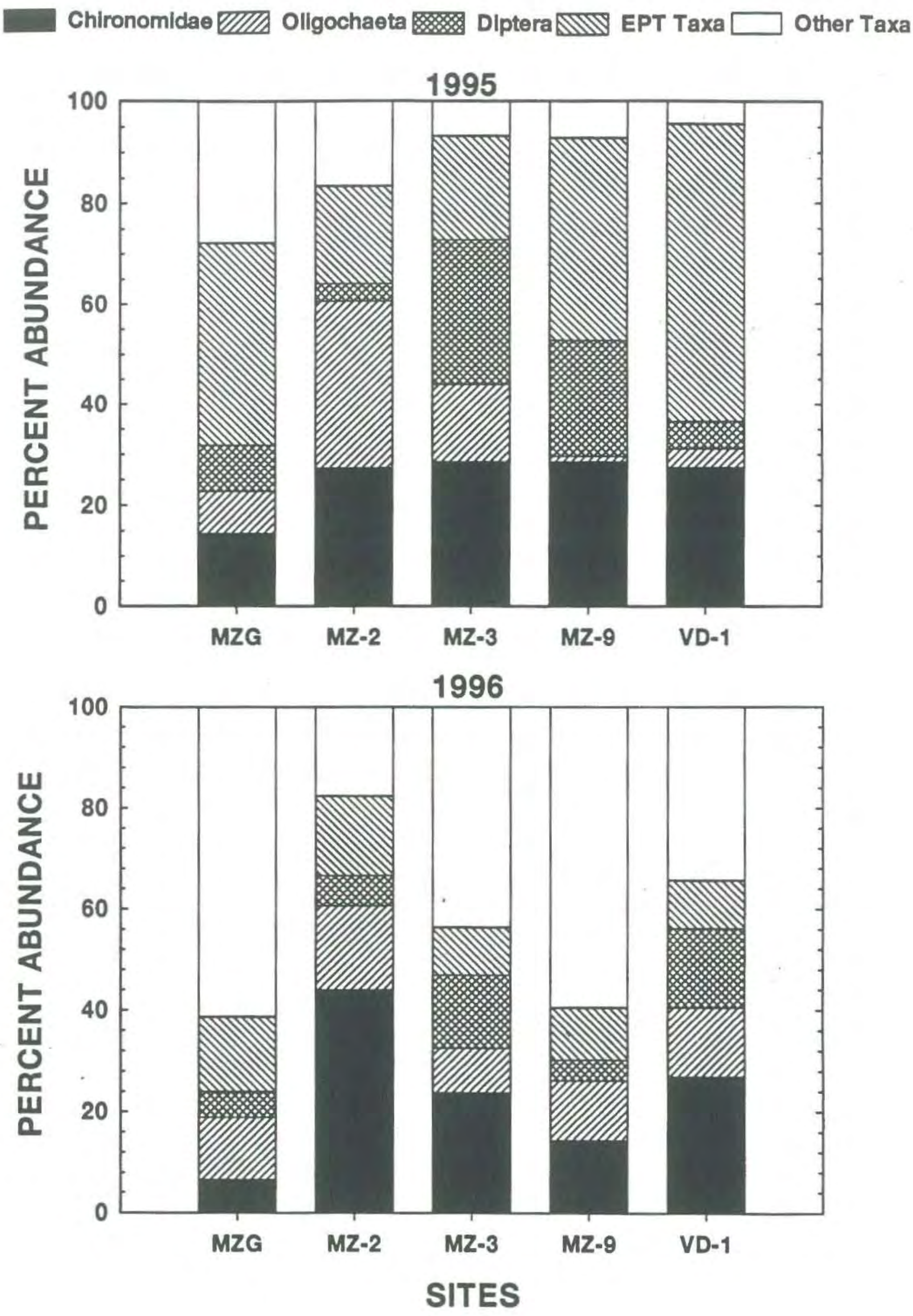

Fig. 5. Percent abundance (percent of total density) of selected macroinvertebrate taxa in Montezuma Creek and Verdure Creek, Monticello, Utah, August 1995 and 1996.

(segmented worms) accounted for the greatest proportions of the organisms collected. In contrast to 1995 however, the chironomids accounted for a higher proportions than the oligochaetes. The proportion of the category "Other Taxa" was much higher in 1996. At MZ-3, MZ-9, and VD-1, much of the increase in "Other Taxa" was due to increases in th numbers of the snail, *Physella*. Other notable increases in the relative abundances of specific taxa within the "Other Taxa" category included *Hyalella azteca*, an amphipod, at MZ-3; beetles (Coleoptera) at MZ-9 and MZG; and the damselfly, *Argia*, at VD-1.

Total taxonomic richness and taxonomic richness of the mayflies, stoneflies, and caddisflies generally showed only minor differences between years, and in Montezuma Creek spatial patterns were generally similar to those exhibited in 1995 (Figs. 3 and 4). The between-year difference at Verdure Creek in EPT richness was a notable exception. EPT richness at this reference site was about two times lower in 1996 than in 1995, and stoneflies were absent from samples in 1996. The average number of mayfly and caddisfly taxa collected in 1996 at Verdure Creek was also about half that of 1995. As in 1995, stoneflies were absent from samples collected at MZ-2, MZ-3, and MZ-9.

Populations of invertebrates exhibit natural annual fluctuations in densities and taxonomic composition for a variety of biological and non-biological reasons. Whether the densities observed at all sites in Montezuma Creek and Verdure Creek in 1995 and 1996 and the extent of change between years were within the normal range for this region cannot be determined from only two sampling periods. However, limited historical data from 1988 for sites on Montezuma Creek near MZG, MZ-2, and MZ-3 (Crist and Trinca 1988), suggest that the densities observed in 1995 may have been unusually high and those in 1996 may have been closer to normal. Even if the densities observed in 1996 were below normal, the fact that taxonomic richness differed little between years at the Montezuma Creek sites suggests that the differences in density were primarily the result of natural causes. However, because concentrations of some contaminants were higher in invertebrates in 1996 than in 1995 (Sect. 3), it is possible that higher concentrations of contaminants may have contributed to reductions in density.

The large between-year differences in densities at all sites and the substantial declines in the richness of the mayflies, stoneflies and caddisflies at Verdure Creek complicated interpretation of spatial differences among the sites. In general, the spatial patterns observed at the four Montezuma Creek sites in composition and structure in 1995 were similar to those observed in 1996. Higher total densities and densities of many other taxa downstream of the mill site continue to suggest that nutrients are probably at least periodically elevated. For example, taxa typically tolerant of enriched conditions (i.e., Oligochaeta and many Chironomidae) were numerically dominant at MZ-2. Because the sites downstream of the mill site have higher densities and taxonomic richness values are similar to those of the reference sites, it is unlikely that contaminants from the mill site are the major factor contributing to the observed differences among the sites.

The drought that occurred in Monticello in 1996 was probably a major factor contributing to spatial differences and the differences in densities between 1995 and 1996. The habitat evaluation (QHEI) documented a decline in habitat quality compared to 1995 that was associated with reduced current velocity, shallower riffles, and increased silt deposition. This may have especially been important in Verdure Creek where much of the stream was reduced to a series of isolated pools with little or no water in the riffles. Not only does less flow reduce the amount of available habitat for invertebrates, if the amount of contaminated ground water that is contributed to stream flow remains unchanged while the amount of surface runoff declines, the concentration of contaminants in the stream water should also increase, thus, increasing exposures to higher concentrations of contaminants. Increases in water temperature may also be associated with shallower, slower flowing water which may partially explain why stoneflies, which tend to be intolerant of warm temperatures, were apparently absent from Verdure Creek in 1996. However, it was not determined whether there actually were any differences between years in temperatures.

5. FISH COMMUNITY STUDIES

Quantitative sampling of the fish populations at the reference stream site, Verdure Creek (VD-1), was conducted by electrofishing with one Smith-Root backpack electrofisher on August 12, 1996. Qualitative surveys were also made at two sites in Montezuma Creek, MZ-3 and MZ-9. At each qualitative site, sampling covered a similar length of stream sampled in August 1995 (Smith et al. 1996). A two-person sampling team electrofished each qualitative site in an upstream direction for one pass.

On August 13, an additional distributional survey was conducted in Montezuma Creek downstream of MZ-9 to the stream's confluence with Verdure Creek. In this survey, a backpack electrofisher was used to sample selected pools and shallow runs to determine the upstream most distribution of fish in Montezuma Creek for this time of year. Four pools were electrofished downstream of MZ-9. Frequent visual surveys were also made where appropriate. Additionally, the channel of the stream was evaluated for potential barriers that might prevent or inhibit fish from migrating upstream from the lower canyon. All field sampling was conducted according to standard operating procedures (Schilling et al. 1996).

Quantitative and qualitative surveys of Verdure Creek and Montezuma Creek failed to find fish at the established sites. Given the length of stream sampled and the variety of habitats covered during sampling, the absence of fish in the surveys could not be a result of insufficient sampling effort. In the quantitative survey of VD-1, unlike the 1995 survey, rainbow trout (*Oncorhynchus mykiss*) were not found. Low water was likely a contributing factor to the absence of fish in Verdure Creek in 1996. However, in Montezuma Creek flow and habitat appeared to be sufficient for fish.

In the qualitative survey of Montezuma Canyon, several tiger salamander (*Ambystoma tigrinum*) larvae were found in the first pool downstream of MZ-9, but fish were absent. The qualitative survey further downstream resulted in the collection of only one species of fish, the speckled dace (*Rhinichthys osculus*). Water was flowing through the upper 2 km of the canyon with most sections of the stream connected and open to possible fish movement. The middle 1 to 2 km of stream consisted of isolated pools separated by dry riffles, and there were a few large, steep slopes (>3 m) that could represent barriers to upstream migration. Eventually, the isolated pools disappeared and the entire channel was dry for about 1 km. Finally water began to reappear in isolated pools, although even at the confluence with Verdure Creek there was no flowing surface water. Electrofishing surveys were made at three pools within the canyon, but no fish were found in these surveys. Fish were first observed in a small isolated puddle about 1.25 to 1.5 km upstream from the mouth of Verdure Creek. After this point, they were seen in considerable numbers in several other locations further downstream, including both shallow (<1 m depth) and deep pools. This survey indicated that fish can and do migrate into the canyon upstream of Verdure Creek during periods of continuous flow, but that substantial physical barriers do exist that could keep these migrating fish from reaching the upper portions of Montezuma Creek where standard sampling sites have been established.

The fish community surveys documented the absence of fish in Montezuma Creek below Lloyds Lake and above site MZ-9 at the Montezuma Canyon. The absence of fish is in agreement with the results of previous surveys by Crist and Trinca (1988) and Smith et al. (1996). The conclusion that fish are absent from upper Montezuma Creek is further supported by the presence of tiger salamander larvae in pools. These salamanders normally reproduce only in bodies of water without fish (Behler and King 1979). The surveys of Montezuma Creek below MZ-9 and above Verdure Creek established that fish could survive in this section, at least for part of the year. However, the absence of rainbow trout in Verdure Creek suggests that fish populations in the streams in this area of similar size and structure as Montezuma Creek above MZ-9 are quite vulnerable to possible extirpation due to low water conditions.

The habitat analysis of sites in Montezuma Creek suggests that an abundance of suitable habitat exists for fish. The habitat variables identified as being of primary importance to rainbow trout include stream flow, maximum stream temperature, instream cover, pool depth, gradient, elevation, and substrate embeddedness (Binns and Eiserman 1979; Baltz et al. 1991; Nelson et al. 1992; Harvey 1993; Hubert and Kozel 1993). Even under the low flow conditions observed in 1996, the QHEI ratings for many of these measures were positive which indicates that these specific variables should not be limiting the establishment of fish populations in Montezuma Creek.

The absence of speckled dace from sites further up in the system appears to be related to access. The dace occur in other western streams with similar elevation, gradient, and habitat (Minckley 1973; Moyle 1976) as Montezuma Creek. Also, the species, at least in Arizona, is described as being extremely tolerant of intermittent stream conditions (John 1964) and a strong recolonizing species (Pearsons et. al. 1992). These characteristics should allow them to successfully survive in Montezuma Creek above MZ-9 or at least re-invade during times of consistent flows. Based on habitat analyses (current report and Smith et al. 1996), habitat quality, food availability, and flow regime do not appear to be limiting factors in upper Montezuma Creek. The survey of Montezuma Creek in the canyon below MZ-9 indicates that speckled dace do occur in the creek above the confluence with Verdure Creek, at least for part of the year. However, the survey did locate substantial barriers between the upper portions of the creek and the canyon pools that contained dace. These barriers, although naturally occurring, do limit colonization of upper Montezuma Creek by restricting the possible development of fish populations. Fish may have occurred in upper Montezuma Creek before operation of the mill, but then eliminated by mill operations. However, it is also possible that naturally low flow (before establishment of Lloyds Lake) and access barriers have combined to preclude any naturally occurring fish populations in upper Montezuma Creek at any time in the past. Therefore, although the stream appears to be capable of sustaining fish populations, unless some proactive approach is used to introduce fish, the recovery of the stream and any associated monitoring of such a process would be restricted to changes in the benthic invertebrate community.

Thus, without knowing historical fish distributions in Montezuma Creek, the current absence of fish from upper Montezuma Creek may not accurately reflect the true quality of the stream and its ability to actually support a fish community. Such a situation has been observed in a flyash contaminated stream in Oak Ridge, Tennessee that underwent remediation, but that was isolated from fish by a downstream barrier. The habitat, food base, and water quality improved enough after remediation, that a planned introduction of a native benthic fish species was successful in establishing a population in the isolated section (Carrico and Ryon 1996).

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APPENDIX A

METAL AND RADIOCHEMISTRY RESULTS

Table A.1. Metal concentrations (µg/g, dry weight) for each macroinvertebrate sample and mean metal concentrations (± SE) at each site in Montezuma and Verdure Creeks, August 1996.

		Analytes																
Site/ sample #	% Moist.	Al	As	Be	Cd	Cr	Co	Cu	Mo	Ni	Pb	Se	Sn	Tl	Sb	U	V	Zn
MZ2-1	84.9	27000	8.2	0.26	0.26	5.7	9.8	24	12.0	10.0	4.2	9.2	0.31	0.26	0.26	6.4	52	120
MZ2-2	83.2	6000	8.0	0.22	0.22	6.6	7.6	19	12.0	8.6	3.7	9.5	0.44	0.22	0.22	4.7	52	100
MZ2-3	84.4	7100	14.0	0.23	0.24	6.7	8.4	19	8.7	9.4	6.4	11.0	0.51	0.23	0.23	5.6	76	100
MZ-2 mean	*84.2*	*13366.0*	*10.1*	*0.2*	*0.2*	*6.3*	*8.6*	*20.7*	*10.9*	*9.3*	*4.8*	*9.9*	*0.4*	*0.2*	*0.2*	*5.6*	*60.0*	*106.7*
SE	*0.5*	*6824.1*	*2.0*	*0.0*	*0.0*	*0.3*	*0.6*	*1.7*	*1.1*	*0.4*	*0.8*	*0.6*	*0.1*	*0.0*	*0.0*	*0.5*	*8.0*	*6.7*
MZ3-1	83.1	1200	9.1	0.23	0.30	5.2	4.4	18	5.0	9.7	2.6	6.9	0.37	0.23	0.23	6.2	37	93
MZ3-2	85.2	1600	11.0	0.22	0.27	4.9	6.8	21	7.0	12.0	3.2	10.0	0.65	0.22	0.28	12	42	110
MZ3-3	85.0	1100	10.0	0.23	0.23	4.8	8.0	19	8.8	12.0	3.2	7.5	0.60	0.23	0.23	7.2	42	97
MZ-3 mean	*84.4*	*1300.0*	*10.0*	*0.2*	*0.3*	*5.0*	*6.4*	*19.3*	*6.9*	*11.2*	*3.0*	*8.1*	*0.5*	*0.2*	*0.2*	*8.5*	*40.3*	*100.0*
SE	*0.7*	*152.8*	*0.5*	*0.0*	*0.0*	*0.1*	*1.1*	*0.9*	*1.1*	*0.8*	*0.2*	*0.9*	*0.1*	*0.0*	*0.0*	*1.8*	*1.7*	*5.1*
MZ9-1	85.7	15000	5.3	0.23	0.24	4.6	4.5	18	3.9	8.5	4.1	6.9	0.29	0.23	0.23	6.7	19	98
MZ9-2	84.0	11000	4.6	0.22	0.22	4.6	3.9	20	3.5	6.8	4.1	6.6	0.30	0.22	0.22	4.6	18	100
MZ9-3	84.5	5300	4.6	0.23	0.23	3.9	4.1	18	3.8	6.9	3.3	6.8	0.28	0.23	0.23	5.9	19	98
MZ-9 mean	*84.7*	*10433.0*	*4.8*	*0.2*	*0.2*	*4.4*	*4.2*	*18.7*	*3.7*	*7.4*	*3.8*	*6.8*	*0.3*	*0.2*	*0.2*	*5.7*	*18.7*	*98.7*
SE	*0.5*	*2814.4*	*0.2*	*0.0*	*0.0*	*0.2*	*0.2*	*0.7*	*0.1*	*0.6*	*0.3*	*0.1*	*0.0*	*0.0*	*0.0*	*0.6*	*0.3*	*0.7*

Table A.1 (continued)

		Analytes																
Site/ sample #	% Moist.	Al	As	Be	Cd	Cr	Co	Cu	Mo	Ni	Pb	Se	Sn	Tl	Sb	U	V	Zn
MZG-1	83.0	30000	5.0	0.30	0.23	9.7	4.7	19	2.0	10.0	6.0	4.6	0.67	0.23	0.30	0.57	23	160
MZG-2	84.9	18000	4.8	0.24	0.23	10.0	4.4	19	2.3	9.2	5.0	7.4	0.36	0.23	0.23	0.79	17	160
MZG-3	84.8	6700	4.7	0.23	0.23	6.4	4.2	19	2.4	8.4	4.9	7.1	0.67	0.23	0.23	0.44	14	160
MZG mean	*84.3*	*18233.3*	*4.8*	*0.3*	*0.2*	*8.7*	*4.4*	*19.0*	*2.2*	*9.2*	*5.3*	*6.4*	*0.6*	*0.2*	*0.3*	*0.6*	*18.0*	*160.0*
SE	*0.6*	*6727.1*	*0.1*	*0.0*	*0.0*	*1.2*	*0.1*	*0.0*	*0.1*	*0.5*	*0.4*	*0.9*	*0.1*	*0.0*	*0.0*	*0.1*	*2.6*	*0.0*
MZUG-1	83.2	2000	3.6	0.23	0.23	4.7	3.8	16	1.7	10.0	3.0	6.6	0.60	0.23	0.23	0.56	10	99
MZUG-2	82.8	6300	3.6	0.22	0.22	5.8	5.0	14	1.5	11.0	4.1	6.0	0.38	0.22	0.26	0.56	15	92
MZGU-3	82.3	4700	3.4	0.23	0.23	6.4	4.4	15	1.5	9.5	3.8	6.0	0.45	0.23	0.23	0.48	16	89
MZUG mean	*82.8*	*4333.3*	*3.5*	*0.2*	*0.2*	*5.6*	*4.4*	*15.0*	*1.6*	*10.2*	*3.6*	*6.2*	*0.5*	*0.2*	*0.2*	*0.5*	*13.7*	*93.3*
SE	*0.3*	*1254.8*	*0.1*	*0.0*	*0.0*	*0.5*	*0.3*	*0.6*	*0.1*	*0.4*	*0.3*	*0.2*	*0.1*	*0.0*	*0.0*	*0.0*	*1.9*	*3.0*
VD1-1	77.6	6300	4.1	0.25	0.64	5.8	6.2	15	2.6	7.8	2.9	6.6	0.43	0.23	0.28	0.6	15	100
VD1-2	78.6	7400	5.6	0.22	0.35	6.7	6.7	16	4.8	8.5	2.8	8.3	0.45	0.22	0.22	0.52	16	100
VD1-3	76.7	6500	3.7	0.22	0.42	7.5	7.0	14	4.5	9.2	3.2	6.6	0.37	0.22	0.22	0.52	15	91
VD1 mean	*77.6*	*6733.3*	*4.5*	*0.2*	*0.5*	*6.7*	*6.6*	*15.0*	*4.0*	*8.5*	*3.0*	*7.2*	*0.4*	*0.2*	*0.2*	*0.5*	*15.3*	*97.0*
SE	*0.5*	*338.3*	*0.6*	*0.0*	*0.1*	*0.5*	*0.2*	*0.6*	*0.7*	*0.4*	*0.1*	*0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.3*	*3.0*

Table A.2. Metal concentrations (μg/g, wet wt.) in aquatic macroinvertebrate samples in Montezuma and Verdure Creeks, August 1996.

	Analyte																
Sample	Al	As	Be	Cd	Cr	Co	Cu	Mo	Ni	Pb	Se	Sn	Tl	Sb	U	V	Zn
MZ2-1	4070	1.24	<0.039	0.045	0.86	1.48	3.6	1.81	1.51	0.63	1.39	0.047	<0.039	<0.039	0.96	7.8	18
MZ2-2	1009	1.35	<0.037	0.045	1.11	1.28	3.2	2.02	1.45	0.62	1.60	0.074	<0.035	<0.035	0.79	8.7	17
MZ2-3	1107	2.18	<0.036	<0.036	1.04	1.31	3.0	1.36	1.47	1.00	1.72	0.080	<0.036	<0.036	0.87	11.9	16
MZ3-1	203	1.54	<0.039	0.041	0.88	0.74	3.0	0.84	1.64	0.44	1.16	0.062	<0.039	<0.039	1.05	6.2	16
MZ3-2	237	1.63	<0.033	<0.033	0.73	1.01	3.1	1.04	1.78	0.47	1.48	0.096	<0.033	0.041	1.78	6.2	16
MZ3-3	165	1.50	<0.035	<0.035	0.72	1.20	2.9	1.32	1.80	0.48	1.13	0.090	<0.035	<0.035	1.08	6.3	15
MZ9-1	2152	0.76	<0.033	<0.041	0.66	0.65	2.6	0.56	1.22	0.59	0.99	0.042	<0.033	<0.033	0.96	2.7	14
MZ9-2	1765	0.74	<0.035	<0.035	0.74	0.63	3.2	0.56	1.09	0.66	1.06	0.048	<0.035	<0.035	0.74	2.9	16
MZ9-3	822	0.71	<0.036	<0.036	0.60	0.64	2.8	0.59	1.07	0.51	1.05	0.043	<0.036	<0.036	0.92	2.9	15
MZG	5087	0.85	0.051	<0.039	1.64	0.80	3.2	0.34	1.70	1.02	<0.78	0.114	<0.039	0.051	0.10	3.9	27
MZG	2711	0.72	0.036	<0.035	1.51	0.66	2.9	0.35	1.39	0.75	1.11	0.054	<0.035	<0.035	0.12	2.6	24
MZG	1017	0.71	<0.035	<0.035	0.97	0.64	2.9	0.36	1.27	0.74	1.08	0.102	<0.035	<0.035	0.07	2.1	24
MZUG	335	0.60	<0.039	<0.039	0.79	0.64	2.7	0.28	1.68	0.50	1.11	0.101	<0.039	<0.039	0.09	1.7	17
MZUG	1086	0.62	<0.038	<0.038	1.00	0.86	2.4	0.26	1.90	0.71	1.03	0.065	<0.038	0.045	0.10	2.6	16
MZUG	833	0.60	<0.041	<0.041	1.13	0.78	2.7	0.27	1.68	0.67	1.06	0.080	<0.041	<0.041	0.09	2.8	16
VD1-1	1409	0.92	0.056	0.107	1.30	1.39	3.4	0.58	1.74	0.65	1.48	0.096	<0.052	0.063	0.13	3.4	22
VD1-2	1586	1.20	<0.047	0.060	1.44	1.44	3.4	1.03	1.82	0.60	1.78	0.096	<0.047	<0.047	0.11	3.4	21
VD1-3	1516	0.86	<0.051	0.074	1.75	1.63	3.3	1.05	2.15	0.75	1.54	0.086	<0.051	<0.051	0.12	3.5	21

Table A.3. Mean metal concentrations (µg/g, wet weight) in composite samples (n=3/site) of aquatic macroinvertebrates collected from Montezuma Creek and Verdure Creek, August 1996. Means expressed ± SE.

Metal	Sites					
	MZ-2	MZ-3	MZ-9	MZG	MZUG	VD-1
Aluminum	2062 ± 1004	202 ± 21[a]	1580 ± 395	2938 ± 1180	751 ± 220	1503 ± 51
Antimony	<0.04	<0.04[b]	<0.04	<0.04[b]	<0.04[b]	<0.05[b]
Arsenic	1.59 ± 0.30	1.56 ± 0.04	0.74 ± 0.01	0.76 ± 0.04	0.61 ± 0.01	0.99 ± 0.11
Beryllium	<0.04	<0.04	<0.04	0.04[a]	<0.04	<0.05[b]
Cadmium	<0.04[b]	0.04[a]	<0.04[b]	<0.04	<0.04	0.11 ± 0.02
Chromium	1.00 ± 0.08	0.7 8± 0.05	0.67 ± 0.04	1.37 ± 0.21	0.97 ± 0.10	1.49 ± 0.13
Cobalt	1.36 ± 0.06	0.98 ± 0.13	0.64 ± 0.006	0.70 ± 0.05	0.76 ± 0.07	1.49 ± 0.08
Copper	3.26 ± 0.19	3.00 ± 0.08	2.86 ± 0.19	2.99 ± 0.12	2.58 ± 0.09	3.35 ± 0.05
Lead	0.75 ± 0.12	0.47 ± 0.01	0.59 ± 0.04	0.84 ± 0.09	0.63 ± 0.06	0.67 ± 0.04
Molybdenum	1.73 ± 0.20	1.07 ± 0.14	0.57 ± 0.01	0.35 ± 0.01	0.27 ± 0.01	0.88 ± 0.15
Nickel	1.47 ± 0.02	1.74 ± 0.05	1.13 ± 0.05	1.45 ± 0.13	1.75 ± 0.07	1.90 ± 0.12
Selenium	1.57 ± 0.10	1.26 ± 0.11	1.04 ± 0.02	0.99 ± 0.11[a]	1.07 ± 0.02	1.60 ± 0.09
Thallium	<0.04	<0.04	<0.04	<0.04	<0.04	<0.05
Tin	0.067 ± 0.010	0.083 ± 0.010	0.044 ± 0.002	0.090 ± 0.018	0.082 ± 0.010	0.093 ± 0.003
Uranium	0.88 ± 0.05	1.30 ± 0.24	0.87 ± 0.07	0.09 ± 0.02	0.09 ± 0.00	0.12 ± 0.01
Vanadium	9.48 ± 1.22	6.26 ± 0.03	2.85 ± 0.07	2.86 ± 0.53	2.37 ± 0.35	3.43 ± 0.04
Zinc	16.8 ± 0.7	15.5 ± 0.5	15.1 ± 0.6	25.2 ± 1.0	16.1 ± 0.3	21.7 ± 0.4

[a] One of three samples were below the detection limit. The detection limit value was used to calculate the mean and SE.

[b] Two of three samples were below the detection limit. The detection limit is cited.

Table A.4. Gross alpha, gross beta, and isotope specific gamma activity in aquatic macroinvertebrates collected from Montezuma and Verdure Creeks, August 1996. Values expressed ± 95% confidence interval for counting.

Sample	Gross Alpha Activity	Gross Beta Activity	Gamma Activity				
			Cs-137	Pa-234m	Th-234	Th-228	U-235
MZ2-1	9.6 ± 6.6	23.8 ± 11.0	7.2 ± 23	2250 ± 5100	873 ± 200	800 ± 460	20 ± 35
MZ2-2	12.4 ± 5.7	23.0 ± 8.9	10 ± 22	2410 ± 4300	626 ± 140	ND	11 ± 32
MZ2-3	18 ± 6.4	20.3 ± 9.3	93 ± 76	3780 ± 4500	-273 ± 280	ND	16 ± 34
MZ3-1	13.0 ± 5.7	20.9 ± 9.1	-1.0 ± 23	6520 ± 4000	-5 ± 270	ND	18 ± 33
MZ3-2	15.8 ± 5.9	24.2 ± 8.9	117.0	3700 ± 4000	529 ± 180	482 ± 610	4.4 ± 31
MZ3-3	25.3 ± 7.3	21.7 ± 9.1	-2.0 ± 19	3330 ± 4500	693 ± 170	544 ± 590	-2.1 ± 30
MZ9-1	10.5 ± 5.8	18.3 ± 9.1	-2.8 ± 19	-26 ± 4500	36 ± 250	1010 ± 640	-0.7 ± 30
MZ9-2	11.6 ± 5.5	15.3 ± 8.7	18 ± 22	-3780 ± 4400	160 ± 250	ND	1.6 ± 33
MZ9-3	16.6 ± 6.2	24.0 ± 9.2	98 ± 74	2030 ± 4500	-274 ± 270	ND	2.9 ± 33
MZG	8.5 ± 5.5	19.9 ± 9.2	89 ± 73	3920 ± 4400	620 ± 170	ND	-0.35 ± 33
MZG	5.3 ± 4.8	11.9 ± 8.8	102 ± 74	2730 ± 4400	-241 ± 280	ND	6.16 ± 33
MZG	4.3 ± 4.6	17.4 ± 9.0	0.8 ± 19	1430 ± 4500	-21 ± 250	557 ± 570	0.94 ± 30
MZUG	3.0 ± 4.5	22.1 ± 9.2	-2.5 ± 19	597 ± 4300	544 ± 180	573 ± 650	1.2 ± 30
MZUG	7.1 ± 5.1	13.5 ± 8.7	76 ± 72	1830 ± 4300	447 ± 190	ND	4.4 ± 32
MZUG	6.2 ± 5.0	7.5 ± 8.5	-5.3 ± 19	543 ± 4400	7 ± 240	837 ± 570	-1.3 ± 30
VD1-1	11.0 ± 5.6	15.2 ± 9.1	-9.1 ± 19	722 ± 4600	200 ± 250	ND	13 ± 31
VD1-2	10.9 ± 5.6	21.4 ± 9.1	-19 ± 23	1130 ± 4100	129 ± 260	443 ± 830	5.6 ± 33
VD1-3	8.6 ± 5.4	17.5 ± 8.9	94 ± 72	4070 ± 4000	516 ± 170	523 ± 660	-6.2 ± 32

Note:
Values within the 95% confidence interval are below the minimum detectable activity (MDA).