Impacts of Coal Resource Development on Surface Water Quality in a Multi-jurisdictional Watershed in the Western United States

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Abstract

This study focuses on water quality and quantity impacts from natural resource development on watersheds originating on Crow tribal lands in southeastern Montana. My field research analysis will focus on the surface water quality in three adjacent watersheds. This study will determine impacts to water quality from reclaimed coal mine spoils surface runoff and produced water discharge from coal bed methane wells within the watersheds. A secondary research objective is to determine a baseline assessment of surface water in watersheds prior to proposed mine development, particularly on tribally owned and allotted tracts. Historical data from state agencies will also be compared to data collected within watersheds on tribal lands. Water quality impacts from mining development may be more pronounced than that of coal bed methane as the reclaimed mining sites have demonstrated lasting impacts on the nearby surface water quality in the study area. Historical and current samples have demonstrated elevated contaminant levels downstream of a mine site in a tributary to the primary watershed. A sample from a pond in another reclaimed mine site contained the most elevated sodium adsorption ratio levels of all surface water samples. Coal bed methane development impacts may have been transient in the primary watershed surface water based on sample results. Historical oil and gas development appears to be impacting surface water quality within the southernmost watershed. Analysis has shown the increasing degradation of water quality in watersheds downstream and across the state boundary of Montana into Wyoming where natural resource development has occurred.

INTRODUCTION

This study assesses the impact of coal mining and coal bed methane (CBM) development on surface water quality. The headwaters of our study watersheds are located within the boundaries of the Crow Indian Reservation. Part of the motivation for this study is to provide baseline, surface water quality data in advance of potential CBM or other coal mining activities proposed for the area, specifically, on the Crow Reservation in Montana, on both tribally owned and allotted tracts. The sampling area will extend beyond the reservation to include areas with current gas extraction as well as reclaimed coal mines.

The first objectives are to determine impacts to water quality, if any, associated with reclaimed mines and produced water discharge or land application from CBM wells. Although there are potential impacts on groundwater, this study focused on surface waters due to difficulties in sampling groundwater. The study focuses largely on the Tanner Creek, Youngs Creek, Little Youngs Creek, and Ash Creek watersheds, with a few auxiliary sampling points outside of these watersheds. The tributaries draining the developed sites flow directly into the Tongue River Reservoir.

Another motive for completing this study is that the impacts on the reservation are understudied in terms of policy and water quality impacts. The watersheds represent a unique regulatory regime as they lie within the jurisdiction of the Crow Tribe and the States of Montana and Wyoming. The policies from each jurisdiction are rarely assessed together in regard to the overall impact on the water management and resulting water quality of the watershed.

The Montana Bureau of Mines and Geology (MBMG) completed a water quality study when coal mines were initially developed in the Tongue River basin during the 1970s (Hedges et al. 1998). Specific sampling sites were chosen that coincided with sites previously sampled by MBMG in September 1977 (Hedges et al. 1998) to make a longitudinal assessment and determine if water quality has changed between the mid-1970s and 2016. Analysis will include comparing the profile of these watersheds to adjacent watersheds that have experienced development.

Monitoring sites also include two locations outside of the study watersheds near the Big Horn and West Decker mines that allowed for the direct assessment of extracted water from either the spoils aquifer or dewatering of the mine site. The standing water in the reclaimed mine site will represent the water quality of the spoils aquifer located within the mine site.

Site Description and Background

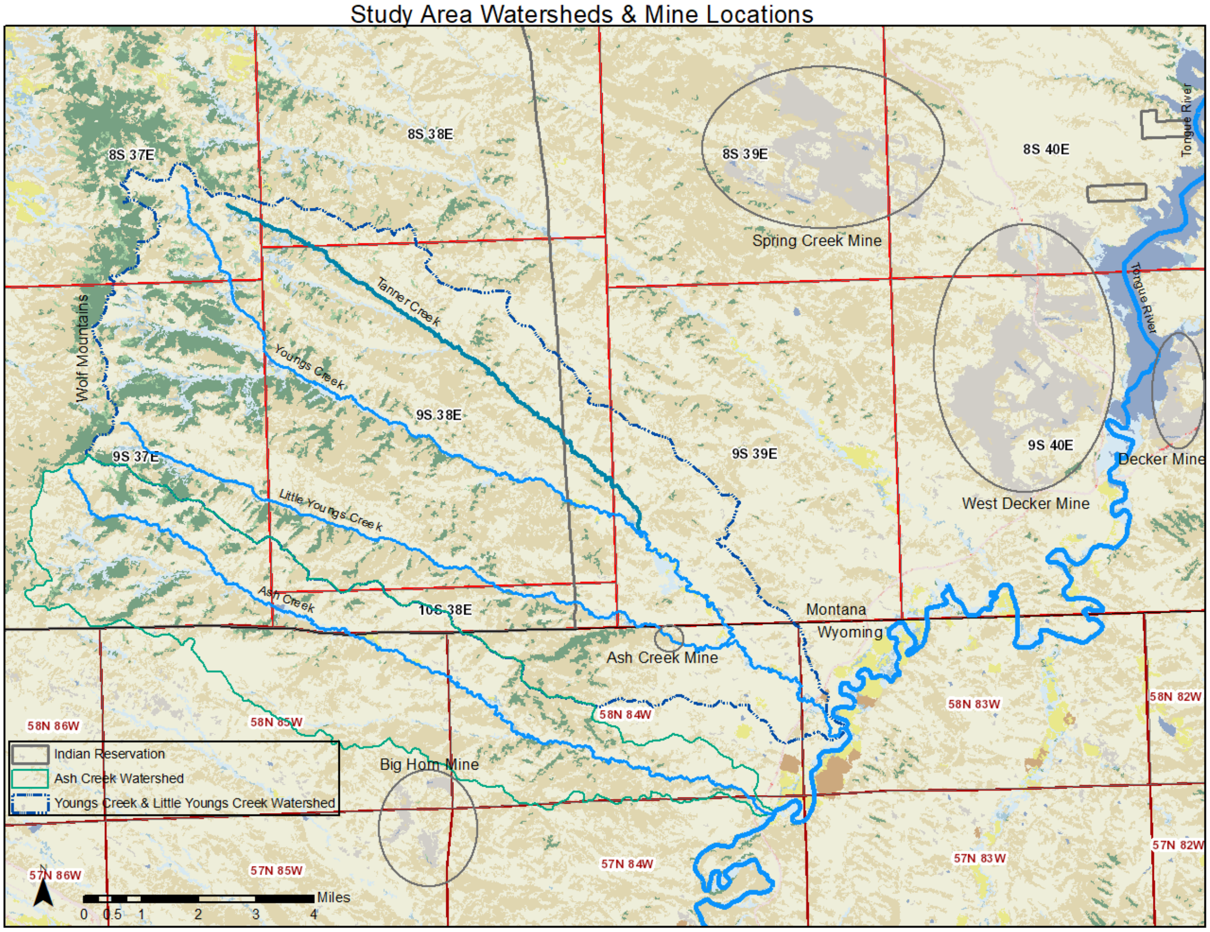

Figure 1.1. Study area watersheds & mine locations.

Rationale for Choosing Sites and Site Contexts:
Previous Studies and Data

In the mid-1970s, the MBMG completed several studies of the study area region that had been identified for the development of potential coal mine sites (Hedges et al. 1974). The MBMG watershed study included Tanner Creek, Youngs Creek, Little Youngs Creek, and Squirrel Creek, all of which are partially located within the Crow Reservation boundary (Figure 1.1.). The majority of the MBMG surface and ground water data were collected in 1974 through 1976. There was a potential to re-sample a sub-set of the sites from the MBMG 1977 study to assess surface water quality changes over time. Watershed characteristics of sampling locations are indicted in Table A.1.

During the time of the MBMG study, several coal mines were being developed east of the reservation boundary including the Decker company mines in Montana and the Ash Creek mine to the south in Wyoming (Figure 1.1.). At the time, the Shell Oil Company had developed mine-project plans and submitted a mine permit application (USDOI 1981). Additional data on coal aquifer locations and depths are in the final environmental impact statement of this permit application (USDOI 1981), however, the majority of the surface water data were cited from the

MBMG 1977 study. For this study, the Shell Oil plans for mine development were used to estimate the extent of mine development in the Tanner and Youngs Creeks' watersheds.

Because the area had been previously studied by both the oil and gas industry and the MBMG, there were many, readily accessible auxiliary data. For example, well logs and coal bed methane well production data in Wyoming are available online at the Wyoming Oil and Gas Commission on the State of Wyoming website (WOGCC 2017). Additional data provided by MBMG include coal bed methane well production and associated produced water as well as locations of coal bed methane infiltration ponds. Coal bed methane well production data are available from the Montana Oil & Gas Commission (MBOGC 2017).

Proposed Coal-Related Development and Geology
Study sites are located in the larger Powder River Basin of Wyoming and Montana, which include both active coal-related fossil fuel extraction activities and undeveloped areas for which water quality can be compared. The coal beds within the Powder River Basin have been developed in this region of Montana and Wyoming. The Powder River Basin has supplied 40 percent of the domestic coal production (USEIA 2017). The active coal developments in Montana within the Decker area are the Decker, West Decker and Spring Creek mines (Figure 1.1.).

The Cloud Peak Energy company has identified three potential mine coal deposit tracts; Squirrel Creek, Tanner Creek, and Upper Youngs Creek project areas based on the locations within the watersheds. Each tract lies entirely within the Crow Indian Reservation (Figure 1.2.) and has a separate option to lease. The project area is referred to as the Big Metal Mine. The Department of Interior Bureau of Indian Affairs has approved Cloud Peak's Exploration Agreement and Option to Lease Agreement with the tribe. In 2013, the tribe received $2.25 million upon signing the agreements and an additional $1.5 million upon the BIA approval of the agreements. The tribe will receive approximately $2 million per year for the 5-year option period. (CPE 2013)

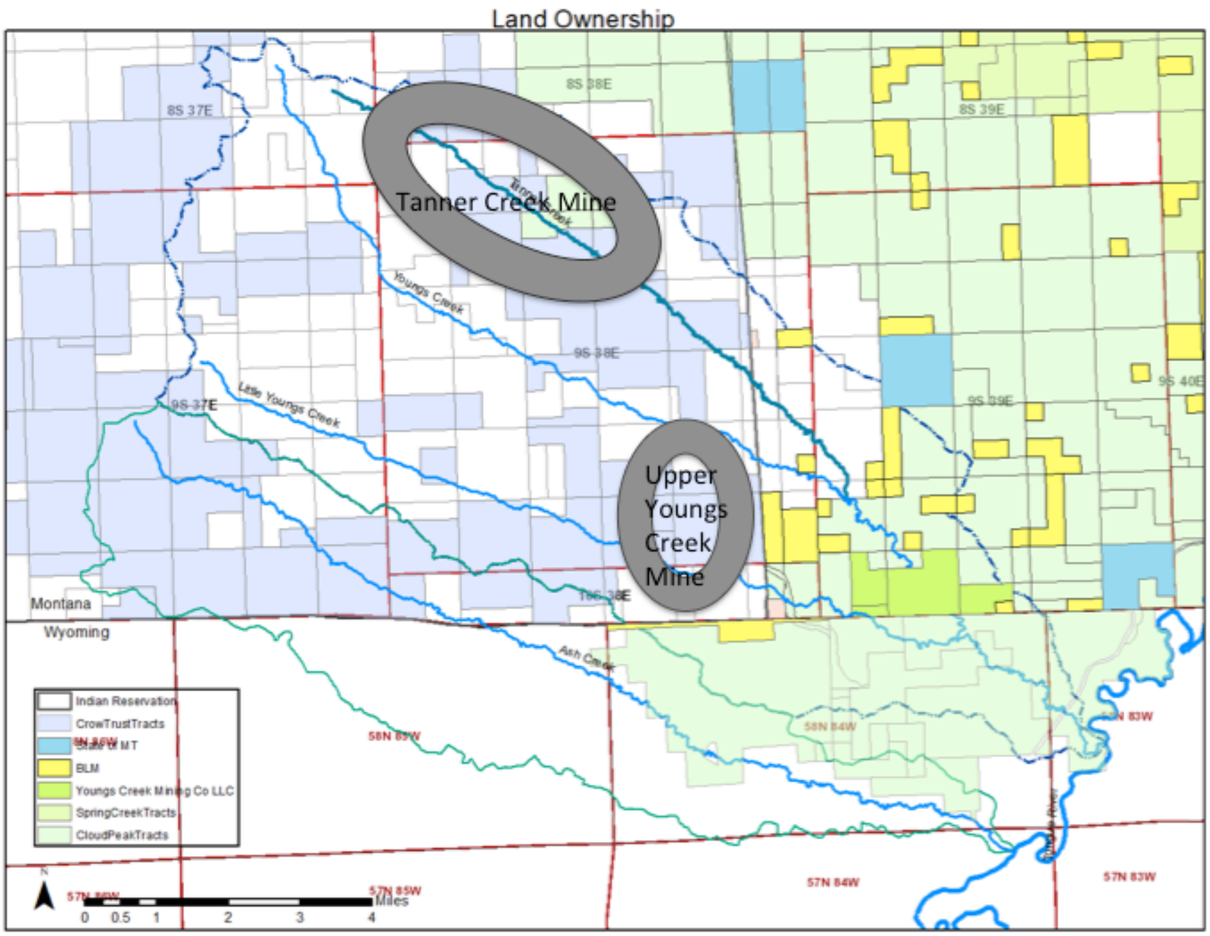

Figure 1.2. Potential coal mine sites.

The coal layers within the basin located in the Tongue River Member lie shallow enough to the surface for coal strip mining development (Wheaton et al. 2004). All of the coalmines in the Powder River Basin are developed as surface strip mines. The coal beds targeted by Cloud Peak, i.e., those on the Crow Reservation, lie at higher elevations than the other regional mines. These coal beds outcrop throughout the target and study area among the foothills and alluvial valleys of the study watersheds.

Powder River Basin CBM Reserves
A vast amount of CBM reserves are stored in coal seams throughout the Powder River Basin. Due to the geological setting, fewer reserves are located in Montana coal seams than in Wyoming. The Montana portion with the basin contains an estimated 0.86 trillion cubic feet (TCF) of CBM gas (Wheaton et al. 2004), while the Wyoming had produced 4.18 TCF through 2010 within the Powder River Basin (USEPA 2010).

In Montana, CBM development is limited to 19.3 kilometers (12 miles) north of the state line and between the Wolf Mountains to the west and the Powder River to the east. This area would include the first two townships within the Crow Reservation west to the Wolf Mountains. This limitation coincides with the area targeted for coal surface mine development. “Of the numerous coal beds in the Powder River Basin, the primary targets for CBM development in Montana have been the Anderson, Dietz, Canyon, and Carney coal beds within the Tongue River Member of the Fort Union Formation." (Wheaton et al. 2004) Active CBM development is located east of the Tongue River Reservoir as of 2017 (MBOGC 2017).

Land Use
Lands located on the Crow reservation within the study area are largely uninhabited and primarily used for pasture and grazing lands. There are a few residences on fee lands located along Youngs Creek based on land records (State of MT 2017) and site visits and personal observation. The land topology is varied with foothills and creek drainages with increasing altitudes upstream to the northwest toward the Wolf Mountains.

Climate
The study region is considered semi-arid and receives relatively low levels of precipitation, ranging from 30 to 38 cm (12 to 15 inches).

Surface Water & Groundwater Quality
Surface waters in the watersheds are classified as calcium-magnesium bicarbonate type water (Hedges et al. 1998). This is consistent with streams that are surface water fed. Tanner Creek has more highly mineralized waters than Youngs and Little Youngs Creeks (Hedges et al. 1998). The overall Total Dissolved Solids (TDS) of all streams increases downstream. (Hedges et al. 1998). Youngs Creek and Little Young Creek have TDS concentrations ranging between 200 and 400 milligrams per liter (mg/L) (Hedges et al. 1998). The Tongue River has and average TDS concentration of 440 mg/L (Hedges et al. 1998).

Groundwater quality of the alluvium in Youngs Creek and Tanner Creek at the mouth of each stream is primarily sulfate (SO_4) anion and relatively high TDS of 1500 mg/L (Hedges et al. 1998). By comparison, Little Youngs Creek alluvium contained less than 1000 mg/L TDS.

Background and Relevant BioGeochemical Processes:
Coal Seam Aquifer Water Quality
Sodium will be the dominant cation in coal bed waters associated with coal bed methane production. The Sodium Adsorption Ratio (SAR, described later) values of coproduced waters in Montana will be greater than 30. Bicarbonate will be the dominant anion with typical TDS levels ranging from 1000 to 2500 mg/L. Depending on the flow influences present in the coal seam aquifer, levels of TDS will be highly variable. The dominance of sodium-bicarbonate waters associated with coal bed methane coproduced waters is of particular concern in monitoring water quality in the study area.

Chemical Composition of Coal Bed Methane Waters
The coal bed waters will favor the dominance of the sodium cation based on the flow path processes of the recharge waters. Waters flowing through clay will be dominated by sodium where calcium and magnesium have been adsorbed to the soils in place of sodium.

In the study area, several processes occur in the coal seam creating conditions for the generation of methane. These include the reduction of sulfate, removal of calcium and magnesium, and the increase in bicarbonate as the dominant anion (Lee 1981). These conditions allow for the biogenic production of methane in coal seams in this portion of the Powder River Basin (Van Voast 2003).

Biogeochemical Processes:
Sulfate Reduction
Sulfate reduction will occur in oxygen depleted conditions in the coal aquifer (Rice and Claypool 1981). With the reduction of sulfate, bicarbonate will increase. The high bicarbonate concentration in coal bed waters is primarily the result of sulfate reduction (Freeze and Cherry 1979). Sulfate reduction is linked to the production of biogenic methane (Rice and Claypool 1981).

Removal of Divalent Cations
The increased concentration of bicarbonate will lead to the process of precipitation of calcium and magnesium (Decker et al. 1987), depleting both divalent cations. The further reduction of calcium and magnesium is driven by the precipitation of calcite, $CaCO_3$, and dolomite, $CaMg(CO_3)_2$, in the presence of elevated levels of bicarbonate (Freeze and Cherry 1979). With the increase in bicarbonate, the resulting pH of formation waters will increase.

Methane Formation
The methane produced will be largely from biogenic origin (Law et al. 1993). Methane production from CO_2 reduction will be the dominant biogenesis process. Carbon dioxide reduction does not increase bicarbonate levels. CO_2 reduction is described by:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

CBM formed in the Powder River basin is primarily the result of methane biogenesis (Rice and Claypool 1981). Methane generation may occur during the sulfate-reduction process, as a concurrent reaction possibly as a catalyst type of reaction. This reaction will depend on the type of methanogenic bacteria present. There is a distinct geochemical signature of coal bed aquifers that will produce methane (Rice and Claypool 1981). The signature will include specific constituents that vary slightly according to marine or freshwater deposition (Van Voast 2003).

Absence of Coal Bed Methane Gas in Coal Aquifers
Certain coal beds in the Tongue River formation do not produce coal bed methane (Van Voast 2003). The Robinson and Rosebud Coal formations in the northernmost portion of the Powder River Basin in Montana are found to have sodium sulfate/bicarbonate rich coal bed waters (Van Voast and Hedges 1980). This geochemical signature of the coproduced water is indicative of coal beds that will not produce methane (Van Voast 2003). The high concentrations of sulfate would prevent the conditions necessary for the biogenic production of methane in the coal bed aquifer.

CBM Regulation
Prior to 2010, operators were allowed to discharge produced water from coalbed methane wells directly into stream drainages in Montana and Wyoming (MCA 82-11-175). Wyoming has separate produced water standards and permitted direct discharge into stream drainages for beneficial use (USBLM 2003). The US Environmental Protection Agency (EPA) delisted coal bed methane produced water from the agency regulation in 2014 (USEPA 2014). The EPA

produced an environmental impact report on coal bed methane produced waters (USEPA 2010).

The Bureau of Land Management, BLM, considers aquifer waters with levels of total dissolved solids less than 10,000 ppm as 'useable water' within federal and tribal land (43 C.F.R. pt. 3160). The EPA considers waters with the same TDS levels to be classified as U.S. drinking water (USDW) sources (40 CFR § 144.3). All of the waters in the coal bed aquifers within the study watersheds would be considered USDW sources and usable sources. This classification as a useable water source may influence the BLM and state agencies regulation of coal bed methane produced waters designated for beneficial use.

Tribal Regulations
All federal statutes placed by the EPA such as the Clean Water Act will apply to tribal lands (USEPA 1984). The state of Montana does not have environmental jurisdiction over tribal lands or over water quality on tribal lands (MCA 85-20-901). The exception to the EPA enforcing regulations on tribal lands applies when the tribe has been granted Treatment As State (TAS) from the EPA (40 CFR 131.8). To attain the TAS status, the tribe has to demonstrate the capacity to run environmental programs (USEPA 2008). The environmental standards must be equivalent to EPA standards. Tribes can also require that environmental standards of surface water quality, for example, exceed standards set by the EPA. The Crow Tribe does not have TAS status and would then have to comply with current EPA water quality standards.

Municipal, Rural, and Industrial (MR&I) Water Supply
Recently, the Crow Tribe has received funding to build a municipal, rural, and industrial water supply system (P.L. 111-291). One water source, the Bighorn River, has been determined to provide adequate amounts and quality for the water system (USBR 2016). The water system will serve all communities within the tribe's 8903 square kilometer (2.2 million acre) land base. The system will connect rural consumers to an adequate domestic water supply where those households rely on low quality groundwater wells. The tribe included initial plans to supply industrial demands to the proposed Big Metal mine development (Bartlett & West 2014). This extension of the water supply line will traverse one of the greatest distances from the source water and gain the most elevation increase in the delivery area.

The tribe has also expressed interest in building and operating coal to liquid coal gasification plants (AAEC 2008). This operation would require vast amounts of water. The tribe has entertained this industrial demand in discussions for sizing the water system.

Volumes of Wastewater & Aquifer Drawdown
Coal mining in the area has also influenced groundwater levels in the coal bed aquifers. The Decker and the West Decker mines have been shown to influence hydrostatic pressures in coal bed aquifers (Wheaton et al. 2004). Coal mining has resulted in a drawdown of 3 meters at a distance of 3.2 km from the mine. The drawdown of 20 feet would correspond to 6.1 m at a distance of 1.6-3.2 km from coal bed methane development.

METHODS

Determining Sampling Points

Like previous studies, sampling points have been based at locations that were generally accessible from nearby roadways such as outlets of roadway culverts, stream crossings, and clearings in brush and tree covering. Sampling points were also located at the confluence of tributary streams, and at the mouth of each stream. Sampling points were generally located within roadway right of way areas. Our study was limited to surface water because groundwater was generally not as accessible. Sampling sites were chosen near MBMG 1977 samples sites. Some MBMG sites on Youngs Creek were not sampled due to time constraints and lack of site information at the time of sampling. Water samples from Tanner Creek were primarily taken in June when the creek was flowing throughout the entire length.

Several sampling locations were selected based on proximity to prior resource development. Locations nearest the Tongue River Reservoir, immediately outside of the eastern edge of the Decker Mine were selected to target surface waters running off the mine site. One location near the reservoir displayed a State of Montana Department of Environmental Quality discharge permit number posted at the site of a discharge point. This point discharged directly into the Tongue River Reservoir through a culvert under Highway 314. The source of the water appeared to come from a pond on the mine site that may be used to retain groundwater pumped from the active mine and associated coal aquifers. The groundwater levels in the mine site are influenced by the water table of the reservoir located immediately adjacent to the mine east of Highway 314.

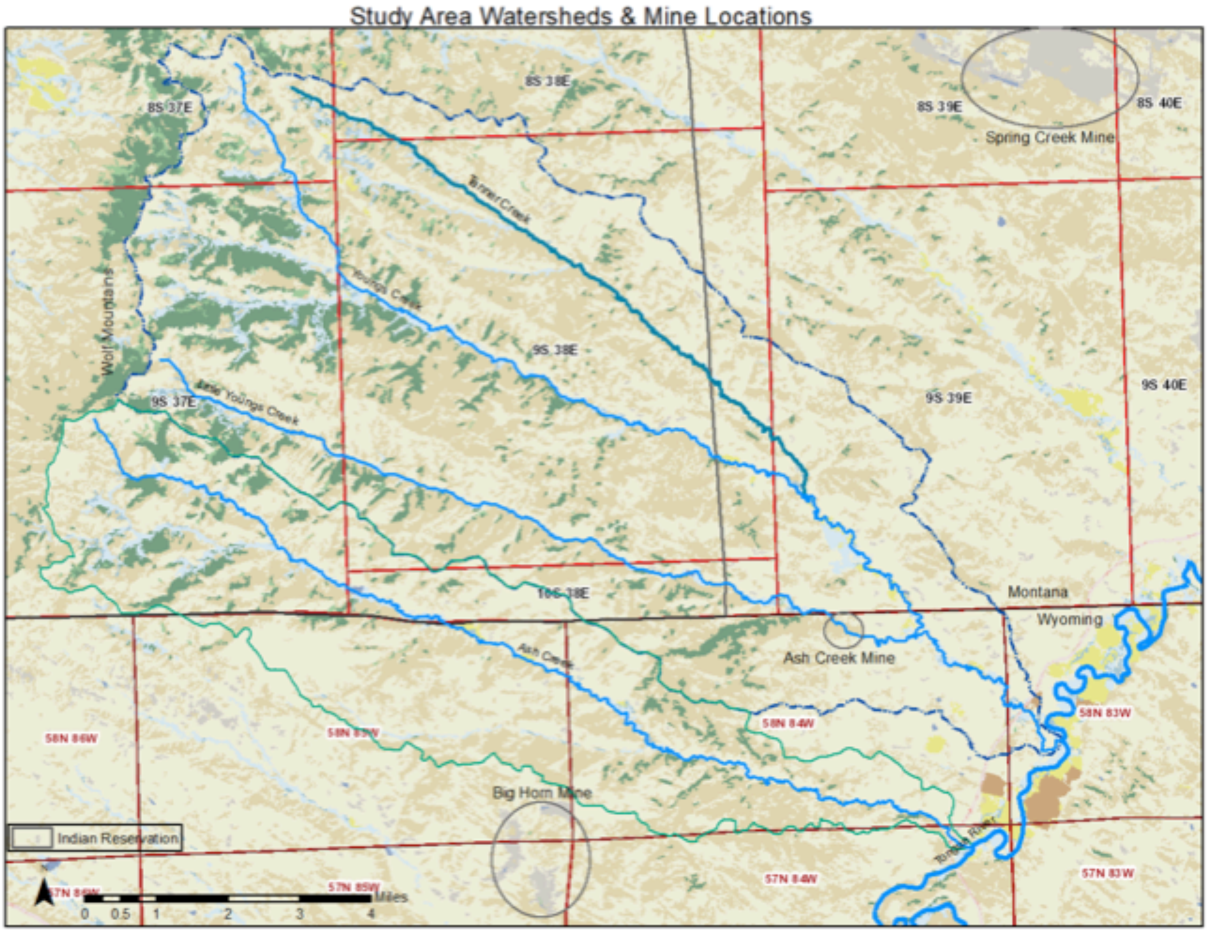

Figure 1.3. Study area watersheds & historical mine locations (indicated with ovals).

Another sampling location was selected at the site of a reclaimed coal mine south of the Ash Creek watershed in the reclaimed Big Horn Mine in Figure 1.3. The location is referred to as Big Horn Mine at Hidden Water Creek as it is in the drainage area that flows into the Tongue River south of Ash Creek. The site was developed with several coal mine pits across the drainage. There is a pond located in one of the reclaimed pit areas. The standing water was sampled during a period of low flow in September. The pond did not appear to flow into a connecting drainage at the time of low flow.

These sampling locations were accessible in open, unfenced areas where signage is posted regarding the permit designation and reclamation status. The permit and reclamation status can be researched and tied to documentation of land use and water quality data. The samples taken in each watershed are indicated in Figure 1.6.

Parameters of water quality that will be measured include; cations, anions, total suspended solids, and metals. Cation and anion measurements will detail the geochemical signature of the stream waters. Metals may be used to detail signature of streams prior to development of the watersheds. Total suspended solids will indicate the turbidity of the stream.

Chemical Analysis
Water samples were collected, filtered preserved, and analyzed at Cornell University. Anions were analyzed by ion chromatograph. Dissolved metals were analyzed by ICP inductively coupled plasma mass spectrometry. Twenty-three samples collected in September were sent to a commercial laboratory in Montana to measure total suspended solids and total dissolved solids. This time period would also coincide with low surface water runoff in the watershed headwaters. During low flow periods, groundwater flow into streams will have a larger impact on the stream flow.

Sodium Adsorption Ratio, SAR
Coal bed methane produced waters are monitored by SAR as the primary indicator for water quality. SAR is described by (Wheaton et al. 2004):

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{(\mathrm{Ca} + \mathrm{Mg})}{2}}}$$

Where Sodium (Na), Calcium (Ca), and Magnesium (Mg) are measured in concentrations of milliequivalents per liter.

Historical SAR levels measured in the Tanner Creek watershed are 0.4 - 0.5 and Youngs Creek 0.1 - 1 during low flow periods (Hedges et al. 1998). Coal bed methane produced water discharges to surface waters are monitored to limit the resultant SAR level of the Tongue River. SAR limits for the Tongue River are 3 for irrigation season and 5 during the rest of the year (ARM 17.30.670). Waters with high SAR levels are limited from land application as salinity may damage soil and crops (Hanson et al 1999). Analysis will focus on the SAR levels of samples as this served as the primary monitoring criteria and limiting factor for produced water discharge in all watersheds.

Density of Wells
The CBM wells in Montana and Wyoming are developed in clusters, each well targeting different coal bed formations. Wells will be co-located drilled primarily in the Dietz 1-3, Carney, Monarch formations and occasionally King and Roberts formations. Each well developed in a separate formation produces varying levels of gas and water. Some formations in co-located wells may not produce gas or water. The density of the CBM wells per section will be outlined. There are also several dry wells listed in the CBM fields that are not included in this analysis.

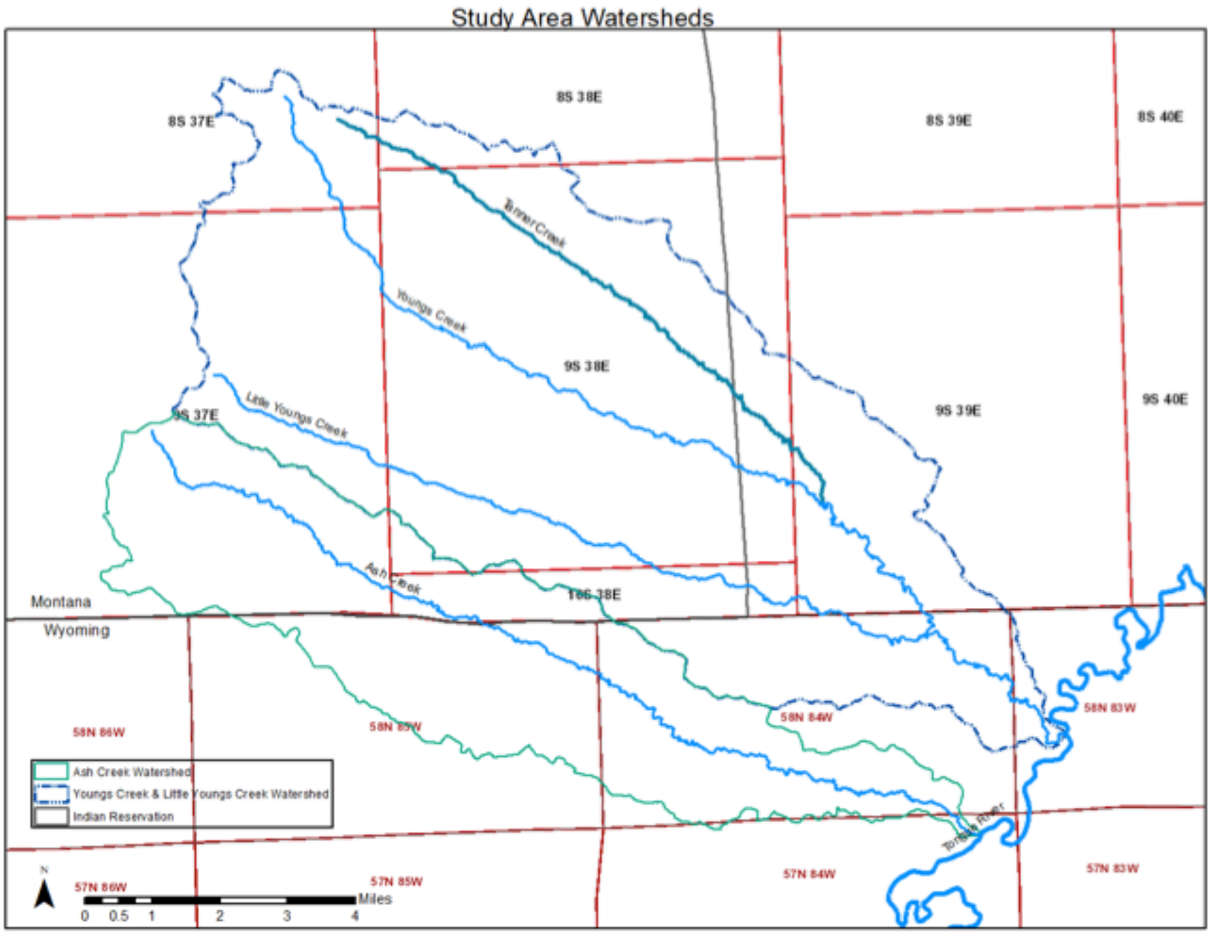

Figure 1.4. Study area watershed townships. Watershed area for the Youngs Creek and tributaries are outlined in townships within Montana and Wyoming.

RESULTS

The results section will focus on the cation and SAR data, as the criteria were indicators for permitted coal bed methane produced water discharged to stream drainages (ARM 17.30.670). Cation and SAR values for each watershed are included in the appendices.

Cation Levels

A spring above Tanner Creek within the watershed had the lowest total measured concentrations of all water samples. It also exhibited the lowest levels of calcium, magnesium, and sodium. The spring had a slight level of sulfate greater than 5 mg/L which can be an indication of being a ground water fed spring. It does have a higher concentration of potassium as compared to other samples (Figure 1.5.). A stock pond in the Tanner Creek watershed did not have sulfate present within the detection limit, which can indicate that it is a surface water fed pond (Hedges et al. 1998). The stock pond also had higher levels of calcium, magnesium and slightly more sodium than the spring above the Tanner Creek watershed.

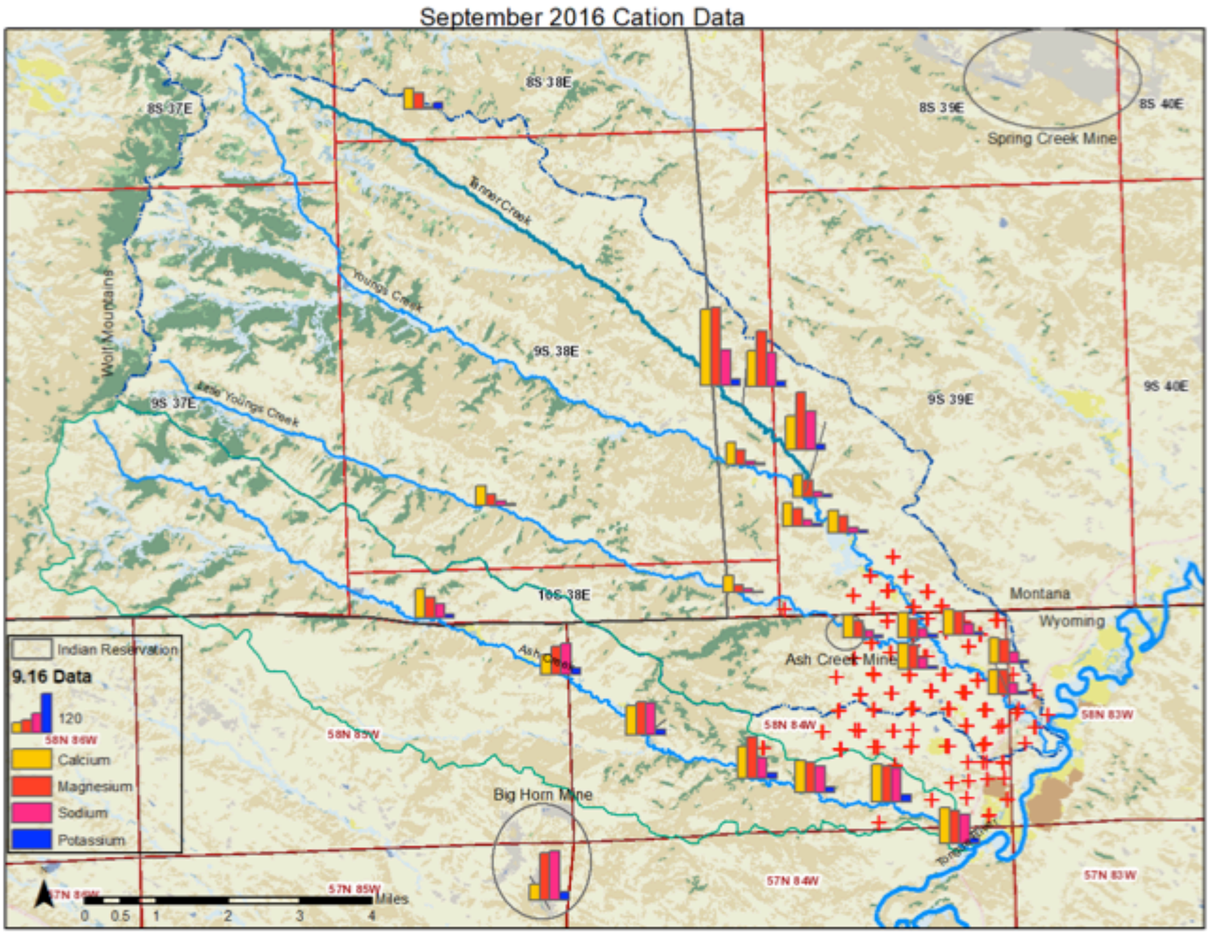

Figure 1.5. September 2016 cation data with CBM wells & mines. Map of watershed study area comparing cations: calcium, magnesium, sodium, & potassium to each cation concentration level in parts per million (ppm).

SAR

A pond in the reclaimed mine site of Hidden Water Creek has elevated levels of sodium, magnesium and moderate levels of calcium. Sulfate was not detected in the sample, which would indicate that groundwater is not influencing the pond. This sample had the highest SAR level of all collected samples that is consistent with the presence of sodium, calcium, and magnesium. SAR measured concentration levels for all samples are indicated in Figure 1.8.

Total Dissolved Solids, TDS

The largest TDS concentration level at the mouth of Youngs Creek during the low flow measurement was 750 mg/L. Tanner Creek has TDS concentrations ranging between 400 and 1200 mg/L.

CBM Development

The concentration of CBM wells per section or square mile in Montana and Wyoming are outlined in the appendix. The majority of the wells in this area are listed as capped or inactive.

DISCUSSION

Surface Water & Groundwater Quality

Initially, headwaters of a stream would have lower SAR levels, as the dominant cations in surface fed waters are calcium and magnesium (Davis 1984). SAR levels would increase with distance downstream as groundwaters contribute increasingly to the stream flow. Groundwater contributing sodium dominated water would increase SAR in stream flows. In general, SAR levels are expected to stabilize after a certain point with overall larger stream flows.

Total Dissolved Solids, TDS

TDS values in surface water will be lower than groundwater concentrations. Where surface flow dominates in the headwaters TDS concentrations will be lower. Groundwater will contribute to stream flow further downstream thereby increasing TDS concentration. (Hedges et al. 1998) The concentration will also be lower in streams during high flow rates.

The spoils aquifers of reclaimed mines will have higher TDS than adjacent coal aquifers. The spoils aquifers will exhibit higher concentrations of sodium, sulfate, and bicarbonate than the coal aquifers. These elevated concentrations are due to the dissolution of minerals and clays in the spoils aquifers. The ion exchange of the calcium and magnesium ions in favor of the sodium ion within the spoils aquifer also increases the TDS. In the spoils aquifer, the predominant anion will be sulfate. Increases in chloride concentrations may occur. Bicarbonate may increase but will be limited to levels of less than 1,000 mg/L in groundwater. TDS levels in spoils aquifers may reach 5,000 mg/L as demonstrated in mined areas in southeastern Montana (Davis et al. 1986).

Indications of CBM and Oil and Gas on Water Quality

CBM impacts to water quality would include elevated levels of sodium and SAR. Additional contaminants may include potassium, sulfate, bicarbonate, fluoride, ammonia, barium, iron, arsenic, and radionuclides according to the EPA (USEPA 2010). Water quality impacts from CBM development may be transient. As Youngs Creek experienced the most development with the highest concentration of well density and closest distance to wells, the flow rate of the stream is high enough to resist impacts of produced water. The impacts of CBM produced water may have been exhibited at the time of well production but the stream water quality is similar to values recorded in 1977 prior to well pre-development.

Active coal bed methane wells in Wyoming were likely to have discharged produced waters directly into surface water drainages. This water, when not discharged directly into stream channels, is often held, on site, in infiltration basins. Water in these basins that does not infiltrate, is usually channeled through culverts or other overflow structures into adjacent streams. Infiltration ponds for CBM wells were shown to impact groundwater quality (Healy et al. 2008). Depending on the well sites, infiltration of the produced water may have affected the water table directly below the pond site. The produced water would have elevated SAR levels and would raise the SAR levels in the groundwater.

Ash Creek did not experience the same amount of CBM development, however, the watershed has a higher concentration of oil and gas development. Contaminant and indicator levels appear to be elevated within the Ash Creek drainage downstream of the Montana border into Wyoming.

There are operating oil wells along the creek in addition to several now abandoned CBM wells. The concentration of oil wells along Ash Creek range from 1 to 7 wells per section (WOGCC 2017). The oil and gas wells are located in formations at greater depths than the coal bed seams.

Background and historical data is limited for the Ash Creek watershed due to the location in Wyoming and lying outside of the study area of Montana agencies and databases. The majority of the Ash Creek watershed sampled is within the state of Wyoming. A few USGS data sets from the 1970s may capture effects of the drilling of the oil wells in the watershed (USEPA 2017). Comparatively, the Ash Creek watershed indicates higher levels of chloride, sodium, and SAR indicators than the Youngs Creek watershed.

Comparison to MBMG Data:
Changes in Land Use and Water Quality Since 1970s Data Collected
As the sampling points were generally accessible by roadway or more accessible due to natural features of the stream, these locations were also readily accessible to livestock grazing in adjacent pasturelands. In the summer months, livestock, mainly cattle, were found watering at most sampling locations throughout Tanner and Youngs Creeks.

Contaminant levels of Youngs Creek did not appear to differ in Table A.6. from initial levels taken in 1976. The land use activities may have changed the Youngs Creek channel in some downstream areas where irrigation canals run throughout the alluvial valley fed by the creek. These areas appear to be downstream of the confluence of Little Youngs Creek and Youngs Creek and upstream of the mouth of Youngs Creek.

There were 4 sampling sites on Youngs Creek that corresponded with the MBMG 1977 sites. On Little Youngs Creek 3 sampling sites corresponded with the 1977 sites. A paired t-test of sample data indicates a slight decrease in SAR levels particularly in the Youngs Creek sites at p-value of 0.06.

Table 1.1. Paired t-test for 1977 and 2016 data. The mean of difference reported represents 2016 data minus 1977 data values. The data for Ca, Mg, Na, & K are in units of ppm. Abbreviations: standard error (SE), degrees of freedom (df).

	Difference Mean	SE	Df	t-value	p-value
Ca					
Youngs Creek	9.8	2.75	3	3.56	0.0189
Little Youngs Creek	18.9	4.63	2	4.07	0.0277
Mg					
Youngs Creek	-2.3	4.93	3	-0.46	0.3384
Little Youngs Creek	0	7.56	2	0	0.5
Na					
Youngs Creek	-9.1	5.78	3	-1.57	0.1072
Little Youngs Creek	-23.3	23.09	2	-1.01	0.2094
K					
Youngs Creek	-0.2	0.72	3	-0.23	0.4164
Little Youngs Creek	0.2	1.42	2	0.16	0.4438
SAR					
Youngs Creek	-0.2	0.08	3	-2.12	0.0609
Little Youngs Creek	-0.5	0.51	2	-1.04	0.2038

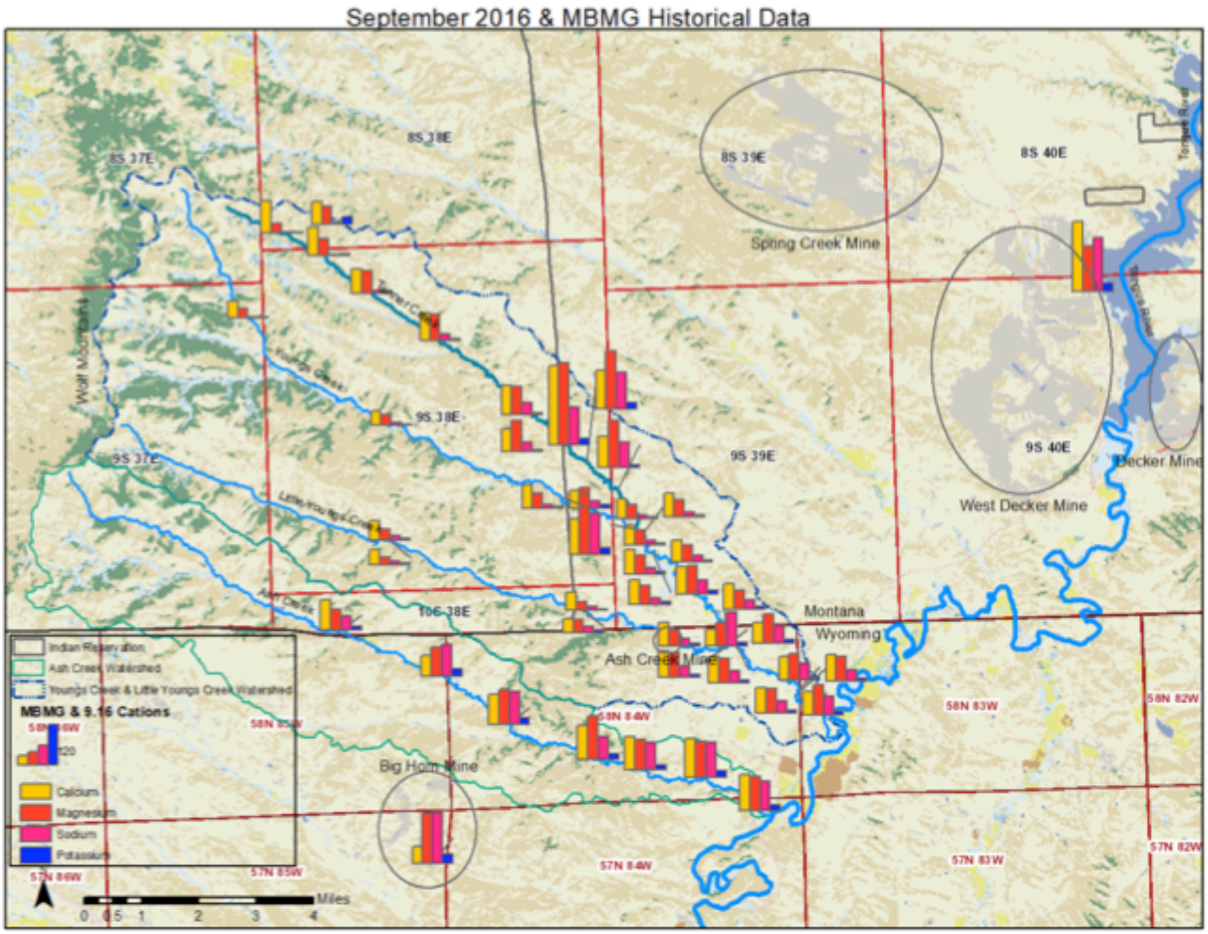

Figure 1.6. September 2016 & MBMG Historical Data. Cation data is shown for all samples and historical data in the watersheds and near mining sites. The legend indicates the symbology of the historical and 2016 data.

Mining Impacts

The Ash Creek Mine was developed and mined through 1978 within a portion of Little Youngs Creek watershed in Wyoming (Figure 1.7.). The mine was inactive after 1978 and the developed portion of 140 acres was later reclaimed in 1996. The Ash Creek Mine project area was amended to include a larger portion in Wyoming extending south and east to the Ash Creek watershed. The amended project was renamed Youngs Creek Mine and permitted in 2010 by Wyoming agencies including the state of Wyoming Department of Environmental Quality.

The Ash Creek mine site was dewatered beginning in 1976 then was reclaimed and dewatering ceased in 1995 (Meredith et al. 2011). The water produced during the dewatering process was likely discharged to infiltration ponds or to nearby streams which would include Little Youngs Creek. A sample was taken downstream from the mine site on Little Youngs Creek. This sample collected by MBMG exhibited elevated levels of sodium at 103 mg/L and a SAR level of 2.2.

Water quality impacts from mining development may be more pronounced than that of CBM because mining development requires significant coal seam dewatering. The reclaimed mine spoils will change the character of the saturated groundwater and surface runoff. As seen with the sample from a pond in the reclaimed area of the former Big Horn Mine, the spoils will have increased SAR. The pond was not connected to a flowing stream, at least not in an obvious way, which would also contribute to the increased level of contaminants found in standing water, i.e., concentration via evaporation. The mine site would be less hydrologically connected to natural groundwater flow paths, therefore, the standing pond water would likely originate from the surface runoff within the site.

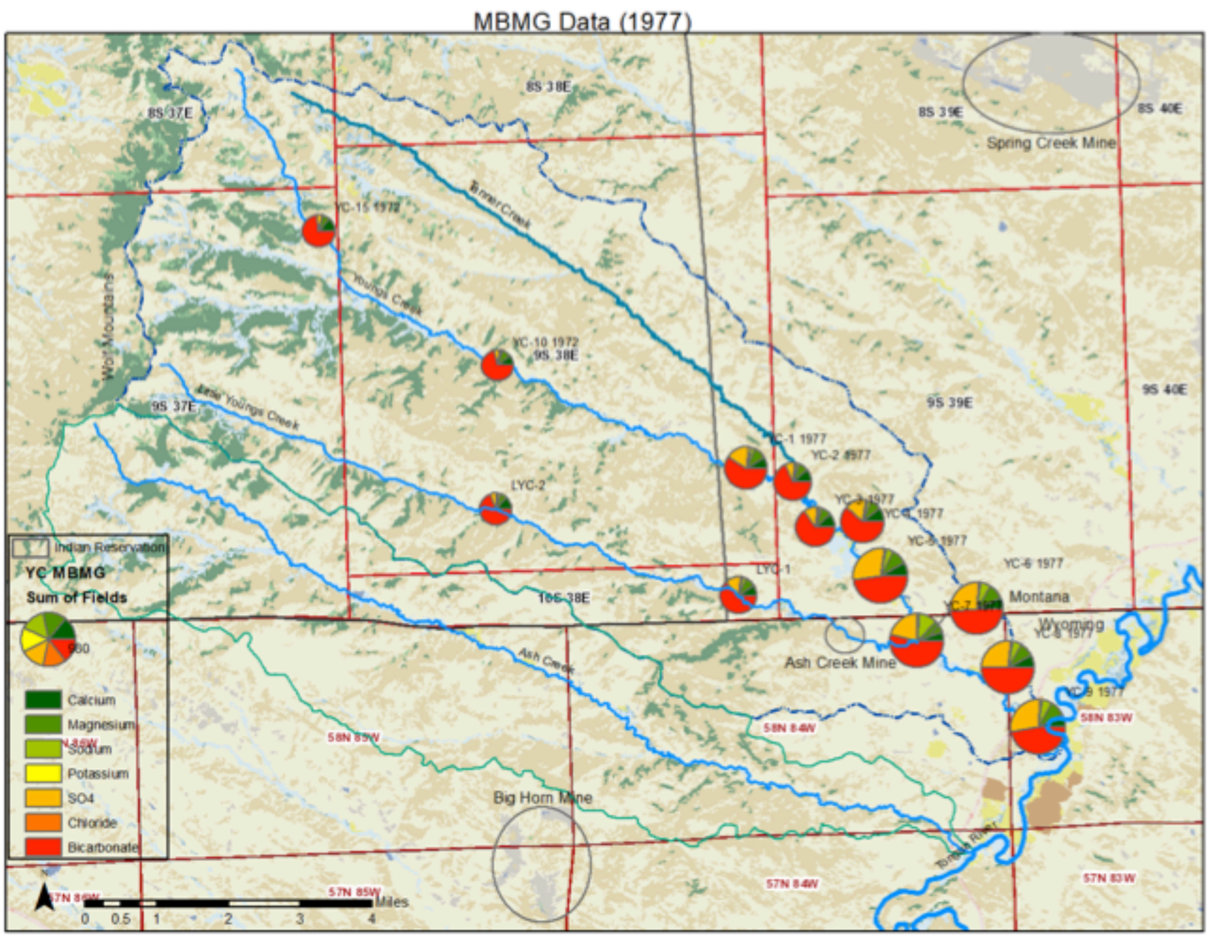

Figure 1.7. MBMG Data & historical mine locations.

The Ash Creek mine site appears to impact the nearby surface water quality on Little Youngs Creek. A MBMG sample from 1977 shows high levels of sodium, sulfate, chloride (Figure 1.7.) and high SAR value (Figure 1.8.). This sample would have been taken during the operational period of the Ash Creek mine. Samples taken downstream of the reclaimed mine site also show elevated sodium and SAR relative to upstream samples. The mine site has been demonstrated to influence Little Youngs Creek as in stream flow is lost within the reclaimed mine site (Hedges et al. 1998). Coal bed methane wells were not developed in the Ash Creek mine site and few wells in the Little Youngs Creek watershed were located upstream of the sampling point at Little Youngs Creek culvert.

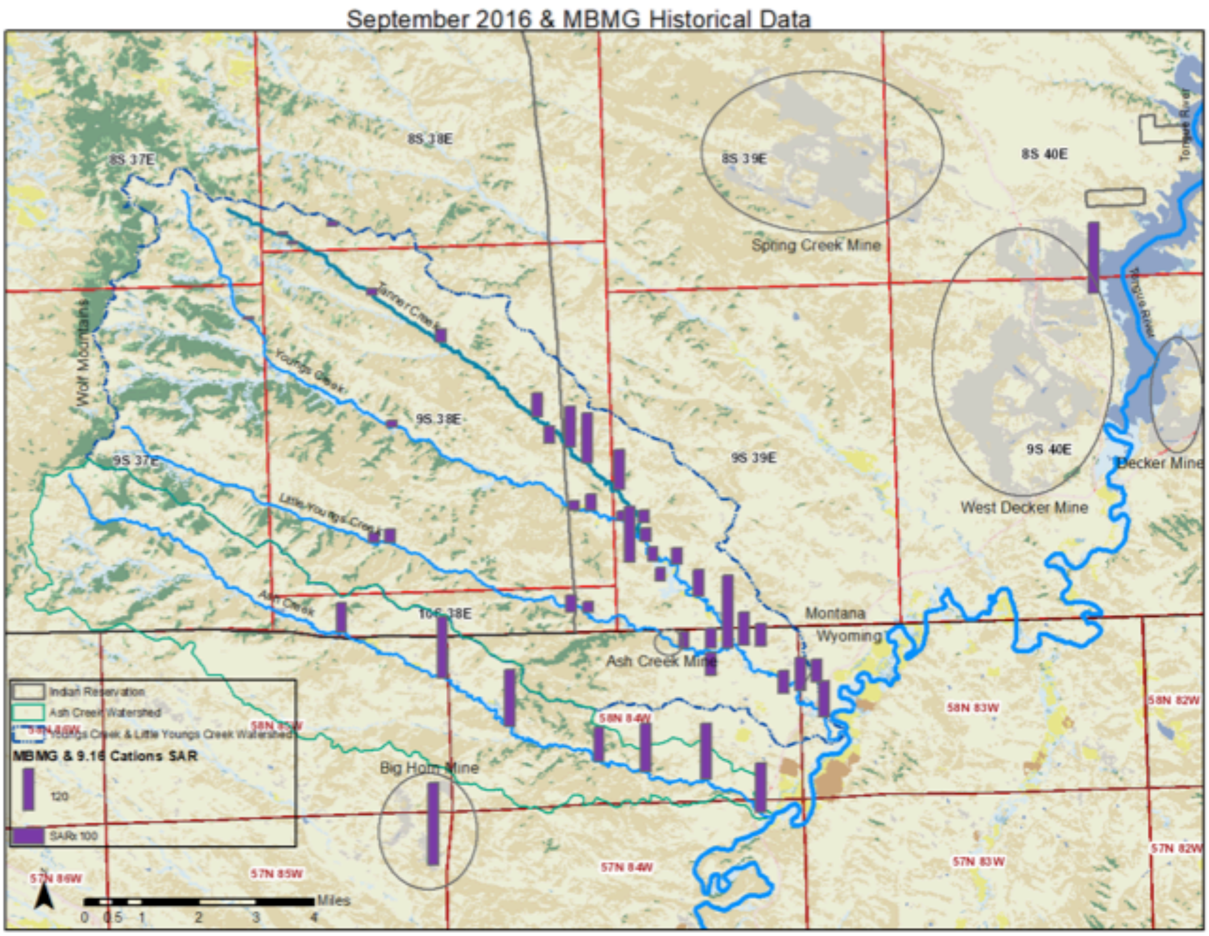

Figure 1.8. September 2016 & MBMBG historical data SAR levels. Maps with labeled collection sites are included in the appendices.

The sample originating from the Decker Mine site also demonstrated an elevated SAR level, the water was likely sourced from dewatering of the coal seam aquifer in an attempt to drawdown the groundwater table. The mine site in the area had not yet been reclaimed and would require continuous dewatering as the nearby Tongue River reservoir would elevate the groundwater table. The outfall fed directly into the Tongue River reservoir. Although the water had elevated SAR levels of 2.1 discharged to the reservoir, the effluent was within SAR permit levels and below the CBM contaminant limit for SAR levels permitted by the Montana Department of Environmental Quality.

Factors Contributing to Elevated Indicator/Contaminant Levels

Variation in Climate/Precipitation

Water samples were collected in April, June, and September. The September sample collection was scheduled to coincide with the 1977 MBMG study during the watershed low flow period. The majority of the upper Tanner Creek watershed was found to be dry during this sample time with stream flow found at the lowest reach of the creek. There were a few bends in the creek with standing water in the lower most 3.2 km (2 mi) of the creek above the confluence with Youngs Creek. Youngs Creek was flowing through the entire stream length. Little Youngs

Creek and Ash Creek were also flowing in the most upstream sampling sites to the downstream confluence sites. The water was sampled during a low flow period in September when runoff would be at minimal levels. The low flow rate would lead to higher expected overall total dissolved solids with less flow contribution from surface water that exhibits lower total dissolved solids.

Drawdown of Groundwater Aquifers

Several coal mines in the region have been shown to draw down water levels in coal seam aquifers (Van Voast et al. 1988). Coal bed methane development significantly decreased water levels in coal seam aquifers that were dewatered for methane production.

Land Area Impacted by Mine

A significant portion of each watershed within the reservation boundary would be impacted by mine development. The entire Tanner Creek watershed would be impacted upstream of the reservation boundary. The Youngs Creek watershed would be altered within the Upper Youngs Creek boundary, a few miles upstream of the reservation boundary as detailed in Figure 1.2. Depending on the extent of the disturbance on the ridge between Tanner Creek and Youngs Creek, the watershed along Youngs Creek will be impacted up past the headwater boundary of Tanner Creek. The greatest disturbance to actual surface land will be most apparent in the Tanner Creek watershed. The Tanner Creek watershed consists of the 70 percent tribal lands, the most tribal land ownership of all the watersheds. Landownership of each watershed (Figure A.4.) is detailed in the appendix.

The drainage from backfilled mine spoils in the headwater areas would alter the stream flow from current dominance of typical surface fed flows of calcium-bicarbonate to elevated TDS levels with increases in sodium, bicarbonate, and sulfate (Davis et al. 1986). This change would be exhibited in surface water runoff. Groundwater changes in the alluvium would also be affected by the higher TDS and increased cation concentration. The alluvium in Tanner Creek would be completely altered throughout nearly the entire stream length upstream from the reservation border. The permeability of the alluvium would also be affected and would take the characteristics of the spoils aquifer. The runoff volume from surface water would be expected to increase due to less vegetation and decreased infiltration or percolation of the saturated spoils soil. The topology would also have more uniform slopes with decreased impediments to flow than the natural rugged landscape. This would lead to increased volumes of surface water runoff from the reclaimed watersheds in Tanner Creek and Youngs Creek. As mine spoil samples were limited, surface water in reclaimed sites should be further studied to determine resulting water quality.

CONCLUSIONS

Reclaimed mining sites may have lasting impacts on the nearby surface water quality in the study area. Historical and current samples have demonstrated elevated contaminant levels downstream of the Ash Creek Mine in the Little Youngs Creek watershed. A sample from a pond in the former Big Horn Mine reclaimed site contained the most elevated SAR levels of all surface water samples. Coal bed methane development impacts may have been transient in the

Youngs Creek surface water based on sample results. Historical oil and gas development appears to be impacting surface water quality within the Ash Creek watershed.

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APPENDIX

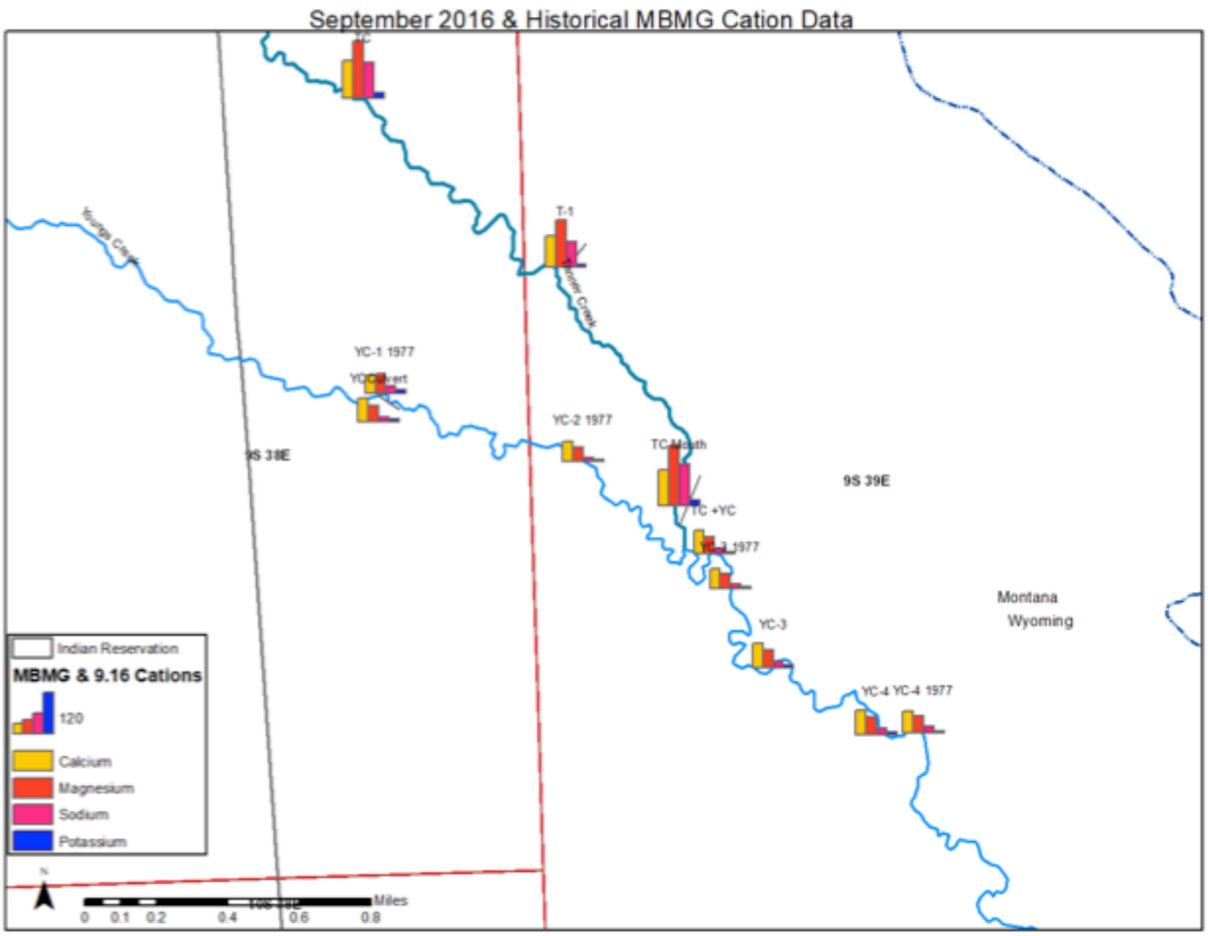

Figure A.1. Cation data from September 2016 compared to historical data in Youngs Creek & Tanner Creek.

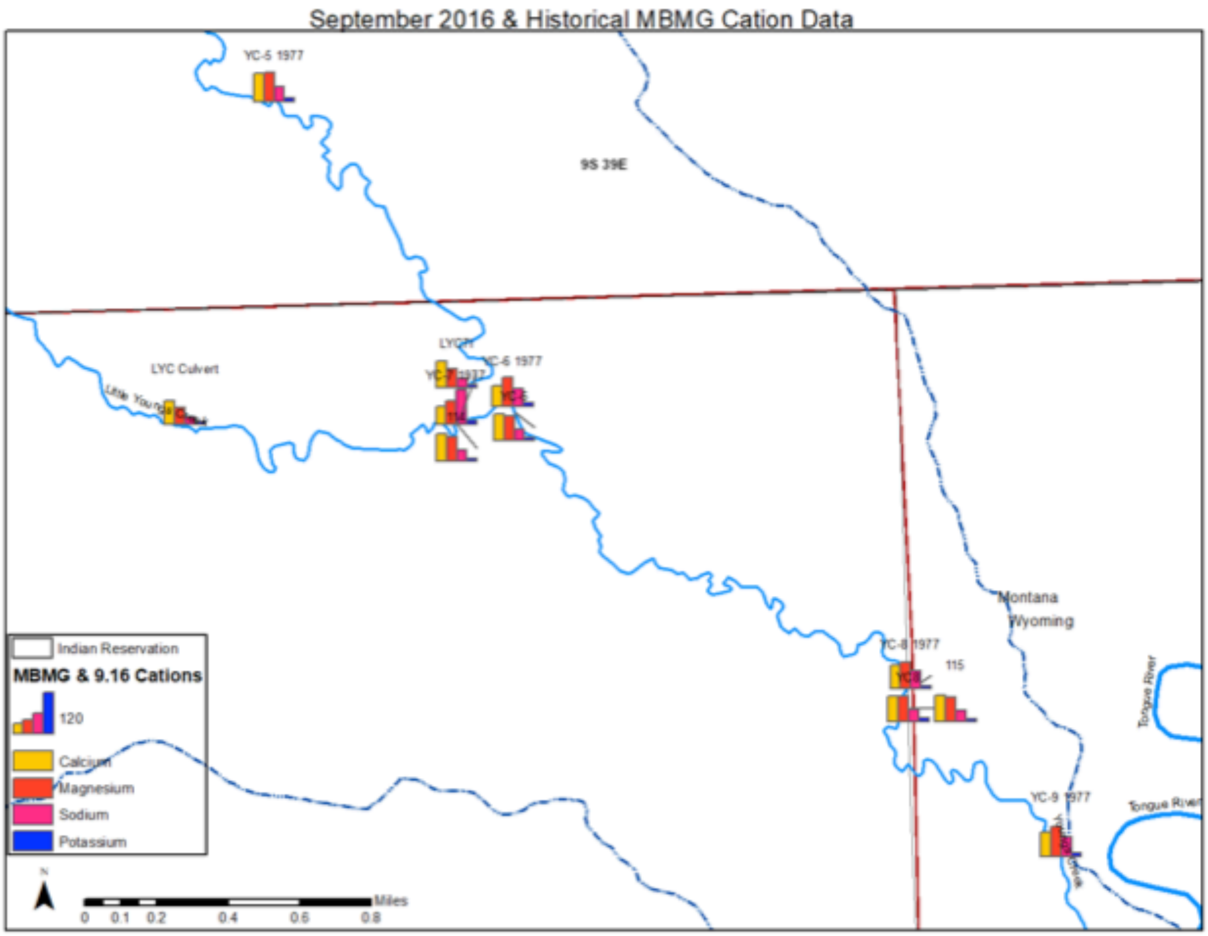

Figure A.2. Cation data from September 2016 compared to historical data in Youngs Creek & Little Youngs Creek.

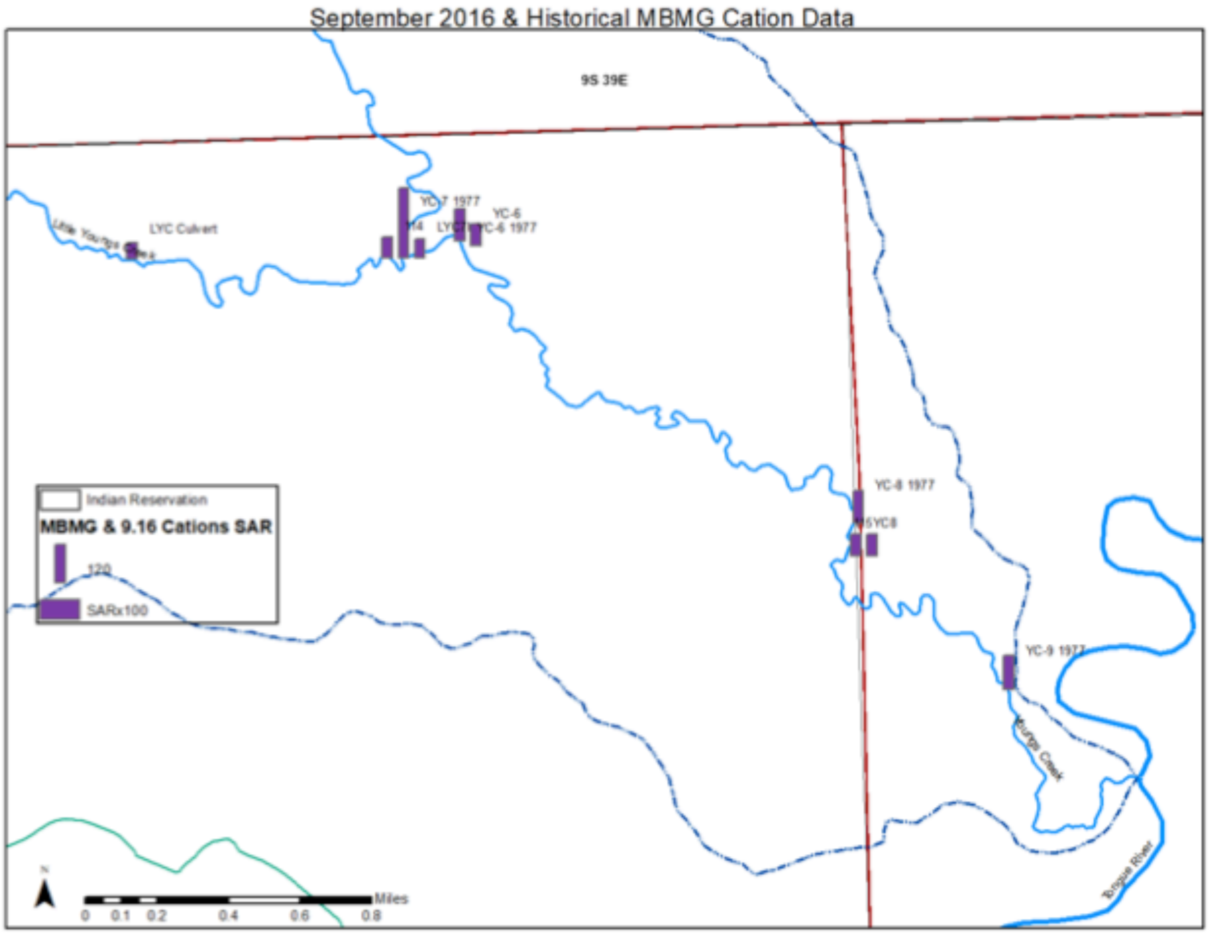

Figure A.3. SAR levels from September 2016 compared to historical data in Youngs Creek & Little Youngs Creek.

Table A.1. Characterization of sampling points.

Watershed Area
Elevation
State: MT/WY
Density of Wells in Watershed
Ownership
Tribal, Fee, State, Federal
(Land Use)

Watershed Area

Youngs Creek represents the largest watershed area, with points downstream of Little Youngs Creek having the largest tributary areas. Tanner Creek would represent the smallest tributary area. The watershed is disconnected from the Wolf Mountains and is surrounded by Upper Youngs Creek and Squirrel Creek. As a result, the watershed has the lowest precipitation and runoff of all the creeks in the study area.

Little Youngs Creek and Ash Creek both have headwaters located in the Wolf Mountains and slightly higher annual precipitation and runoff. Watersheds with headwaters originating in the mountains generally have larger annual precipitation.

Table A.2. Drainage area and annual precipitation and annual discharge of creeks within the study area.

Tanner Creek at Reservation Boundary (Hedges et al. 1998)	
Drainage Area	31.9 km^2 (7882.5 acres)
Average Annual Discharge	39.93 l/s (1.41 cfs)
Average Annual Runoff	3.81 cm (1.5 in)

Youngs Creek at Reservation Boundary (Hedges et al. 1998)	
Drainage Area	56.2 km^2 (13887 acres)
Average Annual Discharge	150.08 l/s (5.3 cfs)
Average Annual Runoff	8.13 cm (3.2 in.)
Annual Precipitation	36.83 cm (14.5 in)

Youngs Creek at Mouth/Confluence with Tongue River (Hedges et al. 1974)	
Drainage Area	166 km^2 (41020 acres)
Average Annual Discharge	0.26 cms (9.16 cfs)
Average Annual Runoff	49.1 mm (1.93 in.)
Annual Precipitation	349 mm (13.74 in.)

Little Youngs Creek at Mouth (Hedges et al. 1974)	
Drainage Area	44.1 km^2 (10897 acres)
Average Annual Discharge	0.05 cms (1.77 cfs)
Average Annual Runoff	34.3 mm (1.35 in.)
Annual Precipitation	356 mm (14.02 in.)

Table A.2. Elevation range of watersheds.

Watershed	Elevation
Tanner Creek	4864 – 3743 ft
Youngs Creek	4349 – 3559 ft
Little Youngs Creek	4171 – 3624 ft
Ash Creek	4143 – 3548 ft

Montana

Sampling points upstream of the reservation boundary are not located near energy development. A few sampling points on Youngs Creek north of the state border are near coal bed methane wells, however, all points are upstream of wells.

Wyoming

All of the sampling points in Wyoming are located downstream of some form of energy development. The Little Youngs Creek watershed, there is past coal mine development and coal bed methane wells. Youngs Creek sampling points are downstream of prior coal bed methane well development. Ash Creek watershed sampling points are downstream of oil and gas and coal bed methane well development.

Ownership (West of Reservation Boundary)
Tanner Creek has the largest tribal ownership with approximately 70 percent tribal land interests in the potential mine area (Figure 1.2.).

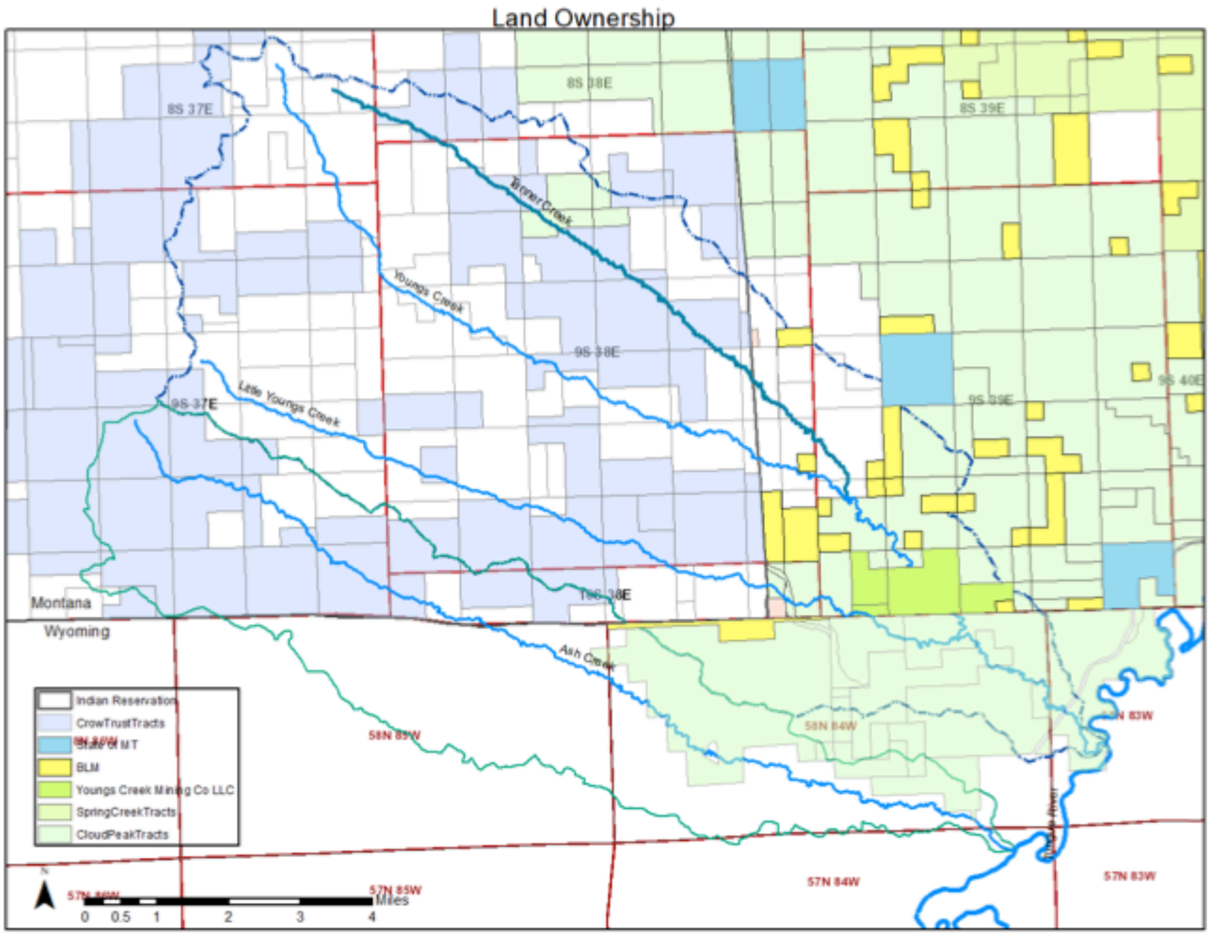

Figure A.4. Land ownership in study area watersheds. The land tracts represent tax parcels and allotments.

Youngs Creek is primarily fee land ownership throughout the watershed. The ownership of tribal lands within the watershed is approximately 40% (Figure A.4.).

The Little Youngs Creek watershed is approximately 60 percent fee land ownership and 40 percent tribal ownership. The Youngs Creek Mine project area contains the majority of the Little Youngs Creek watershed in Wyoming. Within the project area, Chevron has leased or sold its surface land title to Cloud Peak. Fee lands held by private owners comprise the remaining land ownership of the watershed.

The Ash Creek watershed north of the Montana state line is primarily under tribal ownership. The Ash Creek watershed in Wyoming is entirely fee land.

Density of Wells in Watersheds

CBM wells in Montana are located in the Township 9 South and Range 39 East that includes the watersheds of Youngs Creek and Little Youngs Creek east of the reservation boundary. There are 3 sections in Montana within the Youngs Creek drainage where CBM wells had been drilled (Figure A.5.). The concentration ranges from 1 well per 2.59 km^2 (1 mi^2) to 19 wells per 2.59 km^2 (1 mi^2). There are 25 total wells within the Youngs Creek watershed and one well within the Little Youngs Creek watershed in Montana. There are no coal bed methane wells located within the reservation boundary.

Coal bed methane well concentration in Wyoming in the Township 58 North and Range 84 West is higher than the sections in Montana (Figure 1.4.). The largest concentration is 24 wells per 2.59 km^2 (1 mi^2) in section 24, which is located in the Youngs Creek drainage (Figure A.5.). The wells in sections 22, 23, 24, 25, 26, and 27 flow into the Little Youngs Creek and Youngs Creek drainages (Figure A.5.). Coal bed methane wells are also located in Township 58 North and Range 83 West sections 19 and 30 flow into the downstream end of Youngs Creek drainage (Figure A.5.). Each section has one well that flows into the Youngs Creek drainage.

There are several CBM wells in sections within the Ash Creek drainage. Sections 35 and 28 have 5 and 2 CBM wells, respectively, that flow into the Ash Creek drainage. Several oil wells are also located along the Ash Creek drainage. The Dry Creek watershed located south of Youngs Creek watershed and north of the downstream end of Ash Creek watershed also has significant coalbed methane well development but does not appear to interact with drainages in either watershed.

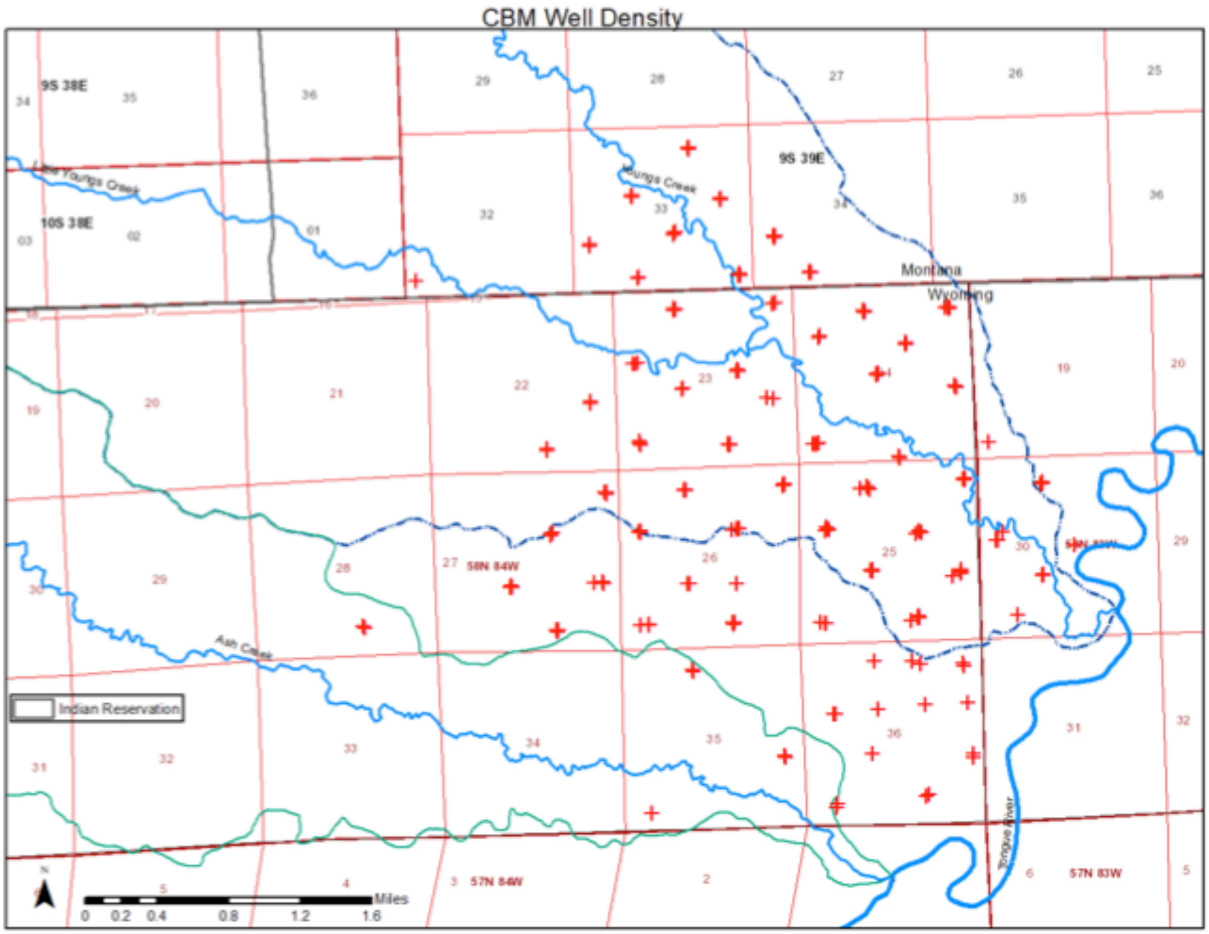

Figure A.5. CBM well locations. Well (+) density located in each section is presented within Little Youngs Creek, Youngs Creek, and Ash Creek watersheds.

Table A.4. Distance of sampling points to wells.

Sampling Site	Distance to CBM wells
In Montana	
Youngs Creek	2 sample points > 1.6 km from CBM wells
Little Youngs Creek	Sampling points were upstream from CBM well development
In Wyoming	
Youngs Creek	
YC-6	354 m & 370 m from CBM wells
YC-7	209 m, 209 m, 225 m from CBM wells
YC-8	145 m, 158 m, 160 m from CBM wells
Little Youngs Creek	
LYC106	515 m, 515 m from CBM wells
Ash Creek	
AC3	692 m, 692 m from CBM wells
AC107	547 m from CBM well
AC86	434 m., 482 m from CBM wells

Table A.5. Distance to mine development.

Sampling Site	Distance to Mine
In Montana	
MPDES Outfall	Immediately adjacent to West Decker Mine
In Wyoming	
LYC Culvert	152 m from Ash Creek mine
YC-7	563 m from Ash Creek mine
Hidden Water Pond	Located within the reclaimed Big Horn mine site

Table A.6. Youngs Creek and Little Youngs Creek water quality results.

	Youngs Creek No. Samples 7	Little Youngs Creek No. Samples 5
Sodium	12 - 36 mg/L	12 - 34 mg/L
Chloride	2 - 3 mg/L	2 - 3 mg/L
SAR	0.28 - 0.69	0.34 - 0.66
Magnesium	47 - 74 mg/L	25 - 73 mg/L
Potassium	6 - 9 mg/L	5 - 9 mg/L
Calcium	70 - 80 mg/L	54 - 80 mg/L
Arsenic	0.006 - 0.011 ppm	0.003 - 0.012 ppm
Barium	0.088 - 0.116 ppm	0.068 - 0.112 ppm
Boron	0.075 - 0.156 ppm	0.053 - 0.163 ppm
Iron	0.002 - 0.029 ppm	0 - 0.018 ppm
Date Sampled	9/2016	9/2016

Table A.7. Tanner Creek and Ash Creek water quality results.

	Tanner Creek No. Samples 3	Ash Creek No. Samples 8
Sodium	109 - 123 mg/L	45 - 105 mg/L
Chloride	7 - 13 mg/L	3 - 45 mg/L
SAR	1.21 - 1.68	0.49 - 1.84
Magnesium	175 - 245 mg/L	52 - 129 mg/L
Potassium	18 - 21 mg/L	8 - 21 mg/L
Calcium	109 - 238 mg/L	62 - 117 mg/L
Arsenic	0.007 - 0.01 ppm	0.002 - 0.011 ppm
Barium	0.028 -0.142 ppm	0.014 - 0.15 ppm
Boron	0.234 - 0.382 ppm	0.136 - 0.429 ppm
Iron	0.034 - 0.255 ppm	0 - 0.016 ppm
Date Sampled	9/2016	9/2016

Table A.8. Reclaimed and developed sites water quality results.

Developed Sites	Hidden Water Creek Big Horn Mine – Reclaimed	MPDES Outfall West Decker Mine
Sodium	154 mg/L	159 mg/L
Chloride	21 mg/L	20 mg/L
SAR	2.47	2.1
Magnesium	149 mg/L	136 mg/L
Potassium	29 mg/L	24 mg/L
Calcium	52 mg/L	209 mg/L
Arsenic	0.16 ppm	0.005 ppm
Barium	0.039 ppm	0.048 ppm
Boron	0.227 ppm	0.466 ppm
Iron	0.009 ppm	0
Date Sampled	9/2016	4/2016

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