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# Influence of Stream Flow on Hydrogen Sulfide Concentrations and Distributions of Two Trout Species in a Rocky Mountains Tailwater

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*Abstract.*—Geothermal springs in or adjacent to streams can contribute hydrogen sulfide ($H_2S$) and affect distributions of fish. We assessed the effects of $H_2S$, relative to discharge, on the locations and movements of cutthroat trout *Oncorhynchus clarki* and brown trout *Salmo trutta* in a regulated river in northwestern Wyoming. Concentrations of $H_2S$ as low as 0.13 mg/L prevented upstream passage and habitation by trout over a 4.2-km reach of the river. The location of the downstream terminus of the $H_2S$ plume was relatively stationary; it varied little when discharge was stable at moderate flows (13.7–14.8 $m^3/s$) and moved within a 300-m reach when flows were declining from 20.9 to 5.7 $m^3/s$. Changes in water temperature and riffle area appeared to be the major mechanisms controlling the concentration and downstream influence of $H_2S$.

Geothermal effluents are present in many watersheds of the Rocky Mountains. Geothermal springs in or adjacent to streams can cause increased water temperatures and inputs of chemicals that might harm aquatic life (Goldstein 1999). The toxicity of one such chemical, hydrogen sulfide ($H_2S$), has been studied extensively (EPA 1976; NRC 1979). Most research has concentrated on $H_2S$ in paper mill effluents (Colby and Smith 1967) and the effects of $H_2S$ on invertebrates (Oseid and Smith 1974) and sedentary life stages of fishes (Adelman and Smith 1970; Smith et al. 1976). Little research has been conducted on the effects of geothermal sources of $H_2S$ on fish, and we are unaware of any studies that have attempted to assess the relationship between discharge and the instream dynamics of $H_2S$.

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DeMaris Springs is a cluster of geothermal springs that contribute approximately 1.8 $m^3/s$ of $H_2S$-enriched water to the Shoshone River, a regulated river in northwestern Wyoming (Figure 1). Discharge from Buffalo Bill Dam is substantially reduced each fall at the end of the agricultural growing season and inputs from DeMaris Springs during fall and winter can constitute 10–20% of the total discharge. Pedlar (1985) reported that, at discharges ranging from 2.8 to 45.3 $m^3/s$, $H_2S$ concentrations directly downstream from DeMaris Springs often exceeded 0.025 mg/L, the lethal concentration for trout (EPA 1976).

The fish community downstream from DeMaris Springs primarily consists of cutthroat trout *Oncorhynchus clarki* and brown trout *Salmo trutta*, but rainbow trout *O. mykiss* and mountain whitefish *Prosopium williamsoni* are also present in the river. Managers have noted low overwinter retention of trout within the 5-km reach directly downstream from the $H_2S$ plume beginning approximately 4 km downstream from DeMaris Springs (Vogt and Annear 1991). One hypothesized mechanism for the overwinter losses of trout is increased downstream influence of $H_2S$ at low discharge and corresponding downstream fish movement.

Our objective was to determine whether low discharge from the upriver Buffalo Bill Reservoir during fall and winter resulted in downstream migration of the $H_2S$ plume from DeMaris Springs and attendant downstream movement of trout. To do this, we compared the $H_2S$ discharge rate and the area affected downstream, hypothesizing that at static discharge, the downstream terminus of the plume would remain relatively stable. However, we expected that with decreasing discharge, the proportionally greater contributions of DeMaris Springs would cause downstream migration of the

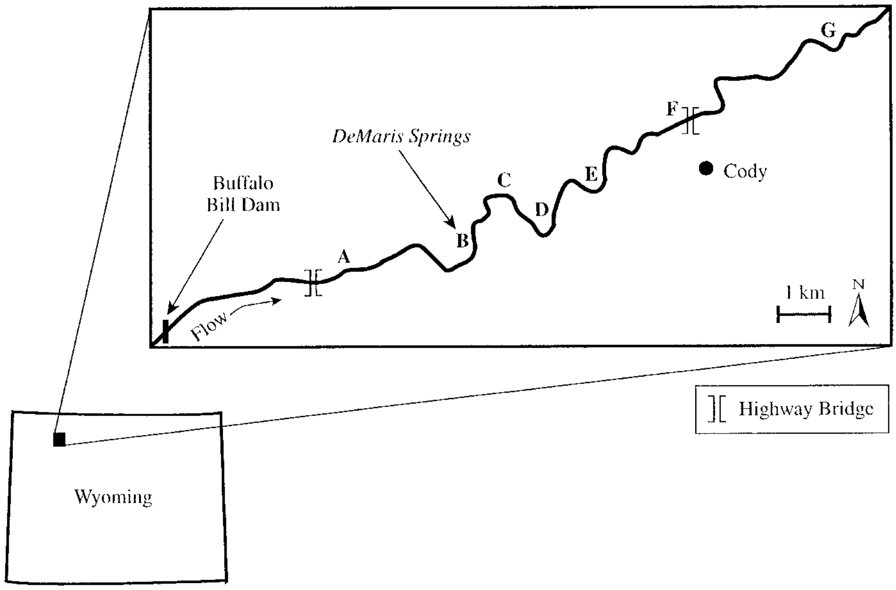


FIGURE 1.—Sampling locations (A–G) in the Shoshone River, Wyoming, where the dispersion of hydrogen sulfide from DeMaris Springs was examined and related to discharge rates from Buffalo Bill Dam.

$H_2S$ plume, resulting in downstream movement of trout.

## Methods

We monitored $H_2S$ concentrations at seven sampling sites in the Shoshone River from October through February of 1997–1998 and 1998–1999. Discharge during the winter of 1997–1998 was relatively stable at 13.7–14.8 $m^3/s$. To determine the dynamics of the $H_2S$ plume during decreasing discharge from Buffalo Bill Reservoir, we monitored the position of the downstream terminus of the $H_2S$ plume from DeMaris Springs during the winter of 1998–1999 (beginning in December) at declining discharges of 20.9, 13.9, 8.2, and 5.7 $m^3/s$. Each discharge was maintained for 2–3 weeks.

Concentration of total reactive sulfide at each site was measured weekly using the Methylene Blue Method (APHA 1995) and a Bausch and Lomb Spectronic Mini-20 spectrophotometer. The minimum detectable level of total reactive sulfide using this technique was 0.01 mg/L, which was below the 0.025 mg/L lethal concentration for trout. The spectrophotometer was calibrated every 2 weeks during the study. Water samples, collected with plastic containers from the middle of the water column at midchannel, were processed on site. Three subsamples were taken and measured from each water sample, and we averaged these values to obtain an estimate of total reactive sulfide. We measured the pH of each water sample with an electronic meter, monitored water temperature using continuously recording thermometers at each sampling site, and took weekly measurements of discharge upstream and downstream from DeMaris Springs.

To determine the location of the downstream terminus of the $H_2S$ plume (sulfide $<0.01$ mg/L) in 1998–1999, we sampled total reactive sulfide every 100 m downstream from site D (Figure 1), where the Wyoming Game and Fish Department has consistently captured fish during fall and spring electrofishing surveys (S. Yekel, Wyoming Game and Fish Department, personal communication). We calculated, using the first and second dissociation constants for $H_2S$ (Langmuir 1997), pH, and water temperature, the proportion of total sulfide that was $H_2S$.

Movements of radio-tagged fish were monitored from December 1998 through February 1999. Using electrofishing gear, we collected cutthroat trout and brown trout (20–30 cm total length) during the last week of November from a 2.4-km section of the Shoshone River extending from about 0.5 km upstream from site E downstream to site F (Figure 1). Each fish was surgically implanted with a radio transmitter (Advanced Telemetry Systems #357) according to the technique of Bidgood (1980) and released near its point of capture fol-

TABLE 1.—Total sulfide and hydrogen sulfide ($H_2S$) concentrations measured at seven sampling sites below the source (DeMaris Springs) in the Shoshone River, Wyoming, during winter of 1997–1998.

| Site | Distance below source (km) | Sulfide (mean; mg/L) | $H_2S$ (mg/L) Mean | Range |
|---|---|---|---|---|
| A | | <0.01 | <0.01 | |
| B | 0.2 | 0.60 | 0.54 | 0.35–0.91 |
| C | 2.2 | 0.25 | 0.21 | 0.13–0.32 |
| D | 4.2 | 0.12 | 0.10 | 0.05–0.21 |
| E | 6.2 | <0.01 | <0.01 | |
| F | 8.7 | <0.01 | <0.01 | |
| G | 11.3 | <0.01 | <0.01 | |

lowing a 30–90 min acclimation period. Each fish was relocated every 3–4 d through the winter. Fish positions were plotted on a topographic map and distance and direction of movements between observed locations were recorded.

## Results and Discussion

Lethal concentrations of $H_2S$ were consistently observed at sites B, C, and D in 1997–1998 (Table 1). Although they varied considerably within a given site (Figure 2), $H_2S$ concentrations at sites B, C, and D were consistently five times or more the lethal limit for trout (EPA 1976). No $H_2S$ was detected at or downstream from site E (Table 1). The $H_2S$ plume emanating from DeMaris Springs remained stationary when discharge was held relatively constant during the winter of 1997–1998. The downstream terminus of the plume was approximately 4.7 km downstream from DeMaris Springs. We determined the plume's position in 1997–1998 by sampling at 100-m intervals downstream from site D. Because surface turbulence causes rapid release of $H_2S$ into the overlying air (NRC 1979), a large riffle directly downstream from site D probably enhanced this process, although microbial and chemical oxidation of $H_2S$ might also have contributed.

The $H_2S$ plume migrated slightly downstream as discharge was reduced during the winter of 1998–1999. When discharge was 20.9 $m^3/s$ in December 1998, the downstream terminus of the plume was approximately 4.5 km downstream from DeMaris Springs. The terminus was 0.2 km further downstream when discharge was decreased to 13.9 $m^3/s$ (Figure 3), and it remained at this location when discharge was reduced to 8.2 $m^3/s$. However, the plume moved upstream approximately 0.3 km about 10 d after discharge was reduced to 5.7 $m^3/s$.

Two factors probably affected the downstream terminus of the plume when discharge was decreased: (1) an increasing proportion of stream flow composed of water from DeMaris Springs, and (2) an increase in water temperature in February 1999. Decreasing discharge results in a decrease in water velocity (Kraft 1972; Cushman 1985). It is likely that decreased water velocity (associated with flow reduction in the Shoshone River) and the proportionally greater contribution of $H_2S$-infused water from DeMaris Springs caused the downstream movement of the plume in January 1999. We noted an increase in the length of two riffles located between DeMaris Springs and site D when discharge was reduced from 8.2 to 5.7 $m^3/s$. However, given the delayed upstream migration of the plume in February 1999, it is unlikely that increased surface turbulence when

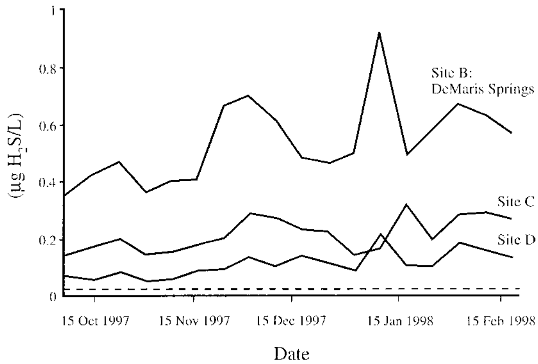


FIGURE 2.—Hydrogen sulfide concentrations at three sampling sites in the Shoshone River, Wyoming (see Figure 1), having detectable levels of $H_2S$ during the winter of 1997–1998. The dashed line denotes the concentration of $H_2S$ that is lethal to trout.

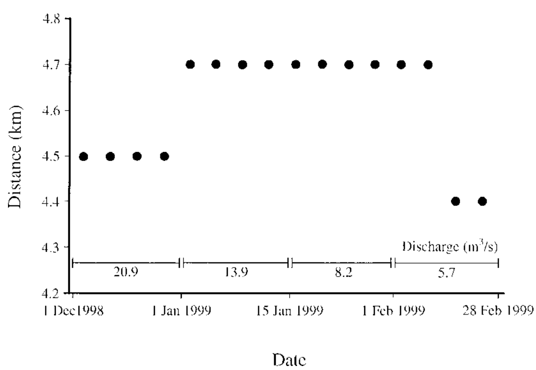


FIGURE 3.—Downstream distance from DeMaris Springs (Shoshone River, Wyoming) of the terminus of the hydrogen sulfide plume versus discharge (by date) from Buffalo Bill Reservoir.

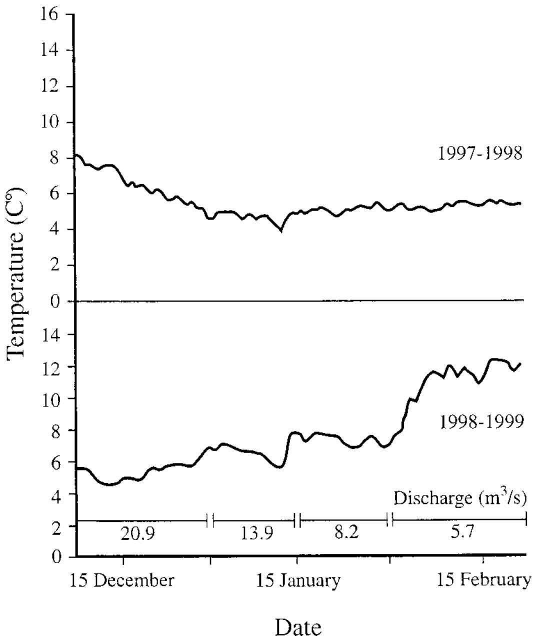


FIGURE 4.—Water temperatures recorded downstream from DeMaris Springs (Shoshone River, Wyoming) during the winters of 1997–1998 and 1998–1999.

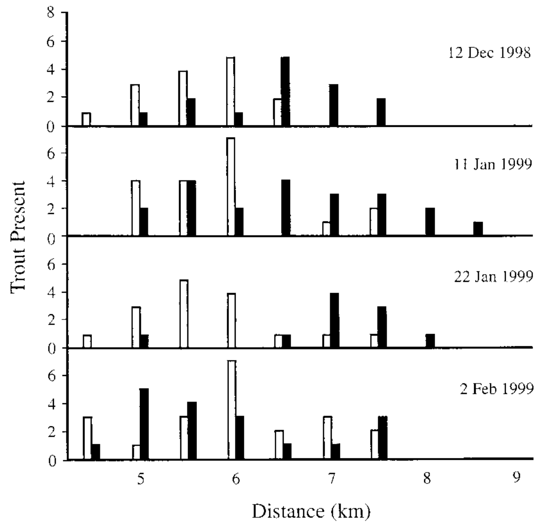


FIGURE 5.—Distributions of cutthroat trout (solid bars) and brown trout (open bars) downstream from DeMaris Springs (Shoshone River, Wyoming) on four sampling dates during the winter of 1998–1999.

discharge was 5.7 m$^3$/s resulted in greater $H_2S$ release into the atmosphere.

A probable explanation for the upstream movement of the plume about 10 d after discharge was reduced to 5.7 m$^3$/s on 1 February, is a 4.5°C increase (from about 8.0°C to 12.5°C) in the mean daily water temperature at DeMaris Springs that occurred early in February 1999 (Figure 4). Because (1) the aqueous solubility of $H_2S$ gas decreases with increasing temperature and (2) the rate of diffusion of gases increases as temperature increases (Morel and Hering 1993), $H_2S$ was probably lost to the air more rapidly at the higher water temperatures causing the upstream migration of the $H_2S$ plume. However, microbial and chemical oxidation of $H_2S$ might have also increased at higher water temperatures.

We did not record downstream movements of trout as discharge was reduced during the winter 1998–1999. Although we recorded radio-tagged trout within 1 km of the downstream terminus of the $H_2S$ plume throughout the fall and winter, we did not record any upstream movements of trout through the plume. The distribution of radio-tagged trout downstream from the $H_2S$ plume did not seem to be affected during the second winter (Figure 5).

When there is a detectable odor in the air above a stream, the concentration of $H_2S$ is 0.25 mg/L or greater (EPA 1979). Because we always noticed a strong odor of $H_2S$ in the air between DeMaris Springs and site D, the downstream attenuation of $H_2S$ as water flowed through several riffles in that reach suggests that surface turbulence effects the removal of $H_2S$ from the Shoshone River. During both winters, $H_2S$ always became undetectable within 0.5 km downstream of the large riffle downstream from site D. The apparent importance of riffles in controlling $H_2S$ concentrations in the Shoshone River suggests that water quality and the upstream boundary of the trout fishery could be enhanced by installing structures that promoted surface turbulence downstream from DeMaris Springs. However, because the $H_2S$ inputs are natural rather than anthropogenic (e.g., paper mills), such management might not be appropriate.

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