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OGMCOAL - Fwd: FW: macroinvertebrate report -- Crandall Canyon

From: Kevin Lundmark
To: pjewkes@fs.fed.us; radavidson@fs.fed.us
Date: 3/29/2010 9:14 AM
Subject: Fwd: FW: macroinvertebrate report -- Crandall Canyon
CC: Ingrid Wieser; OGMCOAL; Steve Christensen
Attachments: Crandall macro report inc appendices 01 28 10.pdf

Pam,
This morning Bob Davidson and I spoke about Crandall Canyon, including the Forest Service's desire to evaluate biological conditions in Crandall Creek. I've forwarded the report for the September 2009 macroinvertebrate study completed at the site by the company's consultant (JBR). The company has committed to perform an on-site inspection of the Crandall Creek drainage with regulatory agencies once access is possible (late spring/early summer 2010). The inspection will include an assessment of the extent of iron accumulation in the creek to help determine what clean-up measures, if any, are necessary. The Forest Service will be notified and invited to the inspection. UT DOGM's biologist Ingrid Wieser will also be participating in the inspection and associated discussions.

Regards,
Kevin

Kevin Lundmark
Environmental Scientist II
Division of Oil, Gas & Mining
kevinlundmark@utah.gov
(801)538-5352

>>> Steve Christensen 2/9/2010 1:43 PM >>>

>>> "Shaver, Dave" <dshaver@coalsource.com> 2/9/2010 10:07 AM >>>

To all......Attached is the macroinvertebrate study recently conducted by JBR for Crandall Creek. Please forward this on to anyone else in your organization that may want or need to have access to it. Thanks

Dave

From: Karla Knoop [mailto:kknoop@jbrenv.com]
Sent: Thursday, January 28, 2010 1:13 PM
To: Shaver, Dave
Subject: macroinvertebrate report -- Crandall Canyon

File in:
- ☐ Confidential
- ☐ Shelf
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Refer to Record No 0025 Date 03292010
In C/0150032, 2010, Outgoing
For additional information

Dave,

Here is a pdf of the macroinvertebrate report for Crandall Canyon, including the appendices. The Figure 1 sampling location map is a draft, but I wanted to get everything to you without waiting for our CAD person to make a better-looking figure. Once you've had a chance to read the report, let me know if you have any questions or concerns.

Regards,

Karla

Karla Knoop, hydrologist

JBR Environmental Consultants, Inc.

ph. 801.943.4144

fax. 801.942.1852

Crandall Canyon Mine Macroinvertebrate Study September 2009

Prepared for:
Genwal Resources, Inc.
Crandall Canyon Mine
P.O. BOX 910
East Carbon, Utah 84520

Prepared by:
JBR Environmental Consultants, Inc.
8160 S. Highland Drive,
Sandy, Utah 84093

801.943.4144

January 28, 2010

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Crandall Canyon Mine Macroinvertebrate Study September 2009

1.0 Introduction

On September 16, 2009, JBR Environmental Consultants, Inc. (JBR) collected benthic macroinvertebrate samples from Crandall Creek, which is located near Huntington, Utah. The samples were collected both upstream and downstream of an underground coal mine operated by Genwal Resources, Inc. (Genwal) and permitted by the Utah Division of Oil, Gas and Mining (DOGM) through its coal mining program. The mine, known as the Crandall Canyon Mine, has been idle for more than two years but intercepted groundwater continues to discharge from the sealed portals. Crandall Creek is the receiving water for the discharge. Genwal hired JBR to sample the creek's benthic macroinvertebrates and assess the resultant data to determine whether or not the mine discharge is affecting Crandall Creek's aquatic community. After giving some relevant background information, this report describes the data collection and analysis methodology, provides the laboratory data, and discusses the results of the September 2009 macroinvertebrate study. The report also provides recommendations for future macroinvertebrates studies in Crandall Creek, which are required by DOGM.

1.1 Background

The Crandall Canyon Mine began discharging groundwater in late 1995, and did so more or less continuously for 12 years. While the mine was operating, groundwater entering the underground mine had to be collected and pumped to the surface to ensure safe operating conditions. Except for some passive in-mine settling, groundwater was not treated prior to being released to Crandall Creek. Its discharge was regulated by the Utah Division of Water Quality (DWQ) through the Utah Pollutant Discharge Elimination System (UPDES) permit program, and water quality limits were imposed to ensure that Crandall Creek and downstream water resources were protected. With very few exceptions, those permit limits were met during the 12 years of near-continuous groundwater discharge.

Subsequent to mine closure in mid-2007, the pumps and other infrastructure were removed from underground and the portals were sealed. Without active pumping, groundwater discharge ceased. The UPDES permit continued to be in effect, and the "no discharge" status was reflected on the monthly discharge monitoring reports. Genwal projected that recovering groundwater levels would never reach the portal elevations and, therefore, this water would never again discharge from the mine. However, after about three months with no discharge, groundwater unexpectedly began flowing out of the mine from beneath the portal seals. It has continued without interruption since that time.

While the more recent gravity-flow rates have been similar to the flow rates that were prevalent during the operational pumping, water quality has been somewhat different since the flow resumed in early 2008. After several weeks during which samples collected from the initial gravity discharge contained elevated total dissolved solids (TDS) and certain metals (zinc, nickel, iron), concentrations of most of the measured constituents diminished and soon returned to a near-normal level. Iron concentrations were the exception – total iron increased from <0.05 mg/L, which was a typical concentration during the active mining and groundwater pumping activities, to about 1.0 to 2.0 mg/L immediately after the gravity discharge began. After several months, total iron concentrations appeared to stabilize at about 0.5 mg/L, but in September 2008, iron again began to climb to a concentration that is currently two orders of magnitude higher than it was during the active mining and pumping period. As an example, concentrations of 5.1 and 3.0 mg/L of total iron were measured in two groundwater discharge samples that were collected in the two months prior to the September macroinvertebrate sampling. Genwal's UPDES permit limit for total iron is 1.0 mg/L. The iron-laden discharge has also resulted in iron-stained streambed substrate along an approximate 3,000-foot reach of Crandall Creek immediately downstream of where the groundwater discharge enters the stream. Based upon water quality sampling, no heavy metals other than iron are present in the discharge water in any problematic concentrations. The water's pH has been near-neutral or slightly alkaline.

Crandall Creek is a small perennial stream that drains a 2,500-acre watershed located within the bounds of the Manti-La Sal National Forest and conveys flow to Huntington Creek. Genwal's intercepted groundwater enters Crandall Creek approximately 1.5 miles upstream of the confluence of those two streams. Both Crandall Creek and Huntington Creek support aquatic resources, and Huntington Creek is a noted trout fishery. These fish rely in part upon a healthy and abundant macroinvertebrate community as a food source. The Utah Division of Wildlife Resources (DWR), in a 1995 letter to Genwal, indicated that Crandall Creek had a small resident cutthroat population and was also important spawning habitat for trout in Huntington Creek (Moretti 1995).

Iron is an essential element for both fish and the macroinvertebrates upon which they rely as a food source, as well as all other terrestrial and aquatic biota. However, in the aquatic environment, iron can be harmful or toxic depending upon its chemical form and its concentration. Largely as a function of the water's pH and its dissolved oxygen content, iron is typically present in either an insoluble ferric form or a soluble ferrous form. It can also be present as an integral component of individual sediment particles whose parent rock contains iron. While the chemistry of iron in water can be complex and is not fully discussed here, it is important to note a couple of key points. Commonly, iron found in groundwater is in the ferrous form, but when exposed to the atmosphere, this dissolved iron often oxidizes to the ferric form and then precipitates (Hem 1985). These iron precipitates can physically degrade aquatic habitat by covering bed substrate and organic matter; the covering can also reduce food sources for both fish and macroinvertebrates. The particulates (either from precipitates or fine sediments) can clog an organism's gills or filtering apparatus, and thereby hinder oxygen intake. Iron can also precipitate directly onto an organism's body, physically harming its body structure and function. In its soluble (dissolved) form, iron can also be toxic when ingested by aquatic life; this is commonly the mechanism of impact in waters where acid mine drainage often elevates the dissolved concentrations of numerous heavy metals including iron. Pelow and Edmunds (1999) provide a comprehensive review of acid mine drainage and its effects on macroinvertebrates.

Taking all of these things into account, EPA has conservatively recommended (nationwide) a criterion (chronic) of 1.0 mg/L iron, as part of their published National Recommended Water Quality Criteria for the protection of aquatic life (EPA 2009). Following EPA's recommendation, Utah, in its Water Quality Standards given at U.A.C. R317-2-14, adopted a maximum dissolved iron criterion of 1.0 mg/L for all streams that are classed for aquatic wildlife beneficial uses. DWQ set the Crandall Canyon Mine's UPDES permit limit at 1.0 mg/L total iron to provide protection at an even more conservative level than the stream standard without accounting for any dilution effects. However, as noted above, this limit is currently being exceeded. Genwal is obligated to take measures to bring its groundwater discharge back into compliance with its UPDES permit. An iron treatment plant was brought online in January 2010, and will presumably significantly reduce the iron concentration in both Genwal's discharge and Crandall Creek downstream of the discharge.

1.2 Purpose of Study

Due to elevated iron concentrations associated with Genwal's permitted groundwater discharge over recent months, the relevant regulatory (DWQ, DOGM) and management (U.S. Forest Service (USFS), DWR) agencies are concerned about the potential impacts of this discharge on aquatic life. In mid-August, 2009, DOGM issued a Citation for Non-Compliance (#10044) that required Genwal to engage a qualified biologist to collect macroinvertebrate samples from Crandall Creek prior to September 30, 2009 and prepare a comprehensive report that describes and evaluates the study results.

This macroinvertebrate study is intended to meet the DOGM requirements, as well as to accommodate the USFS's requests for obtaining results that would be comparable with their routine Huntington Creek benthic studies. Its purpose is to assess both the spatial and temporal variation in the macroinvertebrate community of Crandall Creek with an eye towards determining what, if any, iron-caused impacts have occurred in that community. The spatial assessment was the primary focus of this round of study because it can be based upon the single set of data that was collected on September 16, 2009. The data set also serves the purpose of establishing the current baseline condition, with which future sampling results can be compared to assess changes in the macroinvertebrate community over time as the water quality improves with treatment.

In addition, study results can be used to assess the overall health of Crandall Creek. Because they are sensitive to water quality and respond quickly to stressors including water pollutants, and also because they are fairly stationary within a given stream feature, benthic macroinvertebrates integrate variations in water quality or other habitat components (Davis et al 2001). Numerous indices and metrics such as diversity, taxa ratios, richness, and the like can be calculated and used to assess the macroinvertebrate community at a given site in regard to its ability to tolerate environmental pollution. The presence or absence of a specific macroinvertebrate taxon can indicate a perturbation that may not have been captured by grab samples analyzed for specific water chemistry. Ideally, this study may provide insight on the general condition of Crandall Creek as well as the iron-specific impact (if any) of Genwal's discharge on the creek's aquatic community.

2.0 Previous Studies

The macroinvertebrate samples collected on September 16, 2009 were not the first such samples collected in Crandall Creek. In 1980, prior to the mine start-up, macroinvertebrate samples were collected at several locations along Crandall Creek. A follow-up macroinvertebrate study was conducted in 1994, after several years of mine operations; at the time of sampling, groundwater had not been intercepted in a quantity sufficient to require surface discharge. While these studies' methodologies and site locations appear to be somewhat different from each other and from the 2009 study, their results can perhaps provide some baseline data with which the 2009 Crandall Creek data can be compared. In addition, the USFS samples benthic macroinvertebrates in Huntington Creek every five years. Brief descriptions of each of these studies follow.

2.1 Winget Study

As part of the baseline data collection program that was implemented prior to the development of the Crandall Canyon Mine, macroinvertebrates were collected from Crandall Creek by Robert N. Winget Environmental Consultants in October, 1980. Although his original report (if one was prepared) has not been located, a report describing study results is included in Genwal's Mine and Reclamation Permit (MRP) in Appendix 3-2; the date and author of this report are unclear. Winget's samples were collected near the mouth of Crandall Creek (site CC01) and an upstream site located near the proposed mine disturbance (site CC02). They were collected with a modified Surber sampler using a stratified random criterion (EPA 1973) to determine exact sampler placement for each subsample. Mesh size of the Surber sampler and the feature(s) the stratification was based on are unknown. A limited number of metrics were calculated.

This study indicated that the downstream site had fewer organisms than the upstream site, but a similar number and diversity of taxa. The sites were rated equal in regard to their aquatic community's environmental tolerance. While there were variations in taxa, both sites had representatives of both low- and high-tolerance organisms. The report noted that, based upon the macroinvertebrate communities observed, the downstream site reflected somewhat poorer water quality than the upstream site. However, the above-noted indices indicate only slight differences. The report also described more desirable physical habitat at the upstream site, due to the presence of silts and mineral cementation at the downstream site.

2.2 EIS Study

In July 1994, Environmental Industrial Services (EIS) collected macroinvertebrate samples in Crandall Creek as part of a riparian study prior to an expansion of the Crandall Canyon Mine (EIS 1995). As noted above, intercepted groundwater was not yet being discharged. EIS used a 900-micron mesh Surber sampler to collect samples at 12 sites within different habitat features along Crandall Creek. Specific site locations are not known. In most cases, taxonomic identification was made only to the family level. Functional feeding groups were noted and formed the basis of discussion in the EIS report. Other typical macroinvertebrate indices were not derived or discussed.

The lack of knowledge about site locations limits the value of the 1994 study results. In addition, the difference in level of taxonomic identification hinders meaningful comparison with data collected in 1980. It also makes it difficult to determine tolerance because many families contain some genera with low tolerance and others with higher tolerance. In sum, this study provides a very limited means of comparison with either the 1980 study or the 2009 study.

2.3 Other Studies

In the summer of 1983, the UDWR conducted a stream survey on Crandall Creek, which included some cursory macroinvertebrate information. While no report on the survey has been located, field data sheets are included in Genwal's MRP, in Appendix 3-2. A data sheet describing conditions near the confluence of Crandall and Huntington indicates that the overall macroinvertebrate abundance was "sparse" and that the major taxa represented were of the orders Ephemeroptera (mayfly) and Tricoptera (caddisfly).

In 1984, the Manti-La Sal National Forest began monitoring macroinvertebrate communities in several locations along Huntington Creek. Samples are collected approximately every five years. In 1994 and 1995 (the last years for which published results are available), Huntington Creek's macroinvertebrate community was between 72 and 78 percent of its potential, based upon calculated Biotic Condition Indices (U.S. Forest Service 2001). Unpublished sampling results from 2002 reportedly indicated improvements; results from the 2007 surveys are not yet available (Jewkes, personal communication 2009).

3.0 Site Selection and Site Descriptions

3.1 Site Selection

As required by DOGM, macroinvertebrate sample sites were to be located both upstream and downstream of the Crandall Canyon Mine. In that way, the upstream site would be located outside of any potential influence of the mine's groundwater discharge and could serve as a reference site. DOGM also required that sites be selected with their input, as well as with input from the USFS and DWR.

On September 3, 2009, representatives from JBR, DOGM, and USFS met at the Crandall Canyon Mine to identify the broad reaches wherein macroinvertebrate collection sites would be located (DWR chose not to participate). All three representatives agreed that three reaches would be selected: the previously mentioned upstream location and two reaches downstream of Genwal's groundwater discharge. One of the downstream reaches would be located within the stream section where iron-stained substrate is visible, and the other would be located further downstream outside of the visibly impacted substrate. This selection would enable not only a comparison of results from the upstream reference site and the downstream sites, but would further delineate the receiving waters into two reaches. This would potentially allow for a determination of the spatial extent of impacts (if any) due to Genwal's discharge.

Through a field examination of the stream on September 3rd, these three broad stream reaches were further defined. The intent was to provide a general reach location from which a specific measured reach could be delineated at the time of sampling. The uppermost reach (CRANDUP-01) was defined to be upstream of, but close to, the flow measurement flume located near the upstream edge of the upper parking lot. This site is outside of any influence of the mine's groundwater discharge. The middle reach (CRANDMD-02) was selected to include the area immediately downstream of the discharge location where flow mixing, aeration, and iron precipitation are occurring. In regard to potential iron impacts, this site would presumably represent the worst water quality and stream substrate conditions. The downstream reach (CRANDLWR-03) was chosen to be immediately upstream of the mine road crossing near the confluence with Huntington Creek. This site would have the potential to reflect either continued impacts, reduced impacts, or no impacts from the mine discharge.

3.2 Site Descriptions

Sample reaches were delineated at each location identified in the previous section (CRANDUP-01, CRANDMD-02, and CRANDLWR-03) following the methods outlined in the Environmental Monitoring and Assessment Program (EMAP) Field Operations Manual for Wadeable Streams (EPA 2001). EMAP specifies that a sample reach should be 40 times the average width of the stream channel or a minimum of 150 meters if the average channel width is less than four meters. Due to the small size of Crandall Creek throughout its length (average width less than 4 meters), sample reaches of 150 meters were defined for this study. A principle feature of the EMAP sampling reach is that 11 cross-section transects are established at regular intervals, with macroinvertebrate samples taken at each transect. The start and end points of the sample reaches were flagged and labeled Transect "A" and Transect "K" respectively. Between these points an additional nine transects were identified. These transects were spaced equally, 15 meters apart, and labeled Transects "B" through "J."

3.2.1 CRANDUP-01

The downstream endpoint for the upstream site, CRANDUP-01, was established approximately 2 meters above the flow measurement flume and it extended upstream approximately 150 meters (Figure 1). All transects, including end points, were flagged with yellow construction flagging labeled with the appropriate transect letter. Crandall Creek within this reach is a relatively narrow, steep headwater stream. Stream morphology is generally riffle-pool, with several beaver ponds; there are few meanders. Channel width is generally less than 1 meter, with the exception of the beaver ponds. The reach is bordered by abundant riparian vegetation, composed primarily of willow (*Salix* spp.) and redosier dogwood (*Cornus sericea*). Substrate within the reach is primarily coarse gravel and small cobble; however, substrate within the beaver ponds is primarily silt and fine sediment. Figure 2 shows the stream at the downstream endpoint (Transect A) as seen several weeks following sampling (5 November 2009).

Figure 2. View upstream from the downstream endpoint (Transect A) of CRANDUP-01

3.2.2 CRANDMID-02

The CRANDMD-02 reach was established directly below the mine water discharge (Figure 1). The upstream endpoint (Transect K) was located approximately 5 meters downstream of the discharge point, with the reach extending downstream approximately 150 meters. All transects, including end points, were flagged with yellow construction flagging labeled with the appropriate transect. Crandall Creek within this reach is a bit wider than at CRANDUP-01, with an average width between 1 and 2 meters. Stream gradient is considerably steeper than at the other sites and stream morphology is generally step-pool, with a large cascade approximately 60 meters down from the upstream endpoint (near Transect G). There are also several large beaver ponds within the reach. Riparian vegetation is less dense than at CRANDUP-02 and includes willow, redosier dogwood, and conifers. Substrate within the reach is primarily coarse gravel and cobble, with silt and fine sediment within beaver ponds and large runs. Substrate is heavily stained throughout the reach by iron precipitates. Figure 3 shows the reach at its upstream endpoint (Transect K) as seen several weeks following sampling (5 November 2009).

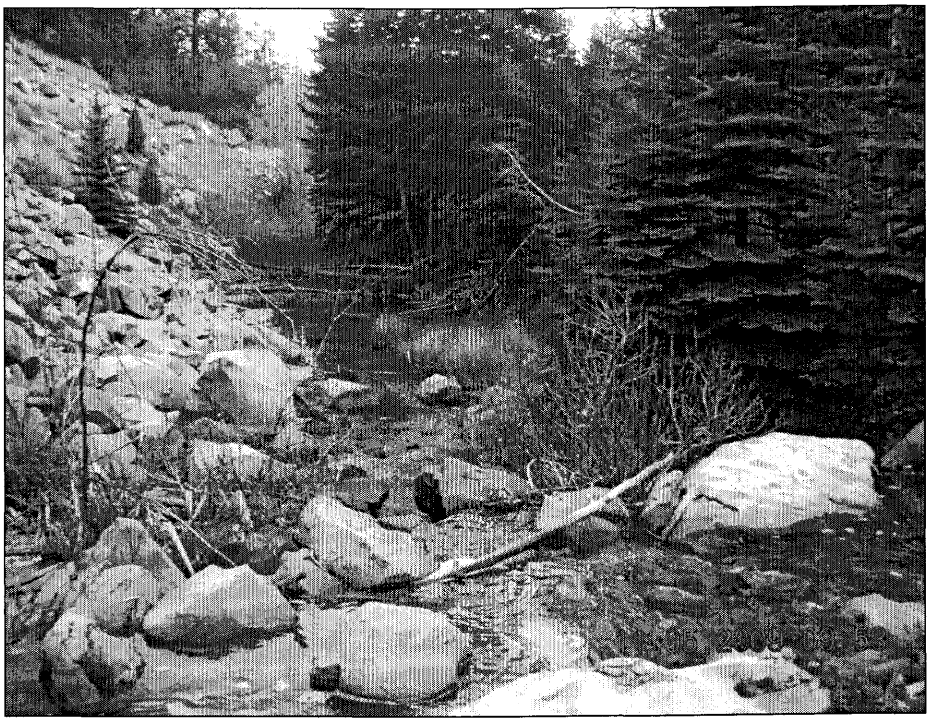

Figure 3. View downstream from the upstream endpoint (Transect K) of CRANDMID-02

3.2.3 CRANDLWR-03

The downstream endpoint for the downstream site, CRANDLWR-03, was established approximately 2 meters above where Crandall Creek passes under the mine road. It extended upstream from that point approximately 150 meters, with all transects flagged as described for the other sites. Crandall Creek within this reach remains relatively narrow and is lower gradient than the two upstream sites. Stream morphology is generally riffle-run, with several beaver ponds and several long runs. Riparian vegetation is similar in composition to CRANDMD-02, with conifers, willows, redosier dogwood, and some cottonwood (*Populus* spp.). Substrate within the reach is primarily gravel; however, substrate within beaver ponds and large runs is primarily silt and fine sediment. Figure 4 shows the stream at the downstream endpoint (Transect A) as seen several weeks following sampling (5 November 2009).

Figure 4. View upstream from the downstream endpoint (Transect A) of CRANDLWR-03

4.0 Methods

JBR collected macroinvertebrate samples from the three above-described stream reaches on Crandall Creek. Sample collection methodology was generally based upon the reach-wide sample methodology outlined in the (EMAP) Field Operations Manual for Wadeable Streams (EPA 2001). The specific application of the reach-wide sample methodology was modified as per discussions with the Manti-La Sal National Forest fisheries biologist who is responsible for USFS macroinvertebrate sampling on the Forest. Section 4.1 below describes the modified methodology. The collected and preserved samples were then delivered to the National Aquatic Monitoring Center (the BugLab) in Logan, Utah for processing and taxonomic identification. The BugLab is a cooperative venture between the U.S. Bureau of Land Management (BLM) and Utah State University. Its focuses on processing macroinvertebrate samples, and processes a large percentage of the samples collected on federal land in the western U.S. The DWQ Monitoring Manual (DWQ 2006) specifies that macroinvertebrate samples be processed by the BugLab. DWQ's methodology is described in Section 4.2., and the BubLab's complete report (Miller 2009) is attached as Appendix 1.

4.1 Sample Collection Methods

The EMAP methodology for the reach-wide sample specifies that one macroinvertebrate subsample is taken at each of the eleven transects within the delineated reach. These subsamples are then combined into a composite reach-wide sample. The sample location at the first transect is randomly selected using a six sided dice (i.e., sample is taken at a location 25, 50, or 75 percent of the distance from the channel's left edge depending upon the roll of the dice), with the sampling point at subsequent transects chosen systematically. However, the Manti-La Sal National Forest regularly collects only 4-5 macroinvertebrate subsamples within each reach, which are then combined into a single composite sample. The 4-5 subsamples are collected from as many habitat types as possible in order to sample the full range of habitat types present within the reach. In order to be more consistent with the methodology used by the Forest, the EMAP reach-wide sample methodology was modified to only include five samples. However, to keep the modified methodology as similar to EMAP procedure as possible (which improves consistency and keeps the samples as replicable as possible), the five samples were collected at every other transect starting with Transect B. The exception was at CRANDMD-02, where one of the samples was taken at an adjacent transect in order to sample a large run that was different than other habitat types within the reach. At the other sites, sampling at every other transect sufficiently captured the range of habitat types present in the reach.

As Crandall Creek is a narrow stream at all sites, and particularly CRANDUP-01, sample location at each transect was not chosen randomly or systematically, rather the site that was most suitable to sampling was chosen (i.e., the location that allowed placement of the sampler). All sampling was conducted using a 1,000-micron mesh Surber sampler. This is also a modification of the EMAP procedures, which specifies a 500-micron mesh kick net. In a couple of cases, a transect directly intersected a beaver dam and the sample was taken below the beaver dam, as sampling the lentic environment behind the dam would not have been feasible using a Surber sampler. None of the transects directly intersected a beaver pond. The samples were collected in a downstream-to-upstream order to avoid including organisms dislodged from upstream samples.

For sampling transects the following procedures were utilized.

1. The Surber sampler was quickly and securely positioned on the bottom of the channel with the opening facing upstream. Gaps between the frame and substrate were minimized.

2. The sample area was checked for heavy organisms, such as mussels and snails. Any such organisms were placed into the composite sample bucket. All substrate particles larger than golf balls and that were at least halfway into the sample area were picked up and rubbed with hands or a brush to dislodge organisms into the net. Particles that were more than halfway outside the sample area were pushed aside and not sampled. After particles were washed, they were placed outside of the sample area.

3. Starting at the upstream end of the sample area, the remaining substrate was kicked vigorously for 30 seconds. The water was allowed to clear before removing the net from the water column.

4. The net was lifted out of the water then quickly immersed several times to concentrate sample material in the end of net. Care was taken not to further disturb channel substrate with the net, or allow for organisms to escape.

5. The net was inverted into the composite bucket, which had been ¼ to ½ filled with stream water. The net was inspected for clinging organisms and forceps were used to place these organisms into the bucket.

6. The net was rinsed in the stream before moving to the next transect.

7. The dominant substrate and habitat type were recorded on the field data sheet.

After sampling was completed at the five transects, the following procedures were employed to prepare a Multi-Habitat composite index sample to be sent to the lab.

1. The contents of the sample bucket were manually swirled to separate organisms from the sample material. The sample material was poured through a 300-micron mesh sieve and the inside of the bucket was inspected for organisms. Organisms were rinsed off any large objects (rocks, organics, etc.) with a spray bottle filled with stream water before discarding the objects. Additional serial bucket rinses were employed until no remaining organisms were noted in the sample bucket.

2. Using the spray bottle, the sample material inside the sieve was rinsed to one side and transferred into the sample container using as little water as possible. The sieve was carefully examined for clinging organisms and these were placed into the sample bottle using forceps.

3. The sample container was completely filled with 95-percent ethanol so that the final concentration was between 75 and 90 percent. The container was slowly tipped horizontally and rotated to allow complete mixing of the ethanol and sample.

4. Sample containers were labeled with the information listed below. A duplicate of this label was written on ethanol-safe paper and placed inside of the container. Samples were then delivered to the BugLab for analysis.

   * Type of Sample (multi-habitat)
   * Stream Name
   * Site I.D.
   * Forest (Manti-La Sal National Forest)
   * Date and Time of Collection
   * Number of Jars

4.2 Analysis Methods

As noted above, the BugLab identified the taxa represented in the macroinvertebrate samples that JBR collected. The lab processed the samples using methods similar to those recommended by the United States Geological Survey (Cuffney et al 1993, as referenced in Miller 2009). Because the samples contained fewer than 600 organisms, 100 percent of the sample material was processed (if more than 600 organisms had been present per sample, a sub-sampling procedure would have been used). Generally, organisms were removed under a dissecting microscope at 10-30 power and separated into taxonomic orders. Organisms were then identified to a lower taxonomic level (family, genus, and/or species, as feasible). Once identified and counted, samples were placed in 20-ml glass scintillation vials with polypropylene lids in 70% ethanol, given a catalog number, and retained. The results report (Miller 2009) includes a complete list of taxa and the number of organisms by taxa (see Appendix 1).

The BugLab also provided data summaries and calculated various indices and metrics (Miller 2009), many of which will be discussed in the results discussion. These include: abundance, total taxa richness, EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa richness, Ephemeroptera taxa richness, Plecoptera taxa richness, Trichoptera taxa richness, percent EPT abundance, percent Ephemeroptera abundance, percent Chironomidae abundance, Intolerant taxa richness, percent tolerant organisms, Hilsenhoff Biotic Index, percent contribution of the dominant taxon, clinger taxa richness, percent clinger abundance, percent collector-filterer abundance, and percent scraper abundance. Definitions/descriptions of these individual metrics and their usefulness are provided below and are taken almost verbatim from the BugLab's data report (Miller 2009). More detail and references for how calculations were made are also given in their report, which can be found in Appendix 1.

Taxa richness - Richness is a component and estimate of community structure and stream health based on the number of distinct taxa. Taxa richness normally decreases with decreasing water quality. In some situations organic enrichment can cause an increase in the number of pollution tolerant taxa. Taxa richness was calculated for operational taxonomic units (OTUs) and the number of unique genera, and families. The values for operational taxonomic units may be overestimates of the true taxa richness at a site if individuals were the same taxon as those identified to lower taxonomic levels or they may be underestimates of the true taxa richness if multiple taxa were present within a larger taxonomic grouping but were not identified. All individuals within all samples were generally identified similarly, so that comparisons in operational taxonomic richness among samples within this dataset are appropriate, but comparisons to other data sets may not. Comparisons to other datasets should be made at the genera or family level.

Abundance - The abundance, density, or number of aquatic macroinvertebrates per unit area is an indicator of habitat availability and fish food abundance. Abundance may be reduced or increased depending on the type of impact or pollutant. Increased organic enrichment typically causes large increases in abundance of pollution tolerant taxa. High flows, increases in fine sediment, or the presence of toxic substances normally cause a decrease in invertebrate abundance. Invertebrate abundance is presented as the number of individuals per square meter for quantitative samples and the number of individuals collected in each sample for qualitative samples.

EPT - A summary of the taxonomic richness and abundance within the insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). These orders are commonly considered sensitive to pollution (Karr and Chu 1998, as referenced in Miller 2009).

Percent contribution of the dominant family or taxon - An assemblage largely dominated (>50%) by a single taxon or several taxa from the same family suggests environmental stress. Habitat conditions likely limit the number of taxa that can occur at the site.

Shannon Diversity Index - Ecological diversity is a measure of community structure defined by the relationship between the number of distinct taxa and their relative abundances. The Shannon Diversity Index was calculated for each sampling location for which there were a sufficient number of individuals and taxa collected to perform the calculations.

Evenness - Evenness is a measure of the distribution of taxa within a community. Value ranges from 0-1 and approach zero as a single taxa becomes more dominant.

Clinger taxa - The number of clinger taxa have been found by Karr and Chu (1998, as referenced in Miller 2009) to respond negatively to human disturbance. These taxa typically cling to the tops of rocks and are thought to be reduced by sedimentation or abundant algal growths.

Long-live taxa - The number of long-lived taxa was calculated as the number of taxa collected that typically have 2-3 year life cycles. Disturbances and water quality and habitat impairment typically reduces the number of long-lived taxa (Karr and Chu 1998, as referenced in Miller 2009).

Biotic indices - Biotic indices use the indicator taxa concept. Taxa are assigned water quality tolerance values based on their tolerance to pollution. Scores are typically weighted by taxa relative abundance. In the USthe most commonly used biotic index is the Hilsenhoff Biotic Index (Hilsenhoff 1987, Hilsenhoff 1988, as referenced in Miller 2009). The USFS and BLM throughout the western U.S. have also frequently used the USFS Community Tolerance Quotient.

Hilsenhoff Biotic Index - The Hilsenhoff Biotic Index (HBI) summarizes the overall pollution tolerances of the taxa collected. This index has been used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts. It is best at detecting organic pollution. Families were assigned an index value from 0 (taxa normally found only in high quality unpolluted water) to 10 (taxa found only in severely polluted waters). Family level values were taken from Hilsenhoff (1987, 1988, as referenced in Miller 2009) and a family level HBI was calculated for each sampling location for which there were a sufficient number of individuals and taxa collected to perform the calculations. Sampling locations with HBI values of 0-2 are considered clean, 2-4 slightly enriched, 4-7 enriched, and 7-10 polluted. Rather than using mean HBI values for a sample, taxon HBI values can also be used to determine the number of pollution intolerant and tolerant taxa occurring at a site. In this report, taxa with HBI values $\leq$2 were considered intolerant clean water taxa and taxa with HBI values $\geq$8 were considered pollution tolerant taxa. The number of tolerant and intolerant taxa and the abundances of tolerant and intolerant taxa were calculated for each sampling location.

USFS community tolerant quotient - Taxa are assigned a tolerant quotient from 2 (taxa found only in high quality unpolluted water) to 108 (taxa found in severely polluted waters). The dominance weighted community tolerance quotient (CTQd) was calculated. Values can vary from about 20 to 100, in general the lower the value the better the water quality.

Functional feeding group measures - A common classification scheme for aquatic macroinvertebrates is to categorize them by feeding acquisition mechanisms. Categories are based on food particle size and food location, e.g., suspended in the water column, deposited in sediments, leaf litter, or live prey. This classification system reflects the major source of the resource, either within the stream itself or from riparian or upland areas and the primary location, either erosional or depositional habitats. The number of taxa and individuals of the following feeding groups were calculated for each sampling location.

Shredders - Shredders use both living vascular hydrophytes and decomposing vascular plant tissue - coarse particulate organic matter. Shredders are sensitive to changes in riparian vegetation. Shredders can be good indicators of toxicants that adhere to organic matter.

Scrapers - Scrapers feed on periphyton - attached algae and associated material. Scraper populations increase with increasing abundance of diatoms and can decrease as filamentous algae, mosses, and vascular plants increase, often in response to increases in nitrogen and phosphorus. Scrapers decrease in relative abundance in response to sedimentation and higher levels of organic pollution or nutrient enrichment.

Collector-filterers - Collector-filterers feed on suspended fine particulate organic matter. Collector-filterers are sensitive to toxicants in the water column and to pollutants that adhere to organic matter.

Collector-gatherers - Collector-gatherers feed on deposited fine particulate organic matter. Collector-gatherers are sensitive to deposited toxicants.

Predators - Predators feed on living animal tissue. Predators typically make up about 25% of the assemblage in stream environments and 50% of the assemblage in still-water environments.

Unknown feeding group - This category includes taxa that are highly variable, parasites, and those that for which the primary feeding mode is currently unknown.

In addition, JBR used the BugLab's data set to calculate several other metrics that various literature sources consistently indicate as being potentially useful for macroinvertebrate analysis, particularly in regard to potential metals pollution. These are described below.

Ratio of Specialist Feeders to Generalist Feeders - Specialist feeders include shredders and scrapers and generalist feeders include filterers and gatherers. Generalists are typically more tolerant to environmental stressors, so their proportion often increases in response to degraded water quality or stream habitat. This ratio has been used successfully to assess impacts from mining (Mize and Deacon 2002).

Ratio of EPT to Chironomidae - Ideally, communities have a near-even distribution among all four of these major groups. The Chironimid Family, in general, is more tolerant than most of the taxa in the Ephemeroptera, Plecoptera, and Trichoptera orders (Barbour et al 1999). Therefore, this ratio can indicate environmental stress when it shows disproportionate numbers of Chironomidae (Davis et al 2001).

Percent *Baetis*, Hydropsychidae, and Orthocladinae; Ratio of *Baetis* to all Ephemeroptera – These two similar measures express the documented higher tolerances of *Baetis*, Hydropsychidae, and Orthocladinae, than other members of their families. Mize and Deacon (2002) among others have used the presence of these taxa when assessing environmental conditions specific to mining (some studies have found the opposite conclusion with *Baetis*; however, the majority appear to consider it one of the more tolerant of the mayflies).

Percent Heptageniidae, Chloroperlidae, and *Rhyacophila*; Ratio of Heptageniidae to all Ephemeroptera – Similarly to the above-noted tolerant taxa, Heptageniidae, Chloroperlidae, and *Rhyacophila* were considered by Mize and Deacon (2002) when assessing elevated trace metals impacts. Heptageniidae, Chloroperlidae, and *Rhyacophila* were chosen due to their apparent sensitivity to such elements, thus their absence can indicate poor water quality. Many other authors have associated a lack of Heptageniidae organisms, in particular, with heavy metals pollution (i.e. Kiffney and Clements 1994).

As with analysis of any set of macroinvertebrate data, multiple metrics and their predicted response to perturbations (as given by EPA (2009a) and others in the scientific community) will be relied upon to make a finding of impact or nonimpact in regard to Genwal's groundwater discharge and Crandall Creek. Whether looking at data from an individual sample, comparing data from different sites for a spatial assessment, or examining temporal changes, no one metric can ever be presumed to tell the whole story. First, there is typically some natural variability in community makeup, so reliance on a single metric can be misleading. Further, some metrics are better at ascertaining specific conditions than others (i.e. organic pollution versus metals pollution). For these reasons, most researchers use a variety of metrics and would expect to see similar indications in several of them before making a conclusion regarding impact to a given site. In contrast, there is some redundancy among metrics because they use at least some of the same data. EPA (Barbour et al 1999) and others have developed techniques for combining various metrics into a single index, and also for ranking sites based upon individual metrics in a way that a potentially impacted site can be compared to reference sites (known to be unimpacted). In this study, the low number of sample sites, lack of replicates, and inadequate information on historical baseline make these techniques impossible or impractical to use. Further, the natural variability of any of one these metrics is not known, so it is difficult to determine whether a difference between sites as shown by one metric is due to degraded conditions or simply a reflection of natural variability. While a data set conducive to statistical handling (assigning confidence limits, assessing significance, etc.) would be ideal, and may be available as sampling continues in the future, those types of data do not currently exist.

Instead, individual metrics were calculated for each site and graphed to provide an easy visual means of comparison (Appendix 2). Although some metrics are not independent of each other, there was a specific intent to choose metrics that are of different types (i.e. tolerance as measured by CTQd, community composition as measured by EPT abundance, feeding mechanism as measured by specialist-to-generalist ratio), as recommended by EPA (Bafour et al 1999). Metrics that would be expected to decrease as site conditions worsen (i.e. richness) are shown in blue and those that would be expected to increase as site conditions worsen (i.e. HBI) are shown in green, further facilitating visual interpretation. Comparisons between CRANDUP-01 and CRANDMD-02, across matrices, allow an assessment of whether conditions are degraded below Genwal's discharge. The presumption is that if multiple matrices indicate the same trend (i.e. impact), there is a greater likelihood that (1) there is a degradation between sites; and (2) the mine discharge is responsible for the degradation. Similarly, comparisons between CRANDMD-02 and CRANDLWR-03 can be made to assess whether there is a spatial limit to the degradation (recovered conditions downstream).

5.0 Results and Discussion

The results report that was prepared by the BugLab (Miller 2009) is provided in full as Appendix 1. That report includes the raw data (taxonomic lists of organisms identified, counts, etc.) as well as numerous tables of various metrics and indices that the lab calculated based upon the data. Many of these metrics and indices were described in Section 4.2 above. The report (Miller 2009) does not discuss or interpret the study results and this section focuses on those tasks, beginning with a brief summary of the data and a general discussion of the results. An analysis of the spatial differences among the three Crandall Creek sites sampled in September 2009 provides the best indication of whether or not Genwal's groundwater discharge has impacted the reach of stream below the discharge. Only limited comparisons with the older study results are provided in this report, due to a lack of knowledge about these studies' methodology and sampling locations, and because few metrics were calculated by their authors. In the future, as additional samples are collected at CRANDUP-01, CRANDMD-02, and CRANDLWR-03, and results will be better suited to begin to address temporal trends.

A total of 57 operational taxonomic units (OTU) were identified in the 3-sample set (OTUs are used as a measure because of the variation in taxonomic levels to which identification is made). There were members of 28 families and 33 genera present within the sample set, and all of the insect orders most commonly found in macroinvertebrate communities (Coleoptera, Diptera, Ephemeroptera, Plecoptera, and Tricoptera) were represented in each of the three samples. In addition, individuals from some non-insect classes were identified in all three samples. The average abundance in the sample set was approximately 660 individual organisms per square meter, which is lower than generally expected in good quality aquatic habitat. Abundance is likely to have been higher if the mesh size of the net used for sampling had been finer, as well as if riffle areas had been the primary focus of the collection efforts. Time of year may also have affected the overall numbers. However, the fairly low abundance may also provide additional evidence in support of the following discussion on the overall health of Crandall Creek.

The 2009 results (including, but not limited to, the abundance measured mentioned above) generally indicate that none of the three Crandall Creek sites was in optimum shape at the time of sampling. As the first graph in Appendix 2 shows, all three sites were dominated by members of the order Diptera. Dominance of any single order often indicates an unbalanced system. Further, while Diptera includes some families or genera that are sensitive to pollution, many taxa in that order (including the majority of the ones found at Crandall Creek) are quite tolerant to perturbations. In addition, all three sites had relatively low proportions of the generally sensitive Ephemeroptera, Plecoptera, and Trichoptera orders. Low proportions of these orders can be indicative of a stressed system. The two tolerance indices calculated by the BugLab also indicate a less than ideal aquatic community throughout Crandall Creek. HBI results, when rated according to the scale provided in Section 4.2 under the HBI description, were at best "slightly enriched" and at worst "enriched"; none of the three sites would be categorized as "clean" by this measure. CTQd, which can range from about 20 in the best quality streams up to about 100 in the poorest, was between 71 and 79 in the Crandall Creek September 2009 samples, which also indicates a stream that is providing less than ideal aquatic habitat. It is unknown whether all of these measures reflect the inherent characteristics of Crandall Creek, or are an indication of a diminished watershed condition.

Although Crandall Creek as a whole may provide less-than-ideal habitat, all of the sites had at least a somewhat diverse assemblage of taxa, and all supported at least some taxa that are considered intolerant to pollution or other habitat alterations. All three sites had individuals from both the most tolerant taxa (HBI>=8) and the least tolerant taxa (HBI<=2). This is useful information because it indicates that, while not ideal, there is suitable aquatic habitat in Crandall Creek, including at the CRANDMD-02 location immediately below Genwal's discharge point. Whatever effects the discharge may have had, the stream at that location is not devoid of life, and in fact is still supporting some sensitive aquatic taxa, albeit taxa that may be more sensitive to organic enrichment and perhaps less sensitive to iron.

Knowing that (1) Crandall Creek overall has an aquatic community that is not optimum, and (2) in spite of Genwal's iron-laden discharge, the creek is still supporting aquatic life provides a useful context for the remainder of the results discussion. Those two things being said, by most of the metrics discussed below, there is a less healthy macroinvertebrate community at CRANDMD-02, immediately below the discharge, than at CRANDUP-01, which is upstream of the discharge. Further downstream, at CRANDLWR-03, conditions are generally (by most but not all metrics) worse or similar to those at CRANDMD-02. Although these metrics do not definitively identify iron (either in the water column or on the substrate) as the cause of the noted impairment, they consistently indicate that Genwal's mine discharge is likely to have impacted the macroinvertebrate community. And, iron is the most logical culprit. This subject is discussed in more detail below.

5.1 Spatial Variation in Macroinvertebrate Community

Numerous metrics and indices based upon the September 2009 sampling at CRANDUP-01, CRANDMD-02, and CRANDLWR-03 have been calculated and graphed. These graphs are included in Appendix 2 and provide the visual means to analyze the spatial variation in the macroinvertebrate community along Crandall Creek. CRANDUP-01 is upstream of any potential impact from Genwal's discharge, CRANDMD-02 is immediately below the discharge where impacts would presumably be the greatest, and CRANDLWR-03 is further downstream where impacts could presumably be either similar those seen at CRANDMD-02 or reduced, thus indicating a spatial limit to the impact.

Out of the 20 metrics graphed in Appendix 2, all but three indicate a decline in macroinvertebrate community health between CRANDUP-01 and CRANDMD-02. It is important to reiterate that the data for any one metric are insufficient to make a statistical significance determination of the differences between sites. Some difference would be expected simply due to natural variations in the measurements and this cannot be determined for any single metric with the available data. Further, each metric is, at best, simply a likely indicator of a condition or trend rather than definitive proof. It is also important to note that some of these metrics are not independent of each other. All that being said, however, the fact that such a high percentage of the metrics showed the same trend between these two sites substantiates a finding of difference and increases the likelihood that the difference is not simply due to natural variation.

The three metrics that did not indicate a decline in macroinvertebrate health between CRANDUP-01 and CRANDMD-02 were Number of Long-lived Taxa, HBI, and Percent Tolerant Organisms. The first of these metrics (Number of Long-lived Taxa) reflected an increase between CRANDUP-01 and CRANDMD-02. However the increase was from two taxa to three taxa, and is most likely not a real difference or indication of trend, but is simply within normal statistical variation.

HBI, as noted in Section 4.2, has been used to detect numerous types of water quality problems. But, it was developed - and is best used for - detecting organic pollution such as would be due to septic contamination, agricultural impacts, and the like. It may simply be an unsuitable indicator for this study (the other tolerance index, the CTQd, uses different tolerance values and showed an opposite trend to the HBI). Further, there is not a ready explanation for HBI at the upstream site to be worse than the middle site, or a ready explanation for HBI to be improved by the addition of Genwal's discharge. The best assumption may be that the HBI variation is simply due to natural variation and is insignificant.

The third metric (Percent Tolerant Organisms) that did not follow the dominant trend was calculated by the BugLab using the same tolerance values as the HBI, so not surprisingly it followed the same pattern as the HBI. For the same reasons as mentioned above, this may not be a good indicator for Crandall Creek (all of the other tolerance-based indices that used difference taxa for the assessment indicated that CRANDMD-02 has a more stressed aquatic community). Last, it is interesting to note that the high Percent Tolerant Organisms metric at CRANDUP-01 is due to the overwhelming presence of a single taxon within the *Pericoma* genus (in the Psychodidae family within the Diptera order). This pollutant-tolerant taxon comprised a full 25 percent of all organisms sampled at the most upstream, unaffected site. While *Pericoma* is not an uncommon organism in Utah, its presence in such a quantity appears to be unusual and is not easily explained.

The other 17 metrics pointed towards a decline in the aquatic community between sites CRANDUP-01 and CRANDMD-02. As shown in Appendix 2, they encompass a range of tolerance, community composition, diversity, and feeding group metrics. Both the CTQd Index, which is a weighted community tolerance index, and Shannon's Diversity Index, which is a measure of variety in the macroinvertebrate community, indicated poorer conditions at CRANDMD-02 than at CRANDUP-01. Taxa richness and evenness, which are different measures of community structure, also pointed towards a less healthy stream at CRANDMD-02. Several metrics assessing various taxa (Chironomids, *Baetis*, Hydropsychidae, and Orthocladiinae) that can withstand poor water quality showed a higher relative abundance of those organisms at CRANDMD-02 than at CRANDUP-01, supporting the contention of degraded conditions at the former. Also supporting that contention were several metrics assessing taxa sensitive to poor water quality (Heptageniidae, Chloroperidae, and *Rhyacophila*, specifically, and all EPT taxa generally). Last, feeding group measures also support the conclusion of these other metrics. Therefore, based upon the number and variety of metrics that indicate at least some level of decline in the macroinvertebrate community between these two sites, it appears that CRANDMD-02 has been subject to some type of perturbation.

Comparing the various metrics (Appendix 2) for CRANDMD-02 and CRANDLWR-03 does not give quite as consistent a set of results as the comparison between CRANDUP-01 and CRANDMD-02. But, out of the same 20 metrics, 16 appeared to indicate either a continuing decline in the stream health between CRANDMD-02 and CRANDLWR-03 or a similar condition between the two. Four metrics indicated improved conditions at CRANDLWR-03 and generally similar levels as those measured at CRANDUP-01. These four metrics are Evenness, Percent EPT Taxa, Percent Chironomids, and EPT:Chironomidae, which are all related to some degree. However, because *Baetis* made up the largest portion of Ephemeroptera at CRANDLWR-03 (as noted previously, *Baetis* is one of the more pollutant tolerant members of a generally sensitive order), in this case Ephemeroptera's increase at CRANDLWR-03 is not necessarily indicative of an improvement at that site. Overall, with the available data, the majority of the indicators suggest that CRANDLWR-03 has also been subject to some type of perturbation.

5.2 Temporal Variation in Macroinvertebrate Community

As previously mentioned, macroinvertebrate studies were conducted in Crandall Creek in 1980 and 1994. However, those data are of limited use due to unknowns in either sampling locations and/or collection methodology. Additionally, few if any metrics were calculated by the study authors. Results from the two sites sampled in 1980 can more easily be compared with the 2009 study because sampling locations were in close proximity: 1980's CC01 is essentially at the same location as CRANDLWR-03, and CC02's location is essentially the same as CRANDUP-01. The 1994 results are not as easily used for comparison in part because site locations are not known, so are only partially included here.

The 1980 study reported a density (equivalent to total abundance) at the downstream site (CC01) of an order of magnitude higher than the 2009 data. CC02 density was an order of magnitude higher than CC01, and thus two orders of magnitude higher than the 2009 data. In 1994, a total of only 329 individuals were collected from 12 sites with a combined area of slightly more than a square meter. Whether the much-reduced densities in 1994 and 2009 (when compared to the 1980 results) are due to seasonal flow or life-cycle differences, annual variation, sampling equipment or methodology differences, or another cause cannot be determined. While abundance alone is not considered to be a particularly useful number for assessing ecological impact, these variations may indicate that other comparisons among the data sets should be approached with caution.

Different dominant families were present in 1980 than were reported in 2009. Nemouridae (a Plecoptera), was the dominant family represented at the upstream site (CC02) in 1980. It made up approximately 26 percent of the total number of individuals sampled. In 2009, Nemouridae individuals were present, but comprised less than 6 percent of the total density. As in 2009, *Baetis* appears to have been the dominant family represented at the downstream-most site (CC01) in Crandall Creek in 1980. These small minnow mayflies made up 17 percent of the total organisms at that site (there was a larger number of Hydracarina organisms reported in the sample, but this suborder of more than 40 families was not further keyed by family). Interestingly, the only dominant family from the 1980 and 2009 surveyed sites that was identified as being present at all during the 1994 survey was Chironomidae.

In 1980, total taxa richness was reported to be 33 at the upstream site and 31 at the downstream site. Because the level of taxonomic identification may have been different in the 1980 data set than in the 2009 data set, it may not be appropriate to compare the taxa richness numbers between the two years. Instead, looking at the spatial difference in 1980 and the spatial difference in 2009, it appears that total richness was similar at the two sites in 1980, but by 2009 total richness was markedly decreased at the downstream site when compared to the upstream site. Similarly, in 1980, EPT richness showed only a slight change downstream (decreasing from 16 to 14), while in 2009, EPT richness decreased substantially from upstream to downstream.

The 1980 data also showed a very slight, almost negligible, decrease in diversity as measured by the Shannon Diversity Index from the upper site (3.46) to the lower site (3.33). Overall, this index indicates a degradation of macroinvertebrate community structure between 1980 and 2009, at both the upstream and downstream sites.

While the CTQd was not calculated in the 1980 study, the related Actual Community Tolerance Quotient (CTQa) was. It may not be appropriate to compare the 2009 CTQd at a given site with the 1980 CTQa at the same site, since the equations use to calculate these measures are different. However, both measures use the same taxa-specific tolerance quotients, so there is some validity in comparing the spatial trend in 1980 with the spatial trend in 2009. As noted above, the 2009 CTQd indicated some degradation between the upstream and downstream sites. In contrast, in 1980, both the upstream and the downstream sites had a CTQa of 60, indicating a similar condition in both locations (i.e. no degradation).

Because sampling locations for the 1994 study are not known, and because metrics were not compiled, that study is less useful for assessing temporal trends beyond what is briefly discussed above. Interestingly, several taxa that were prevalent in 2009 were not reported at all in 1994. No *Baetis* were collected in 1994, though they were found in large numbers both in 1980 and 2009. While the 1980 and 2009 data showed significant numbers of *Pericoma* at the upstream site (where it was the dominant taxa in 2009), it was not reported at all in 1994. Though a large number of *Pisidiinae Pisidium* (a mollusk) was sampled at CRANDMD-02, none were reported in either 1980 or 1994.

As noted, there are numerous limitations in assessing temporal trends between 1980 and 2009, but the 2009 data can provide the basis for comparisons with data that will be collected more regularly beginning in spring 2010.

5.3 Indication of Iron-specific Impacts

As described above, the data indicate that there is some degradation in the aquatic community between CRANDUP-01 and CRANDMD-02. That degradation also appears to continue downstream to CRANDLWR-03. Attributing the degradation directly to iron in Genwal's groundwater discharge is problematic. First, there are no specific taxa or collection of taxa that are known to be absent (or present) in iron-laden waters. Second, there are other variables besides iron that are at play between CRANDUP-01 and CRANDMD-02: most noticeably, Genwal's discharge adds considerably more flow volume and is significantly warmer during at least fall and winter months. Last, even attributing the change in macroinvertebrate community to Genwal's discharge as opposed to other factors (either anthropogenic, natural, or due to inherent variability) is based somewhat on assumptions of cause and effect. However, given that water quality sampling has verified that iron is present in Genwal's discharge in elevated concentrations and that the stream bed has been visibly altered by iron precipitates, the most reasonable assessment is that iron is, at least in large part, responsible for impacts to macroinvertebrate community downstream of the discharge. Whether these are due to iron dissolved in the water column, iron present as suspended or colloidal particles, or iron precipitated onto the streambed cannot be distinguished with the available data and the current level of analysis. However, while there are no known iron indicator taxa, the literature does provide evidence of macroinvertebrate sensitivity to water containing various heavy metals, including iron. This type of information provides the basis for much of the following discussion.

While analyzing the effects on macroinvertebrates of using wetlands to treat landfill effluent, Moolamoottil et al (1999) reviewed literature that discussed iron toxicity and macroinvertebrates. Their analysis concluded that the EPT taxa were more sensitive to iron and Diptera were more tolerant, which are similar conclusions as most of the literature that assesses poor water quality in general. Based upon these measures, as discussed more fully above, there is support for the finding that iron has affected the macroinvertebrate community in Crandall Creek. In contrast, however, their study also included Coleoptera as an iron-sensitive family and CRANDMD-02 had more organisms in this family than either CRANDUP-01 or CRANDLWR-03. Two other species of caddisfly (*Glossosoma* spp. and *Neophylax* spp.) were also indicated as sensitive to iron (at least when it results in bacterial blooms), but neither were identified at all in Crandall Creek, including at the upstream site. Another caddisfly, Hydropsychidae family, was also considered to be sensitive to iron and iron-loving bacteria by Moolamoottil et al (1999). But, coming to the opposite conclusion, Mize and Deacon (2003) found members of this family to be tolerant of trace metals in general. In any case, this family was more prevalent downstream of Genwals' discharge than upstream of it.

Much of the knowledge regarding the effects of heavy metals on macroinvertebrate communities has been derived through study of acid mine drainage (AMD). AMD is known to degrade the water quality and aquatic habitat of receiving streams by contributing significant levels of dissolved metals, including iron. Many of the metals typically found in AMD are more toxic than iron and are more likely to be elevated, so the related literature often does not specifically address iron, but instead focuses on a constellation of other more toxic heavy metals. For example, Giddings et al (2001) studied the relationship of trace metals and macroinvertebrates in several Utah streams, but focused on priority metals such as lead, mercury, and zinc.

Studies that do include iron as a constituent of concern because it is elevated, often address the elevation of numerous other metals and low pH that often go hand-in-hand. This makes it difficult to separate out the effects of iron alone. In a study comparing water quality, sediment, and macroinvertebrates in mining and nonmining sites in Colorado (Mize and Deacon 2002), the mining sites were found to have different macroinvertebrate communities than the nonmining sites. Mining sites had significantly lower total abundance, fewer taxa, and decreased EPT richness when compared to the nonmining sites. Similarly, a study of mine-affected streams in Washington found that elevated heavy metals concentrations resulted in decreased density and diversity of benthic macroinvertebrates, as compared to the non-affected upstream sites (Peplow 1999), though iron was not among the metals that were present in the study stream at high concentrations. The Crandall Creek results showed similar relationships.

The Mize and Deacon (2002) study also found larger percentages of tolerant species at the mining sites, and specifically noted that *Baetis*, Hydropsychidae, Orthocladiinae, and chironomids appeared to be tolerant of elevated trace-element concentrations. Conversely, they attributed the scarcity of Heptageniidae, Chloroperlidae, and *Rhyacophila* spp. at mining sites to their sensitivity to elevated trace-element concentrations. These six taxa were analyzed in the Crandall data set (see Appendix 2), and similar inferences can be made regarding the effect of Genwal's discharge.

In a study that attempted to differentiate macroinvertebrate tolerance among specific individual heavy metals, including iron, Beasley and Kneale (2003) sampled stream sediments subjected to runoff with varying levels of metal pollution. Among its results were rankings of the five macroinvertebrate families most sensitive to iron and the five most tolerant. The study reported some inconsistencies in results (thought in part to be due to the interaction between variations in life cycle and the seasonality of the sampling) and had a different focus than the issue being studied in Crandall Creek. Even so, the September 2009 Crandall Creek macroinvertebrate lists were compared to the two sets of families to see if there appeared to be any parallels. While three of the five most iron-sensitive families, as determined in the Beasley and Kneale (2003) study (Heptageniidae, Perlodidae, and Rhyacophilidae), were among the families reported in the September 2009 Crandall Creek survey, there were no definitive relationships. For example, two of the supposedly most iron-sensitive families were found at CRANDMD-02 (all three were found at CRANDUP-01 and one was found at CRANDWLR-03).

Heptageniidae is indicated by numerous authors and studies to be one of the best single indicators for metals pollution over other types of stream perturbations (Kiffney and Clements 1994; Clements 1994). Although the previous caveats regarding the use of a single metric still apply, it is noteworthy that this family of Ephemeroptera was found only at CRANDUP-01, where it made up about 7 percent of all Ephemeroptera individuals samples (see metrics in Appendix 2). No organisms in this family were found at either CRANDMD-02 or CRANDLWR-03. This provides another strong indication that iron has impacts these downstream receiving waters.

6.0 Recommendations for Future Study

As discussed previously, the data collected in September 2009 are primarily useful in assessing spatial variation in macroinvertebrate communities along Crandall Creek. This allows some inference into impacts from Genwal's discharge as discussed. However, future studies can provide the ability to examine temporal variation and provide some level of statistical analysis. In order to make the data comparable between years, some consistency in sampling methodology should be maintained. However, there were also several shortcomings of the September 2009 sample methodology that should be addressed. These shortcomings primarily include the type of net used for sampling and the types of habitats sampled.

The September 2009 sampling was conducted using a 1,000-micron mesh Surber sampler. Both the EMAP manual and the DWQ manual specify using a 500-micron kick net. In a comparison of sample methodologies, Lenz and Miller (1998) found that the mesh size used in sample nets affected the macroinvertebrate community structure indicated by the samples. Specifically, samples taken using nets with larger mesh sizes had fewer taxa than samples taken with smaller mesh sized nets. Species and genera richness were also lower in samples collected using nets with larger mesh sizes. The differences in community structure also led to variation in several indices, such as percentage EPT and ratio of scrapers to collectors. However, water quality indices that are based on environmental tolerance values were not affected by the differences in community structure (Lenz and Miller 1998). Although mesh size does not affect the current results pertaining to spatial variability and possible impacts (as all sites were sampled using the same equipment and methods), the reduced abundance and richness noted in the September 2009 samples may be due to the use of a larger mesh size net. As a result, it seems reasonable at this time to change to a 500-micron mesh kick net. This would allow for better assessment of overall stream health relevant to other streams, and many of the water quality indices used in this report would be comparable. In addition, use of a kick net would allow more sampling flexibility, particularly in slow water habitats.

The September 2009 samples were collected from multiple habitat types in each reach. This allows for a good general assessment of stream health relative to other streams. However, since the habitat types varied somewhat between each reach, the comparison of data between sites may not be as robust as if the same habitat types were sampled within each reach. As a result, JBR recommends that future sampling include both a composite reach-wide sample at each site (using the same methodology described here), as well as a targeted riffle sample at each site. The targeted riffle sample would be collected following EMAP methodology, which collects eight samples from four different riffles in each reach. The eight samples are then combined into a composite sample that is sent to the lab for analysis. Taking both samples at each site would allow for a better comparison among sites and a better assessment of impacts, while still allowing for an overall assessment of stream health that can be compared to other areas on the Manti-La Sal National Forest.

7.0 Summary and Conclusions

In September 2009, benthic macroinvertebrate samples were collected from three reaches of Crandall Creek. One reach was located upstream of Genwal's Crandall Canyon Mine groundwater discharge, which has become iron-laden in recent months. The other two reaches were located downstream of the discharge. One of the primary goals of the study was to determine whether the elevated iron concentrations have impacted Crandall Creek's macroinvertebrate population. Macroinvertebrate community composition at these three reaches was determined by taxonomic identification of the organisms collected during the September sampling, and numerous indices and metrics were calculated for ease in interpreting results.

Overall, the study results indicate that the Crandall Creek macroinvertebrate community downstream of the mine's discharge has been negatively impacted. Further, results indicate that the impact has not been confined to immediately downstream of the discharge; instead it has occurred as far down as the lowermost sampled site near the mouth of Crandall Creek. However, both downstream reaches of the creek are still supporting a variety of macroinvertebrates, indicating that the discharge has not rendered the stream sterile. Last, the study results indicated that even Crandall Creek upstream of the mine discharge is in less than optimum condition, based on the sampled macroinvertebrate community.

Although there are some historical data for macroinvertebrates in Crandall Creek, these data were of limited use to assess temporal changes. However, those data generally supported the conclusions derived from the analysis of the 2009 data set.

Future sampling will provide additional data, which will be used to assess continued impact or recovery as the iron-laded discharge is treated. Recommendations have been made to refine the sampling methodology so as to enhance the ability to assess both spatial and temporal trends.

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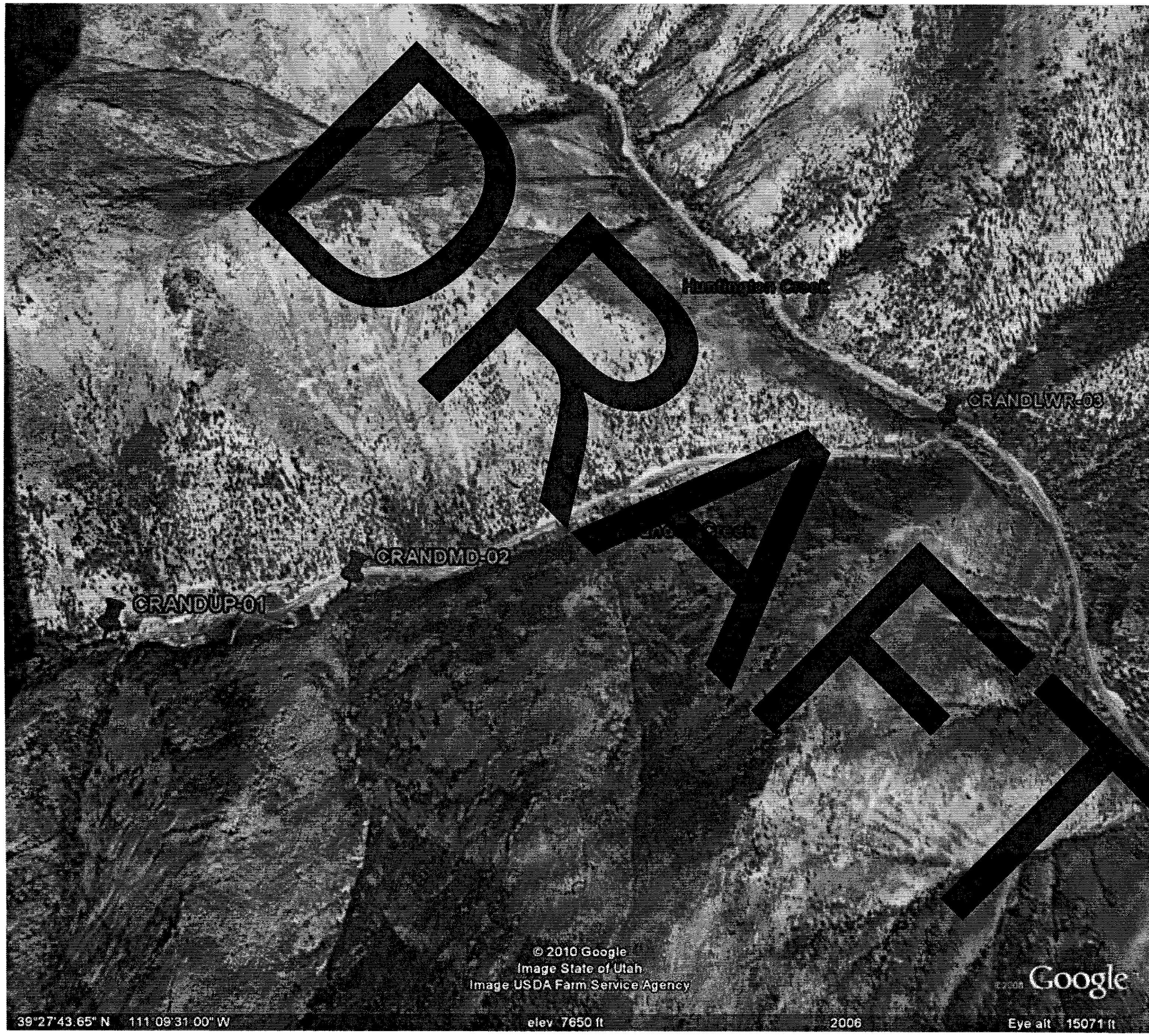

Figure 1
Sampling Locations

APPENDIX 1
BUGLAB REPORT

Aquatic invertebrate report for samples collected by JBR Environmental Consultants

Report prepared for:
Dave Kikkert
JBR Environmental Consultants
8160 S. Highland Drive

Report prepared by:
Scott Miller
U.S.D.I. Bureau of Land Management
National Aquatic Monitoring Center
Department of Watershed & Sciences
5210 Old Main Hill
Utah State University

16 October 2009

Sampling Locations

Table 1. Sampling site locations

Station	Location	Latitude	Longitude	Elevation (meters)
CRANDLWR-03	Crandall Creek, Lower, Emery County, Utah	39.464	-111.146	2363
CRANDMD-02	Crandall Creek, Middle, Emery County, Utah	39.460	-111.165	2384
CRANDUP-01	Crandall Creek, Upstream, Emery County, Utah	39.460	-111.168	2389

Methods

Field sampling

Samples were collected on September 16, 2009 (Table 2). Aquatic invertebrates were collected quantitatively from riffle habitats with a Surber net with a 1000 micron mesh net.

Laboratory methods

General procedures for processing invertebrate samples were similar to those recommended by the United States Geological Survey (Cuffney et al. 1993) and are described in greater detail and rationalized in Vinson and Hawkins (1996). Samples were sub-sampled if the sample appeared to contain more than 600 organisms. Sub-samples were obtained by pouring the sample into an appropriate diameter 500 micron sieve, floating this material by placing the sieve within an enamel pan partially filled with water and leveling the material within the sieve. The sieve was then removed from the water pan and the material within the sieve was divided into two equal parts. One half of the sieve was then randomly chosen to be processed and the other half set aside. The sieve was then placed back in the enamel pan and the material in the sieve again leveled and split in half. This process was repeated until approximately 600 organisms remained in one-half of the sieve. This material was placed into a Petri dish and all organisms were removed under a dissecting microscope at 10-30 power. Additional sub-samples were taken until at least 600 organisms were removed, All organisms within a sub-sample were removed, and separated into taxonomic Orders. When the sorting of the sub-samples was completed, the entire sample was spread throughout a large white enamel pan and searched for 10 minutes to remove any taxa that might not have been picked up during the initial sample sorting process. The objective of this "big/rare" search was to provide a more complete taxa list by finding rarer taxa that may have been excluded during the sub-sampling process. These rarer bugs were placed into a separate vial and the data entered separately from the bugs removed during the sub-sampling process. All the organisms removed during the sorting process were then identified using appropriate identification keys (see literature cited list for list of taxonomic resources used). Once the data had been entered into a computer and checked, the unsorted portion of the sample was discarded. The identified portion of the sample was placed in a 20 ml glass scintillation vial with polypropylene lids in 70% ethanol, given a catalog number, and retained. In this report, metrics were calculated using data from the sub-sampled and big/rare portions of the sample. Abundance data are presented as the estimated number of individuals per square meter for quantitative samples and the estimated number per sample for qualitative samples.

Table 2. Field comments and laboratory processing information.

Sample	Station	Sampling Date	Habitat Sampled	Sampling Method	Sampling Area Sqmts	% of sample processed	Number of individuals identified	Field Comments
141394	CRANDUP-01	09/16/2009	Multiple	Surber net	0.46	100	369	
141395	CRANDMD-02	09/16/2009	Multiple	Surber net	0.46	100	275	
141396	CRANDLWR-03	09/16/2009	Multiple	Surber net	0.46	100	274	

Data summarization

A number of metrics or ecological summaries can be calculated from an aquatic invertebrate sample. A summary and description of commonly used metrics is available in Barbour et al. (1999, http://www.epa.gov/owow/monitoring/rbp/index.html#Table%20of%20Contents) and Karr and Chu (1998). Both of these publications suggest use of the following metrics for assessing the health of aquatic invertebrate assemblages: Total taxa richness, EPT taxa richness, Ephemeroptera taxa richness, Plecoptera taxa richness, Trichoptera taxa richness, % EPT abundance, % Ephemeroptera abundance, % Chironomidae abundance, Intolerant taxa richness, % tolerant organisms, Hilsenhoff Biotic Index, % contribution of the dominant taxon, clinger taxa richness, % clinger abundance, % collector-filterer abundance, and the % scraper abundance. Assessments are best made by comparing samples to samples collected similarly at reference sites or from samples collected prior to impacts or management actions at a location. In this report, the following metrics were calculated for each sample.

Taxa richness - Richness is a component and estimate of community structure and stream health based on the number of distinct taxa. Taxa richness normally decreases with decreasing water quality. In some situations organic enrichment can cause an increase in the number of pollution tolerant taxa. Taxa richness was calculated for operational taxonomic units (OTUs) and the number of unique genera, and families. The values for operational taxonomic units may be overestimates of the true taxa richness at a site if individuals were the same taxon as those identified to lower taxonomic levels or they may be underestimates of the true taxa richness if multiple taxa were present within a larger taxonomic grouping but were not identified. All individuals within all samples were generally identified similarly, so that comparisons in operational taxonomic richness among samples within this dataset are appropriate, but comparisons to other data sets may not. Comparisons to other datasets should be made at the genera or family level.

Abundance - The abundance, density, or number of aquatic macroinvertebrates per unit area is an indicator of habitat availability and fish food abundance. Abundance may be reduced or increased depending on the type of impact or pollutant. Increased organic enrichment typically causes large increases in abundance of pollution tolerant taxa. High flows, increases in fine sediment, or the presence of toxic substances normally cause a decrease in invertebrate abundance. Invertebrate abundance is presented as the number of individuals per square meter for quantitative samples and the number of individuals collected in each sample for qualitative samples.

EPT - A summary of the taxonomic richness and abundance within the insect Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). These orders are commonly considered sensitive to pollution (Karr and Chu 1998).

Percent contribution of the dominant family or taxon - An assemblage largely dominated (>50%) by a single taxon or several taxa from the same family suggests environmental stress. Habitat conditions likely limit the number of taxa that can occur at the site.

Shannon diversity index - Ecological diversity is a measure of community structure defined by the relationship between the number of distinct taxa and their relative abundances. The Shannon diversity index was calculated for each sampling location for which there were a sufficient number of individuals and taxa collected to perform the calculations. The calculations were made following Ludwig and Reynolds (1988, equation 8.9, page 92).

Evenness - Evenness is a measure of the distribution of taxa within a community. The evenness index used in this report was calculated following Ludwig and Reynolds (1988, equation 8.15, page 94). Value ranges from 0-1 and approach zero as a single taxa becomes more dominant.

Clinger taxa - The number of clinger taxa have been found by Karr and Chu (1998) to respond negatively to human disturbance. Clinger taxa were determined using information in Merritt et al. (2008). These taxa typically cling to the tops of rocks and are thought to be reduced by sedimentation or abundant algal growths.

Long-live taxa - The number of long-lived taxa was calculated the number of taxa collected that typically have 2-3 year life cycles. Disturbances and water quality and habitat impairment typically reduces the number of long-lived taxa Karr and Chu (1998). Life-cycle length determinations were based on information in Merritt et al. (2008).

Biotic indices - Biotic indices use the indicator taxa concept. Taxa are assigned water quality tolerance values based on their tolerance to pollution. Scores are typically weighted by taxa relative abundance. In the United States the most commonly used biotic index is the Hilsenhoff Biotic Index (Hilsenhoff 1987, Hilsenhoff 1988). The USFS and BLM throughout the western United States have also frequently used the USFS Community Tolerance Quotient.

Hilsenhoff biotic index - The Hilsenhoff Biotic Index (HBI) summarizes the overall pollution tolerances of the taxa collected. This index has been used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts. It is best at detecting organic pollution. Families were assigned an index value from 0- taxa normally found only in high quality unpolluted water, to 10- taxa found only in severely polluted waters. Family level values were taken from Hilsenhoff (1987, 1988) and a family level HBI was calculated for each sampling location for which there were a sufficient number of individuals and taxa collected to perform the calculations. Sampling locations with HBI values of 0-2 are considered clean, 2-4 slightly enriched, 4-7 enriched, and 7-10 polluted. Rather than using mean HBI values for a sample, taxon HBI values can also be used to determine the number of pollution intolerant and tolerant taxa occurring at a site. In this report, taxa with HBI values $\leq$1 were considered intolerant clean water taxa and taxa with HBI values $\geq$9 were considered pollution tolerant taxa. The number of tolerant and intolerant taxa and the abundances of tolerant and intolerant taxa were calculated for each sampling location.

USFS community tolerant quotient - Taxa are assigned a tolerant quotient (TQ) from 2 - taxa found only in high quality unpolluted water, to 108 - taxa found in severely polluted waters. TQ values were developed by Winget and Mangum (1979). The dominance weighted community tolerance quotient (CTQd) was calculated. Values can vary from about 20 to 100, in general the lower the value the better the water quality.

Functional feeding group measures - A common classification scheme for aquatic macroinvertebrates is to categorize them by feeding acquisition mechanisms. Categories are based on food particle size and food location, e.g., suspended in the water column, deposited in sediments, leaf litter, or live prey. This classification system reflects the major source of the resource, either within the stream itself or from riparian or upland areas and the primary location, either erosional or depositional habitats. The number of taxa and individuals of the following feeding groups were calculated for each sampling location. Functional feeding group designations were from Merritt et al. (2008).

Shredders - Shredders use both living vascular hydrophytes and decomposing vascular plant tissue - coarse particulate organic matter. Shredders are sensitive to changes in riparian vegetation. Shredders can be good indicators of toxicants that adhere to organic matter.

Scrapers - Scrapers feed on periphyton - attached algae and associated material. Scraper populations increase with increasing abundance of diatoms and can decrease as filamentous algae, mosses, and vascular plants increase, often in response to increases in nitrogen and phosphorus. Scrapers decrease in relative abundance in response to sedimentation and higher levels of organic pollution or nutrient enrichment.

Collector-filterers - Collector-filterers feed on suspended fine particulate organic matter. Collector-filterers are sensitive to toxicants in the water column and to pollutants that adhere to organic matter.

Collector-gatherers - Collector-gatherers feed on deposited fine particulate organic matter. Collector-gatherers are sensitive to deposited toxicants.

Predators - Predators feed on living animal tissue. Predators typically make up about 25% of the assemblage in stream environments and 50% of the assemblage in still-water environments.

Unknown feeding group - This category includes taxa that are highly variable, parasites, and those that for which the primary feeding mode is currently unknown.

Results

Abundance data and taxa richness are reported as the estimated number of individuals per square meter for quantitative samples and the number per sample for qualitative samples. NC = Not calculated. * = unable to calculate. EPT = totals for the insect orders, Ephemeroptera, Plecoptera, Trichoptera. QL = qualitative sample.

Sample	Sampling date	Station	Total abundance	EPT abundance	Dominant family	% contribution dominant family
141394	09/16/2009	CRANDUP-01	794	217	Psychodidae	25.18
141395	09/16/2009	CRANDMD-02	592	133	Chironomidae	36.32
141396	09/16/2009	CRANDLWR-03	590	194	Baetidae	25.94
Mean			658.7	181.3		29.14

Diversity indices

Sample	Sampling Date	Station	Total taxa richness	Total genera richness	Total family richness	EPT taxa richness	Shannon diversity index	Evenness
141394	09/16/2009	CRANDUP-01	40	22	23	16	2.780	0.750
141395	09/16/2009	CRANDMD-02	32	20	20	11	2.540	0.730
141396	09/16/2009	CRANDLWR-03	28	12	17	10	2.500	0.750
Mean			33.3	18.0	20.0	12.3	2.610	0.750

Genera richness by major taxonomic group.

Sample	Sampling Date	Station	Coleoptera	Diptera	Ephemerotpera	Heteroptera	Megaloptera	Odonata	Plecoptera	Trichoptera	Annelida	Custacea	Mollusca
141394	09/16/2009	CRANDUP-01	1	18	5	0	0	0	6	5	1	0	1
141395	09/16/2009	CRANDMD-02	2	14	1	0	0	0	6	4	1	0	1
141396	09/16/2009	CRANDLWR-0	1	15	3	0	0	0	4	3	1	0	1
Mean			**1.3**	**15.7**	**3.0**	**0.0**	**0.0**	0.0	**5.3**	**4.0**	1.0	**0.0**	**1.0**

Total abundance by major taxonomic group.

Sample	Sampling Date	Station	Coleoptera	Diptera	Ephemerotpera	Heteroptera	Megaloptera	Odonata	Plecoptera	Trichoptera	Annelida	Custacea	Mollusca
141394	09/16/2009	CRANDUP-01	2	549	95	0	0	0	65	58	2	0	2
141395	09/16/2009	CRANDMD-02	13	297	41	0	0	0	58	34	6	0	116
141396	09/16/2009	CRANDLWR-0 3	9	329	155	0	0	0	32	6	22	0	37
Mean			8.0	391.7	97.0	0.0	0.0	0.0	51.7	32.7	10.0	0.0	51.7

Biotic Indices

Sample	Sampling date	Station	Hilsenhoff Biotic Index		USFS Community CTQd
			Index	Indication	
141394	09/16/2009	CRANDUP-01	5.28	Some organic pollution	71
141395	09/16/2009	CRANDMD-02	3.56	Possible slight organic pollution	78
141396	09/16/2009	CRANDLWR-03	3.82	Possible slight organic pollution	79
Mean			4.22		76.0

Taxa richness and relative abundance values with respect to tolerance or intolerance to pollution were based on the Hilsenhoff Biotic Index (HBI). Intolerant taxa have HBI score <= 1. Tolerant taxa have a HBI score >= 9. Data are presented as estimated count per square meter for quantitative samples and total number per sample for qualitative samples.

Sample	Sampling date	Station	Intolerant taxa				Tolerant Taxa			
			Richness		Abundance		Richness		Abundance	
141394	09/16/2009	CRANDUP-01	11	(28)	136	(17)	1	(3)	200	(25)
141395	09/16/2009	CRANDMD-02	8	(25)	75	(13)	1	(3)	4	(1)
141396	09/16/2009	CRANDLWR-0	5	(18)	34	(6)	1	(4)	2	(0)
Mean			8.0	(23)	81.7	(12)	1.0	(3)	68.7	(9)

Functional feeding groups

Taxa richness by functional feeding group. The percent of the total is shown in parentheses.

Sample	Sampling date	Station	Shredders		Scrapers		Collector-filterers		Collector-gatherers		Predators		Unknown	
141394	09/16/2009	CRANDUP-01	7	(18)	1	(3)	5	(13)	11	(28)	14	(35)	1	(3)
141395	09/16/2009	CRANDMD-02	6	(19)	1	(3)	2	(6)	8	(25)	14	(44)	1	(3)
141396	09/16/2009	CRANDLWR-0	3	(11)	0	(0)	4	(14)	7	(25)	10	(36)	4	(14)
Mean			5.3	(16)	0.7	(2)	3.7	(11)	8.7	(26)	12.7	(38)	2.0	(7)

Invertebrate abundance by functional feed group. The percent of the total is shown in parentheses.

Sample	Sampling date	Station	Shredders		Scrapers		Collector-filterers		Collector-gatherers		Predators		Unknown	
141394	09/16/2009	CRANDUP-01	125	(16)	6	(1)	26	(3)	489	(62)	144	(18)	2	(0)
141395	09/16/2009	CRANDMD-02	32	(5)	2	(0)	131	(22)	276	(47)	140	(24)	11	(2)
141396	09/16/2009	CRANDLWR-0	19	(3)	0	(0)	62	(11)	385	(65)	108	(18)	15	(3)
Mean			58.7	(8)	2.7	(0)	73.0	(12)	383.3	(58)	130.7	(20)	9.3	(2)

The 10 metrics thought to be most responsive to human induced disturbance (Karr and Chu 1998).

Sample	Sampling Date	Station	Total taxa	Ephemeroptera taxa	Plecoptera taxa	Trichoptera taxa	Long-lived taxa	Intolerant taxa	Clinger taxa	% tolerant individuals	% contribution dominant taxon	% predators
141394	09/16/2009	CRANDUP-01	40	2	3	4	2	11	9	25.18	25.18	18.13
141395	09/16/2009	CRANDMD-02	32	1	4	3	3	8	6	0.68	31.25	23.65
141396	09/16/2009	CRANDLWR-03	28	1	1	0	1	5	5	0.34	24.07	18.31
Mean			33.3	1.3	2.7	2.3	2.0	8.0	6.7	8.73	26.83	20.03

Taxonomic list and counts for 3 samples collected on September 16, 2009. Count is the total number of individuals identified and retained. Samples heading refers to the number of samples contain that taxon.

Order	Family	Subfamily/Genus/Species	Samples	Count
Phylum: Annelida				
Class: Clitellata	SubClass: Oligochaeta			
			3	14
Phylum: Arthropoda				
Class: Arachnida	SubClass: Acari			
Trombidiformes	Hydryphantidae	Protzia	1	1
Trombidiformes	Lebertiidae	Lebertia	2	13
Trombidiformes	Sperchonidae	Sperchon	2	7
Class: Insecta	SubClass: Pterygota			
Coleoptera	Dryopidae	Postelichus	1	1
Coleoptera	Elmidae	Narpus concolor	2	9
Coleoptera	Elmidae	Optioservus	1	1
Diptera			1	1
Diptera	Ceratopogonidae		1	1
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	3	16
Diptera	Chironomidae		3	19
Diptera	Chironomidae	Chironominae	2	14
Diptera	Chironomidae	Orthocladiinae	3	201
Diptera	Empididae		3	4
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	3	26
Diptera	Muscidae		3	9
Diptera	Psychodidae	Pericoma	3	96
Diptera	Simuliidae	Simuliinae Simuliini Simulium	2	17
Diptera	Simuliidae	Simuliinae Simuliini Simulium arcticum group	1	1
Diptera	Simuliidae	Simuliinae Simuliini Simulium tuberosum	1	2
Diptera	Stratiomyidae	Caloparyphus	1	2
Diptera	Stratiomyidae	Euparyphus	2	4
Diptera	Tabanidae		1	1
Diptera	Tipulidae		1	2
Diptera	Tipulidae	Dicranota	3	17
Diptera	Tipulidae	Hexatoma	2	7
Diptera	Tipulidae	Limoniinae Antocha monticola	2	42
Diptera	Tipulidae	Limoniinae Eriopterini Ormosia	1	17
Diptera	Tipulidae	Limoniinae Hexatomini Limnophila	1	11
Diptera	Tipulidae	Pedicia	1	1
Diptera	Tipulidae	Tipulinae Tipula	3	35
Ephemeroptera			1	1
Ephemeroptera	Baetidae		1	5
Ephemeroptera	Baetidae	Baetis	3	112
Ephemeroptera	Ephemerellidae		1	3
Ephemeroptera	Ephemerellidae	Drunella grandis	1	6
Ephemeroptera	Heptageniidae		1	3
Ephemeroptera	Leptophlebiidae		1	5
Plecoptera	Capniidae	Capniinae	3	5
Plecoptera	Chloroperlidae		1	1
Plecoptera	Nemouridae		1	6
Plecoptera	Nemouridae	Amphinemurinae Amphinemura	1	1

Plecoptera	Nemouridae	Zapada cinctipes	2	7
Plecoptera	Nemouridae	Zapada oregonensis group	2	18
Plecoptera	Perlodidae		3	22
Plecoptera	Perlodidae	Isoperlinae Isoperla	2	7
Plecoptera	Perlodidae	Megarcys signata	1	5
Trichoptera			1	1
Trichoptera	Brachycentridae		1	1
Trichoptera	Hydropsychidae		1	1
Trichoptera	Hydropsychidae	Arctopsychinae Parapsyche	2	8
Trichoptera	Limnephilidae		2	7
Trichoptera	Limnephilidae	Limnephilinae Limnephilini Hesperophylax	1	1
Trichoptera	Rhyacophilidae	Rhyacophila	2	7
Trichoptera	Rhyacophilidae	Rhyacophila vofixa group	2	20
Phylum: Mollusca				
Class: Bivalvia	SubClass: Heterodonta			
Veneroida	Pisidiidae	Pisidiinae Pisidium	3	72
Phylum: Nemata				
Class:	SubClass:			
			1	1

Total: OTU Taxa : **57** Genera : **33** Families : **28** Individuals : **918**

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Taxa Lists for Individual Samples

Taxonomic list and densities of aquatic invertebrates identified and retained from a sample collected September 16, 2009 at station CRANDUP-01, Crandall Creek, Upstream, Emery county, Utah. The sample was collected from multiple habitat using a surber net. The total area sampled was 0.465 square meters. The percentage of the sample that was identified and retained was 100% of the collected sample. A total of 369 individuals were removed, identified and retained. The sample identification number is 141394. OTU=operational taxonomic unit. Notes - identification to genus or species was not spported because: I - immature organisms, D- damaged organisms, M - poor slide mount, G - gender, U - indistint characters or distribution, R - retained in our reference collection.

Order	Family	Subfamily/Genus/Species	Life Stage	Density	Notes
Phylum: Annelida					
Class: Clitellata		SubClass: Oligochaeta			
			adult	2.15	
Phylum: Arthropoda					
Class: Arachnida		SubClass: Acari			
Trombidiformes	Lebertiidae	Lebertia	adult	10.76	
Trombidiformes	Sperchonidae	Sperchon	adult	8.61	
Class: Insecta		SubClass: Pterygota			
Coleoptera	Dryopidae	Postelichus	adult	2.15	
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	larvae	12.92	
Diptera	Chironomidae		pupae	19.37	
Diptera	Chironomidae	Chironominae	larvae	10.76	
Diptera	Chironomidae	Orthocladiinae	larvae	137.78	
Diptera	Empididae		pupae	2.15	
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	larvae	6.46	
Diptera	Muscidae		larvae	6.46	
Diptera	Psychodidae	Pericoma	larvae	200.21	
Diptera	Simuliidae	Simuliinae Simuliini Simulium	larvae	15.07	
Diptera	Simuliidae	Simuliinae Simuliini Simulium arcticum group	pupae	2.15	
Diptera	Simuliidae	Simuliinae Simuliini Simulium tuberosum group	pupae	4.31	
Diptera	Stratiomyidae	Euparyphus	larvae	4.31	
Diptera	Tipulidae	Dicranota	larvae	2.15	
Diptera	Tipulidae	Limoniinae Antocha monticola	larvae	2.15	
Diptera	Tipulidae	Limoniinae Eriopterini Ormosia	larvae	36.60	
Diptera	Tipulidae	Limoniinae Hexatomini Limnophila	larvae	23.68	
Diptera	Tipulidae	Pedicia	larvae	2.15	
Diptera	Tipulidae	Tipulinae Tipula	larvae	60.28	
Ephemeroptera	Baetidae	Baetis	larvae	58.12	
Ephemeroptera	Ephemerellidae		larvae	6.46	I
Ephemeroptera	Ephemerellidae	Drunella grandis	larvae	12.92	
Ephemeroptera	Heptageniidae		larvae	6.46	D
Ephemeroptera	Leptophlebiidae		larvae	10.76	D
Plecoptera	Capniidae	Capniinae	larvae	4.31	I
Plecoptera	Nemouridae		larvae	12.92	D
Plecoptera	Nemouridae	Zapada cinctipes	larvae	2.15	
Plecoptera	Nemouridae	Zapada oregonensis group	larvae	30.14	
Plecoptera	Perlodidae		larvae	4.31	D,I
Plecoptera	Perlodidae	Megarcys signata	larvae	10.76	
Trichoptera	Hydropsychidae	Arctopsychinae Parapsyche	larvae	2.15	
Trichoptera	Limnephilidae		pupae	6.46	
Trichoptera	Limnephilidae	Limnephilinae Limnephilini Hesperophylax	larvae	2.15	
Trichoptera	Rhyacophilidae	Rhyacophila	larvae	10.76	I
Trichoptera	Rhyacophilidae	Rhyacophila vofixa group	larvae	30.14	
Phylum: Mollusca					
Class: Bivalvia		SubClass: Heterodonta			

Veneroida	Pisidiidae	Pisidiinae Pisidium		adult	2.15
Phylum: Nemata					
Class:		SubClass:			
				adult	2.15

Total:	OTU Taxa : **40**	Genera : **26**	Families : **23**	794.36

Taxonomic list and densities of aquatic invertebrates identified and retained from a sample collected September 16, 2009 at station CRANDMD-02, Crandall Creek, Middle, Emery county, Utah. The sample was collected from multiple habitat using a surber net. The total area sampled was 0.465 square meters. The percentage of the sample that was identified and retained was 100% of the collected sample. A total of 275 individuals were removed, identified and retained. The sample identification number is 141395. OTU=operational taxonomic unit. Notes - identification to genus or species was not spported because: I - immature organisms, D- damaged organisms, M - poor slide mount, G - gender, U - indistint characters or distribution, R - retained in our reference collection.

Order	Family	Subfamily/Genus/Species	Life Stage	Density	Notes
Phylum: Annelida					
Class: Clitellata		SubClass: Oligochaeta			
			larvae	6.46	
Phylum: Arthropoda					
Class: Arachnida		SubClass: Acari			
Trombidiformes	Hydryphantidae	Protzia	adult	2.15	
Trombidiformes	Lebertiidae	Lebertia	adult	17.22	
Trombidiformes	Sperchonidae	Sperchon	adult	6.46	
Class: Insecta		SubClass: Pterygota			
Coleoptera	Elmidae	Narpus concolor	larvae	10.76	
Coleoptera	Elmidae	Optioservus	larvae	2.15	
Diptera	Ceratopogonidae		larvae	2.15	
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	larvae	19.37	
Diptera	Chironomidae		pupae	10.76	
Diptera	Chironomidae	Chironominae	larvae	19.37	
Diptera	Chironomidae	Orthocladiinae	larvae	185.14	
Diptera	Empididae		pupae	2.15	
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	larvae	21.53	
Diptera	Muscidae		larvae	10.76	
Diptera	Psychodidae	Pericoma	larvae	4.31	
Diptera	Stratiomyidae	Caloparyphus	larvae	4.31	
Diptera	Stratiomyidae	Euparyphus	larvae	4.31	
Diptera	Tipulidae	Dicranota	larvae	6.46	
Diptera	Tipulidae	Hexatoma	larvae	2.15	
Diptera	Tipulidae	Tipulinae Tipula	larvae	4.31	
Ephemeroptera	Baetidae	Baetis	larvae	40.90	
Plecoptera	Capniidae	Capniinae	larvae	2.15	I
Plecoptera	Nemouridae	Amphinemurinae Amphinemura	larvae	2.15	
Plecoptera	Nemouridae	Zapada cinctipes	larvae	12.92	
Plecoptera	Nemouridae	Zapada oregonensis group	larvae	8.61	
Plecoptera	Perlodidae		larvae	19.37	I
Plecoptera	Perlodidae	Isoperlinae Isoperla	larvae	12.92	
Trichoptera	Hydropsychidae	Arctopsychinae Parapsyche	larvae	15.07	
Trichoptera	Limnephilidae		larvae	2.15	I
Trichoptera	Rhyacophilidae	Rhyacophila	larvae	4.31	I
Trichoptera	Rhyacophilidae	Rhyacophila vofixa group	larvae	12.92	
Phylum: Mollusca					
Class: Bivalvia		SubClass: Heterodonta			
Veneroida	Pisidiidae	Pisidiinae Pisidium	adult	116.25	
Total: OTU Taxa : **32**		Genera : **22**	Families : **20**	592.00	

Taxonomic list and densities of aquatic invertebrates identified and retained from a sample collected September 16, 2009 at station CRANDLWR-03, Crandall Creek, Lower, Emery county, Utah. The sample was collected from multiple habitat using a surber net. The total area sampled was 0.465 square meters. The percentage of the sample that was identified and retained was 100% of the collected sample. A total of 274 individuals were removed, identified and retained. The sample identification number is 141396. OTU=operational taxonomic unit. Notes - identification to genus or species was not spported because: I - immature organisms, D- damaged organisms, M - poor slide mount, G - gender, U - indistint characters or distribution, R - retained in our reference collection.

Order	Family	Subfamily/Genus/Species	Life Stage	Density	Notes
Phylum: Annelida					
Class: Clitellata		SubClass: Oligochaeta			
			adult	21.53	approximate
Phylum: Arthropoda					
Class: Insecta		SubClass: Pterygota			
Coleoptera	Elmidae	Narpus concolor	larvae	8.61	
Diptera			larvae	2.15	I
Diptera	Ceratopogonidae	Ceratopogoninae Sphaeromiini Probezzia	larvae	2.15	
Diptera	Chironomidae		pupae	10.76	
Diptera	Chironomidae	Orthocladiinae	larvae	109.79	
Diptera	Empididae		larvae	2.15	I
Diptera	Empididae	Hemerodromiinae Hemerodromiini Chelifera	larvae	27.99	
Diptera	Muscidae		larvae	2.15	
Diptera	Psychodidae	Pericoma	larvae	2.15	
Diptera	Simuliidae	Simuliinae Simuliini Simulium	pupae	10.76	
Diptera	Tabanidae		larvae	2.15	U
Diptera	Tipulidae		larvae	4.31	I,D
Diptera	Tipulidae	Dicranota	larvae	27.99	
Diptera	Tipulidae	Hexatoma	larvae	12.92	
Diptera	Tipulidae	Limoniinae Antocha monticola	larvae	88.26	
Diptera	Tipulidae	Tipulinae Tipula	larvae	10.76	
Ephemeroptera			adult	2.15	
Ephemeroptera	Baetidae		larvae	10.76	I,D
Ephemeroptera	Baetidae	Baetis	larvae	142.08	
Plecoptera	Capniidae	Capniinae	larvae	4.31	I
Plecoptera	Chloroperlidae		larvae	2.15	D
Plecoptera	Perlodidae		larvae	23.68	I
Plecoptera	Perlodidae	Isoperlinae Isoperla	larvae	2.15	
Trichoptera			pupae	2.15	D
Trichoptera	Brachycentridae		larvae	2.15	I
Trichoptera	Hydropsychidae		larvae	2.15	D
Phylum: Mollusca					
Class: Bivalvia		SubClass: Heterodonta			
Veneroida	Pisidiidae	Pisidiinae Pisidium	adult	36.60	

Total: OTU Taxa : **28** Genera : **12** Families : **17** 589.85

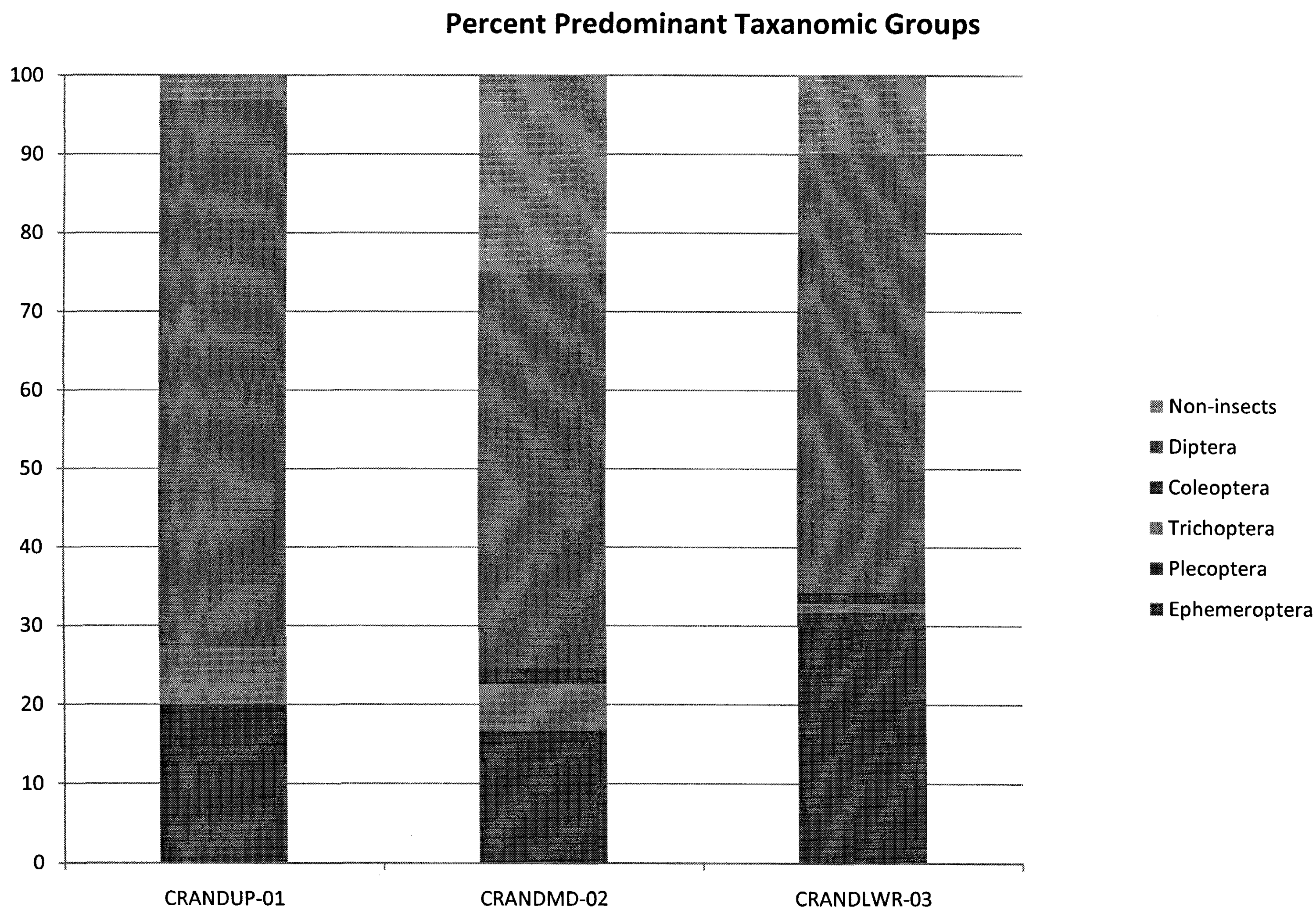
APPENDIX 2
MACROINVERTEBRATE METRICS

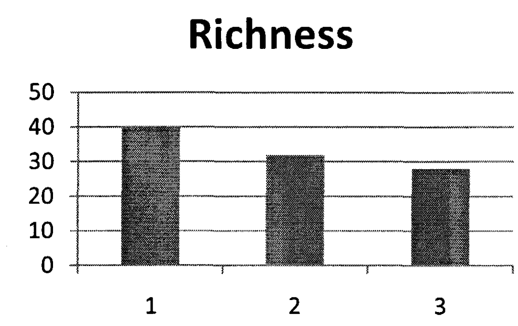
Notes:

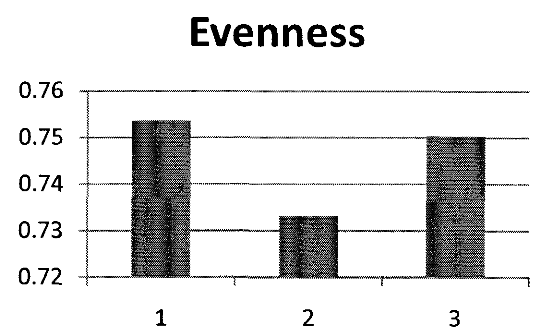
1. Most metrics were calculated by the National Aquatic Monitoring Center's BugLab and included in their October 16, 2009 report on the September 16 Crandall Creek samples. Remaining metrics were calculated by JBR Environmental Consultants using data contained in the BugLab's report.

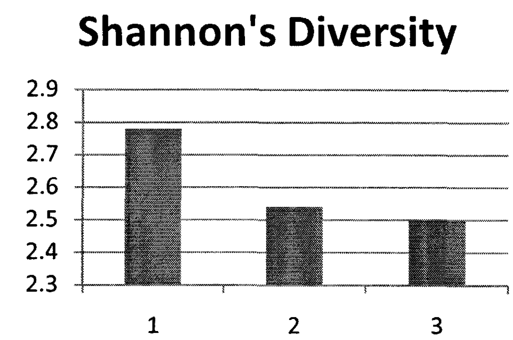
2. Samples designated on the graphs as 1, 2, and 3 represent sample sites CRANDUP-01, CRANDMD-02, and CRANDLWR-03, respectively.

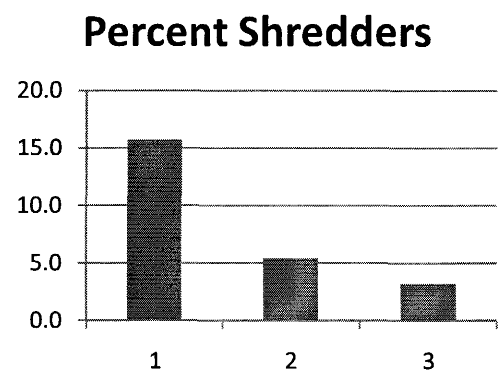
3. Graphs shown with blue bars represent metrics for which a decrease would be expected to occur with a decline in stream health. Graphs shown with green bars represent metrics for which an increase would be expected to occur with a decline in stream health.

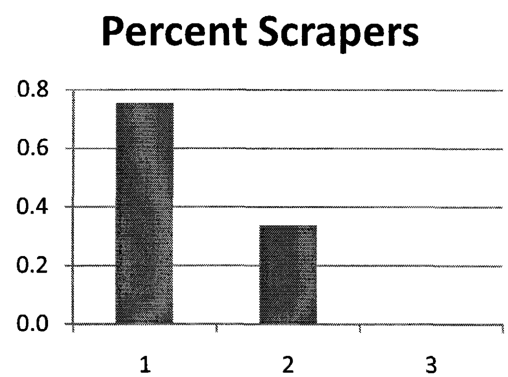

Percent Predominant Taxonomic Groups
100
90
80
70
60
50
40
30
20
10
0
CRANDUP-01
CRANDMD-02
CRANDLWR-03
Non-insects
Diptera
Coleoptera
Trichoptera
Plecoptera
Ephemeroptera

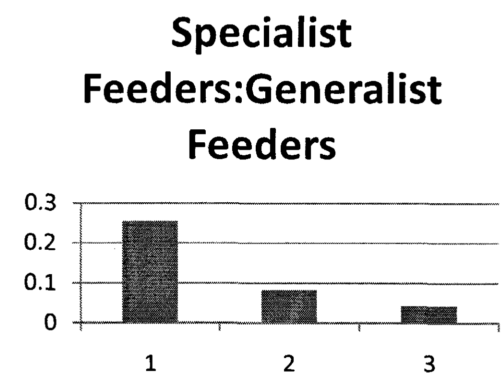


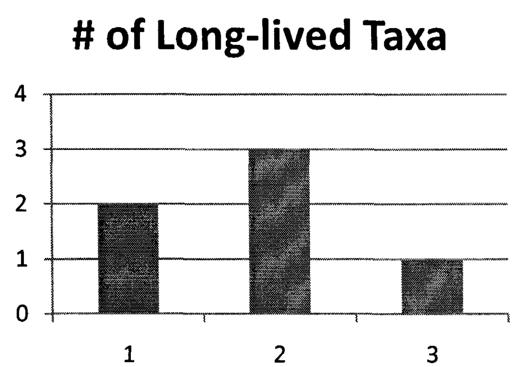


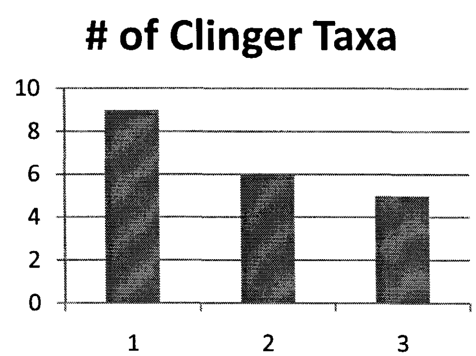


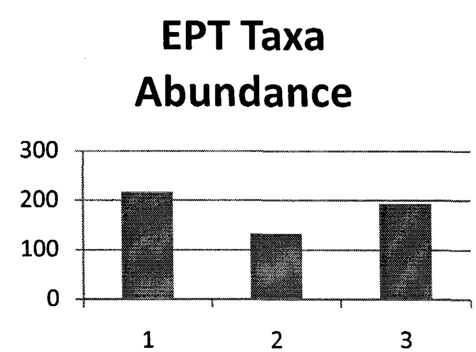




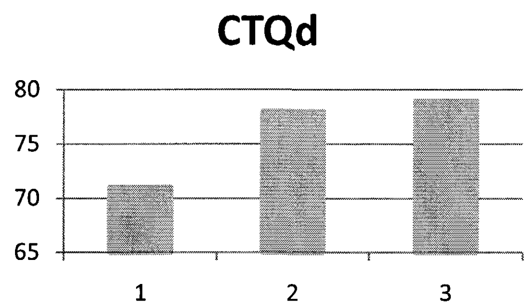


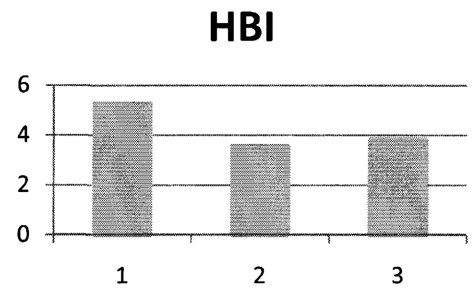


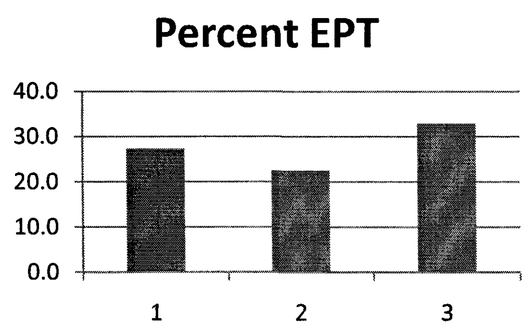


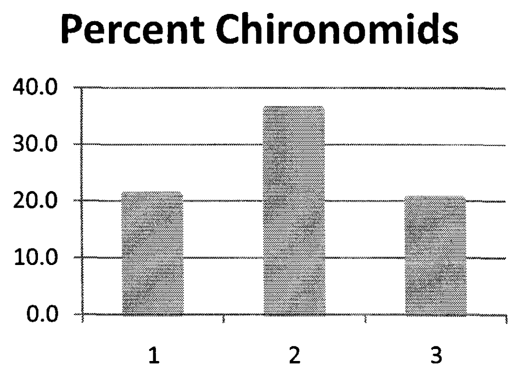


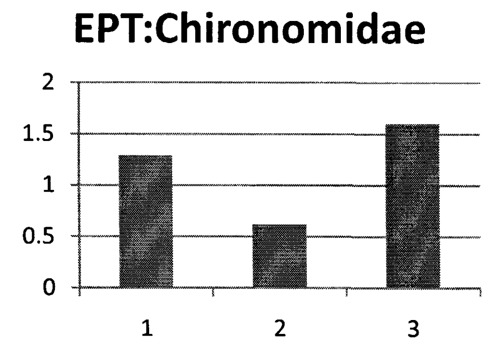
See notes on Page 1











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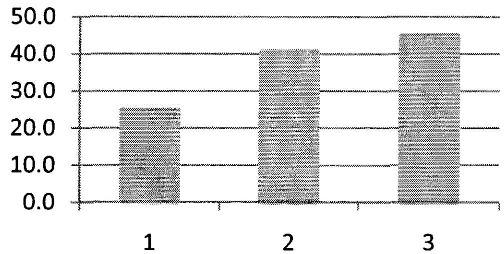
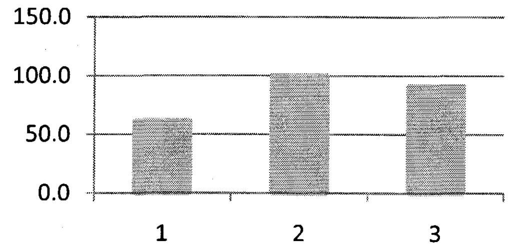
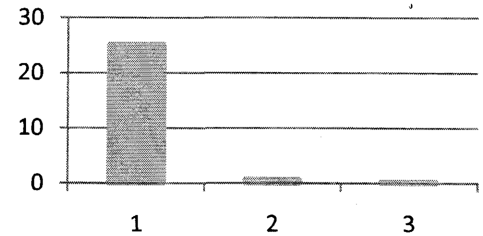
Percent Baetis, Hydropsychidae, & Orthocladiinae



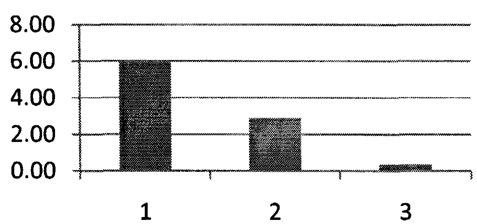
Baetis:All Ephemeroptera (Percent)



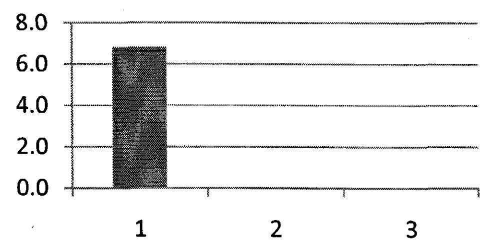
Percent Tolerant Organisms (HBI-based)



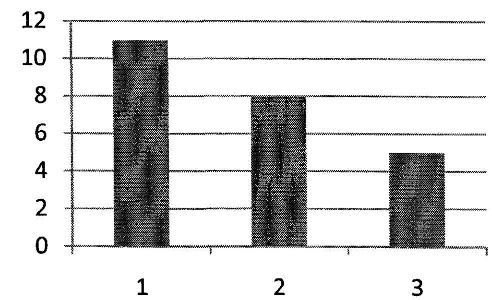
Percent Heptageniidae, Chloroperlidae, &...



Heptageniidae:All Ephemeroptera (Percent)



# of Intolerant Taxa (HBI-based)



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