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Coal aquifer contribution to streams in the Powder River Basin, Montana

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SUMMARY

Groundwater contributions to streams can be reduced by groundwater withdrawal associated with coalbed methane and coal mine production. Quantifying the groundwater contribution to streams aids the assessment of potential impacts to in-stream flow and provides information necessary for energy producers to use coproduced water for beneficial purposes, rather than treating it as a waste product. Stream flow, field parameters, common ions, and isotopes of carbon and strontium were measured on Otter Creek and the Powder River in southeastern Montana. Direct streamflow measurements were ineffective because of the magnitude and nature of coalbed contribution. The coal groundwater contribution did not exceed the geochemical detection threshold on two nearby streams. Geochemical models based on isotopic data proved to be the most effective analytical method, resulting in baseflow measurements from coal aquifers of 28–275 l s^{-1}.

1. Introduction

1.1. Project purpose and scope

Groundwater withdrawal during coalbed methane (CBM) production or coal mine development, upgradient from where a developed coalbed subcrops to streams, has the potential to reduce the coal aquifer contribution (baseflow) to those streams. This study quantified coal aquifer contributions to streams to help assess potential impacts to total flow. This information is necessary for environmental permitting of mines and for energy producers to apply for permits to put CBM coproduced water to beneficial purposes.

Measuring flowrate gain and loss along a river reach is a common method to quantify baseflow. However, this method is of limited use along short reaches where water moves in and out of bank storage and contribution from baseflow is small compared to overall streamflow. The best time to measure small gains in flow from groundwater is during low flow periods in the winter; but in winter the rivers are often too dangerous to measure or are ice covered. Additionally, gain/loss measurement does not identify the aquifer source of the baseflow. However, carbon and strontium isotopes have been shown to effectively fingerprint the contribution of coal aquifer groundwater to surface water in the Powder River Basin of Montana and Wyoming (e.g. Brinck and Frost, 2007; Meredith and Kuzara, 2012; Sharma and Frost, 2008).

1.2. Previous investigations

Surface coal mining in the Powder River Basin drove the initial description of the regional hydrogeology and the decades long monitoring of groundwater (Van Voast and Reiten, 1988). The network of monitoring wells, established in the mid-1970s, continues to be maintained and supplemented through the on-going monitoring of CBM development. Annual reports published since 2004 document groundwater geochemistry and drawdown of water levels in coal aquifers, followed by recovery in some areas where CBM production rates have decreased (Meredith and Kuzara, 2015).

The carbon isotope ratio in coal aquifers is controlled by the native $^{13}C/^{12}C$ ratio of the coal and microbial processes, such as methanogenesis, which fractionate the carbon isotopes. Methanogens preferentially use ^{12}C in their biological processes because the ^{12}C–H bond is more easily broken than ^{13}C–H bond. This causes the ratio of $^{13}C/^{12}C$ to increase and generally results in groundwater that is isotopically distinct from surface water (Bates et al., 2011; Bottinga, 1969; Flores et al., 2008; Schoell, 1980; Sharma and Frost, 2008).

The ratio of $^{87}Sr/^{86}Sr$ in aquifer matrices is determined by radioactive decay of 87-Rubidum. Variability in the strontium isotope ratio of the aquifer is caused by the original ^{87}Rb

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concentration and age of the rock. Therefore aquifers with distinct geologic history often have unique strontium isotope ratios. Coal aquifers are often distinguishable from alluvial and sandstone aquifers and surface water (Brinck and Frost, 2007). Coal aquifers of different ages can also be distinguished (Campbell et al., 2008).

Use of isotopes to trace groundwater-surface water interaction is well established for both carbon and strontium (Brinck and Frost, 2007; Clark and Fritz, 1997; Frost and Toner, 2004; Frost et al., 2002; Meredith and Kuzara, 2012; Sharma and Frost, 2008). Carbon isotopes to identify coal aquifer groundwater in surface water have been used by Sharma and Frost (2008) and Meredith and Kuzara (2012). Strontium isotopes to identify aquifer mixing, including that of groundwater associated with CBM, have been used in several studies (Brinck and Frost, 2007; Frost and Toner, 2004; Frost et al., 2002).

Previous work on Otter Creek by Meredith and Kuzara (2012) demonstrated the potential to use carbon isotopes to trace coal aquifer contributions to this small Powder River Basin stream. Carbon isotope ratios increased as the stream crossed the Knobloch coal outcrop in response to the higher carbon isotope ratio found in coal aquifer baseflow. The study presented here builds upon this work by adding analyses of DIC concentrations, strontium isotope ratios and concentrations, and conservative anions as well as comparing these results to results from the nearby Powder River.

1.3. Study area

The semi-arid Powder River Basin typically has warm, wet summers and cool, dry winters. The Moorhead, Montana meteorological station (Fig. 1) has recorded an average 30.7 cm (12.09 in.) of precipitation per year since 1970 (National Weather Service, 2013). The surface geology is mostly flat-lying, Tertiary Fort Union Formation: interbedded sandstone, shale and coal. The landscape is notable for its red clinker beds created by naturally occurring coal fires. Clinker is highly transmissive and can be a significant conduit for recharge to regional aquifers. The geology has been described by the United States Geological Survey (USGS) and the Montana Bureau of Mines and Geology (MBMG) (Culbertson, 1987; Culbertson and Klett, 1979; Heffern et al., 2013; Lopez, 2006; Lopez and Heath, 2007; McLellan, 1991; McLellan et al., 1990; Vuke et al., 2001a, 2001b).

In the Powder River Basin, groundwater is the primary source for both domestic and stock water. Coal beds, because of their relatively high transmissivity, reasonably low salinity water, and lateral continuity, are the targets for many of the water wells in the Powder River Basin. Irrigation water comes almost exclusively from surface water sources, either pumped directly from the rivers or diverted through ditches.

The Powder River Basin economy is agricultural, primarily cattle ranching with dry-land and irrigated hay grass and alfalfa grown in support of ranching. Irrigation typically starts in May and continues through September (Art Hayes, written personal communication November 18, 2014). Much of the valley floor along Otter Creek is sub-irrigated hay (plant roots reach the water table) with few diversions or sprinklers adding water to the soil surface. Most land along the Powder River is used as pasture for cattle but several hay fields are also harvested. Irrigation along the Powder River valley floor is through a combination of ditch diversions from the river and center pivot sprinklers using surface or groundwater.

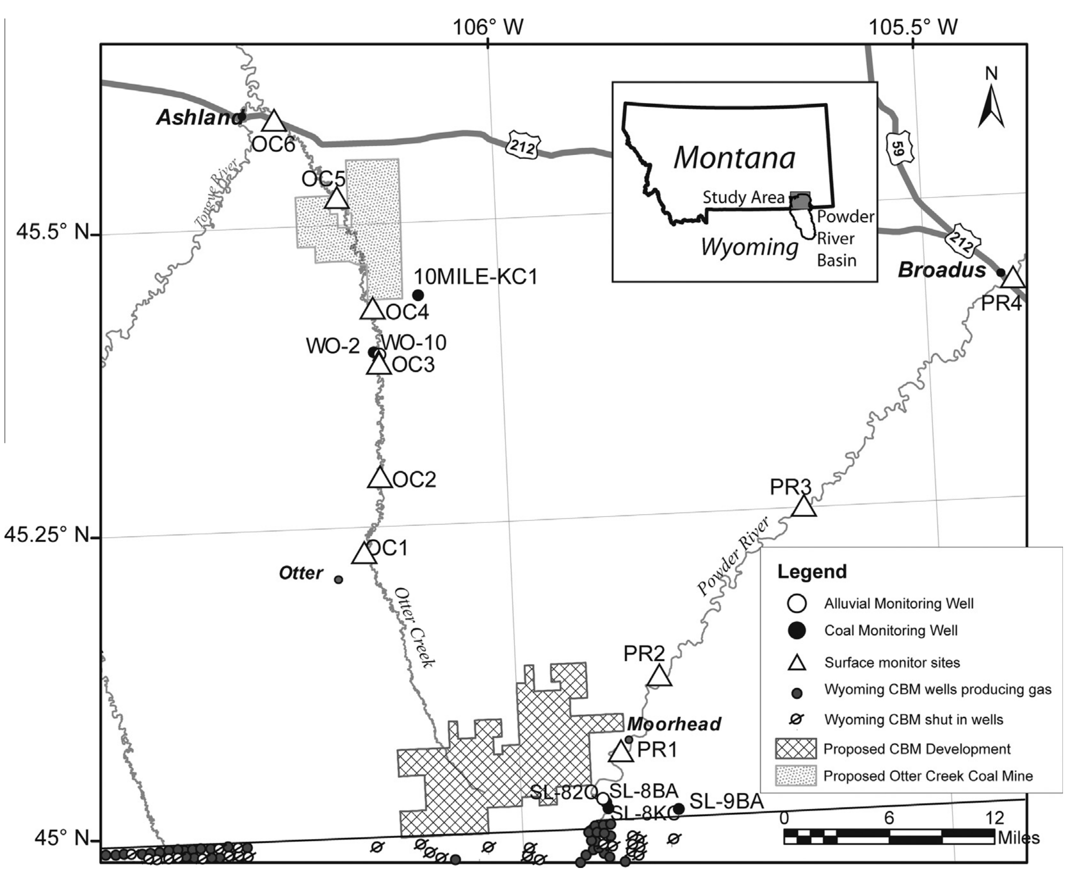

Fig. 1. The study area includes Otter Creek and the Powder River in southeastern Montana.