# Forest Fire Effects on Benthic Invertebrate Populations

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**ABSTRACT**

The Walker Ranch fire just west of Boulder, Colorado, lasted from September $15^{th}$ to September $20^{th}$, 2000. The fire severely burned some slopes and created high erosion potential. Also, firefighting retardant, Fire-Trol LCA-R, was used to contain the fire. Sediment loading from erosion and the toxicity of the firefighting retardant can both have negative impacts on the stream biota. This study is an investigation of the effects on the benthic invertebrate population in the South Boulder Creek and an attempt to indicate the precise cause of the hypothesized negative impacts. Three sites along the stream were sampled: one upstream of the fire area, one within the fire zone and one slightly downstream of the fire zone. On November $4^{th}$, 2000, conductivity, pH, DO, temperature, DOC and flow were measured. Benthic invertebrates were collected with a Surber sampler and identified and counted. We found that site number 2, within the zone of the fire, had the smallest populations of benthic invertebrates. And site number 1, above the fire zone, had the greatest numbers of benthic invertebrates. Water quality measurements did not differ significantly six and one half weeks after the fire. Data is also compared with the City of Boulder's data from the last day of the fire. There are some similarities between the two sets of data. We conclude that the immediate effects of the fire or the entry of fire retardant into the South Boulder Creek are likely to have caused the smaller populations of benthic invertebrates within the area of the fire and downstream of the fire.

**INTRODUCTION**

Wildfire has several effects on an ecosystem. Fire can rejuvenate the forest allowing new growth of fire dependant plants and releasing otherwise unavailable nutrients. Invasive species are also removed by wildfire. Intense fire can also destroy habitat and push animals to find new areas. A fire can remove dense riparian growth, allowing more light to penetrate to a stream causing increased primary production. Intense fire can also strip the soil of vegetational support and humic and detrital matter limiting infiltration into the soil (Chandler, 1983). Overland flow is initiated by smaller rain events after a fire than before a fire. Overland flow picks-up sediment and soil causing erosion, which is carried through the watershed to the streams and lakes, causing increased turbidity and sedimentation.

Sedimentation and turbidity can adversely affect the benthic invertebrates in a stream. High turbidity can limit light penetration to algae, limiting growth and reducing the food supply to algae grazing benthic invertebrates. Sedimentation can have a similar effect by covering algae and substrate. Also sediment can fill spaces within the stones and cobbles, eliminating appropriate benthic habitat.

Firefighting efforts can also have an effect on the stream. Fire retardants are typically composed of ammonium salts with a thickening agent such as ammonium sulfate or ammonium polyphosphate with a attapulgite clay thickener or diammonium phosphate with a guargum derivative thickener (Gaikowski, 1996a). Fire retardants and foams help hold water in the material and/or alter the combustion properties of the material to induce charring instead of burning. Both compounds effectively reduce the fuel to the fire. The effectiveness of a fire retardant is a function of the concentration of salt applied per unit of surface area (Gaikowski, 1996a). The ammonium salt solution is more effective at higher concentrations. The high concentration of salts makes the retardants corrosive to storage containers. A corrosion inhibitor is necessary to store and transport the material. Typically, either sodium ferrocyanide, tolytriazol or sodium dichromate is used as an inhibitor. Ferric oxides are also added to color the slurry so the drop point can be marked. Occasionally retardants may be accidentally dropped over streams or runoff may transport the slurry into the streams.

Studies have shown that certain fire fighting retardants and fire suppressant foams are toxic to fish and macroinvertebrates (Buhl, 1998; McDonald, 1997; Gaikowski, 1996a, Gaikowski, 1996b). This group of studies determined 96 hour LC50 (lethal concentration for 50% of the population) of three retardants, -Fire-Trol LCG-R, Fire-Trol GTS-R, and Phos-Chek D75-F-, and two foams, -Phos-Chek WD-881 and Silv-EX-, on three fish species and one amphipod. The research on Rainbow Trout (Gaikowski, 1996a) and Chinook Salmon (Buhl, 1998) life stages showed that the two Fire-Trol compounds were the least toxic of those tested. The toxicity study on *Hyalella azteca*, a bottom dwelling amphipod, also showed the Fire-Trol compounds to be less toxic than the other formulations. The LC50 on the amphipod for Fire-Trol GTS-R was 127 mg/L in soft water and LC50 for Fire-Trol LCG-R was 535 mg/L in hard water (McDonald, 1997). The researchers indicated that an accidental drop into a stream could easily produce the toxic concentrations and, therefore, adversely affect the fish and invertebrate populations.

The aforementioned studies observed different effects of water hardness on toxicity of the retardants. Gaikowski (1996a) found greater toxicity to Rainbow trout in hard water than in soft water, while McDonald (1997) found that hard water lowered toxicity to the amphipod. There may be different mechanisms of toxicity to the different organisms. McDonald (1997) points out that fish appear to be more sensitive to ammonia concentrations than macroinvertebrates. The toxicity could be due to another component in the solution or a combination of components. In a stream setting McDonald (1997) suggests that the thickeners could accumulate on the stream bed substrate and potentially cause respiratory congestion and physically impair mobility of benthic organisms.

**The Walker Ranch Fire**

The recent Walker Ranch Fire, also referred to as the Eldorado Fire, located just west of Boulder, Colorado, burned 1,054 acres over 6 days from Friday, September 15$^{th}$ to Wednesday, September 20$^{th}$. Most of the affected area is on the Boulder County Open Space property called Walker Ranch. See figure 1 for a map of the burned area. The fire was contained by the actions of 500 people using 74 firefighting engines, 273,000 gallons of water, and 133,000 gallons of fire retardant (Anderson, 2000).

The aftermath left two main areas of concern in terms of aquatic biota. Fire retardant entered the South Boulder Creek by an accidental drop and the intense burn has caused high erosion potential. Dead fish sightings in South Boulder Creek were reported on the 3$^{rd}$ and 4$^{th}$ days of the fire (Regensberg, Sept.2000). The red fire retardant slurry was visible on the rocks along the creek. The Daily Camera reported that Denver Water Board was asked to release more water from Gross Reservoir to flush the retardant from the creek. This was done on the 4$^{th}$ evening of the fire (Regensberg, Sept. 2000).

Fire-Trol LCA-R was used to contain the Walker Ranch fire (personal communication with Mark Michelson of Jef-Co airfield). This is not one of the formulations tested in the previously mentioned studies. However, The Daily Camera cites a study by the U.S. Geological Survey that found the corrosion inhibitor, sodium ferrocyanide, and ammonia increase toxicity 100-fold when exposed to sunlight (Regensberg, Sept.2000). The City of Boulder monitored the cyanide levels in the creek following the fire. Low levels of cyanide were detected on the 20th of September. The creek was sampled again in October; cyanide was not detected in the second sampling (personal communication from Donna Scott of the City of Boulder). It is evident that many fish died because of the fire retardant, but the effects on the benthic invertebrates in the stream were not examined immediately during or after the fire.

Officials from the USDA Forest Service and Boulder County Open Space began working to reduce erosion by stabilizing the area and creating a re-vegetation plan for the severely burned slopes (Wohlberg, Sept.2000, Basin Web site, Dec.2000). Erosion can be a potential problem for up to 2 years. Large rain events soon after the fire are the main concern.

### Objective

The objective of this study was to determine the effects of both the fire and the firefighting efforts on the benthic invertebrate populations in the South Boulder Creek. Our hypothesis was that the changes caused by fire and the addition of fire retardant to the creek negatively impacted benthic invertebrate populations in the stream. Also, our intent was to gather data on water quality to indicate the causes of the expected decrease in populations, whether it be from the retardant or other water quality changes.

## PROJECT METHODS

### Field Plan

Coupled with the literature search presented above, we directly communicated via phone calls with the parties involved in the fire fighting and the burn area. We spoke with representatives of the USDA Forest Service, the primary party involved in fighting the fire; Boulder County Open Space department, the landowners of the burn area; and the Denver Water Board, owners of Gross Reservoir and its dam. Through the USDA Forest Service we were able to speak with the air tanker base that delivered the fire retardant and were given specific information on the fire retardant used on the Walker Ranch Fire.

With this important background information, we designed the field study to achieve our objective of evaluating the effects of the fire on benthic invertebrates in South Boulder Creek. First, we selected our sampling sites utilizing a map of the burn area, which is shown along with the field site locations in Figure 1. We chose one site upstream of the fire zone, which was less than one mile downstream of Gross Dam where County Road 77 (also called Gross Dam road) crosses South Boulder Creek. We wanted the second and third sites to be in the burn area and down stream of the burn area, respectively; however, we were not able to determine their exact locations until we were on site and could assess the accessibility of the stream in those areas.

**Figure 1**. Burn area with the locations of the three sampling sites along South Boulder Creek shown.


**Field Sampling**

The field sampling was performed on November 4, 2000. The primary metric of this field study was benthic-invertebrate abundance. Benthic invertebrates were sampled using a Surber Sampler. Surber Sampler sampling size is a 1 foot square area. We took two benthic-invertebrate samples at each of the three sites. We stored the benthic invertebrates in glass jars, to which we added ethanol for preservation. In the field we observed that the samples at Site 1 had the largest and most abundant insects of the three sites.

We were also interested in measuring general water quality parameters to determine if any differences could be detected between the three sites. Thus, at each of the sites we measured dissolved oxygen (DO), pH, conductivity, dissolved organic carbon (DOC), flow, and temperature. *In situ* we measured DO and temperature with a DO probe and flow with a pygmy meter. We also collected water samples in order to measure pH and conductivity in the lab. For DOC analysis, we filtered water into previously combusted amber bottles.

### Lab Analysis

On the same day the field samples were taken we measured pH with a pH meter and conductivity with a conductivity meter from the collected water samples. Within the next week, we identified and counted the benthic invertebrates using the book, *An Illustrated Guide to Mountain Stream Insects of Colorado*, and a stereoscope. We analyzed the filtered samples with a Total Organic Carbon Analyzer to determine DOC concentrations. Because the samples were filtered, the TOC reading gave only the DOC in the sample.

## RESULTS AND DISCUSSION

### Site Description

All three sampling sites were located in sections of the creek that ran through canyon like areas (steep, rocky, hillsides leading down to the creek bed). Site 1 was upstream of where the fire had occurred. Site 1 had the narrowest streambed of the three sites and the narrowest surrounding canyon walls. This site was likely to get the shortest number of sunlight hours per day. The streambed consisted of small to medium sized boulders. Where the stream widened and became shallower, still within the sampling site, small to medium rocks were intermixed with very course gravel. There was not an abundance of detrital material. The riparian vegetation consisted mostly of pine type conifers and some herbaceous shrubs.

Site 2 was at the most down stream point of the fire zone. At our sampling site a burnt tree was visible. This site was likely to have had most of the fire retardant and firefighting water runoff go through it. At site 2, the canyon opened up slightly. This area had slightly more herbaceous riparian vegetation and more detrital matter, in the form of sticks and old leaf litter, was found at this site. The stream bed was variable going from small to mid sized boulders in the narrow portion to medium sized rocks and course gravel in the wider shallower portions of the stream.

Site 3 was approximately ¾ mile further downstream of site 2. This site was likely to be affected by any mechanisms that affected site 2, but possibly to a milder degree due to the distance. Site 3 had the widest streambed and was most open to the sunlight. This area also had herbaceous shrubs as well as grasses along the stream banks. Similar to site 2 this area had detrital matter in the form of sticks and decayed leaf parts. This site was wider and had shallows on the river left where small rocks and sand to course gravel accumulated. The main channel was deeper and fast flowing with a medium to large boulders making up the streambed. Due to the depth of the stream at this site we were not able to calculate flow through this area.

There had not been any large rain events between the fire and the time of sampling. We believe that no extensive sediment runoff into stream had occurred based on rain amounts and observations of the surroundings. Therefore sedimentation in the stream was ruled out as a cause for any observed difference in benthic invertebrate abundance between the three sites.

**Benthic Invertebrates**

**Site 1:** There are five taxa and several caddisfly cases found from the Site 1. Quantities found for each taxa are shown in Table 1.

**Table 1.** Benthic-invertebrate abundance at Site 1.

| Taxa | Common Name | Quantity Oganisms/ 2ft$^2$ |
|---|---|---|
| Plecoptera: Perlidae | Stonefly | 9 |
| Diptera: Chironomidae | True Fly (Chironomids) | 19 |
| Ephemeroptera: Ephimerillidae | Mayfly | 10 |
| Ephermeroptera: Heptageniidae | Mayfly | 2 |
| Ephermeroptera: Baetidae | Mayfly | 3 |
| Caddisfly case | Trichoptera (cases) | 35 |
| **Total number of taxa found = 6, Total number of individuals = 43, Total number of caddisfly cases = 35** | | |

All observed caddisfly cases were empty cases; there were no live caddisflies found in any case. Chironomids were the most abundant living benthic invertebrate found, followed by mayflies and stoneflies.

**Site 2:** There were only two taxa besides caddisfly cases found at Site 2, as shown in Table 2.

**Table 2.** Benthic-invertebrate abundance at Site 2.

| Taxa | Common Name | Quantity Oganisms/ 2ft$^2$ |
|---|---|---|
| Diptera: Chironomidae | True Fly (Chironomids) | 11 |
| Caddisfly case | Trichoptera (cases) | 30 |
| Caddis | Clam (White shell) | 1 |
| **Total number of taxa found = 3, Total number of individuals = 12, Total number of caddisfly cases = 30** | | |

Similar to site 1, chironomids are the most abundant living benthic invertebrate at site 2. Overall there was a low abundance of living organisms found. Empty caddisfly cases and one clam (white shell) were found as evidence of previous inhabitants.

We also found a case of *Brachycentrus Americanus* (Trichoptera Brachycentridae) in good condition.

**Site 3:** Again, we found a low abundance of living organisms, similar to observations at site 2. See Table 3.

**Table 3.** Benthic-invertebrate abundance at site 3.

| Taxa | Common Name | Quantity Oganisms/ $2ft^2$ |
|---|---|---|
| Plecoptera: Perlidae | Stonefly | 2 |
| Coleptera: Elmidae | Aquatic Beetle | 1 |
| Diptera: Muscidae | True Fly (Chironomids) | 1 |
| Diptera: Ceratopogonidae | True Fly (Chironomids) | 1 |
| Diptera: Simuliidae | True Fly (Chironomids) | 1 |
| Caddisfly case | Trichoptera (cases) | 23 |
| Worm | Worm | 2 |
| **Total number of taxa found = 7, Total number of individuals = 8, Total number of caddisfly cases = 23** | | |

Overall, site 1 showed the highest populations of benthic invertebrates. This area was the control site and was not impacted by fire/fire retardant. The populations of benthic invertebrates decreased in site 2 and 3. These sites are in the area of the fire and downstream of the fire respectively. The lowest abundance of benthic invertebrates was found at site 2. That result possibly reflected the negative impacts of fire/fire retardant causing a reduction in the populations of benthic invertebrates. Along the same line, a low abundance of benthic invertebrates were found at site 3, which is downstream and likely to be impacted by fire/fire retardant as well. A graphic comparison of invertebrate abundance is shown in figure 1a.

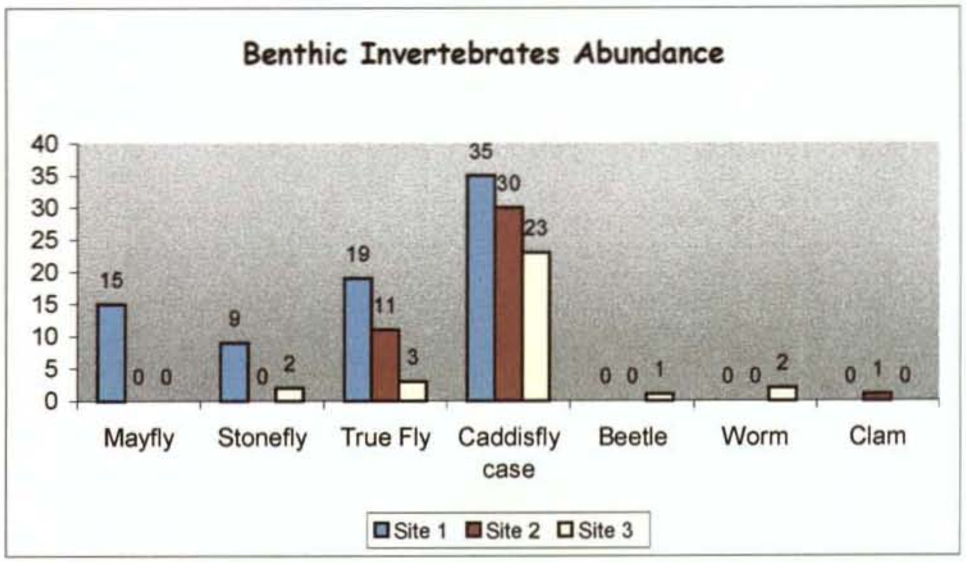


**Figure 1a**: Benthic invertebrate abundance at the 3 sites.

Chironomids are the most common found taxa in all sampling sites. They are common species usually found in Rocky Mountain streams and are tolerant to extreme conditions. Even though there were a high number of caddisfly cases, we do not conclude that they were the most abundant taxa. This is because only empty cases were observed from all samples. It is possible that the cases are either from former years or from stressed caddisflies or more recent deaths this fall. We, therefore, did not count them as the current benthic invertebrate in the stream as they were not alive at the time of sampling.

**Water Quality Data**

Water quality of South Boulder Creek was investigated after the fire. As previously mentioned, the following common parameters that determine water quality and condition were measured:

- pH
- conductivity
- temperature
- dissolved oxygen (DO)
- dissolved organic carbon (DOC)
- stream flow

Water quality data is not available for pre-fire conditions.

**pH:** pH of the stream water could possibly change by fire ash and/or the chemistry of fire retardant. The measured pH from the three sampling sites, after the fire, were 7.55, 7.65, and 7.60 respectively. See Figure 2. Considering the accuracy of the pH meter, the pH difference is not a significant between the three sites.

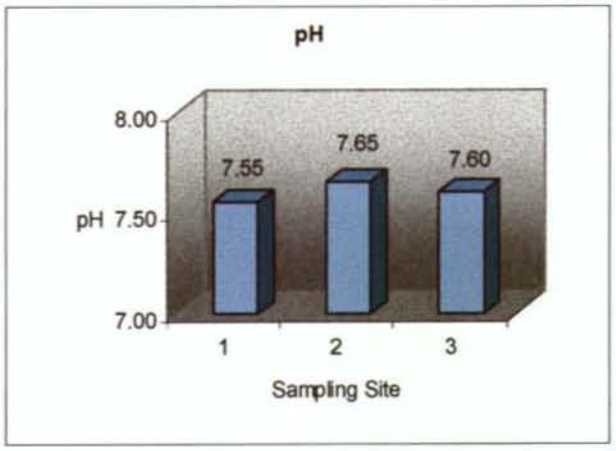


**Figure 2**. pH at the three sites

**Conductivity:** Conductivity can be used to give an estimate of ion concentration in the stream. The measured conductivities are 52.30, 52.60, and 53.20 µs. (See Figure 3). The slight differences are not significant within the error of the meter.

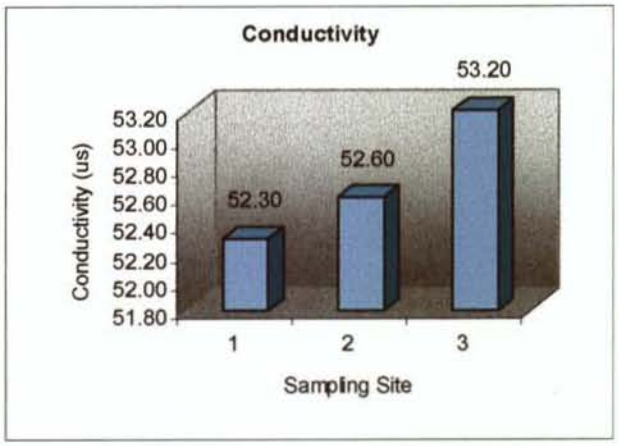


**Figure 3.** Conductivity at the three sites

**Dissolved Oxygen (DO):** The amount of dissolved oxygen is important for biota. The DO can give an indication of BOD loading possibly due to the chemistry of fire retardant. The measured DO values are 9.10, 8.80, and 9.15. (See figure 4) DO saturation is approximately 10 mg/L, in the stream. The differences are significant considering the DO meter used for sampling. The lower value at site 2 may reflect greater rates of heterotrophic respiration compared to photosynthesis at this site compared to the other sites. (See study done by classmates measuring the periphyton growth at similar sites along the South Boulder Creek).

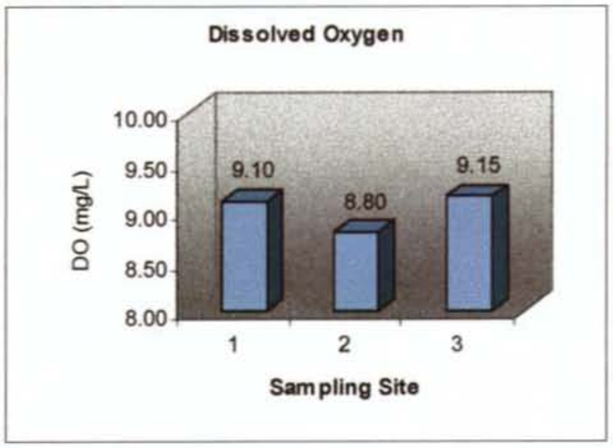


**Figure 4.** DO values at the three sites

**Dissolved Organic Carbon (DOC):** Typical DOC ranges for small to medium rivers in the United States run from 0.7-28 mg/l, with values from 1-4 mg/l being most common (Allen, 1996). Many factors influence DOC concentrations. Seasonal changes such as high runoff, production of riparian vegetation, and leaf fall all contribute to DOC concentrations. Dissolved organic carbon is removed from streams by both biotic and abiotic processes. Biotic processes include uptake by microorganisms, assimilation into biomass by organisms and the consequential consumption of these organisms by higher trophic levels and its eventual re-mineralization to $CO_2$ via respiration. Abiotic processes responsible for the removal of dissolved organic carbon include adsorption, flocculation and precipitation, and photochemical destruction. Organic carbon can also become mobile after a fire. Runoff can carry DOC into the stream. Measured DOC were 2.11, 2.72, and 2.55 mg/L. See figure 5. There are slight differences, but not significant in terms of potential fire effects. The values are also in the common range for the US stream DOC values.

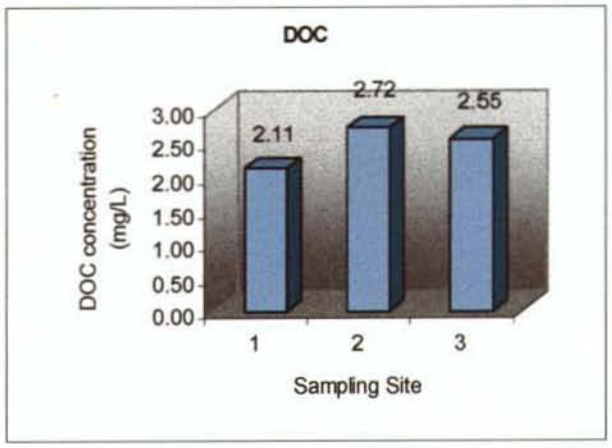


**Figure 5.** DOC values at the three sites.

**Temperature:** The differences in temperatures are not significant in terms of potential fire effects. See Figure 6.

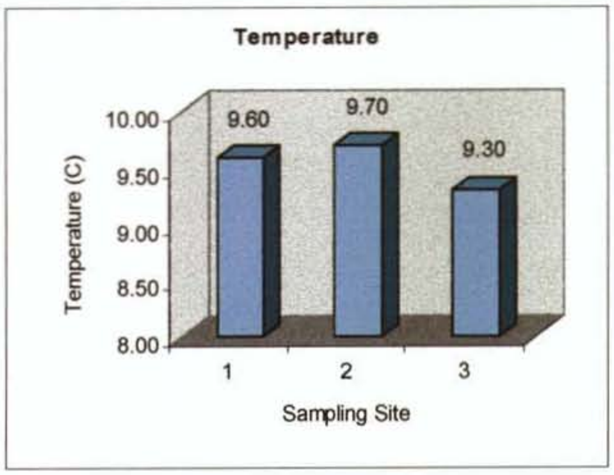


**Figure 6.** Temperature at the three sites.

The overall results reflect no significant change in water quality of South Boulder Creek along the three sampling sites. Consequently, the impacts of fire and fire retardant (accidentally dropped into the creek) on water quality could not be detected six and a half weeks after the fire. The stream water quality probably had recovered. We, therefore, were not able to determine precise cause and effect for the differences in benthic invertebrate populations between our three sampling sites.

## Data from the City of Boulder

The City of Boulder collected water quality data on September 20th, the last day of the fire. They sampled five different sites, three of which matched fairly closely to the sites we sampled. Site number 1' was at the same location as our Site 1, where Gross Dam Road crossed the South Boulder Creek. Site number 2' was just above the Denver Water Board diversion structure on the creek. This site is within the zone of the fire and is upstream from our Site 2 site in Walker Ranch. Site 3' was upstream of Eldorado State Park Visitor Center. This site is well below the zone of the fire and is downstream of our Site 3, but the sites still appear close enough for comparison.

A comparison with the City of Boulder's data shows some similarities and some differences (data courtesy of Donna Scott, City of Boulder). See Table 4 for data. pH data shows a slight (~0.5 pH unit) but significant drop at site 2'. This difference was not detected in our sampling. Temperature was within 0.5 degree for all three sites on both days. Conductivity values are lower than our values for all three sites. However, both sampling dates show uniformity among the sites. So, the change in conductivity between the two sampling days is most likely due to some event other than the fire. Dissolved oxygen at the 1st and 3rd sites was similar during both sampling days. However, the City's 2nd site, within the fire zone, had a DO value higher than the oxygen saturation of 10 mg/L. This point appears questionable; however, there may have been other unknown factors that influenced the DO at this site.

| | Sample Site | 1' | 2' | 3' |
|---|---|---|---|---|
| pH | SU | 7.44 | 6.99 | 7.45 |
| Temperature | °C | 9.6 | 10.6 | 10.1 |
| Conductivity | mmhos/cm | 30.5 | 32.6 | 32.8 |
| DO | mg/L | 8.91 | 11.99 | 9.27 |
| BOD total | mg/L | 1 | 1 | 1 |
| COD | mg/L | 7 | 2 | 7 |
| Cyanide | mg/L | ND | 0.018 | ND |

**Table 4.** September 20th, 2000 data from Boulder Creek. Sampled by City of Boulder.

The City also measured biological oxygen demand (BOD), chemical oxygen demand (COD), and cyanide. We were not able to measure these parameters; however, they are interesting to examine. BOD was uniform at the three sites. COD, on the other hand was lower at the site within the fire zone. This is contrary to expected results. It is expected that fire retardant would increase the COD, but both COD and DO are different than expected at this site. An unknown factor may be responsible for both these results. Cyanide, a component of the corrosion inhibitor in the fire retardant, was not detected at site 1' and 3' but was detected at low levels, although high enough to be toxic to fish, at site 2'. It is likely that it also affected the benthic organisms in the stream.

**CONCLUSION**

With respect to our hypothesis, our field results do not show any significant change in water quality, but there is an evident decrease in the number of benthic invertebrates in the area of fire and downstream. It is likely that the stream was impacted by fire/fire retardant. From our data and the data from City of Boulder, we conclude that the fire/fire retardant is the cause of decreased populations of benthic invertebrates in South Boulder Creek after the Walker Ranch fire and the accidentally dropped fire retardant.

**ACKNOWLEDGEMENTS**

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