BIOCONCENTRATIONS OF HEAVY METALS

Copper, Chromium (Tot), Lead, Zinc, Nickel and Mercury in the Missouri River 1991

Prepared For

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and

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by

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INTRODUCTION

The presence of heavy metals within aquatic environments can be attributed to sources such as industry, municipal discharges, agriculture and natural processes which release various amounts into natural systems. Metals such as copper, zinc and chromium are listed as essential micronutrients for many plant and animal species. Of potential concern, however, is the tendency of heavy metals to accumulate within the food webs of ecosystems. Classified as biologically hard to degrade, heavy metals may concentrate to significant amounts within the trophic levels of a particular ecosystem. At these increased concentrations many of these heavy metals become toxic to living organisms.

Previous research had detected the presence of heavy metals in water samples collected from the Missouri River near Sioux City, Iowa. Levels of zinc, copper and lead exceeding state quality standards water were observed in 1984-85 (Tondreau, 1984-86). The direct source of the metals was unknown but two local industries involved in metal-plating were suspected. Around this time the secondary treatment phase of Sioux City's wastewater treatment plant was shut down due to a shock load of zinc. The high metal levels were impetus to conduct studies on the bioaccumulation of metals within the aquatic communities found in the main channel border habitat of the channelized Missouri River. Conducted during the years 1986 and 1987, concentrations of copper, chromium, lead and zinc were measured in water, fish, periphyton and invertebrates collected at two sites just upstream from Sioux City R.M. 735 and downstream from Sioux City at R.M. 722. (Shane and Tondreau, 1987). Bioconcentration factors (BCF) were calculated by dividing the metal concentration of each aquatic group by the metal concentration in the water. Bioconcentration factors for the aquatic communities of periphyton, invertebrates and fish for 1987 are listed in Table 1.

Table 1

BIOCONCENTRATION OF HEAVY METALS IN THE MISSOURI RIVER - 1987

	Bioconcentration Factors - Average Values			
Community*	Cr(Tot.)	Cu	Pb	Zn
Periphyton	1100	3200	1400	1100
Invertebrates	600	4100	1100	3400
Fish (muscle tissue)	40	350	170	500

*Dry weight samples

Additional funding was sought to further research issues not addressed in the previous studies. They include:

1. Further upstream/downstream extent of the bioconcentration.
2. Analysis for two additional metals; mercury and nickel.
3. Bioconcentration in the zooplankton community.
4. Studies of periphyton productivity and sediment composition as to their relationship to metal concentrations.

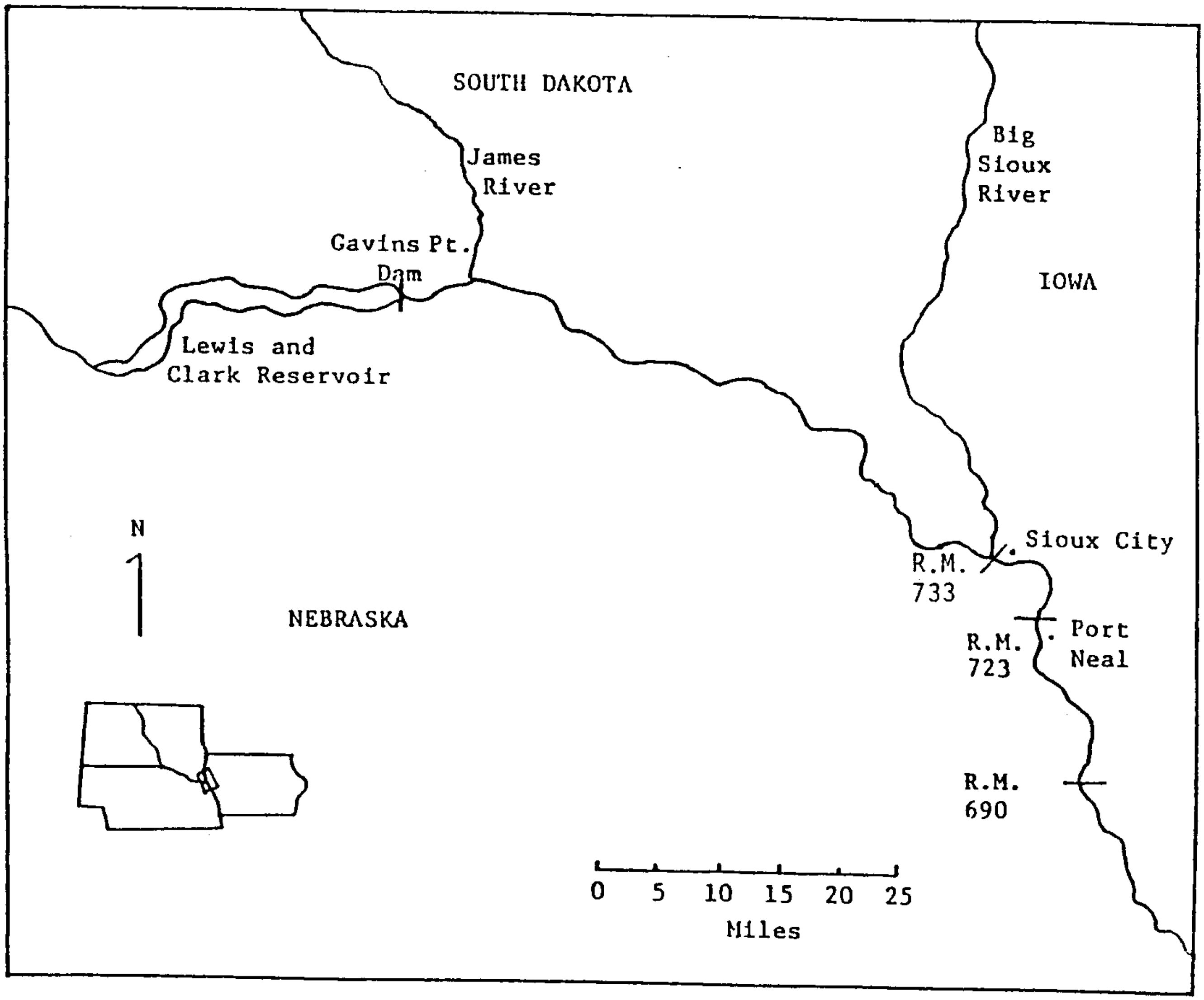

Figure 1. Map of Missouri River in the Study Area.

EXPERIMENTAL

Sample site locations are identified in Figure 1. The north sample site was located below the confluence of the Big Sioux River but above any discharges from the metropolitan Sioux City area. The central (R.M. 723) and south (R.M. 694) sites were located downstream from Sioux City at distances of ten and thirty-nine river miles.

The Missouri River in the study area has been channelized with rock rip-rap to a channel width of 700-800 feet. All samples were collected from the main channel border habitat which is considered one of the most productive of the limited aquatic habitats available in the channelized river (Hey, 1982).

Table 2 lists the sample type, sampling device and other sampling information. Sample collection, storage, preservation and transport was carried out according to E.P.A. recommended procedures.

Table 2

Sample	Device	Container	Preservative	Holding Time
Water-metals	Grab	Nalgene	HNO pH<2	6 mos
Water-Tot. Alk. Hardness	Grab	Nalgene	Cool 4 C	24 hrs
Sediment	Phleger Core Sampler	Nalgene	Cool 4 C	48 hrs
Periphyton	Floating Slide Rack	Glass Jars	Frozen/Dark	2 wks
Macro-invertebrates	Hilsenhof Rock Basket	Glass Jars	70% Ethanol	2 wks
Zooplankton	Plankton Net	Glass Jars	70% Ethanol	2 wks
Fish (muscle)	Pulsed D.C. Electroshocker	Plastic Bags	Frozen	3 mos

Multiple samples were collected at each location in order to determine any statistically significant differences between sample sites by accounting for any within site variability.

Analytical methods used for this study are listed in Table 3.

Table 3

Test	E.P.A./Standard Methods Procedure
Heavy metals	
Chromium (total)	218.1
Copper	220.1
Lead	239.1
Mercury	245.1
Nickel	449.1
Zinc	289.1
Alkalinity	310.1
Hardness	130.2
pH	150.1
Chlorophyll	1002 G(1) Std. Methods
Biomass	1003 C(4) Std. Methods
Productivity	1003 D(1) Std. Methods
Organic/inorganic content	1003 C(4) Std. Methods

Metal content was determined in the following aquatic communities: fish (muscle), periphyton, macroinvertebrates and zooplankton. Water and sediment metal analysis was also performed: Periphyton chlorophyll, biomass and productivity was also determined. Sediment biomass determinations were made to determine the relative organic/inorganic composition of the sediment.

At each site the following number of samples for each sample medium were obtained: fish (5 of each of three species, carp yprinas carpio, flathead catfish Plyodictis olivaris and smallmouth/bigmouth buffalo Ictiobus buballus/I. cyprinellus); periphyton (3); macroinvertebrates (3); zooplankton (3); sediment (3); and water (2).

Biological tissue samples were collected and preserved in the field and stored prior to analysis according to recommended procedures (Table 2). Sample preparation was performed using methods which would minimize any contamination from metal devices nromally used to prepare samples for digestion.

For statistical analysis of the data, 95% confidence intervals around each sample mean were calculated. The standard error of the mean (standard deviation divided by the square root of the sample number) is multiplied by the critical value from the t-table at the 95% confidence level. Differences in mean which fall outside these range of values would indicate a between site difference for the particular value. This difference was checked utilizing a +-test at the (.05) level of confidence. A Q-test (Dixon Test) was used to test for rejection of individual measurements which appear to vary excessively from typical observed values. The difference between the questionable value and its nearest neighbor is divided by the range of the entire set. The resulting ratio Q is compared to rejection values at the 90% level of confidence. The statistical methods employed in this study were taken from Skoog and West, Fundamentals of Analytical Chemistry, 4th edition.

The minimum detection limit (units ug/liter) for the digested samples was determined from multiple replicates of 6 blanks. A pooled standard deviation was calculated for three separate blank rows of six, six, and ten blanks each using the following relationship:

$$\text{S-pooled} = \left(\frac{V_1S_1^2+V_2V_2^3+V_3S_3^2}{V_1+V_2V+V_3}\right)^{\frac{1}{2}}$$

$$S = \left(\frac{\sum(Xi-X)^2}{n_i-1}\right)^{\frac{1}{2}}$$

ni = number replicate blanks, e.g., $n_1 = 6$, $n_2 = 6$, $n_3 = 10$
vi = degrees of freedom, e.g., $V_1 = 5$, $V_2 = 5$, $V_3 = 9$
S = standard deviation
S-pooled = pooled standard deviation for three sets of blanks

The Minimum Detection Limit (MDL) was calculated from the pooled standard deviation.

MDL = t99%, S-pooled

t99% - Students' t-value at the 99 percent confidence level

The Minimun Detection Limits for the six metals in this study are reported as follows: Cr = 36; Cu = 9.3; Hg = 1.9; Pb = 126; Ni = 173; Zn = 196. All values are in ug/liter.

RESULTS

The mean metal content in the fish muscle tissue of carp (Cyprinus carpio), flathead catfish (Plyodictis olivaris) and buffalo (Ictiobus bubalus and Ictiobus cyprinellus) are given in Table 4. Mean metal content in periphyton, macroinvertebrates, zooplankton, sediment and water samples are listed in Tables 5-9. Table 10 lists a summary of statistical analysis for site to site differences in metal concentrations. Average metal bioconcentration factors for fish, periphyton macroinvertebrates and zooplankton are listed in Table 11. Water hardness alkalinity, pH and temperature values are given in Table 12. Periphyton chlorophyll, biomass and productivity data are listed in Table 13. Sediment biomass and percent organic composition data are given in Table 14. Lastly, metal content in selected fish livers and gills are presented in Table 15.

Metal concentrations are reported in parts per million (µg/g) with the exception of water values which are reported in parts per billion - (µg/l). All metals samples were analyzed on a dry weight basis. For comparison with net weight data, dry weight-wet weight ratios were determined wherever possible.

Fish livers and gills were kept for metals analysis due to their physiological role in the excretion and collection of toxic compounds.

Table 4

METAL SUMMARY ug/g DRY WEIGHT
SMALLMOUTH AND BIGMOUTH BUFFALO

Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
6/26/92	North	$\bar{X}$	1.1	15.4	1.0	3.2	4.6	.54
		S.D.	.36	7.0	.5	0.0	.60	.36
		*C.I.(±)	.34	6.6	.5	0.0	.57	.34
	Central	$\bar{X}$	1.2	19.9	1.4	3.3	4.4	.88
		S.D.	.30	4.9	.3	.17	.11	.19
		C.I.(±)	.30	4.6	.3	.16	.10	.18
	South	$\bar{X}$	1.1	15.2	2.1	3.2	4.6	.48
		S.D.	.15	7.5	.7	0.0	.57	.13
		C.I.(±)	.14	7.1	.6	0.0	.53	.12

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/12/91	North	$\bar{X}$	1.2	19.3	2.4	4.6	7.3	.64
		S.D.	.5	3.8	1.8	3.0	2.7	.30
		C.I.(±)	.4	3.6	1.7	2.9	2.5	.28
	Central	$\bar{X}$	1.3	18.6	1.7	3.9	5.1	.77
		S.D.	.6	2.9	1.5	.9	1.2	.32
		C.I.(±)	.5	2.7	1.4	.8	1.1	.30
	South	$\bar{X}$	.9	14.5	1.3	3.6	5.6	.33
		S.D.	.1	5.6	.7	.8	2.1	.07
		C.I.(±)	.1	5.3	.7	.8	2.0	.07

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/24/91	North	$\bar{X}$	.9	17.3	1.1	3.2	4.4	.36
		S.D.	0.0	5.5	.2	0.0	.16	.05
		C.I.(±)	0.0	5.0	.2	0.0	.15	.05
	Central	$\bar{X}$	1.04	18.6	1.5	3.2	4.3	.52
		S.D.	.30	5.6	.6	0.0	0.0	.40
		C.I.(±)	.28	5.0	.6	0.0	0.0	.38
	South	$\bar{X}$	.96	12.7	1.4	3.2	4.4	.42
		S.D.	.08	5.0	.7	0.0	.20	.10
		C.I.(±)	.08	5.0	.7	0.0	.19	.09

*C.I.(±) = 95% Confidence Interval about the mean

Table 4 continued

METAL SUMMARY ug/g DRY WEIGHT
CARP

Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
6/26/92	North	$\bar{X}$	1.6	30.0	1.4	3.2	4.3	.72
		S.D.	.8	14.0	.08	0.0	0.0	.25
		C.I.(±)	.75	15	.08	0.0	0.0	.24
	Central	$\bar{X}$	1.4	36	2.2	3.2	4.3	.57
		S.D.	.6	19	.43	0.0	.11	.29
		C.I.(±)	.57	18	.40	0.0	.10	.33
	South	$\bar{X}$	1.3	28	2.2	3.2	4.1	.42
		S.D.	.4	9	.86	0.0	.8	.09
		C.I.(±)	.38	9	.81	0.0	.75	.08

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/12/91	North	$\bar{X}$	1.0	29.4	1.5	7.9	4.6	.75
		S.D.	.08	10.5	.50	6.5	.7	.46
		C.I.(±)	.08	10	.47	6.1	.6	.43
	Central	$\bar{X}$	1.0	29.1	1.2	4.4	4.3	.48
		S.D.	.08	8.8	.30	2.0	0.0	.19
		C.I.(±)	.08	8	.28	1.9	0.0	.18
	South	$\bar{X}$	1.2	23.2	1.3	5.2	4.3	.48
		S.D.	.27	4.8	.70	4.5	0.0	.20
		C.I.(±)	.25	4.5	.66	4.2	0.0	.19

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/24/91	North	$\bar{X}$	1.2	26.6	2.4	3.2	4.3	.32
		S.D.	.3	11.5	1.8	0.0	0.0	.06
		C.I.(±)	.3	11	1.7	0.0	0.0	.06
	Central	$\bar{X}$	1.0	33.9	3.2	3.2	4.3	.33
		S.D.	.08	17.8	2.3	0.0	0.0	.08
		C.I.(±)	.1	17	2.2	0.0	0.0	.08
	South	$\bar{X}$	1.1	46.7	2.0	3.2	4.3	.30
		S.D.	.3	32.4	.70	0.0	0.9	.05
		C.I.(±)	.3	31	.70	0.0	0.0	.05

Table 4 continued

METAL SUMMARY ug/g DRY WEIGHT
FLATHEAD CATFISH

Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
6/26/92	North	$\bar{X}$	1.4	24.9	1.7	3.2	4.5	.43
		S.D.	.44	5.4	1.0	0.0	.4	.13
		C.I.(±)	.4	5.1	1.0	0.0	.3	.12
	Central	$\bar{X}$	1.3	27.3	3.3	3.2	4.4	.47
		S.D.	.20	7.3	2.5	0.0	.1	.32
		C.I.(±)	.19	6.9	2.4	0.0	.1	.30
	South	$\bar{X}$	1.3	30.0	.92	3.2	4.7	.45
		S.D.	.40	20.0	.4	0.0	.4	.17
		C.I.(±)	.38	18.8	.3	0.0	.4	.16

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/12/91	North	$\bar{X}$	1.1	21.7	1.1	4.8	4.3	.38
		S.D.	.2	5.1	.4	3.5	0.0	.19
		C.I.(±)	.2	.5	.3	3.3	0.0	.18
	Central	$\bar{X}$	1.6	19.2	1.1	8.2	5.4	.52
		S.D.	.14	1.9	.1	10.2	1.5	.23
		C.I.(±)	.13	1.8	.1	9.6	1.4	.22
	South	$\bar{X}$	1.0	19.8	1.2	3.8	4.9	.28
		S.D.	.3	3.1	.4	1.3	1.3	.10
		C.I.(±)	.2	2.9	.4	1.2	1.2	.09

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/24/91	North	$\bar{X}$	1.5	25.4	2.1	3.2	4.3	.27
		S.D.	.50	4.8	.8	0.0	.04	.02
		C.I.(±)	.50	4.5	.8	0.0	.04	.20
	Central	$\bar{X}$	1.3	20.8	1.2	4.0	4.3	.33
		S.D.	.40	4.3	.3	1.7	.04	.08
		C.I.(±)	.40	4.0	.3	1.6	.04	.08
	South	$\bar{X}$	1.2	22.4	1.0	3.2	4.3	.28
		S.D.	.14	6.6	.1	0.0	0.0	.03
		C.I.(±)	.10	6.0	.1	0.0	0.0	.03

Table 5

METAL SUMMARY ug/g DRY WEIGHT
PERIPHYTON

Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
6/26/92	North	$\bar{X}$	24	107	21	55	76	1.05
		S.D.	7	56	3	47	64	.71
		C.I.(±)	11	94	5	78	107	1.20
	Central	$\bar{X}$	18	67	19	32	43	.18
		S.D.	7	1.3	1	14	10	.09
		C.I.(±)	12	2.2	1	23	17	.15
	South	$\bar{X}$	18	58	16	30	36	.17
		S.D.	3	8	2	15	9	.09
		C.I.(±)	5	13	3	26	15	.15

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/12/91	North	$\bar{X}$	17.7	78	21	46	96	.73
		S.D.	4.9	29	2.5	23	32	.23
		C.I.(±)	8.2	48	4	38	53	.39
	Central	$\bar{X}$	12	68	17	33	47	.2
		S.D.	1	10	1	2	9	.00
		C.I.(±)	2	17	2	3	15	.00
	South	$\bar{X}$	10.7	64	14	36	41	.23
		S.D.	3.5	8	5	10	3	.15
		C.I.(±)	5.9	13	8	17	5	.25

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/24/91	North	$\bar{X}$	14	83	22	44	83	.59
		S.D.	6	24	6	22	39	.36
		C.I.(±)	10	40	10	36	65	.60
	Central	$\bar{X}$	11	66	17	28	48	.22
		S.D.	1	7	1.5	6	9	.10
		C.I.(±)	1	12	2.5	10	15	.17
	South	$\bar{X}$	6	45	13	18	47	.44
		S.D.	1	5	3	7	18	.25
		C.I.(±)	1	8	4.5	12	30	.42

Table 6

METAL SUMMARY ug/g DRY WEIGHT
INVERTEBRATES

Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
6/26/92	North	$\bar{X}$	15	104	61	50	78	.84
		S.D.	9	36	24	37	46	.51
		C.I.(±)	15	60	40	62	77	.85
	Central	$\bar{X}$	30	168	30	104	143	1.9
		S.D.	13	60	7	46	62	1.2
		C.I.(±)	22	60	12	77	104	2.0
	South	$\bar{X}$	70	392	44	246	343	4.3
		S.D.	49	381	13	171	228	.78
		C.I.(±)	82	639	22	287	382	1.30

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/12/91	North	$\bar{X}$	4	114	31	11	14	.12
		S.D.	0.6	5	16	4	2.5	.07
		C.I.(±)	1	8	27	7	4	.11
	Central	$\bar{X}$	6	100	34	24	25	.40
		S.D.	3	3	6	5	6	.22
		C.I.(±)	5	5	10	8	10	.37
	South	$\bar{X}$	6	111	41	51	27	.18
		S.D.	1	29	17	49	10	.07
		C.I.(±)	2	48	28	82	16	.12

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/24/91	North	$\bar{X}$	4	227	19	14	28	.56
		S.D.	1	174	3	4	4	.51
		C.I.(±)	2	291	5	7	7	.85
	Central	$\bar{X}$	5	114	18	10	26	.14
		S.D.	1	16	2	4	9	.05
		C.I.(±)	2	26	3	7	15	.08
	South	$\bar{X}$	4	286	20	11	14	.10
		S.D.	1	208	3	5	2.5	.01
		C.I.(±)	1.5	348	5	8	4	.01

Table 7

METAL SUMMARY ug/g DRY WEIGHT
ZOOPLANKTON

Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
6/26/92	North	$\bar{X}$	273	593	71	390	524	7.13
		S.D.	361	442	26	274	376	7.7
	Central	$\bar{X}$	209	1139	71	732	1005	7.6
		S.D.	136	739	41	388	653	4.7
	South	$\bar{X}$	133	588	93	377	539	5.7
		S.D.	87	250	21	161	191	2.5

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/12/91	North	$\bar{X}$	11	104	72	41	86	.6
		S.D.	1.6	8	8	3	14	.08
	Central	$\bar{X}$	11	110	61	68	97	1.4
		S.D.	2.2	30	13	3	25	.7
	South	$\bar{X}$	16	119	70	84	134	.84
		S.D.	2.4	35	5	41	29	.10

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/24/91	North	$\bar{X}$	21	110	72	87	86	1.1
		S.D.	8	11	8	49	21	.4
	Central	$\bar{X}$	22	115	64	47	68	.73
		S.D.	14	33	7	9	9	.12
	South	$\bar{X}$	16	109	66	55	77	.89
		S.D.	.5	10	1	2	3	.13

Table 8

METAL SUMMARY ug/g DRY WEIGHT
SEDIMENT

Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
6/26/92	North	$\bar{X}$	3.2	15.0	3.4	8.6	16	.11
		S.D.	1.3	4.4	1.0	0.6	2	.03
		C.I.(±)	2.2	7.0	1.7	1.0	3	.05
	Central	$\bar{X}$	9.2	51.1	14.7	17.0	28	.10
		S.D.	0.6	8.4	2.9	4.3	3	.01
		C.I.(±)	1.0	14.1	4.9	7.2	5	.02
	South	$\bar{X}$	11.9	51.8	15.7	18.5	30	.19
		S.D.	2.7	8.2	1.8	3.5	4	.16
		C.I.(±)	4.5	13.7	3.0	5.9	7	.27

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/12/91	North	$\bar{X}$	13	55.7	12.1	17.0	34	.12
		S.D.	1.0	22.7	0.8	.70	14	.04
		C.I.(±)	1.7	37.0	1.3	1.2	23	.06
	Central	$\bar{X}$	10	40.2	9.8	18	27	.09
		S.D.	1.0	3.7	1.4	5	5	.00
		C.I.(±)	1.7	6.0	2.3	8	8	.00
	South	$\bar{X}$	11	41.4	10.1	16	23	.29
		S.D.	4.0	8.0	3.0	4	3	.28
		C.I.(±)	8.0	13.0	5.0	7	5	.47

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Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
7/24/91	North	$\bar{X}$	9.0	41.0	11.0	11.0	29	.09
		S.D.	.5	1.1	1.7	2.5	1.2	0.00
		C.I.(±)	.8	1.8	2.8	4.2	2	0.00
	Central	$\bar{X}$	9.0	39.9	8.5	16.0	26	.09
		S.D.	2.8	6.7	1.9	4.5	2.5	0.00
		C.I.(±)	4.7	11.2	3.2	7 5	4	0.00
	South	$\bar{X}$	12.0	52.0	12.5	15.0	32	.09
		S.D.	2.8	4.6	1.5	1.4	1.9	0.00
		C.I.(±)	4.7	7.7	2.5	2.3	3	0.00

Table 9

METAL SUMMARY ug/g
WATER

Date	Site		Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
6/26/92	North	$\bar{X}$	20	105	45.8	61	78	1.4
	Central	$\bar{X}$	12	65	8.5	48	68	.92
	South	$\bar{X}$	12	121	11.2	48	60	2.5
********								
7/12/91	North	$\bar{X}$	12	65	9.3	44	58	.63
	Central	$\bar{X}$	12	65	11.0	44	58	.65
	South	$\bar{X}$	12	432	10.2	45	58	.63
********								
7/24/91	North	$\bar{X}$	12	17	10.2	42	58	.63
	Central	$\bar{X}$	12	29	23.4	62	78	.63
	South	$\bar{X}$	12	37	12.3	44	58	.63
		S.D.						

Table 10

SUMMARY OF STATISTICAL ANALYSIS* FOR DIFFERENCES BETWEEN SITES

Community	Date	Site	Metal	Statistical Difference
Buffalo	6/26/91	Central	Hg	Central > North and South
Buffalo	7/12/91	South	Hg	South < North and Central
Flathead Catfish	7/24/91	North	Cu	North > Central and South
Carp	6/26/91	North	Cu	North < Central and South
Periphyton	8/2/91	South	Cr(Tot.)	South < Central and South
Sediment	6/26/91	North	Cr(Tot.)	North < Central and South
			Zn	North < Central and South
			Cu	North < Central and South
			Pb	North < Central and South
			Ni	North < Central and South

*Site value lies outside the 95% confidence interval and confirmed with t-test at .05 level of confidence

Table 11

BIOCONCENTRATION FACTORS

Community	Site	Cr(Tot.)	Zn	Cu	Pb	Ni	Hg
Fish	$\bar{X}$	95	504	140	82	74	596
	S.D.	17	423	80	33	15	268
Periphyton	$\bar{X}$	1128	1477	1471	744	915	537
	S.D.	319	1322	618	218	358	345
Invertebrates	$\bar{X}$	1278	3930	2610	1205	1237	752
	S.D.	1738	3917	1148	1529	1676	657
Zooplankton	$\bar{X}$	5581	4997	5946	4213	4403	2709
	S.D.	6180	4825	2280	4576	4532	2285

Table 12

WATER -- HARDNESS, ALKALINITY, pH
RUN 1

Sample	Hardness	Alkalinity	pH	Temp.
North 1	290	169	7.6	27.5
North 2	290	171		
Mean	290	170		
Central 1	274	172	7.6	27
central 2	271	173		
Mean	272.5	172.5		
South 1	243	158	7.7	27
South 2	244	160		
Mean	243.5	159		

WATER -- HARDNESS, ALKALINITY, pH
RUN 2

Sample	Hardness	Alkalinity	pH	Temp.
NORTH 1	296	169	7.7	25
2	295	169		
Mean	295.5	169		
CENTRAL 1	261	157	7.6	25
2	263	156		
Mean	262	156.5		
SOUTH 1	253	164	7.5	25
2	255	163		
Mean	254	163.5		

Table 12 continued

WATER -- HARDNESS, ALKALINITY, pH
RUN 3

Sample		Hardness	Alkalinity	pH	Temp.
NORTH	1	292	182	7.6	25
	2	291	184		
Mean		291.5	183		
CENTRAL	1	243	147	7.9	25.8
	2	243	144		
Mean		243	146		
SOUTH	1	238	159	8.2	26
	2	235	158		
Mean		236	158.5		

Table 13

PERIPHYTON MEASUREMENTS
BIOMASS, CHLOROPHYLL, PRODUCTIVITY
RUN 1

SAMPLE	BIOMASS g/m2	CHLOROPHYLL mg/m2	PRODUCTIVITY mg/m2/day
North 1	0.63	4.8	31
North 2	0.44	3.1	22
North 3	3.5	14.4	176
Mean	1.52	7.43	76.33
Std. Dev.	1.4	5.0	70.6
Central 1	13.2	30.5	628
Central 2	112	36.4	5332
Central 3	1.3	11.9	63
Mean	42.17	26.27	2007.67
Std. Dev.	49.6	10.4	2361.9
South 1	35.6	76.8	1693
South 2	22.3	32.8	1063
South 3	1.4	29.3	66
Mean	19.77	46.30	940.67
Std. Dev.	14.1	21.6	669.8

BIOMASS = g/m^2

CHLOROPHYLL = mg CHL. A/m^2

PRODUCTIVITY = mg ash-free weight per slide/ tA

where t = number of days
A = total area of slides, m^2

Table 13 continued

PERIPHYTON MEASUREMENTS
BIOMASS, CHLOROPHYLL, PRODUCTIVITY
RUN 2

SAMPLE	BIOMASS g/m2	CHLOROPHYLL mg/m2	PRODUCTIVITY mg/m2/day
North 1	1.1	15.3	61
North 2	0.45	2.2	26
North 3	1.1	2	62
Mean	0.88	6.50	49.67
Std. Dev.	0.3	6.2	16.7
Central 1	2.9	42	181
Central 2	3.1	38.5	194
Central 3	6	46.8	378
Mean	4.00	42.43	251.00
Std. Dev.	1.4	3.4	90.0
South 1	1.1	10.2	67
South 2	3.1	22.2	182
South 3	2.1	21.1	123
Mean	2.10	17.83	124.00
Std. Dev.	0.8	5.4	47.0

Table 13 continued

PERIPHYTON MEASUREMENTS
BIOMASS, CHLOROPHYLL, PRODUCTIVITY
RUN 3

SAMPLE	BIOMASS g/m2	CHLOROPHYLL mg/m2	PRODUCTIVITY mg/day
North 1	1.7	4.5	85
North 2	0.7	3.2	34
North 3	0.8	3.9	42
Mean	1.07	3.87	53.67
Std. Dev.	0.4	0.5	22.4
Central 1	2.4	16.3	108
Central 2	3.3	35.5	151
Central 3	3.4	40.2	155
Mean	3.03	30.67	138.00
Std. Dev.	0.45	10.34	21.28
South 1	2.7	32.4	136
South 2	2.1	23	102
South 3	3.7	32.5	183
Mean	2.83	29.30	140.33
Std. Dev.	0.66	4.45	33.21

BIOMASS = g/m^2

CHLOROPHYLL = mg CHL. A/m^2

PRODUCTIVITY = mg ash-free weight per slide/ tA

where t = number of days
A = total area of slides, m^2

Table 14

SEDIMENT BIOMASS
RUN 1

SAMPLE	BIOMASS mg	ORGANIC COMP. % Organic
North 1	14.5	0.6
North 2	19.4	0.5
North 3	17.8	0.5
Mean	17.23	0.53
Std. Dev.	2	0.05
Central 1	86.3	1.8
Central 2	85.1	4
Central 3	78.2	6
Mean	83.2	3.9
Std. Dev.	3.6	1.7
South 1	106.7	3
South 2	79.9	4
South 3	103.5	3
Mean	96.7	3.3
Std. Dev.	12	0.5

Table 14 continued SEDIMENT BIOMASS
RUN 2

SAMPLE	BIOMASS mg	ORGANIC COMP. % Organic
North 1	50.8	1.8
North 2	42.5	1.3
North 3	56.8	1.2
Mean	50.03	1.43
Std. Dev.	5.9	0.3
Central 1	21.6	0.6
Central 2	30.8	0.7
Central 3	27.7	1.1
Mean	26.7	0.8
Std. Dev.	3.8	0.2
South 1	NS	NS
South 2	25.3	0.8
South 3	19.2	0.4
Mean	22.25	0.6
Std. Dev.	3.05	0.2

NS = NO SAMPLE

Table 14 continued SEDIMENT BIOMASS
RUN 3

SAMPLE	BIOMASS mg	ORGANIC COMP. % Organic
North 1	68.2	1.2
North 2	52.5	1
North 3	39.9	1
Mean	53.5	1.1
Std. Dev.	11.6	0.1
Central 1	43.7	1.9
Central 2	39.2	0.7
Central 3	25.7	0.9
Mean	36.2	1.2
Std. Dev.	7.6	0.5
South 1	74.1	2
South 2	110.1	3
South 3	153.8	3
Mean	112.7	2.7
Std. Dev.	32.6	0.5

Table 15

METAL SUMMARY
Fish Liver (ppm)

SAMPLE		Cr (Total)	Zn	Cu	Pb	Ni	Hg
CATFISH	1	1.4	219	1.4	<3.2	<4.5	ND
	2	1.02	165	24	4.9	<4.3	0.26
	3	1.02	118	6	4.2	<5.8	0.29
	4	<.9	68	2.5	<3.2	<4.3	0.22
	5	1.5	181	46	<2.8	<3.9	0.27
Mean		1.45	150.2	15.98	4.55		0.26
BUFFALO	1	<.9	414	163	<3.2	13.5	0.08
	2	<.9	221	217	<3.2	<5.8	0.2
	3	<.9	176	20	<3.2	<4.3	0.86
	4	<.9	222	158	<3.2	<4.3	0.3
	5	<1.1	196	134	<3.7	<5.1	0.4
Mean			245.8	138.4		13.5	0.37
CARP	1	1.4	1895	3.3	<3.2	<5.1	0.38
	2	<1.0	244	59	4.6	<4.3	0.32
	3	<.9	1030	116	10.1	<4.3	0.05
	4	<.9	481	59	<3.2	<4.3	0.14
	5	<1.9	4560	47	<3.3	9	1.2
Mean		1.4	1642	56.86	6.03	9	0.42

< = DETECTION LIMIT VALUE

Table 15 continued

METAL SUMMARY
Fish Gills (ppm)

SAMPLE		Cr (Total)	Zn	Cu	Pb	Ni	Hg
CATFISH	1	<.9	83	1.5	<3.2	5.9	0.38
	2	<.9	77	9.1	<3.2	<4.3	0.78
Mean			80	5.3		5.9	0.58
BUFFALO	1	1.8	94	6.2	16.7	16.4	0.16
	2	2.9	75	3.4	13.4	9	0.11
	3	2	101	6.9	14.6	14.6	0.18
	4	2.2	125	16.9	14.6	14.2	0.26
	5	1.9	112	5.9	11.4	10.3	0.24
	6	2.6	91	NS	21.9	13.8	0.15
Mean		2.23	99.67	7.86	15.43	13.05	0.18
CARP	1	2.4	1455	2.9	11.6	10.4	0.23
	2	1.8	1870	2.5	13.2	12.6	0.21
	3	2.2	1791	4.2	11	11.8	0.2
	4	2.6	2297	9.9	11.3	11.8	0.22
	5	1.9	1962	4.1	11.2	12.4	0.21
Mean		2.18	1875	4.72	11.66	11.80	0.21

< = DETECTION LIMIT VALUE

DISCUSSION

WATER

Mean water concentrations (Table 16) of total chromium, zinc, copper, and nickel were below present chronic Iowa Class B (warm water) standards for those metals. For individual collected samples, the chronic standard for copper (30 ppb) was exceeded by one of North samples on 6/27/91 and one South sample collected on 7/12/91 exceeded both the chronic (450 ppb) and acute (500 ppb) criteria for zinc. All other individual sample values for those metals were below present state standards. Lead concentration in water samples collected during this study did exceed the chronic criteria of 30 ppb for Iowa Class B (WW) streams. No individual water sample exceeded the acute criteria of 200 ppb for this type of designated stream. It should be noted that many of the samples analyzed were at the detection limit for the lead analysis methods used for this study. Actual lead values for these samples may be lower since the detection limit value was used in the calculation of mean values. Mercury concentration in all water samples were ablve the Iowa Class B (WW) chronic standard of .05 ppb but well below the acute standard of 6.5 ppb mercury. A number of water samples analyzed were at the detection limit for the cold vapor analysis method and the inclusion of these values would result in arbitrarily higher mean values. In addition, a separate digestion for mercury samples as recommended by the E.P.A. was not used. For these reasons the higher water mercury levels may be a reflection of shortcomings with the analysis procedure. Some of the observed values were similar to STORET data values from the Missouri River (Table 16) but were above values reported for the Des Moines and Raccoon Rivers in Iowa.

Levels of lead and zinc have declined considerably from levels observed downstream from Sioux City during the years 1984 and 1985 (Tondreau, 1984-86). Mean zinc and lead values observed in 1984-85 studies by Morningside College (Table 16) were significantly higher (t-test, .05 level of confidence) than zinc and lead values measured during the present study. Water metal concentrations observed during this study are comparable to values reported for the Missouri River by other researchers and more recently by Morningside College in 1987 (Table 16). Copper and nickel values reported from the Mississippi River at Clinton, Iowa (U.S.G.S. 1987) were similar to Missouri River values found at that time while chromium, lead and zinc concentrations were lower (below detection limits) for the Mississippi River samples. Metals concentrations in the lower Mississippi River for the years 1978 to 1983 found mean copper (100 ppb) and chromium (20 ppb) values which were higher than Missouri River values and lead values (300 ppb) which were similar (Newchurch and Kahwa, 1984). Mean mercury concentrations in the lower Mississippi River were higher (1.0 ppb) than values reported from the upper Mississippi River and Missouri Rivers. This difference would be expected due to increased amounts of industrial contaminants which drain into the lower Mississippi River system.

Table 16

MEAN WATER METAL CONCENTRATIONS (ppb) REPORTED IN PREVIOUS RESEARCH

	Cr	Zn	Cu	Pb	Ni	Hg
Missouri R[1]	9	66	17	21	12	0.4
Missouri R[2]	13	74	7	30	--	--
Missouri R[4]	13	2570	22	240	--	--
Missouri R[5]	13	104	16	48	64	0.96
Mississippi R[3]	< 5	<50	20	<50	10	.05

[1]STORET data Missouri River above Omaha, NE 1974-78
[2]Morningside College 1987
[3]USGS 1986
[4]Morningside College 1984-85
[5]Morningside College Present Study

Water hardness, alkalinity and pH values were within expected levels representative of midwestern alkaline buffered surface waters. Hardness values were in the 240-290 mg/l range. Alkalinity values of between 150-180 mg/l were common. The range of pH values of 7.5-8.2 is within the recommended range of 6.5-9.0 for Iowa Class B surface waters.

SEDIMENT

Sediment metal concentrations in samples collected from the main-channel border habitat were higher than water metal concentrations observed for the same sample sites (Table 8). Concentrations of chromium, copper, lead, nickel and zinc were typically in the 10-50 ppm range with chromium the lowest and zinc present in the greatest concentrations. Mercury was detected in the sediment samples but to a much lesser degree of concentration than the other metals. Mercury concentrations were below detection limits for 15 of the 45 samples collected. Sediment deposition of mercury in Missouri River sediment below Sioux City does not appear to be significant.

Site to site differences in sediment metal concentrations occurred only for the north samples collected during Run 1. Concentrations of chromium, zinc, copper, lead and nickel were significantly lower (t-test, .05 level) at the north site on this date when compared to central and south sites. However for sample Runs 2 and 3 no between site differences were observed.

Sediment metal concentrations were similar for this study to values found for previous Missouri River research, Table 16. Lead levels in the sediment appear to be higher in the Sioux City area when compared to downstream. Nickel concentrations were also slightly higher, however these differences may only indicate fluctuations in background sediment concentrations since upstream-downstream concentrations at Sioux City did not vary consistently.

According to the study by the U. S. Environmental Protection Agency (Crisp, 1984), the Missouri River sediment metal concentrations found during that study are not considered to be of any significant environmental concern.

The concentrations which are similar to levels found during that study, probably reflect normal background concentrations that result from the natural processes which contribute to a river system. Sedimentation of suspended soil particles is thought to be one of the major sources of heavy metals to the sediment. Bonding to organic matter and soil particles (especially claey types) and co-precipitation with iron, aluminum and manganese hydrous oxides are mechanisms discussed by Coggins, et al. (1979). These oxides tend to have a high sorbtive capacity and Crisp found a statistical correlation between heavy metal concentrations and concentrations of iron and aluminum. Previous research by Morningside College (Tondreau, 1984-86) and U.S.G.S. data collected at Sioux City, (Melcher, 1986) have indicated the presence of iron, aluminum and manganese at levels which would tend to support this mechanism for metal precipitation. Bonding to organize material is a less likely alternative due to the extremely low organic content of the sediment. (Table 14).

This range of values (0.5 to 3%) for sediment organic composition is nearly identical to the range of values reported by Crisp for the Missouri River in the Omaha vicinity. It should be noted that the sediment samples for the study by Crisp were collected from the pockets below the wingdikes while the sediment samples for this study were collected from the main-channel border habitat. The composition of sediments from the two habitats appear to be very similar.

Table 17

SEDIMENT METAL COMPARISONS (ppm)

	Cr	Zn	Cu	Pb	Ni	Hg
Missouri R[1]	24	72	19	5	23	--
Missouri R[2]	12	40	9	9	14	--
Missouri R[3]	11	56	14	13	--	--
Missouri R[4]	10	43	11	15	27	.06

[1] STORET data Missouri River above Omaha, NE 1974-78
[2] Missouri R., Omaha, NE, Crisp, 1984
[3] Missouri R., Sioux City, Morningside College, 1987
[4] Missouri R., present study, 1991

PERIPHYTON

Periphyton samples were collected from artificial substrates placed within the main-channel border habitat and designed to float upright at a depth just below the water surface. The normal two-week colonization period was extended to three weeks due to unusually slow growth of periphyton. Longer colonization periods are not feasible due to sedimentation on the substrate which interferes with growth. A major factor contributing to the slow growth involved unusual hydrologic conditions encountered during the 1991 summer period. Varying releases from the upper reservoirs by the Corps of Engineers results in constantly changing river elevations which had a direct impact on the artificial substrates. Although designed to adjust to changes in elevation, the substrates could not keep up with the almost daily fluctuations.

The reason for the unusual releases was to prohibit two endangered bird species, the Piping Plover and the Least Tern, from nesting too close to the river's edge. Unfortunately, this had a negative impact on uniform colonization of the artificial substrates. Growth on the natural rock substrate, which normally exhibits heavy periphytic growth, was also visibly impacted by these conditions.

Periphyton growth on the plexiglass slides was dominated by golden brown algae (diatoms) with Navicula and Nitzchia genera the most abundant and smaller numbers of Fragilaria, Cocconeis, and Cyclotella also present. Green algae genera, which are usually more abundant but slower to colonize, were limited to small numbers of filamentous green algae such as Cladophora and Ulothrix.

Metal concentrations in the periphyton samples (Table 5) did demonstrate a certain amount of uniformity despite the less than ideal growing conditions just discussed. Noting the variability which occurs between each of the three substrate samples, few statistically significant differences between site metal concentrations were apparent (Table 10). Zinc (60 ppm), nickel (50 ppm), lead (31 ppm), copper (18 ppm), chromium (14 ppm), and mercury (0.4 ppm) were mean metal concentrations observed for the periphyton samples. Values for zinc, copper, and chromium were similar to values of Zn (83 ppn), pb 41 (ppm), Cu (23 ppm) and Cr (14 ppm) found during the 1987 Missouri River study by Morningside College. Mercury and nickel were not tested for in that study. Typical metal concentrations for periphyton in the parts per million range, when compared to water metal concentrations in the parts per billion range, demonstrate the apparent ability of the periphyton community to bioconcentrate metals from the surrounding water column.

No literature information was available on metal uptake by periphyton from the Missouri River. Very little data for other aquatic systems is available. A majority of previous research dealt with metal uptake by individual algae species within laboratory environments to determine levels of toxicity, effects on metabolism and bioconcentration factors. Wium-Anderson (1974) found that chromium can affect the growth and photosynthesis of diatoms in a manner similar to copper and mercury, yet is more than one hundred times less toxic than those two metals. Prasad and Prasad (1981) found that lead can be toxic to some freshwater green algae at concentrations above 5 ppm while nickel was not toxic between concentrations of 0.1 to 10.0 ppm. These are concentrations well above those found in the present study. Baker, et al. (1983) found that mercury toxicity is much more pronounced at a water pH of 5 than of pH 7. Like most metals, mercury is more soluble under acidic conditions and can reach greater concentrations within the water column. Water pH values during this study were consistently above pH 7. Wong, et al. (1982) suggest the possibility of synergistic effects of a combination of metals which included Cr, Cu, Pb, Ni, Zn and Hg. The primary productivity of Scenedesmus and Chlorella and the diatom Navicula was reduced by a combination of these metals present in concentrations below their individual toxic levels. Levels of copper, lead and zinc found in Missouri River periphyton would be considered typical of non-polluted rivers according to studies by Foster (1982). Typical values for algal metal contnet according to her study would be <100 ppm copper, <1000 ppm zinc, and <50 ppm lead.

Periphyton biomass, chlorophyll and productivity (amount of biomass growth per day) was measured at all sites (Table 12). As previously noted, heavy metals have been shown to significantly reduce the growth and productivity of periphytic algae according to studies by Wium-Anderson (1974) and Wong, et al. (1982).

The adverse growing conditions already discussed contributed to the variability observed both within and between sample sites. Most north values for periphyton biomass, chlorophyll and productivity were significantly (t-test .05 level) below values determined at the remaining sites. Since the data found no significant differences in metal concentrations at this site, the reason for the lower productivity may be due to decreased water clarity observed at this site. This north site was located just downstream from the Big Sioux River inflow and the samplers were exposed to tributary waters with higher turbidity which reduced light availability at this location.

MACROINVERTEBRATES

Macroinvertebrates were collected from rock basket artificial substrates (Hilsenhoff type) placed within the main-channel border. Colonization time was approximately three weeks. The macroinvertebrates in this habitat are represented by a diverse community dominated by Trichoptera (caddisflies), Diptera (flies and midges), Ephemeroptera (mayflies), Turbellaria (planaria), Hydrozoa (hydra) and Crustaceans. Among the most abundant organisms were the caddisflies of the Hydrophsychidae and Rhyacophilidae families; the mayflies Caenis, Isonychia and Stenonema; the Dipteran Chironomidae and the Crustacean Asellus.

Metal concentrations in the macroinvertebrates were highest for zinc and lowest for chromium and mercury. Concentrations of zinc, copper, lead and chromium were similar to levels found in macroinvertebrates collected above and below Sioux City in 1987. Mercury concentrations were also low but concentrations were above levels present in the water. An extremely large mercury value found in the South 1, Run 1 macroinvertebrate sample should be discounted because of the small sample size collected from that sample. Non-uniformally small sample amounts give results which are highly unreliable due to the error involved in working with such a small sample size. No statistically significant differences in mean concentrations between sites was observed. High variablility in values for sample replicates, resulted in mean values with large standard deviations.

Much of the previous research on metals concentration in invertebrates suggests a high level of metal tolerance by members of this community. Krantzberg and Stokes (1989) found that Chironomids have the ability to bioregulate zinc, copper and nickel but not lead. However Spehar, et al. (1978) found that caddisflies can withstand high water concentrations of lead (565 ppb) without significant decreases in survival.

ZOOPLANKTON

Zooplankton samples were collected from the main-channel border using a .5M diameter, 178 mesh plankton net (Wildco) fitted with a 4 liter collecting bucket. Dominant zooplankters include the microcrustacean Calanoid and Cyclopoid adults, copepoditos and nauplii; the cladocerans Bosmina, Daphnia and Diaphanosoma; the rotifers Keratella and Brachionus and the protozoans Ceratium, Difflugia and Dinobryon. Zooplankton densities in the Missouri River tend to decline during the summer period which necessitated the filtering of larger quantities of water to obtain a suitable sample amount. A sedimentation and centrification technique was used to separate zooplankton from collected debris. The mesh size of the collecting net was designed to allow smaller phytoplankton to pass through. With the increase in time of the net suspension, inner surface clogging may result in some phytoplankton being inadvertently collected. The procedure to separate and obtain zooplankton from the field samples was refined and improved following the first sample run and as a result the metal concentrations measured for Runs 2 and 3 may more accurately represent actual zooplankton metal content.

Zooplankton metal concentrations (Table 7) were highest for zinc and lowest for chromium and mercury. A large variability in metal concentrations was observed for zooplankton. The lack of adequate sample sizes for digestion contributed to the non-uniformity. This factor was evident for the samples north 3, Run 1 and north 1, Run 3 whose sample sizes were very small. Zinc and copper exhibited the most uniform concentrations for a majority of sample sites especially for sample Runs 1 and 2. No statistical differences in concentrations between sites was observed due to the variability between the multiple samples at each site. The lotic nature of the zooplankton community would also reduce the likelihood of any site-to-site differences in metal concentrations.

Much of the previous research on metal concentrations in zooplankton has been devoted to toxicity studies of selected heavy metals to individual zooplankton genera. Chapman, et al. (1980) found that low water hardness increased the toxicity of chromium, nickel, lead, zinc and cadmium metals to Daphnia magna. Hardness values measured during this study would suggest minimal toxological effects according to this study. Soft, acidic waters which have high concentrations of humic acids were shown to increase the toxicity of copper to Daphnia, Giesy, et al. (1983). These characteristics are not typical of Missouri River waters.

FISH

Metal concentrations were determined in muscle tissue collected at three sites from five each of carp, buffalo and flathead catfish (Table 4). Concentrations are reported in ppm (ug/g) dry weight. Metal concentrations were highest for zinc and lowest for mercury. Metal concentrations for each species varied significantly between sample locations on only a few occasions (Table 10). No difference was observed for each species between sample dates for any of the metals. The lack of any upstream/downstream differences or for each sample date was a trend also observed for fish of these species collected during the 1987 study. Nickel and mercury were not measured in the 1987 study. Trends in metal concentrations between different species were difficult to observe due to the variability in measured concentrations between the five individual fish samples of each species. Although not statistically significant, the following trends were observed. Chromium, copper, nickel and lead concentrations appear similar for all species. Zinc concentrations were highest in carp. Highest mercury concentrations were found in buffalo and to a lesser extent in carp species. Mercury concentrations were consistently lower in the flathead catfish. Bigmouth buffalo Ictiobus cyprinellus were occasionally substituted for smallmouth buffalo Ictiobus bubalus in the samples due to the scarcity of smallmouth buffalo in the collections. Of forty-five total buffalo collected, fourteen were bigmouth buffalo. Although the feeding habitats differ between the bigmouth buffalo (vegetation) and smallmouth buffalo (invertebrates) no distinct differences in tissue metal concentrations were observed. Fish metal concentrations from this study were compared to data obtained from STORET for fish samples analyzed from the Missouri River. A limited amount of data was available and only carp were tested with any frequency. No data on flathead catfish or buffalo species was available. Most of the tissue data was based on wet weight analysis while samples from the present study were analyzed on a dry weight basis. A wet weight/dry weight conversion factor was determined comparing sample weights before and after drying to remove water. Based on these measurements reducing fish metal concentration measured in this study by a factor of four would make them comparable to wet weight determinations. Estimated mean wet weight mercury concentrations converted from dry weight concentrations are as follows: Buffalo, .14 ppm; Carp, .12 ppm and Flathead Catfish, .10 ppm. A review of metal data by Phillips and Russo (1978) found that water composes 75-80% of typical wet weight samples. STORET data on nineteen carp samples was converted from wet to dry weight concentrations and compared to data from the present study. Copper and chromium concentrations in carp were similar for both. Nickel concentrations in the present study were higher by a factor of one and mercury higher by a factor of five. Zinc concentrations were lower by a factor of six in this study. Mercury concentrations in fish from this study remain well below the U. S. Food and Drug Administration action level of 1.0 ppm wet weight for food intended for human consumption. These concentrations are similar to statewide averages for Channel Catfish reported in the 1990 Regional Fish tissue monitoring program for the State of Iowa. Concentrations of mercury, copper and zinc were similar to levels found by Blevins and Pancorbo (1985) in a study on the Holston and Nolichucky Rivers in eastern Tennessee.

FISH LIVER AND GILLS

Metal concentrations in gill tissue and liver tissue were determined in a small number of carp, buffalo and catfish (Table 4). In most cases, five liver and five gill samples from each species were analyzed. Fish are known to accumulate metals in these tissues due to the regulatory and excretory roles these organs have in the physiological mechanisms of fish. Highest accumulations were found for zinc and copper which is consistent with findings of other research on metal accumulation (Phillips and Russo, 1978). Lead and nickel appeared to be concentrated to a lesser extent in gill tissue but not liver tissue. Mercury concentrations were low for both organs and were comparable to levels found in the muscle tissue. Zinc accumulation in gill tissue was significantly higher in carp (t-test, .05 level) than for buffalo or flathead catfish. Carp also exhibited the highest concentrations of zinc in liver tissue. Copper concentrations in gill and liver tissue were highest in buffalo. Catfish generally had the lowest levels in both liver and gill tissue for any of the metals tested for. The exception to this trend was for mercury which exhibited no significant variability between fish species.

BIOACCUMULATION

Biocentration factors (BCFs) were calculated by dividing the metal concentration in each community sample on each sample date for each metal (ex: copper, periphyton, north, 6/22/91) by the measured water metal concentration. Individual BCF values were pooled to obtain a mean value for each community. The mean biocentration values and standard deviations are listed in Table 11.

Fish BCFs were lowest of all aquatic groups for all metals except mercury. This result is not unexpected due to the ability of fish to bioregulate most other heavy metals. These metals therefore do not accumulate in the edible portions of the fish and do not represent a danger for human consumption (Phillips and Russo, 1979). The bioconcentration factor for mercury was higher than for any of the remaining metals. Unlike most other metals mercury has the ability to become bound in ionic form to the active sites of protein molecules within the living tissue of the fish and thereby resist excretion (Hawker, 1990). Hawker states that with the exception of mercury, the accumulation of metals does not increase in the higher trophic levels and therefore true bioconcentration of most metals does not occur in most aquatic food chains. Most aquatic organisms do accumulate metals in concentrations well above ambient water concentrations. These concentrations are lowest however in the higher order organisms which are subject to use as a human food source so the potential concern from a human health perspective is minimized.

Biocencentration factors for this study were similar to those observed during the 1987 study on the Missouri River. Those mean values are listed in Table 1 of the introduction of this report. Bioconcentration factors for this study are comparable to literature bioconcentration factors reported by Hawker (1990) and Foster (1982) for fish and invertebrate samples. No other literature data was available for the other aquatic communities.

CONCLUSIONS/RECOMMENDATIONS

Water metal concentrations with the exception of lead and mercury were consistently below Iowa chronic criteria for Class B (WW) streams.

Lead and mercury water concentrations did exceed chronic water quality criteria for these metals. Observed concentrations however may reflect the limited sensitivity of the analyses for these metals and additional studies on Missouri River lead and mercury water concentrations are recommended.

No significant site to site differences in water metal concentrations were observed.

Sediment metal concentrations are similar to levels reported by other Missouri River researchers although lead values in this study were slightly higher than reported values.

According to E.P.A. studies, these sediment metal concentrations are not considered to be of significant environmental concern.

Most metal accumulating in Missouri River sediment is a result of inorganic complexing and not due to bonding to organic compounds.

Periphyton studies were hampered by fluctuating river levels which affected colonization on artificial substrates. With low water metal concentrations and the alkaline nature of the water, the toxicity of metals to periphytic algae is believed to be minimal.

Low periphyton biomass, chlorophyll and productivity observed at the north side appears to be related to the location of the artificial substrates rather than any effects due to metal concentrations. Reduced water clarity from the Big Sioux River had an observable impact upon artificial substrates placed at this location.

Invertebrate metal concentrations were similar at all sites and were comparable to results found in macroinvertebrates above and below Sioux City in 1987.

Zooplankton metal analyses were hampered by low summer zooplankton densities and the difficulty in separating zooplankton from other material entrained in the net. Small sample sizes tend to increase the error in the measurement of metal concentrations and it is recommended that additional zooplankton studies be conducted during periods of higher zooplankton densities and lesser amounts of debris.

Metal concentrations in fish muscle tissue do not vary significantly from site to site. Statistical differences in metal concentrations between species were not observed. When converted to wet weight concentrations, samples analyzed on a dry weight basis for this study are comparable to values found by other researchers.

Mercury concentrations in fish tissue were higher than other Missouri River reported values but very similar to values for channel catfish reported in the Iowa Fish Tissue monitoring program.

No mercury tissue concentrations exceeded the action level of 1.0 ppm wet weight as established by the U.S. Food and Drug Administration.

High zinc and copper concentrations were found in fish liver and gill tissue and is a reflection of their regulatory role in the physiological mechanisms of fish. Mercury concentrations in these tissues were similar to levels found in the muscle tissue.

Bioaccumulation of heavy metals was observed in all of the aquatic communities but only mercury was bioconcentrated within the food chain, reaching highest concentrations in the fish muscle tissue.

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Appendix - Table 1

METAL SUMMARY -- RUN 1 6/26/91
SMALLMOUTH BUFFALO AND BIGMOUTH BUFFALO

Sample	Fish Wt. lb., oz.	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	3,0	1.3	15.2	<.2	<3.2	<4.3	<.05
North 2	8,1	<.9	7.5	1.83	<3.2	5.7	0.90
North 3BB	4,4	<.9	26.7	1.10	<3.2	<4.3	0.70
North 4BB	6,1	0.9	14.6	0.73	<3.2	<4.3	0.50
North 5BB	4,5	1.7	13.3	1.07	<3.2	4.6	(2.70)
Mean	5.2	1.1	15.4	0.99	3.2	4.6	0.54
Std. Dev.	1.7	0.4	7.0	0.53	0.0	0.6	0.36
Central 1	5,12	1.1	20.6	1.74	3.5	<4.3	0.80
Central 2	6,6	1.5	17.4	1.54	<3.2	<4.3	0.60
Central 3BB	5,8	1.4	14.0	1.22	<3.2	<4.5	1.00
Central 4BB	7,8	0.9	27.2	(3.06)	<3.2	4.5	1.10
Central 5BB	4,8	(4.7)	20.5	1.21	<3.2	<4.3	0.90
Mean	6.0	1.2	19.9	1.40	3.3	4.4	0.88
Std. Dev.	1.0	0.3	4.9	0.30	0.2	0.11	0.19
South 1	2,12	<0.9	13.6	2.86	<3.2	5.3	0.50
South 2BB	9,8	1.2	8.9	1.22	<3.2	3.9	0.30
South 3BB	5,6	1.2	13.5	1.64	<3.2	4.3	0.50
South 4BB	5,8	1.1	28.2	2.34	<3.2	5.0	0.60
South 5	4,12	1.3	11.6	2.52	<3.2	<4.3	(1.60)
Mean	5.5	1.1	15.2	2.12	3.2	4.6	0.48
Std. Dev.	2.5	1.5	7.5	0.67	0.0	0.6	0.13

** ALL NUMBERS IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

VALUES IN BRACKETS ( ) FAILED THE Q-TEST AT THE 90% CONFIDENCE LEVEL AND ARE REPORTED BUT NOT USED TO CALCULATE MEAN

BB = Bigmouth Buffalo

Table 1 continued METAL SUMMARY -- RUN 1 6/26/91
CARP

Sample	Fish Wt. lb., oz.	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	5,8	1.0	50.0	1.52	<3.2	<4.3	0.63
North 2	3,14	1.7	25.2	1.32	<3.2	<4.3	0.67
North 3	5,8	1.3	23.1	1.39	<3.2	<4.3	1.14
North 4	4,5	<.9	(167.0)	1.42	<3.2	<4.3	0.71
North 5	7,9	2.9	20.6	1.48	<3.2	<4.3	0.46
Mean	5.4	1.6	30.0	1.43	3.2	4.3	0.72
Std. Dev.	1.6	0.8	14.0	0.08	0.0	0.0	0.25
Central 1	3,8	2.4	68.0	2.58	<3.2	4.5	0.32
Central 2	5,0	0.9	25.4	1.97	<3.2	<4.3	0.98
Central 3	3,8	1.2	29.9	1.55	<3.2	<4.3	0.44
Central 4	3,6	<.8	37.6	2.55	<3.2	<4.3	0.53
Central 5	2,12	1.5	19.0	2.14	<3.2	<4.3	LOST
Mean	3.7	1.4	36.0	2.16	3.2	4.3	0.57
Std. Dev.	.9	0.6	19.0	0.43	0.0	0.11	0.29
South 1	3,2	2.0	(131.0)	2.20	<3.2	5.1	0.38
South 2	2,14	1.2	20.9	1.45	<3.2	2.9	0.32
South 3	2,12	0.9	20.1	1.29	<3.2	<3.8	0.56
South 4	2,8	1.2	33.3	2.37	<3.2	<4.3	0.44
South 5	2,9	1.2	36.6	3.45	<3.2	<4.3	0.39
Mean	2.6	1.3	28.0	2.15	3.2	4.1	0.42
Std. Dev.	.5	0.4	9.0	0.86	0.0	0.8	0.09

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VALUES IN BRACKETS ( ) FAILED THE Q-TEST AT THE 90% CONFIDENCE LEVEL AND ARE REPORTED BUT NOT USED TO CALCULATE MEAN

Table 1 continued METAL SUMMARY -- RUN 1 6/26/91
FLATHEAD CATFISH

Sample	Fish Wt. lb., oz.	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	1,8	2.2	20.3	0.74	<3.2	<4.4	0.46
North 2	1,8	1.2	32.0	1.94	<3.2	<4.3	0.35
North 3	2,12	<1.1	20.2	1.16	<3.2	<5.1	0.26
North 4	2,1	1.3	23.0	1.25	<3.2	<4.3	0.47
North 5	1,9	1.3	29.2	3.34	<3.2	<4.3	0.60
Mean	1.94	1.4	24.9	1.69	3.2	4.4	0.43
Std. Dev.	.14	0.4	5.4	1.02	0.0	0.35	0.13
Central 1	5,4	1.1	29.0	1.33	<3.2	<4.5	0.1
Central 2	1,4	1.4	26.0	2.54	<3.2	<4.3	0.43
Central 3	1,6	1.4	19.6	1.65	<3.2	<4.5	0.22
Central 4	1,7	1.1	38.7	7.57	<3.2	4.6	0.70
Central 5	1,3	1.5	23.1	3.71	<3.2	<4.3	0.89
Mean	1.7	1.3	27.3	3.36	3.2	4.4	0.47
Std. Dev.	1.6	0.2	7.3	2.53	0.0	0.13	0.32
South 1	1,4	0.9	44.0	0.30	<3.2	<5.1	<.05
South 2	5,2	1.4	13.0	1.06	<3.2	5.0	0.69
South 3	2,14	1.1	58.0	(3.01)	<3.2	<4.7	0.39
South 4	2,8	1.2	21.2	1.09	3.2	<4.3	0.30
South 5	1,14	2.0	14.2	1.22	<3.2	4.3	0.43
Mean	2.5	1.3	30.0	1.10	3.2	4.7	0.37
Std. Dev.	1.4	0.4	20.0	0.10	0.0	0.38	0.23

** ALL NUMBERS IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

VALUES IN BRACKETS ( ) FAILED THE Q-TEST AT THE 90% CONFIDENCE LEVEL AND ARE REPORTED BUT NOT USED TO CALCULATE MEAN

Table 1 continued METAL SUMMARY -- RUN 2 7/12/91
SMALLMOUTH BUFFALO AND BIGMOUTH BUFFALO

Sample	Fish Wt. lb., oz.	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	3,12	1.6	24.3	2.69	10.0	<5.8	0.62
North 2	3,4	1.0	19.9	1.00	<3.2	<5.8	0.46
North 3	2,12	1.0	19.8	5.38	<3.2	12.7	0.29
North 4	5,0	<.9	18.9	1.03	<3.2	6.4	0.71
North 5	14,6	1.5	13.7	1.97	<3.2	<5.8	1.10
Mean	5.7	1.2	19.3	2.4	4.6	7.3	0.64
Std. Dev.	4.6	0.5	3.8	1.80	3.0	2.7	0.30
Central 1BB	5,4	<.9	17.0	1.33	5.3	6.0	1.10
Central 2BB	3,0	<.9	15.3	<.2	<3.2	<4.3	0.53
Central 3	2,6	2.1	23.0	0.72	4.1	6.7	0.50
Central 4	4,4	1.8	19.9	2.12	3.7	<4.3	1.12
Central 5	7,0	<.9	17.9	3.92	<3.2	<4.3	0.58
Mean	4.5	1.3	18.6	1.66	3.9	5.1	0.77
Std. Dev.	1.6	0.6	2.9	1.45	0.9	1.2	0.32
South 1	2,0	<.9	23.0	1.40	<3.2	<5.8	0.28
South 2	7,8	1.0	9.8	0.87	3.2	6.3	0.38
South 3	5,8	1.0	14.1	0.87	<3.2	<4.3	0.39
South 4BB	4,6	<.9	9.1	0.85	<3.2	<4.3	0.38
South 5BB	10,10	<.9	16.4	2.57	5.0	7.5	0.23
Mean	6.1	0.9	14.5	1.3	3.6	5.6	0.33
Std. Dev.	2.8	0.1	5.6	0.7	0.8	2.1	0.07

** ALL NUMBERS IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

BB - Bigmouth Buffalo

Table 1 continued METAL SUMMARY -- RUN 2 7/12/91

CARP

Sample	Fish Wt. lb., oz.	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	5,12	<.9	29.7	1.18	19.5	<4.3	1.35
North 2	5,14	1.0	16.5	1.83	2.7	<5.8	0.32
North 3	6,6	1.1	21.6	0.87	10.8	<4.3	0.72
North 4	6,14	<.9	41.7	1.40	3.2	<4.3	0.29
North 5	5,6	<.9	37.5	2.28	<3.2	<4.3	1.06
Mean	5.7	0.96	29.4	1.50	7.9	4.6	0.75
Std. Dev.	.5	0.08	10.5	0.50	6.5	0.7	0.46
Central 1	4,4	<.9	33.3	1.45	<3.2	<4.3	0.37
Central 2	4,7	<.9	(111.5)	(3.38)	--	<4.3	0.81
Central 3	4,2	<.9	31.5	0.88	3.6	<4.3	0.48
Central 4	3,4	1.1	16.1	1.30	7.4	<4.3	0.41
Central 5	2,8	<.9	35.5	1.07	<3.2	<4.3	0.32
Mean	3.9	0.94	29.1	1.20	4.4	4.3	0.48
Std. Dev.	.6	0.08	8.8	0.30	2.0	0.0	0.19
South 1	3,10	1.1	23.2	0.65	<3.2	<4.3	0.73
South 2	4,8	1.3	21.2	2.03	<3.2	<4.3	0.49
South 3	7,4	<.9	16.4	0.57	13.2	<4.3	0.16
South 4	4,13	1.0	26.4	1.15	<3.2	<4.3	0.50
South 5	3,11	1.6	28.7	2.05	<3.2	<4.3	0.50
Mean	4.5	1.18	23.2	1.29	5.2	4.3	0.48
Std. Dev.	1.6	0.27	4.8	0.70	5	0.0	0.20

** ALL NUMBERS IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

VALUES IN BRACKETS ( ) FAILED THE Q-TEST AT THE 90% CONFIDENCE LEVEL AND ARE REPORTED BUT NOT USED TO CALCULATE MEAN

Table 1 continued METAL SUMMARY -- RUN 2 7/12/91
FLATHEAD CATFISH

Sample	Fish Wt. lb., oz.	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	3,8	1.1	30.0	1.72	<3.2	<4.3	0.66
North 2	1,13	1.0	20.3	1.10	<3.2	<4.3	0.38
North 3	1,3	1.0	16.6	0.85	<3.2	<4.3	0.14
North 4	1,12	1.7	19.2	0.85	11.0	<4.3	0.34
North 5	1,0	<.9	22.4	1.02	<3.2	<4.3	0.37
Mean	1.7	1.1	21.7	1.11	4.8	4	0.38
Std. Dev.	.8	0.2	5.1	0.36	3.5	0	0.19
Central 1	8,12	1.4	20.5	1.00	<3.2	6.4	0.84
Central 2	1,2	1.1	16.7	1.15	<3.2	<4.3	0.67
Central 3	1,1	1.9	20.8	1.25	26.5	<4.3	0.39
Central 4	2,4	2.1	17.8	1.08	5.1	<4.3	0.42
Central 5	1,15	1.5	20.3	(3.87)	<3.2	7.6	0.26
Mean	2.8	1.6	19.2	1.12	8.2	5.4	0.52
Std. Dev.	2.7	0.14	1.9	0.10	10.2	1.5	0.23
South 1	1,13	1.5	20.6	0.95	<3.2	7.1	0.33
South 2	1,14	<.9	17.8	1.67	<3.2	<4.3	0.17
South 3	1,8	<.9	24.9	1.47	6.0	<4.3	0.26
South 4	3,0	1.0	18.0	1.02	<3.2	<4.3	0.42
South 5	1,1	<.9	17.6	0.77	<3.2	<4.3	0.20
Mean	1.6	1.1	19.8	1.18	3.8	4.9	0.28
Std. Dev.	.7	0.3	3.1	0.38	1.3	1.3	0.10

** ALL NUMBERS IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

VALUES IN BRACKETS ( ) FAILED THE Q-TEST AT THE 90% CONFIDENCE LEVEL AND ARE REPORTED BUT NOT USED TO CALCULATE MEAN

Table 1 continued METAL SUMMARY -- RUN 3 7/24/91
SMALLMOUTH BUFFALO AND BIGMOUTH BUFFALO

Sample	Fish Wt. lb.,	oz.	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	2	12	<.9	10.5	1.20	<3.2	<4.3	0.42
North 2	2	12	<.9	25.4	1.30	<3.2	<4.3	0.28
North 3	2	12	<.9	21.9	0.80	<3.2	4.7	0.40
North 4	4	3	<.9	14.9	1.00	<3.2	<4.3	0.34
North 5	5	12	<.9	14.0	1.30	<3.2	<4.3	0.37
Mean	3.2		0.9	17.3	1.12	3.2	4.4	0.36
Std. Dev.	1.3		0.0	5.5	0.20	0.0	0.2	0.05
Central 1	1	13	1.6	27.7	2.40	<3.2	<4.3	0.26
Central 2BB	5	13	<.9	17.6	1.00	<3.2	<4.3	0.60
Central 3	2	8	<.9	14.0	0.90	<3.2	<4.3	0.30
Central 4BB	7	10	<.9	12.0	1.60	<3.2	<4.3	1.34
Central 5	2	6	<.9	21.5	(23.4)	<3.2	<4.3	0.10
Mean	3.8		1.04	18.6	1.5	3.2	4.3	0.52
Std. Dev.	2.1		0.30	5.6	0.60	0.0	0.0	0.40
South 1	7	10	<.9	5.6	1.50	<3.2	<4.3	0.33
South 2	5	0	1.1	20.0	2.70	<3.2	4.8	0.50
South 3	4	4	1.0	13.0	1.00	<3.2	2.9	0.34
South 4	5	4	<.9	15.6	1.20	<3.2	<4.3	0.60
South 5BB	5	3	<.9	9.3	0.50	<3.2	<4.3	0.32
Mean	5.4		0.96	12.7	1.38	3.2	4.4	0.42
Std. Dev.	.9		0.08	5.0	0.70	0.0	0.2	0.10

** ALL NUMBERS IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

BB = Bigmouth Buffalo

VALUES IN BRACKETS ( ) FAILED THE Q-TEST AT THE 90% CONFIDENCE LEVEL AND ARE REPORTED BUT NOT USED TO CALCULATE MEAN

Table 1 continued   METAL SUMMARY -- RUN 3 7/24/91
CARP

Sample	Fish Wt. lb.,	oz.	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	4	10	1.5	16.1	1.40	<3.2	<4.3	0.37
North 2	4	0	1.5	30.3	1.40	<3.2	<4.3	0.20
North 3	4	0	1.0	(183.7)	5.90	6.1	<4.3	0.36
North 4	4	0	<.9	16.1	1.00	<3.2	<4.3	0.34
North 5	7	14	<.9	43.9	2.50	<3.2	<4.3	0.34
Mean	4.7		1.2	26.6	2.4	3.8	4.3	0.32
Std. Dev.	1.25		0.3	11.5	1.8	1.2	0.0	0.06
Central 1	2	3	<.9	26.7	3.00	<3.2	<4.3	0.23
Central 2	3	2	1.0	64.5	7.10	<3.2	<4.3	0.42
Central 3	1	12	<.9	20.1	1.00	<3.2	<4.3	0.27
Central 4	2	12	<.9	24.3	1.50	<3.2	<4.3	0.39
Central 5			NS	NS	NS	NS	NS	NS
Mean	2.2		1.00	33.9	3.2	3.2	4.3	0.33
Std. Dev.	.74		0.08	0.1	2.30	0.0	0.0	0.08
South 1	4	0	<.9	23.3	2.90	<3.2	<4.3	0.33
South 2	5	4	1.0	78.5	2.80	<3.2	<4.3	0.38
South 3	5	5	1.2	93.0	1.50	<3.2	<4.3	0.26
South 4	3	5	1.7	24.8	1.80	<3.2	<4.3	0.26
South 5	3	7	<.9	13.8	1.20	<3.2	<4.3	0.29
Mean	4.4		1.1	46.7	2.0	3.2	4.3	0.30
Std. Dev.	.86		0.3	32.4	0.70	0.0	0.0	0.05

** ALL NUMBERS IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE
NS = NO SAMPLE

VALUES IN BRACKETS ( ) FAILED THE Q-TEST AT THE 90% CONFIDENCE LEVEL AND ARE REPORTED BUT NOT USED TO CALCULATE MEAN

Table 1 continued METAL SUMMARY -- RUN 3 7/24/91
FLATHEAD CATFISH

Sample	Fish Wt. lb.,	oz.	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	3	8	1.0	30.7	2.70	<3.2	<4.3	0.30
North 2	1	13	2.4	28.8	1.10	<3.2	4.2	0.27
North 3	1	3	1.0	17.1	1.60	<3.2	<4.3	0.25
North 4	1	12	1.6	23.1	3.30	<3.2	<4.3	0.28
North 5	1	0	1.3	27.2	1.60	<3.2	4.3	0.26
Mean	1.7		1.5	25.4	2.1	3.2	4.3	0.27
Std. Dev.	1.1		0.5	4.8	0.80	0.0	0.04	0.02
Central 1	8	12	1.6	26.8	1.00	<3.2	<4.3	0.36
Central 2	1	2	0.9	(206.7)	1.60	7.4	4.2	0.47
Central 3	1	1	<.9	19.8	1.10	<3.2	<4.3	0.27
Central 4	2	4	1.8	14.9	0.80	<3.2	<4.3	0.27
Central 5	1	15	1.4	21.5	1.30	<3.2	<4.3	0.30
Mean	2.8		1.1	20.8	1.2	4.0	4.3	0.33
Std. Dev.	2.7		0.4	4.3	0.30	1.7	0.04	0.08
South 1	1	13	1.2	18.6	1.00	<3.2	<4.3	0.27
South 2	1	14	1.2	21.3	1.00	<3.2	<4.3	0.29
South 3	1	8	1.3	21.5	1.20	<3.2	<4.3	0.32
South 4	3	0	1.2	35.0	1.20	<3.2	<4.3	0.27
South 5	1	1	<.9	15.7	0.80	<3.2	<4.3	0.24
Mean	1.6		1.2	22.4	1.0	3.2	4.3	0.28
Std. Dev.	.7		0.14	6.6	0.10	0.0	0.0	0.03

** ALL NUMBERS IN ug/g DRY WEIGHT

< =DETECTION LIMIT VALUE

VALUES IN BRACKETS ( ) FAILED THE Q-TEST AT THE 90% CONFIDENCE LEVEL AND ARE REPORTED BUT NOT USED TO CALCULATE MEAN

Appendix - Table 2

METAL SUMMARY -- RUN 1 6/27-28/91
PERIPHYTON

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	18.0	65.3	18.1	30.0	34	<.24
North 2	<31	<170	24.3	<109	<150	<1.6
North 3	21.6	85.4	20.3	26.0	45	1.30
Mean	24.0	107.0	20.9	55.0	74	1.05
Std. Dev.	6.7	56.0	3.1	47.0	64	0.71
Central 1	11.7	65.0	19.9	24.7	38	<.12
Central 2	15.9	67.7	18.7	24.4	37	<.13
Central 3	25.9	66.7	18.5	48.1	55	<.29
Mean	17.8	66.5	19.0	32.4	43	0.18
Std. Dev.	7.3	1.3	0.8	13.6	10	0.09
South 1	15.6	65.5	14.9	21.4	30	<.09
South 2	15.8	58.6	16.2	20.1	32	<.13
South 3	21.2	50.3	17.8	47.2	47	<.29
Mean	17.5	58.1	16.3	29.6	36	0.17
Std. Dev.	3.2	7.6	1.5	15.3	9	0.09

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

Table 2 continued METAL SUMMARY -- RUN 2 7/16/91

PERIPHYTON

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	12	<59	18.6	<38	72	<.6
North 2	<20	<111	23.3	<72	132	<1.0
North 3	21	<63	20.1	28.5	85	<.6
Mean	18	77.7	20.6	46.2	96	0.73
Std. Dev.	5	29.0	2.4	22.9	32	0.23
Central 1	11	79.2	16.6	34.7	56	<.2
Central 2	12	60.3	18.3	32.8	41	<.2
Central 3	14	63.2	16.5	31.0	43	<.2
Mean	12	67.6	17.1	32.9	47	0.20
Std. Dev.	1	10.2	1.0	1.8	9	0.00
South 1	<7	72.8	17.3	45.7	44	<.4
South 2	11	56.8	17.1	34.9	40	<.2
South 3	14	63.7	7.7	26.0	38	<.1
Mean	11	64.4	14.0	35.5	41	0.23
Std. Dev.	4	8.0	5.0	9.9	2.5	0.15

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

Table 2 continued METAL SUMMARY -- RUN 3 8/1/91
PERIPHYTON

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	14	78.5	21.2	37.0	60	0.38
North 2	<27	<115	28.8	<74	137	1.10
North 3	6	56.7	14.6	23.0	51	0.29
Mean	13.7	83.4	21.5	44.7	82.7	0.59
Std. Dev.	6.1	24	5.8	22	39	0.36
Central 1	10	75.0	18.3	32.0	58	0.30
Central 2	12	66.1	18.2	32.0	50	0.19
Central 3	11	58.1	15.2	19.0	36	0.16
Mean	11	66.4	17.2	27.7	48.0	0.22
Std. Dev.	0.8	6.9	1.4	6.1	9.1	0.1
South 1	5.4	42.4	10.5	<8.0	25	0.15
South 2	<6.2	52.2	16.7	24.0	68	0.77
South 3	<6.8	41.4	11.7	<23	47	0.40
Mean	6.0	45.3	13.0	18.3	46.7	0.44
Std. Dev.	0.7	4.9	2.7	7.3	17.6	0.25

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

Appendix - Table 3

METAL SUMMARY -- RUN 1 6/27-28/91
INVERTEBRATES

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	<9.5	83.7	87	<33	67	0.70
North 2	<27	<145	39	<93	<128	<1.4
North 3	<7	82.9	56	<25	38	0.41
Mean	15	104	60.5	50	78	0.84
Std. Dev.	9	36	24.0	37	46	0.51
Central 1	<16	108	32	<55	<77	<.89
Central 2	<42	227	35	<146	<201	3.3
Central 3	<31	<170	22	<110	<150	<1.7
Mean	30	168	29.7	104	143	1.9
Std. Dev.	13	60	6.9	46	62	1.2
South 1*	<126	877	59	<441	<605	(57.0)
South 2	<51	<279	34	<179	245	<2.7
South 3	<34	<185	40	<119	180	5.8
Mean	70	392	44.3	246	343	4.25
Std. Dev.	49	381	13.0	171	228	0.78

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

* SMALL SAMPLE SIZE

Table 3 continued METAL SUMMARY -- RUN 2 7/16/91

INVERTEBRATES

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	4	113	23	9	12	<.07
North 2	<4	110	50	16	<17	0.20
North 3	5	119	20	8	14	0.10
Mean	4.3	114	31	11	14	0.12
Std. Dev.	0.6	5	16	4	3	0.07
Central 1	8.0	103	33	<28	<32	<.36
Central 2	<4	96	40	<24	<22	0.64
Central 3	8.2	100	29	19	<22	<.2
Mean	6.7	100	34	24	25	0.40
Std. Dev.	1.9	3	6	4.5	6	0.22
South 1	6.6	144	21	10	16	<.10
South 2	<5	98	52	106	30	<.24
South 3	6.5	90	49	39	35	<.20
Mean	6.3	111	41	51	27	0.18
Std. Dev.	1.2	29	17	49	10	0.07

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

Table 3 continued METAL SUMMARY -- RUN 3 7/17/91
INVERTEBRATES

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	5	472	21	20	32	<.16
North 2	3	110	15	11	22	1.28
North 3	<3.1	98	22	12	30	0.24
Mean	3.7	227	19	14	28.0	0.51
Std. Dev.	0.9	173.6	3.1	4.0	4.3	0.51
Central 1	<3.9	124	21	16	37	<.20
Central 2	6	92	17	<8	24	<.12
Central 3	6	125	17	7	16	<.09
Mean	5.3	114	18	10.3	25.7	0.14
Std. Dev.	1.0	15.7	1.8	4.0	8.7	0.05
South 1	4	580	24	18	17	0.10
South 2	5	144	18	<7	12	0.10
South 3	3	134	19	8	12	0.11
Mean	3.90	286	20	11.0	13.7	0.10
Std. Dev.	0.80	208	2.7	4.9	2.4	0.005

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

Appendix - Table 4

METAL SUMMARY -- RUN 1 6/27-28/91
ZOOPLANKTON

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	<79	<428	48.0	295	<378	2.70
North 2	<50	<275	65.8	<176	<242	<2.7
North 3*	690	<1077	98.9	698	<951	16
Mean	273	593	70.9	390	524	7.13
Std. Dev.	361	442	25.8	274	376	7.7
Central 1	<207	<1126	63.0	<724	<994	13.0
Central 2	<346	<1885	115.0	<1212	<1663	<5.6
Central 3	<75	<407	35.3	<261	<358	4.2
Mean	209	1139	71.0	732	1005	7.6
Std. Dev.	136	739	41.0	388	653	4.7
South 1	<108	<587	74.9	<377	<518	<5.6
South 2	<62	<338	87.9	<217	<359	<3.3
South 3*	230	<838	115.4	<538	<739	<8.2
Mean	133	588	92.7	377	539	5.7
Std. Dev.	87	250	20.7	161	191	2.5

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

* SMALL SAMPLE SIZE

Table 4 continued METAL SUMMARY -- RUN 2 7/16/91
ZOOPLANKTON

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	<9	107	78.0	38.9	70	<.5
North 2	<11	111	63.5	<39	93	<.6
North 3	<13	96	75.9	<46	95	<.70
Mean	11	104	72.4	41.3	86	0.6
Std. Dev.	2	8	7.8	4.1	14	0.1
Central 1	<19	<102	50.4	<65	<89	<.9
Central 2	<20	150	57.4	<71	131	2.42
Central 3	<15	79	75.5	66.5	<70	<.8
Mean	11	110	61.1	67.5	97	1.37
Std. Dev.	3	36	13.0	3.1	50	0.91
South 1	<13	168	67.1	<46	114	<.7
South 2	<19	<101	67.3	<65	124	<.9
South 3	<16	<89	75.0	140.0	165	0.91
Mean	16	119	69.8	83.7	134	0.84
Std. Dev.	3	43	4.5	49.7	27	0.12

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

Table 4 continued METAL SUMMARY -- RUN 3 7/27/91

ZOOPLANKTON

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1*	<32	(6101.2)	78.2	155.0	110.0	<1.7
North 2	<18	<99	61.2	<63	<88	<.9
North 3	<13	121.6	75.5	<44	<60	<.7
Mean	21.0	110.3	71.6	87.3	86.0	1.1
Std. Dev.	8.0	11.3	7.5	48.5	20.5	0.4
Central 1	<11	162.0	69.1	<39	63.0	<.6
Central 2	42.0	<92	68.4	<59	<81	<.9
Central 3	<12	90.1	54.1	<44	<60	<.7
Mean	21.7	114.7	63.9	47.3	68.0	0.73
Std. Dev.	14.4	33.4	6.9	8.5	9.3	0.12
South 1	<16	102.9	66.8	<56	80.0	0.8
South 2	<16	101.2	64.6	<56	<77	0.8
South 3	<15	123.0	67.0	<53	<73	1.08
Mean	15.7	109.0	66.1	55.0	76.7	0.89
Std. Dev.	0.5	9.9	1.1	1.4	2.9	0.13

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

* SMALL SAMPLE SIZE

VALUES IN BRACKETS ( ) FAILED THE Q-TEST AT THE 90% CONFIDENCE LEVEL AND ARE REPORTED BUT NOT USED TO CALCULATE MEAN

Apendix - Table 5

METAL SUMMARY -- RUN 1 6/27-28/91
SEDIMENT

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	4.2	19.7	4.3	9.0	18	0.14
North 2	3.7	14.4	3.5	9.0	16	0.10
North 3	<1.8	11.0	2.4	8.0	14	0.09
Mean	3.2	15.0	3.4	8.6	16	0.11
Std. Dev.	1.3	4.4	1.0	0.6	2	0.03
Central 1	8.6	42.9	11.8	13	25	0.11
Central 2	9.8	59.7	17.6	22	32	0.09
Central 3	9.3	50.8	14.8	16	26	0.09
Mean	9.2	51.1	14.7	17.0	28	0.10
Std. Dev.	0.6	8.4	2.9	4.3	3	0.01
South 1	10.0	45.4	14.6	16	27	0.10
South 2	15.0	61.0	17.7	22	34	0.38
South 3	10.7	48.9	14.6	18	29	0.10
Mean	11.9	51.8	15.7	18.5	30	0.19
Std. Dev.	2.7	8.2	1.8	3.5	4	0.16

ALL VALUES IN ug/g DRY WEIGHT

M = DETECTION LIMIT VALUE

Table 5 continued METAL SUMMARY -- RUN 2 7/16/91

SEDIMENT

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	13	43.8	11.2	17	26	0.16
North 2	13	81.2	12.7	16	50	<.09
North 3	14	42.1	12.4	18	25	0.11
Mean	13	55.7	12.1	17	34	0.12
Std. Dev.	1	22.1	0.8	0.7	14	0.04
Central 1	8	35.9	8.9	23	29	<.09
Central 2	11	42.5	9.2	16	21	<.09
Central 3	11	42.1	11.4	13	31	<.09
Mean	10	40.2	9.8	18	27	<.09
Std. Dev.	1	3.7	1.4	5	5	0.00
South 1	13	49.0	13.2	12	25	0.69
South 2	14	41.1	9.9	16	24	<.09
South 3	6	33.0	7.2	19	19	<.09
Mean	11	41.1	10.1	16	23	0.29
Std. Dev.	4	8.0	3.0	4	3	0.28

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

Table 5 continued METAL SUMMARY -- RUN 3 7/25/91

SEDIMENT

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	8	40.3	9.5	10	29	<.09
North 2	9	39.3	10.0	8	28	<.09
North 3	9	42.0	13.4	14	31	<.09
Mean	9	41	11.0	11	29	<.09
Std. Dev.	0.5	1.1	1.7	2.5	1.2	0
Central 1	13	49.4	11.1	21	29	<.09
Central 2	7	34.8	6.7	10	25	<.09
Central 3	7	35.4	7.8	16	23	<.09
Mean	9	40	8.5	16	26	<.09
Std. Dev.	2.8		1.9	4.5	2.5	0
South 1	10	46.0	10.4	13	31	<.09
South 2	16	56.4	13.9	16	31	<.09
South 3	10	54.7	13.3	16	35	<.09
Mean	12	52	12.5	15	32	<.09
Std. Dev.	2.8	4.6	1.5	1.4	1.9	0

ALL VALUES IN ug/g DRY WEIGHT

< = DETECTION LIMIT VALUE

Appendix - Table 6

METAL SUMMARY -- RUN 1 6/27-28/91
WATER

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	22.7	120	75.0	47	90	NS
North 2	17.3	90	16.7	75	65	1.4
Mean	20.0	105	45.8	61	78	1.4
Central 1	<12	<65	7.3	<42	65	1.2
Central 2	<12	<65	9.7	53	72	<.63
Mean	12	65	8.5	48	68	0.92
South 1	<12	94	10.3	53	<58	3.6
South 2	<12	148	12.0	<42	61	1.3
Mean	12	121	11.2	48	60	2.5

ALL VALUES IN ug/l

< = DETECTION LIMIT VALUE

NS = NO SAMPLE

Table 6 continued METAL SUMMARY -- RUN 2 7/16/91

WATER

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	<12	<65	9.3	<42	<58	<.63
North 2	<12	<65	9.3	45	58	<.63
Mean	12	65	9.3	44	<58	.63
Central 1	<12	<65	10.3	45	<58	0.67
Central 2	<12	<65	11.7	<42	<58	<.63
Mean	12	65	11.0	44	58	0.65
South 1	<12	316	9.7	45	<58	<.63
South 2	<12	547	10.7	<42	<58	<.63
Mean	12	431.5	10.2	44	58	.63

ALL VALUES IN ug/l

< = DETECTION LIMIT VALUE

Table 6 continued METAL SUMMARY -- RUN 3 7/25/91

WATER

Sample	Cr (Total)	Zn	Cu	Pb	Ni	Hg
North 1	<12	18	10.7	<42	<58	<.63
North 2	<12	16	9.7	<42	<58	0.63
Mean	12	17	10.2	42	58	0.63
Central 1	<12	32	35.0	73	81	<.63
Central 2	<12	26	11.7	51	75	<.63
Mean	12	29	23.4	62	78	0.63
South 1	<12	39	5.0	<42	<58	<.63
South 2	<12	34	12.3	46	<58	<.63
Mean	12	37	8.7	44	58	0.63

ALL VALUES IN ug/l

< = DETECTION LIMIT VALUE