

**IMPACT OF COAL SURFACE MINING AND RECLAMATION ON  
 SURFACE WATER CHEMICAL CONCENTRATIONS AND  
 LOAD RATES IN THREE OHIO WATERSHEDS<sup>1</sup>**

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**ABSTRACT:** Information is lacking on the watershed scale effects of mining and reclaiming originally undisturbed watersheds for coal on surface water chemical concentrations and load rates for a variety of constituents. These effects were evaluated on three small, geologically dissimilar watersheds subjected to surface mining in Ohio. Comparisons were made between phases of land disturbances using ratios of average concentrations and load rates: Phase 1 (natural), subphases of Phase 2 (mining and reclamation), and subphases of Phase 3 (partial reclamation and final condition) using 4,485 laboratory analyses of 34 constituents. Average concentration and load rate ratios were categorized into three classes – minor, moderate, and substantial. Mining and reclamation (M/R) affected flow duration curves in different ways – baseflow changes were variable, but high flows generally increased. The average concentration ratios for all sites were classified as 15 percent “minor,” 36 percent “moderate,” and 49 percent “substantial” (average ratio of 2.4.) Generally load rate ratios increased due to mining and reclamation activities (average ratio of 3.3). Minor, moderate, and substantial impacts were found on average for 7 percent, 23 percent, and 70 percent, respectively, of load rate ratios. The impact of M/R on average load rates was not necessarily the same as on average concentrations due to changed hydrology and can be opposite in effect. The evaluation of the impacts of M/R requires knowledge of changing hydrologic conditions and changing supplies and rates of release of chemicals into streams. Median sediment concentration ratio is an indicator of average constituent load rate ratio of a wide variety of chemical constituents and is useful for development of best management practices to reduce chemical loads. The site at which diversion ditches were not removed during final reclamation sustained large chemical load rates, and removal of diversions at the other mined site reduced load rates. Revegetation of poorly reclaimed areas decreased chemical load rates. Chemical load rates were sensitive to geology, mining, and reclamation methods, diversions, and changing hydrology, concentration flow rate regressions, and watershed areas.

(KEY TERMS: water chemistry; NRCS curve number; strip mining; water quality; flow duration curves; diversions.)

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INTRODUCTION

Extraction of coal by surface mining and subsequent reclamation cause drastic disturbances to landscapes, potentially affecting streams and aquatic organisms adversely. These disturbances include tree and topsoil removal, blasting, mining, road installation and removal, changes in watershed areas, spoil grading, respreading of topsoil, fertilizing, mulching, etc. Concern over environmental issues led to enactment of the Surface Mining and Reclamation Act (PL95-87), and few studies were available that comprehensively documented the impacts of mining and reclamation on hydrology and water quality for science-based regulation development (Musser, 1963; Collier *et al.*, 1964, 1970; Curtis, 1971, 1974; Grubb and Ryder, 1972; Dyer and Curtis, 1977; G. A. Upham, 1975, unpublished M.S. Thesis, University of Tennessee, Knoxville, Tennessee). The USDA Agricultural Research Service (ARS) at the North Appalachian Experimental Watershed (NAEW) near Coshocton, Ohio, the Ohio State University/Ohio Agricultural Research and Development Center, and the U.S. Geological Survey (USGS) jointly initiated a research project to quantify the effects of mining and reclamation on three small experimental watersheds with widely varying physical characteristics and different mining operations and reclamation practices. This project was funded by the U.S. Bureau of Mines (USBM), and later by the ARS, for a total of about nine years. The overall objective of the project was to evaluate the effects of these drastic disturbances on surface water hydrology and water quality, ground water hydrology and water quality, and sedimentation. Different

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aspects of the study have been documented in many publications (Bonta, 2000; Bonta *et al.*, 1992a,b, 1997; Bonta *et al.*, 1991; Bonta and Sutton, 1983; Bonta and Hamon, 1980; Dick *et al.*, 1983, 1986; Amerman *et al.*, 1982; USBM, 1978, 1982a,b, 1983a,b,c, 1984).

The objectives of the present study are to evaluate the effects of land disturbances at the three watersheds during different phases of coal mining and reclamation activities (including reclamation practices and diversions used for runoff control) upon average concentrations and load rates of a variety of chemical constituents in stream water.

## PROCEDURE

### *Approach*

The approach used in this study is empirical, statistical, and exploratory. Three geologically dissimilar, undisturbed experimental watersheds were monitored from six to nine years during undisturbed conditions and during mining and reclamation disturbances. All watersheds were mined under state regulations similar to PL95-87, and normal commercial scale mining and reclamation activities were used. Small watersheds were selected so that near complete disturbance would occur to document the effects of complete disturbances and to minimize undisturbed areas. Comparisons of average concentrations and load rates were made between chronological and specific disturbances within and across watersheds for 34 chemical constituents to investigate the effects of surface mining on stream water quality. This approach provides a comprehensive evaluation of mining and reclamation that includes the effects on individual constituents and across dissimilar watersheds so generalizations regarding impacts can be made for a range of watershed conditions.

### *Instrumentation, Sampling, and Constituents*

The instrumentation used at the watersheds is described in detail by Bonta *et al.* (1992a) and is only briefly described here. Runoff was measured continuously at watershed outlets with drop box weirs (Johnson *et al.*, 1966). Water samples were obtained over a range of flows manually. About 10 samples/year/site were planned, allowing evaluation to be made of the most apparent effects of mining and reclamation.

Water samples were analyzed in the laboratory as described by Dick *et al.* (1983). The 34 soluble constituents analyzed were: Ag, Al, alkalinity, As, Ba, Ca,

Cd, Cl, CN, CO<sub>2</sub>, Cr, Cu, dissolved solids, DO, Fe, Fl, H<sub>2</sub>S, hardness, HCO<sub>3</sub>, Hg, Mg, Mn, Na, NH<sub>4</sub>-N, Ni, NO<sub>3</sub>-N, P, Pb, phenols, Sb, Se, SO<sub>4</sub>, Sr, and Zn. Fe was measured with dissimilar methods during Phase 1 at C06 and M09, and these comparisons are only qualitative. An in-depth investigation of the effects of mining and reclamation on suspended sediment concentrations and loads at the three sites (7,099 field samples) has been published elsewhere (Bonta, 2000). Sediment chemistry results were reported by Dick *et al.* (1986). Due to lack of continued funding, fewer constituents were analyzed at J11 at the end of monitoring.

### *Physical Conditions During the Study*

Details on physical conditions and weather at the three small experimental watersheds can be found in Bonta *et al.* (1992a) and Bonta (2000) and are only briefly described here. The three watersheds are in east-central Ohio (Watersheds C06, M09, and J11). They were monitored during three broad phases of disturbance – Phase 1 (the premine/undisturbed/natural watershed condition); Phase 2 (during mining and/or reclamation activities); and Phase 3 (almost completely reclaimed or after final reclamation). Watershed areas during Phase 1 were 19.83, 17.60, and 11.79 ha at C06, M09, and J11, respectively, and each watershed experienced nearly 100 percent disturbance. Bonta (2000) documented the drastically changing probable watershed area and the spatial distribution of types of disturbances in each watershed.

The watersheds were subjected to different mining schedules, and two different mining methods were used. Contour area mining was used at C06 and M09, and the haul back method was used at J11. In the contour area method, coal is extracted starting at the coal outcrop, and successive cuts along the contour are made into the hillside. The spoil from this first cut is thrown downslope and generally forms a much smaller probable watershed area for most of Phase 2. Spoil is subsequently placed on the underclay as mining progresses toward the center of the hilltop. With the haul back method, successive blocks of coal are mined from the hillside. The spoil removed from the actively mined block is placed on the adjacent mined out block. Coal is mined along the contour to a high wall. Concurrent mining and reclamation create a diverse land surface during the activities.

Geologic strata during Phase 1 at the three sites were nearly flat and composed of shale, siltstone, sandstone, limestone, coal, and clay. During Phase 2, the strata above the elevation of the mined coal seam were converted to fragmented overburden (spoil) by

blasting operations. Phase 3 hillsides were composed of spoil graded above the elevation of the coal seam and over the original land surface below the coal seam, adding to the near complete watershed disturbance. Detail on undisturbed and post-reclamation soils can be found in USBM (1978, 1983a,b,c).

Reclamation practices at C06 consisted of diversions that concentrated runoff water on the contour to a rock chute in the headwater area of the watershed (Figure 1a). Water flowing from the rock chute and

from diversions at lower elevations was conveyed through a series of dry dams. Initial reclamation practices at J11 consisted of diversions during the earlier part of Phase 3. These diversions were removed for the final reclamation at this site during the latter part of Phase 3 (Figure 1c). At M09 diversions were not used, and the reclamation practice consisted of mechanically crimping straw into the topsoil (Figure 1b).

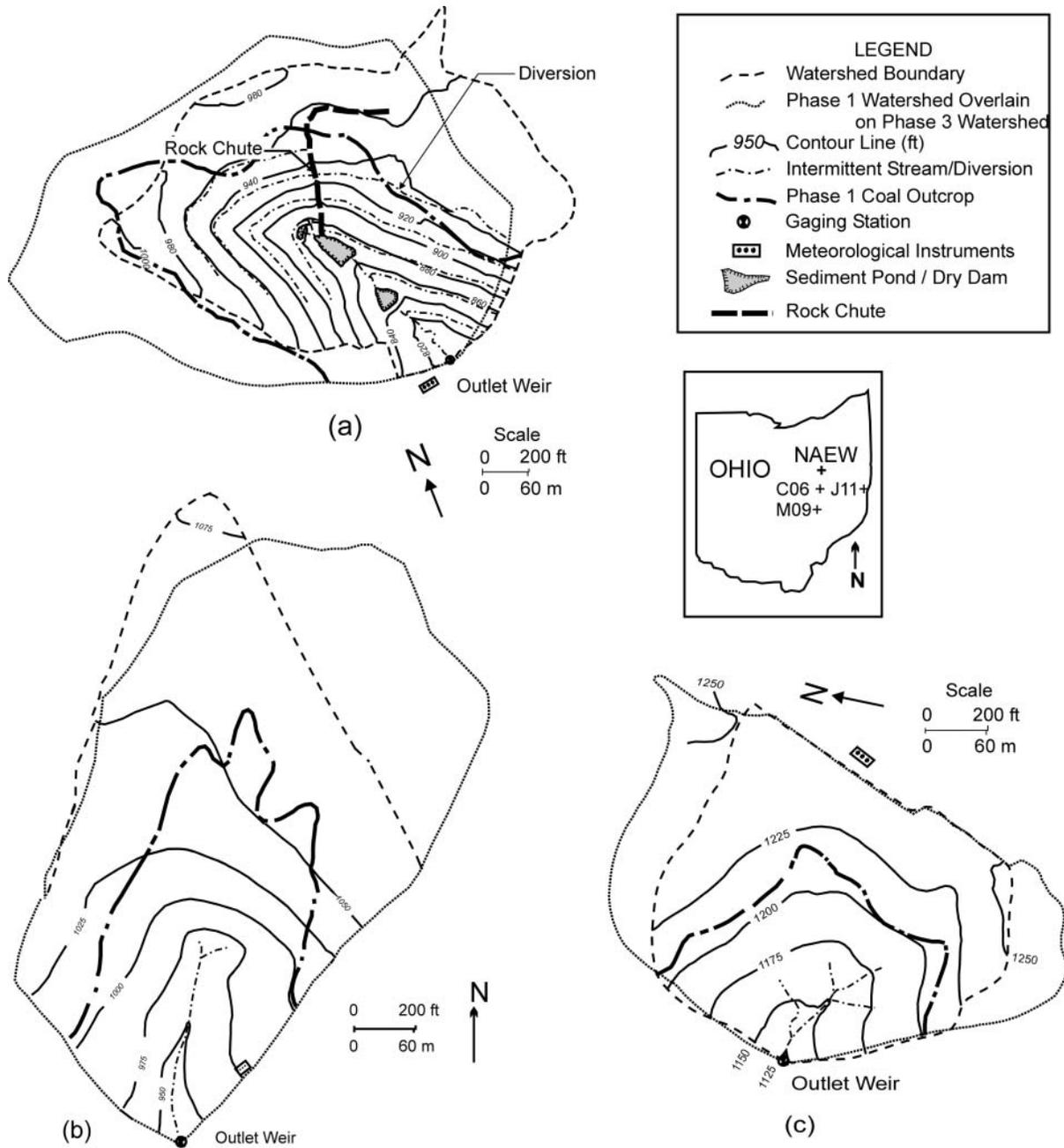


Figure 1. Topographic Maps With Instrumentation for Phase 3F Final Reclamation at End of Monitoring): (a) C06 (diversions remain); (b) M09 (straw crimping with no diversions); and (c) J11 (after diversions removed).

During Phase 1, forest cover comprised the vegetative cover at C06, and forest and forage grasses comprised the cover at M09 and J11. Vegetative cover during Phase 3 was primarily grass at all sites, with some small trees at C06.

#### *Division of Data Into Phases of Disturbance for Analyses*

Phases 1, 2, and 3 were divided into subphases of similar disturbances (constrained by the number of samples). Two subphases of Phase 2 were identified at

C06 and M09 and one at J11 (Table 1). For Phase 3, one phase was identified at C06 and two subphases at M09 and J11 (Table 1). A subphase is denoted by the numbers 1, 2, or 3 to describe the broad phase of disturbance, followed by characters denoting the particular types of activities listed in Table 1. For example, "Phase 2B" means the Phase 2 mining period, subphase "B" type disturbances. At all sites, the undisturbed watershed is called "Phase 1," and the "final" reclaimed watershed at the end of monitoring is denoted "Phase 3F." For simplicity, all phases and subphases are called "phases" of disturbance. A total of 4,485 chemical analyses of 34 constituents were

TABLE 1. Division of Surface Water Quality Record Into Phases of Disturbance at the Three Experimental Sites.

Watershed Designation	Beginning Date	Duration in Months	Watershed Activity	Phase
C06	January 1, 1976	11.1	Data collection began.	1
	November 4, 1976	17.8	Mining began on watershed (tree & topsoil removal, mining, roads); watershed mined, no active disturbances.	2A
	March 30, 1978	6.8	Some mining activities; watershed disturbances during reclamation (grading, topsoiling, seeding, mulching).	2B
	October 24, 1978	41.4	Watershed reclaimed with dry dams in place.	3F
	April 6, 1982	75.2 (6.3)*	Data collection terminated.	—
M09	June 8, 1976	7.0	Data collection began.	1
	January 9, 1977	10.0	Mining began on watershed (tree & topsoil removal, mining, some grading of spoil).	2A
	November 8, 1977	11.1	Reclamation activities (replace topsoil, fertilizer, seed); some mining.	2B
	September 12, 1978	10.6	Watershed reclaimed, but one-quarter area sparsely covered; gas-well maintenance, rip-rap placement.	3A
	July 1, 1979	37.2	Watershed reclaimed, minimal disturbance, good cover.	3F
	July 7, 1982	73.0 (6.1)*	Data collection terminated.	—
J11	April 30, 1977	37.7	Data collection began.	1
	May 20, 1980	17.1	Mining began; regrade; replace topsoil, install diversions, fertilize, seed, regrade, replace topsoil; haul-road, diversions, new seeding.	2
	September 29, 1981	12.6	Watershed reclaimed with diversions in place; poor cover; actively eroding diversions and outlets - some diversion failure; road maintenance in reclaimed watershed, diversions removed.	3A
	September 16, 1982	39.0	Minimal disturbance, good cover.	3F
	December 14, 1985	103.6 (8.9)*	Data collection terminated.	—

\*Duration of watershed monitoring in years.

analyzed, with 1,538 analyses of field samples for C06, 1,321 for M09, and 1,626 for J11.

Because the project was exploratory, all combinations of constituents between phases were compared. However, emphasis is on comparing the undisturbed (Phase 1) condition with the other phases at each site, and in particular with the “final” Phase 3F watershed. The effects of different mining and reclamation activities can be explored by comparing changes among all phases.

#### *Regressions of Concentration Against Flow Rate*

Calculation of average concentrations and loads is complicated by potential relationships between flow rate and constituent concentration. Such relationships are often found in stable watersheds (Lewis and Grant, 1979). A power equation (log-log) often characterized the relationships for constituents in the present study, and standard regression techniques were used to determine parameters. A significance probability of 0.10 was used to detect significant correlations.

When concentration and flow are positively correlated, concentrations increase with flow rate (positive log-log slope; e.g., sediment concentration versus flow rate). When they are negatively correlated (negative log-log slope; e.g.,  $\text{SO}_4$  versus flow rate), larger concentrations occur at smaller flow rates. Therefore, average concentrations and load rates are dependent on measured runoff and regression parameters. Drastic disturbances due to surface mining create unstable conditions, and regression relationships can change due to changing hydrological and surface conditions. These changes are manifested by changes in the regression slope (including its sign) and/or by changes in intercept. Alternatively, relationships may not statistically change.

#### *Calculation and Comparison of Average Concentrations and Load Rates*

**Flow Duration Curves.** For each phase of disturbance, a flow duration curve (FDC) of nonzero flows was developed. Each FDC was used to compute an average flow rate for the phase. Maximum flow rates and percent zero flows during each phase were also computed. FDCs visually summarize changes in hydrology due to activities such as mining, diversion installation and removal, reclamation practices, etc. Changes in FDCs are important for comparing constituent load rates.

**Average Concentrations.** Average concentrations were computed for each phase in Table 1 by using one of two methods – FDCs as outlined by Miller (1951) and by simple averages of field data. When regressions were statistically significant, the FDC flows were used as the independent variable in the regression equation to compute a concentration duration curve (CDC). The resulting curve was used to compute the average concentration during the phase. This method provides a representative average concentration that accounts for concentration flow relationships. When regressions were not significant, a simple average of measured concentrations was computed.

**Average Load Rates.** Changes in average concentrations quantify how drastic land disturbances affect the supply and magnitudes of various constituent concentrations. However, land alteration due to mining and reclamation also changes the hydrology of the watershed (Bonta *et al.*, 1997). The combined effects of changed hydrology and water chemistry can be investigated by quantifying rates of loads of chemical constituents in the stream (e.g., kg/day). When regressions were significant, load rates were computed by multiplying the concentration obtained through regression by the corresponding flow rates to compute a load rate and form a load rate duration curve (LRDC). The resulting LRDC was then used to compute an average load rate (Miller, 1951). When a regression was not significant, the average concentration was multiplied by the average flow rate determined from the FDC to yield an average load rate.

**Comparisons Between Phases of Disturbance.** Because CDCs and LRDCs for specific constituents are not statistically comparable, ratios of average concentration or load rates were computed to compare phases of disturbance. The numerator is the average concentration or load rate of the phase of interest, and the denominator is the corresponding average of the reference phase of disturbance (e.g., ratio of 3F:1 means Phase 3F average concentration or load rate divided by that of Phase 1). A “comparison ratio” was classified into one of three impact classes (“minor,” “moderate,” or “substantial”). Constituents with ratios between 0.9 and 1.1 were classified as having a “minor” impact due to the contrasting disturbances. Those with ratios less than 0.5 or greater than 1.5 were classified as having been impacted “substantially,” and those not falling in either of these two classes as having been impacted “moderately” ( $0.5 < \text{ratio} < 0.9$  or  $1.1 < \text{ratio} < 1.5$ ). Comparison ratios for each phase comparison were summarized in table form and by box and whisker plots. A ratio close to the unity reference line on the graph implies little impact for the particular comparison. Points below a unity

reference line show an impact causing decreased average concentration or load rates (or water quality improvement) and vice versa. Only “substantially” impacted constituents between Phase 1 and other phases were listed.

## RESULTS AND DISCUSSION

### *Changes in Watershed Hydrology*

At C06, Phase 1 flows were higher between 2 percent and 80 percent of the time compared with other phases (solid line in Figure 2a). However, baseflows and larger flows were higher during other phases. Phase 2A and 2B curves were generally less than the Phase 3F curve at C06.

At M09 (Figure 2b), all phases had similar FDCs for flow rates occurring between 20 to 100 percent of the time. For smaller exceedance levels the FDCs diverged. The Phase 3F FDC was located in the center of the curves (dashed), and the FDC for Phase 3A generally showed larger flows (dot-dashed).

At J11 (Figure 2c), lower flow rates occurred more often during Phase 3F (dashed) than Phase 1 (solid) and during the other phases. Higher flow rates occurred more often during Phase 3F and during the other phases compared with Phase 1. The Phase 3F FDC was lower than that of 3A, partly because watershed area decreased from 13.3 ha to 9.9 ha after diversion removal, a 26 percent reduction.

Different phases of disturbance caused average flow rates ranging from 0.47 L/sec to 3.50 L/sec (Table 2). Generally the highest average flows were associated with mining and reclaimed phases (about 2 to 3.5 L/sec). At C06 higher flows also occurred during Phase 1 (2.53 L/sec). Mining and reclamation affected J11 flows the most, where zero flows occurred 64 percent of the time during the initial reclamation phase (3A), compared with only 7 percent during the pre-mine phase. This was due to the inability of aquifers to support baseflow after reclamation at this site (Bonta *et al.*, 1992b). Average flow rates are dependent on weather experienced and changed physical conditions. NRCS watershed curve numbers found during Phases 2 and 3 were mostly between 87 and 91 (Table 2) (Bonta *et al.*, 1997). NRCS curve numbers were generally larger during Phases 2 and 3 compared with Phase 1 (Table 2). Curve number increases are attributed to destruction of soil profiles and surface sealing that reduced infiltration. More discussion on hydrological changes that affect water quality is presented in sections dealing with load rates.

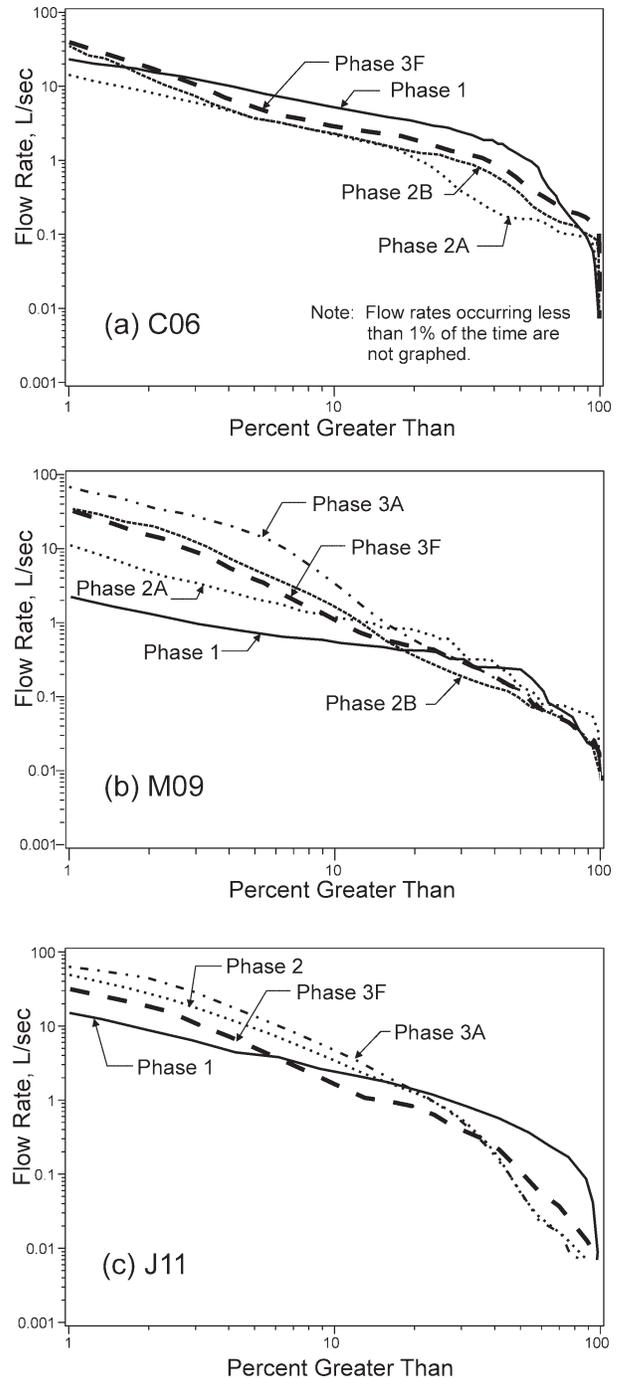


Figure 2. Instantaneous Nonzero Flow Duration Curves (FDCs) for Different Phases of Disturbance (flow exceedances > 1 percent): (a) C06; (b) M09; (c) J11.

### *Comparison of Average Concentrations*

**Overview of Average Concentrations.** Tables 3 through 5 summarize average concentrations for all constituents and for all watersheds and phases. Averages for each constituent and phase are presented on

TABLE 2. Average Flow Rates (from flow-duration curves) and Percent Zero Flows for Each Watershed and Phase of Disturbance.

Watershed	Phase	Duration of Nonzero Flow (days)	Average Flow (L/sec)	Maximum Flow (L/sec)	Percent Zero Flows	NRCS Curve Number*
C06	1	247	2.53	160	17	81 (65)
	2A	269	1.05	364	47	88
	2B	161	2.25	1,380	23	
	3F	1,040	2.55	1,520	0.2	87
M09	1	214	0.47	1,140	0	71 (69)
	2A	302	0.94	828	0	91
	2B	300	1.65	1,110	2	
	3A	290	3.01	420	0.3	91
	3F	1,090	1.67	643	0	
J11	1	1,010	1.28	496	7	75 (73)
	2	235	2.76	912	51	83
	3A	106	3.50	667	64	88
	3F	766	1.50	205	32	

\*From Bonta (1997). Phase 1 CN in parentheses is from the NRCS handbook (USDA, 1972). All other values were computed using measured data.

the left side of each table, along with whether the average was based on a regression and subsequent use of an FDC (“R”) or computed from the raw data (no significant correlation, “N”). Of the 429 regressions between concentration and flow rate for all watersheds and phases, 154 were statistically significant (36 percent).

The largest average concentrations among all sites were found at C06 for dissolved solids, hardness, and SO<sub>4</sub> concentrations (1,640 mg/L, 1,010 mg/L, and 672 mg/L, respectively; Phase 3F, Table 3). Average concentrations for trace constituents generally were at concentrations less than 1 mg/L at all sites. Average HCO<sub>3</sub> ion concentration was generally larger during Phase 1 at M09 than at the other sites (212 mg/L compared with 47.3 mg/L at C06 and 123 mg/L at J11). The larger HCO<sub>3</sub> ion concentrations at M09 and J11 originate from the limestone dominated geology of M09 and to a lesser extent at J11. Average Mn concentrations (regulated constituent) were largest at C06 (7.04 mg/L; Phase 2B; Table 3) and J11 (2.12 mg/L; Phase 2; Table 5).

**Comparisons Between Phases.** The right side of Tables 3 through 5 lists the ratios of average concentrations for the comparisons shown with impact classifications. These comparisons show the impacts of different types of mining and reclamation activities on average concentrations. For example, at M09, the effects of reclaiming (Phase 3F) the mined watershed (Phase 2A) on barium is read as a ratio of 1.14 on the right side of the Table 4 under the column heading

“3F:2A.” The corresponding impact class is “moderate” (M). Comparison ratios are useful for documenting the magnitudes of changes for specific chemical constituents when changes in mining and reclamation activities occur (e.g., revegetation, etc.). Figure 3 summarizes the comparison ratios in Tables 3 through 5 with box and whisker plots and shows the overall impacts of mining and reclamation on average concentration for all watersheds and comparisons. The end of monitoring/premine comparison ratios are highlighted in Figure 3 (3F:1 ratios – the “final” state of the watersheds at the end of monitoring). Corresponding 3F:1 ratios for constituents are in bold in Tables 3 through 5.

Among the 665 ratios of average concentrations computed for all constituents, watersheds, and phases (Tables 3 through 5; Figure 3), the minimum was 0.02 (NH<sub>4</sub>-N) at M09 (3A:2B; Table 4) and the maximum was 66.2 (Mn) at C06 (2B:1; Table 3), with an average concentration ratio of 2.4 across all sites. However, few ratios were extremes, with only 5 percent exceeding 7.4 and 5 percent less than 0.26.

Minor, moderate, and substantial impacts were found in 13 percent, 29 percent, and 58 percent of comparisons at C06 (Table 3), 16 percent, 44 percent, and 40 percent at M09 (Table 4), and 17 percent, 34 percent, and 49 percent at J11 (Table 5), respectively. These percentages of impact classes are similar at all the sites, with more substantial impacts at C06 at the expense of “moderate” impacts. This is apparent in Figure 3, in which more ratios lie above the unity reference line at C06, compared with the other two sites.

TABLE 3. Summary of Average Constituent Concentrations and Phase Comparison Results at C06. (Bold comparison shows the state of the watershed at end of monitoring period. All comparison ratios are shown in Figure 3.)

Constituent	Average Concentrations (mg/l) and Regression Test Results for Each Phase of Disturbance										Ratio of Average Concentrations and Impact Classes for Each Phase Comparison									
	1	S*	2A	S	2B	S	3F	S	2A:1	C†	2B:1	C	3F:1	C	2B:2A	C	3F:2A	C	3F:2B	C
Ag	<0.01	R	<0.01	N	<0.01	N	<0.01	N	1.10	M	1.13	M	1.04	m	1.02	m	0.95	m	0.92	m
Al	0.08	R	0.07	N	0.03	N	0.09	R	0.78	M	0.32	S	1.05	m	0.41	S	1.33	M	3.29	S
Alkalinity	42.0	R	15.6	N	7.76	N	132	R	0.37	S	0.19	S	3.15	S	0.50	S	8.47	S	17.0	S
As	<0.01‡	N	<0.01	N	<0.01‡	N	<0.01	N	1.46	M	2.00	S	2.67	S	1.38	M	1.83	S	1.33	M
Ba	0.03	N	0.03	N	0.02	N	0.01	N	0.83	M	0.58	M	0.39	S	0.70	M	0.47	S	0.67	M
Ca	19.5	R	51.9	N	83.7	N	235	R	2.66	S	4.29	S	12.1	S	1.61	S	4.54	S	2.81	S
Cd	<0.01	N	<0.01	N	<0.01‡	N	<0.01	N	1.04	m	1.73	S	1.23	M	1.67	S	1.18	M	0.71	M
Cl	2.15	R	1.38	N	5.90	N	10.8	N	0.64	M	2.74	S	5.02	S	4.29	S	7.85	S	1.83	S
CN	0.01	N	0.01	N	0.01‡	N	0.01‡	N	1.20	M	0.88	M	0.88	M	0.73	M	0.73	M	1.00	m
CO <sub>2</sub>	4.06	N	9.56	R	29.3	N	33.8	R	2.36	S	7.21	S	8.34	S	3.06	S	3.54	S	1.16	M
Cr	0.01	N	0.01‡	N	0.01‡	N	0.01‡	N	0.94	m	0.94	m	0.94	m	1.00	m	1.00	m	1.00	m
Cu	<0.01	N	<0.01	N	<0.01	N	<0.01	N	0.56	M	0.52	M	0.80	M	0.94	m	1.43	M	1.53	S
Diss Sol	120	R	428	N	560	N	1640	R	3.56	S	4.66	S	13.7	S	1.31	M	3.85	S	2.94	S
DO	n	n	n	n	10.9‡	N	9.05	N	n	n	n	n	n	n	n	n	n	n	0.83	M
Fe	0.08	R	0.03	N	0.02	N	0.05	R	0.33	S	0.20	S	0.64	M	0.60	M	1.96	S	3.28	S
Fl	0.10	N	0.07	N	0.06	N	0.14	R	0.69	M	0.64	M	1.40	M	0.92	m	2.03	S	2.21	S
H <sub>2</sub> S	<0.01‡	N	0.30‡	N	0.30‡	N	0.01‡	N	60.0	S	60.0	S	2.00	S	1.00	m	0.03	S	0.03	S
Hardness	78.6	R	198	N	317	N	1010	R	2.51	S	4.04	S	12.8	S	1.61	S	5.11	S	3.18	S
HCO <sub>3</sub>	47.4	R	19.1	N	9.41	N	161.	R	0.40	S	0.20	S	3.40	S	0.49	S	8.45	S	17.1	S
Hg	<0.01	N	<0.01	N	<0.01‡	N	<0.01	N	0.77	M	1.13	M	1.13	M	1.47	M	1.47	M	1.00	m
Mg	7.22	R	16.5	N	26.2	N	122	R	2.28	S	3.63	S	16.9	S	1.59	S	7.42	S	4.67	S
Mn	0.11	N	0.16	R	7.04	N	2.08	R	1.52	S	66.2	S	19.5	S	43.7	S	12.9	S	0.30	S
Na	3.72	R	2.35	N	2.40	N	11.4	R	0.63	M	0.65	M	3.06	S	1.02	m	4.84	S	4.74	S
NH <sub>4</sub> -N	0.02	R	0.07	N	0.08	N	0.22	N	3.28	S	3.89	S	10.4	S	1.19	M	3.17	S	2.67	S
Ni	0.02	R	0.02	R	0.04	N	0.01	N	0.91	m	2.12	S	0.63	M	2.34	S	0.69	M	0.30	S
NO <sub>3</sub> -N	0.23	R	0.95	N	1.68	N	0.70	N	4.15	S	7.30	S	3.04	S	1.76	S	0.73	M	0.42	S
P	0.09	N	0.09	N	0.04	N	0.09	N	0.97	m	0.38	S	0.99	m	0.39	S	1.02	m	2.59	S
Pb	0.03	R	0.01	R	0.02	N	0.02	N	0.40	S	0.63	M	0.67	M	1.56	S	1.67	S	1.07	m
Phenols	<0.01	N	<0.01	R	<0.01‡	N	<0.01	N	1.42	M	1.12	M	1.32	M	0.79	M	0.93	m	1.19	M
Sb	0.03	R	<0.01	R	0.02	N	0.02	R	0.35	S	0.79	M	0.84	M	2.30	S	2.42	S	1.05	m
Se	<0.01	N	<0.01	R	<0.01	N	<0.01	R	3.65	S	10.0	S	1.03	m	2.75	S	0.28	S	0.10	S
SO <sub>4</sub>	39.2	R	65.0	R	338	N	672	R	1.66	S	8.62	S	17.1	S	5.20	S	10.3	S	1.99	S
Sr	0.07	R	0.13	N	0.17	N	0.51	R	1.90	S	2.44	S	7.29	S	1.28	M	3.83	S	2.98	S
Zn	0.02	N	0.01	N	0.02	N	0.01	R	0.65	M	0.88	M	0.49	S	1.35	M	0.76	M	0.56	M

\*Regression significance result: R = concentration based on regression equation with Pearson correlation significance probability level of 0.10. N = concentration based on average concentration of field samples (correlation not significant at the 0.10 probability level). n = not applicable.  
 †Classification of comparison ratio between the two phase comparisons: m = "minor" (0.9 < ratio < 1.1). M = "moderate" (0.5 < ratio < 0.9 or 1.1 < ratio < 1.5). S = "substantial" (ratio < 0.5 or ratio > 1.5).  
 ‡Based on one field sample.

Table 4. Summary of Average Constituent Average Concentrations and Phase Comparison Results at M09. (Bold comparison shows the state of the watershed at end of monitoring period. All comparisons are shown in Figure 3.)

Constituent	Average Concentrations (mg/l) and Regression Test Results for Each Phase of Disturbance															Ratio of Average Concentrations and Impact Classes for Each Phase Comparison																		
	1	S*	2A	S	2B	S	3A	S	3F	S	2A:1	C†	2B:1	C	3A:1	C	3F:1	C	2B:2A	C	3A:2A	C	3F:2A	C	3A:2B	C	3F:2B	C	3F:2A	C	3F:2B	C		
Ag	<0.01	N	<0.01	N	<0.01	N	<0.01	N	<0.01	N	0.98	m	0.72	M	1.03	M	1.07	m	0.74	M	1.05	M	1.10	m	1.42	M	1.49	M	1.05	m	1.49	M	1.05	m
Al	0.03	R	0.01	N	0.01	N	0.02	R	0.03	N	0.48	S	0.36	S	0.59	M	1.10	m	0.76	M	1.24	M	2.30	S	1.64	S	3.03	S	1.85	S	1.85	S	1.85	S
Alkalinity	174	R	142	R	95.5	R	81.3	R	150	R	0.82	M	0.55	M	0.47	S	0.86	M	0.67	M	0.57	M	1.05	m	0.85	M	1.57	S	1.84	S	1.84	S	1.84	S
As	<0.01	N	<0.01	N	<0.01	N	<0.01	N	<0.01	N	0.19	S	0.13	S	0.27	S	0.40	S	0.71	M	1.43	M	2.14	M	2.00	S	3.00	S	1.50	M	1.50	M	1.50	M
Ba	0.07	N	0.03	N	0.03	N	0.02	N	0.04	R	0.49	S	0.40	S	0.25	S	0.56	M	0.82	M	0.51	M	1.14	M	0.62	M	1.38	M	2.22	S	2.22	S	2.22	S
Ca	90.0	R	67.8	N	49.5	N	28.7	N	108	R	0.75	M	0.55	M	0.32	S	1.20	M	0.73	M	0.42	S	1.59	S	0.58	M	2.18	S	3.76	S	3.76	S	3.76	S
Cd	<0.01	N	<0.01	N	<0.01	N	<0.01	N	<0.01	N	1.24	M	2.33	S	2.12	S	1.07	S	1.87	S	1.71	S	0.86	M	0.91	m	0.46	S	0.51	M	0.51	M	0.51	M
Cl	14.7	R	15.9	R	13.3	N	8.98	N	12.6	R	1.08	m	0.90	m	0.61	M	0.86	M	0.84	M	0.57	M	0.79	M	0.68	M	0.95	m	1.40	M	1.40	M	1.40	M
CN	0.01	R	0.01	N	0.01	N	0.01	N	0.01	N	1.22	M	1.11	M	1.11	M	1.11	M	0.91	m	0.91	m	0.91	m	1.00	m	1.00	m	1.00	m	1.00	m	1.00	m
CO <sub>2</sub>	9.83	N	34.5	N	18.9	N	87.6	R	22.8	R	3.51	S	1.92	S	8.91	S	2.32	S	0.55	M	2.54	S	0.66	M	4.65	S	1.21	M	0.26	S	0.26	S	0.26	S
Cr	0.01	N	0.01	N	0.01	N	0.01	N	0.01	N	0.88	M	0.88	M	0.88	M	0.88	M	1.00	m	1.00	m												
Cu	<0.01	N	<0.01	N	<0.01	N	<0.01	N	<0.01	N	0.92	m	0.45	S	0.88	M	1.22	M	0.50	S	0.96	M	1.33	M	1.94	S	2.69	S	1.39	M	1.39	M	1.39	M
Diss Sol	209	N	332	N	351	N	137	N	586	R	1.59	S	1.68	S	0.66	M	2.81	S	1.06	m	0.41	S	1.77	S	0.39	S	1.67	S	4.29	S	4.29	S	4.29	S
DO	n	n	n	n	6.91	R	9.23	R	8.63	R	n	n	n	n	n	n	n	n	n	n	n	n	n	n	1.34	M	1.25	M	0.94	m	0.94	m	0.94	m
Fe	0.03	R	0.02	N	<0.01	N	0.02	N	0.03	N	0.56	M	0.21	S	0.72	M	0.95	m	0.37	S	1.28	M	1.70	S	3.50	S	4.64	S	1.33	M	1.33	M	1.33	M
Fl	0.17	N	0.09	R	0.13	R	0.09	R	0.13	R	0.54	M	0.79	M	0.54	M	0.77	M	1.46	M	1.00	m	1.42	M	0.68	M	0.97	m	1.42	M	1.42	M	1.42	M
H <sub>2</sub> S	0.30	N	0.30	N	0.30	N	0.01	N	0.01	N	1.00	m	1.00	m	0.03	S	0.03	S	1.00	m	0.03	S	0.03	S	0.03	S	0.03	S	1.00	m	1.00	m	1.00	m
Hardness	335	R	243	N	167	N	113	N	237	R	0.73	M	0.50	M	0.34	S	0.71	M	0.69	M	0.46	S	0.97	m	0.67	M	1.41	M	2.10	S	2.10	S	2.10	S
HCO <sub>3</sub>	212	R	174	R	116	R	99.0	N	183	R	0.82	M	0.55	M	0.47	S	0.86	M	0.67	M	0.57	M	1.05	m	0.85	M	1.58	S	1.85	S	1.85	S	1.85	S
Hg	<0.01	N	<0.01	N	<0.01	N	<0.01	N	<0.01	N	0.83	M	1.50	M	1.50	M	2.25	S	1.82	S	1.82	S	2.73	S	1.00	m	1.50	M	1.50	M	1.50	M	1.50	M
Mg	27.1	R	21.8	R	15.1	R	14.7	R	37.8	R	0.80	M	0.56	M	0.54	M	1.40	M	0.70	M	0.68	M	1.74	S	0.97	m	2.50	S	2.57	S	2.57	S	2.57	S
Mn	0.05	N	0.11	N	0.08	N	0.05	N	0.06	R	2.21	S	1.63	S	0.92	m	1.15	M	0.74	M	0.41	S	0.52	M	0.56	M	0.70	M	1.26	M	1.26	M	1.26	M
Na	7.55	R	5.85	R	5.18	R	4.12	N	8.35	R	0.78	M	0.69	M	0.55	M	1.11	M	0.89	M	0.70	M	1.43	M	0.80	M	1.61	S	2.03	S	2.03	S	2.03	S
NH <sub>4</sub> -N	0.01	R	0.02	R	0.70	N	0.01	N	0.08	N	1.51	S	64.5	S	1.15	M	7.06	S	42.7	S	0.76	M	4.67	S	0.02	S	0.11	S	6.16	S	6.16	S	6.16	S
Ni	0.02	N	0.03	N	0.01	N	0.01	N	<0.01	N	1.03	m	0.45	S	0.50	M	0.29	S	0.44	S	0.49	S	0.28	S	1.11	M	0.64	M	0.58	M	0.58	M	0.58	M
NO <sub>3</sub> -N	0.85	N	1.24	N	6.82	N	0.28	N	1.06	N	1.46	M	8.02	S	0.32	S	1.25	M	5.50	S	0.22	S	0.86	M	0.04	S	0.16	S	3.86	S	3.86	S	3.86	S
P	0.04	N	0.04	N	0.12	N	0.07	N	0.04	R	0.81	M	2.70	S	1.56	S	0.94	m	3.35	S	1.93	S	1.17	M	0.58	M	0.35	S	0.61	M	0.61	M	0.61	M
Pb	0.02	N	0.01	N	0.01	N	0.02	N	0.01	R	0.76	M	0.59	M	0.88	M	0.80	M	0.78	M	1.17	M	1.05	m	1.49	M	1.35	M	0.90	m	0.90	m	0.90	m
Phenols	<0.01	R	<0.01	N	<0.01	N	<0.01	N	<0.01	N	1.72	S	1.02	m	0.90	m	0.90	m	0.59	M	0.53	M	0.53	M	0.89	M	0.89	M	1.00	m	1.00	m	1.00	m
Sb	0.03	N	0.01	N	0.02	N	0.02	N	0.03	R	0.46	S	0.55	M	0.60	M	0.89	M	1.19	M	1.30	M	1.93	S	1.09	m	1.63	S	1.49	M	1.49	M	1.49	M
Se	<0.01	N	<0.01	R	<0.01	N	<0.01	N	<0.01	N	2.12	S	9.88	S	2.54	S	2.21	S	4.65	S	1.19	M	1.04	m	0.26	S	0.22	S	0.87	M	0.87	M	0.87	M
SO <sub>4</sub>	50.1	R	48.2	R	75.6	N	55.3	R	147	R	0.96	m	1.51	M	1.11	M	2.94	S	1.57	S	1.15	M	3.06	S	0.73	M	1.95	S	2.67	S	2.67	S	2.67	S
Sr	0.44	R	0.25	N	0.17	N	0.11	N	0.42	R	0.56	M	0.38	S	0.25	S	0.97	m	0.67	M	0.44	S	1.71	S	0.66	M	2.55	S	3.86	S	3.86	S	3.86	S
Zn	0.02	N	<0.01	R	<0.01	N	<0.01	N	<0.01	N	0.22	S	0.33	S	0.30	S	0.42	S	1.49	M	1.33	M	1.88	S	0.90	M	1.26	M	1.41	M	1.41	M	1.41	M

\*Regression significance result: R = concentration based on regression equation with Pearson correlation significance probability level of 0.10. N = concentration based on average concentration of field samples (correlation not significant at the 0.10 probability level), n = not applicable.  
 †Classification of comparison ratio between the two phase comparisons: m = "minor" (0.9 < ratio < 1.1), M = "moderate" (0.5 < ratio < 0.9 or 1.1 < ratio < 1.5), S = "substantial" (ratio < 0.5 or ratio > 1.5).  
 ‡Based on one field sample.

TABLE 5. Summary of Average Constituent Concentrations and Phase Comparison Results at J11.  
(Bold comparison shows the state of the watershed at end of monitoring period. All comparison ratios are shown in Figure 3.)

Constituent	Average Concentrations (mg/l) and Regression Test Results for Each Phase of Disturbance										Ratio of Average Concentrations and Impact Classes for Each Phase Comparison									
	1	S*	2	S	3A	S	3F	S	2:1	C†	3A:1	C	3F:1	C	3A:2	C	3F:2	C	3F:3A	C
Ag	<0.01	N	<0.01	N	<0.01	N	n	n	0.97	m	0.90	m	n	n	0.93	m	n	n	n	n
Al	0.02	N	0.26	N	0.04	N	0.12	N	16.7	S	2.75	S	8.00	S	0.16	S	0.48	S	2.91	S
Alkalinity	101	R	101	R	32.2	N	n	n	0.99	m	0.32	S	n	n	0.32	S	n	n	n	n
As	<0.01	N	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Ba	0.03	N	0.04	N	0.04	N	0.03	N	1.25	M	1.30	M	0.87	M	1.03	m	0.70	M	0.67	M
Ca	42.9	R	41.0	N	94.9	R	69.2	R	0.96	m	2.21	S	1.61	S	2.31	S	1.69	S	0.73	M
Cd	<0.01	N	<0.01	N	<0.01	N	n	n	0.80	M	0.65	M	n	n	0.82	M	n	n	n	n
Cl	9.71	R	8.21	N	8.80	N	n	n	0.85	M	0.91	m	n	n	1.07	m	n	n	n	n
CN	0.01	N	0.01‡	N	0.01‡	N	n	n	0.93	m	0.93	m	n	n	1.00	m	n	n	n	n
CO <sub>2</sub>	22.4	N	12.0	N	8.20	N	n	n	0.54	M	0.37	S	n	n	0.68	M	n	n	n	n
Cr	0.01¶	N	0.01‡	N	0.01‡	N	n	n	1.00	m	1.00	m	n	n	1.00	m	n	n	n	n
Cu	<0.01	N	<0.01	N	<0.01‡	N	0.01	N	1.23	M	1.29	M	5.33	S	1.05	m	4.33	S	4.13	S
Diss Sol	220	R	243	N	479	R	n	n	1.11	M	2.18	S	n	n	1.97	S	n	n	n	n
DO	9.10	R	6.71	R	10.1	R	n	n	0.74	M	1.12	M	n	n	1.51	S	n	n	n	n
Fe	<0.01	R	0.04	N	0.03	N	0.02	R	4.15	S	3.00	S	2.50	S	0.72	M	0.60	M	0.83	M
Fl	0.11	N	0.23	R	0.11	N	n	n	2.15	S	1.00	m	n	n	0.46	S	n	n	n	n
H <sub>2</sub> S	0.09	N	0.01‡	N	0.01‡	N	n	n	0.11	S	0.11	S	n	n	1.00	m	n	n	n	n
Hardness	151	R	151	N	347	R	n	n	1.00	m	2.31	S	n	n	2.31	S	n	n	n	n
HCO <sub>3</sub>	123	R	110	R	39.0	N	n	n	0.89	M	0.32	S	n	n	0.36	S	n	n	n	n
Hg	<0.01	N	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
Mg	10.5	R	11.7	N	16.7	N	20.6	R	1.11	M	1.59	S	1.96	S	1.43	M	1.76	M	1.23	M
Mn	0.05	N	2.12	N	1.35	N	0.23	R	42.0	S	26.9	S	4.49	S	0.64	M	0.11	S	0.17	S
Na	5.45	R	5.47	R	3.23	R	3.63	R	1.00	m	0.59	M	0.67	M	0.59	M	0.66	M	1.13	M
NH <sub>4</sub> -N	0.03	R	0.85	N	0.39	N	n	n	33.2	S	15.1	S	n	n	0.46	S	n	n	n	n
Ni	0.01	N	0.04	N	0.02	N	<0.01	N	3.40	S	1.99	S	0.30	S	0.59	M	0.09	S	0.15	S
NO <sub>3</sub> -N	0.97	R	3.90	N	3.90	N	n	n	4.02	S	4.02	S	n	n	1.00	m	n	n	n	n
P	0.03	N	0.02‡	N	0.03	N	0.06	N	0.62	M	0.80	M	1.87	S	1.30	M	3.04	S	2.34	S
Pb	0.02	N	0.02	N	0.02	N	n	n	0.97	m	1.36	M	n	n	1.39	M	n	n	n	n
Phenols	<0.01	N	<0.01	N	<0.01‡	N	n	n	0.83	M	1.20	M	n	n	1.44	M	n	n	n	n
Sb	0.02	N	0.02	N	0.04‡	N	n	n	1.28	M	2.43	S	n	n	1.89	S	n	n	n	n
Se	<0.01	N	<0.01	N	n	n	n	n	4.70	S	4.74	S	n	n	2.07	S	1.02	m	0.49	S
SO <sub>4</sub>	57.1	R	131	N	270	R	133	R	2.29	S	2.34	S	2.34	S	2.07	S	1.02	m	0.49	S
Sr	0.24	R	0.21	R	0.32	R	0.29	R	0.89	M	1.33	M	1.19	M	1.50	S	1.34	M	0.89	M
Zn	<0.01	N	0.06	N	0.02	N	<0.01	N	9.36	S	2.42	S	1.03	m	0.26	S	0.11	S	0.43	S

\*Regression significance result: R = concentration based on regression equation with Pearson correlation significance probability level of 0.10. N = concentration based on average concentration of field samples (correlation not significant at the 0.10 probability level). n = not applicable.

†Classification of comparison ratio between the two phase comparisons: m = "minor" (0.9 < ratio < 1.1). M = "moderate" (0.5 < ratio < 0.9 or 1.1 < ratio < 1.5). S = "substantial" (ratio < 0.5 or ratio > 1.5).

‡Based on one field sample.

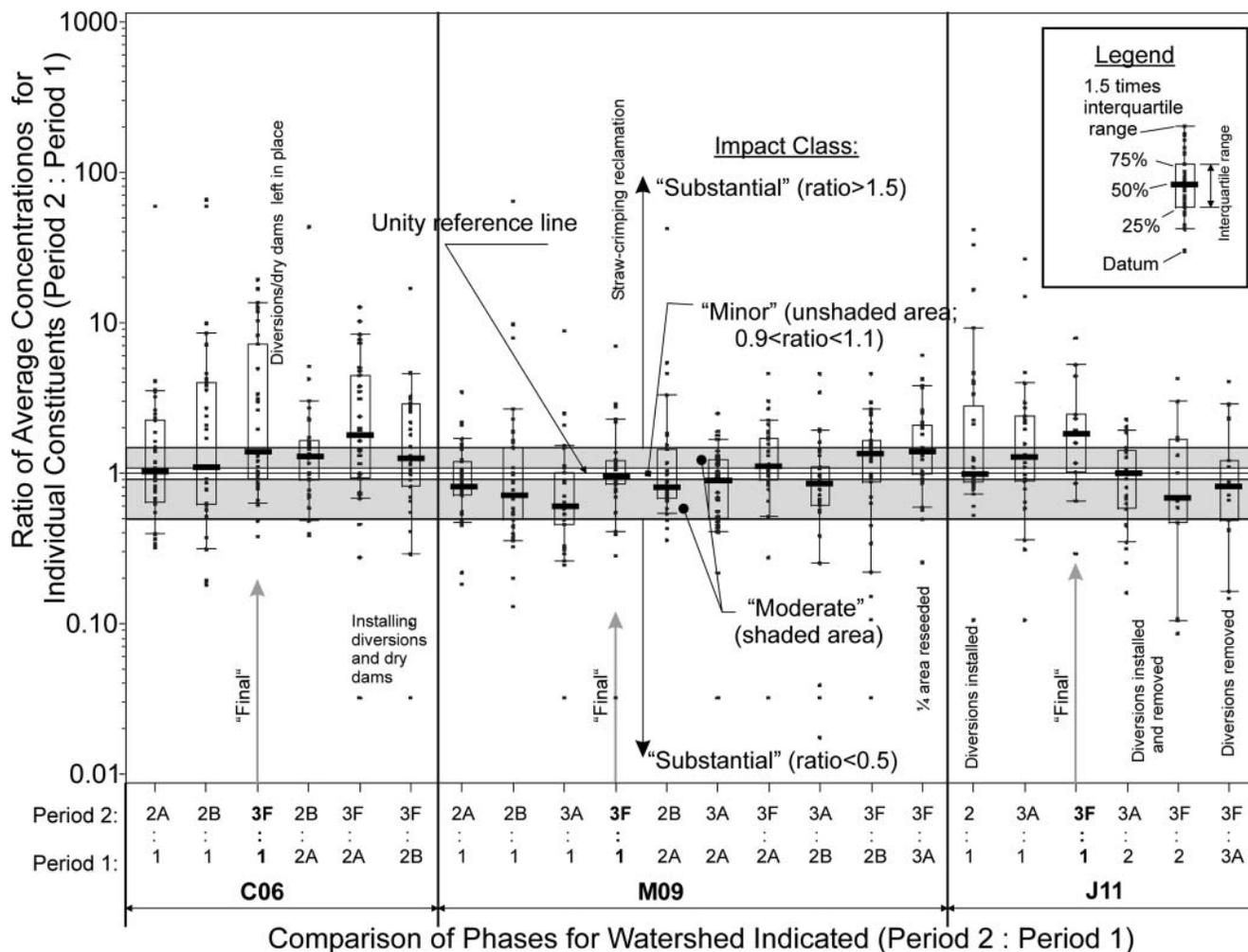


Figure 3. Comparisons of Average Chemical Constituent Concentration Ratios and Classifications of Impacts (“minor,” “moderate,” and “substantial”) Between Phases of Disturbance at the Three Watersheds (see Tables 3, 4, and 5 for constituents associated with ratio comparisons).

This suggests that water quality at this watershed was the most sensitive to drastic land disturbances.

At M09 the interquartile ranges of phase comparisons followed closely the bounds for the “moderate” classification (Figure 3). Also, average concentration ratios for 2A:1, 2B:1, and 3A:1 showed a general decreasing trend (Figure 3), suggesting improved water quality after each disturbance compared with the undisturbed watershed. The Phase 3F:1 comparison shows a narrow interquartile range close to unity, suggesting that final reclamation returned average concentrations at this watershed to near premine conditions for many constituents. The transition from Phases 3A to 3F (improved reclamation over a large part of the area; 3F:3A) shows an increase in the median ratio to near the boundary of the “substantial” category for an unknown reason.

At J11, comparison ratios increased compared with Phase 1 (2:1, 3A:1, and 3F:1; Figure 3). Median Phase 3F concentrations increased “substantially” only at this site. The data suggest that final reclamation increased concentrations compared with Phase 1, as at C06.

Geology was an important determinant of the results of the project, both during mining and reclamation activities. Geologic beds were fractured, forming spoil (fragmented overburden) on top of the watershed and over the original land surface below the elevation of the mined coal seam. At C06, overburden was mainly composed of sandstone (USBM, 1978) and was acidic. At M09 the overburden consisted mainly of limestone (alkaline), and at J11 the overburden was mainly sandstone. However, at J11 the beds below the elevation of the coal seam were primarily shale with some limestone (USBM, 1978).

The spoil type had an impact on the success of vegetation establishment. At MO9, vegetation generally covered the watershed surface better except for a period during which a large area had to be revegetated. The better vegetation protected against erosion and thus lowered chemical concentrations. At C06, the routing of water through diversions (discussed later) and poorly vegetated areas initially caused higher chemical concentrations. At J11, spoil did not support vegetation well initially, and large areas were incompletely reclaimed. This resulted in large load rates compared with the premine condition during reclamation activities.

**Constituent Changes.** The only constituent that substantially increased (ratio > 1.5) from the premine

(1) to reclaimed (3F) phases at all sites was SO<sub>4</sub> (3F:1; upper Table 6). Other constituents that increased at two watersheds were CO<sub>2</sub>, Ca, dissolved solids, Mg, Mn, and NH<sub>4</sub>-N. Constituent ratios that changed only at one site were Al, alkalinity, As, Cl, Cu, Fe, H<sub>2</sub>S, HCO<sub>3</sub>, hardness, Hg, NO<sub>3</sub>-N, Na, P, Se, and Sr. Constituents for which mining disturbances increased concentrations at all sites compared with Phase 1 (2:1, 2A:1, and 2B:1) were Mn, NH<sub>4</sub>-N, NO<sub>3</sub>-N, SO<sub>4</sub>, and Se (upper Table 6). Other constituents that increased at two watersheds were CO<sub>2</sub>, Cd, Cl, dissolved solids, and Ni. The only constituent that “substantially” decreased (ratio < 0.5) between Phase 1 and Phase 3F at two sites was Ni (3F:1; lower Table 6). A comparison between a Phase 2 period and Phase 1 showed reduced average concentrations across

TABLE 6. Lists of Constituents Changing in Average Concentration “Substantially” Between Phases 1 and Other Phases in Tables 3, 4 and 5 and Figure 3.

Watershed C06			Watershed M09				Watershed J11		
2A:1	2B:1	3F:1	2A:1	2B:1	3A:1	3F:1	2:1	3A:1	3F:1
<b>Constituents Ranked from Largest to Smallest Concentration Ratio (ratio ≥ 1.5)</b>									
H <sub>2</sub> S	Mn	Mn	CO <sub>2</sub>	NH <sub>4</sub> (N)	CO <sub>2</sub>	NH <sub>4</sub> (N)	Mn	Mn	Al
NO <sub>3</sub> (N)	H <sub>2</sub> S	SO <sub>4</sub>	Mn	Se	Se	SO <sub>4</sub>	NH <sub>4</sub> (N)	NH <sub>4</sub> (N)	Cu
Se	Se	Mg	Se	NO <sub>3</sub> (N)	Cd	Diss Sol	Al	SO <sub>4</sub>	Ma
Diss Sol	SO <sub>4</sub>	Diss Sol	Phenols	P	P	CO <sub>2</sub>	Zn	NO <sub>3</sub> (N)	Fe
NH <sub>4</sub> (N)	NO <sub>3</sub> (N)	Hardness	Diss Sol	Cd		Hg	Se	Fe	SO <sub>4</sub>
Ca	CO <sub>2</sub>	Ca	NH <sub>4</sub> (N)	CO <sub>2</sub>		Se	Fe	Al	Mg
Hardness	Diss Sol	NH <sub>4</sub> (N)		Diss Sol			NO <sub>3</sub> (N)	Sb	P
CO <sub>2</sub>	Ca	CO <sub>2</sub>		Mn			Ni	Zn	Ca
Mg	Hardness	Sr		SO <sub>4</sub>			SO <sub>4</sub>	Hardness	
Sr	NH <sub>4</sub> (N)	Cl						Ca	
SO <sub>4</sub>	Mg	HCO <sub>3</sub>						Diss Sol	
Mn	Cl	Alkalinity						Ni	
	Sr	Na						Mg	
	Ni	NO <sub>3</sub> (N)							
	As	As							
	Cd	H <sub>2</sub> S							
<b>Constituents Ranked from Largest to Smallest Concentration Ratio (ratio ≤ 0.5)</b>									
HCO <sub>3</sub>	P	Zn	Ba	Cu	Alkalinity	Zn	H <sub>2</sub> S	CO <sub>2</sub>	Ni
Pb	Al	Ba	Al	Ni	HCO <sub>3</sub>	As		Alkalinity	
Alkalinity	HCO <sub>3</sub>		Sb	Ba	Hardness	Ni		HCO <sub>3</sub>	
Sb	Fe		Zn	Sr	NO <sub>3</sub> (N)	H <sub>2</sub> S		H <sub>2</sub> S	
Fe	Alkalinity	As	Al	Ca					
			Zn	Zn					
			Fe	As					
			As	Ba					
				Sr					
				H <sub>2</sub> S					

different sites for Al, Fe, alkalinity, As,  $\text{HCO}_3$ , Ni,  $\text{CO}_2$ , Zn, and several other constituents.

**Effects of Diversions.** Water conveyance diversions are often used during reclamation to reduce slope lengths for erosion control. Data from Tables 3 through 5 and Figure 3 can be used to show the effects of removing diversions installed during reclamation, of not removing diversions, of not using diversions, and of reclamation practices on average constituent concentrations. Their effects can be evaluated by examining relative increases and decreases in particular comparison ratios as described below.

At C06, the average Phase 3F concentration ratios were generally larger compared with the other phase comparisons at this site (Figure 3 – 55 percent of all 3F ratios were classified as substantial, 30 percent as moderate, and 15 percent as minor in Table 4). A total of 48 percent of the substantial ratios were greater than 1.5, and 6 percent were less than 0.5. The larger ratios are attributed to “final” reclamation consisting of a network of diversions (Figure 1a) that routed water to the headwater area, down a rock chute to the main stream channel, and then through a series of dry dams. Field observations revealed that this drainage pattern enhanced erosion of the rock chute and the main stream channel in spite of the dry dams. The rock chute was repaired on several occasions. Bonta (2000) found median sediment concentration during Phase 3F at C06 was four times that of Phase 1. This is compared with an average chemical constituent 3F:1 ratio of 4.7 (median = 1.4).

At M09 straw crimping was the “final” reclamation practice and diversions were not used (Figure 1b). Here 30 percent of constituent ratios were substantial, 49 percent were moderate, and 21 percent were minor (Table 5; Figure 3). Among the substantial impacts, 18 percent were greater than 1.5, and 12 percent that were less than 0.5. At this site the median Phase 3F:1 sediment concentration ratio was 0.5 (Bonta, 2000). This is compared with an average chemical constituent ratio of 1.3 (median = 1.0).

At J11, diversions were installed but removed during Phase 3A, and the “final” Phase 3F watershed had no diversions (Figure 1c). Sixty-nine percent of Phase 3F:1 ratios were substantial, 23 percent were moderate, and 8 percent were minor. Substantial impacts with ratios greater than 1.5 comprised 61 percent of the ratios, and ratios less than 0.5 comprised 8 percent. However, at this site there were fewer ratios (14) due to lack of data, compared with C06 and M09 (about 35 each). At J11, median Phase 3F:1 sediment concentration ratio was 2 (Bonta, 2000). This is compared with an average 3F:1 chemical constituent ratio of 2.5 (median = 1.9).

Generally, the impacts of mining and reclamation on *average* chemical constituent concentrations between Phases 1 and 3F at all sites paralleled the impact of mining and reclamation on *median* sediment concentrations. However, at M09 average chemical constituent concentration ratios were greater than unity after reclamation, whereas median sediment concentration ratios were less than unity. Nevertheless, they were the smallest and had the narrowest interquartile range among the three sites (Figure 3), and median constituent ratio was unity. At J11, diversions were removed between Phases 3A and 3F, and a general reduction in average chemical concentration ratios between these two phases is apparent from the Phase 3F:3A comparison ratios in Figure 3 (Table 5). The data suggest that diversions left in place (e.g., C06) at the end of reclamation may aggravate average constituent concentrations as found for sediment. Diversion removal appears to reduce ratios of average chemical concentrations (e.g., J11). Furthermore, straw crimping without diversions (e.g., M09) is a good reclamation practice that causes average constituent concentrations to decrease and approach premine levels (median Phase 3F:1 ratio of 1.0).

#### *Comparison of Average Load Rates*

**Overview of Average Load Rates.** Unlike concentrations, constituent load rates account for the comprehensive effects of changing hydrology (Table 2) and water chemistry due to mining and reclamation. Tables 7 through 9 have a format similar to concentration results in Tables 3 through 5 and summarize average load rates for each constituent and phase (left side of Tables 3 through 5).

Largest load rates were found for dissolved solids, hardness, and  $\text{SO}_4$ . Dissolved solids had values as large as 130 kg/day (C06 Phase 3F, Table 7), and  $\text{SO}_4$  values were as large as 65.7 kg/day at C06 (Phase 2B, Table 7). Mn load rates were generally larger at C06 (1.37 kg/day – Phase 2B, Table 7) and at J11 (0.51 kg/day – Phase 2, Table 9). Lesser load rates of 0.1 kg/day to 1.0 kg/day occurred for some major ions, and many substances had load rates less than 0.1 kg/day.

**Comparisons Between Phases.** The right side of Tables 7 through 9 lists the ratios of average load rates for the comparisons between the indicated phases along with the classifications of ratios into impact classes (similar to concentrations in Tables 3 through 5). The stages of mining and reclamation during which the watersheds were at a greater risk for increased load rates can be identified from the

TABLE 7. Summary of Average Constituent Load Rates and Phase Comparison Results at C06.  
(Bold comparison shows state of watershed at end of monitoring period. All comparisons shown in Figure 4.)

Constituent	Average Load Rates (kg/day) for Each Phase Disturbance				Ratio of Average Load Rates and Impact Classes for Each Phase Comparison											
	1	2A	2B	3F	2A:1	C <sup>†</sup>	2B:1	C	3F:1	C	2B:2A	C	3F:2A	C	3F:2B	C
Ag	<0.01	<0.01	<0.01	<0.01	0.53	M	1.17	M	<b>1.22</b>	M	2.20	S	2.29	S	1.04	m
Al	0.03	0.01	<0.01	<0.01	0.20	S	0.17	S	<b>0.27</b>	S	0.87	M	1.35	M	1.55	S
Alkalinity	5.47	1.42	1.51	10.7	0.26	S	0.28	S	<b>1.97</b>	S	1.07	m	7.57	S	7.11	S
As	<0.01 <sup>‡</sup>	<0.01	<0.01 <sup>‡</sup>	<0.01	0.61	M	1.78	S	<b>2.69</b>	S	2.95	S	4.45	S	1.51	S
Ba	<0.01	<0.01	<0.01	<0.01	0.35	S	0.52	M	<b>0.39</b>	S	1.50	S	1.13	M	0.75	M
Ca	3.18	4.71	16.3	19.0	1.48	M	5.12	S	<b>5.97</b>	S	3.46	S	4.04	S	1.17	M
Cd	<0.01	<0.01	<0.01 <sup>‡</sup>	<0.01	0.43	S	1.54	S	<b>1.24</b>	M	3.57	S	2.86	S	0.80	M
Cl	0.30	0.13	1.15	2.38	0.42	S	3.86	S	<b>7.98</b>	S	9.20	S	19.0	S	2.07	S
CN	<0.01	<0.01	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	0.50	M	0.79	M	<b>0.89</b>	M	1.57	S	1.78	S	1.13	M
CO <sub>2</sub>	0.89	1.65	5.69	4.69	1.87	S	6.43	S	<b>5.30</b>	S	3.45	S	2.84	S	0.82	M
Cr	<0.01	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	0.39	S	0.84	M	<b>0.95</b>	m	2.14	S	2.43	S	1.13	M
Cu	<0.01	<0.01	<0.01	<0.01	0.23	S	0.47	S	<b>0.81</b>	M	2.01	S	3.47	S	1.73	S
Diss Sol	22.2	38.8	109.	130.	1.75	S	4.91	S	<b>5.85</b>	S	2.81	S	3.35	S	1.19	M
DO	n	n	2.12 <sup>‡</sup>	1.99	n	n	n	n	<b>n</b>	n	n	n	n	n	0.94	m
Fe	0.03	<0.01	<0.01	<0.01	0.08	S	0.11	S	<b>0.27</b>	S	1.28	M	3.20	S	2.50	S
Fl	0.02	<0.01	0.01	0.04	0.29	S	0.57	M	<b>1.80</b>	S	1.97	S	6.25	S	3.17	S
H <sub>2</sub> S	<0.01 <sup>‡</sup>	0.03 <sup>‡</sup>	0.06 <sup>‡</sup>	<0.01 <sup>‡</sup>	25.0	S	53.5	S	<b>2.02</b>	S	2.14	S	0.08	S	0.04	S
Hardness	12.6	17.9	61.7	80.4	1.42	M	4.89	S	<b>6.38</b>	S	3.44	S	4.48	S	1.30	M
HCO <sub>3</sub>	6.15	1.73	1.83	13.1	0.28	S	0.30	S	<b>2.13</b>	S	1.06	m	7.54	S	7.13	S
Hg	<0.01	<0.01	<0.01 <sup>‡</sup>	<0.01	0.32	S	1.00	m	<b>1.14</b>	M	3.14	S	3.56	S	1.13	M
Mg	1.12	1.50	5.10	8.94	1.33	M	4.54	S	<b>7.96</b>	S	3.41	S	5.98	S	1.75	S
Mn	0.02	0.17	1.37	0.24	7.30	S	59.0	S	<b>10.5</b>	S	8.09	S	1.44	M	0.18	S
Na	0.56	0.21	0.47	0.82	0.38	S	0.83	M	<b>1.45</b>	M	2.19	S	3.83	S	1.75	S
NH <sub>4</sub> -N	<0.01	<0.01	0.02	0.05	0.84	M	2.13	S	<b>6.46</b>	S	2.54	S	7.68	S	3.03	S
Ni	<0.01	<0.01	<0.01	<0.01	0.88	M	2.86	S	<b>0.96</b>	m	3.25	S	1.09	m	0.34	S
NO <sub>3</sub> -N	0.11	0.09	0.33	0.15	0.83	M	3.12	S	<b>1.47</b>	M	3.77	S	1.78	S	0.47	S
P	0.02	<0.01	<0.01	0.02	0.40	S	0.34	S	<b>1.00</b>	m	0.84	M	2.47	S	2.93	S
Pb	<0.01	<0.01	<0.01	<0.01	0.26	S	0.77	M	<b>0.93</b>	m	2.92	S	3.51	S	1.21	M
Phenols	<0.01	<0.01	<0.01 <sup>‡</sup>	<0.01	0.80	M	0.99	m	<b>1.34</b>	M	1.24	M	1.67	S	1.34	M
Sb	<0.01	<0.01	<0.01	<0.01	0.2	S	0.78	M	<b>0.84</b>	M	4.00	S	4.28	S	1.07	m
Se	<0.01	<0.01	<0.01	<0.01	5.43	S	8.95	S	<b>2.06</b>	S	1.65	S	0.38	S	0.23	S
SO <sub>4</sub>	7.15	11.8	65.7	58.0	1.64	S	9.19	S	<b>8.11</b>	S	5.59	S	4.93	S	0.88	M
Sr	0.01	0.01	0.03	0.04	1.07	m	2.93	S	<b>3.77</b>	S	2.75	S	3.54	S	1.29	M
Zn	<0.01	<0.01	<0.01	<0.01	0.27	S	0.78	M	<b>0.42</b>	S	2.90	S	1.54	S	0.53	M

<sup>†</sup>Classification of comparison between the two phase comparisons: m = “minor” (0.9 < ratio < 1.1). M = “moderate” (0.5 < ratio < 0.9 or 1.1 < ratio < 1.5). S = “substantial” (ratio < 0.5 or ratio > 1.5).

<sup>‡</sup>Based on one field sample.

individual comparison ratios and impact classes. Improvements in load rate can be similarly identified and quantified. Figure 4 summarizes the load rate comparison ratios in Tables 7 through 9 with box and whisker plots. The “final” watershed condition (at the end of monitoring) is shown in Figure 4, and the ratios for individual constituents are in bold in Tables 7 through 9 (3F:1 ratios).

For the 665 ratios of constituent load rate ratios (Tables 7 through 9; Figure 4), the minimum was 0.02

(Mn, J11, 3F:2; Table 9) and the maximum was 98.9 (NH<sub>4</sub>-N, M09, 2B:2A; Table 8), with an average load rate ratio of 3.3 across all sites. Few ratios were at the extremes, with only 5 percent exceeding a ratio of 8.1 and 5 percent less than a ratio of 0.21. The 10 largest load rate ratios (ratios ranging from 29.6 to 98.9) included only the constituents Mn, NH<sub>4</sub>-N, H<sub>2</sub>S, Al, and Se. Large ratios for Mn (59.0 at C06, and 73.8, 90.9 at J11) involved small load rates (maximum of 1.37 kg/day found at C06). The 10 smallest ratios

TABLE 8. Summary of Average Constituent Load Rates and Phase Comparison Results at M09. (Bold comparison shows state of watershed at end of monitoring period. All comparisons shown in Figure 4).

Constituent	Average Load Rates (kg/day) for Each Phase of Disturbance				Ratio of Average Concentrations and Impact Classes for Each Phase Comparison																						
	1	2A	2B	3A	3F	2A:1	C <sup>†</sup>	2B:1	C	3A:1	C	3F:1	C	2B:2A	C	3A:2A	C	3F:2A	C	3A:2B	C	3F:2B	C	3F:2A	C		
Ag	<0.01	<0.01	<0.01	<0.01	<0.01	1.94	S	2.52	S	6.52	S	<b>3.79</b>	S	1.30	M	3.36	S	1.95	S	2.59	S	1.50	S	1.50	S	0.58	M
Al	0.02	<0.01	<0.01	<0.01	<0.01	0.06	S	0.08	S	0.15	S	<b>0.23</b>	S	1.33	M	2.57	S	4.09	S	1.93	S	3.06	S	3.06	S	1.59	S
Alkalinity	4.40	6.09	6.62	21.1	9.17	1.38	M	1.51	S	4.80	S	<b>2.08</b>	S	1.09	m	3.47	S	1.51	S	3.18	S	1.38	M	1.38	M	0.44	S
As	<0.01	<0.01	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	0.37	S	0.47	S	1.70	S	<b>1.41</b>	M	1.26	M	4.58	S	3.81	S	3.64	S	3.03	S	3.03	S	0.83	M
Ba	<0.01	<0.01	<0.01	<0.01	<0.01	0.97	m	1.41	M	1.59	S	<b>1.43</b>	M	1.45	M	1.64	S	1.48	M	1.13	M	1.02	m	1.02	m	0.90	m
Ca	2.11	5.50	7.06	7.44	6.20	2.61	S	3.35	S	3.53	S	<b>2.94</b>	S	1.29	M	1.35	M	1.13	M	1.05	m	0.88	M	0.88	M	0.83	M
Cd	<0.01	<0.01	<0.01	<0.01	<0.01	2.47	S	8.13	S	10.35	S	<b>3.78</b>	S	3.30	S	4.20	S	1.53	S	1.27	M	0.47	S	0.47	S	0.37	S
Cl	0.26	0.40	1.89	2.33	0.85	1.56	S	7.35	S	9.04	S	<b>3.28</b>	S	4.73	S	5.81	S	2.11	S	1.23	M	0.45	S	0.45	S	0.36	S
CN	<0.01	<0.01	<0.01 <sup>‡</sup>	<0.11 <sup>‡</sup>	<0.01 <sup>‡</sup>	1.61	S	2.57	S	4.68	S	<b>2.60</b>	S	1.60	S	2.91	S	1.62	S	1.82	S	1.01	m	1.01	m	0.56	M
CO <sub>2</sub>	0.40	2.80	2.69	8.42	2.01	6.96	S	6.70	S	21.0	S	<b>5.01</b>	S	.96	m	3.01	S	.72	M	3.13	S	0.75	M	0.75	M	0.24	S
Cr	<0.01	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	1.75	S	3.08	S	5.61	S	<b>3.12</b>	S	1.76	S	3.20	S	1.78	S	1.82	S	1.01	m	1.01	m	0.56	M
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	1.82	S	1.59	S	5.61	S	<b>4.31</b>	S	0.87	M	3.08	S	2.37	S	3.54	S	2.72	S	2.72	S	0.77	M
Diss Sol	8.53	26.9	50.1	35.5	29.5	3.16	S	5.87	S	4.16	S	<b>3.46</b>	S	1.86	S	1.32	M	1.10	m	0.71	M	0.59	M	0.59	M	0.83	M
DO	n	n	1.2	2.72	1.55	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	0.57	M
Fe	0.01	<0.01	<0.01	<0.01	<0.01	0.10	S	0.06	S	0.39	S	<b>0.29</b>	S	0.65	M	4.11	S	3.03	S	6.37	S	4.69	S	4.69	S	0.74	M
Fl	<0.01	0.01	0.04	0.05	0.04	1.74	S	5.38	S	7.89	S	<b>5.29</b>	S	3.10	S	4.55	S	3.05	S	1.47	M	0.98	m	0.98	m	0.67	M
H <sub>2</sub> S	0.01	0.02 <sup>‡</sup>	0.04 <sup>‡</sup>	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	1.98	S	3.49	S	0.21	S	<b>0.12</b>	S	1.76	S	0.11	S	0.06	S	0.06	S	0.03	S	0.03	S	0.56	M
Hardness	7.57	19.7	23.9	29.2	17.2	2.60	S	3.16	S	3.86	S	<b>2.27</b>	S	1.21	M	1.48	M	0.87	M	1.22	M	0.72	M	0.72	M	0.59	M
HCO <sub>3</sub>	5.37	7.42	8.04	25.7	11.2	1.38	M	1.50	M	4.79	S	<b>2.08</b>	S	1.08	m	3.46	S	1.5	S	3.20	S	1.39	M	1.39	M	0.43	S
Hg	<0.01	<0.01	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	1.64	S	5.24	S	9.54	S	<b>7.94</b>	S	3.20	S	5.82	S	4.85	S	1.82	S	1.52	S	1.52	S	0.83	M
Mg	0.56	1.27	1.41	1.54	1.21	2.25	S	2.51	S	2.74	S	<b>2.15</b>	S	1.12	M	1.22	M	0.96	m	1.09	m	0.86	M	0.86	M	0.79	M
Mn	<0.01	<0.01	0.01	0.01	<0.01	4.39	S	5.71	S	5.82	S	<b>2.15</b>	S	1.30	M	1.33	M	0.49	S	1.02	m	0.38	S	0.38	S	0.37	S
Na	0.16	0.27	0.29	1.07	0.30	1.71	S	1.86	S	6.77	S	<b>1.89</b>	S	1.09	m	3.97	S	1.11	M	3.64	S	1.01	m	1.01	m	0.28	S
NH <sub>4</sub> -N	<0.01	<0.01	0.10	<0.01	0.01	0.15	S	15.0	S	0.49	S	<b>1.66</b>	S	98.9	S	3.19	S	10.9	S	0.03	S	0.11	S	0.11	S	3.42	S
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	2.04	S	1.57	S	3.18	S	<b>1.02</b>	m	0.77	M	1.56	S	0.50	M	2.03	S	0.65	M	0.65	M	0.32	S
NO <sub>3</sub> -N	0.04	0.10	0.97	0.07	0.15	2.90	S	28.0	S	2.06	S	<b>4.40</b>	S	9.68	S	0.71	M	1.52	S	0.07	S	0.16	S	0.16	S	2.14	S
P	<0.01	<0.01	0.02	0.02	0.02	1.60	S	9.45	S	9.90	S	<b>9.91</b>	S	5.89	S	6.18	S	6.18	S	1.05	m	1.05	m	1.05	m	1.00	m
Pb	<0.01	<0.01	<0.01	<0.01	<0.01	1.50	S	2.07	S	5.61	S	<b>3.42</b>	S	1.38	M	3.74	S	2.28	S	2.71	S	1.65	S	1.65	S	0.61	M
Phenols	<0.01	<0.01	<0.01	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	1.97	S	2.05	S	3.32	S	<b>1.84</b>	S	1.04	m	1.69	S	0.94	m	1.62	S	0.90	M	0.90	M	0.56	M
Sb	<0.01	<0.01	<0.01	<0.01	<0.01	0.91	m	1.91	S	3.79	S	<b>2.63</b>	S	2.09	S	4.16	S	2.88	S	1.99	S	1.38	M	1.38	M	0.69	M
Se	<0.01	<0.01	<0.01	<0.01	<0.01	29.6	S	34.5	S	16.1	S	<b>7.81</b>	S	1.16	M	0.54	M	0.26	S	0.47	S	0.23	S	0.23	S	0.49	S
SO <sub>4</sub>	1.21	7.89	10.8	7.39	8.55	6.50	S	8.88	S	6.09	S	<b>7.04</b>	S	1.37	M	0.94	m	1.08	m	0.69	M	0.79	M	0.79	M	1.16	m
Sr	0.01	0.02	0.02	0.03	0.02	2.07	S	2.45	S	2.93	S	<b>1.96</b>	S	1.19	M	1.42	M	.95	m	1.20	M	0.80	M	0.80	M	0.67	M
Zn	<0.01	<0.01	<0.01	<0.01	<0.01	0.31	S	1.16	M	1.89	S	<b>1.48</b>	M	3.79	S	6.18	S	4.83	S	1.63	S	1.27	M	1.27	M	0.78	M

<sup>†</sup>Classification of comparison between the two phase comparisons: m = "minor" (0.9 < ratio < 1.1), M = "moderate" (0.5 < ratio < 0.9 or 1.1 < ratio < 1.5), S = "substantial" (ratio < 0.5 or ratio > 1.5).

<sup>‡</sup>Based on one field sample.

TABLE 9. Summary of Average Constituent Load Rates and Phase Comparison Results at J11. (Bold comparison shows state of watershed at end of monitoring period. All comparisons shown in Figure 4.)

Constituent	Average Load Rates (kg/day) for Each Phase Disturbance				Ratio of Average Load Rates and Impact Classes for Each Phase Comparison											
	1	2	3A	3F	2:1	C <sup>†</sup>	3A:1	C	3F:1	C	3A:2	C	3F:2	C	3F:3A	C
Ag	<0.01	<0.01	<0.01	n	2.09	S	2.47	S	<b>n</b>	n	1.18	M	n	n	n	n
Al	<0.01	0.06	0.01	0.02	36.2	S	7.54	S	<b>9.42</b>	S	0.21	S	0.26	S	1.25	M
Alkalinity	5.41	1.99	9.74	n	0.37	S	1.80	S	<b>n</b>	n	4.90	S	n	n	n	n
As	<0.01	n	n	n	n	n	n	n	<b>n</b>	n	n	n	n	n	n	n
Ba	<0.01	<0.01	0.01	<0.01	2.71	S	3.56	S	<b>1.03</b>	m	1.31	M	0.38	S	0.29	S
Ca	3.18	9.78	8.54	3.74	3.07	S	2.68	S	<b>1.18</b>	M	0.87	M	0.38	S	0.44	S
Cd	<0.01	<0.01	<0.01	n	1.72	S	1.79	S	<b>n</b>	n	1.04	m	n	n	n	n
Cl	0.81	1.96	2.66	n	2.43	S	3.30	S	<b>n</b>	n	1.36	M	n	n	n	n
CN	<0.01	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	n	2.02	S	2.56	S	<b>n</b>	n	1.27	M	n	n	n	n
CO <sub>2</sub>	2.47	2.86	2.48	n	1.16	M	1.01	m	<b>n</b>	n	0.87	M	n	n	n	n
Cr	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	n	2.16	S	2.74	S	<b>n</b>	n	1.27	M	n	n	n	n
Cu	<0.01	<0.01	<0.01 <sup>‡</sup>	<0.01	2.66	S	3.55	S	<b>6.28</b>	S	1.33	M	2.36	S	1.77	S
Diss Sol	17.1	58.1	49.9	n	3.39	S	2.92	S	<b>n</b>	n	0.86	M	n	n	n	n
DO	1.21	2.16	3.65	n	1.78	S	3.01	S	<b>n</b>	n	1.69	S	n	n	n	n
Fe	<0.01	<0.01	<0.01	<0.01	5.99	S	5.49	S	<b>2.81</b>	S	0.92	m	0.47	S	0.51	M
Fl	0.01	0.02	0.03	n	1.75	S	2.73	S	<b>n</b>	n	1.56	S	n	n	n	n
H <sub>2</sub> S	0.01	<0.01 <sup>‡</sup>	<0.01 <sup>‡</sup>	n	0.23	S	0.30	S	<b>n</b>	n	1.27	M	n	n	n	n
Hardness	10.9	35.9	31.4	n	3.29	S	2.88	S	<b>n</b>	n	0.88	M	n	n	n	n
HCO <sub>3</sub>	6.60	2.44	11.8	n	0.37	S	1.79	S	<b>n</b>	n	4.83	S	n	n	n	n
Hg	<0.01	n	n	n	n	n	n	n	<b>n</b>	n	n	n	n	n	n	n
Mg	0.72	2.78	5.05	1.02	3.88	S	7.05	S	<b>1.43</b>	M	1.82	S	0.37	S	0.20	S
Mn	0.01	0.51	0.41	0.01	90.9	S	73.8	S	<b>2.13</b>	S	0.81	M	0.02	S	0.03	S
Na	0.44	0.57	0.54	0.21	1.29	M	1.22	M	<b>0.48</b>	S	0.94	m	0.37	S	0.39	S
NH <sub>4</sub> -N	<0.01	0.20	0.12	n	51.7	S	29.8	S	<b>n</b>	n	0.58	M	n	n	n	n
Ni	<0.01	<0.01	<0.01	<0.01	7.36	S	5.46	S	<b>0.35</b>	S	0.74	M	0.05	S	0.06	S
NO <sub>3</sub> -N	0.20	0.93	1.18	n	4.57	S	5.80	S	<b>n</b>	n	1.27	M	n	n	n	n
P	<0.01	<0.01 <sup>‡</sup>	<0.01	<0.01	1.33	M	2.20	S	<b>2.20</b>	S	1.65	S	1.66	S	1.00	m
Pb	<0.01	<0.01	<0.01 <sup>‡</sup>	n	2.10	S	3.72	S	<b>n</b>	n	1.77	S	n	n	n	n
Phenols	<0.01	<0.01	<0.01 <sup>‡</sup>	n	1.80	S	3.29	S	<b>n</b>	n	1.83	S	n	n	n	n
Sb	<0.01	<0.01	0.01	n	2.77	S	6.65	S	<b>n</b>	n	2.40	S	n	n	n	n
Se	<0.01	<0.01	n	n	10.2	S	n	n	<b>n</b>	n	n	n	n	n	n	n
SO <sub>4</sub>	4.73	31.2	21.4	7.88	6.60	S	4.52	S	<b>1.67</b>	S	0.69	M	0.25	S	0.37	S
Sr	0.02	0.03	0.03	0.01	1.73	S	1.69	S	<b>0.86</b>	M	0.98	m	0.50	S	0.51	S
Zn	<0.01	0.01	<0.01	<0.01	20.3	S	6.63	S	<b>1.22</b>	M	0.33	S	0.06	S	0.18	S

<sup>†</sup>Classification of comparison between the two phase comparisons: m = “minor” (0.9 < ratio < 1.1). M = “moderate” (0.5 < ratio < 0.9 or 1.1 < ratio < 1.5). S = “substantial” (ratio < 0.5 or ratio > 1.5).

<sup>‡</sup>Based on one field sample.

(0.23 to 0.61) included many of the same constituents as the 10 largest ratios – Mn, NH<sub>4</sub>-N, H<sub>2</sub>S, Ni, Al, and Zn.

“Minor,” “moderate,” and “substantial” impacts were found in 7 percent, 25 percent, and 69 percent of comparisons of load rate ratios at C06 (Table 7), 8 percent, 24 percent, and 68 percent at M09 (Table 8), and 5 percent, 20 percent, and 69 percent at J11 (Table 9), respectively. The ratio data show that the percentage of impact classifications are nearly uniform at all the

sites. The average percentage of “substantial” load rate impacts across sites (approximately 69 percent) is much larger than the corresponding average percentage for average concentrations (approximately 49 percent), showing the importance of incorporating changing hydrology into evaluations of stream water chemistry. Lesser average percentages of “moderate” and “minor” classes were also notable for average load rate ratios (23 percent for load rate compared with 36 percent for concentration for “moderate” changes and

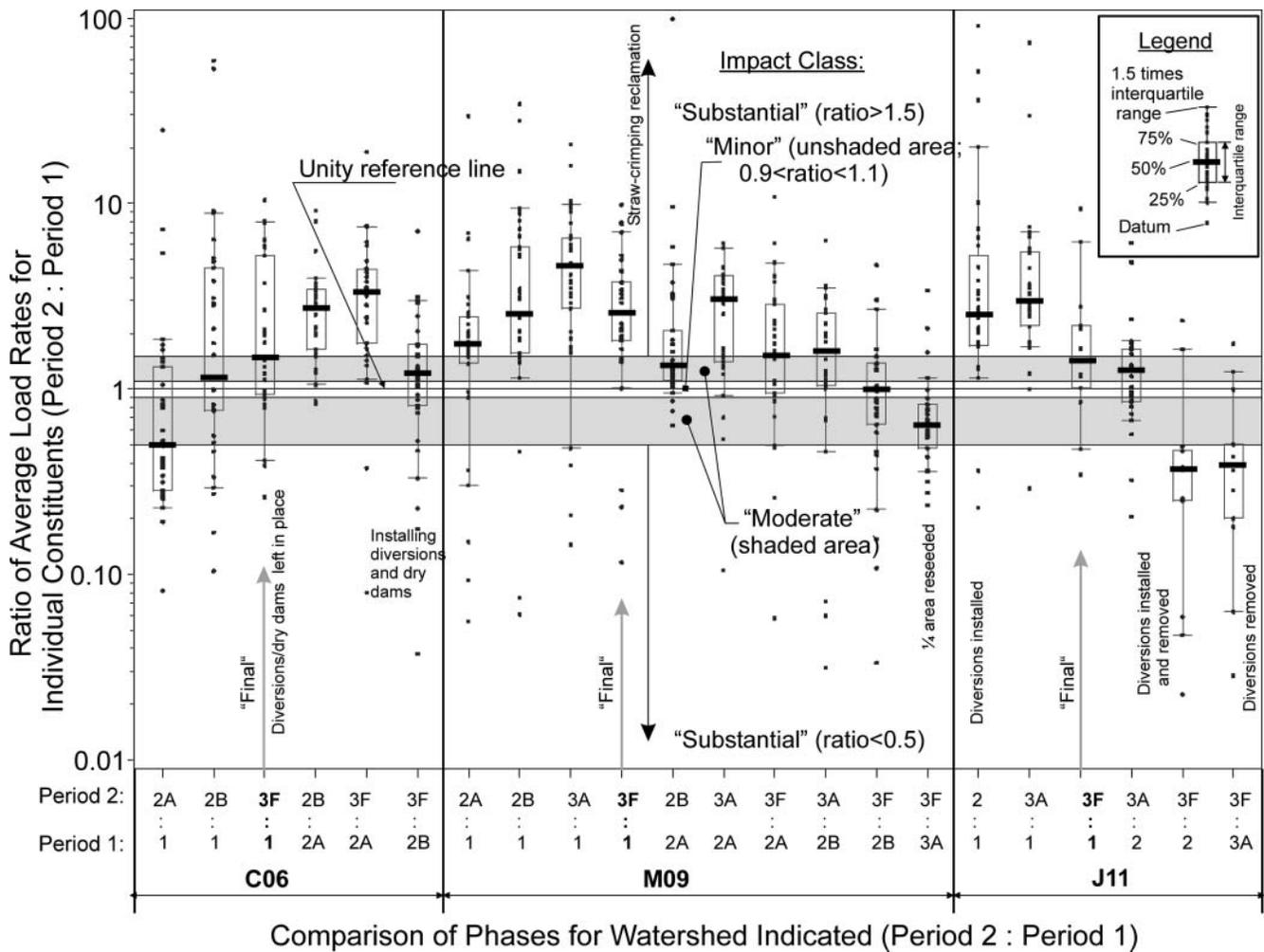


Figure 4. Comparisons of Average Chemical Constituent Load Rate Ratios and Classifications of Impacts (“minor,” “moderate,” and “substantial”) Between Phases of Disturbance at the Three Watersheds (see Tables 7, 8, and 9 for constituents associated with ratio comparisons).

7 percent for load rate compared with 15 percent for average concentration for “minor” changes, respectively; Tables 3 through 5). Figure 4 shows that median and interquartile ranges of load rate ratios were often above the unity reference line and upper “substantial” boundary, showing notable increases in load rates for many changes in land disturbances.

The Phase 3F:1 average load rate ratios were generally larger at M09 (median ratio = 2.6) than at the other sites, as apparent from the largest median ratio at this site (Figure 4, Tables 7 through 9). Median load rate 3F:1 ratios at C06 and J11 were about the same – both near the moderate-substantial impact borderline (median = 1.5 at C06 and = 1.4 at J11). This is in contrast to median average concentrations that were larger at J11 (median average concentration ratio = 1.9) and C06 (median = 1.4) and smallest at M09 (median = 1.0).

At M09, 88 percent of all Phase 3F:1 load rate ratios were classified as “substantial,” 9 percent as “moderate,” and 3 percent as “minor.” Larger load rate ratios at M09 are in contrast to C06 and J11, which had nearly identical 3F:1 distributions (61 percent, 27 percent, and 12 percent at C06, respectively, and 62 percent, 31 percent, and 8 percent at J11, respectively). Notably fewer load rate ratios were in the substantial class, and more ratios were in the moderate class at C06 and J11 compared with M09. At M09, 88 percent of substantial load rate ratios were increases and 12 percent were decreases. This is compared with 48 percent increases and 12 percent decreases at C06 and 46 percent increases and 15 percent decreases at J11.

The notably larger percentage of ratios at M09 is due in part to the most substantive change in watershed hydrology caused by mining and reclamation at

this site compared with other sites (3F:1; Table 2; Figure 2; Bonta *et al.*, 1997). The drastic change in M09 hydrology is apparent by a 22 percent increase in curve number at M09 from Phase 1 to Phase 3F (71 to 91; Table 2), compared with C06, which experienced only a 7 percent increase (81 to 87), and J11, which experienced a 17 percent increase (75 to 88). Furthermore, Table 2 shows that M09 average flow was 3.6 times greater during Phase 3F than Phase 1, whereas at C06 and J11 the increases were 1.1 times and 1.2 times, respectively.

At all three sites, larger flows during Phase 3F were often greater than Phase 1, and Phase 3F low flows were often lower during Phase 3F compared with Phase 1 (Figure 2). Concentrations for negative regression slopes are more sensitive to low flows, and those for positively sloped regressions are more sensitive to large flow rates. Magnitudes are dependent on regression-parameter values, weather experienced, changing watershed hydrology, and statistically significant changes in regressions. These factors combined to yield the higher percentage of larger ratios at M09.

At C06, average load rates decreased for 2A:1 (median ratio = 0.5; Figure 4). The reduction is attributed to generally a larger percent of time of smaller flows (dotted line in Figure 2a) during Phase 2A. The generally larger load rate ratios between Phases 2A and 2B and Phases 1 and 2B are ascribed to the increased disturbances due to reclamation (Table 1) and generally larger flows during Phase 2B compared with 2A (Figure 2a). Also, during Phase 2A probable watershed area decreased to 23 percent of the original watershed area (4.70 ha; Bonta, 2000), also decreasing the potential for larger flow rates during Phase 2A. The increases in load rate ratios from Phase 2A to Phase 3F (median = 3.3) are attributed to many reclamation activities (grading, topsoiling, etc.) and the initial installation of a diversion network to control erosion during vegetation establishment (Figure 1a). Smaller load rate ratios from Phase 2B to Phase 3F (median = 1.2) are due to installation of diversions to control erosion after vegetation was established (more discussion on diversions later).

At M09 the increases in average load rates between Phases 1 and 2A, 1 and 2B, and 1 and 3A (Figure 4) are attributed to the increased surface disturbances due primarily to mining. During Phase 2A, watershed area decreased to 36 percent of the Phase 1 area (6.40 ha; Bonta, 2000), and then area increased by 40 percent to about 9 ha during Phase 2B. Larger area partly explains the higher large flows during Phase 2B. Watershed surface characteristics were similar for these two phases, causing smaller increases from Phase 2A to Phase 2B. Load rate ratios also increased

from Phases 2A to 3A and Phases 2A to 3F. The generally high 3A:2A ratios (median = 3.1) were attributed to the large area (about one-fourth of the area) that was poorly covered after reclamation on which rills developed and to an increase of 3.2 times in average flow rate (0.95 to 3.01 L/sec; Table 2). Phase 3A:2B load rate ratios (median = 1.6; Figure 4) are large due to the poor cover combined with an 82 percent increase in average flow rate from Phase 2B to Phase 3A (from 1.65 L/sec to 3.01 L/sec; Table 2). These data document the larger chemical load rates that can be expected from areas that are poorly reclaimed.

Little load rate change was found for many constituents between Phases 2B and 3F, which had nearly identical flows (1.65 L/sec for Phase 2B and 1.67 L/sec for Phase 3F; Table 2). Also, the FDCs were similarly located in Figure 2b.

Load rate ratios decreased from 3A to 3F (median = 0.8), showing the benefits of establishing a good stand of vegetation over 1/4 of the area of the watershed that was poorly covered during Phase 3A. The Phase 3F:1 ratios were large (median = 1.5) and are partly attributed to low average Phase 1 flow (0.47 L/sec compared with 1.67 L/sec during Phase 3F; Table 2).

At J11, increases in average load rate ratios between Phases 1 and 2 (median ratio = 2.5) and 1 and 3A (median = 3.0) were due to mining and reclamation activities and diversion installation (3A; Table 1). Watershed area decreased to 39 percent of the original area during Phase 2 (4.62 ha; Bonta, 2000). Average flow rate increased 2.2 times from Phase 1 to 2 and 2.7 times from Phase 1 to 3A (Table 2). The load rate ratio reductions from Phase 2 to 3F and from 3A to 3F (medians = 0.4) are attributed to a smaller watershed area due to diversion removal and to better vegetative cover than during Phase 3A (a period when diversions were failing).

The load rate ratio comparison results are affected by the distribution of different types of disturbances within the runoff area of each watershed (e.g., changing probable runoff areas, percent of areas reclaimed, undisturbed, undergoing spoil grading, etc.; Bonta, 2000). The results are also affected by statistically significant changes in regressions between phases of disturbances. Regression line slope and intercept changes suggest that the supply of constituents and the sensitivity of constituent yields by flowing water changed due to mining and reclaiming the watersheds as indicated by changes in the coefficient and exponent in the power equation. Impacts of watershed disturbances on regressions were different at each site, and an evaluation of these changes is beyond the scope of the present study.

**Constituent Changes.** The only constituents that “substantially” increased (load rate ratios > 1.5) from the premine to reclaimed phases (3F) for all sites were SO<sub>4</sub> and Mn (upper Table 10 and Tables 7 through 9). Other constituents that increased at two watersheds were alkalinity, CO<sub>2</sub>, Ca, Cl, Cu, dissolved solids, Fl, hardness, HCO<sub>3</sub>, Mg, NH<sub>4</sub>-N, P, Se, and Sr. For all Phase 3F:1 comparisons for which two watersheds showed increases for the same constituent, M09 was always one site, suggesting that average load ratios for these constituents at M09 were affected most by reclamation. Constituents that substantially increased from Phases 1 to 3F at only one site included Ag, Al, As, CN, Cd, Cr, Fe, H<sub>2</sub>S, Hg, Na, NO<sub>3</sub>-N, Pb, Sb, and phenols.

Constituents increasing in average load rate between Phase 1 and a subphase within Phase 2 or the beginning of Phase 3 (seven of seven possible comparisons) were dissolved solids, Mn, and SO<sub>4</sub> (upper Table 7). Constituents occurring for six of seven comparisons across all watersheds were Ca, Cd, hardness, Mg, NO<sub>3</sub>-N, Ni, Se, and Sr. Common constituents occurring for five of seven comparisons were Ag, CN, CO<sub>2</sub>, Cr, Cu, Fl, Pb, and phenols.

“Substantial” load rate ratios less than 0.5 for comparisons between Phases 1 and 3F for all watersheds showed reduced average load rates for seven trace constituents (lower Table 10): Al, Ba, Fe, H<sub>2</sub>S, Na, Ni, and Zn. “Substantial” decreases between Phase 1, and subphases of Phase 2 and the beginning of Phase 3 were not as consistent across sites as substantial increases. Average load rates decreased for Al and Fe for five of seven comparisons.

**Effects of Diversions and Reclamation Practices on Load Rates.** At C06, diversions were installed and left in place at the end of Phase 3F, and ratios of average 3F:1 load rate ratios were large (median = 1.5; Figure 4). Bonta (2000) found that average sediment load rate during Phase 3F was nine times that of Phase 1. This was attributed to the network of diversions left after final reclamation (Figure 1a), which routed runoff to the headwater area of the watershed, concentrating flows and enhancing erosion. The sediment observations suggest that constituent loads were also elevated because of the high erosion and sediment transport rates during Phase 3F at this site. The lesser ratio increase from Phase 2B to 3F at C06 (median ratio = 1.2) occurred during a transition period when diversions were installed to reduce spoil slope lengths while slopes were not well covered.

At J11, diversions were installed between Phases 1 and 2 and 1 and 3A, periods when average chemical load rate ratios increased (median ratios = 2.5 and 3.0, respectively). Diversions failed and overtopped and excessive overland erosion occurred during Phase

3A. Diversions also increased the watershed area by 44 percent (Bonta, 2000). When diversions were removed at J11 (3F:3A; Figure 1c), watershed area decreased by 25 percent to 9.88 ha (Bonta, 2000), and more vegetative cover existed due to reseeded (Table 1). Ratios of load rates decreased, indicating an improvement in constituent loads (median = 0.4). Diversions were also removed between Phases 2 and 3F, and the land surface changed from active disturbances to a stable watershed. Average concentration ratios were lower between Phases 2 and 3F (median concentration ratio = 0.7) and 3A and 3F (median = 0.8) at this site. The final Phase 3F watershed had average load rate ratios that were larger than the Phase 1 watershed (median = 1.9; Figure 4). Bonta (2000) found that Phase 3F sediment load rates were at about premine levels (average = 1.0).

At M09, diversions (straw crimping) were not used, and the final load rate ratios were greater after reclamation than during Phase 1 (median 3F:1 comparison load rate ratio = 2.6; Figure 4). Median chemical constituent concentrations were near premine levels between Phases 1 and 3F at this site (median = 1.0; Figure 3). The increased load rates are attributed to changing hydrology, as explained earlier (Table 2, Figure 2). Bonta (2000) found that average sediment load rate was 30 percent of Phase 1. Also, a notable reduction in chemical load rate ratios was apparent between Phases 3A and 3F at this site (median = 0.6). This suggests a reduction in water chemistry loads due to reestablishment of vegetative cover more than one-fourth of the area during Phase 3F.

The specific and chronological load rate comparison ratios for all the sites leads to guidance on use of diversions and reclamation practices. Diversions left after reclamation caused relatively large chemical load rates compared with Phase 1 (e.g., C06), and removal of diversions reduced chemical load rates (e.g., Phase 3F at J11). However, in spite of average chemical concentrations that were close to premine levels caused by straw crimping at M09, greater flow rates caused large 3F:1 chemical load rate ratios. Revegetation of poorly reclaimed areas decreased chemical loads (e.g., M09 and J11). Diversion installation to reduce slope lengths and erosion increased constituent load rates (e.g., Phases 2B to 3F at C06 and Phases 1 and 2 and 1 and 3A at J11).

## CONCLUSIONS

The comprehensive effects are documented in this study of near complete disturbance of three small, undisturbed, geologically dissimilar experimental watersheds (C06, M09, and J11) due to mining of coal

TABLE 10. Lists of Constituents Changing in Average Load Rates "Substantially" Between Phases 1 and Other Phases in Tables 7, 8 and 9 and Figure 4.

Watershed C06			Watershed M09				Watershed J11		
2A:1	2B:1	3F:1	2A:1	2B:1	3A:1	3F:1	2:1	3A:1	3F:1
<b>Constituents Ranked from Largest to Smallest Load Ratio (ratio <math>\geq</math> 1.5)</b>									
H <sub>2</sub> S	Mn	Mn	Se	Se	CO <sub>2</sub>	P	Mn	Mn	Al
Mn	H <sub>2</sub> S	SO <sub>4</sub>	CO <sub>2</sub>	NO <sub>3</sub> -N	Se	Hg	NH <sub>4</sub> -N	NH <sub>4</sub> -N	Cu
Se	SO <sub>4</sub>	Cl	SO <sub>4</sub>	NH <sub>4</sub> -N	Cd	Se	Al	Al	Fe
CO <sub>2</sub>	Se	Mg	Mn	P	P	SO <sub>4</sub>	Zn	Mg	P
Diss Sol	CO <sub>2</sub>	NH <sub>4</sub> -N	Diss Sol	SO <sub>4</sub>	Hg	Fl	Se	Sb	Mn
SO <sub>4</sub>	Ca	Hardness	NO <sub>3</sub> -N	Cd	Cl	CO <sub>2</sub>	Ni	Zn	SO <sub>4</sub>
	Diss Sol	Ca	Ca	Cl	Fl	NO <sub>3</sub> -N	SO <sub>4</sub>	NO <sub>3</sub> -N	
	Hardness	Diss Sol	Hardness	CO <sub>2</sub>	Na	Cu	Fe	Fe	
	Mg	CO <sub>2</sub>	Cd	Diss Sol	Ag	Ag	NO <sub>3</sub> -N	Ni	
	Cl	Sr	Mg	Mn	SO <sub>4</sub>	Cd	Mg	SO <sub>4</sub>	
	NO <sub>3</sub> -N	As	Sr	Fl	Mn	Diss Sol	Diss Sol	Pb	
	Sr	NCO <sub>3</sub>	Ni	Hg	Pb	Pb	Hardness	Ba	
	Ni	Se	H <sub>2</sub> S	H <sub>2</sub> S	Cu	Cl	Ca	Ca	
	NH <sub>4</sub> -N	H <sub>2</sub> S	Phenols	Ca	Cr	Cr	Sb	Cl	
	As	Alkalinity	Ag	Hardness	Alkalinity	Ca	Ba	Phenols	
	Cd	Fl	Cu	Cr	HCO <sub>3</sub>	Sb	Cu	DO	
			Cr	CN	CN	CN	Cl	Diss Sol	
			Fl	Ag	Diss Sol	Hardness	Cr	Hardness	
			Na	Mg	Hardness	Mg	Pb	Cr	
			Hg	Sr	Sb	Mn	Ag	Fl	
			CN	Pb	Ca	Alkalinity	CN	Ca	
			P	Phenols	Phenols	HCO <sub>3</sub>	Phenols	CN	
			Cl	Sb	Ni	Sr	DO	Ag	
			Pb	Na	Sr	Na	Fl	P	
				Cu	Mg	Phenols	Sr	Alkalinity	
				Ni	NO <sub>3</sub> -N	NH <sub>4</sub> -N	Cd	Cd	
				Alkalinity	Zn			HCO <sub>3</sub>	
					As			Sr	
					Ba				
<b>Constituents Ranked From Largest to Smallest Load Ratio (ratio <math>\leq</math> 0.5)</b>									
Cd	Cu	Zn	As	As	NH <sub>4</sub> -N	Fe	HCO <sub>3</sub>	H <sub>2</sub> S	Na
Cl	P	Ba	Zn	Al	Fe	Al	Alkalinity		Ni
P	HCO <sub>3</sub>	Al	NH <sub>4</sub> -N	Fe	H <sub>2</sub> S	H <sub>2</sub> S	H <sub>2</sub> S		
Cr	Alkalinity	Fe	Fe		Al				
Na	Al		Al						
Ba	Fe								
Hg									
Fl									
HCO <sub>3</sub>									
Zn									
Pb									
Alkalinity									
Cu									
Al									
Sb									
Fe									

and subsequent reclamation on surface water chemical concentrations and loads (34 constituents, 4,485 laboratory analyses). Comparisons were made between average concentrations and load rates (e.g.,

kg/day) during different phases of land disturbances: Phase 1 (natural, premine), subphases of Phase 2 (mining and reclamation activities), subphases of Phase 3 (incomplete reclamation), and Phase 3F

(“final” condition of the watersheds at the end of monitoring). Impacts of concentrations and load rates were made by calculating the ratio of average concentration or load rate for a given chemical constituent during one phase of disturbance to that of another phase. Ratios were classified into impact classes designated “substantial” (ratio < 0.5 or ratio > 1.5), “moderate” (0.5 < ratio < 0.9 or 1.1 < ratio < 1.5), and “minor” (0.9 < ratio < 1.1). The following conclusions can be made.

### *Concentrations*

- A statistically significant relationship was found between concentration and flow for 36 percent of the 429 regressions for all regression in all watersheds and phases.

- The data taken as whole showed an increase of 2.4 times in the ratios of average concentrations across sites and phases (665 comparisons), suggesting an overall increase in average concentrations due to mining and reclamation activities (90 percent of the ratios of average concentrations had ratios between 0.26 and 7.4).

- About 49 percent of all comparisons of average chemical constituent concentrations were classified as having been “substantially” impacted, 36 percent were “moderately” impacted, and 15 percent were affected in a “minor” way.

- The impact of mining and reclamation on average concentration was greatest at the C06 site (diversions left in place) and was least at M09 (no diversions – and reclamation by straw crimping). Reclamation restored concentrations to near Phase 1 levels at M09.

### *Load Rates*

- In spite of Phase 3F constituent concentrations approaching Phase 1 levels at M09, increased load rates were observed because of increased flow rates due to drastic hydrologic changes at this site.

- Chemical loads for the three watersheds increased an average of 3.3 times for all comparisons and constituents, suggesting increased load rates during mining and reclamation activities.

- “Minor,” “moderate,” and “substantial” impacts were found in 7 percent, 25 percent, and 69 percent of comparisons of load rate ratios at C06, 8 percent, 24 percent, and 68 percent at M09, and 5 percent, 20 percent, and 69 percent at J11, respectively – uniform at all sites.

### *Concentrations and Load Rates*

- Median sediment concentration of discrete sediment samples is an indicator of average change in load rates for a wide variety of constituents between Phases 1 and 3F. This suggests that best management practices that reduce median sediment concentration also reduce average concentrations and vice versa.

- M09 was the most impacted watershed in terms of average load rates and the number of increased constituents but least impacted in terms of average concentrations. This is attributed to the largest change in hydrology, leading to increased transport of constituents.

- Average concentrations and load rates can decrease from one type of land disturbance to the next, resulting in improved water quality for many constituents.

- The impact of mining and reclamation on average load rates was not necessarily the same as the impact on average concentrations, mainly because of changed hydrology. This suggests that in addition to concentration, changing hydrologic conditions must be included when evaluating water quality in mining and reclamation areas.

- SO<sub>4</sub> and Mn load rates increased substantially at all three sites, and only SO<sub>4</sub> concentrations increased substantially at all sites from Phases 1 to 3F.

- Concentrations and load rates are sensitive to the varying types of spoil and soil exposed to the weather and durations of exposure created by mining and reclamation methods (contour mining versus haul-back method, use of diversions, etc.)

- Concentrations and load rates are sensitive to changing hydrology (increased curve numbers and changed flow duration curves) caused by draining and irregular recovery of ground water levels, baseflow increases and reductions, and destruction of soil profiles, causing higher runoff.

- Concentrations and load rates are sensitive to the extent of change in regressions (slope and/or intercept changes) causing changed sensitivity of concentration to flow rate, changed supply of constituents, and changing relative importance of baseflow and large flows.

- Concentrations and load rates are sensitive to changing watershed areas as spoil was moved to form the final reclaimed watersheds.

- Concentrations and load rates are sensitive to differing lithologies of the watersheds as apparent by the relative concentrations of constituents comprising geologic strata and soils.

- The many comparisons of concentrations and load rates between phases of land disturbance in the

present study can be used to identify stages of mining and reclamation and causes when a watershed is at risk for increased load rates and concentrations and when they decrease (improvement in water quality).

#### *Diversions and Reclamation*

- Concentrating runoff water using diversions is a reclamation practice that may increase or maintain large average concentrations (e.g., C06). Diversion removal may reduce average concentrations (e.g., J11). No diversions and the straw-crimping reclamation practice may help return a watershed close to premine concentrations (e.g., M09).

- Diversions can sustain large chemical load rates, and removal of diversions can reduce chemical load rates. Straw crimping without diversions led to higher Phase 3F:Phase 1 chemical load rate ratios due to increased runoff caused by mining and reclamation.

- Diversion installation increased constituent load rates at the two sites where they were used.

- Reclamation in areas inadequately covered with vegetation causes increased load rates.

- Revegetation of poorly reclaimed areas decreases chemical load rates.

Drastic land disturbances due to coal mining and subsequent reclamation resulted in altered surface features and surface and subsurface flow paths, significantly affecting surface and subsurface hydrology. These disturbances also resulted in significant changes in surface water chemistry as fractured geologic material exposed new facies to the weathering process. This study documents the most apparent impacts of mining and reclamation due to the complex interactions of these two important factors on chemical concentrations and load rates. The study shows the specific changes in average concentrations and load rates due to mining and reclamation activities of 34 chemical constituents and general changes in water chemistry across watersheds for three geologic settings and mined coal seams, two mining methods, and three reclamation practices.

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