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MEMORANDUM FOR: Mr. Russ Forba, USEPA Region 8 Montana Office

FROM: Paul R. Schroeder, PhD, PE, Research Civil Engineer

SUBJECT: Estimation of Contaminant Release from Dredging of Clark Fork and Blackfoot River Sediments in Area 1 of Milltown Reservoir

1. Introduction: This memorandum was prepared in response to comments on my memorandum, "Estimation of Contaminant Release from Dredging of Clark Fork and Blackfoot River Sediments in Milltown Reservoir," dated 10 August 2001. Since Area 1 represents a large fraction of the sediments proposed for dredging and some of the higher levels of contamination, the USEPA Region 8 Montana Office requested the U.S. Army Corps of Engineers to generate predictions of the range of changes in water quality in the Clark Fork River at Missoula, MT, during dredging of contaminated sediments in Area 1 of Milltown Reservoir at Milltown, MT, taking into consideration the comments on the previous memorandum. Milltown Reservoir is a Superfund site contaminated by metals from mining and smelting activities on the Upper Clark Fork River. The principal contaminants of concern are arsenic, cadmium, copper, lead, and zinc. Milltown Dam and Reservoir are located at the confluence of the Blackfoot and Clark Fork Rivers about 5 miles upstream from Missoula, MT. A number of remediation alternatives exist, and they generally include dredging or excavating at least 1 million cubic yards of sediment by one or more hydraulic or mechanical dredges or conventional excavation equipment over a five-month construction period from July through November in one or more years.

2. Key Factors Affecting Water Quality During Dredging: The range of effects of dredging on total suspended solids (TSS), arsenic, cadmium, copper, lead and zinc concentrations is likely to be quite broad due to variability in the chemical and physical characteristics of sediments as well as variability in the dredging losses, dredging production rates, effectiveness of best management practices (BMPs), flow rates, water depths, and water velocities. BMPs for dredging consist primarily of the proper selection of dredge type and model, control of the dredge operation to reduce releases of resuspended material, and use of silt curtains to control losses of contaminated suspended solids. Sediments will vary in their contaminant concentrations, contaminant distribution between liquid and solid phases, dry bulk density, and grain-size distributions. Higher contaminant concentrations and higher fine-grained sediment concentrations will increase the losses of contaminants to the water column. Dredging losses, expressed as a fraction of the volume or dry mass of the sediment, vary based on operation of the dredge and operating conditions. For example, hydraulic dredges tend to lose more material at the end of their swings, when cutting upward through the material (moving left with a clockwise turning cutterhead) rather than cutting downward (moving right with a clockwise turning cutterhead), and when making partial cuts in depth rather than full cuts. Higher dredging losses will increase the losses of contaminants to the water column. Dredging production rates vary with the number, movement, maintenance, and size of dredges. Higher production rates increase the rate of contaminant losses to the water column; however, maintaining higher production rates for a given dredge tends to decrease the fraction of the material and contaminants lost. Flow rates are variable with season, snow accumulations, groundwater levels, and current weather. Low flow rates reduce the dilution of the contaminant losses. Therefore, a wide range of changes in water quality is likely to result from dredging, and predictions of the effects must include the likely variability of the system. Analysis of impacts on water quality should incorporate known or estimated probability distributions for key factors; a common procedure for doing so is Monte Carlo analysis.

3. Objectives: The objectives of this analysis are:

a. Determine the variability in the principal parameters affecting water quality during dredging. Quantify the probability distribution function for the principal parameters by estimating their values at the 5th, 15th, 25th, 35th, 45th, 55th, 65th, 75th, 85th and 95th percentiles.

b. Predict the probability distribution function for the increase in total concentration of suspended solids, arsenic, cadmium, copper, lead and zinc in the Clark Fork River below the Milltown Dam at Missoula, MT, during cutterhead hydraulic dredging of the Area 1 sediments in Milltown Reservoir without implementation of BMPs using a Monte Carlo approach. (It is assumed that mechanical dredging or excavation of sediments would be performed in the dry and, therefore, would not affect the water quality. The analysis does not account for any resuspension resulting from mechanical removal of debris.)

c. Estimate the probability distribution function for the increase in dissolved concentration of arsenic, cadmium, copper, lead and zinc in the Clark Fork River below the Milltown Dam at Missoula, MT, during cutterhead hydraulic dredging of Area 1 sediments in Milltown Reservoir without implementation of BMPs based on predictions of total contaminant concentrations and the distribution of contaminants between the liquid and solid phases in the water column and in the pore water.

d. Estimate the probability distribution function for total and dissolved concentrations of arsenic, cadmium, copper, lead and zinc in the Clark Fork River below the Milltown Dam at Missoula, MT, during cutterhead hydraulic dredging of Area 1 sediments in Milltown Reservoir without implementation of BMPs using a Monte Carlo approach to include the variability of the background water quality. Conservatively estimate the frequency of exceedances of water quality standards and criteria and increases in the exceedances due to dredging.

e. Estimate the potential effectiveness of BMPs on reduction of water quality impacts by dredging.

4. Sediment Contaminant Concentrations: Site-specific total contaminant concentrations in the sediment were compiled from Appendix 5B of the Milltown Reservoir Sediments Operable Unit, Draft Remedial Investigation Report (Titan Environmental Corporation 1995). A database of Area 1 contaminant concentrations was tabulated and sorted in ascending order, containing 27 values each for arsenic, cadmium, copper, lead, and zinc. The statistics of the values are presented in Table 1. The sediment contaminant concentrations appear to be log normally distributed.

5. Dredging Losses: Dredging loss estimates expressed as a fraction of the dry weight or volume of the in situ sediment were obtained from the Hayes and Wu (2001) paper entitled "Simple Approach to TSS Source Strength Estimates" (Western Dredging Association [WEDA] Proceedings, WEDA XXI, Houston, TX, June 25-27, 2001). The data consist of 294 estimates of losses of fine-grained solids from two 12-inch cutterhead dredges (12 estimates from one site and 282 estimates from another site);

TABLE 1. DISTRIBUTIONS OF AREA 1 SEDIMENT CONTAMINANT CONCENTRATIONS

Percentile	Sediment Contaminant Concentration (mg/kg)				
	Arsenic	Cadmium	Copper	Lead	Zinc
5	17	0.96	170	34	453
15	83	2.56	880	108	726
25	148	3.60	1231	140	1027
35	222	4.40	1570	177	1840
45	363	5.20	2904	295	3205
55	611	6.00	4221	390	4162
65	657	9.44	4976	421	5268
75	812	12.00	6040	495	6190
85	900	19.00	6698	538	6949
95	1116	27.00	7752	689	8224
Mean	510	13.96	3704	335	3837
Minimum	8	0.87	20	12	27
Maximum	1540	30.50	10600	794	9520

additionally, the database has 43 estimates of losses from 18-inch cutterhead dredges collected at two sites and 51 estimates of losses from a 10-inch cutterhead dredge at one site. The dredging loss was computed by measuring the TSS concentration and velocity in a vertical cross-section of the plume downstream from the dredge, but in close proximity. These field data were used to compute the mass loss rate which was divided by dredging fine-grained solids production rate (the volumetric production rate x dry bulk density of the in situ sediment x fine-grained fraction) to compute the dredging loss fraction. All estimates of dredging losses were made in the absence of best management practices. The data for 12-inch dredges were used to estimate the distribution of losses for this analysis. The data for other cutterhead dredges were similar in distribution although the average and maximum loss fractions were smaller. Therefore, data for the 12-inch cutterhead dredge are more conservative (predicts higher losses). The dredging loss data were sorted in ascending order and its distribution is shown below in Table 2. Resuspension data for horizontal auger dredges (Mudcat dredge) and mechanical dredges (open and closed clamshells) are significantly (at least 3 times) higher than for the cutterhead dredges used in this analysis (Hayes and Wu, 2001; Cullinane et al., 1986, "Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material Requiring Restrictions").

6. Stream Flow: Daily mean stream discharge data (4743 values) from USGS Station Number 12340500 at Clark Fork River above Missoula, MT, and below Milltown Dam for the months of July through November in years 1969 through 1999 were compiled and sorted in ascending order. Fifty data points exceeding 7500 cfs (all in early July from 7 of the 31 years of data) were excluded from the data set. Flows below 7500 cfs are expected to yield near bank velocities below 1.5 fps; these velocities are consistent with use of Best Management Practices such as silt curtains (see paragraph 18). Exclusion from the data set is based on the reasonable assumption that this flow rate would be the upper limit for cutterhead dredging in a given year. The distribution of the stream flow data is shown in Table 2.

TABLE 2. DISTRIBUTIONS OF DREDGING RESUSPENSION FRACTIONS AND STREAM FLOW RATES

Percentile	Dredging Resuspension Fraction of Dry Mass or Volume (w/w) or (v/v)	Flow Rate in Clark Fork River at Missoula, MT (cfs)
5	0.00007	854
15	0.00018	1130
25	0.00029	1310
35	0.00041	1450
45	0.00060	1580
55	0.00098	1710
65	0.00134	1850
75	0.00154	2000
85	0.00183	2470
95	0.00272	4100
Mean	0.000944	1881
Minimum	0.000005	558
Maximum	0.003840	7460

7. Dredging Production Rates: Two dredging production rates were evaluated: 140 m^3/hr and 280 m^3/hr. The lower rate is representative of the hourly production rate of a 12- to 14-inch cutterhead dredge while the upper rate is representative of the hourly production rate of two 12- to 14-inch cutterhead dredges. The production rates were selected to meet the overall project requirements of a million cubic yards in a 5-month period of time. It is assumed that one or two dredges would be used for all or part of the dredging period. Many other dredging alternatives could be examined, but the variability in the production rate is captured by these two rates.

8. Sediment Dry Bulk Density: An average dry bulk density was computed for the sediments. Moisture content data were available for 58 sediment samples (McCulley, Frick & Gilman, Inc. 1998). To compute dry bulk density from moisture content data, it was necessary to estimate the specific gravity of the sediment particles. Specific gravity was measured for 48 samples (Titan Environmental Corporation 1995). The average specific gravity was 2.53; the specific gravity ranged from 2.45 to 2.70. The average dry bulk density was 1343 kg/cubic meter; the dry bulk densities ranged from 811 to 1705 kg/cubic meter.

9. ΔTotal Contaminant Concentration Calculations: The increase in the total suspended solids concentration from dredging in the absence of BMPs is equal to:

$$\Delta TSS = \text{Dry Bulk Density} \times \text{Production Rate} \times \text{Dredging Loss Fraction} / \text{Flow Rate}$$

The increase in the water column total contaminant concentration from dredging in the absence of BMPs is equal to:

$$\Delta \text{Total Concentration} = \text{Sediment Contaminant Concentration} \times \Delta \text{TSS}$$

A Monte Carlo analysis was performed using the above equations to determine the distribution of the increase in total contaminant concentrations in the water column below the Milltown Dam at Missoula, MT. In the analysis for each of the 2 production rates, each of the 10 dredging loss factors was used with the 10 flow rates to generate a collection of 100 ∆TSS concentrations that have equal likelihood of occurrence in the absence of BMPs for the given production rate. These two sets of 100 ∆TSS values were used with each of the 27 sediment contaminant concentrations for each of the 5 contaminants to generate 2700 ∆Total Concentration values for each of the 5 contaminants.

10. Total Contaminant Concentration Results: The ∆TSS and ∆Total Concentration in the absence of BMPs were sorted and their distributions are presented in Tables 3 and 4. The increase in total concentration (including both acid soluble and insoluble arsenic and metals fractions from suspended particulates) are predicted by the method used in this paper because the sediment contaminant concentrations available for use in this analysis were reported as total concentrations and not as total recoverable concentrations. The increases in total concentrations reported in this paper will be higher than the increases in total recoverable concentrations (containing only the acid soluble portions of the suspended particulates) that are measured in the water column and form the basis for the Montana Circular WQB-7 Standards. Therefore, the ∆Total Concentration approach is considered to be a conservative overestimate for the increase in Total Recoverable Metals. The ∆TSS and ∆Total Concentration results appear to be log normally distributed.

11. Ambient Water Quality: Dissolved and total recoverable contaminant concentrations in the ambient water column were compiled from the USGS Surface Water Quality database for USGS Station 12340500 on the Clark Fork River at Missoula, MT; approximately 33 samples collected between June 1990 and December 1999 during the months of July through November were analyzed in this evaluation. The distributions of total recoverable and dissolved contaminant concentrations in the ambient water are given in Tables 5 and 6.

12. Impact of Ambient Conditions on Exceedances of Total Recoverable Contaminant Concentrations During Dredging Without BMPs: The ambient water quality data was sorted and used in a Monte Carlo simulation with the 2700 ∆Total Concentration values for each of the 5 contaminants. Due to limitations in the software, every third value in the set of ambient water quality data, starting with the second value, was dropped in the analysis. The analysis generated 59,400 values of total concentrations for each of the 5 contaminants at low (one dredge) and high production rates (two dredges). Estimates of the total recoverable contaminant concentrations were computed as follows:

$$\text{Total Recoverable Concentration} = \Delta \text{Total Concentration} + \text{Ambient Water Total Recoverable Concentration}$$

The distributions of predicted total recoverable concentrations are given in Tables 7 and 8. The predicted probabilities of exceedance of Montana water quality standards are summarized in Table 9; the increases in exceedances are given in Table 10. The results show that the predicted total recoverable concentrations of arsenic and zinc would be well below the acute and chronic toxicity. The predicted total recoverable concentration of cadmium would also be below the acute toxicity standards, but there is about a 5 percent probability that the chronic standard could be exceeded for short periods of time when two dredges are operating. However, this is because the ambient concentration nearly equals the chronic toxicity standard about 75 percent of the time. The predicted total recoverable concentration of lead would be well below the acute toxicity standard; however, the predicted total recoverable concentration of lead would exceed the chronic toxicity standard about 10 percent of the time without dredging, 17 percent of the time with one dredge, and 25 percent of the time with two dredges. The predicted total recoverable concentration of copper would exceed the acute toxicity standard about 20 percent of the time without dredging, 31 percent of the time with one dredge, and 43 percent of the time with two dredges. The predicted total recoverable concentration of copper would exceed the chronic toxicity standard 24 percent of the time without dredging, 43 percent of the time with one dredge, and 57 percent of the time with two dredges.

TABLE 3. PREDICTED DISTRIBUTIONS OF INCREASES IN TSS AND TOTAL CONTAMINANT CONCENTRATIONS FOR PRODUCTION BY ONE DREDGE

Percentile	ΔTotal Contaminant Concentration (ug/L) in the Water Column					
	TSS	Arsenic	Cadmium	Copper	Lead	Zinc
0.1	31	0.0005	0.00005	0.0013	0.0008	0.0018
0.5	31	0.0009	0.00008	0.0034	0.0016	0.0045
1	52	0.0015	0.00012	0.0064	0.0026	0.0092
3	70	0.0042	0.00025	0.0232	0.0065	0.0363
5	81	0.0070	0.00038	0.0450	0.0099	0.0608
10	129	0.0163	0.00072	0.1246	0.0202	0.1588
20	249	0.0446	0.00163	0.3627	0.0433	0.4175
30	386	0.0870	0.00282	0.6708	0.0771	0.7498
50	793	0.2525	0.00723	1.9018	0.1943	1.8911
70	1544	0.5960	0.01714	4.3975	0.4262	4.6386
80	1985	1.0000	0.02792	7.2122	0.6597	7.6355
90	2730	1.6952	0.04595	12.253	1.0599	12.6838
95	3332	2.4083	0.06345	17.059	1.4486	17.6740
97	3833	2.9056	0.07550	20.564	1.7366	21.0193
99	4453	3.9464	0.10136	28.535	2.3547	27.9317
99.5	5874	4.8892	0.12053	34.303	2.7979	34.3617
99.9	5874	6.6961	0.17210	46.873	3.7769	46.1681
Mean	1178	0.6014	0.01646	4.3650	0.3949	4.5223
Minimum	31	0.0003	0.00003	0.0006	0.0004	0.0009
Maximum	5874	9.0457	0.17915	62.2623	4.6638	55.9186
Montana Numerical Water Quality Standards for Surface Water*						
Acute		360**	3.9	18***	82	120
Chronic		190**	1.1	12***	3.2	110

* Assumes a 100 mg/L hardness; standard is based on actual hardness measured at time of sampling (Montana Circular WQB-7).
** The Federal primary drinking water standard for arsenic is 10 ug/L (dissolved).
*** Site specific trout toxicity reference value for dissolved copper is 37 ug/L.

TABLE 4. PREDICTED DISTRIBUTIONS OF INCREASES IN TSS AND TOTAL CONTAMINANT CONCENTRATIONS FOR PRODUCTION BY TWO DREDGES

Percentile	ΔTotal Contaminant Concentration (ug/L) in the Water Column					
	TSS	Arsenic	Cadmium	Copper	Lead	Zinc
0.1	63	0.0065	0.00022	0.0537	0.0069	0.0552
0.5	63	0.0099	0.00037	0.0891	0.0115	0.0924
1	104	0.0168	0.00056	0.1339	0.0167	0.1395
3	139	0.0324	0.00107	0.2616	0.0294	0.2794
5	161	0.0471	0.00153	0.3770	0.0399	0.3998
10	258	0.0827	0.00251	0.6374	0.0643	0.6635
20	497	0.1654	0.00501	1.2653	0.1271	1.3252
30	771	0.2795	0.00829	2.1136	0.2087	2.2261
50	1586	0.6378	0.01831	4.7667	0.4562	4.9390
70	3088	1.3691	0.03845	10.0659	0.9335	10.5133
80	3970	1.9883	0.05561	14.6506	1.3099	15.0757
90	5459	3.0741	0.08303	22.1995	1.9480	22.8783
95	6665	4.1232	0.11006	29.7299	2.5937	30.5900
97	7666	4.9480	0.13203	35.3869	3.0542	36.7796
99	8907	6.5847	0.17236	47.6002	4.0502	48.6775
99.5	11748	7.6273	0.19978	54.0869	4.7958	56.4360
99.9	11748	10.0922	0.26434	71.3153	6.0741	74.6626
Mean	2357	1.1944	0.03286	8.7221	0.7881	9.0451
Minimum	63	0.0032	0.00013	0.0310	0.0041	0.0327
Maximum	11748	12.9224	0.31366	91.8075	7.4926	91.6431
Montana Numerical Water Quality Standards for Surface Water*						
Acute		360**	3.9	18***	82	120
Chronic		190**	1.1	12***	3.2	110

* Assumes a 100 mg/L hardness; standard is based on actual hardness measured at time of sampling (Montana Circular WQB-7).
** The Federal primary drinking water standard for arsenic is 10 ug/L (dissolved).
*** Site specific trout toxicity reference value for dissolved copper is 37 ug/L.

TABLE 5. DISTRIBUTIONS OF TSS AND TOTAL RECOVERABLE CONTAMINANT CONCENTRATIONS IN AMBIENT WATER WITHOUT DREDGING

Percentile	Total Recoverable Contaminant Concentration (ug/L) in Ambient Water					
	TSS	Arsenic	Cadmium	Copper	Lead	Zinc
5	2000	3.00	0.11	3.06	0.91	10.00
15	3000	3.56	0.34	4.00	1.00	10.00
25	5000	4.00	1.00	4.88	1.00	10.00
35	6000	4.06	1.00	5.00	1.00	10.00
45	6000	4.64	1.00	5.50	1.00	18.80
55	6700	5.00	1.00	6.15	1.00	20.00
65	9000	5.96	1.00	8.00	1.36	30.80
75	12750	6.50	1.00	10.30	2.00	31.00
85	23800	7.11	1.00	20.27	2.70	31.87
95	34300	8.02	1.00	23.18	4.40	40.00
Mean	11180	5.24	0.85	9.31	1.79	21.48
Minimum	2000	3.00	0.11	2.00	0.70	10.00
Maximum	42000	10.00	1.00	24.83	8.59	44.00
Montana Numerical Water Quality Standards for Surface Water*						
Acute		360**	3.9	18***	82	120
Chronic		190**	1.1	12***	3.2	110

* Assumes a 100 mg/L hardness; standard is based on actual hardness measured at time of sampling (Montana Circular WQB-7).
** The Federal primary drinking water standard for arsenic is 10 ug/L (dissolved).
*** Site specific trout toxicity reference value for dissolved copper is 37 ug/L.

TABLE 6. DISTRIBUTIONS OF DISSOLVED CONTAMINANT CONCENTRATIONS IN AMBIENT WATER WITHOUT DREDGING

Percentile	Dissolved Contaminant Concentration (ug/L) in Ambient Water Column				
	Arsenic	Cadmium	Copper	Lead	Zinc
5	3.00	0.10	1.13	0.50	1.04
15	3.00	0.10	1.55	0.50	1.72
25	3.78	0.10	1.79	0.50	3.00
35	4.00	0.10	2.00	0.50	3.00
45	4.00	0.10	2.00	0.50	3.00
55	4.23	0.10	2.00	0.50	3.00
65	4.94	0.10	3.00	0.50	3.24
75	5.21	0.10	3.20	0.50	5.00
85	5.53	1.00	4.20	1.00	6.14
95	6.04	1.00	5.24	1.00	10.00
Mean	4.32	0.26	2.66	0.60	4.19
Minimum	2.00	0.10	1.00	0.50	1.00
Maximum	6.34	1.00	6.70	1.00	20.00

TABLE 7. PREDICTED DISTRIBUTIONS OF TOTAL CONTAMINANT CONCENTRATIONS FOR PRODUCTION BY ONE DREDGE

Percentile	Total Contaminant Concentration (ug/L) in the Water Column					
	TSS	Arsenic	Cadmium	Copper	Lead	Zinc
0.1	2052	3.0012	0.11009	2.0146	0.7070	10.0022
0.5	2081	3.0050	0.11028	2.1449	0.7243	10.0120
1	2134	3.0113	0.11054	2.4095	0.7505	10.0274
3	2440	3.0518	0.11183	3.3959	1.0013	10.1041
5	2979	3.1292	0.11396	3.8927	1.0083	10.2121
10	4031	3.7005	0.13014	4.9090	1.0269	10.5483
20	5253	4.0989	1.00019	5.7606	1.0811	11.7983
30	6229	4.5293	1.00113	6.9428	1.1855	15.4483
50	8442	5.5005	1.00441	9.8557	1.5436	23.9317
70	11692	6.8533	1.01280	18.9318	2.3720	32.9176
80	19226	7.3710	1.02237	23.4065	2.8514	38.8470
90	35979	8.2721	1.04056	26.6729	4.0277	44.2166
95	38896	10.0189	1.05870	31.3342	5.3131	48.0314
97	42441	10.2641	1.07050	34.9229	8.6877	51.6758
99	43887	11.2469	1.09557	42.9905	9.1983	59.4327
99.5	44577	11.9654	1.11579	47.7338	9.5974	64.4479
99.9	45952	13.6868	1.13980	60.7933	10.4902	75.9186
Mean	12951	5.8536	0.86773	13.8961	2.2174	26.2405
Minimum	2031	3.0003	0.11003	2.0006	0.7024	10.0009
Maximum	47874	19.0457	1.17915	87.0943	13.2558	99.9186
Montana Numerical Water Quality Standards for Surface Water*						
Acute		360**	3.9	18	82	120
Chronic		190**	1.1	12	3.2	110

* Assumes a 100 mg/L hardness; standard is based on actual hardness measured at time of sampling (Montana Circular WQB-7).
** The Federal primary drinking water standard for arsenic is 10 ug/L (dissolved).
*** Site specific trout toxicity reference value for dissolved copper is 37 ug/L.

TABLE 8. PREDICTED DISTRIBUTIONS OF TOTAL CONTAMINANT CONCENTRATIONS FOR PRODUCTION BY TWO DREDGES

Percentile	Total Contaminant Concentration (ug/L) in the Water Column					
	TSS	Arsenic	Cadmium	Copper	Lead	Zinc
0.1	2105	3.0132	0.11048	2.2163	0.7260	10.0724
0.5	2162	3.0382	0.11123	2.6840	0.7721	10.1569
1	2269	3.0633	0.11197	3.2299	0.8458	10.2358
3	2880	3.1854	0.11560	4.2118	1.0238	10.5153
5	3388	3.3758	0.12102	4.9181	1.0429	10.7757
10	4539	4.0016	0.15348	5.7400	1.0895	11.6936
20	6129	4.4193	1.00087	7.3210	1.2299	14.7454
30	7038	4.9383	1.00346	8.9702	1.4120	20.2208
50	9650	6.1279	1.01196	14.8638	2.0476	31.0670
70	14184	7.3694	1.03011	23.7282	2.8435	38.0448
80	20750	8.0585	1.04737	27.3093	3.4881	43.5381
90	36448	9.6431	1.07575	34.6384	4.5641	50.6391
95	41907	10.6727	1.10186	42.3406	6.8713	58.5746
97	43045	11.4546	1.12315	48.0568	8.8507	64.4589
99	45918	13.2011	1.16756	60.4447	9.8411	76.9998
99.5	47425	14.3290	1.19364	68.5718	10.4730	84.9746
99.9	49855	16.9224	1.26432	86.6506	11.9142	101.6585
Mean	14130	6.4466	0.88413	18.2532	2.6106	30.7632
Minimum	2063	3.0032	0.11013	2.0310	0.7061	10.0327
Maximum	53748	22.9224	1.31366	116.6395	16.0846	135.6431
Montana Numerical Water Quality Standards for Surface Water*						
Acute		360**	3.9	18	82	120
Chronic		190**	1.1	12	3.2	110

* Assumes a 100 mg/L hardness; standard is based on actual hardness measured at time of sampling (Montana Circular WQB-7).
** The Federal primary drinking water standard for arsenic is 10 ug/L (dissolved).
*** Site specific trout toxicity reference value for dissolved copper is 37 ug/L.

TABLE 9. PROBABILITY OF TOTAL RECOVERABLE CONTAMINANT CONCENTRATIONS EXCEEDING MONTANA WATER QUALITY STANDARDS FOR SURFACE WATER

Contaminant	Montana Water Quality Standard	Probability of Exceeding Montana WQS (percent)		
		Operating Condition		
		Ambient Water	One Dredge	Two Dredges
Arsenic	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	0.0	0.0	0.0
	Human Health	0.0	0.0	0.0
Cadmium	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	0.0	0.9	5.2
Copper	Acute Toxicity	20.0	31.2	42.6
	Chronic Toxicity	24.0	43.4	57.4
Lead	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	9.5	17.1	24.7
Zinc	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	0.0	0.0	0.0

TABLE 10. INCREASES IN FREQUENCY OF TOTAL RECOVERABLE CONTAMINANT CONCENTRATIONS EXCEEDING MONTANA WATER QUALITY STANDARDS FOR SURFACE WATER

Contaminant	Montana Water Quality Standard	Probability of Ambient Water Quality Exceeding Montana WQS (percent)	Increase in Frequency of Water Quality Exceeding Montana WQS (percent)	
			Operating Condition	
			One Dredge	Two Dredges
Arsenic	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	0.0	0.0	0.0
	Human Health	0.0	0.0	0.0
Cadmium	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	0.0	0.9	5.2
Copper	Acute Toxicity	20.0	11.2	22.6
	Chronic Toxicity	24.0	19.4	33.4
Lead	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	9.5	7.6	15.2
Zinc	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	0.0	0.0	0.0

13. Distribution (Partitioning) Data: The distribution of contaminants between the liquid and solid phases presently in the water column and in the pore water was examined to estimate the distribution coefficients for the contaminants. The calculated distribution coefficients for both the Clark Fork River and the pore water were then used to estimate the changes in dissolved contaminant concentrations during dredging in the absence of BMPs. Dissolved concentrations provide the most accurate indications of potential environmental impacts. Distribution coefficients (K_d) for all five contaminants of concern were computed for each of the 27 sediment samples from Area 1 using measurements of pore water and total contaminant concentrations presented in the Draft Remedial Investigation Report for ARCO (Titan Environmental Corporation 1995). The K_d computed for a given sediment sample was used to compute the increase in dissolved contaminant concentration in the water column from dredging losses of the corresponding sediment. The statistics of the K_d values for each contaminant are presented in Table 11. The distribution coefficients for the contaminants would be expected to be different in the water column than in the in situ sediments due to differences in pH and oxidation conditions. As such, distribution coefficients were also computed for the ambient water in the Clark Fork River at Milltown Reservoir and at Missoula, MT. Dissolved and total recoverable contaminant concentrations in the water column were compiled from the USGS Surface Water Quality database for USGS Station 12340500 on the Clark Fork

River at Missoula, MT; approximately 33 samples collected between June 1990 and December 1999 were analyzed in this evaluation. The distribution coefficients in the water column were larger than in the sediments. Lower distribution coefficients yield the higher prediction of dissolved concentration. The results of the distribution evaluation for the water column are also summarized in Table 11.

14. Δ Dissolved Contaminant Concentration Calculations: Since the distribution coefficients in the water column and sediments were quite different, the increase in the water column dissolved contaminant concentration from dredging without BMPs is equal to:

$$\Delta \text{ Dissolved Concentration} = \Delta\text{Total Concentration} / [1 + (K_d \times \Delta\text{TSS})]$$

Δ Dissolved Concentrations were computed for the 2700 ΔTotal Concentrations estimates for each contaminant using the corresponding K_d of the sediment sample and ΔTSS value for which the ΔTotal Concentration estimates was computed.

15. Predictions of Δ Dissolved Contaminant Concentrations: The Δ Dissolved Concentration results for each contaminant were sorted and their distributions are presented in Tables 12 and 13. The results appear to be log normally distributed. Actual increases in dissolved concentrations may be somewhat smaller because the ambient TSS concentrations are much larger than the increases in TSS from dredging. As such, some of the predicted dissolved contaminants may partition to the ambient TSS or iron oxides formed from the dredging releases. The difference between total contaminant concentration and dissolved concentration increases greatly with increases in TSS. On average in the ambient water, the dissolved concentrations of contaminants were typically less than 50 percent of the total recoverable concentrations of contaminants; however, on average in dredging losses, the predicted increases in dissolved concentrations ranged from 75 percent of the total concentration of copper to more than 99 percent of the total concentration of arsenic and cadmium. These percentages are much larger than the typical fraction of the total metals that are leachable or recoverable; as such, the predictions of the increases in dissolved contaminant concentrations are very conservative and considerably overestimated.

TABLE 11. SUMMARY OF DISTRIBUTION COEFFICIENTS

Location	Distribution Coefficient, L/kg				
	Arsenic	Cadmium	Copper	Lead	Zinc
In Situ Sediment					
Mean	1110	2340	141000	66500	5450
Minimum	5.5	9.0	413	2040	2.5
Median	89.5	1860	121000	41600	4190
Maximum	10000	7530	526000	344000	20800
Water Column					
Mean	21100	101000	94800	78800	117000
Minimum	112	6990	19400	20000	22000
Median	11600	64300	83000	62500	83100
Maximum	83300	450000	333000	250000	350000

TABLE 12. PREDICTED DISTRIBUTIONS OF DISSOLVED CONTAMINANT CONCENTRATION INCREASES FOR PRODUCTION BY ONE DREDGE WITHOUT BMPs

Percentile	Δ Dissolved Contaminant Concentration (ug/L) in the Water Column				
	Arsenic	Cadmium	Copper	Lead	Zinc
0.1	0.0005	0.00005	0.0013	0.0008	0.0018
0.5	0.0009	0.00008	0.0034	0.0016	0.0045
1	0.0015	0.00012	0.0063	0.0026	0.0092
3	0.0042	0.00025	0.0231	0.0064	0.0362
5	0.0070	0.00038	0.0449	0.0099	0.0608
10	0.0163	0.00072	0.1241	0.0201	0.1578
20	0.0446	0.00163	0.3551	0.0429	0.4175
30	0.0870	0.00282	0.6469	0.0751	0.7492
50	0.2524	0.00722	1.7171	0.1850	1.8890
70	0.5951	0.01710	3.6480	0.3866	4.6138
80	0.9970	0.02776	5.6678	0.5891	7.5487
90	1.6805	0.04569	8.8085	0.9066	12.4585
95	2.3936	0.06290	11.7542	1.1925	17.4213
97	2.8940	0.07467	13.7700	1.3898	20.6236
99	3.9426	0.09957	18.2001	1.8041	27.6082
99.5	4.8878	0.11952	21.0831	1.9903	32.0436
99.9	6.6927	0.16887	27.6072	2.5345	43.7709
Mean	0.5997	0.01634	3.2801	0.3405	4.4466
Minimum	0.0003	0.00003	0.0006	0.0004	0.0009
Maximum	9.0409	0.17693	34.2305	2.9462	53.0124
Federal Freshwater Water Quality Criteria for Protection of Aquatic Life*					
Acute	340**	4.3	13***	65	120
Chronic	150**	2.2	9***	2.5	120

* Assumes a 100 mg/L hardness; criterion is based on actual hardness measured at time of sampling.
** The Federal primary drinking water standard for arsenic is 10 ug/L (dissolved).
*** Site specific trout toxicity reference value for dissolved copper is 37 ug/L.

TABLE 13. PREDICTED DISTRIBUTIONS OF DISSOLVED CONTAMINANT CONCENTRATION INCREASES FOR PRODUCTION BY TWO DREDGES WITHOUT BMPs

Percentile	Δ Dissolved Contaminant Concentration (ug/L) in the Water Column				
	Arsenic	Cadmium	Copper	Lead	Zinc
0.1	0.0065	0.00022	0.0533	0.0069	0.0552
0.5	0.0099	0.00037	0.0880	0.0115	0.0924
1	0.0168	0.00056	0.1317	0.0167	0.1394
3	0.0324	0.00107	0.2580	0.0287	0.2793
5	0.0471	0.00153	0.3665	0.0394	0.3996
10	0.0826	0.00251	0.6110	0.0632	0.6629
20	0.1654	0.00500	1.1786	0.1234	1.3234
30	0.2795	0.00826	1.8792	0.1995	2.2182
50	0.6378	0.01823	3.7092	0.4083	4.8893
70	1.3620	0.03819	6.8681	0.7944	10.3699
80	1.9791	0.05487	9.2886	1.0866	14.7923
90	3.0587	0.08159	13.1862	1.5083	22.2245
95	4.1220	0.10806	16.9000	1.9170	29.4149
97	4.9309	0.12798	19.5358	2.1757	35.0769
99	6.5814	0.16849	24.7824	2.7036	47.0247
99.5	7.6087	0.19452	27.3714	3.0653	51.7321
99.9	9.7708	0.25517	32.4394	3.7649	67.9579
Mean	1.1905	0.03238	5.5820	0.6310	8.7827
Minimum	0.0032	0.00013	0.0310	0.0041	0.0327
Maximum	12.9149	0.30515	40.4583	4.3329	83.4072
Federal Freshwater Water Quality Criteria for Protection of Aquatic Life*					
Acute	340**	4.3	13***	65	120
Chronic	150**	2.2	9***	2.5	120

* Assumes a 100 mg/L hardness; criterion is based on actual hardness measured at time of sampling.
** The Federal primary drinking water standard for arsenic is 10 ug/L (dissolved).
*** Site specific trout toxicity reference value for dissolved copper is 37 ug/L.

16. Impact of Ambient Conditions on Exceedances of Dissolved Contaminant Concentrations During Dredging Without BMPs: The dissolved contaminant concentrations were computed for the 59,400 combinations in the Monte Carlo simulation as follows:

$$\text{Dissolved Concentration} = \Delta\text{Dissolved Concentration} + \text{Ambient Dissolved Concentration}$$

The distributions of predicted dissolved concentrations are given in Tables 14 and 15. The predicted probabilities of exceedance of Federal Freshwater Water Quality Criteria for Protection of Aquatic Life, the Federal primary drinking water standard for arsenic, and the Clark Fork River site-specific trout toxicity reference value (TRV) for copper are summarized in Table 16. The results show that the predicted dissolved concentrations of arsenic, cadmium, and zinc would be well below the acute and chronic toxicity criteria during the dredging period, even without utilization of silt curtains. The predicted dissolved concentration of lead would be well below the acute toxicity criterion; however, the predicted dissolved concentration of lead would exceed the chronic toxicity criterion about 1 percent of the time with one dredge operating and 5 percent of the time with two dredges operating. The predicted dissolved concentration of copper would exceed the acute toxicity criterion about 7 percent of the time with one dredge operating and 17 percent of the time with two dredges operating without employing BMPs. The predicted dissolved concentration of copper would exceed the chronic toxicity criterion about 18 percent of the time with one dredge operating and 33 percent of the time with two dredges operating without employing BMPs. The predicted dissolved concentration of arsenic would exceed the drinking water standard about 0.4 percent of the time with one dredge operating and 2.4 percent of the time with two dredges operating. The predicted dissolved concentration of copper would exceed the trout TRV about 0.01 percent of the time with one dredge operating and 0.10 percent of the time with two dredges operating.

17. Extreme Events: The extreme events (>90% and <10%) predicted in this analysis are not likely to be seen at Missoula. Dredging losses are highly variable in short periods of time; therefore, longitudinal dispersion will decrease the magnitude of the extreme events with distance from the source. In addition, the contaminant concentrations in the sediment are highly variable spatially and with depth. As such, the loss of highly contaminated sediments is likely to occur for short periods of time. The duration of high dredging losses or exposure of high contamination may be on the order of minutes while the time available for longitudinal dispersion may be an hour or more.

18. Best Management Practices: BMPs for dredging consist primarily of proper selection of dredge type and model, control of the dredge operation to minimize resuspension, and the use of silt curtains around the dredging site to control release of resuspended materials. Cutterhead hydraulic dredges, when well operated, produce among the lowest resuspension of common dredge types. Control of cut depth, swing speed, cutterhead rotational velocity, and flow rate can reduce resuspension. Silt curtains, when used in the right setting have been shown to be very effective in controlling the loss of resuspended materials (Fort James Corporation et al. 2001 and Averett et al. 1996). For example, no statistically significant increase in suspended solids concentrations was measured outside of the silt curtains at Fox River and Buffalo River. Silt curtains are not recommended for use in areas with velocities greater than 1.5 fps or in areas with significant tidal fluctuations (Otis 1994 and Johanson 1976, 1977 and 1978). To be effective silt curtains should not block a large fraction of the cross-sectional area of the flow and should be arranged to direct the flow around the area to be enclosed.

19. Application of Silt Curtains at Milltown Dredging Site: During the dredging the flow in the Clark Fork River above the Milltown Dam will average about 900 cfs with a maximum flow of about 4000 cfs. The typical cross-section of the Clark Fork River in the Milltown Reservoir in the vicinity of proposed dredging is about 2500 sq ft in area. Therefore, typical velocities would range from 0.2 to 0.6 fps. Velocities exceeding 1.0 fps should occur on average only about 4 days per dredging season (July - November), and velocities during dredging are not predicted to exceed 1.5 fps (see paragraph 6). Due to the low velocity regime during the assumed dredging period, silt curtains should be highly effective so long as the area of blockage is kept below 25 percent of the cross-sectional area of flow. Significant increases in resuspension for short periods of time may be expected when the silt curtains are repositioned from one dredging location to the next.

TABLE 14. PREDICTED DISTRIBUTIONS OF DISSOLVED CONTAMINANT CONCENTRATION FOR PRODUCTION BY ONE DREDGE WITHOUT BMPs

Percentile	Dissolved Contaminant Concentration (ug/L) in the Water Column				
	Arsenic	Cadmium	Copper	Lead	Zinc
0.1	2.0030	0.10005	1.0072	0.5008	1.0104
0.5	2.0187	0.10008	1.0504	0.5017	1.0677
1	2.0518	0.10013	1.1440	0.5032	1.1840
3	2.4946	0.10028	1.3803	0.5076	1.8320
5	3.0160	0.10045	1.6795	0.5121	2.3727
10	3.1274	0.10094	2.0493	0.5248	3.0589
20	3.8409	0.10210	2.5728	0.5551	3.5070
30	4.0564	0.10396	3.2499	0.6058	4.0852
50	4.6784	0.11153	4.5458	0.7760	6.2996
70	5.6752	0.13646	6.6912	1.0691	10.0967
80	6.0542	0.18189	8.4758	1.2320	13.1475
90	6.6200	1.00584	11.6534	1.5405	20.0863
95	7.2893	1.01929	14.6010	1.8365	23.6226
97	7.8127	1.03290	16.7595	2.0406	27.0068
99	8.9426	1.06021	21.3242	2.4531	34.3417
99.5	9.6833	1.07607	24.0162	2.7220	39.1753
99.9	11.4534	1.11571	29.9645	3.2700	49.8888
Mean	4.9124	0.27997	5.8786	0.9314	8.8883
Minimum	2.0003	0.10003	1.0006	0.5004	1.0009
Maximum	15.3809	1.17693	40.7305	3.9462	73.0124
Federal Freshwater Water Quality Criteria for Protection of Aquatic Life*					
Acute	340**	4.3	13***	65	120
Chronic	150**	2.2	9***	2.5	120

* Assumes a 100 mg/L hardness; criterion is based on actual hardness measured at time of sampling.
** The Federal primary drinking water standard for arsenic is 10 ug/L (dissolved).
*** Site specific trout toxicity reference value for dissolved copper is 37 ug/L.

TABLE 15. PREDICTED DISTRIBUTIONS OF DISSOLVED CONTAMINANT CONCENTRATION FOR PRODUCTION BY TWO DREDGES WITHOUT BMPs

Percentile	Dissolved Contaminant Concentration (ug/L) in the Water Column				
	Arsenic	Cadmium	Copper	Lead	Zinc
0.1	2.0262	0.10022	1.1368	0.5069	1.1433
0.5	2.0894	0.10042	1.3460	0.5127	1.4229
1	2.1852	0.10062	1.4946	0.5176	1.7165
3	3.0183	0.10123	1.9845	0.5323	2.6982
5	3.1060	0.10174	2.2371	0.5450	3.1913
10	3.3983	0.10294	2.7159	0.5752	3.6630
20	4.0662	0.10636	3.6596	0.6566	4.6585
30	4.3382	0.11098	4.5361	0.7581	6.0218
50	5.3307	0.12746	6.5399	1.0524	9.5821
70	6.1845	0.16776	9.6076	1.4129	15.5640
80	6.7232	0.23919	12.0706	1.6966	20.6889
90	7.7624	1.01503	15.8941	2.1407	27.6251
95	8.8350	1.04164	19.6201	2.5473	35.0439
97	9.6240	1.06191	22.1908	2.8293	40.7177
99	11.4047	1.10441	27.4388	3.3782	52.1590
99.5	12.5687	1.13236	30.5964	3.6669	59.4716
99.9	15.0658	1.18933	38.9339	4.4863	77.4251
Mean	5.5033	0.29602	8.1805	1.2219	13.2244
Minimum	2.0032	0.10013	1.0310	0.5041	1.0327
Maximum	19.2549	1.30515	46.9583	5.3329	103.4072
Federal Freshwater Water Quality Criteria for Protection of Aquatic Life*					
Acute	340**	4.3	13***	65	120
Chronic	150**	2.2	9***	2.5	120

* Assumes a 100 mg/L hardness; criterion is based on actual hardness measured at time of sampling.
** The Federal primary drinking water standard for arsenic is 10 ug/L (dissolved).
*** Site specific trout toxicity reference value for dissolved copper is 37 ug/L.

TABLE 16. PROBABILITY OF DISSOLVED CONTAMINANT CONCENTRATIONS EXCEEDING FEDERAL WATER QUALITY CRITERIA FOR FRESHWATER WITHOUT BMPs

Contaminant	Federal Water Quality Criteria for Freshwater	Probability of Exceeding Federal WQC (percent)		
		Operating Condition		
		Ambient Water	One Dredge	Two Dredges
Arsenic	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	0.0	0.0	0.0
	Human Health	0.0	0.4	2.4
Cadmium	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	0.0	0.0	0.0
Copper	Acute Toxicity	0.0	7.3	17.0
	Chronic Toxicity	0.0	17.8	33.1
	Trout Toxicity	0.0	0.01	0.10
Lead	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	0.0	0.8	5.4
Zinc	Acute Toxicity	0.0	0.0	0.0
	Chronic Toxicity	0.0	0.0	0.0

20. Estimates of Increase in Water Column Contaminant Concentrations During Dredging with BMPs: When effective, no increase in suspended solids concentrations can be measured outside of the silt curtains. Data on the effectiveness of silt curtains for controlling release of dissolved contaminants are not available in the literature. Reduction of dissolved contaminant losses would be a function of the reduction of the flow in the vicinity of the dredge by the silt curtain. Flow is equal to cross-sectional area times velocity. Therefore, to estimate the fraction of the stream flow passing through the enclosed area, it is necessary to estimate the fraction of the cross-sectional area of flow enclosed by the silt curtain and the reduction of velocity through the enclosed area. Next, it is necessary to estimate the dissolved concentration of contaminants within the silt curtain assuming equilibrium with the estimated total suspended solids inside the silt curtain. Finally, the dissolved concentration within the silt curtain must be mixed with the ambient water column total recoverable contaminant concentration in proportion to the flow of each to estimate the total recoverable contaminant concentration during dredging with BMPs. Three sets of example estimates of the total recoverable contaminant concentrations during dredging with BMPs for a single dredge are given in Table 17 for one operating dredge and in Table 18 for two operating dredges using average sediment total contaminant concentrations and average ambient water column total recoverable contaminant concentrations with equal flow from the Blackfoot and Clark Fork Rivers. Each set of estimates gives the predicted total recoverable contaminant concentrations for a range of velocity or flow reductions through the area enclosed by silt curtains. Each set represents a different configuration or size of area enclosed by the silt curtains: 50%, 25% or 10% of the cross-sectional area of either the Clark Fork River or Blackfoot River. Larger areas or volumes of enclosures would tend to produce lower steady-state concentrations of TSS, which are estimated to vary from

200 mg/L to 500 mg/L for the three example configurations with one operating dredge and from 200 mg/L to 500 mg/L with two operating dredges. It should be noted that, given the configuration of Area 1, the cross-sectional area would be expected to be 10% or less. Similarly, three sets of example estimates of the dissolved contaminant concentrations during dredging with BMPs for a single dredge are given in Table 19 for one operating dredge and in Table 20 for two operating dredges using average sediment total contaminant concentrations, median sediment distribution coefficients, and average ambient water column dissolved contaminant concentrations with equal flow from the Blackfoot and Clark Fork Rivers. As stated previously, these estimates of dissolved concentrations are likely to show considerably greater increases in dissolved concentrations than is likely due to prediction of solubilization in excess of typical ranges. Nevertheless, the estimates show that under average conditions with the employment of BMPs the concentrations of contaminants should be well below the standards and criteria if the area of river enclosed by the silt curtain and the flow through and under the silt curtain are limited to extent practicable. Turbidity and metals concentrations are likely to increase for short periods of time when silt curtains are relocated.

21. Conclusions: Arsenic, cadmium, lead, and zinc concentrations are not predicted to exceed the Montana acute toxicity standards during dredging with or without implementation of BMPs. Similarly, arsenic and zinc concentrations are not predicted to exceed the Montana chronic toxicity standards during dredging with or without BMPs. Cadmium concentrations are predicted to exceed the Montana chronic toxicity standard about 5 percent of the time when two dredges are operating without BMPs. Lead concentrations in the ambient water column are predicted to exceed Montana water quality standards for chronic toxicity to aquatic life about 10 percent of the time without dredging, about 17 percent of the time with one dredge operating without BMPs, and about 25 percent of the time with two dredges operating without BMPs. Arsenic concentrations are predicted to exceed the Federal Primary Drinking Water Standard about 0.4 percent of the time when one dredge is operating and about 2.4 percent of the time when two dredges are operating without BMPs. Copper concentrations are the only concentrations in this analysis that are predicted to exceed Montana water quality standards for acute toxicity to aquatic life. Copper concentrations in the ambient water column are predicted to exceed Montana water quality standards for acute toxicity to aquatic life about 20 percent of the time without dredging, about 31 percent of the time with one dredge operating without BMPs, and about 43 percent of the time with two dredges operating without BMPs. Under average conditions, copper concentrations in the ambient water column are not predicted to exceed Montana water quality standards for acute toxicity to aquatic life during dredging with BMPs. Copper concentrations in the ambient water column are predicted to exceed Montana water quality standards for chronic toxicity to aquatic life about 24 percent of the time without dredging, about 43 percent of the time with one dredge operating without BMPs, and about 57 percent of the time with two dredges operating without BMPs. The predicted dissolved concentration of copper would exceed the trout TRV about 0.01 percent of the time with one dredge operating and 0.10 percent of the time with two dredges operating. Under average conditions with limited blockage of the river and flow through the dredging area, copper and lead concentrations are not predicted to exceed Montana water quality standards for chronic toxicity to aquatic life during dredging with BMPs. Based on conservative predictions of dissolved concentrations of the contaminants during dredging, the increased frequencies of exceedances of Federal water quality criteria are similar to the increased frequencies of exceedances of the Montana standards. Under average conditions with limited blockage of the river and flow through the dredging area, dissolved concentrations of copper and lead concentrations are not predicted to exceed Federal water quality criteria for chronic toxicity to aquatic life during dredging with BMPs. Concentrations of copper and lead may be elevated for short durations during times of high production, low flows, and high sediment contamination, when silt curtains are repositioned during changes in dredging location, and when debris is being mechanically removed to facilitate hydraulic dredging operations.

TABLE 17. EXAMPLE ESTIMATES OF TOTAL RECOVERABLE CONTAMINANT CONCENTRATIONS FOR ONE OPERATING DREDGE WITH BMPs

Velocity Fraction	Average Total Recoverable Concentrations During Dredging w/BMPs (ug/L)				
	As	Cd	Cu	Pb	Zn
Area Fraction = 0.5, TSS Concentration = 200 mg/L					
1	28.98	1.15	14.35	3.25	120.23
0.75	21.69	1.01	12.32	2.75	89.85
0.5	15.21	0.89	10.52	2.31	62.83
0.25	9.41	0.78	8.91	1.91	38.66
0.1	6.22	0.72	8.03	1.69	25.35
0.05	5.19	0.70	7.74	1.62	21.09
Area Fraction = 0.25, TSS Concentration = 350 mg/L					
1	26.22	1.11	11.90	2.64	86.56
0.75	20.34	1.02	10.92	2.39	68.08
0.5	14.80	0.92	9.99	2.16	50.68
0.25	9.59	0.84	9.12	1.93	34.28
0.1	6.60	0.79	8.62	1.81	24.88
0.05	5.62	0.77	8.45	1.77	21.82
Area Fraction = 0.1, TSS Concentration = 500 mg/L					
1	17.18	0.99	10.37	2.23	51.08
0.75	14.02	0.94	9.98	2.13	43.05
0.5	10.94	0.90	9.61	2.03	35.23
0.25	7.93	0.85	9.24	1.94	27.59
0.1	6.16	0.83	9.03	1.88	23.09
0.05	5.57	0.82	8.96	1.87	21.61
Montana Acute Standards	360.	3.9	18.	82.	120.
Montana Chronic Standards	190.	1.1	12.	3.2	110.
Avg. Amb. TR Conc. (ug/L)	5.24	0.85	9.33	1.94	21.14

TABLE 18. EXAMPLE ESTIMATES OF TOTAL RECOVERABLE CONTAMINANT CONCENTRATIONS FOR TWO OPERATING DREDGES WITH BMPs

Velocity Fraction	Average Total Recoverable Concentrations During Dredging w/BMPs (ug/L)				
	As	Cd	Cu	Pb	Zn
Area Fraction = 0.5, TSS Concentration = 400 mg/L					
1	53.17	1.44	14.50	3.35	159.24
0.75	38.76	1.22	12.43	2.82	117.38
0.5	25.96	1.02	10.59	2.35	80.17
0.25	14.50	0.84	8.94	1.93	46.88
0.1	8.19	0.74	8.04	1.70	28.53
0.05	6.17	0.71	7.75	1.62	22.66
Area Fraction = 0.25, TSS Concentration = 700 mg/L					
1	46.58	1.27	11.95	2.67	103.86
0.75	35.15	1.13	10.95	2.41	80.66
0.5	24.39	1.00	10.01	2.17	58.82
0.25	14.24	0.87	9.13	1.94	38.24
0.1	8.43	0.80	8.62	1.81	26.44
0.05	6.53	0.78	8.46	1.77	22.59
Area Fraction = 0.1, TSS Concentration = 1000 mg/L					
1	28.38	1.05	10.38	2.24	57.05
0.75	22.32	0.99	9.99	2.14	47.48
0.5	16.40	0.93	9.62	2.04	38.14
0.25	10.63	0.87	9.25	1.94	29.03
0.1	7.23	0.83	9.03	1.88	23.67
0.05	6.11	0.82	8.96	1.87	21.90
Montana Acute Standards	360.	3.9	18.	82.	120.
Montana Chronic Standards	190.	1.1	12.	3.2	110.
Avg. Amb. TR Conc. (ug/L)	5.24	0.85	9.33	1.94	21.14

TABLE 19. EXAMPLE ESTIMATES OF DISSOLVED CONTAMINANT CONCENTRATIONS FOR ONE OPERATING DREDGE WITH BMPs

Velocity Fraction	Average Dissolved Concentrations During Dredging w/BMPs (ug/L)				
	As	Cd	Cu	Pb	Zn
Area Fraction = 0.5, TSS Concentration = 200 mg/L					
1	28.29	0.70	9.34	2.25	107.52
0.75	23.50	0.61	8.01	1.92	86.86
0.5	18.02	0.51	6.48	1.54	63.24
0.25	11.70	0.40	4.72	1.11	35.98
0.1	7.41	0.32	3.52	0.81	17.52
0.05	5.89	0.29	3.10	0.71	10.97
Area Fraction = 0.25, TSS Concentration = 350 mg/L					
1	25.41	0.60	6.07	1.47	71.73
0.75	20.65	0.52	5.30	1.27	56.48
0.5	15.57	0.44	4.48	1.06	40.21
0.25	10.14	0.35	3.60	0.84	22.82
0.1	6.70	0.30	3.04	0.70	11.80
0.05	5.52	0.28	2.85	0.65	8.02
Area Fraction = 0.1, TSS Concentration = 500 mg/L					
1	17.17	0.45	4.24	1.00	36.81
0.75	13.95	0.40	3.85	0.90	28.66
0.5	10.74	0.36	3.45	0.80	20.50
0.25	7.53	0.31	3.06	0.70	12.35
0.1	5.60	0.28	2.82	0.64	7.45
0.05	4.96	0.27	2.74	0.62	5.82
Federal Acute Criteria	340.	4.3	13.	65.	120.
Federal Chronic Criteria	150.	2.2	9.	2.5	120.
Federal Drinking WQS	10.				
Site Specific Trout TRV			37.		
Avg. Amb. Diss. Conc. (ug/L)	4.32	0.26	2.66	0.60	4.19

TABLE 20. EXAMPLE ESTIMATES OF DISSOLVED CONTAMINANT CONCENTRATIONS FOR TWO OPERATING DREDGES WITH BMPs

Velocity Fraction	Average Dissolved Concentrations During Dredging w/BMPs (ug/L)				
	As	Cd	Cu	Pb	Zn
Area Fraction = 0.5, TSS Concentration = 400 mg/L					
1	52.48	1.00	9.49	2.35	146.53
0.75	42.85	0.85	8.13	2.00	118.06
0.5	31.84	0.68	6.56	1.60	85.53
0.25	19.14	0.49	4.76	1.14	47.99
0.1	10.53	0.35	3.54	0.83	22.56
0.05	7.48	0.31	3.11	0.71	13.52
Area Fraction = 0.25, TSS Concentration = 700 mg/L					
1	45.77	0.76	6.11	1.50	89.03
0.75	36.41	0.65	5.33	1.30	69.87
0.5	26.43	0.53	4.50	1.08	49.44
0.25	15.76	0.40	3.61	0.85	27.59
0.1	8.99	0.32	3.05	0.70	13.75
0.05	6.67	0.29	2.86	0.65	9.00
Area Fraction = 0.1, TSS Concentration = 1000 mg/L					
1	28.96	0.52	4.26	1.01	43.10
0.75	22.80	0.45	3.86	0.91	33.37
0.5	16.64	0.39	3.46	0.81	23.65
0.25	10.48	0.32	3.06	0.70	13.92
0.1	6.78	0.29	2.82	0.64	8.08
0.05	5.55	0.27	2.74	0.62	6.14
Federal Acute Criteria	340.	4.3	13.	65.	120.
Federal Chronic Criteria	150.	2.2	9.	2.5	120.
Federal Drinking WQS	10.				
Site Specific Trout TRV			37.		
Avg. Amb. Diss. Conc. (ug/L)	4.32	0.26	2.66	0.60	4.19

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