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Source and fate of inorganic solutes in the Gibbon River, Yellowstone National Park, Wyoming, USA
I. Low-flow discharge and major solute chemistry

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ABSTRACT

The Gibbon River in Yellowstone National Park (YNP) is an important natural resource and habitat for fisheries and wildlife. However, the Gibbon River differs from most other mountain rivers because its chemistry is affected by several geothermal sources including Norris Geyser Basin, Chocolate Pots, Gibbon Geyser Basin, Beryl Spring, and Terrace Spring. Norris Geyser Basin is one of the most dynamic geothermal areas in YNP, and the water discharging from Norris is much more acidic (pH 3) than other geothermal basins in the upper-Madison drainage (Gibbon and Firehole Rivers). Water samples and discharge data were obtained from the Gibbon River and its major tributaries near Norris Geyser Basin under the low-flow conditions of September 2006. Surface inflows from Norris Geyser Basin were sampled to identify point sources and to quantify solute loading to the Gibbon River. The source and fate of the major solutes (Ca, Mg, Na, K, SiO_2, Cl, F, HCO_3, SO_4, NO_3, and NH_4) in the Gibbon River were determined in this study and these results may provide an important link in understanding the health of the ecosystem and the behavior of many trace solutes. Norris Geyser Basin is the primary source of Na, K, Cl, SO_4, and N loads (35–58%) in the Gibbon River. The largest source of HCO_3 and F is in the lower Gibbon River reach. Most of the Ca and Mg originate in the Gibbon River upstream from Norris Geyser Basin. All the major solutes behave conservatively except for NH_4, which decreased substantially downstream from Gibbon Geyser Basin, and SiO_2, small amounts of which precipitated on mixing of thermal drainage with the river. As much as 9–14% of the river discharge at the gage is from thermal flows during this period.

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1. Introduction

The Gibbon River originates at Grebe Lake and flows nearly 40 km to the Firehole River where they combine to form the Madison River (Fig. 1). The Madison River is one of four major rivers leaving Yellowstone National Park. The Gibbon River is of special interest because it receives water and solutes from several geothermal basins. Norris and Gibbon Geyser Basins constitute most of the geothermal activity in the Gibbon River drainage (Fournier et al., 1976). The chemistry of geothermal water varies both within and between geyser basins depending on water–rock interactions, geothermal reservoirs, water-flow paths, subsurface mixing of waters, boiling, and cooling (Truesdell and Fournier, 1976; Truesdell et al., 1977; Fournier, 1989, 2005). Consequently, the water discharging from the basins can be very different. The water discharging from Norris Geyser Basin is much more acidic (pH 3) than water from other geothermal basins in the upper-Madison drainage; and as a result, the effect of Norris Geyser Basin on the Gibbon River is markedly different from other geyser basins. There are numerous water analyses of individual geothermal features within the Gibbon River watershed (see table of references in Ball et al. (2006)). However, these detailed geochemical studies provide little or no information on the mass of solutes leaving the geyser basins. The Gibbon River integrates these and other geothermal discharges within its 326 km^2 watershed.

This study is the first to systematically determine the chemical mass loading in the Gibbon River, identify sources of major solutes, and identify processes of attenuation. Concurrent water samples and discharge data were collected from the Gibbon River upstream from Norris Geyser Basin to Madison Junction under the low-flow conditions of September 2006. Solute loading from Norris Geyser Basin was of particular interest because its inflows have a wide variety of chemical types of waters and its thermal activity changes more rapidly and often more vigorously than that of any other geyser basin in YNP (White et al., 1988). Therefore, water samples and discharge data were also collected from the major tributaries along the Norris Geyser Basin reach.

Numerous studies on the water and solute loads in the Madison River exist (e.g., Norton and Friedman, 1985; Friedman and Norton, 1990; Hurwitz et al., 2007b; Nimick et al., 2007); however, there are no

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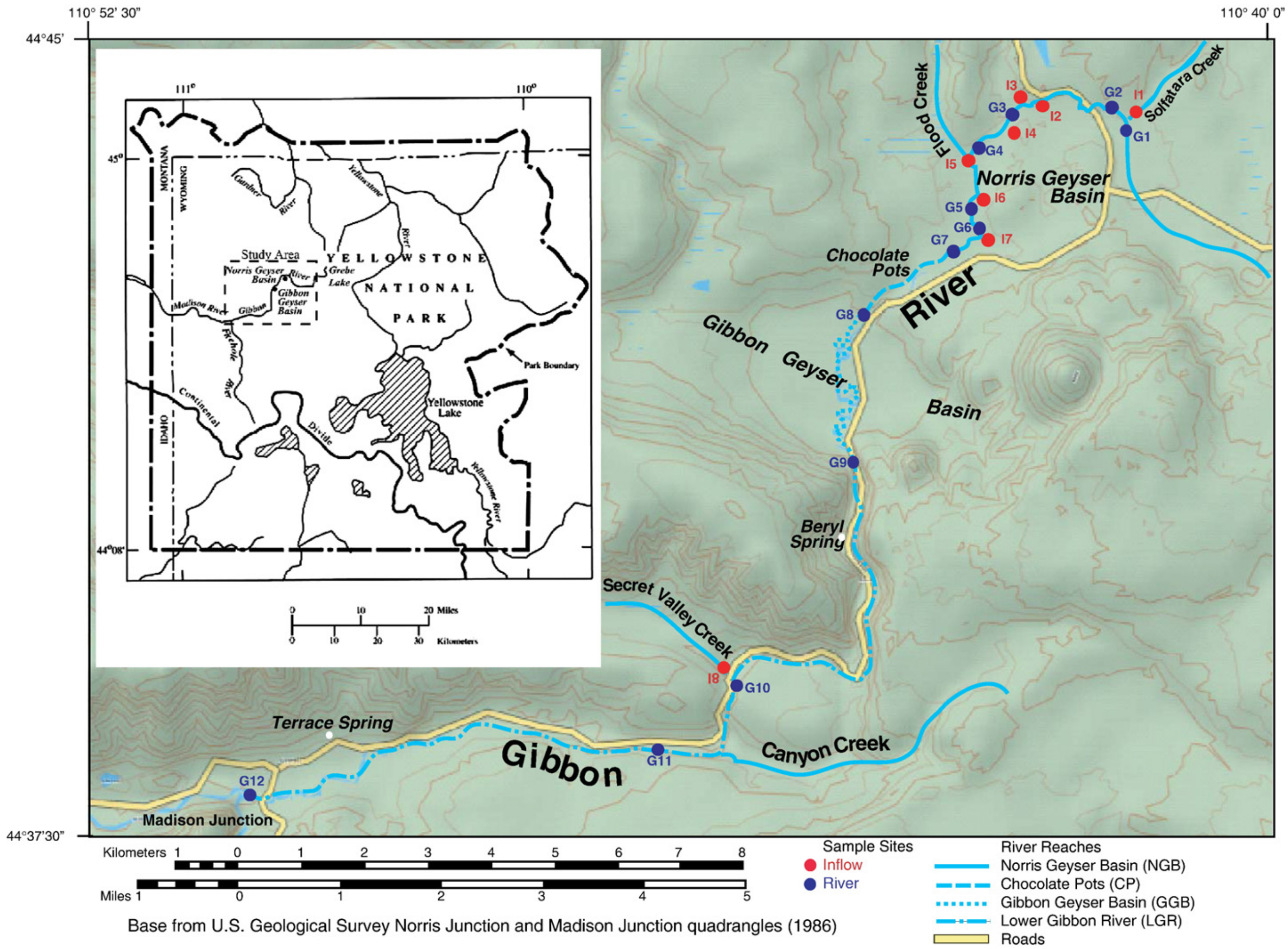

Fig. 1. Map of the Gibbon River, sampling sites, Geyser Basins, and river reaches.

comprehensive chemical surveys that include discharge measurements allowing for the identification of sources, loads, and attenuation of major solutes in the Gibbon River. Hurwitz et al. (2007b) describe a detailed study on solute fluxes from the major rivers leaving YNP for the 2002–2004 water years. They found that the Madison River accounts for only 9–10% of the total water and SO_4 fluxes from YNP, but much greater proportions of Cl (46–47%), F (41–42%), and HCO_3 (19–20%) fluxes. There are few geothermal features downstream from the Gibbon and Firehole River confluence; thus, the solute load in the Madison River should reflect that of the Gibbon and Firehole Rivers. According to Hurwitz et al. (2007b), the Gibbon River discharge accounted for 32–39% of the Madison River discharge but contributed a higher percentage of SO_4 (44–46%) and smaller amounts of Cl (25–30%), HCO_3 (20–22%), and F (19–21%). The National Park Service Inventory and Monitoring Program established the Greater Yellowstone Network (GRYN) and in 2005 began monitoring the water-quality of the Gibbon River near the confluence with the Firehole River (O'Ney et al., 2007). Monitoring data from GRYN provides a useful chemical baseline to identify changes in thermal activity and shows the seasonal chemical variability.

2. Study area and sample locations

2.1. Geology

The Gibbon River runs close to the contact between the Central Plateau Rhyolite on the south side and the Lava Creek Tuff on the north side, both of Pleistocene age. The Lava Creek Tuff erupted 640,000 years ago and has two members, A and B, that are divided by a change in the phenocryst concentration and a change from densely welded to non-welded or moderately welded (Christiansen, 2001). These changes suggest a pause in the eruptive cycle or a change in the composition and/or nature of the eruptions. The Lava Creek member A dominates from the southwestern edge of the Gibbon Geyser Basin to Madison Junction and member B dominates from Gibbon Geyser Basin northeast to the headwaters of the Gibbon River. Both members have phenocrysts of quartz, sanidine, and sodic plagioclase but member A is rich in hornblende and member B rarely contains hornblende. The Plateau Rhyolite is composed of several eruptive flows ranging in age from 70,000 to 640,000 yr following the formation of the Yellowstone caldera. The primary flow members adjacent to the Gibbon River are the Nez Perce flow (age about 160,000 yr) and the Gibbon River flow (90,000 yr). The Nez Perce flow extends from the Canyon Creek confluence west to Madison Junction, and the Gibbon River flow extends to the north of Canyon Creek and east of the Gibbon River. Their mineralogy and petrography is very similar to the Lava Creek Tuff. Both the Lava Creek Tuff and the Central Plateau Rhyolite have high concentrations of fluoride consistent with the high fluoride concentrations found in hot springs and in the Gibbon River.

2.2. Sample locations

Nineteen water samples were collected along a 28.7-km reach of the Gibbon River beginning upstream from Norris Geyser Basin and ending at the U.S. Geological Survey (USGS) streamflow-gaging station (06037100) at Madison Junction (Fig. 1 and Table 1). Eleven samples (G2–G12) were