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Cross-sectional variability in suspended sediment and associated trace element concentrations in selected rivers in the US

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ABSTRACT Detailed sampling and subsequent physical and chemical analysis of suspended sediment obtained at different locations in the U.S. has indicated that there are substantial differences in suspended sediment concentrations and possibly in some associated trace elements depending on whether depth-integrated, point, or pumping samplers are used. In addition, the data from time-series, depth-integrated sampling indicate that there are substantial short-term (on the order of 30 minutes) spatial variatiations in suspended sediment concentrations. Despite this, major element concentrations are remarkably stable spatially and temporally. Trace element concentrations are stable; however, occasional spatial and temporal variations may occur.

#### INTRODUCTION

The role of suspended sediment in the biological and geochemical cycling of trace elements in fluvial systems is well-established (e.g., Forstner and Wittmann, 1981; Salomons and Forstner, 1984). In water-quality studies, as in other studies, the collection of a representative sample is of paramount importance, as it is impossible to sample and analyze an entire water body (Childress, et al., 1987). Unfortunately, representative sampling in fluvial cross sections to determine suspended sediment concentrations and for subsequent quantitation of associated trace elements, has long been a subject of controversy. One view suggests that adequate, representative sampling of suspended sediment requires a composite of a series of depth-integrated, isokinetic samples obtained either at equal discharge or at equal width increments across a river (Feltz and Culbertson, 1972; OWDC, 1982). Another is predicated on the view that only the <63-µm suspended sediment is geochemically significant; this material is believed to be evenly distributed in river cross sections, thus a surface or near-surface 'grab' sample taken near the centroid of flow, or a sample obtained after extended pumping (over an 8 to 12 hour period) at a point at or near the water's surface, will provide a representative sample (Ongley and Blachford, 1982). Additional suggestions indicate that the depth of a stream or its discharge, should control the type of sampling procedure employed (OWDC, 1982). Finally, little data are available on short-term spatial or temporal cross-sectional suspended sediment variations;

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as such, it is difficult to assess how much interpolation can be applied to single or multiple samples for the calculation of long-term trends, or for calculation of annual transport. The purpose of this study was to examine a series of hydrologically different river systems to determine if substantial differences could be detected between different sampling techniques (e.g., depth-integrated, point, and pump sampling). The study also was designed to examine the extent of short-term spatial and temporal variations (on the order of 20 to 30 minutes) in river cross sections. Although studies were carried out on 6 different rivers, two of which were sampled twice, several weeks/months apart, this paper presents results from two of them. However, the results are typical for all the rivers.

#### SAMPLE LOCATIONS AND METHODOLOGY

#### Sampling sites

Selected sampling sites had to meet certain criteria which included the presence of a bridge (preferably open-span); suspended sediment concentrations of at least 50 mg/L, and preferably 100 mg/L; moderate river widths (between 30 to 120 m); maximum river depth not to exceed 5 m; and maximum river velocity not to exceed 2.4 m/s. Two sites, which met these requirements, were the Cowlitz River at Kelso, Washington, and the Arkansas River at Portland, Colorado. The Cowlitz River drainage area is 6085 km<sup>2</sup> and is dominated by andesitic material resulting from recent Mt. St. Helen's eruptions. The Arkansas River drainage area is 10,420 km<sup>2</sup> and is affected by local sulfide ore mining and agricultural activities.

#### On-site procedures

At each site mean velocity was determined using the current-meter method. Discharges were computed and 5 equal discharge incremental vertical station locations (EDIV) were identified. In addition to the 5 EDIV's, a location near the centroid of flow, if possible, was selected for the placement of a point sampler and a pump sampler. A two-man crew was located at each EDIV and equipped with a four-wheel crane, a D-77 sampler, a current meter, and a stop watch to obtain depth-integrated samples. Point samples were collected by using a D-77 bag sampler modified with a solenoid valve which permitted sampling at 20% of depth. The pump sample also was obtained at 20% of depth by using an impeller pump equipped with a 3.8 cm intake. Sampling times, based on initial velocity measurements, were selected to limit sample volumes to 2700 to 3000 mL of whole water. The sizes of the D-77 intake nozzles were selected based upon either direct measurement of flow velocities, or from discharge measurements made at each EDIV.

The first series of EDIV samples was collected simultaneously at each sample site and was composited in a churn splitter after sieving through a 63- $\mu$ m screen to provide an initial representative cross-sectional sample of the silt- and clay-sized material. The coarser composited material was washed from the screen by using deionized water. Immediately afterwards, a second set of EDIV samples was collected along with point and pump samples which were treated as individual samples and were not composited. Five additional EDIV, point, and pump samples were collected at fixed-time intervals (roughly 20 to 30 min apart). Immediately after the 5 additional samples were collected, a seventh set of EDIV samples was collected and composited to provide a final representative cross-sectional sample. After collection, each sample (composite, EDIV, point, or pump) was stored in acid-washed, polyethylene bottles and kept on ice at 4°C until processed.

Sample processing took up to three days owing to the large number of samples. Field processing entailed a two-step procedure. Each sample was wet-sieved through a 63- $\mu$ m stainless steel sieve (the mesh was held in the frame by crimping; no solder was used) to separate the sand-sized material from the silt- and clay-sized material. This separation was followed by centrifugation to concentrate the <63- $\mu$ m suspended sediment fractions, and was performed by using a laboratory centrifuge. Spin times were selected to limit particle

separations to  $0.45\mu m$  or larger. The >63- $\mu m$  material was washed from the sieves by using deionized water. Final sample concentrate volumes were about 100 mL. The concentrated suspended sediment was then frozen in pre-tared containers and shipped on dry ice to Atlanta, Georgia, for initial laboratory processing.

#### Laboratory procedures

Upon arrival, each sample was freeze dried, and the weight of suspended sediment was determined. Each sample was then subjected to surface-area analysis using a single-point BET procedure to provide data on grain-size variations within the >63- $\mu$ m and the <63- $\mu$ m fractions (Horowitz and Elrick, 1987). Suspended sediment concentrations were determined by using the freeze-dried weights of both fractions after correction for dried dissolved solids contributions. The dried samples were then repacked and shipped to Menlo Park, California, for chemical analysis.

Chemical analyses of the various samples were performed by using a direct-reading emission spectrometer. Prior to analysis, pre-weighed (ground if necessary) samples were mixed with a combination of graphite, buffer, and internal standards and packed in graphite electrodes. The electrodes were burned in an argon/oxygen (70%/30%) atmosphere for 90 seconds, with the current programmed as follows: 3 amps for 3 seconds, 8 amps for 10 seconds, and 17.5 amps to completion. The internal standards provided a means of correcting analytical results for variations in the dc arc. Analytical precision and bias were monitored by replicate analyses and through the use of various reference materials (e.g., G-2, AGV-1). Precision and bias varied from element to element but were about  $\pm 15$  to 20%.

#### **RESULTS AND DISCUSSION**

The results for both sets of samples are presented in paired tables to allow examination of potential spatial and temporal variability (Tables 1 and 2: Arkansas River; Tables 3 and 4: Cowlitz River). Data in Tables 1 and 3 permit comparison of spatial variability of simultaneously collected depth-integrated samples from the EDIV's. The data also allow comparisons with the initial and the final depth-integrated composite samples and the simultaneously-collected EDIV's. A calculated composite (C. Comp 1, C. Comp 3) also is provided for each set of EDIV's. Data in Tables 2 and 4 permit comparison of temporal variability of 6 depth-integrated samples. Data for the point and the pump samples, and calculated means for each group, are also provided. The data on surface areas and chemistries are for the <63- $\mu$ m fractions.

#### Arkansas River

During the course of sampling the Arkansas River, and after the fourth set of EDIV's was collected, a thunderstorm initially occurred upstream from the sampling site and then at the site. An increase in turbidity was visually detected during the sampling operations. This should be kept in mind when reviewing the data in Tables 1 and 2. The data in Table 1 indicate that cross-sectional suspended sediment concentrations vary substantially; concentrations differ by as much as 250% (e.g., for the first set EDIV's, concentrations range from 182 to 494 mg/L; for the fourth set of EDIV's, concentrations range from 199 to 638 mg/L). Note that the major source for this variation is the >63-µm material; within the limits of analytical error, the <63-µm sediment concentrations essentially are constant. This type of distribution has been noted before (Feltz and Culbertson, 1972; Ongley and Blachford, 1982). The concentration of coarse material (>63µm) increases substantially from near the banks toward the center of the river. This probably is a function of stream velocity, which is higher toward the center of the river where frictional resistance is lower.

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The lower velocities reduce a river's capacity for suspending and transporting larger sediment particles. It would seem that bank deposits are not major contributors to the suspended sediment load in the river, as the samples obtained closest to the banks (D-20, D-95) tend to have the lowest suspended sediment concentrations.

The surface-area results, on an individual basis, do not correlate well with the silt-clay percentages; this is somewhat surprising since previous findings indicated a strong positive correlation between surface area and the %<63- $\mu$ m concentrations (Horowitz and Elrick, 1987). This lack of correlation also may be due to the separation of the 63- to 125- $\mu$ m fraction, which also displayed a strong positive correlation with surface area. However, the calculated composite values for surface area (C. Comp 1, C. Comp 2, etc.) do show a steady increase with increasing calculated composite concentrations of the %<63- $\mu$ m fractions.

For the most part, within the analytical precision of the method employed, the chemistry of the EDIV samples does not vary substantially, ( $<63-\mu$ m fractions). There are a few exceptions; for example, the Cu concentration in the sixth set at the fifth EDIV (D6-80) is higher than the Cu levels found for the other EDIV's. The same can be said for the Pb concentration for D1-50.

The effects of the upstream thunderstorm are reflected in a number of the results for the fifth (D5) and particularly the sixth (D6) set of simultaneous EDIV samples. In the fifth set, the most apparent changes are increased concentrations of Pb and Zn, and to a lesser extent, Cu. The changes displayed in the sixth set are more substantial. Suspended sediment concentrations increased by 25%, the concentration of <63- $\mu$ m material increased by 50%, the surface area increased by 25%, and the concentrations of Cu, Zn, and Pb, increased by 2- to 10-fold. Surprisingly, the concentration of >63- $\mu$ m material remained constant, or decreased slightly. Throughout the sampling program, the concentrations of the major elements (Fe, Mn, Al, and Ti), and some of the trace elements (Cr, Ni, and Co) for the <63- $\mu$ m material remained constant. The increases noted in the sixth set of EDIV samples also continue into the final cross-sectional composite sample (Comp 2).

There are several conclusions that can be drawn from the spatial variability results. Sampling only in the centroid of flow (D-50 and D-80 sites) would provide biased results for a number of constitutents relative to composite samples and relative to other locations in the river. Biased results would include high suspended sediment concentrations, high concentration of >63- $\mu$ m material, low %<63- $\mu$ m material, and high %>63 $\mu$ m material. Interestingly, sampling in the centroid would have provided a reasonable estimate of surface area, the concentration of <63- $\mu$ m material, and the sediment chemistry of the <63- $\mu$ m material. Finally, the observed changes due to the thunderstorm indicate the potential importance of event sampling.

The effects of the upstream storm were responsible for the dominant temporal variations shown in Table 2, which are similar to those differences noted for the spatial comparisons. There are substantial increases in surface area, suspended sediment concentration, the concentration of <63- $\mu$ m material, the %<63- $\mu$ m fraction, and the concentrations of Cu, Zn, and Pb (D1 to D4 compared with D5 and D6). If the storm effects are ignored, and the data from the first EDIV samples (D1 to D4) are examined, it is apparent that substantial differences in the means of such factors as suspended sediment concentration, concentration of <63- $\mu$ m material, the %>63- $\mu$ m and <63- $\mu$ m fractions, and Zn and Pb concentrations occurred over relatively short time spans.

If data obtained from material collected with the point and the pump samplers are compared with similar data from material collected from the two nearest EDIV's (D-50 for the point, D-80 for the pump), differences can be detected in surface area, in suspended sediment concentration, and in the concentrationes of the >63- $\mu$ m and <63- $\mu$ m material. Additional differences exist when the point and pump sample data are compared with calculated cross-sectional composite values (Table 1). Interestingly, comparison of the chemical data indicate that the type of sampler used is immaterial. However, the chemical data associated with the point samples are slightly closer to the results from the EDIV samples, or the calculated composite concentrations, than to the concentrations associated with the pump samples. Thus, it seems that point or pump samples obtained in the cen

### Table 1 Spatial Variability of Samples Collected from the Arkansas River\*

[DX-XX-L: individual verticals, X: vertical number, XX: distance from left bank; Comp: collected composite sample; C. Comp: calculated composite; m2/g: square meters per gram; N/A: not available]

	Surface	Sus. Sed.	Conc.	Conc.	%	%								_		
	Area	Conc.	<63µm	>63µm	<63µm	>63µm	Fe	Mn	٨I	Ti	Cu	Zn	РЬ	Cr	Ni	Co
Sample	(m2/g)	(mg/L)	(mg/L)	(mg/L)	(%)	(%)	(%)	(ppm)	(%)	(%)	(ppm	) (ppm)	(ppm)	(ppm	) (ppm)	)(ppm)
Comp 1	13.6	Ν/Λ	108	N/A	N/A	N/A	3.6	950	7.4	0.33	41	340	54	43	28	13
D1-20-L	13.5	182	105	77	58	42	3.5	900	7.2	0.38	41	410	71	45	29	13
D1-40-L	10.8	263	103	160	39	61	3.6	930	7.0	0.34	39	410	66	46	28	12
D1-50-L	8.6	416	112	304	27	73	3.4	970	6.7	0.33	43	480	87	46	30	12
D1-80-L	10.4	494	107	387	22	78	3.9	1100	7.9	0.39	45	440	69	47	30	13
D1-95-L	9.1	254	99	155	39	61	3.6	940	7.0	0.34	40	440	64	44	27	12
C. Comp 1	10.5	322	105	217	37	63	3.6	970	7.2	0.36	42	440	71	46	29	12
D2-20-L	8.6	204	128	76	63	37	3.0	770	6.2	0.31	37	430	68	46	30	11
D2-40-L	18.0	264	125	139	47	53	3.5	840	7.1	0.33	40	460	70	47	32	12
D2-50-L	13.2	536	131	405	24	76	3.4	810	7.0	0.33	37	420	61	51	31	12
D2-80-L	15.8	511	128	383	25	75	3.5	890	7.2	0.38	40	470	72	50	33	13
D2-95-1,	18.0	263	120	143	46	54	3.6	890	7.2	0.33	42	360	63	47	31	12
C. Comp 2	14.7	356	126	229	41	59	3.4	840	6.9	0.34	39	428	67	48	31	12
D3-20-L	20.9	216	149	67	69	31	3.5	850	6.8	0.30	40	350	54	48	35	12
D3-40-L	17.6	274	145	129	53	47	3.6	780	7.4	0.35	38	430	65	52	34	13
D3-50-L	14.1	344	143	201	42	58	3.5	850	7.3	0.34	41	370	59	51	36	13
D3-80-L	13.4	624	151	473	42	58	3.3	760	7.0	0.32	38	310	47	45	31	11
D3-95-L	21.0	272	140	132	51	49	3.5	770	7.0	0.34	37	410	61	51	33	12
C. Comp 3	17.4	346	146	200	51	49	3.5	800	7.1	0.33	39	370	57	49	34	12
D4-20-L	18.1	199	136	63	68	32	3.2	660	6.2	0.29	35	360	58	45	31	12
D4-40-L	16.8	238	129	109	54	46	3.7	880	7.5	0.36	40	460	75	51	34	13
D4-50-L	19.0	307	128	179	42	58	3.5	860	7.3	0.33	41	360	61	49	34	13
D4-80-L	19.7	638	130	508	42	58	3.5	880	7.0	0.34	52	440	71	56	37	12
D4-95-L	18.4	225	132	93	59	41	3.3	750	6.7	0.31	33	350	48	51	30	12
C. Comp 4	18.4	321	131	190	53	47	3.4	810	6.9	0.33	40	390	63	50	33	12
D5-20-L	18.4	190	131	59	69	31	3.5	810	7.1	0.34	54	530	130	45	31	12
D5-40-L	16.6	253	134	119	53	47	3.6	920	7.0	0.34	50	470	130	50	31	12
D5-50-L	19.9	298	135	163	45	55	3.6	800	7.3	0.35	42	370	100	46	30	13
D5-80-L	17.5	550	134	416	45	55	3.8	850	7.1	0.33	47	420	110	47	31	13
D5-95-L	19.1	241	123	118	51	49	3.6	870	6.8	0.34	41	550	120	48	31	13
C. Comp 5	18.3	306	131	175	53	47	3.6	850	7.1	0.34	47	470	120	47	31	13
D6-20-L	23.7	254	199	55	78	22	3.5	650	5.9	0.26	63	>1000	>1300	43	32	11
D6-40-L	23.1	319	222	97	70	30	3.9	690	6.8	0.31	69	920	>1300	49	35	12
D6-50-L	23.1	401	222	179	55	45	3.8	720	6.6	0.28	71	>1000	>1300	46	35	12
D6-80-L	20.1	642	209	433	55	45	4.0	720	6.5	0.30	100	980	>1300	48	37	12
D6-95-L	23.8	317	198	119	62	38	4.1	800	6.9	0.30	74	870	>1300	48	34	12
C. Comp 6	22.8	387	210	177	64	36	3.9	720	6.5	0.29	75	950	>1300	47	35	12
Comp 2	26.1	406	245	161	60	40	3.9	710	6.5	0.29	74	>1000	>1300	49	38	12

<sup>\*</sup>The data is presented to permit examination of spatial variability in the cross-section of the Arkansas River. Each group of samples contains simultaneously collected depth-integrated verticals. Thus, the first group (D1-20-L through D1-95L) contains simultaneously collected samples at 20, 40, 50, 80, and 95 feet from the left bank of the river. C. Comp 1 is the calculated composite for that group of simultaneous samples. The next group (D2-20-L through D2-95L) contains the next set of simultaneous samples; however, these were collected some 20 minutes after the first group. All the other groups follow the same pattern. Surface Sus. Sed. Conc. Conc.

## Table 2 Temporal Variability of Samples Collected from the Arkansas River\*

[DX-XX-L: individual verticals, X: vertical number, XX: distance from left bank; BX-XX-L: pump samples,
X: sample number, XX: distance from left bank; PX-XX-L: point samples, X: sample number, XX: distance
from left bank; Mean-XX: calculated means for each column; m2/g: square meters per gram; N/A: not
available

%

%

	Area	Conc.	<63µm	>63µm	<63µm	>63µm	Fe	Mn	A1	Ti	Cu	Zn	Рb	Cr	Ni	Co
Sample	(m2/g)	(mg/L)	(mg/L)	(mg/L)	(%)	(%)	(%)	(ppm)	(%)	(%)	(ppm)	(ppm)	(ppm)	(ppm	)(ppm)	)(ppm)
D1-20-L	13.5	182	105	77	58	42	3.5	900	7.2	0.38	41	410	71	45	29	13
D2-20-L	8.6	204	128	76	63	37	3.0	770	6.2	0.31	37	430	68	46	30	11
D3-20-L	20.9	216	149	67	69	31	3.5	850	6.8	0.30	40	350	54	48	35	12
D4-20-L	18.1	199	136	63	68	32	3.2	660	6.2	0.29	35	360	58	45	31	12
D5-20-L	18.4	190	131	59	69	31	3.5	810	7.1	0.34	54	530	130	45	31	12
D6-20-L	23.7	254	199	55	78	22	3.5	650	5.9	0.26	63	>1000	>1300	43	32	11
Mean -20	17.2	208	141	66	68	33	3.4	773	6.6	0.31	45	416	76	45	31	12
D1 40 I	10.8	263	103	160	30	61	36	030	70	0 34	30	410	66	46	28	12
D1-40-L	18.0	261	125	130	17	53	35	840	71	0.33	40	460	70	47	32	12
D2-40-C	17.6	204	145	120	53	17	3.6	780	7 4	0.35	38	430	65	52	34	13
D3-40-L	16.8	274	120	100	54	46	3.0	880	75	0.35	40	460	75	51	34	13
D4-40-L	16.6	250	123	110	53	40	3.6	020	7.0	0.30	50	400	130	50	31	12
DJ-40-L	10.0	233	134	07	70	20	2.0	920 600	6.0	0.34	60	020	>1200	10	25	12
D0-40-L	23.1	319	142	126	52	30	3.9	840	0.0	0.31	46	920	21300	49	22	12
Mean-40	17.2	269	145	120	55	47	5.1	640	7.1	0.54	40	525	01	49	32	12
D1-50-L	8.6	416	112	304	27	73	3.4	970	6.7	0.33	43	480	87	46	30	12
D2-50-L	13.2	536	131	405	24	76	3.4	810	7.0	0.33	37	420	61	51	31	12
D3-50-L	14.1	344	143	201	42	58	3.5	850	7.3	0.34	41	370	59	51	36	13
D4-50-L	19.0	307	128	179	42	58	3.5	860	7.3	0.33	41	360	61	49	34	13
D5-50-L	19.9	298	135	163	45	55	3.6	800	7.3	0.35	42	370	100	46	30	13
D6-50-L	23.1	401	222	179	55	45	3.8	720	6.6	0.28	71	>1000	>1300	46	35	12
Mean-50	16.3	384	145	239	39	61	3.5	835	7.0	0.33	46	400	74	48	33	13
D1-80-L	10.4	494	107	387	22	78	3.9	1100	7.9	0.39	45	440	69	47	30	13
D2-80-L	15.8	511	128	383	25	75	3.5	890	7.2	0.38	40	470	72	50	33	13
D3-80-L	13.4	624	151	473	42	58	3.3	760	7.0	0.32	38	310	47	45	31	11
D4-80-L	19.7	638	130	508	42	58	3.5	880	7.0	0.34	52	440	71	56	37	12
D5-80-L	17.5	550	134	416	45	55	3.8	850	7.1	0.33	47	420	110	47	31	13
D6-80-L	20.1	642	209	433	55	45	4.0	720	6.5	0.30	100	980	>1300	48	37	12
Mean-80	16.2	577	143	433	39	62	3.7	867	7.1	0.34	54	510	74	49	33	12
D1-95-L	9.1	254	99	155	39	61	3.6	940	7.0	0.34	40	440	64	44	27	12
D2-95-L	18.0	263	120	143	46	54	3.6	890	7.2	0.33	42	360	63	47	31	12
D3-95-L	21.0	272	140	132	51	49	3.5	770	7.0	0.34	37	410	61	51	33	12
D4-95-L	18.4	225	132	93	59	41	3.3	750	6.7	0.31	33	350	48	51	30	12
D5-95-L	19.1	241	123	118	51	49	3.6	870	6.8	0.34	41	550	120	48	31	13
D6-95-L	23.8	317	198	119	62	38	4.1	800	6.9	0.30	74	870	>1300	48	34	12
Mean-95	18.2	262	135	127	51	49	3.6	837	6.9	0.33	45	497	71	48	31	12
B1-70-L	10.3	485	97	388	20	80	3.4	890	6.7	0.34	41	340	51	41	27	11
B2-70-L	15.8	334	117	217	35	65	3.7	910	7.7	0.35	42	390	61	48	33	13
B3-70-L	19.2	435	140	295	32	68	3.4	800	7.3	0.33	40	390	59	48	32	12
B4-70-L	19.3	N/A	N/A	N/A	N/A	N/A	3.3	870	7.0	0.33	48	410	78	49	33	12
B5-70-L	21.3	305	97	208	32	68	3.6	900	7.5	0.37	49	380	100	49	31	13
B6-70-L	24.9	400	200	200	50	50	4.0	850	6.3	0.29	75	>1000	) >1300	47	35	12
Mcan B-70	18.5	392	130	262	34	66	3.6	870	7.1	0.34	49	382	70	47	32	12
P1.551	12.4	272	102	221	16	51	2 4	060	65	0.24	15	200	61	15	20	11
P2.55.1	17.4	325	102	200	56	44	3.4	840	64	0.34	4.) 19	390	70	43	20	11
P3-55-1	17.5	218	139	80	63	37	3.3	730	70	0.31	54	340	60	41	21	12
P4-55-1	1/.5	197	100	64	605	21	2.1	790	63	0.00	27	210	50	. 43	21	12
P5-55 I	24.7 20.4	202	123	77	60	27	2.0	010	77	0.29	וכ	510 A70	140	44	22	10
P6.55.I	20.4	200	217	68	76	24	3.7	700	62	0.55	77	<100C	140	40	25	- 12
Mean D.SS	18 2	203	130	112	67	29	4.0 2 A	925	67	0.20	50	2000	· 71300	, JU 17	22	12
Intern Faild	10.3	200	1.37	110	02		5.4	0.3.5	0.7	V.24		200	11	- 4/		14

The data is presented to permit examination of temporal variability in the cross-section of the Arkansas River. Each group of samples contains sediments collected at a single EDIV site; each sample was collected approximately 20 minutes apart. Thus, the first group (D1-20-L through D6-20-L) contains all the samples collected at the EDIV site 20 feet from the left bank. Mean -20 contains the calculated values for the entire group of samples collected over the sampling period. The next group (D1-40-L through D6-40-L) contains samples collected at the EDIV site 40 feet from the left bank. All the other groups follow the same pattern. The table also contains data for the pump (B1-70 through B6-70) and point samples (P1-55 through P6-55)

troid of a river, relative to either EDIV samples or to cross-sectional composites, would provide a fairly accurate measure of river cross-sectional sediment chemistry, but would provide biased data on such factors as suspended sediment concentration, surface area, and the concentrationes of <63- $\mu$ m and >63- $\mu$ m material.

#### Cowlitz River

The data in Table 3 indicate that many of the suspended sediment spatial variations noted for the Arkansas River also appear for the Cowlitz River (e.g., suspended sediment concentrations and the concentration of >63- $\mu$ m material increase from the banks toward the center of the river, while the concentration of <63- $\mu$ m material essentially remains constant). However, unlike the Arkansas River, the chemistry of the <63- $\mu$ m material from the EDIV's varies substantially. At the third (D3) and fourth (D4) EDIV's, sediments collected furthest from the left bank (D3-325, D4-325) have elevated Cu, Cr, and Ni concentrations. The elevated concentrations are restricted to this single EDIV. Also, at the fifth (D5) and sixth (D6) EDIV's, the sediments closest to the left bank (D5-75, D6-75) show elevated Cu, Cr, and Ni levels. Again, the elevated concentrations are restricted to this single EDIV. In each case, the higher concentrations occur in the EDIV's closest to the river banks, and may be due to the resuspension of finer-grained river bank deposits. However, neither the D3 and D4-325 nor the D5 and D6-75 samples display substantial changes in either their >63- $\mu$ m or <63- $\mu$ m concentrationes.

Examination of the calculated composite data (e.g., C. Comp 3, C. Comp 5) indicate that the elevated levels of Cu, Cr, and Ni noted above, have a substantial impact on the calculated cross-sectional (composite) concentrations for these elements as compared to the calculated composites, where these elevated levels did not occur (2 to 3 times higher). The elevated Cu, Cr, and Ni concentrations did not occur in either the initial or the final composite samples (Comp 1, Comp 2). These data indicate the potential transitory (on the order of 40 minutes or less) and localized (the higher concentrations did not occur in the adjacent EDIV's 30 m away) nature of chemical variations in river cross sections. Such findings indicate the need to sample an entire cross section rather than only in the centroid of flow, to obtain an adequate measure of suspended sediment-associated trace elements. These findings also may place potential limits on the utility of infrequent single-sample suspended sediment chemical data (whether single point, or cross sectional) for calculating such factors as annual sediment-associated trace element transport.

The temporal variability data (Table 4) reflect similar differences to those noted for the spatial variability data. Owing to local conditions, pump samples could not be taken in the centroid of flow, hence, those data have been excluded. The point samples (P1) differ from the the depth-integrated samples obtained at the nearest EDIV and from the calculated composite samples in terms of suspended sediment concentration and the concentration of  $>63-\mu m$  material. These differences also were noted for the Arkansas River. However, unlike the Arkansas River data, the point-sample data do not have similar chemical concentrations when compared to the depth-integrated or the calculated composite concentrations. Major differences for the concentrations of Cu, Zn, Pb, and Cr occur, primarily, as a result of the elevated concentrations associated with the first point sample (P1-195). These differences could be due to a localized spatial/temporal chemical variation of the type noted above, they could be due to differences in the samplers (point vs. depth-integrated), or they could be due to differences in how the samples were obtained (fixed point at 20% of depth vs. depth-integrated). The nearest EDIV sample did not contain elevated Cu, Zn, Pb, and Cr levels, even though it was less than 2 m away. This probably would preclude a localized spatial/temporal suspended sediment-associated variation; however, it does not clarify whether the noted differences are due to sampler type or to how the samples were collected. In conclusion, the data presented herein highlight the potential difficulties of attempting to compare suspended sediment-chemical data from sediments obtained either with different types of samplers, or by using different sampling techniques.

# Table 3 Spatial Variability of Samples Collected from the Cowlitz River\*

### [DX-XX-L: individual verticals, X: vertical number, XX: distance from left bank; Comp: collected composite sample; C. Comp: calculated composite; m2/g: square meters per gram; N/A: not available]

-	0 č	6	<i>G</i>	C												
	Surface	Sus. Sed.	Conc.	Conc.	% ~62um	%	T/a	Ma	A 1	т	Cu	7.	Db	<b>C</b> -	NG	Co
Comunito	Area	Conc.	(mall)	>05µm		205μm	(01)	(0000)	(07)	(07.)	(nnm)	(nnm)	(nnm)	(nnm)	(19)	(100)
Comp 1	(m2/g)	(1112/1.)	201	(ing/c) 275	(70)	59	40	(ppin) 650	(10)	0 4 2	76	71	13	27 27	20 20	11
Comp 1	3.5	470	201	215	42	20	4.0	050	0.2	0.42	70	/1	15	21	20	14
D1-75-L	3.8	430	186	244	43	57	3.8	650	8.4	0.43	51	57	<10	19	15	14
D1-130-L	3.3	475	181	294	38	62	4.1	680	8.6	0.38	58	58	<10	18	15	14
D1-190-L	3.4	576	181	395	31	69	4.0	690	8.5	0.43	59	58	<10	20	15	14
D1-230-L	3.2	499	188	311	38	62	3.5	650	7.4	0.40	56	62	<10	27	17	14
D1-325-L	4.1	285	159	126	56	44	3.3	510	7.8	0.40	69	80	14	21	15	13
C. Comp 1	3.6	453	179	274	41	59	3.7	636	8.1	0.41	59	63	14	21	15	14
D2-75-L	36	428	187	241	44	56	3.4	500	73	0.37	51	51	<10	15	13	12
D2-130-1	34	458	183	275	40	60	4.0	660	82	0 37	55	72	<10	18	15	14
D2-190-L	31	578	179	300	31	69	37	610	79	0.38	59	79	11	22	16	24
D2-230-L	33	693	178	515	26	74	4.0	710	8.5	0.42	62	61	10	23	17	14
D2-325-I	30	281	168	113	60	40	37	690	8.9	0.43	65	75	17	21	16	14
C Comp 2	35	488	179	309	40	60	3.8	634	82	0.39	58	68	13	20	15	16
e. comp z	5.5	100		507	10		5.0	051	0.2	0.57	50	00	15	20	15	10
D3-75-L	3.4	428	217	211	51	49	4.1	700	8.6	0.46	53	60	10	19	16	15
D3-130-L	3.8	457	203	254	44	56	4.3	780	8.2	0.42	59	51	12	25	18	15
D3-190-L	3.2	551	177	374	32	68	3.5	650	7.9	0.38	59	61	11	19	15	13
D3-230-L	3.1	578	193	385	33	67	3.7	660	8.3	0.45	60	51	<10	27	18	14
D3-325-L	3.1	315	175	140	56	44	4.1	700	9.3	0.43	105	63	14	240	160	16
C. Comp 3	3.3	466	193	273	43	57	3.9	698	8.5	0.43	67	57	12	66	45	15
D4-75-L	3.3	423	180	243	43	57	3.8	680	8.6	0.42	63	57	10	18	16	14
D4-130-L	4.0	449	162	287	36	64	3.8	630	8.5	0.43	55	55	11	19	15	14
D4-190-L	3.6	519	174	345	34	66	3.7	670	9.0	0.43	53	55	11	20	15	14
D4-230-L	3.2	579	175	404	30	70	3.4	540	8.0	0.42	58	55	10	19	15	14
D4-325-L	3.5	285	162	123	57	43	3.4	630	8.4	0.40	90	75	15	58	41	14
C. Comp 4	3.5	451	171	280	40	60	3.6	630	8.5	0.42	64	59	11	27	20	14
D5-75-L	3.6	424	189	235	45	55	3.8	650	8.2	0.42	110	67	14	190	130	14
D5-130-L	3.4	441	176	265	40	60	3.8	660	8.5	0.44	54	65	11	21	16	14
D5-190-L	3.7	510	148	362	29	71	3.3	670	8.2	0.36	55	50	<10	15	13	12
D5-230-L	3.3	583	177	406	30	70	3.8	590	8.9	0.44	54	50	<10	20	15	14
D5-325-L	3.7	293	167	126	57	43	3.6	600	8.3	0.39	55	66	13	18	14	13
C. Comp 5	3.5	450	171	279	40	60	3.7	634	8.4	0.41	66	60	13	53	38	13
D6-75-L	3.4	441	186	255	42	58	4.1	700	8.5	0.43	77	85	14	140	93	15
D6-130-L	3.8	407	170	237	42	58	30	680	8.2	0.41	62	59	10	10	15	14
D6-190-L	3.1	446	162	284	36	64	3.8	540	8.1	0.40	56	51	<10	18	15	13
D6-230-I.	3.4	540	167	373	31	69	3.7	620	8.5	0.40	57	52	11	23	17	14
D6-325-L	4.1	296	165	131	56	44	3.4	640	8 2	0.39	53	60	12	19	15	13
C. Comn 6	3.6	426	170	256	41	59	3.8	636	8.3	0.41	61	61	12	44	31	14
c. comp 0	5.0		110	<i></i>	-71		5.0	050	0.5	0.71	01	01	12		51	14
Comp 2	3.3	460 <sup>•</sup>	182	278	40	60	4	690	8.5	0.46	52	54	11	22	16	15

\*The data is presented to permit examination of spatial variability in the cross-section of the Cowlitz River. Each group of samples contains simultaneously collected depth-integrated verticals. Thus, the first group (D1-75-L through D1-325-L) contains simultaneously collected samples at 75, 130, 190, 230, and 325 feet from the left bank. The next group (D2-75-L through D2-325-L) contains the next set of simultaneous samples; however, these were collected some 20 minutes after the first group. All the other groups follow the same pattern.

# Table 4 Temporal Variability of Samples Collected from the Cowlitz River\*

[DX-XX-L: individual verticals, X: vertical number, XX: distance from left bank; PX-XX-L: point samples, X: sample number, XX: distance from left bank; Mean-XX: calculated means for each column; m2/g: square meters per gram; N/A: not available]

					• •											
	Surface	Sus. Sed.	Conc.	Conc.	%	%										
	Arca	Conc.	<63µm	>63µm	<63µm	>63µm	Fe	Mn	A1	Ti	Cu	Zn	РЬ	Cr	Ni	Co
Sample	(m2/g)	(mg/L)	(mg/L)	(mg/L)	(%)	(%)	(%)	(ppm)	(%)	(%)	(ppm	)(ppm	) (ppm	)(ppm	)(ppm	) (ppm)
D1-75-L	3.8	430	186	244	43	57	3.8	650	8.4	0.43	51	57	<10	19	15	14
D2-75-L	3.6	428	187	241	44	56	3.4	500	7.3	0.37	51	51	<10	15	13	12
D3-75-L	3.4	428	217	211	51	49	4.1	700	8.6	0.46	53	60	10	19	16	15
D4-75-L	3.3	423	180	243	43	57	3.8	680	8.6	0.42	63	57	10	18	16	14
D5-75-L	3.6	424	189	235	45	55	3.8	650	8.2	0.42	110	67	14	190	130	14
D6-75-L	3.4	441	186	255	42	58	4.1	700	8.5	0.43	77	85	14	140	93	15
Mean-75	3.5	429	191	238	45	55	3.8	647	8.3	0.42	68	63	12	67	47	14
D1-130-L	3.3	475	181	294	38	62	4.1	680	8.6	0.38	58	58	<10	18	15	14
D2-130-L	3.4	458	183	275	40	60	4.0	660	8.2	0.37	55	72	<10	18	15	14
D3-130-L	3.8	457	203	254	44	56	4.3	780	8.2	0.42	59	51	12	25	18	15
D4-130-L	4.0	449	162	287	36	64	3.8	630	8.5	0.43	55	55	11	19	15	14
D5-130-L	3.4	441	176	265	40	60	3.8	660	8.5	0.44	54	65	11	21	16	14
D6-130-L	3.8	407	170	237	42	58	30	680	82	0.41	62	59	10	10	15	14
Mean-130	3.6	448	179	269	40	60	4.0	682	8.4	0.41	57	60	11	20	16	14
D1-190-L	3.4	576	181	395	31	69	4.0	690	8.5	0.43	59	58	<10	20	15	14
D2-190-L	31	578	179	300	31	69	37	610	79	0 38	59	70	11	22	16	24
D3-190-I	3.7	551	177	374	32	68	35	650	70	0.38	50	61	11	10	15	13
D4-100-L	3.6	510	174	345	34	66	3.7	670	0.0	0.30	53	55	11	20	15	14
D5 100 I	27	510	1/9	262	20	71	22	670	87	0.45	55	50	~10	15	12	12
DS-190-L	21	110	140	202	29	61	3.3	540	0.2	0.30	55	51	<10	10	15	12
Mean-190	3.4	530	170	264 360	32	68	3.8 3.7	638	8.3	0.40	57	59	11	19	15	15
D1 220 I	2.0	400	100		20	~	25	650	7.4	0.40		~	.10	07	17	14
DI-230-L	3.2	499	188	311	38	62	3.5	050	1.4	0.40	20	62	<10	21	17	14
D2-230-L	3.3	693	178	515	26	14	4.0	/10	8.5	0.42	62	61	10	23	17	14
D3-230-L	3.1	5/8	193	385	33	67	3.7	660	8.3	0.45	60	51	<10	27	18	14
D4-230-L	3.2	579	175	404	30	70	3.4	540	8.0	0.42	58	55	10	19	15	14
D5-230-L	3.3	583	177	406	30	70	3.8	590	8.9	0.44	54	50	<10	20	15	14
D6-230-L	3.4	540	167	373	31	69	3.7	620	8.5	0.40	57	52	11	23	17	14
Mean-230	3.3	579	180	399	31	69	3.7	628	8.3	0.42	58	55	10	23	17	14
D1-325-L	4.1	285	159	126	56	44	33	510	78	0.40	69	80	14	21	15	13
D2-325-L	30	281	168	113	60	40	37	690	80	0 43	65	75	17	21	16	14
D3-325-L	31	315	175	140	56	40	A 1	700	0.7	0.43	105	63	14	240	160	16
D4-325-1	35	285	162	173	57	13	3 1	630	81	0.45	00	75	15	58	<b>1</b> 100	14
D5-325-L	37	203	167	125	57	43	26	600	0.4	0.40	55	66	12	10	14	12
D6-325-L	A 1	295	165	120	56	43	24	640	0.5	0.37	52	60	13	10	15	12
Maan 225	37	290	165	107	50	44	2.4	640	0.2	0.39	77	70	12	67	1.5	1.5
Ivicali-525	5.7	293	100	127	57	43	3.0	028	8.3	0.41	13	70	14	03	44	14
P1-195L	3.7	427	184	243	43	57	4.1	660	8.3	0.43	100	140	74	30	18	14
P2-195L	3.9	355	192	163	54	46	3.8	650	8.2	0.42	66	98	19	19	14	14
P3-195L	3.7	344	182	162	53	47	3.9	580	7.3	0.40	64	90	17	23	16	14
P4-195L	3.6	455	216	239	47	53	3.9	620	8.2	0.45	74	110	23	22	17	15
P5-195L	4.9	299	155	144	52	48	3.8	660	8.0	0.43	77	98	16	21	15	14
P6-195L	3.9	316	165	151	52	48	3.9	650	1.7	0.40	64	86	13	20	14	13
Mean P-195	4.0	366	182	184	50	50	3.9	637	8.0	0.42	74	104	27	23	16	14
	محاطف من	an in the	5.	i si i	الفتي مناطق	in an	9-95 19-19	al te Naviore	- \$2 	43. s. ; 1 <sup>2000</sup>	5	ng San San San	an a	4	Songer og	e
	AC1 12			at .	- USA	24			ज्यां व		synthe a		to the second	alter of	1978 1	12.5 929

\*The data is presented to permit examination of temporal variability in the cross-section of the Cowlitz River. Each group of samples contains sediments collected at a single EDIV site; each sample was collected approximately 20 minutes apart. Thus, the first group (D1-75-L through D6-75-L) contains all the samples collected at the EDIV site 75 feet from the left bank. Mean -75 contains the calculated values for the entire group of samples collected over the sampling period. The next group (D1-130-L through D6-130-L) contains samples collected at the EDIV site 130 feet from the left bank. All the other groups follow the same pattern. The table also contains data for the point samples (P1-195 through P6-195).

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