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Bioassessment and Water Quality Sampling of Middle Creek and Mammoth Crystal Spring Yellowstone National Park, WY 2002-2005

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Ecologist Jeff Arnold rinses benthic material from Mammoth Crystal Spring for the collection of aquatic invertebrates.

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Photos courtesy of Jeff Arnold and Todd Koel.

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Ecologist Jeff Arnold acquires GPS position for location of invertebrate samples at Mammoth Crystal Spring.

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EXECUTIVE SUMMARY

Yellowstone National Park (YNP) forms the core of the Greater Yellowstone Ecosystem which is the largest intact ecosystem in the lower 48 states. It was created in 1872 to protect the unique geothermal features and headwaters of the Madison, Snake and Yellowstone rivers. All waters in YNP are classified as Outstanding Natural Resource Waters (Class I) and are afforded the highest protection possible. As a result, degradation of these waters is prohibited.

Bioassessment of streams using benthic macroinvertebrates assemblages has been widely used among state water resource agencies since 1989. Aquatic benthic invertebrates are ideal biotic indicators because they are easy to collect, relatively immobile, have long life spans, and are sensitive to environmental changes. In this study we used a variety of invertebrate metrics to evaluate the overall water quality at select points within the Middle Creek drainage, Yellowstone National Park. Invertebrate sampling was conducted at two sites between 2002 and 2005 as well as the collection of basic water quality parameters. An additional two invertebrate sites were sampled during August 2005 in the vicinity of Mammoth Crystal Spring. In this area we also collected water samples from Middle Creek and Mammoth Crystal Spring for analysis of select anions, cations, nutrients, and semi-volatile organic compounds.

Results from the physical and chemical attributes collected from water in Middle Creek suggests that these parameters, at the time of collection, pose very little threat or impairment to the Middle Creek watershed. Conductivity values in Mammoth Crystal Spring were about twice as high as values recorded in the adjacent section of Middle Creek. Water chemistry from Mammoth Crystal Spring also indicate that values for total alkalinity, bicarbonate, sulfate, and calcium were also higher than in the adjacent section of Middle Creek. Additional sampling determined that there were no detectable concentrations of petroleum-based hydrocarbons found in the water column in Mammoth Crystal Spring, but detectable levels of hydrocarbons were found in sediment collected from the area. These hydrocarbons, however, were later determined to be of a natural origin. From an observational standpoint, sediment and increased turbidities pose the most serious threat to Mammoth Crystal Spring and the Middle Creek drainage which the invertebrate data supports. Invertebrate samples collected from two sites on Middle Creek and one site on an unnamed tributary suggest that the quality of water is very good to excellent in these stream segments. These sites contain very high numbers of intolerant taxa (taxa most sensitive to pollution), the majority of which belong to the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). By contrast, invertebrates collected from Mammoth Crystal Spring contain very high numbers of tolerant taxa (taxa least sensitive to pollution) which belong to the insect order Diptera. These organisms are generally more tolerant of impaired streams and are most abundant in waterbodies that experience high temperatures, low dissolved oxygen and/or heavy sediment loads.

INTRODUCTION

Yellowstone National Park (YNP) is located in the northwest corner of Wyoming and portions of southwest Montana and eastern Idaho and lies within the Middle Rockies ecoregion (Omernik and Bailey, 1997). It was created in 1872 as the nation's first national park, primarily to protect the unique geothermal features and watersheds of the upper Yellowstone River, and encompasses approximately 898,321 hectares of pristine landscape. YNP forms the core of the Greater Yellowstone Ecosystem, which is the largest intact ecosystem in the lower 48 states. There are approximately 11,216 kilometers (km) of streams and 43,706 hectares of lakes in YNP (Varley and Schullery 1998). All water bodies within YNP are classified as outstanding natural resource waters and designated as Class I waters by the state of Wyoming. Class I waters in Wyoming are afforded the highest protection possible and, as a result, long-term degradation of these waters is prohibited (Wyoming, 2001).

Bioassessment of streams using benthic macroinvertebrate assemblages has been widely used among state water resource agencies since 1989 (Southerland and Stribling, 1995). Aquatic benthic macroinvertebrates are ideal biotic indicators because they are easy to collect, relatively immobile, have long life spans (1 to 3 years), and are sensitive to environmental changes (Barbour, et al. 1999). Specific objectives for this study were to: 1) collect synoptic water quality information (i.e. temperature, dissolved oxygen, pH, conductivity, turbidity, and discharge) from various locations within the Middle Creek drainage; 2) collect synoptic water samples from the Mammoth Crystal Spring area for inorganic and organic compound analysis and collect sediment samples for organic compound analysis; 3) collect aquatic benthic macroinvertebrates from selected sites within the Middle Creek drainage of YNP using protocols established by Wyoming Department of Environmental Quality's Beneficial Use Reconnaissance Project (WYDEQ BURP) for water quality monitoring; and 4) use aquatic benthic macroinvertebrates to evaluate stream health within the Middle Creek watershed of YNP.

STUDY AREA

Middle Creek is located in the east-central portion of YNP with the headwaters forming near the base of Top Notch Peak (Figure 1) which lies within the Absaroka Mountain Range. The mainstem of Middle Creek flows in an easterly direction for approximately 12 km before leaving the park. Within YNP boundary the lower 10 km of the creek parallels the east entrance road, with the last 3 km flowing directly adjacent to the road. Impacts to the water quality from this road segment appear to be minimal. The watershed of Middle Creek is a relatively small with a total catchment area of approximately 8,414 hectares contained within the borders of YNP. Middle Creek exits YNP near the east entrance gate and flow another 3 km before it merges with the North Fork Shoshone River. The North Fork Shoshone River, along with the South Fork Shoshone River, is the major water source for Buffalo Bill Reservoir near Cody, Wyoming.

Benthic macroinvertebrate sampling began within the Middle Creek drainage during late August, 2002. During this time, 2 sites were established; one site on the mainstem of Middle Creek near the east entrance gate and one site on an unnamed tributary at a location directly downstream from the east entrance road crossing (Figure 1). Between 2002 and 2005 both sites were sampled once each year during late August or early September. Because of recent concerns from road construction activity within the Middle Creek drainage, 2 additional stream sites were sampled during late August 2005 near the vicinity of Mammoth Crystal Spring (Figure 1). Mammoth Crystal Spring is a small tributary of Middle Creek whose headwaters originate near Sylvan Pass. The geology of the Sylvan Pass area is dominated by talus which is generated by the adjacent mountains. A large gravel mine and rock crushing operation is the primary land-use in the Sylvan Pass vicinity. The rock extracted from this area is being used for various road construction projects within YNP. During the summer 2004, water was pumped from Sylvan Lake, a tributary to the Yellowstone drainage, up to Sylvan Pass and used to wash crushed gravel. The effluent from the gravel washing operation collected in a borrow

Middle Creek Drainage
Yellowstone National Park

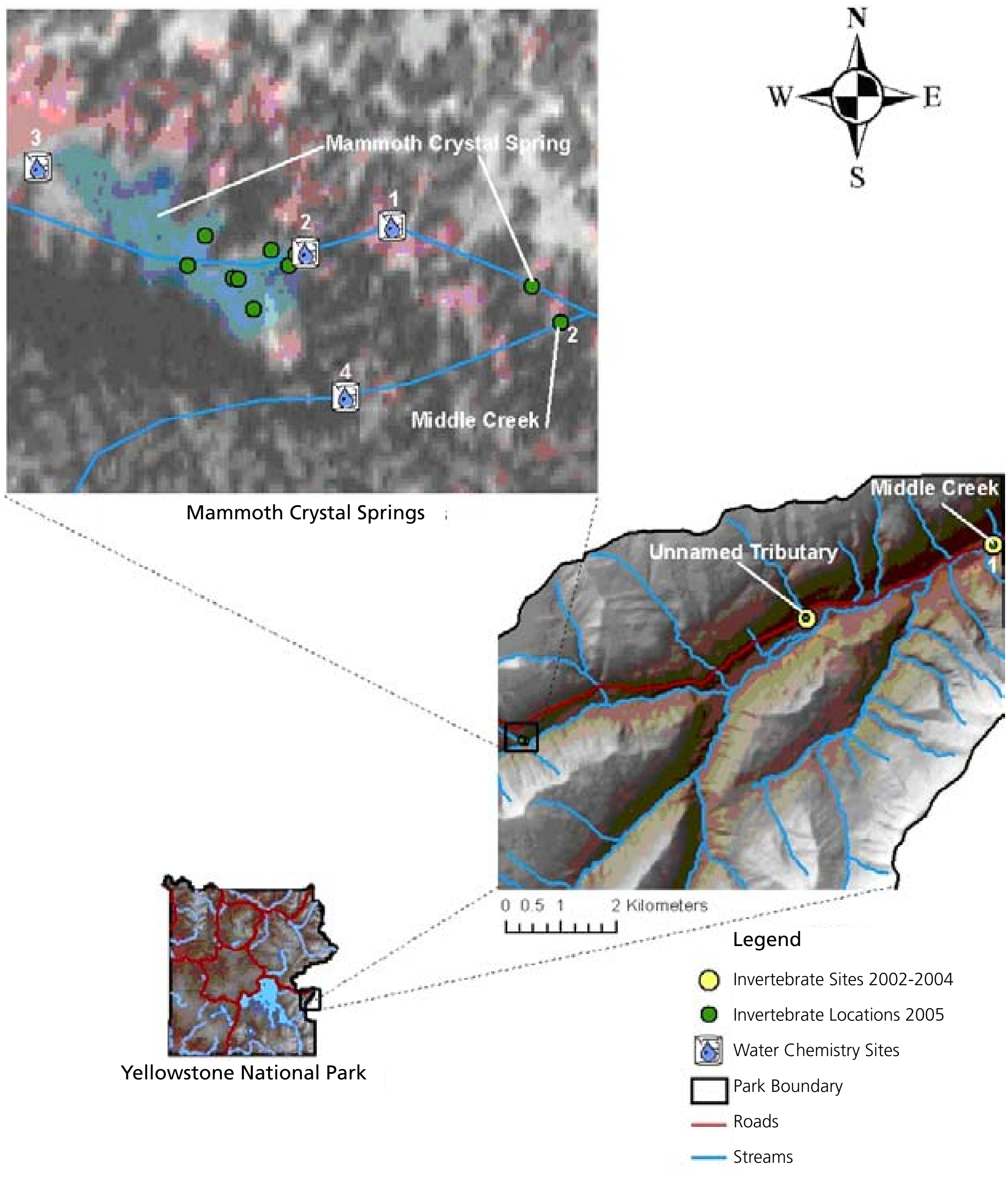


Figure 1. The Middle Creek drainage within Yellowstone National Park. The two invertebrate sites on Middle Creek are labeled 1-2; the four water chemistry sites within Mammoth Crystal Springs are labeled 1-4.

pit immediately west of Sylvan Pass where it was allowed to enter into the groundwater system. Concurrent with the gravel washing operation, a whitish suspended material was observed in the lower portions of Middle Creek near the park boundary. It was assumed that the rock crushing/washing operations on Sylvan Pass was contributing to this suspended material in the Middle Creek drainage. Subsequent investigations confirmed the source of suspended material originated from Mammoth Crystal Spring which is approximately 2.5 km east of Sylvan Pass. Groundwater dye tests conducted in the Sylvan Pass area during the summer of 2005 suggest that there is a direct hydrological link between Sylvan Pass and Mammoth Crystal Spring. If this is true, the major threat to Middle Creek is increased turbidity and sediment loads that could threaten the aquatic biotic community. An additional concern is that pollutants generated from the rock crushing operation (i.e. petroleum-based products) could be introduced into the drainage via the hydrology of Mammoth Crystal Spring.

METHODS

Site selection was primarily based on accessibility, water depth, and a minimum riffle or riffle-run stretch of at least 15 meters (m). Prior to sampling, a global positioning systems unit (Garmin V) was used to record location in Universal Transverse Mercator coordinates. Basic water quality measurements were collected from each site using a Hydrolab datasonde 4a, mulitparameter probe. Water quality parameters that were collected include water temperature, dissolved oxygen (DO), pH, and specific conductance. A HACH 2100P instrument was used to measure turbidity readings from each site. Instruments were calibrated twice daily (i.e. once prior to sampling and once after sampling was completed) following manufacturer instructions for calibration procedures. During 2005, water and sediment samples were collected for inorganic and organic analytes from the immediate vicinity of Mammoth Crystal Spring. Water samples were collected from 3 locations and analysis was performed to measure concentrations of select cations, anions, total nitrogen, total phosphorus, and semi-volatile organics, including diesel range organics (DRO) and gasoline range organics (GRO); sediment samples were collected from 2 locations and analyzed for semi-volatile organics (including DRO and GRO). Established protocols (USGS, 1998) were used to collect water and sediment samples. All samples were sent to Energy Laboratories in Billings, Montana for chemical analysis.

Methods used to sample stream invertebrates were adapted from those used by WYDEQ BURP (Wyoming Department of Environmental Quality, 1999). A Surber sampler (0.09 m^2 plot and 500 micron mesh) was utilized to collect benthic aquatic invertebrates. Eight Surbers were randomly placed within each sample reach. Prior to disturbance, individual plot areas were characterized by percent coverage of substrate, silt, and vegetation (i.e. aquatic macrophytes and algae) by using a 20 cm^2 piece of Plexiglas to view underwater benthic habitat. Stream substrate within plot areas were divided into 6 classes: boulder, >25.4 centimeter (cm); cobble, 6.35–25.4 cm; coarse gravel, 2.54–6.35 cm; fine gravel, 0.76–2.54 cm; sand, 0.76–0.15 cm, gritty; and silt, <0.15, soft and fine. Substrate values for each of the 8 sample plots were then tallied and an average percent was obtained for substrate, silt, and vegetation cover. Following substrate characterization, aquatic benthic macroinvertebrates were then collected by gently rubbing the surface area of cobble and coarse gravel by hand and by thoroughly scrubbing the plot area with a soft bristle brush. Water currents washed materials that were dislodged from the substrate into the collection net. Subsequent to invertebrate collection and removal of each Surber net, water depth was recorded using a meter stick and velocity was obtained using a Marsh McBirney Flo-Mate Model 2000. The 8 Surbers were composited in the field and preserved in 99% ethanol for future sample processing. Discharge was then calculated and a habitat assessment was conducted within the area immediately upstream of the sample reach. Habitat assessment was calculated by assigning a number to each of 13 separate habitat parameters outlined on the data sheet (Appendix A). The range of values for each parameter is dependent upon the category of

Table 1. Habitat and water quality parameters measured in the Middle Creek drainage, YNP (adapted from Gerritsen et al. 2000).

	Water Quality		
Habitat Assessment	***in situ***	**Chemistry****	**Physical**
% fines, bottom substrate	Temperature	Anions	UTM easting
Embeddedness	Dissolved Oxygen	Cations	UTM northing
Instream cover	pH	Total nitrogen	Ecoregion
Velocity/depth ratio	Specific conductivity	Total phosphorus	Elevation
Channel flow status	Turbidity	Organic compounds	Discharge
Channel shape			
Pool/riffle ratio			
Channelization or alteration			
Bank vegetation stability			
Bank stability			
Disruptive pressures to riparian zone			
Riparian zone width			
% composition of substrate*			

* Percent composition of substrate determined by 6 classes: boulder, cobble, coarse gravel, fine gravel, sand, and silt
** Parameters that were collected only during 2005 in the immediate vicinity of Mammoth Crystal Spring

habitat being characterized. A higher habitat score is indicative of a higher quality of habitat for a sample reach. Scores for individual habitat parameters were averaged for each site with a possible range between 0 and 15.41. A complete list of measurements taken from each site is listed in Table 1.

After sampling all sites, invertebrate samples were sent to Aquatic Biology Associates Inc., an independent laboratory in Corvallis, Oregon, for processing, invertebrate identification, and analysis. In the laboratory, samples were prepared by placing them on a 500 micron sieve and rinsing them with cold water. They were then elutriated by placing them in a large, white container and washing them several times to suspend all organic matter. The suspended material was poured back into the 500 micron sieve. This process was repeated until all organic matter was removed from the mineral residue. The mineral residue remaining in the container was searched for stonecased caddisfly and molluscs that may have been retained in the sample (Aquatic Biology Associates Inc., n/a). The sample was evenly distributed on a gridded Canton Tray and individual grids were randomly selected until a minimum of 550 organisms were counted. The remaining sample was searched for large/rare organisms that were not collected during the original subsampling process and placed in a separate container. Any organism found during the large/rare search and not found in the original subsample was given the abundance of 1.

DATA ANALYSIS

For each sample, total numbers of invertebrates were tallied for individual taxa, invertebrate abundance was converted to density per square meters (m^2), and tolerance values (percent tolerant and intolerant taxa) were calculated. In addition, EPT (Ephemeroptera, Plecoptera, and Trichoptera) Richness Index values and modified Hilsenhoff's Biotic Index (HBI) values, which are known water quality indicators (Lenz, 1997), were also calculated for each site.

EPT Richness Index is calculated by tallying distinct invertebrate taxa belonging to the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). As a group, EPT taxa are more pollution-sensitive organisms that respond readily to environmental changes in aquatic environments. Generally, number of EPT taxa increase with lower water temperatures, increased dissolved oxygen (DO) concentration and little organic pollution and decrease with higher water temperatures, decreased DO concentrations and increased organic pollution.

Modified HBI values (Hilsenhoff, 1987 and 1988) are obtained by evaluating the number of benthic invertebrates in the phylum Arthropoda at a site and their tolerance to pollution to ascertain the degree to which natural organic compounds, elevated temperatures, and low DO are likely to be present (USGS, 1999). Each benthic invertebrate is assigned a tolerance value from 0 to 10, with 0 assigned to invertebrates least tolerant to pollution and 10 assigned to invertebrates most tolerant of pollution (USGS, 1999). In general, benthic invertebrate taxa that are most sensitive to pollution are in the insect orders Ephemeroptera, Plecoptera, and Trichoptera; those organisms that are least sensitive to water pollution are in the orders Oligochaeta (segmented worms), Hirudinea (leeches), Odonata (dragonflies/damselflies), and Diptera (true flies). The HBI is divided into 7 categories (Table 2). A low HBI value indicates excellent water quality with no pollution and a high HBI value indicates poor water quality with high amounts of pollution (USGS, 1999; Hilsenhoff, 1988).

Table 2. Hilsenhoff Biotic Index values as an evaluation of water quality (Hilsenhoff, 1987)

Biotic Index	Water Quality	Degree of pollution
0.00 - 3.50	Excellent	None apparent
3.51 - 4.50	Very Good	Possible slight
4.51 - 5.50	Good	Some
5.51 - 6.50	Fair	Fairly Significant
6.51 - 7.50	Fairly Poor	Significant
7.51 - 8.50	Poor	Very Significant
8.51 - 10.00	Very Poor	Severe

Table 3. Site information and water quality measurements taken at benthic macroinvertebrate sampling locations in the Middle Creek drainage, 2002–2005.

Stream Name	Sample Year	Sample Time	Water Discharge (m^3/sec)	Temp. (°C)	DO (mg/L)	pH	Cond (uS)	Turbidity (NTU)	Average Velocity (m/sec.)	Average Depth (m)
Middle Creek - site 1	2002	1349	0.753	13.1	8.8	7.7	85	0.7	0.46	0.16
	2003	935	0.501	9.5	9.6	8.0	86	0.8	0.35	0.19
	2004	1028	1.565	6.8	10.5	7.9	68	27.4	0.67	0.22
	2005	926	0.685	7.2	9.5	7.6	87	1.5	0.45	0.21
Middle Creek - site 2	2005	1050	0.037	6.3	9.1	7.3	55	0.7	0.33	0.15
unnamed tributary	2002	811	0.013	6.2	9.2	7.7	71	0.8	0.24	0.14
	2003	1433	0.009	10.6	8.9	7.5	74	0.8	0.22	0.13
	2004	1408	0.025	11.6	8.0	8.1	62	1.8	0.31	0.15
	2005	1401	0.009	12.3	8.6	7.6	78	1.8	0.24	0.10
Mammoth Crystal Spring										
1st Replicate	2005	1343		5.7	8.8	7.6	166	3.1	0.30	0.24
2nd Replicate	2005	1612	0.025	4.8	10.0	7.6	166	2.2	0.31	0.10

RESULTS AND DISCUSSION

Water Quality

Middle Creek, at the park boundary, and the unnamed tributary were sampled four consecutive years. Measured discharge for these sites ranged between 0.501 and 1.565 m^3/sec (cubic meters per second) for Middle Creek and from 0.009 to 0.025 m^3/sec for the unnamed tributary (Table 3). The highest discharge for both sites occurred during the 2004 sample year at which time there was a substantial amount of rainfall within the Middle Creek drainage prior to sampling. Ranges for additional *in situ* water quality measurements for both sites are as follows: water temperature, 6.2–13.1 °C; DO, 8.0–10.5 mg/L (milligrams per liter); pH 7.5–8.1; conductivity, 62–87 $\mu S\ cm^{-1}$ (μSiemens); turbidity, 0.7–27.4 NTU (nephlometric turbidity units); average velocity, 0.22–0.67 m/sec; and average depth, 0.10–0.22 m (Table 3). As expected, both water temperature and DO values varied depending on time of day sampled while pH values exhibited less variability between sample years (Table 3). For both sites, conductivity values are very comparable during years when stream flows were low (i.e. 2002, 2003, and 2005) while lower conductivity values were recorded during 2004 when stream flows were higher (Table 3). Lower conductivity values are expected during high flow conditions because the larger volume of water dilutes the dissolved ion concentration, thus producing lower conductivity measurements. For the most part, *in situ* water quality measurement recorded from the two remaining stream sites sampled in 2005 (i.e. Middle Creek, site 2, and Mammoth Crystal Spring) demonstrated that most *in situ* water quality measurements were within a range expected for the Middle Creek watershed during low flow conditions. However, both conductivity and turbidity values for Mammoth Crystal Spring seem slightly higher than expected when compared to the mainstem of nearby Middle Creek, site 2 (Table 3). Although conductivity and turbidity values are higher at this site, these concentrations are well below values that would negatively impact stream biota and stream water quality.

Corresponding to *in situ* measurements, results from water samples taken around Mammoth Crystal Spring, sites 1 and 3 show that alkalinity and bicarbonates are nearly twice as high as water collected from the nearby Middle Creek site (Table 4). Similarly, sulfate is 10 times higher and calcium is 4 times higher at the two Mammoth Crystal Spring sites as compared to the Middle Creek site (Table 4). Both magnesium and sodium concentrations were comparable among the three sites while carbonate, chloride, and potassium were not detected from any of the three water samples (Table 4). The higher concentrations of anions and cations most likely contribute to the higher conductivity values observed in the Mammoth Crystal Spring area and are likely a result of increased sediment loads within the drainage. Analysis for total nitrogen and phosphorus concentrations show that contributions of these two analytes to the Middle Creek drainage are minimal

Table 4. Aqueous water quality concentrations for anions, cations, and nutrients collected from four sites near Mammoth Crystal Spring, 2005. Site numbers correspond to water chemistry sites indicated in Figure 1.

	Anions (mg/L)					Cations (mg/L)				Nutrients (mg/L)	
Site and Number	CaCO3	HCO3	CO3	Cl	SO4	Ca	Mg	K	Na	Total N	Total P
MCS site 1	53	64	ND	ND	30	25	3	ND	4	0.2	0.01
MCS site 2 (outlet)											
MCS site 3 (inlet)	53	65	ND	ND	29	26	3	ND	5	0.2	ND
MC site 4	28	34	ND	ND	3	6	1	ND	5	ND	0.02

(CaCO3 = Total Alkalinity, HCO3 = Bicarbonate, CO3 = Carbonate, Cl = Chloride, SO4 = Sulfate, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, Total N = Total Nitrogen, and Total P = Total Phosphorus, ND = nondetectable)

Table 5. Hydrocarbon concentraions from water and sediment samples collected from Mammoth Crystal Spring during August 2005.

	Hydrocarbon Concentrations			
	Aqueous (ug/L)		Soil (mg/kg)	
Site and Number	**DRO**	**GRO**	**DRO**	**GRO**
MCS site 2 (outlet)	ND	ND	193	1.6
MCS site 3 (inlet)	ND	ND	16	ND

(ug/L = micrograms per liter, mg/kg = milligrams per kilogram)
(DRO = Diesel Range Organics; GRO = Gasoline Range Organics)

(Table 4). In addition to analysis of dissolved inorganic compounds, two sites were analyzed for petroleum based organic compounds at the spring inlet and outlet. Both water and sediments samples were targeted for the presence of DRO and GRO. Results indicate that petroleum based organics were not detectable within the water samples, but DRO's and GRO's were detected in sediments from the spring outlet and small traces of DRO's were detected in sediments at the spring inlet (Table 5). Upon further laboratory analysis of these samples, it was concluded that hydrocarbon profiles for these sites were not characteristic of refined petroleum products but more closely resembled naturally occurring organics.

Substrate Coverage

Substrates with a high percentage of cobble and coarse gravel are important to the instream benthic community because larger substrates provide more interstitial space (i.e. open areas between substrate) for organisms to reside. As a result, a large variety of niches are available to instream biota which usually contributes to a more diverse aquatic community. For all years combined, mean substrate cover comprised of both cobble and coarse gravel had a range between 58% and 91%. The lowest percentage of cobble/coarse gravel substrate was recorded for Middle Creek, site 2, (58%) while the remaining three sites had a cobble/coarse gravel composition that averaged near 80% (Table 6). Given the abundant amounts of both cobble and coarse gravel at the four sample locations, substrate should not play a role as a limiting factor for the invertebrate communities residing with the streams.

Overall, both sites on Middle Creek and the unnamed tributary had low silt cover ratings with less than 25% of the substrate being covered by silt, while substrate from the two samples collected at Mammoth Crystal Spring exhibited a high silt cover rating with >75% of the substrate covered by silt (Table 6). The high percentage of silt covering the substrate at this site is of concern because silt can interfere with respiratory processes of aquatic organisms, reduce reproduction potential by suffocating eggs, and limit feeding opportunities of visual predators. In addition, silt can shift the invertebrate community from organisms that are intolerant of environmental stressors to those organisms that are tolerant of environmental stressors.

Aquatic macrophytes play an important role in species composition and abundance of aquatic organisms by providing additional shelter and food sources to the invertebrate community. The range for percent cover of aquatic macrophytes was between 0% and 41% (Table 6). Aquatic macrophytes were absent from the Middle Creek and Mammoth Crystal Spring sites and were present each sample year on the unnamed tributary. Macrophytes on this stream were in the form of dense bryophyte mats that grew on the larger substrates within the main stream channel. Similarly, filamentous algae had a percent cover that ranged from 0% to 28%. Algae was most prevalent at the unnamed tributary during

Table 6. Site information and average percent substrate type, silt cover and vegetation cover recorded from benthic macroinvertebrate sampling locations in the Middle Creek drainage, 2002–2005.

		% Substrate					% Silt Cover					%Vegetation Cover	
							Low		Moderate		High		
Stream Name	Sample Year	Cobble	Coarse Gravel	Fine Gravel	Sand	Other	<5	5–25	25–50	50–75	>75	Macrophyte	Algae
Middle Creek - site 1	2002	82	9	7	1	0	100	0	0	0	0	0	0
	2003	61	23	11	5	0	100	0	0	0	0	0	0
	2004	64	15	9	5	6	100	0	0	0	0	0	0
	2005	64	14	9	6	7	100	0	0	0	0	0	0
Middle Creek - site 2	2005	37	21	29	13	0	92	3	1	0	4	0	0
unnamed tributary	2002	73	12	2	2	11	100	0	0	0	0	1	28
	2003	56	15	15	14	0	100	0	0	0	0	19	0
	2004	55	30	10	5	0	100	0	0	0	0	24	0
	2005	54	28	12	5	0	100	0	0	0	0	41	0
Mammoth Crystal Spring													
1st Replicate	2005	48	29	20	3	0	30	9	0	0	61	0	3
2nd Replicate	2005	27	52	21	2	0	26	1	0	0	73	0	1

Table 7. Summary of select benthic invertebrate metrics for the Middle Creek drainage in YNP between 2002 and 2005 sampling years.

							Tolerance Values			
Stream Name	Sample Year	Number Taxa	Invertebrate Abundance (m2)	EPT Richness Index	Modified Hilsenhoff Biotic Index	HBI Water Quality Rating	Number Tolerant Taxa	Percent Tolerant Taxa	Number Intolerant Taxa	Percent Intolerant Taxa
Middle Creek - site 1	2002	41	1,781	30	3.37	Excellent	0	0.0	11	24.2
	2003	44	5,844	29	3.09	Excellent	1	0.2	11	33.9
	2004	50	1,546	26	3.15	Excellent	2	1.1	13	46.1
	2005	43	1,508	27	3.05	Excellent	2	0.2	12	33.0
Middle Creek - site 2	2005	37	1,007	20	2.15	Excellent	1	0.2	11	32.0
unnamed tributary	2002	50	7,330	30	3.8	Very Good	1	0.2	15	34.1
	2003	59	2,947	31	3.54	Very Good	2	1.0	15	32.6
	2004	47	2,534	26	3.38	Excellent	1	1.9	14	63.1
	2005	55	7,915	32	3.23	Excellent	1	1.2	20	48.9
Mammoth Crystal Spring										
1st Replicate	2005	20	23,525	6	5.78	Fair	2	19.9	3	1.0
2nd Replicate	2005	17	23,080	5	5.47	Good	3	24.7	2	3.5

the 2002 sample season while the two samples collected at Mammoth Crystal Spring had an average algae covering of 1% and 3%; algae covering was absent from the two Middle Creek sites (Table 6).

Aquatic Invertebrates

A total of 113 unique invertebrate taxa were collected from the Middle Creek drainage between the 2002 and 2005 sample seasons. Distinct benthic invertebrate taxa from individual locations range from 23 at the Mammoth Crystal Spring site (one year of collection) to 82 at the unnamed tributary (four years of collection). Benthic macroinvertebrate densities range from 1,007 to 23,525 organisms/m^2. The lowest and highest invertebrate densities were collected at Middle Creek, site 2, and the Mammoth Crystal Spring site respectively during the 2005 sample period (Table 7). The most abundant invertebrate taxa collected from Middle Creek, near the park boundary, (sample years 2002–2005) include four mayfly species (*Baetis tricaudatus, Cinygmula sp., Drunella doddsi* and *Rhithrogena*), and a caddisfly, *Glossosoma sp*; the most abundant invertebrate taxa collected from Middle Creek, site 2, (sample year 2005) include one mayfly, *Rhithrogena sp.*, and two stoneflies (*Zapada columbiana* and *Zapada Oregonensis Group*). All of these species, with the exception of *Cinygmula*, are highly intolerant of polluted or stressed water conditions (Appendix B). In addition, the abundance of these intolerant taxa was relatively high for both sites. Total percent intolerant taxa from Middle Creek, near the park boundary, was high (range 24.2–46.1%) for all sample years while the total percent of tolerant taxa was low (range 0–1.1%) for all sample years (Table 7). Similarly, Middle Creek, site 2, had a high percent of intolerant taxa (32%) and a low percent of tolerant taxa (0.2%) for the 2005 sample year.

Invertebrate species composition collected at the unnamed tributary contains a healthy mix of both intolerant and tolerant taxa. The most abundant intolerant taxa include three mayflies (*Ameletus sp., Baetis tricaudatus* and *Ephemerella infrequens*), two stoneflies (*Zapada cinctipes* and *Zapada columbiana*) and two caddisflies (*Neothremma sp.*, and *Rhyacophila Betteni Group*); the most abundant tolerant taxa include three midge species (*Cricotopus Nostococladius, Eukiefferiella sp.,* and *Eukiefferiella Devonica Group*) (Appendix C). Although this site contained both intolerant and tolerant taxa, the percent of intolerant taxa for this stream reach was high for all sample years (range 32.6–63.1%) while the percent tolerant taxa remained very low (range 0.2–1.9%) for all sample years, thus indicating that this stream reach is also in excellent condition (Table 7).

Two sample collections were made at the Mammoth Crystal Spring site to better evaluate this stream reach. Chironomids (midges), generally a tolerant group of aquatic insects, dominated the invertebrate community. The most abundant intolerant midge was a *Pagastia sp.*; the most abundant tolerant midges included *Diamesa sp., Hydrobaenus sp., Orthocladius Complex,* and *Tvetenia Bavarica Group* (Appendix D). The high abundance of chironomids is one indication that this stream reach is under severe environmental stress which is most likely caused by increases in turbidity and stream embeddedness. In addition, the total percent of intolerant invertebrate taxa was 1% and 3.5% for the first and second replicate respectively; while the total percent of tolerant invertebrate taxa was 19.9% and 24.7% for the first and second replicate respectively (Table 7).

Aside from the number of intolerant and tolerant taxa, another metric that is widely used to evaluate stream health is the EPT Richness Index value, which is basically the number of EPT taxa present at a given site. In summary, EPT taxa were most abundant on the unnamed tributary (range 26–32 EPT taxa) and least abundant at the Mammoth Crystal Spring site (range 5–6 EPT taxa). By comparison, 20 EPT taxa were collected from the Middle Creek site adjacent to the Mammoth Crystal Spring while Middle Creek near the park boundary also had a high number of EPT taxa for all years combined (range 27–30 EPT taxa) (Figure 2). Modified HBI values for all sites and years combined range between 2.15 and 5.78 (Table 7). Overall, the two sites on Middle Creek and the site on unnamed tributary rated very good to excellent for each year

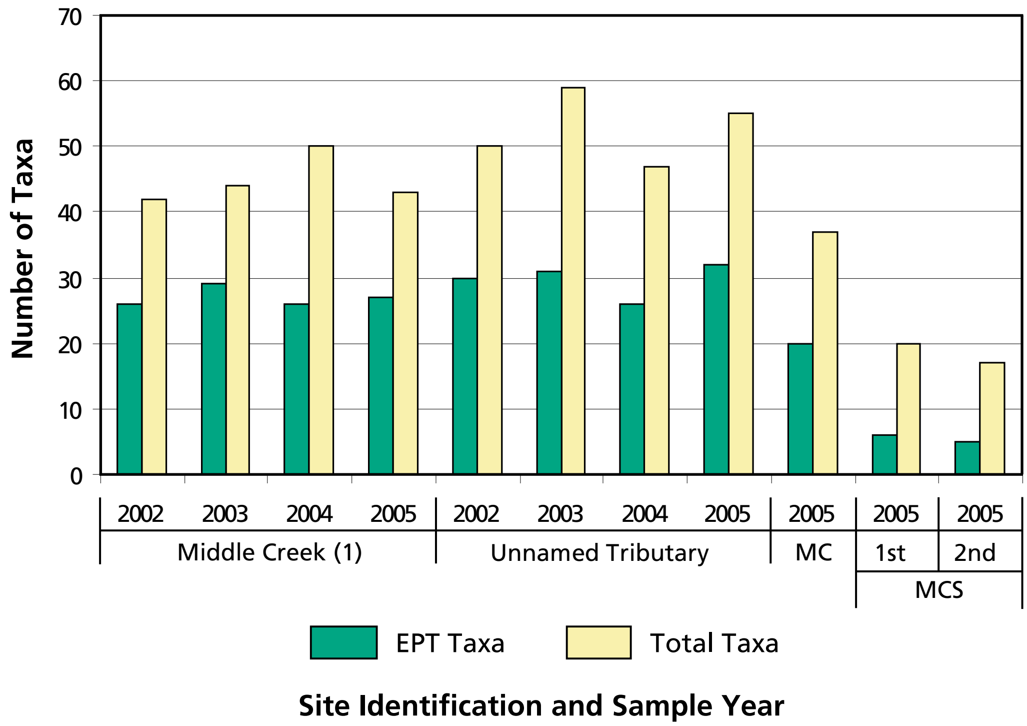


Figure 2. Number of EPT taxa and total number of taxa for 11 site visits to the Middle Creek drainage between sample years 2002-2005. (MC=Middle Creek, site 2; MCS=Mammoth Crystal Spring; and 1st=first replicate, 2nd=second replicate.

sampled indicating that no pollution or stressors were evident at these sample locations. Conversely, the modified HBI water quality rating for the two samples collected on Mammoth Crystal Spring were rated both good and fair (Figure 3). This rating indicates that some to a fairly significant amount of stress has occurred at this site, presumably from the increased sediment loads from Mammoth Crystal Spring (Table 7).

As a group, EPT taxa dominated the mainstem of Middle Creek and the unnamed tributary segment. Total percent EPT taxa combined for Middle Creek near the park boundary had a range between 74% and 86% with the lowest percentage occurring during the 2004 sample year (Table 8). Similarly, total percent of EPT taxa combined for the unnamed tributary was between 29% and 62% with the lowest percentage also occurring during the 2004 sample year (Table 8). The upstream site on Middle Creek exhibited the highest percent EPT taxa for all sites and all years combined (92%) while the invertebrate collected at Mammoth Crystal Spring had the lowest percent EPT for all sites and combined years with <2% EPT taxa for the 1st replicate sample, and <4% EPT taxa for the 2nd replicate sample. Conversely, percent Dipterans, primarily Chironomids, made up the remainder of the invertebrate taxa collected from each sample location (Figure 4).

CONCLUSIONS

Various water quality and habitat measurements, along with invertebrate samples, have been collected within the Middle Creek watershed since August, 2002. In general, water chemistry characteristics from all sample locations in the Middle Creek drainage look very good. *In situ* water quality parameters collected during the fall period of each sample season indicate that water temperature, DO, pH, and specific conductance measurements are well below acceptable limits. The high turbidity reading at the Middle Creek site recorded during August 2004 was an anomaly, but not totally unexpected due to the considerable amount of rain that fell within the

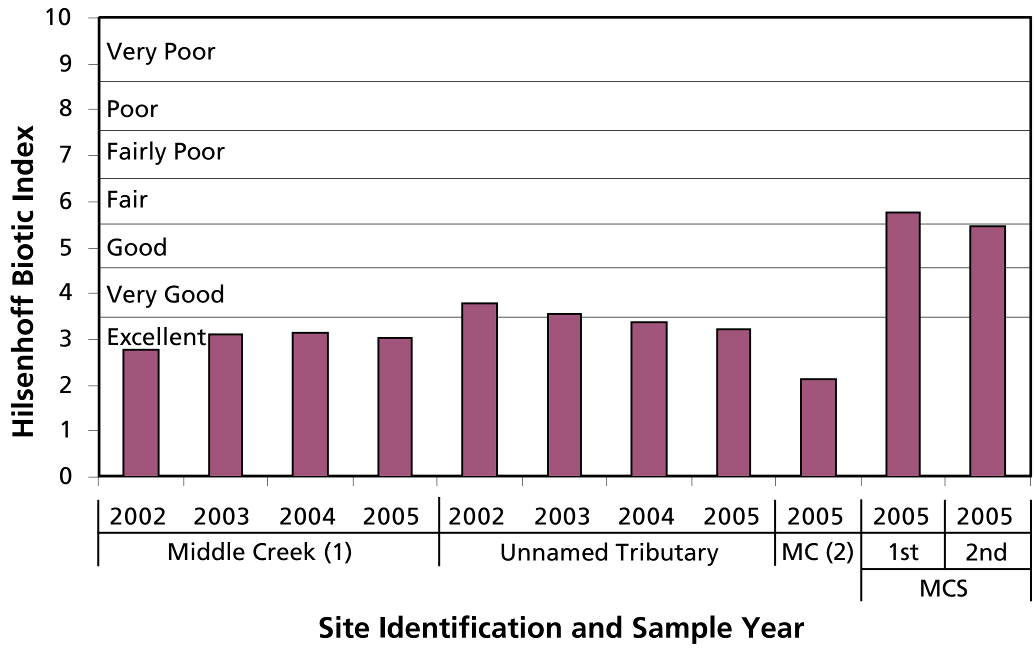


Figure 3. Modified HBI values for individual sites sampled in the Middle Creek drainage between 2002-2005. Horizontal lines indicate individual HBI rankings.

drainage during the days prior to sampling. In addition, the slightly elevated specific conductance and turbidity levels at the Mammoth Crystal Spring sites, although evident, are not an immediate reason for concern due to the relatively low values. The anion, cation, and nutrient concentrations recorded from Mammoth Crystal Spring are also higher than levels recorded from the nearby Middle Creek site, but again these levels are still very low when compared to other streams in YNP. There were no petroleum-based products detected from water or sediment samples collected from the Mammoth Crystal Spring area.

It is apparent that the immediate and continued threat to the Middle Creek drainage is the increased sediments being discharged from Mammoth Crystal Spring. These sediments are settling in the pool area of Mammoth Crystal Spring and flowing into the Middle Creek drainage. These increased sediment loads, as indicated by the aquatic invertebrate data, have drastically impaired the water quality in this reach of the Middle Creek drainage. All invertebrate metrics typically used to evaluate water quality show or indicate degradation of the Mammoth Crystal Spring watershed. The overall diversity of Mammoth Crystal Spring is low with few EPT taxa and many chironomids taxa being present. The overall percentage of intolerant taxa present in Mammoth Crystal Spring is extremely low when compared to the overall percentage of tolerant taxa. The HBI values for the Middle Creek drainage also support the argument that impairment has occurred within the Mammoth Crystal Spring area of Middle Creek. However, the extent of this impairment within the Middle Creek watershed appears to be confined within boundaries of YNP. This is indicated by the high number and percentage of EPT taxa present in Middle Creek near the park boundary. This aquatic invertebrate site has a high number of EPT taxa, a high percentage of EPT taxa, and a very low HBI value, all of which are indicative of an excellent water quality rating.

To evaluate the full extent of impairment to the Middle Creek drainage, additional water quality monitoring and aquatic invertebrate sampling should be conducted downstream from the confluence of Mammoth Crystal Spring and Middle Creek. This type of sampling will allow spatial references to be made in regard to degradation of the Middle Creek watershed.

Table 8. Percentages for select benthic invertebrate groups for sites in the Middle Creek drainage, YNP.

		Annelida	Crustacea	Arachnida	Turbellaria	Nematoda	Insecta			
Stream Name	Sample Year	Oligochaeta %	Ostracoda %	Acari %	Turbellaria %	Nematoda %	Ephemeroptera %	Plecoptera %	Trichoptera %	Diptera %
Middle Creek - site 1	2002	0	0	<1	0	0	71	8	9	12
	2003	0	0	<1	<1	<1	39	13	29	18
	2004	0	0	<1	<1	<1	58	8	8	25
	2005	0	0	<1	0	<1	66	9	11	13
Middle Creek - site 2	2005	0	0	<1	0	0	54	36	2	8
unnamed tributary	2002	<1	0	2	1	0	20	22	7	48
	2003	0	3	2	<1	0	26	25	11	33
	2004	0	2	2	<1	<1	13	9	7	66
	2005	<1	4	1	1	<1	24	19	18	32
Mammoth Crystal Spring										
1st Replicate	2005	<1	<1	0	0	<1	<1	1	<1	98
2nd Replicate	2005	0	0	0	0	0	<1	4	<1	96

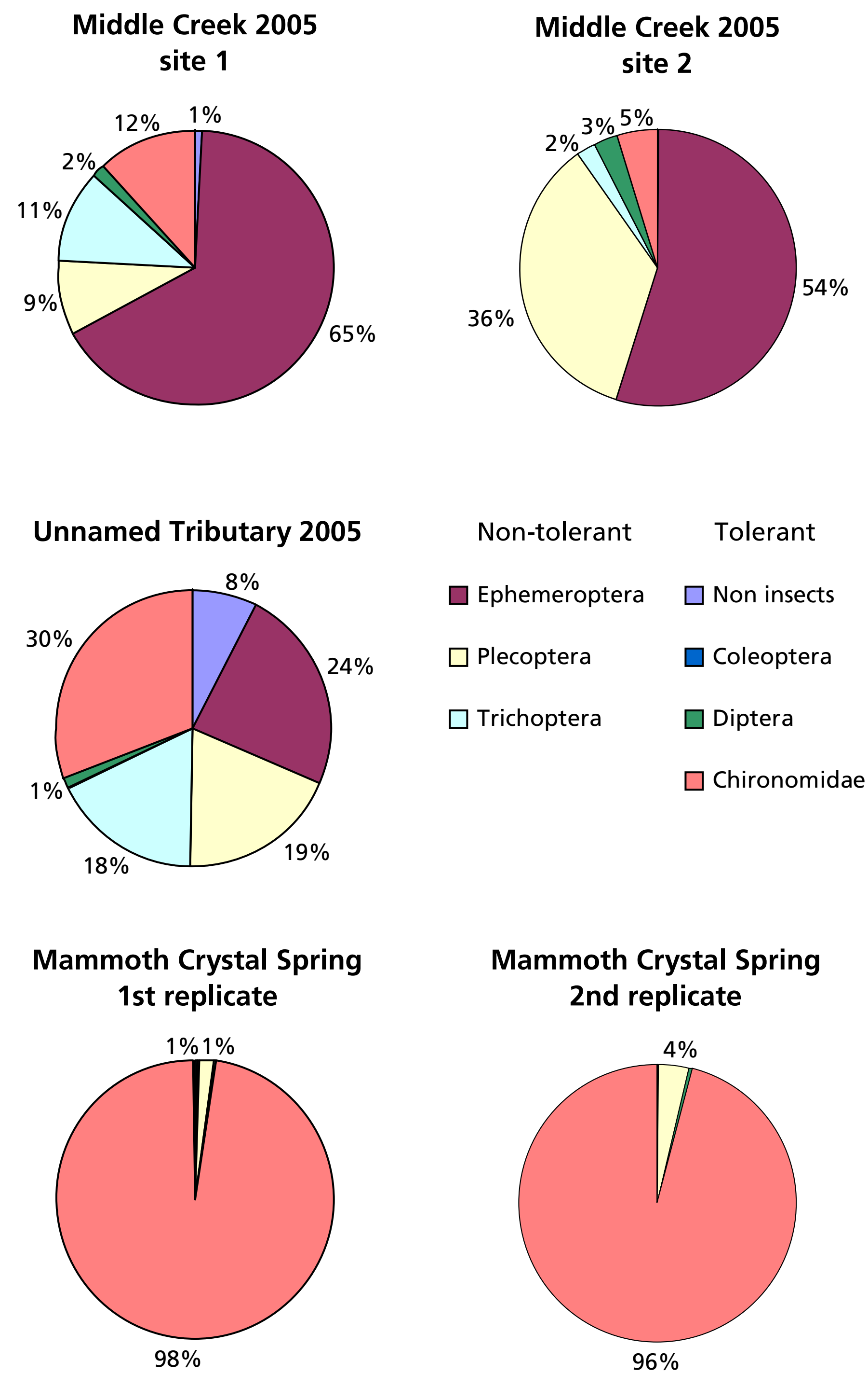


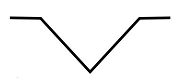
Figure 4. Percentage of major invertebrate groups collected in the Middle Creek drainage during the 2005 sample season.

Ecologist Jeff Arnold collects water samples for analysis of volatile organic compounds.

Yellowstone National Park fisheries technician Jeremy Erickson prepares and processes aquatic invertebrate samples collected from Mammoth Crystal Spring.

APPENDIX A. Habitat data sheet for invertebrate sampling in YNP.

HABITAT ASSESSMENT FOR RIFFLE/RUN STREAMS (>10% IN REACH) **YELLOWSTONE NATIONAL PARK**	STREAM: SITE: ____________ DATE: ____________ TIME: ____________ ____________ PLACE SHEET CODE HERE

	HABITAT PARAMETER	**HIGH** → **LOW** **Record Estimated Percentages if applicable, circle individual components that are present, use field notes if necessary.**			
1	BOTTOM SUBSTRATE-PERCENT FINES* SCORE Est. (__________) SCORE Calc. (_________)	<10% Fines (Sand + Silt) (20-16)	10-20% Fines (15-11)	20-50% Fines (10-6)	>50% Fines (5-0)
2	SILT COVERING (EMBEDDEDNESS)* SCORE Est. (__________) SCORE Calc. (_________)	Large and fine gravel, cobble, and boulder particles are 0-25% covered or surrounded by fine sediment. Layering of cobble provides diversity of niche space. (20-16)	Large and fine gravel, cobble, and boulder particles are 25-50% covered or surrounded by fine sediment. (15-11)	Large and fine gravel, cobble, and boulder particles are 50-75% covered or surrounded by fine sediment. (10-6)	Large and fine gravel, cobble, and boulder particles are >75% covered or surrounded by fine sediment. (5-0)
NOTE: ASSESS HABITAT PARAMETERS #1 AND #2 ONLY FOR THE RIFFLE OR RUN SAMPLED FOR MACROINVERTEBRATES. REMAINING HABITAT PARAMETERS #3 THROUGH #13 ARE ASSESSED FOR ENTIRE REACH.					
3	INSTREAM COVER (FOR FISH) SCORE (___________)	>50% of large cobble, gravels, boulders, submerged logs, scags, undercut banks, variety of substrate and habitat types; other stable fish habitat most favorable is a mix of the above. (20-16)	30-50% for all previous criteria: adequate fish cover. (15-11)	10-30% for all previous criteria: less than desired variety of substrate and habitat types; reduced fish cover. (10-6)	<10% for all previous criteria; poor variety of substrate and habitat types; obvious lack of fish cover. (5-0)
4	VELOCITY/ DEPTH SCORE (___________)	All four velocity/ depth regimes present (slow-deep; slow-shallow; fast-deep; fast-shallow). (20-16)	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes). (15-11)	Only 2 of the 4 regimes present (if fast-shallow or slow-shallow are missing score low). (10-6)	Dominated by 1 velocity/ depth regime. (5-0)
5	CHANNEL FLOW STATUS SCORE (___________)	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed. (20-16)	Water fills > 75% of the available channel; or <25% of channel substrate is exposed. (15-11)	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed. (10-6)	Very little water in channel and mostly present as standing pools. (5-0)
6	CHANNEL SHAPE (Bankfull Channel) SCORE (___________)	Trapezoidal (undercut banks)  (15-12)	Rectangular  (11-8)	Triangular  (7-4)	Inverse Trapezoidal  (3-0)
7	POOL/RIFFLE SEQUENCE (Mean distance between riffles in the sample reach divided by wetted stream width). SCORE (___________)	Ratio 5-7: Occurrences of riffles relatively frequent; ratio of distance between riffles divided by the width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important. (15-12)	Ratio 5-7: Occurrences of riffles infrequent; ratio of distance between riffles divided by the width of the stream is between 7 to 15. (11-8)	Ratio 15-25; Occasional riffle or bend; bottom contours provide some habitat; distances between riffles divided by the width of the stream is between 15 to 25. (7-4)	Ratio > 25; homogenous habitat. Generally all flat water or shallow riffles; poor habitat distance between riffles divided by the width of the stream is a ratio of >25. (3-0)

*NOTE: ESTIMATE THESE PARAMETERS IN THE FIELD FIRST AND THEN CALCULATE AND REPORT CALCULATED PERCENT FINES AND SILT COVERING VALUES OBTAINED DURING MACROINVERTEBRATE SAMPLING.

HABITAT ASSESSMENT FOR RIFFLE/RUN STREAMS (>10% IN REACH) **YELLOWSTONE NATIONAL PARK**					STREAM: SITE: __________ DATE: __________ TIME: __________ __________ PLACE SHEET CODE HERE
	HABITAT PARAMETER	**HIGH** **Record Estimated Percentages if applicable, circle individual components that are present, use field notes if necessary.**			**LOW**
8	CHANNELIZATION/ ALTERATION SCORE (________)	Channelization or dredging absent or minimal, stream with normal pattern (15-12)	Some channelization present, usually downstream of bridges, evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization not present. (11-8)	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted. (7-4)	Excessive channelization, banks shored with gabion or cement; heavily urbanized areas; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely. (3-0)
9	WIDTH TO DEPTH (Wetted width divided by mean depth) SCORE (________)	<7 (15-12)	8 to 15 (11-8)	15 to 25 (7-4)	>25 (3-0)
10	BANK VEGETATION PROTECTION (Bankfull) NOTE: DETERMINE LEFT OR RIGHT SIDE BY FACING DOWNSTREAM IN REACH SCORE (________) LB SCORE (________) RB	>90% Stream bank covered by vegetation, boulders, cobble, or large woody debris. (10-9)	70-90% Stream bank by vegetation, boulders, cobble, or large woody debris. (8-6)	50-70% Stream bank covered by vegetation, boulders, cobble, or large woody debris. (10-6)	<50% Stream bank covered by vegetation, boulders, cobble, or large woody debris. (5-0)
11	BANK STABILITY (Bankfull) SCORE (________) LB SCORE (________) RB	Bank stable: no erosion or bank failure; little potential for future problems. (10-9)	Moderately stable; few small areas of erosion mostly healed over (8-6)	Moderately unstable; up to 60% of banks in reach have areas of erosion; high erosion potential during floods. (5-3)	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing: 60-100% of bank has erosional scars. (2-0)
12	DISRUPTIVE PRESSURES (Riparian Zone immediately adjacent to stream) SCORE (________) LB SCORE (________) RB	Vegetative disruption minimal or not evident; almost all potential plant biomass at present stage of development remains. (10-9)	Disruption evident but not affecting community vigor; ≥ 50% potential biomass remains. (8-6)	Disruption obvious, some patches of bare soil or closely cropped vegetation; < 50% potential biomass remains. (5-3)	Very high disruption of vegetation; patches of bare soil; vegetation removed to ≤ 2 inches average stubble height. (5-0)
13	RIPARIAN VEGETATIVE ZONE WIDTH (From bankfull to upland) SCORE (________) LB SCORE (________) RB	Natural riparian zone intact. Human activities (ie. Roads, parking lots, clear-cuts, lawns, or crops) have not impacted natural zone. Potential for impacts from adjacent uplands low or high based on stream type (natural riparian width and percent slope of uplands). (10-9)	Human activities have impacted natural riparian zone only minimally, either directly or through upland contributions. Existing riparian zone provides good, moderate, or limited filtering potential to channel due to width of unimpacted zone. (8-6)	Human activities have impacted natural riparian zone a great deal. Existing riparian zone provides good, moderate, or limited filtering potential to channel due to width of unimpacted zone. (5-3)	Little or no riparian vegetation due to human activities. Existing riparian zone provides limited, poor, or no filtering potential to channel due to proximity of human activities to the channel. (2-0)

FOR INTER-CREW OR INTRA-CREW DUPLICATE HABITAT ASSESSMENTS ONLY:
NAME OF PERSON(S) DOING DUPLICATE: ______________________________

DATE: ________________ NOTES: ______________________________

APPENDIX B. Benthic invertebrate taxon and densities collected from Middle Creek, site 1, between 2002 and 2005. Invertebrate densities are recorded in square meters. Stream name, date of collection and sample year are indicated for each site. Tolerance value are derived from Barbour et al.,(1999). Lower number indicates organisms most sensitive to pollution; higher number indicates organisms least sensitive to pollution.

Taxon	**Middle 19-Aug 2002**	**Middle 5-Sep 2003**	**Middle 31-Aug 2004**	**Middle 29-Aug 2005**	**Tolerance Value**
Acari	3	30	5	13	
Oligochaeta	0	0	0	0	5
Ostracoda	0	0	0	0	5
Nematoda	0	20	13	5	8
Turbellaria	0	50	3	0	4
TOTAL: NON INSECTS	**3**	**101**	**22**	**19**	
Ameletus	3	20	0	0	0
Baetis bicaudatus	0	424	188	110	
Baetis tricaudatus	430	91	188	183	2
Caudatella hystrix	16	20	83	22	
Cinygma	0	0	0	0	4
Cinygmula	54	394	3	11	4
Drunella coloradensis	0	0	0	0	
Drunella coloradensis/flavilinea	51	61	24	51	
Drunella doddsi	186	151	81	164	
Drunella grandis/spinifera	0	0	13	0	
Drunella grandis	8	61	0	46	
Drunella spinifera	0	0	0	0	
Epeorus albertae	196	172	27	102	0
Epeorus deceptivus	0	0	8	5	0
Epeorus longimanus	5	0	0	0	0
Epeorus grandis	59	0	175	83	3
Ephemerella inermis	0	182	3	0	
Ephemerella infrequens	0	0	0	3	
Rhithrogena	194	676	105	204	0
Serratella tibialis	70	0	0	8	
TOTAL: EPHEMEROPTERA	**1272**	**2250**	**898**	**993**	
Capniidae	3	0	32	0	1
Chloroperlidae	24	0	13	27	1
Kogotus	5	0	0	0	2
Isoperla	0	0	0	0	2
Leuctridae	0	0	0	5	0
Megarcys	16	61	24	59	2
Paraperla	0	0	0	0	1
Perlodidae	5	61	0	0	2
Sweltsa	54	192	43	24	1
Taeniopterygidae	0	192	0	0	2
Visoka cataractae	0	0	0	0	1
Yoraperla	0	0	0	0	2
Zapada cinctipes	3	212	0	3	2
Zapada columbiana	5	10	3	0	2
Zapada frigida	0	0	0	0	2
Zapada Oregonensis Group	22	10	8	16	2
TOTAL: PLECOPTERA	**137**	**737**	**124**	**135**	

APPENDIX B (continued)

Taxon	Middle 19-Aug 2002	Middle 5-Sep 2003	Middle 31-Aug 2004	Middle 29-Aug 2005	Tolerance Value
Apatania	16	61	0	3	1
Arctopsyche grandis	0	10	0	0	2
Anagapetus	0	0	0	0	0
Brachycentrus americanus	3	10	0	3	1
Ecclisomyia	0	0	0	0	
Dicosmoecus atripes	0	0	0	0	1
Glossosoma	24	333	19	102	0
Lepidostoma cascadense	0	0	0	0	1
Limnephilidae	0	0	0	0	
Neothremma	0	0	0	0	0
Oligophlebodes	0	1009	3	0	1
Parapsyche elsis	43	91	19	24	1
Rhyacophila	0	10	0	0	0
Rhyacophila Alberta Group	0	0	0	0	
Rhyacophila Angelita Group	3	0	8	0	
Rhyacophila Bettenia Group	0	0	0	0	
Rhyacophila Brunnea/Vemna Group	19	111	32	13	
Rhyacophila Coloradensis Group	0	0	5	5	
Rhyacophila Hyalinata Group	30	20	22	5	
Rhyacophila Iranda Group	13	0	0	0	0
Rhyacophila pellisa/valuma	5	20	0	0	1
Thyacophila Vofixa Group	0	20	5	5	0
TOTAL: TRICHOPTERA	**156**	**1965**	**113**	**161**	
Heterlimnius	0	0	3	0	4
TOTAL: COLEOPTERA	**0**	**0**	**3**	**0**	
Atherix	0	0	0	3	2
Ceratopogoninae	0	30	11	3	6
Chelifera/Metachela	0	0	0	5	6
Clinocera	0	0	5	0	6
Deuterophlebia	3	0	3	5	0
Dicranota	0	0	0	0	3
Dixa	0	0	0	0	1
Empididae	0	10	0	0	6
Glutops	0	10	0	0	3
Hexatoma	11	61	13	0	2
Limonia					6
Mycetophilidae	0	0	0	0	
Muscidae	0	0	0	0	6
Oreogeton	0	0	0	0	5
Pericoma	0	61	3	0	4
Prosimulium	0	0	13	0	3
Rhabdomastix	0	0	0	0	8
Simulium	0	0	51	11	6
Thaumaleidae	0	0	0	0	
Wiedemannia	0	0	0	0	6
TOTAL: DIPTERA	**13**	**172**	**100**	**27**	

APPENDIX B (continued)

Taxon	Middle 19-Aug 2002	Middle 5-Sep 2003	Middle 31-Aug 2004	Middle 29-Aug 2005	Tolerance Value
Boreoheptagyia	0	0	0	3	6
Brillia	0	0	5	0	5
Chaetocladius	0	0	19	11	6
Chironomidae-pupae	38	50	51	30	
Chironomus	0	0	0	0	10
Cladotanytarsus	0	0	0	0	7
Corynoneura	0	0	0	0	7
Cricotopus Nostococladius	67	81	108	11	7
Diamesa	0	0	40	11	5
Diplocladius	0	0	0	0	
Eukiefferiella	5	10	19	11	8
Eukiefferiella Devonica Group	5	0	11	0	8
Heleniella	0	0	0	0	6
Hydrobaenus	0	10	5	3	8
Krenosmittia	0	0	0	0	1
Micropsectra	11	575	3	0	7
Orthocladius	0	0	3	0	
Orthocladius Complex	8	40	19	94	6
Pagastia	0	0	3	0	1
Parametriocnemus	0	0	0	0	5
Parorthocladius	0	0	0	0	6
Pseudodiamesa	0	0	0	0	6
Psilometriocnemus	0	0	0	0	
Rheocricotopus	0	0	0	0	6
Rheotanytarsus	0	0	0	0	6
Smittia	0	0	0	0	
Stempellinella	11	0	0	0	4
Thienemanniella	0	0	0	0	6
Tvetenia Bavarica Group	54	121	3	3	5
TOTAL: CHIRONOMIDAE	**199**	**888**	**288**	**175**	
GRAND TOTAL	**1781**	**5842**	**1547**	**1509**	

APPENDIX C. Benthic invertebrate taxon and densities collected from the unnamed tributary between 2002 and 2005. Invertebrate densities are recorded in square meters. Stream name, date of collection and sample year are indicated for each site. Tolerance value are derived from Barbour et al.,(1999). Lower values indicate organisms most sensitive to pollution; higher values indicates organisms least sensitive to pollution.

Taxon	unnamed 19-Aug 2002	unnamed 5-Sep 2003	unnamed 31-Aug 2004	unnamed 29-Aug 2005	Tolerance Value
Acari	135	66	49	0	
Oligochaeta	13	0	0	54	5
Ostracoda	0	81	58	323	5
Nematoda	0	0	4	67	8
Turbellaria	40	15	9	81	4
TOTAL: NON INSECTS	**188**	**161**	**120**	**605**	
Ameletus	27	176	13	202	0
Baetis bicaudatus	0	176	85	188	
Baetis tricaudatus	511	45	36	188	2
Caudatella hystrix	13	0	0	13	
Cinygma	27	0	0	27	4
Cinygmula	94	35	31	256	4
Drunella coloradensis	0	0	0	0	
Drunella coloradensis/flavilinea	27	101	0	121	
Drunella doddsi	40	0	4	40	
Drunella grandis/spinifera	0	50	9	0	
Drunella grandis	0	0	0	0	
Drunella spinifera	108	0	0	27	
Epeorus albertae	202	15	9	0	0
Epeorus deceptivus	0	0	0	54	0
Epeorus longimanus	27	0	0	0	0
Epeorus grandis	81	35	9	94	3
Ephemerella inermis	0	0	0	0	
Ephemerella infrequens	282	121	120	659	
Rhithrogena	40	10	9	13	0
Serratella tibialis	0	0	0	0	
TOTAL: EPHEMEROPTERA	**1480**	**766**	**326**	**1883**	
Capniidae	13	5	0	0	1
Chloroperlidae	0	0	0	0	1
Kogotus	0	0	0	0	2
Isoperla	81	45	18	94	2
Leuctridae	0	0	0	0	0
Megarcys	0	5	4	27	2
Paraperla	0	0	4	0	1
Perlodidae	13	30	4	0	2
Sweltsa	67	66	31	121	1
Taeniopterygidae	0	5	0	0	2
Visoka cataractae	0	5	0	13	1
Yoraperla	13	35	18	40	2
Zapada cinctipes	135	161	31	256	2
Zapada columbiana	1278	338	103	915	2
Zapada frigida	0	10	0	0	2
Zapada Oregonensis Group	27	35	18	13	2
TOTAL: PLECOPTERA	**1627**	**741**	**232**	**1480**	

APPENDIX C (continued)

Taxon	unnamed 19-Aug 2002	unnamed 5-Sep 2003	unnamed 31-Aug 2004	unnamed 29-Aug 2005	Tolerance Value
Apatania	40	35	0	67	1
Arctopsyche grandis	0	0	0	0	2
Anagapetus	0	15	0	0	0
Brachycentrus americanus	0	0	0	0	1
Ecclisomyia	0	0	0	13	
Dicosmoecus atripes	13	0	0	0	1
Glossosoma	0	60	22	108	0
Lepidostoma cascadense	0	0	0	13	1
Limnephilidae	0	5	4	13	
Neothremma	121	71	36	1089	0
Oligophlebodes	0	0	0	0	1
Parapsyche elsis	27	30	18	27	1
Rhyacophila	27	0	0	0	0
Rhyacophila Alberta Group	0	0	0	0	
Rhyacophila Angelita Group	0	0	0	0	
Rhyacophila Bettenia Group	188	76	54	40	
Rhyacophila Brunnea/Vemna Group	27	20	31	13	
Rhyacophila Coloradensis Group	0	0	0	0	
Rhyacophila Hyalinata Group	0	0	0	0	
Rhyacophila Iranda Group	67	0	0	0	0
Rhyacophila pellisa/valuma	13	5	0	13	1
Thyacophila Vofixa Group	0	0	9	13	0
TOTAL: TRICHOPTERA	**525**	**318**	**174**	**1412**	
Heterlimnius	0	0	0	0	4
TOTAL: COLEOPTERA	**0**	**0**	**0**	**0**	
Atherix	0	0	0	0	2
Ceratopogoninae	0	15	0	13	6
Chelifera/Metachela	0	10	4	0	6
Clinocera	27	5	0	0	6
Deuterophlebia	0	0	0	0	0
Dicranota	0	0	0	0	3
Dixa	13	5	0	0	1
Empididae	27	15	9	0	6
Glutops	40	15	27	27	3
Hexatoma	0	0	0	0	2
Limonia	13	0	0	0	6
Mycetophilidae	0	0	0	0	
Muscidae	0	0	0	0	6
Oreogeton	0	0	0	0	5
Pericoma	13	5	18	27	4
Prosimulium	0	0	4	0	3
Rhabdomastix	0	0	0	0	8
Simulium	0	10	0	0	6
Thaumaleidae	0	10	0	0	
Wiedemannia	40	35	22	27	6
TOTAL: DIPTERA	**175**	**126**	**85**	**94**	

APPENDIX C (continued)

Taxon	unnamed 19-Aug 2002	unnamed 5-Sep 2003	unnamed 31-Aug 2004	unnamed 29-Aug 2005	Tolerance Value
Boreoheptagyia	13	0	0	0	6
Brillia	0	0	0	0	5
Chaetocladius	0	0	0	0	6
Chironomidae-pupae	54	35	22	40	
Chironomus	0	5	0	0	10
Cladotanytarsus	0	5	0	0	7
Corynoneura	54	5	0	0	7
Cricotopus Nostococladius	525	131	1276	1170	7
Diamesa	0	0	4	0	5
Diplocladius	0	0	0	0	
Eukiefferiella	673	35	22	94	8
Eukiefferiella Devonica Group	390	25	49	94	8
Heleniella	0	10	0	13	6
Hydrobaenus	0	0	0	0	8
Krenosmittia	0	0	0	13	1
Micropsectra	0	186	27	565	7
Orthocladius	40	0	0	0	
Orthocladius Complex	0	35	58	40	6
Pagastia	108	10	18	135	1
Parametriocnemus	0	5	0	13	5
Parorthocladius	0	0	0	0	6
Pseudodiamesa	0	0	0	0	6
Psilometriocnemus	0	5	0	0	
Rheocricotopus	0	0	0	0	6
Rheotanytarsus	0	0	4	13	6
Smittia	0	0	0	0	
Stempellinella	0	50	4	27	4
Thienemanniella	94	0	0	13	6
Tvetenia Bavarica Group	1385	297	0	215	5
TOTAL: CHIRONOMIDAE	**3336**	**842**	**1601**	**2448**	
GRAND TOTAL	**7330**	**2953**	**2538**	**7922**	

APPENDIX D. Benthic invertebrate taxon and densities collected from Middle Creek, site 2, and Mammoth Crystal Spring during 2005. Invertebrate densities are recorded in square meters. Stream name and date of collection are indicated for each site. Tolerance value are derived from Barbour et al.,(1999). Lower values indicate organisms most sensitive to pollution; higher values indicate organisms least sensitive to pollution.

Taxon	Middle-2 30-Aug	MSC -1 30-Aug	MCS-2 30-Aug	Tolerance Value
Acari	2	0	0	
Oligochaeta	0	81	0	5
Ostracoda	0	40	0	5
Nematoda	0	40	0	8
Turbellaria	0	0	0	4
TOTAL: NON INSECTS	**2**	**161**	**0**	
Ameletus	27	0	0	0
Baetis bicaudatus	5	0	0	
Baetis tricaudatus	47	0	0	2
Caudatella hystrix	0	0	0	
Cinygma	0	0	0	4
Cinygmula	16	40	0	4
Drunella coloradensis	0	0	40	
Drunella coloradensis/flavilinea	0	0	0	
Drunella doddsi	2	0	0	
Drunella grandis/spinifera	0	0	0	
Drunella grandis	0	0	0	
Drunella spinifera	0	0	0	
Epeorus albertae	21	0	0	0
Epeorus deceptivus	0	0	0	0
Epeorus longimanus	0	0	0	0
Epeorus grandis	86	0	0	3
Ephemerella inermis	0	0	0	
Ephemerella infrequens	0	0	0	
Rhithrogena	342	0	0	0
Serratella tibialis	0	0	0	
TOTAL: EPHEMEROPTERA	**546**	**40**	**40**	
Capniidae	7	0	0	1
Chloroperlidae	32	0	0	1
Kogotus	0	0	0	2
Isoperla	0	0	0	2
Leuctridae	4	0	0	0
Megarcys	63	121	202	2
Paraperla	0	0	0	1
Perlodidae	0	0	0	2
Sweltsa	13	40	0	1
Taeniopterygidae	0	0	0	2
Visoka cataractae	7	0	0	1
Yoraperla	0	0	0	2
Zapada cinctipes	0	0	0	2
Zapada columbiana	124	81	605	2
Zapada frigida	0	0	0	2
Zapada Oregonensis Group	107	81	40	2
TOTAL: PLECOPTERA	**356**	**323**	**847**	

APPENDIX D (continued)

Taxon	Middle-2 30-Aug	MSC -1 30-Aug	MCS-2 30-Aug	Tolerance Value
Apatania	0	0	0	1
Arctopsyche grandis	0	0	0	2
Anagapetus	0	0	0	0
Brachycentrus americanus	0	0	0	1
Ecclisomyia	0	0	0	
Dicosmoecus atripes	0	0	0	1
Glossosoma	0	0	0	0
Lepidostoma cascadense	0	0	0	1
Limnephilidae	0	0	0	
Neothremma	0	0	0	0
Oligophlebodes	0	0	0	1
Parapsyche elsis	9	0	0	1
Rhyacophila	0	0	40	0
Rhyacophila Alberta Group	0	40	0	
Rhyacophila Angelita Group	0	0	0	
Rhyacophila Bettenia Group	2	0	0	
Rhyacophila Brunnea/Vemna Group	2	0	0	
Rhyacophila Coloradensis Group	0	0	0	
Rhyacophila Hyalinata Group	11	0	0	
Rhyacophila Iranda Group	0	0	0	0
Rhyacophila pellisa/valuma	0	0	0	1
Thyacophila Vofixa Group	0	0	0	0
TOTAL: TRICHOPTERA	**23**	**40**	**40**	
Heterlimnius	0	0	0	4
TOTAL: COLEOPTERA	**0**	**0**	**0**	
Atherix	0	0	0	2
Ceratopogoninae	0	0	0	6
Chelifera/Metachela	2	0	0	6
Clinocera	0	0	0	6
Deuterophlebia	0	0	0	0
Dicranota	4	0	0	3
Dixa	0	0	0	1
Empididae	0	0	0	6
Glutops	0	0	0	3
Hexatoma	0	0	0	2
Limonia	0	0	0	6
Mycetophilidae	2	0	0	
Muscidae	0	0	40	6
Oreogeton	13	0	0	5
Pericoma	0	0	0	4
Prosimulium	7	0	0	3
Rhabdomastix	2	0	0	8
Simulium	0	0	0	6
Thaumaleidae	0	0	0	
Wiedemannia	0	0	0	6
TOTAL: DIPTERA	**29**	**0**	**40**	

APPENDIX D (continued)

Taxon	**Middle-2 30-Aug**	**MSC -1 30-Aug**	**MCS-2 30-Aug**	**Tolerance Value**
Boreoheptagyia	0	0	0	6
Brillia	4	0	0	5
Chaetocladius	4	121	121	6
Chironomidae-pupae	7	1009	1533	
Chironomus	0	0	0	10
Cladotanytarsus	0	0	0	7
Corynoneura	0	0	0	7
Cricotopus Nostococladius	0	0	0	7
Diamesa	0	1372	404	5
Diplocladius	0	202	242	
Eukiefferiella	0	121	767	8
Eukiefferiella Devonica Group	0	0	0	8
Heleniella	0	0	0	6
Hydrobaenus	2	4479	5407	8
Krenosmittia	0	0	0	1
Micropsectra	5	0	0	7
Orthocladius	0	0	0	
Orthocladius Complex	0	11702	8231	6
Pagastia	72018	3874	1	
Parametriocnemus	2	0	0	5
Parorthocladius	0	121	525	6
Pseudodiamesa	0	121	121	6
Psilometriocnemus	0	0	0	
Rheocricotopus	2	0	0	6
Rheotanytarsus	0	0	0	6
Smittia	2	0	0	
Stempellinella	0	0	0	4
Thienemanniella	0	0	0	6
Tvetenia Bavarica Group	13	1695	888	5
TOTAL: CHIRONOMIDAE	**47**	**22959**	**22112**	
GRAND TOTAL	**1002**	**23524**	**23080**	

Aerial view of Sylvan Pass and road construction activites during 2004.

LITERATURE CITED

Aquatic Biology Associates. n/a. (http://www.aquaticbio.com/index.shtml). Accessed 03/03/04.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish, second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Gerritsen, J., M.T. Barbour, and K. King. 2000. Apples, oranges, and ecoregions: on determining pattern in aquatic assemblages. Journal of the North American Benthological Society 19:487–496.

Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution: the Great Lakes Entomologist, 20:31–39.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. Journal of the North American Benthological Society, 7:65–68.

Lenz, B.N. 1997, Feasibility of combining two aquatic benthic macroinvertebrate community databases for water-quality assessment: U.S. Geological Survey Fact SheetFS-132-97, 4p.

Omernik, J.M. and R.G. Bailey. 1997. Distinguishing between watersheds and ecoregions. Journal of the American Water Resources Association. 33: 935–949.

Southerland, M.T. and J.B. Stribling. 1995. Status of biological criteria development and implementation. Pages 81-96 in W.S. Davis and T.P. Simon (editors). Biological assessment and criteria: Tools for water resource planning and decision making. Lewis Publishers, Boca Raton, Florida.

Wyoming Department of Environmental Quality, Water Quality Division, Water Quality Program, Cheyenne, Wyoming. July 2001. Water Quality Rules and Regulation, Chapter 1, Wyoming Surface Water Quality Standards.

U.S. Geological Survey, 1998. National Field manual for the Collection of Water-Quality data, Book 9, U.S. Department of the Interior.

U.S. Geological Survey, 1999. Benthic Invertebrates and quality of streambed sediments in the White River and selected tributaries in and near Indianapolis, Indiana, 1994-96. Water-Resources Investigations Report 99-4276.

Varley J.D. and P. Schullery. 1998. Yellowstone fishes: ecology, history, and angling in the park. Stackpole books, Mechanicsberg, PS. 154pp.