

FINAL REPORT

LITERATURE REVIEW AND DEVELOPMENT OF A STUDY PLAN TO ASSESS THE EFFECTS
OF COALBED NATURAL GAS ACTIVITIES ON FISH ASSEMBLAGES

WINDY N. DAVIS

ROBERT G. BRAMBLETT

ALEXANDER V. ZALE

MONTANA COOPERATIVE FISHERY RESEARCH UNIT
FISH AND WILDLIFE MANAGEMENT PROGRAM
DEPARTMENT OF ECOLOGY
MONTANA STATE UNIVERSITY
BOZEMAN, MONTANA 59717

PREPARED FOR :

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
MILES CITY FIELD OFFICE
111 GARRYOWEN ROAD
MILES CITY, MONTANA 59301

FEBRUARY 2006

Foreword

This report fulfills the requirements of a CESU Research Proposal contract. It contains a comprehensive literature review on the effects of CBNG development and discharge of CBNG ground water on fish assemblages, a study plan and proposal to conduct a multiyear research project on the effects of coalbed natural gas (CBNG) on fish assemblages in streams in Montana and Wyoming, and a list of the supplies purchased for the research project.

THE EFFECTS OF COALBED NATURAL GAS ACTIVITIES ON FISH ASSEMBLAGES: A REVIEW OF THE LITERATURE

Executive Summary

Effects of coalbed natural gas (CBNG) development on fish assemblages in the Powder River Basin are generally unknown. Fishes endemic to the Powder River Basin have evolved life history strategies that allow them to survive in extreme conditions. However, water development that alters water quality or water quantity may nevertheless result in changes in the fish assemblage. Few studies have been conducted to specifically address the effects of CBNG development on fish assemblages in the Powder River Basin, but studies conducted elsewhere have addressed changes in water quality and water quantity, and surface environment alterations such as road building. We reviewed the literature pertaining to these potential effects and considered the applicability of these studies to CBNG development. However, CBNG development in the Powder River Basin is unique because product water in other basins is not typically discharged to surface waters.

An exception is the Black Warrior Basin, Alabama, where no significant decline in fish species diversity or total fish biomass occurred after discharge of CBNG product water began. However, the abundance of Gulf darters (*Etheostoma swaini*) decreased with the presence of product water, and reproduction of the rough shiner (*Notropis baileyi*) was significantly greater downstream of discharge. These subtle patterns of fish species variation suggested that the aquatic system was changing and that long periods of CBNG product water discharge may result in changes in assemblage composition.

The inferences that can be made among geologic basins with CBNG development are limited because the major ion composition of product water varies among basins. Moreover, CBNG product water can be variable within a geologic basin. In the Powder River Basin, CBNG product water is highly variable among wells and chemistry changes as it mixes with surface waters and equilibrates with the atmosphere.

Information on chronic toxicity of saline discharges on fish in the Powder River Basin is generally lacking, presenting a substantial gap in predicting effects. Hatch and survival rates of fathead minnow eggs exposed to sodium bicarbonate (NaHCO_3), the major salt associated with CBNG product water in the Powder River Basin, were lower than controls in both acute and chronic exposures. However, use of the fathead minnow, a species tolerant to adverse biological conditions, including a high salinity tolerance, likely underestimates the potential effects to more sensitive native species. Although water quality standards for total dissolved solids (TDS) and conductivity are established by the Montana and Wyoming departments of environmental quality to protect aquatic life, general parameters such as TDS and conductivity do not account for the differing toxicities of individual ions or combinations of ions. Instream acute and chronic toxicity tests with native fish species of various tolerance levels should be conducted to better understand the effects of CBNG product water to fish assemblages in the field.

The effects that other water quality parameters may have on fish assemblages in the Powder River Basin are uncertain. Reported pH levels of CBNG product water are within the optimal range for fish productivity. Metals may be a concern, because the levels of several metals and trace elements in CBNG product water, wetlands, impoundments, sediments and biological tissues exceeded either Wyoming Department of Environmental Quality chronic standards or other biologically relevant thresholds. CBNG product water is low in dissolved oxygen, but no information exists on the potential for CBNG discharges to change instream dissolved oxygen levels. No information is available on the turbidity levels of CBNG product water, but the authors have noted product water can be less or more turbid than surface water. If CBNG product water reduces turbidity, non-native sight feeding fish may be afforded a competitive advantage over native fish. Increased turbidity may also alter native fish assemblages.

Coalbed natural gas development may change natural stream flow and temperature regimes in the Powder River Basin where intermittent or ephemeral surface water discharges are typical. The pumping of coal seam aquifers may lead to the reduction of water inputs from springs and hyporheic flow that help maintain important refugia for fish. Conversely, discharge of CBNG product water to streams increases stream discharge in some areas. The temperature of

CBNG product water is within the range of temperatures found in surface waters in the Powder River Basin, but is relatively constant year-round. Continuous input of constant-temperature product water may disrupt natural environmental cues and result in changes in fish behavior and reproduction.

Road construction associated with CBNG development may increase stream sedimentation and constructed stream crossings may fragment fish populations and lead to decreased diversity. Whereas some streams of the Powder River Basin have naturally high sediment loads, others have rocky substrate and provide important spawning habitat for migratory fish. Increased sedimentation of these streams may lead to the elimination of reproductive opportunities for litho-obligate species such as goldeye (*Hiodon alosoides*), sturgeon chub (*Macrhybopsis gelida*), longnose dace (*Rhinichthys cataractae*), and sand shiner (*Notropis stramineus*).

Uncertainty exists concerning the potential effects of CBNG development on fish in the Powder River Basin. The severity and direction of effects that are known are ambiguous because of differing environmental conditions and spatial and temporal differences in product and surface water chemistry among geologic basins and within the Powder River Basin. This highlights the need for further field and laboratory research. Field-based research, including baseline biomonitoring and directed field studies will be beneficial because stream biota are indicators of instream environmental conditions. Directed field studies in drainages with and without CBNG development, upstream and downstream of CBNG development, and before and after CBNG development are needed to ascertain if CBNG development has affected fish assemblages. Laboratory and instream acute and chronic toxicity tests with native fish species should be conducted to better understand the effects of CBNG product water on fish.

Physical Setting of the Powder River Basin

Geology

In geologic terms, the Powder River Basin (PRB) is a structural basin characterized by Cenozoic sediments of continental origin (Brown 1993) that formed during the Laramie Orogeny about 60 million years ago (Alt and Hyndman 1986; Glass and Blackstone 1996). The PRB is bounded by the Bighorn Mountains on the west, the Black Hills on the east, and extends north from near Douglas, Wyoming, to Miles City, Montana. The PRB is about 31,000 km² in area (Ellis et al. 1999), extending about 354 km from north to south and up to about 153 km from east to west, with about two-thirds of its area in Wyoming and one-third in Montana.

The PRB is rich in energy resources including oil, gas, and coal deposits. It contains some of the world's largest deposits of low-sulfur bituminous coal, most of which is federally owned (BLM 2003). The most important coal seams in the PRB are associated with the Fort Union and Wasatch Formations where coalbed natural gas (CBNG) retention is enhanced by the hydrostatic pressure of groundwater within the coal seam. The recoverable CBNG resource has been estimated at 24 to 39 trillion cubic feet, of which less than one trillion cubic feet occurs in Montana (Decker 2001; BLM 2003; Ruckelshaus Institute of Environment and Natural Resources 2005). The relatively small amount of CBNG in Montana reflects less favorable geologic structure and topography for CBNG production, as well as the smaller area of the PRB in Montana (Wheaton and Donato 2004a).

Physiography

The PRB is located in the Northwestern Great Plains ecoregion (Woods et al. 2002; Chapman et al. 2004). It was unglaciated. Elevations of the PRB range from about 2,200 m in the foothills of the Bighorn Mountain in Wyoming to 719 m at the mouth of the Tongue River in Montana. The region has a semiarid continental climate with annual precipitation ranging from 30 to 48 cm, and mean annual frost free-days ranging from 90 to 135 days. Mean monthly minimum and maximum January air temperatures are -19° C and 2° C, whereas mean monthly minimum and maximum July air temperatures are 10° C and 32° C.

A wide range of vegetative types exist in the PRB, ranging from grasslands with grama, needlegrass, and wheatgrass, to shrubs including rabbitbrush, fringed sage, and snowberry, to Rocky Mountain juniper-ponderosa pine forests in the pine scoria hills. Riparian areas often contain deciduous woody vegetation including cottonwood, boxelder, and chokecherry. Land use in the PRB is primarily rangeland grazing, with dryland agriculture and limited irrigated and sub-irrigated agriculture along the major stream valleys. Coal mining, coalbed natural gas production, oil production, and uranium mining are localized land uses in the PRB (Woods et al. 2002; Chapman et al. 2004).

Hydrology

Surface water.—The PRB contains portions of several surface hydrologic basins including most of the Tongue and Powder rivers, the upper portions of the Belle Fourche and Cheyenne rivers, Rosebud and Armells creeks in Montana, and a small portion of the North Platte River. All of the surface waters of the PRB are within the Missouri River basin. The Tongue and Powder rivers and Rosebud and Armells creeks are north-flowing tributaries of the Yellowstone River. The Belle Fourche River is a tributary of the Cheyenne River, which joins the Missouri River at Lake Oahe Reservoir in South Dakota. The North Platte River and the South Platte River form the Platte River in Nebraska, which joins the Missouri River south of Omaha, Nebraska.

Streams of the PRB have headwaters in either montane or plains regions. Although each stream has unique topography, geology, vegetative cover, and drainage basin area, some generalizations can be made in distinguishing streams of the PRB with montane headwaters from those of plains origin (Clark et al. 2001; BLM 2003). Streams with montane headwaters have stream flows that are dominated by snowmelt (Lowham 1988), have lower temperatures and concentrations of dissolved and suspended solids (but which increase downstream as they traverse the plains), and more perennial flows than plains streams (BLM 2003). In contrast, plains streams tend to be ephemeral, containing water only after rains or snowmelt (Lowham 1988), or intermittent, with flow in response to rain or snowmelt, but maintaining isolated pools year-round. Only the largest plains streams approach conditions of perennial flow. Plains rivers and streams have highly variable hydrographs, as illustrated by the Powder River, which had an

estimated peak discharge of 100,000 cfs at Moorhead, Montana, in 1923 (USGS 2005a), but also has 146 days on record when streamflow was 0 or less than 1 cfs (USGS 2005b).

The headwaters of the Tongue River are in the Bighorn Mountains west of Sheridan, Wyoming. The river then flows generally northeast to meet the Yellowstone River at Miles City, Montana. The Tongue River Dam forms the 1,416 ha (at full pool) Tongue River Reservoir near Decker, Montana, and regulates the downstream hydrograph and thermograph. Additionally, four lowhead irrigation diversion dams are located on the Tongue River between the Tongue River Dam and the confluence with the Yellowstone River. The Tongue River drainage basin area is 13,932 km², 70% of which is in Montana (Elser et al. 1980). In Wyoming, perennial tributaries of the Tongue River include Goose Creek, Prairie Dog Creek, and Youngs Creek (Wesche and Johnson 1981). The largest tributaries in Montana are Hanging Woman, Otter, and Pumpkin creeks; these three plains tributaries lack discharge data but are likely intermittent.

The Powder River is the largest hydrologic basin in the PRB; its drainage basin area is 34,318 km² (Rehwinkle 1978). The North Fork of the Powder River originates in the Bighorn Mountains in Wyoming, the Middle Fork originates in the Wyoming basin ecoregion (Chapman et al. 2004), and the South Fork originates on the northwestern Great Plains near Powder River, Wyoming. The Powder River is recognized as perhaps the most pristine remaining example of a Great Plains river and is characterized by its high turbidity, salinity, flashy hydrograph, shallow water depths, and shifting sand substrate (Rehwinkle 1978; Elser et al. 1980; Hubert 1993). Only four perennial tributaries enter the Powder River—Crazy Woman Creek and Clear Creek in Wyoming and the Little Powder River and Mizpah Creek in Montana (Hubert 1993).

Groundwater.—Groundwater resources are found in several aquifers that are located at varying depths below the land surface in the PRB. Aquifers that occur at or near the land surface are associated with alluvial or basin fill deposits, sandstones, coal beds, or clinker (Whitehead 1996; Heffern and Coates 1999). Groundwater flows generally northward in the PRB and springs that discharge ground water are commonly found where coal seams crop out in the Montana portion of the PRB (Wheaton and Donato 2004a). Groundwater associated with coal seams is generally suitable for drinking and livestock water (Wheaton and Donato 2004a).

Deeply buried aquifers in the PRB are geologically older and isolated from the shallow aquifers, and are too deep to be affected by CBNG development (BLM 2003). The chemistry of groundwater changes with depth. Calcium (Ca^{2+}), magnesium (Mg^{2+}), and sulfate (SO_4^{2-}) decrease, whereas bicarbonate (HCO_3^-) increases with depth to about 152 m. Below 152 m deep, the water chemistry is more static, and sodium (Na^+) and bicarbonate are the dominant ions (Rankl and Lowry 1990; BLM 2003a). The water quality of water co-produced by traditional oil and gas activities from deep aquifers is so poor that surface disposal is normally not permitted (Wheaton and Donato 2004a).

Fish of the Tongue and Powder Rivers

The Great Plains region was likely drained by three major river systems prior to Pleistocene glaciations: an Arctic river that flowed to Hudson Bay (today's upper Missouri River), the southward flowing Mississippi river system, and a preglacial Plains river that also drained southward, but largely independent of the preglacial Mississippi. Southward advances of glacial ice deflected the northward- and eastward-flowing drainages to the south and contributed glacial runoff. Thus, glacial advances created the contemporary Missouri/Mississippi drainage pattern and allowed mingling of the ichthyofaunas of the three preglacial drainage basins (Cross et al. 1986).

Currently, 30 native and 22 introduced fish species representing 13 families occur in the Powder and Tongue river basins (Brown 1971; Baxter and Stone 1995; Holton and Johnson 2003; Table 1). Cyprinids (minnows) are most speciose, with 11 native and 3 introduced species, followed by catostomids (suckers) with 8 native species.

The primary aquatic habitats of this area are the Powder and Tongue rivers, large plains streams, small plains streams, and cold water habitats. The Yellowstone River has a fairly diverse fish assemblage of 56 species (White and Bramblett 1993) and because it is connected to the Powder and Tongue rivers, provides a link to large river habitats for many species including pallid and shovelnose sturgeon, blue sucker, and sauger (Table 1). The ichthyofaunas of the

Powder and Tongue rivers have at least 13 species in common, but introduced species are much more common in the Tongue River (Table 1). The Tongue River has about 16 introduced species that do not occur, or rarely occur, in the Powder River. This is because of the altered habitat conditions and the increased probability of species introductions associated with the Tongue River Reservoir and the cool, clear hypolimnetic water released from the Tongue River Dam. In contrast, only two introduced species commonly occur in the Powder River (common carp and plains killifish); both species are tolerant of environmental extremes (Bramblett et al. 2005). Two native species that are adapted to naturally turbid plains rivers, shovelnose sturgeon and sturgeon chub, are found in the Powder River and not in the Tongue River. The ichthyofauna of large plains streams (e.g., Hanging Woman Creek, Otter Creek, Little Powder River) is similar to the ichthyofauna of smaller plains streams except that fewer species are found in the small plains streams (Table 1). Brook stickleback are the only species found primarily in small plains streams and not in large plains streams (Table 1; Bramblett, unpublished data). Fishes found in cold water habitats occur in streams of montane origin or immediately downstream of Tongue River Dam.

A total of nine fish species of concern occur in the Powder and Tongue river basins (Montana Natural Heritage Program 2004; Wyoming Natural Diversity Database 2005) (Table 1). The larger rivers have more species of concern than cold water habitats or small prairie streams. Five species of concern occur primarily in at least one of the larger rivers (Yellowstone, Powder, and Tongue rivers): pallid sturgeon, shovelnose sturgeon, paddlefish, sturgeon chub, and blue sucker. Three species of concern occur in large prairie streams in addition to the larger rivers: goldeye, western silvery minnow, and sauger. Yellowstone cutthroat trout is the only species of concern that occurs in coldwater habitats. None of the nine species of concern has primary habitat in small prairie streams (Table 1).

Coalbed Natural Gas Development in the Powder River Basin

General process of CBNG extraction

Coalbed natural gas (CBNG) is formed in buried coal seams. Gas molecules are held in small cracks and pores of the coal seam by overlaying sediment layers and by hydrostatic pressure created by water in the coal seams. Gas is brought to the surface by drilling a well and pumping water out of the coal seam. When the hydrostatic pressure is reduced, the natural gas can migrate out of the spaces of the coal seam and move up the well to be piped away (Wheaton and Donato 2004a). The water that is pumped out of the coal seam is referred to as CBNG product water.

Potential for coalbed natural gas development exists in over 20 countries (Talkington 2002). Active exploration or production of coalbed natural gas is taking place in the United States, Canada, western Europe, Japan, Australia, and New Zealand (Talkington 2002; Johnson 2004). Currently, the United States is by far the largest producer of coalbed natural gas with six major basins actively developed, including the Black Warrior in Alabama, San Juan and Raton in Colorado and New Mexico, Piceance and Uinta in Utah, and the Powder River in Montana and Wyoming (Van Voast 2003).

Growth of CBNG development has been the greatest in the PRB. Coalbed natural gas development in the PRB is unique because of shallow coal beds that are inexpensive to drill and product-water quality that has been deemed suitable for inexpensive disposal (Wheaton and Donato 2004a). The rank, or quality, of coal is determined by the depth of burial overtime. Lower rank coals, such as those in the PRB, are buried at shallower depths and are generally less dense. Deeply buried, higher rank coal beds are the targets for coalbed natural gas development in other basins of the United States (Van Voast 2003). The difference in burial depths results in production of two distinct types of methane gas. Biogenic natural gas is biologically driven and produced by microbial action in shallow basins, such as the PRB. Thermogenic natural gas is produced by the changes coal undergoes from heat and pressure in deep, marine sedimentary basins, such as the other CBNG-producing basins in the United States (Van Voast 2003). These deeply buried coal seams are generally dense, whereas lower rank coal seams are less dense and

have more interstitial spaces to hold water and gas molecules (Van Voast 2003). Low rank coal seams of the PRB have a low gas to water ratio and therefore, large quantities of CBNG product water are associated with the extraction of CBNG in the basin. Whereas great quantities of product water are produced in the PRB, its water quality is more similar to surface waters than the product water of the deeply buried coal beds, making it more eligible for surface water discharges or other uses (Rice et al. 2000; Van Voast 2003).

Product water disposal

Current management practices for the disposal of CBNG product water in the PRB include direct discharge to surface waters, discharge of treated water, impoundment, reinjection, irrigation, and other “beneficial uses.”

Direct discharge to surface waters.—Direct discharge to surface waters occurs when product water is delivered directly to a stream with a pipeline or when product water is released into an ephemeral channel that subsequently flows into an existing surface water. Permits for such point source discharges are subject to the National Pollution Discharge Elimination System (NPDES) permitting system and the regulations imposed by individual states. This permitting system generally considers water quality and quantity; however, limits established in permits may be less strict than necessary to protect biota and irrigation suitability (Confluence Consulting, Inc. 2004). In Montana, direct discharge to stream channels is not typically allowed on wells permitted after about 1999, but operations existing prior to this date were “grandfathered” and are still discharging directly into streams (ALL Consulting 2003). Proposals are being advanced to allow regulated direct discharges during certain flow periods on new well developments (BLM et al. 2003). The Wyoming Department of Environmental Quality (WYDEQ) had issued about 600 NPDES permits as of 2002 for CBNG product water discharges at nearly 3,000 different direct discharge points (Veil 2002). Multiple CBNG wells may be discharged from a single discharge point. Concerns surrounding direct discharge into stream channels include changes in flow regimes, the potential for bank erosion and degradation of stream beds, and changes in water quality that may be detrimental to native biota or irrigation suitability (ALL Consulting 2003). Direct discharge would be expected to have the greatest potential effect on fish assemblages of all disposal methods.

Discharge of treated water.—In some cases, product water is treated before it is discharged to surface waters. Product water subject to treatment is typically of poor water quality (>15,000 ppm TDS) and is placed in lined holding ponds during treatment. Treatment techniques include desalinization, UV sterilization, chemical treatment, reverse osmosis, and ion exchange processes (ALL Consulting 2003). Treatment technologies are limited to treating dissolved solids, organics, and conductive ions in concentrated product water (ALL Consulting 2003).

Impoundment.—Several types of impoundments are used depending on specific product water management needs. Impoundments may be in-channel or off-channel, and lined or unlined. In-channel impoundments use structures to create a barrier to downstream flow and capture water that would otherwise flow downstream. Potential discharges of product water down the stream channel occur during flooding or upon barrier failure (ALL Consulting 2003). Off-channel impoundments are typically placed and constructed to minimize the capture of surface water. Lined impoundments are used for holding product water until the next management action, such as irrigation or reinjection, is taken. In contrast, unlined impoundments are used as infiltration ponds that discharge product water to the subsurface. Whereas most water evaporates or infiltrates to deeper groundwater sources, an estimated 15-20% of water from unlined impoundments is likely to reach nearby stream channels by subsurface flow (ALL Consulting 2003). The most common use of impoundments is for disposal through evaporation or infiltration (ALL Consulting 2003).

As of June 2005, over 3,000 impoundments had been permitted in Wyoming (WOGCC 2005). The permitting requirements for impoundments vary from state to state, but are largely dependent on the quality of the impounded water and its eventual use (ALL Consulting 2003). Coalbed natural gas producers in Montana and Wyoming should collect hydrogeologic information at each site to determine the ability of the product water to affect the chemistry of shallow, unconfined groundwater, reach surface waters, or infiltrate into the subsurface (ALL Consulting 2003). Impoundment, particularly the use of infiltration ponds, may affect fish assemblages if product water enters surface waters.

Irrigation.—Some CBNG product water may be suitable for crop and rangeland irrigation by sprinkling or flooding. However, the potentially high salinity hazard of CBNG product water requires irrigators to carefully manage the dispersal of CBNG waters on their crops or rangeland (Keith et al. 2003). Surplus irrigation water will percolate through the soil and may seep into shallow aquifers or stream channels (Lindner-Lunsford et al. 1992). When irrigation rates are high, significant amounts of CBNG water can enter stream channels by surface and subsurface flow and mix with surface water (ALL Consulting 2003). As with infiltration ponds, irrigation may affect fish assemblages if product water enters stream channels.

Reinjection.—Underground injection wells currently are used in conventional oil, gas, and CBNG fields across the country. This water management strategy is dependent on the quality of the product water, the quality of the receiving water, the availability of a receiving geologic formation, and the storage capacity of the receiving geologic formation. The goal of reinjection is to dispose of poor-quality product water at depths that will not influence ground or surface waters used for anthropogenic purposes. Reinjection has proven to be environmentally safe and economical in many instances, but it is important that site-specific analyses be done. The current permitting system in Wyoming allows for area permits that apply to all reinjection wells in a given area. Differences in local hydrogeology and the design construction of some of the classes of reinjection wells may not provide adequate protection against possible groundwater contamination (ALL Consulting 2003). Reinjection of CBNG product water likely poses little threat to fish assemblages because the product water typically does not mix with surface waters. However, reinjection is not common in the PRB because it is not as economical as permitted surface discharges or impoundments.

Other “beneficial uses.”—Product water may have beneficial uses for the CBNG and coal industries and farmers and ranchers (BLM et al. 2003). Product water is used for dust control, stock water, wildlife habitat, fisheries, and mining. Product water that is suitable for livestock and wildlife consumption has been used to create watering sites. These can be beneficial to ranchers by expanding cattle grazing into areas formerly limited by a lack of watering sites. Additionally, moving cattle to water sources away from streams may decrease the effects of grazing on stream banks and riparian vegetation, which may be good for fish.

Product water has been used to sustain privately owned fish ponds where water quality has been sufficient to support rainbow trout and smallmouth bass (ALL Consulting 2003). Wetlands have been created in some areas to provide wildlife habitat. However, any beneficial uses of CBNG product water for livestock, wildlife, and fisheries will be short-lived because CBNG development is not projected to last more than 20 years (ALL Consulting 2003). Beneficial uses of CBNG product water likely poses little threat to fish assemblages because there is little contact with surface waters, or in the case of fish ponds, product water quality is high.

Potential Effects on Fish in the Powder River Basin

Effects of CBNG development on fish in the PRB are generally unknown. Fishes native to the PRB have evolved life history strategies that allow them to survive in extreme conditions. However, water development that alters water quality or water quantity may nevertheless result in changes in the fish assemblage (Hubert 1993). Unfortunately, pre-development baseline data for small streams in the area are minimal, but many efforts are currently being made to gain a better understanding of the local fish assemblages. Whereas few studies have been conducted looking specifically at effects of CBNG development on fish in the PRB (Confluence Consulting, Inc. 2003; 2004), other studies conducted elsewhere addressed similar questions regarding changes in water quality and water quantity, and surface environment alterations such as road building. We reviewed the literature pertaining to these potential effects and considered the applicability of these studies to CBNG development in this section.

Water quality

All natural waters contain dissolved chemicals introduced from the atmosphere, soil, rocks, or by human activities. The geologic setting plays an important role in creating the chemical signature of water, which may be used to infer its source (Van Voast 2003). Dissolved chemicals found in CBNG product water can be highly variable among wells and differ greatly from those in surface waters in the PRB because of their origin within coal seam aquifers (Clearwater et al. 2002; Van Voast 2003). Whereas the chemistry of CBNG product water is highly variable, generalizations exist. Water from coal seam aquifers is higher than surface waters in dissolved Na^+ and HCO_3^- whereas surface waters in the PRB generally are higher in

dissolved Ca^{2+} , Mg^{2+} , chloride (Cl^-), and SO_4^{2-} (Clearwater et al. 2002; Figure 1). Conductivity, TDS, and alkalinity of CBNG product water tends to increase from wells located in the southeast portion of the PRB to wells located in the northern and western areas of the PRB (Clearwater et al. 2002). CBNG product water can be highly variable even among wells located at similar depths in the same geological formation and less than 32 km apart (Clearwater et al. 2002). CBNG product water was significantly higher in pH, electrical conductivity, TDS, alkalinity, Na^+ , Ca^{2+} , Mg^{2+} , and K^+ in wells located in the Little Powder River drainage basin than wells in Cheyenne River drainage basin (McBeth et al. 2003).

The chemical properties of CBNG product water at or near the point of discharge are monitored and generally well known. However, as product water mixes with surface water and achieves equilibrium with the atmosphere, product water chemistry changes (Sessoms et al. 2002). Several efforts have been made to understand and monitor the chemistry of the product water, and more recently to understand the changes CBNG water undergoes when exposed to environmental factors (Rice et al. 2000; Sessoms et al. 2002; McBeth et al. 2003; Patz et al. 2004). Monitoring CBNG product water only at well heads may not be sufficient to detect actual effects to downstream water (Patz et al. 2004).

Surface waters in the drainage basins of the PRB also vary in water quality. The ranks of conductivity in surface water basins of the PRB from highest to lowest is the Belle Fourche River, the Little Powder River, the Powder River, Piney Creek, and the Tongue River (Figure 2). Because both surface waters and product water in the PRB are variable, surface waters can be lower or higher in conductivity than product water (Figure 2). Therefore, in some locations product water may tend to “salinize” surface waters, and in other locations, product water may tend to “dilute” surface waters. However, both dilution and salinization have potential to affect native aquatic biota (Clearwater et al. 2002), particularly if ion composition differs from that found in the surface waters where the biota evolved.

Salinity.—The salinity of water generally refers to the concentration of mineral salts dissolved in water. Salinity may be measured by weight (total dissolved solids) or electrical conductivity (APHA 1998). Total dissolved solids are a quantitative measure of the residual

minerals dissolved in water that remain after evaporation of a solution, typically expressed in milligrams per liter (mg/L) or in parts per million (ppm), which are equivalent. Conductivity is a measure of the ability of an aqueous solution to carry an electric current. The presence of ions, their total concentration, mobility, and valence as well as water temperature determine the conductivity of water (APHA 1998). Sodium adsorption ratio (SAR) is a measurement of the relative proportion of sodium to other cations and is typically used in agriculture to determine the suitability of water for irrigation (Jain 2005). Whereas SAR is an important water quality issue for irrigators, it has limited inference to aquatic environments.

Salinity can be a dominant factor in structuring stream fish assemblages (Higgins and Wilde 2005). Increases in salinity as intermittent pools lost water volume by evaporation were related to the likelihood of persistence of fish species in Texas streams (Ostrand and Wilde 2001; Ostrand and Wilde 2004; Higgins and Wilde 2005). Whereas cyprinids were absent from pools where salinity exceeded 21‰, cyprinodontids persisted in pools with salinities ranging to 44‰ (Ostrand and Wilde 2004). Biodiversity typically decreases in salinized rivers and streams as low salinity tolerant taxa are extirpated and only high salinity tolerant taxa can persist (Williams 2001). About 60% of low and moderate salinity tolerant fishes present before a period of drought in the 1950s were apparently extirpated in the Red River drainage of Oklahoma and Texas from the 1950s to the 1990s, compared to the apparent extirpation of only 14% of high salinity tolerant species (Higgins and Wilde 2005).

Oilfield brine discharges can increase salinity of nearby streams and have negative effects on aquatic biota. Oilfield brines raised instream chloride levels from an average of less than 10 ppm to often exceeding 1,000 ppm in Green River, Kentucky, and fish species richness averaged 38 species in stream sections receiving brines compared to an average of 56 species in stream sections upstream of brine sources (Charles 1964). Petroleum well brine discharges in Petronella Creek, Texas, increased conductivity from 974 μmhos above discharge sites to as high as 29,551 μmhos below discharge sites. Fish species richness was reduced from about 20 species above brine discharge sites to 0 to 4 species below discharge sites (Shiple 1991).

Salt Creek, a tributary to the Powder River in Wyoming, receives oil field brines (Boelter et al. 1992). Conductivity, alkalinity, pH, and concentrations of Na^+ , K^+ , Cl^- , HCO_3^- , and CO_3^{2-} increased in the oil fields and generally decreased downstream. Conductivity in Salt Creek above the oil fields ranged from 4,170 to 4,840 μmhos ($N = 5$), whereas it ranged from 6,000 to 6,740 μmhos ($N = 5$) below the oil fields. Conductivity in the Powder River above the confluence of Salt Creek ranged from 828 to 2,500 μmhos ($N = 3$), whereas it ranged from 1,688 to 5,930 μmhos ($N = 4$) below Salt Creek. Survival and reproduction of *Ceriodaphnia dubia* was significantly reduced in ambient water samples collected downstream of the oil fields, and toxicity increased as ion and element concentrations increased during periods of low stream discharge. Alkalinity, Cl^- , Na^+ , K^+ , and pH explained from 81% to 94% of the variance in *C. dubia* survival. In contrast to *C. dubia*, the survival of fathead minnows was not affected by the test conditions. However, during a period of low stream discharge and increased ion concentrations, growth of fathead minnows was significantly reduced in water samples collected below oil fields (and from the Powder River upstream of Salt Creek), relative to growth of fathead minnows in water from Salt Creek upstream of the oil fields (Boelter et al. 1992).

Metals and trace elements.—Levels of several metals and trace elements in water, sediments, aquatic vegetation, aquatic invertebrates, salamanders, and fish from wetlands and containment ponds receiving CBNG product water exceeded WYDEQ standards, or other biologically relevant levels (Ramirez 2005). One CBNG product water discharge exceeded the WYDEQ chronic criterion for copper (Cu) and several CBNG product water discharges exceeded the WYDEQ chronic criterion for iron (Fe). Concentrations of arsenic (As), cadmium (Cd), nickel (Ni), and zinc (Zn) in sediment samples from a wetland receiving CBNG product water were high enough for potential adverse effects on sediment-dwelling organisms. Boron (B), cadmium, and chromium (Cr) levels in some aquatic vegetation samples and cadmium levels in some aquatic invertebrate samples exceeded levels of concern for wildlife dietary thresholds. Chromium levels in tiger salamanders (*Ambystoma tigrinum*) and fathead minnows were indicative of chromium contamination. Selenium (Se) levels in CBNG product water and impoundments exceeded a threshold for bioaccumulation in sensitive species of fish and aquatic birds. However, because no data exist for this area prior to the development of CBNG, it is not known if these levels are natural or related to CBNG development (Ramirez 2005).

pH.—Fish tolerance of pH levels depends on factors such as dissolved oxygen, temperature, prior acclimatization, and ion composition. Direct lethal effects of pH to fish are not observed within a range of 5.0 to 9.5 and productivity is highest within a range of 6.5 to 8.2 (Anonymous 1955). Several fish species were able to tolerate extensive and rapid changes in pH from 7.2 to 9.6 and 8.1 to 6.0 (Weibe et al. 1934). The mean pH of product water from 47 wellheads in the PRB was 7.3 and ranged from 6.8 to 7.7 (Rice et al. 2000), whereas pH of surface waters in the PRB ranges from 7.7 to 8.8 (Linder-Lunsford et al. 1992; Clearwater et al. 2002). These pH levels of CBNG product water (Rice et al. 2000) are within the optimal range for fish productivity, however pH of product water discharged to ephemeral stream channels increased from 7.1 to 8.8 after being exposed to the atmosphere and reacting with soils (McBeth et al. 2003; Patz et al. 2004). These spatial and temporal changes in water chemistry make it difficult to predict the pH fluctuations of CBNG product water and the potential effects on fish assemblages.

Dissolved oxygen.—Dissolved oxygen concentration (DO), the amount of oxygen that is dissolved in water, is one of the most important parameters of water quality to fish. Dissolved oxygen levels below 5.0 mg/L can stress aquatic life and prolonged periods of low DO can result in fish kills (Ji 2005). The amount of DO in perennial surface waters of the PRB ranged temporally from 5.4 to 14.7 mg/L (Linder-Lunsford et al. 1992). Isolated pools in intermittent streams also experience large daily fluctuations in dissolved oxygen levels (Tramer 1977; Ostrand and Wilde 2001). Fish tolerance to low dissolved oxygen concentrations decreases with increased pH (Powers 1922; Weibe et al. 1934; Townsend and Cheyene 1944). Low DO levels (2.8 to 3.2 ppm) in headwater streams were associated with oil field discharge (Whiteside and McNatt 1972). CBNG product waters are typically low in DO (ALL Consulting 2003), but no information was found regarding specific DO levels of CBNG product waters in the PRB. However, DO concentrations in CBNG product water likely vary depending on the aquifer source and the level of aerobic or anaerobic activity at the extraction point (ALL Consulting 2003). Additionally, DO concentrations will increase above ground as a result of surface agitation (ALL Consulting 2003).

Turbidity.—Turbidity is a measure of water clarity and light transmission. Suspended matter such as silt, clay, and fine organic and inorganic matter create the levels of turbidity found in water. Turbidity is considered an adverse water quality characteristic affecting about 34% of the streams in the United States (Judy et al. 1988). However, most Great Plains streams are characteristically turbid and support native fish assemblages that have evolved under such conditions. Surface waters of the PRB have stochastic flow regimes resulting in fluctuating turbidity levels. The Powder River was named for its milky appearance. Turbidity of the Powder River ranges from 20 to 8,000 JCU with a median of 475 JCU (Clearwater et al. 2002). No information is available on the turbidity levels of CBNG product water, but the authors have noted that product water can be less or more turbid than nearby surface waters.

Non-native sight feeding fish may have a competitive advantage over native fish if CBNG product water decreases the turbidity of surface waters in the PRB. Many of the native fish found in the Powder River are non-sight feeders. Reduced turbidity in Midwestern prairie rivers has been hypothesized as contributing to the replacement of non-sight feeders with sight-feeding species. Turbid water gave non-sight feeding gizzard shad (*Dorosoma cepedianum*) competitive advantage over sight feeding bluegill (*Lepomis macrochirus*) (O'Brien 1977). Decreased turbidity may also increase predation on native species where introduced sight-feeding predators have become established. For example, turbidity may visually isolate creek chubs from predators such as brook trout (Gradall and Swenson 1982). Conversely, increased turbidity of surface waters caused by CBNG product water may affect fish assemblages by favoring those species more tolerant of turbid conditions. Elevated turbidity had less effect on prey consumption by species adapted to turbid environments (flathead chub) than on fish adapted to less turbid environments (sand shiner) (Bonner and Wilde 2002). Increased turbidity in areas of the PRB with relatively low turbidity may allow native species adapted to turbidity to expand their ranges or relative abundances in these areas.

Temperature.—Temperature affects virtually all activities of fishes. Most fish are ectotherms, with low metabolic rates and no insulation or countercurrent lamellar blood-water flow; therefore body temperature of most fish is a direct function of water temperature (Beitinger et al. 2000). The uppermost temperature tolerances of fish species are above the ambient

temperatures of their natural habitats (Mundahl 1990). Major fish families of the PRB (i.e., Cyprinidae, Catostomidae, Centrarchidae and Ictaluridae) all have critical thermal maxima greater than 30 °C (Beitinger et al. 2000). Temperatures of CBNG product water and surface waters do not exceed this threshold; the mean temperature of product water from 47 wellheads in the PRB was 19.6 °C and ranged from 13.8 to 28.7 °C (Rice et al. 2000) whereas surface waters ranged from 0.0 to 30.0 °C (Linder-Lunsford et al. 1992).

Surface waters of the PRB normally freeze in winter, but continual addition of CBNG product water to surface waters has resulted in some isolated areas that do not freeze (B. Stewart, Wyoming Game and Fish Department, personal communication 2005). Moreover, seasonal change in water temperature is an important environmental cue for the movement and spawning behavior some fish species (Gale 1986; Bjornn and Reiser 1991). Continuous input of constant-temperature CBNG product water may disrupt natural environmental cues and result in temporal changes in fish behavior and reproduction (Clearwater et al. 2002).

Potential effects of CBNG product water on fish.—Demonstrated effects of CBNG product water on fish are ambiguous. Fathead minnows and rough shiners exposed to CBNG product water from the Black Warrior basin, Alabama, had no significant mortality at Cl⁻ concentrations as high as 2,160 mg/L (Mount et al. 1993). Acute toxicity of 7 water samples from CBNG wellheads and 23 water samples from streams receiving CBNG product water in the PRB was tested on fathead minnows (Forbes 2003). None of the CBNG well head samples were toxic to fathead minnows, but two stream-water samples caused significant acute mortality of fathead minnows. However, these results are equivocal with respect to CBNG product water because the proximity of CBNG product water discharge relative to the sample location was not known. Moreover, the chemical constituent that caused the observed mortality could not be identified because constituent concentrations were either in concentrations below published lethal levels or were below levels in other samples from the study that did not cause mortality (Forbes 2003).

Newly hatched pallid sturgeon and fathead minnows were exposed to 518, 864, 1,440 and 4,000 mg/L NaHCO₃ to determine acute toxicity under two separate test conditions (Skaar et al.

2004). The two test conditions were reconstituted “Tongue River” and “Powder River” water, which were based on average water quality conditions in the two rivers. The “Powder River” water had higher Cl^- , SO_4^{2-} , Ca^{2+} , Mg^{2+} , Na^+ , potassium (K^+), and HCO_3^- levels than the “Tongue River” water. Ninety-six h LC50s of pallid sturgeon were 1,158 mg/L NaHCO_3 in Powder River water, and 1,828 mg/L NaHCO_3 in Tongue River water. The 96-h LC50 of fathead minnows was 1,643 mg/L NaHCO_3 in Powder River water. Mortality was insufficient (23% at the 4,000 mg/L NaHCO_3) to calculate a LC50 for fathead minnows in Tongue River water (Skaar et al. 2004).

Of ten salts tested in the laboratory for acute toxicity to fathead minnows, the four salts with the lowest 96-h LC50s values were KHCO_3 (<510 mg/L), K_2SO_4 (680 mg/L), NaHCO_3 (<850 mg/L), and KCl (880 mg/L) (Mount et al. 1997). The most toxic (96-h fathead minnow LC50) two-salt combinations were $\text{K}_2\text{SO}_4/\text{KHCO}_3$ (720 mg/L), $\text{NaHCO}_3/\text{KHCO}_3$ (740 mg/L), $\text{KCl}/\text{K}_2\text{SO}_4$ (760 mg/L), and KCl/KHCO_3 (770 mg/L). Laboratory-derived logistic regression models for toxicity of major ions to fathead minnows predicted 50% mortality at the following ion concentrations: $\text{K}^+ \approx 500$ mg/L, $\text{Mg}^{2+} \approx 1,800$ mg/L, $\text{HCO}_3^- \approx 2,000$ mg/L, and $\text{Cl}^- \approx 4,500$ mg/L. However, SO_4^{2-} was not predicted to cause 50 % mortality at concentrations up to 5,000 mg/L, and Na^+ and Ca^{2+} concentrations were not significant variables in fathead minnow mortality models (Mount et al. 1997).

Short-term laboratory tests do not capture potential longer term effects on growth, reproduction, and survival of fish because culturally derived salts in concentrations below known lethal concentrations affect growth and survival in chronic exposures. Fathead minnow eggs were hatched at 500, 800, 1,100, and 1,400 mg/L NaHCO_3 to assess the chronic toxicity of NaHCO_3 , the major salt in CBNG product water from the PRB (Skaar et al. 2004). The estimated hatch rate was 43.9% at 1,400 mg/L NaHCO_3 , and 62.5% in the control tank. Post hatch survival rate of the 96-h control was 94.3% whereas the survival rate was only 8.1% at NaHCO_3 concentrations of 1,400 mg/L. At 37 d, survival rate was 89% in the control and only 2.4% at 1,400 mg/L NaHCO_3 . Excessive mortality by day 37 in tests at 800, 1,100, and 1,400 mg/L NaHCO_3 prohibited calculation of a 60-d LC50 (Skaar et al. 2004). Gill lesions, kidney damage, and degeneration of ovarian tissue in fathead minnows increased with NaHCO_3

concentrations or number of days of exposure (Skaar et al. 2005). White suckers were more tolerant to elevated levels of NaHCO₃ than fathead minnows and pallid sturgeon (Skaar et al. 2005). The 96-h LC50 of newly hatched fry was 5,121 mg/L NaHCO₃ in Tongue River water and 5,421 mg/L NaHCO₃ in Powder River water. An LC50 could not be calculated for older fry; they appeared to be more tolerant than newly hatched fry (Skaar et al. 2005).

Laboratory tests provide some insight, but cannot address all of the potential effects of CBNG waters on fish because they do not characterize actual field conditions. Surface water chemistry fluctuates in the field, and CBNG product water changes as it reacts with soils, the atmosphere (Patz et al. 2004), and surface waters. Moreover, CBNG product water in the PRB is spatially variable (Clearwater et al. 2002). Laboratory tests typically use the fathead minnow, which is relatively tolerant of salts. Fathead minnow eggs and larvae withstood concentrations of salts four times greater than concentrations lethal to walleye and northern pike eggs and larvae (Peterka 1972). Fathead minnows can survive NaCl concentrations of up to 8,700 mg/L (Kochsiek and Tubb 1967) and were more tolerant than *Daphnia magna* of most salt combinations (Mount et al. 1997). Use of a tolerant species such as fathead minnow would underestimate effects on more sensitive species. Information on toxicity of CBNG product water on many fish species in the PRB is generally lacking, presenting a substantial gap in predicting effects of saline discharges on these ecosystems (Confluence Consulting, Inc. 2003). Survival rates to hatching of white suckers, walleye, northern pike, yellow perch, and common carp were significantly lower in sodium sulfate type waters greater than 2,400 mg/L TDS than in fresh water of 200 mg/L (Koel and Peterka 1995). Oxygen consumption rates and overall metabolic rates increased significantly in southern redbelly dace (*Phoxinus erythrogaster*) and northern studfish (*Fundulus catenatus*) as salinity was increased from 0‰ to 4‰ to 10‰ (Toepfer and Barton 1992). Sublethal concentrations of dissolved solids reduced growth in chinook salmon (*Oncorhynchus tshawytscha*) and striped bass (*Morone saxatilis*) (Saiki et al. 1992). Total dissolved solids decreased growth and survival of Lahontan cutthroat trout (*O. clarkii henshawii*) (Dickerson and Vineyard 1999).

Few field studies have examined the effects of CBNG product water on fish. Water chemistry and fish assemblages in Squirrel Creek, a Tongue River tributary, downstream of

CBNG development areas were markedly different than those found upstream of the CBNG development area (Confluence Consulting, Inc. 2003). Levels of HCO_3^- (541 mg/L), total alkalinity as CaCO_3 (443 mg/L), SO_4^{2-} (420 mg/L), Mg^{2+} (124 mg/L), Na^+ (76 mg/L), and conductivity (1,440 μmhos) in upper Squirrel Creek were lower than levels of HCO_3^- (892 mg/L), total alkalinity as CaCO_3 (731 mg/L), SO_4^{2-} (3,450 mg/L), Mg^{2+} (621 mg/L), Na^+ (936 mg/L), and conductivity (5,790 μmhos) in lower Squirrel Creek. The levels of these parameters in lower Squirrel Creek in 2003 were higher than the maximum levels measured in the 1970s. Moreover, levels in lower Squirrel Creek in 2003 also exceeded the 90th percentiles of measurements from a reference data set generated by summarizing historical measurements in an Environmental Protection Agency database for 26 comparable streams in the Tongue and Powder drainage basins (Confluence Consulting, Inc. 2003). Fish assemblages in upper Squirrel Creek were healthy, of high density, and diverse (five native species), but no fish were captured in lower Squirrel Creek. No direct discharges of CBNG product water are permitted on Squirrel Creek, suggesting the source of salt loading may be seepage from holding ponds in the drainage or geologic formations (Confluence Consulting, Inc. 2003). Some measurements of HCO_3^- (1,570 mg/L), and Cl^- (19.6 to 28.1 mg/L) in Spotted Horse Creek, a Powder River tributary receiving CBNG product water, exceeded the maximum levels from the reference data set, and SO_4^{2-} (2,520 to 3,810 mg/L), Ca^{2+} (175 to 225 mg/L), Mg^{2+} (249 to 338 mg/L), Na^+ (76 mg/L), K^+ (19.8 to 23.3 mg/L), and conductivity (4,560 to 6,460 μmhos) exceeded the 90th percentiles of the reference data set (Confluence Consulting, Inc. 2004).

Varying levels of water quality alterations of Little Hurricane Creek (O'Neil et al. 1991) and the Big Sandy Creek drainage (Shepard et al. 1993) in the Black Warrior Basin of Alabama occurred with the direct discharge of CBNG product water. During low flows, Cl^- , Na^+ , HCO_3^- , iron (Fe), and some metal concentrations below discharge points were elevated 5 to 15 fold above pre-discharge levels. However, HCO_3^- levels in product water discharged into the Big Sandy Creek drainage were lower than those more typical of the Black Warrior Basin (O'Neil et al. 1991; Shepard et al. 1993). Average annual flow was typically sufficient to dilute the CBNG product water, although discharge of Little Hurricane Creek dropped to less than 0.03 m^3/s for four days of the study, during which instream Cl^- concentrations exceeded the threshold of 565

mg/L determined to be safe for fish. However, no significant decline in fish species diversity or total fish biomass occurred after discharge of CBNG product water began (O'Neil et al. 1989; O'Neil et al. 1991; Shepard et al. 1993). Fish species differed in their response to CBNG discharge in the drainage. Whereas the abundance of Gulf darters decreased in the presence of product water, reproduction of the rough shiner was significantly greater downstream of discharge (O'Neil et al. 1991). These subtle patterns of fish species variation observed suggested that the aquatic system was changing and that long periods of CBNG product water discharge may result in changes in assemblage composition (O'Neil et al. 1991). Fish populations were reflective of water-quality conditions and should be used to assess the biological integrity of streams (O'Neil 1993).

The major ion composition of product water varies among geologic basins limiting the inferences that can be made between basins (Mount et al. 1993). For example, Cl^- was the primary concern in CBNG product water in the Black Warrior Basin, whereas HCO_3^- and Na^+ are likely more important in the PRB. Additionally, naturally intermittent streams may not provide the same opportunity for dilution in the arid environment of the PRB as found in the Black Warrior Basin. Chemistry of CBNG product water and surface water also varies within the PRB (Clearwater et al. 2002; McBeth et al. 2003).

Discharge limitations on TDS and conductivity are implemented by the Montana and Wyoming departments of environmental quality, but because ions, salts, and salt combinations vary widely in their toxic effects on aquatic life (Mount et al. 1997) general parameters such as TDS and conductivity may not be sufficient to protect aquatic life. Relative toxicity of different ions varies (Mount et al. 1997); K^+ is the most toxic to *C. dubia*, *Daphnia magna*, and fathead minnows, followed by HCO_3^- , Mg^{2+} , Cl^- , and SO_4^{2-} . Tolerance levels are typically determined through tests of single ions, but the presence of other constituents complicates toxicity determinations (Mount et al. 1993). Mortality of sheepshead minnow (*Cyprinodon variegatus*) in oil well brines was reached at salinity levels within their normal tolerance range, indicating a synergistic effect of other toxic constituents (Andreasen and Spears 1983).

Water quantity

The naturally stochastic and unaltered flow regime of the Powder River makes it unique and relatively pristine (Hubert 1993). Fishes endemic to the PRB have evolved life history strategies that allow them to survive in extreme conditions. However, water development that alters flow regimes or water quality may result in changes in the fish assemblage (Hubert 1993). Proposed reservoirs on the mainstem of the Powder River would have threatened the continued existence of the sturgeon chub, goldeye, and shovelnose sturgeon (Wyoming Game and Fish Department 1983). Alterations to the natural flow regime should be considered potentially harmful to the native fish fauna of the PRB (Wyoming Game and Fish Department 1983; Hubert 1993).

Increased discharge.—During CBNG production, wells pump water to the surface to lower the hydrostatic pressure near the top of the coal seam. Water levels are then maintained at this elevation during production (Wheaton and Donato 2004b). The large amount of groundwater pumped to the surface during CBNG development increases surface water quantity and may decrease groundwater sources. As of August 2003, the 11,809 producing CBNG wells in the Wyoming portion of the PRB collectively pumped about 227 million L of product water per day, an amount equivalent to a stream of 2.6 m³/s (WOGCC 2005). The amount of water produced varies among wells and generally decreases over the lifetime of the well. However, total discharge from all wells will increase as new wells are completed (Wheaton and Donato 2004b). Variability in amounts of water produced and rapidly evolving water disposal methods complicate quantifying product water in a manner useful for assessing the effects to aquatic biota.

Coalbed natural gas product water may change natural patterns of stream discharge in the PRB, particularly in streams where intermittent or ephemeral surface water discharges are typical. Coalbed natural gas wells transport product water to this arid surface environment throughout the year. The environmental cues associated with seasonal cycles in water quantity may be dampened by constant inflows of CBNG product potentially affecting spawning and migratory cues of resident aquatic biota (Clearwater et al. 2002). Fishes of the PRB are adapted to a naturally stochastic flow regime and stabilized discharge could allow for invasion of non-

natives. Also, constant discharge of water in streams may alter the habitat found in slow moving waters or standing pools. Intermittent streams provided an ideal nursery environment for white suckers and creek chubs because they warmed earlier than perennial streams allowing for a longer growing season for age-0 fish, and the lack of discharge excluded large predators (Williams and Coad 1979).

Local geology, climate, well densities, water production rates, water disposal methods, and groundwater resources influence the amount of deviation from normal historic flow regimes (Greystone Environmental Consultants, Inc. and ALL Consulting 2003). Obvious increases in surface water volumes attributable to direct discharge have occurred in some areas such as Burger Draw, Beaver Creek, and Pumpkin Creek, Wyoming. These creeks were ephemeral or intermittent tributaries of the Powder River that have been perennialized by continuous addition of CBNG product water and could potentially alter the flow regime of the Powder River itself. Additionally, direct discharges into the mainstem Powder and Tongue rivers are permitted. The effects of the addition of product water on the annual hydrograph and aquatic habitats have not been quantified. Currently, USGS is conducting a study to assess the habitat and geomorphology of the Powder River at various discharge levels. This study may provide useful information about changes in habitats caused by the input of product water to the Powder River.

Decreased discharge.—Pumping of coal seam aquifers may lead to the reduction of water inputs from springs and hyphorheic flow that help maintain pools in some parts of the PRB (Wheaton and Metesh 2002). The long term potential for aquifer drawdown by CBNG production in southeastern Montana has been predicted by a model, USGS Modflow, which predicts the relative declines in potentiometric head in CBNG aquifers that may result from CBNG development (Wheaton and Metesh 2002). Maximum drawdown was predicted to range from 67 to 167 m within areas of active CBNG development. Drawdown of more than 3 m within the coal aquifers can be expected to reach 1.6 to 3.2 km outside the producing fields during the early years of production and distances of 8 to 16 km, or more, during long-term production. Hydrology differs throughout the PRB and the USGS Modflow model was created using site-specific data from the Anderson, Canyon, and Wall coals, which are all undergoing CBNG development. The model recognizes that drawdown may not affect some waterways,

including the Tongue River and Squirrel Creek, but it also claims to probably underestimate drawdown outside the field, overestimate water production, and underestimate the time to recover (Wheaton and Metesh 2002). Discharge from springs and the water available at wells supplying water for livestock, wildlife, and domestic uses may be diminished or eliminated within the areas of drawdown. These springs often create important refugia for fish during low discharge. The decrease in discharge will be proportional to the decrease in hydrostatic pressure in the aquifer at the well or spring. Lowering the water level may also dry up intermittent pools of streams because they are directly connected to groundwater (Dodds et al. 2004).

Great Plains streams exist in a flux between flooding and drying (Dodds et al. 2004). Therefore, many fishes of the PRB are adapted to periods of low water availability, particularly those that inhabit small prairie streams (Table 1). Isolated pools in intermittent streams provide important refugia for fish during such extreme conditions (Zale et al. 1989; Bramblett and Fausch 1991; Fausch and Bramblett 1991; Bramblett and Zale 2000; Labbe and Fausch 2000; Dodds et al. 2004; Bramblett et al. 2005). Heat death of orangethroat darters was observed in small intermittent pools of Brier Creek, Oklahoma, but not in larger pools (Matthews et al. 1982). Brassy minnows were more likely to survive in large pools than smaller pools (Scheurer et al. 2003). Land use alterations that may reduce the size and frequency of permanent pools may deleteriously affect fish assemblages in intermittent streams (Zale et al. 1989).

Surface environment alterations

A set of wells in a grid pattern called a pod is created to efficiently produce CBNG (Wheaton and Donato 2004a). Pods allow the hydrostatic pressure to be reduced over a large area of the coalbed, thereby increasing the rate of gas production. Pods typically cover 13 to 39 km² and contain about four wells per 2.6 km² in each coal seam. Well densities vary because in some areas up to five coal seams of different depths are targeted. In these situations, separate wells are drilled to each coal seam raising densities to as many as twenty wells per section (Wheaton and Donato 2004a).

Development of a pod involves several types of surface modifications (Wheaton and Donato 2004a). Typically, a central road is built or a pre-existing road is used as the center

divider of a pod. Secondary roads, buried gas and water pipelines, and buried electric cables are installed in a branching formation to each CBNG well site. Low-pressure compression stations are built at the center of each pod to receive CBNG from each well. Additionally, product water is piped to treatment facilities, discharge points, or holding impoundments. About 1.3 to 1.7 ha are disturbed by the installation of each CBNG well and road densities may reach from 5 to 19 km per km² (BLM et al. 2003).

Sedimentation.—The construction of roads, well pads, compressor stations, and pipelines associated with CBNG development has the potential to increase sedimentation of local streams. The effects of sedimentation on fish have been intensively studied in relation to road building, urban development, logging, and dam construction. Sediments can affect salmonid fishes by interfering with the development of eggs and larvae, modifying natural movements and migrations, and reducing the abundance of food organisms available to fish (Newcombe and MacDonald 1991). Additionally, sedimentation reduces the amount of habitat diversity and in turn the diversity of fish than can be supported in a stream (Berkman and Rabeni 1987). Great Plains streams are naturally high in fine substrates, but the scarcity of coarse substrates may make them particularly important (Bramblett et al. 2005). Whereas some streams of the PRB have naturally high sediment loads, others have a rockier substrate than the Powder River and provide important spawning habitat for migratory fish (Smith and Hubert 1989). The elimination of rare exposed coarse substrates could cause changes in the fish assemblages by reducing reproductive opportunities for litho-obligate species such as goldeye (*Hiodon alosoides*), sturgeon chub (*Macrhybopsis gelida*), longnose dace (*Rhinichthys cataractae*), and sand shiner (*Notropis stramineus*).

Culverts.—Increased road construction associated with CBNG development may lead to increased stream crossings. Poorly designed and installed stream crossings may create artificial barriers to fish (Gibson et al. 2005). Culverts create more barriers to fish passage than other forms of crossings. However, they are relatively inexpensive and are installed more frequently than bridges (Warren and Pardew 1998). Movement of stream fishes is important for gene flow (Bell and Richkind 1981) and recolonization of dewatered sites (Labbe and Fausch 2000). Fragmentation of fish assemblages in Great Plains streams can lead to decreased diversity

(Winston et al. 1991). Culvert crossings reduced or blocked movement of centrarchids, cyprinids, cyprinodontids, and percids in small streams in Arkansas (Warren and Pardew 1998). However, preliminary data from tributaries of the Yellowstone River suggest that properly installed culverts with little or no outlet drop allow passage of small prairie fish at most discharge levels (L. Rosenthal, Montana State University, personal communication 2005).

Impoundments.—Whereas in-channel impoundments built to retain CBNG product water are no longer commonly permitted, existing impoundments may alter flow regimes and block migration of fish. Impoundment of prairie streams has created barriers to fish movement and led to the extirpation of several minnow species (Eberle et al. 1986; Winston et al. 1991). Failure of impoundments may lead to an influx of CBNG product water or sediments into streams.

Impoundments are often a source of introduced fish species. In Wyoming, impoundment of the Laramie River at Grayrocks Reservoir served as a source of introduced piscivorous fishes that had a substantial effect on native fish assemblages (Quist et al. 2005). Impoundments for CBNG waters may be stocked with non-native fish such as western mosquitofish (*Gambusia affinis*) for mosquito control because of concerns regarding West Nile virus. Resource managers should consider using native fish species for mosquito control because flooding events may allow fish from impoundments to migrate into surface waters where they will interact with native fishes (Harrel et al. 1967). Western mosquitofish may have negative effects on native fish assemblages. They reduced average survival of juvenile least chub (*Iotichthys phlegethontis*) by one-third in experiments in a desert spring ecosystem (Mills et al. 2004). Moreover, native fathead minnows are probably an ideal fish species for mosquito control because they are ubiquitous, tolerant of poor water quality, and easy to culture.

References

- ALL Consulting. 2003. Handbook on coal bed methane product water: Management and beneficial use alternative. Report to Ground Water Resource Protection Foundation, U.S. Department of Energy, National Petroleum Technology Office, and the Bureau of Land Management. Available : <http://www.all-llc.com/CBM/BU/index.htm> (December 2005).
- Alt, D., and D. W. Hyndman. 1986. Roadside geology Montana. Mountain Press Publishing Company, Missoula, Montana.
- APHA (American Public Health Association). 1998. Standard methods for the examination of water and wastewater. 20th edition. APHA, Washington, D.C.
- Andreasen, J., and R. Spears. 1983. Toxicity of Texan petroleum well brine to the sheepshead minnow (*Cyprinodon variegatus*), a common estuarine fish. Bulletin of Environmental Contamination and Toxicology 30:277-283.
- Anonymous. 1953. Aquatic life and water quality criteria. First progress report. Ohio River Valley Water Sanitation Commission, Aquatic Life Advisory Committee. Sewage and Industrial Wastes 27:321.
- Baxter, G. T., and M. D. Stone. 1995. Fishes of Wyoming. Wyoming Game and Fish, Cheyenne.
- Beitinger, T. L., W. A. Bennett, and R. W. McCauley. 2000. Temperature tolerance of North American freshwater fishes exposed to dynamic changes in temperature. Environmental Biology of Fishes 58:237-275.
- Berkman, H. E., and C. F. Rabeni. 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes 18:285-294.

- Bjornn, T. C., and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138 in W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Bethesda, Maryland.
- BLM (Bureau of Land Management). 2003. Final environmental impact statement and proposed plan amendment for the Powder River Basin oil and gas project. WY-070-02-065. Buffalo Field Office.
- BLM (Bureau of Land Management), Montana Board of Oil and Gas Conservation, and Montana Department of Environmental Quality. 2003. Final statewide oil and gas environmental impact statement and proposed amendment of the Powder River and Billings resource management plans. Volume II. Billings.
- Boelter, A. M., F. N. Lamming, A. M. Farag, and H. L. Bergman. 1992. Environmental effects of saline oil-field discharges on surface waters. *Environmental Toxicology and Chemistry* 11:1187-1195.
- Bonner, T. H., and G. R. Wilde. 2002. Effects of turbidity on prey consumption by prairie stream fishes. *Transactions of the American Fisheries Society* 131:1203-1208.
- Bramblett, R. G., and K. D. Fausch. 1991. Fishes, macroinvertebrates, and aquatic habitats of the Purgatoire River in Pinon Canyon, Colorado. *Southwestern Nat.* 36:281-294.
- Bramblett, R. G., and A. V. Zale. 2000. The ichthyofauna of small streams on the Charles M. Russell National Wildlife Refuge, Montana. *Intermountain Journal of Sciences* 6:57-67.
- Bramblett, R. G., T.R. Johnson, A. V. Zale, and D. G. Heggem. 2005. Development and evaluation of a fish assemblage index of biotic integrity for northwestern Great Plains streams. *Transactions of the American Fisheries Society* 134:624-640.

- Brown, C. J. D. 1971. Fishes of Montana. Big Sky Books, Montana State University, Bozeman.
- Brown, J. L. 1993. Sedimentology and depositional history of the lower Paleocene Tullock Member of the Fort Union Formation, Powder River Basin, Wyoming and Montana. U.S. Geological Survey Bulletin 1917-L.
- Chapman, S. S., S. A. Bryce, J. M. Omernik, D. G. Despain, J. ZumBerge, and M. Conrad. 2004. Ecoregions of Wyoming (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,400,000).
- Charles, J. R. 1964. Effects of oilfield brines. Proceedings of the Southeastern Association of Game and Fish Commissioners 18:371-403.
- Clark, M. L., K. A. Miller, and M. H. Brooks. 2001. U.S. Geological Survey monitoring of Powder River Basin stream-water quantity and quality. Water-resources investigation report 01-4279. Cheyenne, Wyoming.
- Clearwater, S. J., B. A. Morris, and J. S. Meyer. 2002. A comparison of coalbed natural gas product water quality versus surface water quality in the Powder River Basin of Wyoming, and an assessment of the use of standard aquatic toxicity testing organisms for evaluating the potential effects of coalbed natural gas product waters. Report to University of Wyoming, Laramie.
- Confluence Consulting, Inc. 2003. Biological, physical, and chemical integrity of select streams in the Tongue River Basin. Report to Bureau of Land Management, Mile City, Montana.
- Confluence Consulting, Inc. 2004. Powder River biological survey and implications for coalbed natural gas development. Report to Powder River Basin Resource Council, Sheridan, Wyoming.

- Cross, F. B., R. L. Mayden, and J. D. Stewart. 1986. Fishes in the western Mississippi basin (Missouri, Arkansas, and Red rivers). Pages 363-412 *in* C. H. Hocutt and E. O. Wiley, editors. The zoogeography of North American freshwater fishes. J. Wiley and Sons, New York.
- Decker, M. K. 2001. Potential supply of natural gas in the United States. Report of the Potential Gas Committee, December 2000: Golden, CO. Potential Gas Agency, Colorado School of Mines Report.
- Dickerson, B. R., and G. L. Vineyard. 1999. Effects of high levels of total dissolved solids in Walker Lake, Nevada, on survival and growth of Lahontan cutthroat trout. Transactions of the American Fisheries Society 128:507-515.
- Dodds, W. K., K. Gido, M. R. Whiles, K. M. Fritz, and W. J. Matthews. 2004. Life on the edge: the ecology of Great Plains prairie streams. BioScience 54:205-216.
- Eberle, M., G. Ernsting, and J. Tomelleri. 1986. Aquatic macroinvertebrates and fishes of Big Creek in Trego, Ellis, and Russel Counties, Kansas. Transactions of Kansas Academy of Science 89:146-151.
- Ellis, M. S., G. L. Gunther, A. M. Ochs, S. B. Roberts, E. M. Wilde, J. H. Schuenemeyer, H. C. Power, G. D. Stricker, and D. Blake. 1999. Coal resources, Powder River Basin. In U.S. Geological Survey Professional paper 1625-A.
- Elser, A. A., M. W. Gorges, and L. M. Morris. 1980. Distribution of fishes in southeastern Montana. Montana Department of Fish, Wildlife and Parks, Helena, and USDI Bureau of Land Management, Miles City.
- Fausch, K. D., and R. G. Bramblett. 1991. Disturbance and fish communities in intermittent tributaries of a western Great Plains river. Copeia 1991:659-674.

- Forbes, M. B. 2003. Toxicity of coalbed natural gas product waters and receiving waters in the Powder River Basin, Wyoming. Master's thesis. University of Wyoming. Laramie.
- Gale, W. F. 1986. Indeterminate fecundity and spawning behavior of captive red shiners—fractional, crevice spawners. *Transactions of the American Fisheries Society*. 115:429-437.
- Gibson, R. J., R. L. Haedrich, and C. M. Wernerheim. 2005. Loss of fish habitat as a consequence of inappropriately constructed stream crossings. *Fisheries* 30(1):10-17.
- Glass, G. B., and D. L. Blackstone, Jr. 1996. *Geology of Wyoming*. Wyoming State Geological Survey Information Pamphlet No. 2.
- Gradall, K. S., and W. A. Swenson. 1982. Responses of brook trout and creek chubs to turbidity. *Transactions of the American Fisheries Society* 111:392-395.
- Greystone Environmental Consultants, Inc., and ALL Consulting. 2003. Surface water modeling of water quality impacts associated with coal bed methane development in the Powder River Basin. Report prepared for Bureau of Land Management, Buffalo, Wyoming, and Billings, Montana.
- Harrel R. C., B. J. Davis, T. C. Dorris. 1967. Stream order and species diversity of fishes in an intermittent Oklahoma stream. *American Midland Naturalist* 78:428-436.
- Heffern, E. L., and D. A. Coates. 1997. Clinker – Its occurrence, uses, and effects on coal mining in the Powder River Basin. Pages 151–166 in R. W. Jones and R. E. Harris, editors. *Proceedings of the 32nd Annual Forum on the Geology of Industrial Minerals*. Wyoming State Geological Survey Public Information Circular 38.
- Higgins, C. L. and G. R. Wilde. 2005. The role of salinity in structuring fish assemblages in a prairie stream system. *Hydrobiologia* 549:197-203.

- Holton, G. D., and H. E. Johnson. 2003. A field guide to Montana fishes, 3rd edition. Montana Fish, Wildlife, and Parks, Helena.
- Hubert, W. A. 1993. The Powder River: a relatively pristine stream on the Great Plains. Pages 387-395 *in* L. W. Hesse, C. B. Stalnaker, N. G. Benson, and J. R. Zuboy, editors. Restoration planning for the rivers of the Mississippi River ecosystem. Biological Report 19, National Biological Survey, Washington, D.C.
- Jain, C. K. 2005. Irrigation water quality in areas adjoining River Yamuna at Delhi, India. Pages 155-161 *in* J. H. Lehr and J. Keeley, editors. Water encyclopedia: Water quality and resource development. John Wiley and Sons, Inc., Hoboken, New Jersey.
- Ji, Z.-G. 2005. Water quality models: chemical principles. Pages 269- 272 *in* J. H. Lehr and J. Keeley, editors. Water encyclopedia: water quality and resource development. John Wiley and Sons, Inc., Hoboken, New Jersey.
- Johnson, K. C. 2004. The New Zealand coal seam gas scene. Proceedings of the New Zealand petroleum conference. March 7-10, 2004. Available: <http://www.crownminerals.govt.nz/petroleum/publications/nzpconf/nzpconf-2004.html> (December 2005).
- Judy, R. D., Jr., P. N. Seeley, T. M. Murray, S. C. Svirsky, M. R. Whitworth, and L. S. Ishinger. 1988. 1982 National Fisheries Survey. U.S. Fish and Wildlife Service Biological Service Program FWS-OBS-84/06 technical report, Washington, D.C.
- Keith, K., J. Bauder, and J. Wheaton 2003. Frequently asked questions. Coalbed natural gas. Montana State University. Available: <http://waterquality.montana.edu/docs/methane/cbmfaq.shtml> (October 2004).

- Kochsiek, K. A., and R. A. Tubb. 1967. Salinity tolerance of *Fundulus diaphanous*, *Culaea inconstans* and *Pimephales promelas*. Proceedings of South Dakota Academy of Science 46:97-100.
- Koel, T., and J. Peterka. 1995. Survival to hatching of fishes in sulfate-saline waters, Devils Lake, North Dakota. Canadian Journal of Fisheries and Aquatic Science 52:464-469.
- Labbe, T. R., and K. D. Fausch. Dynamics of intermittent stream habitat regulate persistence of a threatened fish at multiple scales. Ecological Applications 10:1774-1791.
- Linder-Lunsford, J. B., C. Parrett, J. Wilson, Jr., and C. A. Eddy-Miller. 1992. Chemical quality of surface water and mathematical simulation of the surface-water system, Powder River drainage basin, northeastern Wyoming and southeastern Montana. U.S. Geological Survey, Water-resources investigation report 91-4199, Cheyenne.
- Lowham, H. W. 1988. Streamflows in Wyoming. U.S. Geological Survey Water-Resources Investigations Report 88-4045.
- Matthews, W. J., E. Surat, and L. G. Hill. 1982. Heat death of the orangethroat darter *Etheostoma spectabile* (Percidae) in a natural environment. Southwestern Naturalist 27:216-217.
- McBeth, I., K. Reddy, and Q. Skinner. 2003. Coalbed natural gas product water chemistry in three Wyoming watersheds. Journal of the American Water Resources Association 39:575-585.
- Mills, M. D., R. B. Rader, and M. C. Belk. 2004. Complex interactions between native and invasive fish: the simulations effects of multiple negative interactions. Oecologia 141:713-721.
- Montana Natural Heritage Program. 2004. Montana animal species of concern. Helena.

- Mount, D. R., P. E. O'Neil, and J. M. Evans. 1993. Discharge of coalbed product water to surface waters: assessing, predicting, and preventing ecological effects. *Quarterly Review of Methane from Coal Seams Technology* 11(2):18-25.
- Mount, D. R., D. D. Gulley, J. R. Hockett, T. D. Garrison, and J. M. Evans. 1997. Statistical models to predict the toxicity of major ions to *Ceriodaphnia dubia*, *Daphnia magna*, and *Pimephales promelas*. *Environmental Toxicology and Chemistry* 16:2009-2019.
- Mundahl, N. D. 1990. Heat death of fish in shrinking stream pools. *American Midland Naturalist* 123:40-46.
- Newcombe, C. P., and D. D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. *North American Journal of Fisheries Management* 11:72-82.
- O'Brien, W. J. 1977. Feeding of forage fish in turbid Kansas reservoirs. University of Kansas, Kansas Water Resources Research Institute Report 187, Manhattan.
- O'Neil, P. E., S.C. Harris, M. F. Mettee, K. R. Drottat, D. R. Mount, and J. P. Fillo. 1989. Biomonitoring of a produced water discharge from the Cedar Cove degasification field, Alabama. GRI-89/0073 Final Report to Gas Research Institute, Chicago, Illinois.
- O'Neil, P. E., S. C. Harris, M. F. Mettee, S. W. McGregor, and T. E. Shepard. 1991. Long-term biomonitoring of a product water discharge from the Cedar Cove degasification field, Alabama. *Geological Survey of Alabama, Bulletin* 141, Tuscaloosa.
- O'Neil, P. E. 1993. A review of water quality, biological risk, and discharge monitoring studies relative to the surface disposal of produced waters from the development of coal-seam methane in Alabama. *Geological Survey of Alabama, Circular* 177, Tuscaloosa.

- Ostrand, K. G., and G. R. Wilde. 2001. Temperature, dissolved oxygen, and salinity tolerances of five prairie stream fishes and their role in explaining fish assemblage patterns. *Transactions of the American Fisheries Society* 130:742-749.
- Ostrand, K. G., and G. R. Wilde. 2004. Changes in prairie stream fish assemblages restricted to isolated streambed pools. *Transactions of the American Fisheries Society* 133:1329-1338.
- Patton, T. M., Hubert, W. A., and F. J. Rahel. 1998. Ichthyofauna in streams of the Missouri River Drainage, Wyoming. *The Prairie Naturalist* 30:9-21.
- Patz, M. J., J. K. Reddy, and Q. D. Skinner. 2004. Chemistry of coalbed natural gas discharge water interacting with semi-arid ephemeral stream channels. *Journal of the American Water Resources Association* 4:1247-1255.
- Peterka, J. J. 1972. Effects of saline waters upon survival of fish eggs and larvae and upon the ecology of the fathead minnow. Research project technical completion report. North Dakota State University, Fargo.
- Powers, E. B. 1922. The physiology of the respiration of fishes in relation to the hydrogen ion concentration of the medium. *Journal of General Physiology* 4:305.
- Quist, M. C., W. A. Hubert, and F. J. Rahel. 2005. Fish assemblage structure following impoundment of a Great Plains river. *Western North American Naturalist* 65:53-63.
- Ramirez, P., Jr. 2005. Assessment of contaminants associated with coalbed methane –produced water and its suitability for wetland creation or enhancement projects. U. S. Fish and Wildlife Service Contaminant Report R6/721C/05, Cheyenne, Wyoming.

- Rankl, J. G., and M. E. Lowry. 1990. Ground-water flow systems in the Powder River structural basin, Wyoming and Montana. U.S. Geological Survey Water-Resources Investigations Report 85-4229, Denver, Colorado.
- Rehwinkle, B. J. 1978. Powder River ecology project. Montana Fish, Wildlife, and Parks, Helena.
- Rice, C. A., M. S. Ellis, and J. H. Bullock, Jr. 2000. Water co-produced with coalbed natural gas in the Powder River Basin, Wyoming. Preliminary compositional data. USGS Open-file Report 00-372, Denver, Colorado.
- Ruckelshaus Institute of Environment and Natural Resources. 2005. Water production from coalbed methane development in Wyoming: a summary of quantity, quality, and management options. Final Report prepared for the Office of the Governor, State of Wyoming, Cheyenne. Available: <http://www.uwyo.edu/enr/ienr/cbm.asp> (December 2005).
- Saiki, M. K., M. R. Jennings, and R. H. Wiedmeyer. 1992. Toxicity of agricultural subsurface drainwater from the San Joaquin Valley, California, to juvenile chinook salmon and striped bass. *Transactions of the American Fisheries Society* 121:78-93.
- Scheurer, J. A., K. D. Fausch, and K. R. Bestgen. 2003. Multiscale processes regulate brassy minnow persistence in a Great Plains river. *Transactions of the American Fisheries Society* 132:840-855.
- Sessoms, H. N., J. W. Bauder, K. Keith, and K. E. Pearson. 2002. Chemical changes in coal bed methane product water over time. Department of Land Resources and Environmental Science, Montana State University, Bozeman. Available: <http://waterquality.montana.edu/docs/methane/cbmwater.shtml> (March 2005).

- Shepard, T. E., P. E. O'Neil, S. C. Harris, and S.W. McGregor. 1993. Effects of coalbed natural gas development on the water-quality and fish and benthic invertebrate communities of the Big Sandy Creek Drainage System, Alabama. Geological Survey of Alabama Circular 171, Tuscaloosa.
- Shiple, F. 1991. Oil field-produced brines in a coastal stream: water quality and fish community recovery following long term impacts. *Texas Journal of Science* 43:51-64.
- Skaar, D., B. Morris, and A. Farag. 2004. National pollution discharge elimination system. Toxicity of the major salt (sodium bicarbonate) from coalbed natural gas production on fish in the Tongue and Powder river drainages in Montana. Progress report prepared for U.S. Environmental Protection Agency, Helena.
- Skaar, D., A. Farag, and D. Harper. 2005. National pollution discharge elimination system. Toxicity of the major salt (sodium bicarbonate) from coalbed methane production to fish in the Tongue and Powder river drainages in Montana. Semi-annual progress report prepared for U.S. Environmental Protection Agency, Helena.
- Smith, J. B., and W. A. Hubert. 1989. Use of a tributary by fishes in a Great Plains river system. *Prairie Naturalist* 21:27-38.
- Talkington, C. 2002. An overview of the global market for coalbed methane and coalmine methane. Presented at the SMI Coalmine Methane and Coalbed Methane Conference March, 18-19 2002, London, England. Available: <http://www.epa.gov/coalbed/international.html> (November 2005).
- Toepfer, C., and M. Barton. 1992. Influence of salinity on the rates of oxygen consumption in two species of freshwater fishes, *Phoxinus erythrogaster* (family Cyprinidae), and *Fundulus catenatus* (family Fundulidae). *Hydrobiologia* 242:149-154.

- Townsend, L. D., and H. Cheyne. 1944. The influence of hydrogen ion concentration on the minimum dissolved oxygen toleration of the silver salmon, *Oncorhynchus kisutch*. Ecology 25:461.
- Tramer, E. J. 1977. Catastrophic mortality of stream fishes trapped in shrinking pools. American Midland Naturalist 97:469-478.
- USGS. (United States Geological Survey). 2005a. Surface Water for Montana. Available:http://nwis.waterdata.usgs.gov/mt/nwis/peak?site_no=06324500&agency_cd=USGS&format=html (December 2005).
- USGS. (United States Geological Survey). 2005b. Surface Water for Montana. Available:http://nwis.waterdata.usgs.gov/nwis/discharge/?site_no=06324500&agency_cd=USGS (December 2005).
- Van Voast, W. A. 2003. Geochemical signature of formation waters associated with coalbed methane. American Association of Petroleum Geologists Bulletin 87:667-676.
- Veil, J. A. 2002. Regulatory issues affecting management of produced water from coal bed methane wells. Prepared for United States Department of Energy, Office of Fossil Energy, Washington, D. C.
- Warren, M. L., and M. G. Pardew. 1998. Road crossings as barriers to small-stream fish movement. Transactions of the American Fisheries Society 127:637-644.
- Weibe, A. H., A. M. McGavok, A. C. Fuller, and H. C. Markus. 1934. The ability of freshwater fish to extract oxygen at different hydrogen ion concentrations. Physiological Zoology 7:435.

- Wesche, T. A., and L. S. Johnson. 1981. The Tongue River in Wyoming: A baseline assessment-Monarch to the stateline. Report ANL/LRP-10 to Argonne National Laboratory's Land and Reclamation Program and Peter Kiewit Sons' Company. Water Resources Research Institute, University of Wyoming, Laramie.
- Wheaton, J. R., and J. Metesh. 2002. Potential ground-water drawdown and recovery from coalbed natural gas development in the Powder River Basin, Montana. U. S. Bureau of Land Management. Report to BLM. Montana Bureau of Mines and Geology Open-File Report 458, Butte.
- Wheaton, J. R., and T. A. Donato. 2004a. Coalbed methane basics: Powder River Basin, Montana. Montana Bureau of Mines and Geology Information Pamphlet 5. Butte.
- Wheaton, J. R., and T. A. Donato. 2004b. Ground-water monitoring program in prospective coalbed-methane areas of southeastern Montana: year one. Montana Bureau of Mines and Geology. Report to BLM. MBMG-508, Butte.
- White, R. G., and R. G. Bramblett. 1993. The Yellowstone River: its fish and fisheries. Pages 396-414 *in* L. W. Hesse, C. B. Stalnaker, N. G. Benson, and J. R. Zuboy, editors. Restoration planning for the rivers of the Mississippi River ecosystem. Biological Report 19, National Biological Survey, Washington, D.C.
- Whitehead, R. L. 1996. Ground water atlas of the United States, Segment 8—Montana, North Dakota, South Dakota, Wyoming. U.S. Geological Survey Hydrologic Investigations Atlas 730-I.
- Whiteside, B. G., and R. M. McNatt. 1972. Fish species in relation to stream order and physicochemical conditions in the Plum Creek drainage basin. *American Midland Naturalist* 88:90-101.

- Williams, D. D., and B. W. Coad. 1979. The ecology of temporary streams. III. Temporary stream fishes in southern Ontario, Canada. *Hydrobiologia* 64:501-515.
- Williams, W. D. 2001. Anthropogenic salinization of inland waters. *Hydrobiologia* 466:329-337.
- Winston, M. R., C. M. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. *Transactions of the American Fisheries Society* 120:98-105.
- Woods, A. J., J. M. Omernik, J. A. Nesser, J. Sheldon, J. A. Comstock, and S. H. Azevedo. 2002. Ecoregions of Montana, 2nd edition (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U. S. Geological Survey (map scale 1:1,500,000).
- Wyoming Game and Fish Department. 1983. Powder River: Level I report on potential fishery impacts. Project completion report for the State of Wyoming and the Wyoming Water Development Commission, Cheyenne.
- Wyoming Natural Diversity Database. 2005. Available:
<http://uwadmnweb.uwyo.edu/WYNDD/> (December 2005).
- WOGCC (Wyoming Oil and Gas Conservation Commission). 2005. On-line oil and gas database. Available: <http://wogcc.state.wy.us>. (November 2005).
- Zale, A. V., D. M. Leslie, Jr., W. L. Fisher, and S. G. Merrifield. 1989. The physicochemistry, flora, and fauna of intermittent prairie streams: a review of the literature. U.S. Fish and Wildlife Service, Biological Report 89(5), Washington, D.C.

Table 1. Fishes of the Tongue and Powder rivers, Montana and Wyoming.

Family	Common name, <i>Genus species</i>	Species of concern ^a	Origin ^b	Primary habitats ^c					
				Yellowstone River	Powder River	Tongue River	Large prairie streams	Small prairie streams	Cold water habitats
Acipenseridae									
	pallid sturgeon, <i>Scaphirhynchus albus</i>	MT	N	X					
	shovelnose sturgeon, <i>Scaphirhynchus platyrhynchus</i>	WY	N	X	X				
Polyodontidae									
	paddlefish, <i>Polyodon spathula</i>	MT	N	X					
Hiodontidae									
	goldeye, <i>Hiodon alosoides</i>	WY	N	X	X	X	X		
Cyprinidae									
	goldfish, <i>Carassius auratus</i>		I			X			
	lake chub, <i>Couesius plumbeus</i>		N			X	X	X	
	common carp, <i>Cyprinus carpio</i>		I	X	X	X	X	X	
	western silvery minnow, <i>Hybognathus argyritis</i>	WY	N	X	X	X	X		
	brassy minnow, <i>Hybognathus hankinsoni</i>		N				X	X	
	plains minnow, <i>Hybognathus placitus</i>		N		X	X	X	X	
	sturgeon chub, <i>Macrhybopsis gelida</i>	MT, WY	N	X	X				
	golden shiner, <i>Notemigonus crysoleucas</i>		I			X			
	emerald shiner, <i>Notropis atherinoides</i>		N	X		X	X		
	sand shiner, <i>Notropis stramineus</i>		N		X	X	X	X	
	fathead minnow, <i>Pimephales promelas</i>		N		X	X	X	X	
	flathead chub, <i>Platygobio gracilis</i>		N	X	X	X	X		
	longnose dace, <i>Rhinichthys cataractae</i>		N	X	X	X	X	X	X
	creek chub, <i>Semotilus atromaculatus</i>		N			X	X	X	
Catostomidae									
	river carpsucker, <i>Carpoides carpio</i>		N	X	X	X	X		
	longnose sucker, <i>Catostomus catostomus</i>		N	X		X			X
	white sucker, <i>Catostomus commersonii</i>		N	X		X	X	X	
	mountain sucker, <i>Catostomus platyrhynchus</i>		N	X		X	X		X
	blue sucker, <i>Cycleptus elongatus</i>	MT	N	X					
	smallmouth buffalo, <i>Ictiobus bubalus</i>		N	X					
	bigmouth buffalo, <i>Ictiobus cyprinellus</i>		N	X					

Table 1. Continued.

Family	Common name, <i>Genus species</i>	Species of concern ^a	Origin ^b	Primary habitats ^c					
				Yellowstone River	Powder River	Tongue River	Large prairie streams	Small prairie streams	Cold water habitats
Catostomidae									
	shorthead redhorse, <i>Moxostoma macrolepidotum</i>		N	X	X	X	X		
Ictaluridae									
	black bullhead, <i>Ameiurus melas</i>		I			X	X	X	
	yellow bullhead, <i>Ameiurus natalis</i>		I			X			
	channel catfish, <i>Ictalurus punctatus</i>		N	X	X	X	X		
	stonecat, <i>Noturus flavus</i>		N	X	X	X	X		
Esocidae									
	northern pike, <i>Esox lucius</i>		I			X	X		
Cyprinodontidae									
	plains killifish, <i>Fundulus zebrinus</i>		I		X		X	X	
Gasterosteidae									
	brook stickleback ^d , <i>Culaea inconstans</i>		N					X	
Salmonidae									
	golden trout, <i>Oncorhynchus aguabonita</i>		I						X
	Yellowstone cutthroat trout, <i>Oncorhynchus clarkii bouvieri</i>		N						X
	rainbow trout, <i>Oncorhynchus mykiss</i>		I						X
	mountain whitefish, <i>Prosopium williamsoni</i>		N						X
	brown trout, <i>Salmo trutta</i>		I						X
	brook trout, <i>Salvelinus fontinalis</i>		I						X
	lake trout, <i>Salvelinus namaycush</i>		I						X
Gadidae									
	burbot, <i>Lota lota</i>		N	X	X	X			
Centrarchidae									
	rock bass, <i>Ambloplites rupestris</i>		I			X			X
	green sunfish, <i>Lepomis cyanellus</i>		I		X	X	X	X	
	pumpkinseed, <i>Lepomis gibbosus</i>		I			X	X		
	bluegill, <i>Lepomis macrochirus</i>		I				X		
	smallmouth bass, <i>Micropterus dolomieu</i>		I	X	X				

Table 1. Continued.

Family	Common name, <i>Genus species</i>	Species of concern ^a	Origin ^b	Primary habitats ^c				
				Yellowstone River	Powder River	Tongue River	Large prairie streams	Small prairie streams
Centrarchidae								
	largemouth bass, <i>Micropterus salmoides</i>		I		X			
	white crappie, <i>Pomoxis annularis</i>		I		X			
	black crappie, <i>Pomoxis nigromaculatus</i>		I		X			
Percidae								
	yellow perch, <i>Perca flavescens</i>		I		X			
	sauger, <i>Sander canadensis</i>	MT	N	X	X	X	X	
	walleye, <i>Sander vitreus</i>		I	X		X		

^aMT = Species of concern in Montana; WY = Species of concern in (Montana Natural Heritage Program 2004; Wyoming Natural Diversity Database 2005)

^bN = Native; I = Introduced (Brown 1971; Holton and Johnson 2003; Baxter and Stone 1995)

^cHabitats in which the species has been captured, although each species may occasionally be found in other habitats (Brown 1971; Elser et al. 1980; Patton et al. 1998; Holton and Johnson 2003)

^dThere is just one record of brook stickleback in the Tongue and Powder river basins. The record was from Locate Creek, a tributary of the Powder River in Montana (Elser et al. 1980)

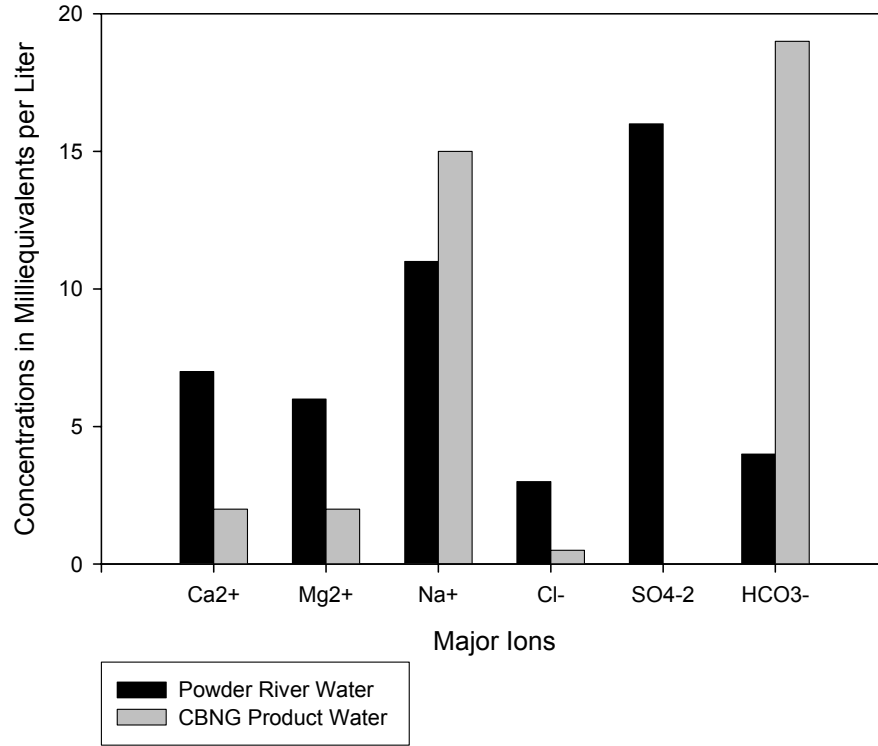


Figure 1. Major-ion chemistry of samples from the Powder River at Arvada, Wyoming, July 21, 1999 and CBM well 441451105375501, June 18, 1999 (Figure modified from Clark et al. 2001).

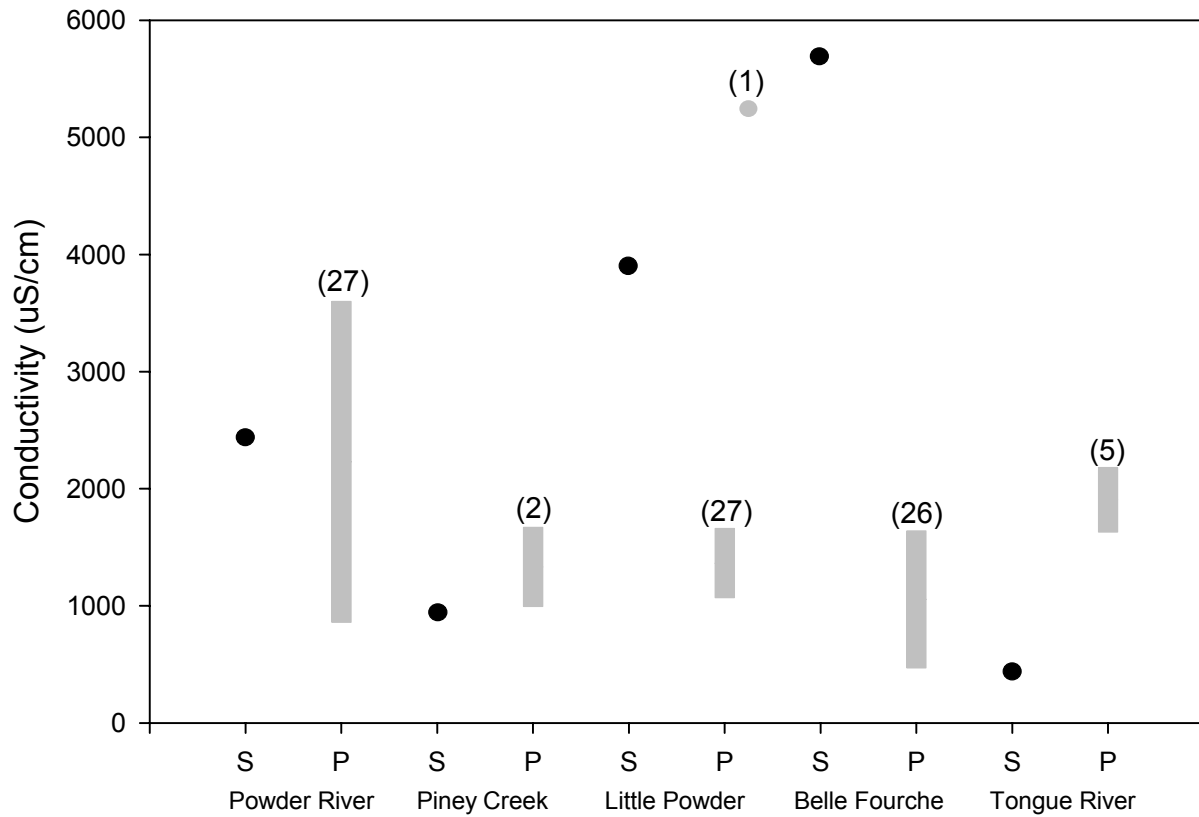


Figure 2. Comparison of conductivity measured in surface waters versus coalbed natural gas product water in drainage basins of the Powder River geologic basin. S = Surface water, P = product water; black dots represent medians of U.S. Geological Survey surface water data, gray bars represent ranges of product water values from the same drainage basin (with sample sizes in parentheses). Gray dot is a single outlier value from the Little Powder drainage basin. Data are from Clearwater et al. (2002).

STUDY PLAN

Effects of Coalbed Natural Gas Development on Fish Assemblages in the Powder River Basin, Montana and Wyoming

Graduate Student: Windy N. Davis
Graduate Research Assistant
Department of Ecology
Montana State University, Bozeman, MT 59717
(406) 944-6643
Email: wdavis@montana.edu

Principal Investigators: Dr. Alexander V. Zale
Montana Cooperative Fishery Research Unit
Department of Ecology
Montana State University
Lewis Hall
Bozeman, MT 59717
(406) 994-2380
Email: zale@montana.edu

Dr. Robert G. Bramblett
Department of Ecology
Montana State University
Lewis Hall
Bozeman, MT 59717
(406) 994-4433
Email: bbram@montana.edu

Study Duration: April 2005- May 2007

Project summary

Worldwide exploration and development of coalbed natural gas (CBNG) resources is proceeding rapidly. The Powder River Basin in Wyoming and Montana is currently undergoing one of the world's largest coalbed natural gas developments with about 12,000 wells in place in 2003, 14,200 in 2005, and up to 70,000 projected over the next 20 to 30 years (WOGCC 2005). Because CBNG development involves production and disposal of large quantities of coalbed ground water that differs from surface waters, potential exists for substantial effects on aquatic ecosystems. Coalbed natural gas product-water typically has high concentrations of dissolved solids, including elevated levels of sodium and bicarbonate ions. Information on chronic toxicity of CBNG product water to warmwater fishes of the Powder River Basin is lacking, presenting a substantial gap in predicting the potential effects of saline discharges in the Great Plains ecosystem.

The goal of our study is to determine the effects of coalbed natural gas development on fish assemblages in streams of the Powder River Basin. We will employ four different approaches to assess the local and large-scale effects of CBNG on fish assemblages of the Powder River Basin. First, we will compare fish assemblages in streams with CBNG development (treatments) and streams without development (controls). Second, we will compare the longitudinal distribution patterns of fish assemblages at multiple points above and below CBNG development. Third, we will compare fish assemblages before and after the initial development of CBNG. Finally, we will compare fish assemblages present to fish survey data from the mid 1990s in areas with and without CBNG development.

Currently, little is understood about the potential effects of CBNG development on fish assemblages in the Powder River Basin. This study is designed to provide scientifically sound information to aid agency, tribal, and industry resource managers in making land and water use decisions in Montana and Wyoming. Additionally, it creates a framework for the evaluation of potential effects of CBNG development to aquatic life worldwide.

Introduction

The Great Plains ecosystem, has been altered by anthropogenic pressures and is considered one of the most threatened in North America. The Powder River is one of the last Great Plains rivers with unaltered flows and may represent one of the most intact and pristine river systems remaining in the ecosystem (Hubert 1993). The river is a turbid, saline, meandering stream that supports a unique fish assemblage of 32 fish species composed of primarily endemic fishes (Rehwinkle et al. 1978, Patton et al. 1998a). Currently, the Powder River Basin in Wyoming and Montana is undergoing one of the world's largest coalbed natural gas developments. As of October 2005, 14,200 producing CBNG gas wells had been developed in the Powder River Basin, Wyoming (WOGCC 2005), and up to 70,000 are projected over the next 20 to 30 years (Rice et al. 2000). Because CBNG development involves production and disposal of large quantities of coalbed ground water that differs chemically from surface waters, potential exists for substantial effects on aquatic ecosystems.

Coalbed natural gas product-water chemistry and disposal

Methane natural gas is created as a by-product during the diagenesis of carbon-rich deposits such as peat into coal. In the process of coalification, gas is sorbed to the coal, and retained under hydrologic pressure. To extract CBNG, water is pumped out of the coal seam aquifer to relieve the hydrologic pressure, thereby allowing the gas to desorb. The resultant water co-produced from this drilling process is referred to as CBNG product-water. Coalbed natural gas product-water has highly variable water chemistry depending on underlying geology. However, general trends in conductivity and major chemical constituents exist. Water from coal seam aquifers is typically high in dissolved sodium (Na^+) and bicarbonate (HCO_3^-), whereas surface waters in the Powder River Basin generally are high in dissolved calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), and sulfate (SO_4^{2-}), (Rice et al. 2000; Clearwater et al. 2002; McBeth et al. 2003) (Figure 1.).

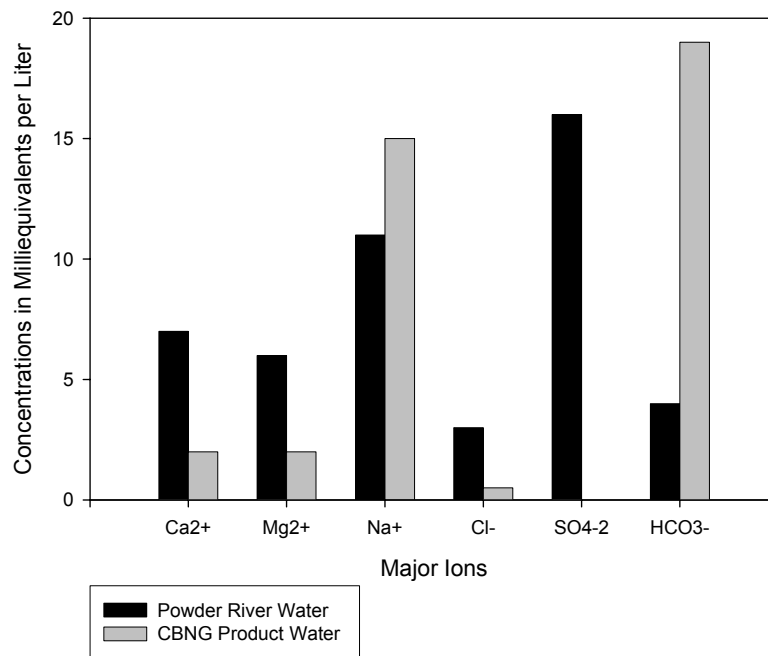


Figure 1. Major-ion chemistry of samples from the Powder River at Arvada, Wyoming, July 21, 1999 and CBM well 441451105375501, June 18, 1999 (Figure modified from Clark et al. 2001).

As of August 2003, the 12,000 producing CBNG wells in the Wyoming portion of the Powder River Basin collectively pumped about 60 million gallons of product water per day (Wyoming Oil and Gas Conservation Commission 2005). The amount of water produced by a single well varies between wells and generally decreases over the lifetime of the well. However, total discharge from all wells will increase as new wells are completed (Wheaton and Donato 2004a). Predictions of the actual volume of product water have been made for various basins in different stages of development. Variability in amounts of water produced and rapidly evolving water disposal methods complicate quantifying product water in a manner useful for assessing the effects to aquatic biota.

Current management practices for the disposal of product-water in the Powder River Basin include impoundment and direct discharge to surface waters. Lined holding

impoundments are designed to hold water before it is treated, reinjected, or discharged into surface waters. In contrast, infiltration impoundments are unlined structures that discharge product-water to the subsurface. Whereas some water evaporates or infiltrates to deeper groundwater sources, an estimated 15-20% of water from impoundments is likely to reach some stream channels by subsurface flow (ALL 2003). Direct discharge to surface waters occurs when product-water is delivered directly to a stream using a pipeline or when product-water is released into an ephemeral channel that subsequently flows into existing surface water.

Permits for such point source discharges are subject to the National Pollution Discharge Elimination System (NPDES) permitting system and the regulations imposed by individual states. The Clean Water Act (CWA) of 1972 was created to restore and maintain the chemical, physical, and biological integrity of U.S. waters. The NPDES permitting system generally considers water quality and quantity; however, limits established in permits may be less strict than necessary to protect biota and in turn may violate the CWA (Confluence Consulting, Inc. 2004).

Effects of salinity and dissolved solids on fish

Little is known about the effects of CBNG development on fish in the Powder River Basin. Fishes endemic to the Powder River Basin have evolved life history strategies that allow them to survive in extreme conditions. However, water development that alters flow regimes or water quality may result in changes in the fish assemblage (Hubert 1993). Unfortunately, pre-development baseline data for the area are minimal, but many efforts are currently being made to gain a better understanding of the local fish assemblages. Whereas few studies have been conducted specifically assessing the effects of CBNG development on fish in the Powder River Basin, other studies addressed similar questions regarding changes in water quality.

Salinity is a dominant factor structuring prairie stream fish assemblages and high salinity tolerance is related to the likelihood of persistence of individual species (Higgins and Wilde 2005). Additionally, salinity, which is often associated with disturbed habitats, can affect the ability of species to persist in altered environments over long periods, potentially leading to decreases in biodiversity (Higgins and Wilde 2005). Saline effluent released into Lily Creek,

Kentucky, may have rendered several km of the stream uninhabitable by fish (Toepfer and Barton 1992). Petroleum well brine discharge resulted in decreased diversity and extreme dysfunction of many rivers and streams in Texas (Spears 1971; Barclay and Harrel 1985; Shipley 1991). Discharges from oil and gas development, irrigation, drought, and impoundments are all potential sources of inland salinization and potential loss of diversity (Williams et al. 2001).

Whereas discharge limitations on water-quality indices such as total dissolved solids (TDS) and conductivity are implemented by the Montana and Wyoming Departments of Environmental Quality to protect aquatic life, a correlation between ion concentrations and the toxicity of ion composition does not always exist (Mount et al. 1997). Relative toxicity of different ions varies (Mount et al. 1997); potassium is the most toxic to *Ceriodaphnia dubia*, *Daphnia magna*, and fathead minnows (*Pimephales promelas*), followed by bicarbonate, magnesium, chloride, and sulfate. Tolerance levels are typically determined through tests of single ions, but the presence of other constituents complicates toxicity determinations (Mount et al. 1993). Mortality of fish in well brines was reached at salinity levels within the normal tolerance range indicating a synergistic effect of other toxic constituents (Andreasen and Spears 1983).

Few studies have looked specifically at the effects of CBNG product-water on fish although some CBNG product-waters exceed TDS and bicarbonate levels shown to be toxic to fish (Rice et al. 2000). Only two cases of significant mortality of mature fathead minnows occurred in 96-h acute tests using product-water samples taken directly from CBNG well heads (Forbes 2003). Fathead minnow eggs in 1400 mg/L sodium bicarbonate (NaHCO_3), the major salt associated with CBNG product-water, had a hatch rate of 43.9% whereas it was 62.5% in the control tank (Skaar et al. 2004). Post hatch, survival rate of the 96-h control was 94.3% whereas the survival rate was only 8.1% at NaHCO_3 concentrations of 1400 mg/L.

Whereas these acute tests show preliminary results, they did not capture all of the potential effects of CBNG waters on fish by accounting for actual field conditions. Field conditions show fluctuating changes in water chemistry and changes in CBNG product-water as it reacts with soils and the atmosphere (Patz et al. 2004). Moreover, laboratory tests typically

use the fathead minnow, which is tolerant of salts. Fathead minnow eggs and larvae withstood concentrations of salts four times greater than concentrations lethal to walleye and northern pike eggs and larvae (Peterka 1972). Fathead minnows were also found to be more tolerant than *Daphnia magna* to most salt combinations (Mount et al. 1997). Use of a species tolerant to adverse biological conditions including a high salinity tolerance, up to 8,700 mg/L NaCl (Kochsiek and Tubb 1967), could underestimate the potential effects to more sensitive species native to the Powder River Basin. Additionally, short-term acute tests do not capture potential longer term effects on growth, reproduction, and survival of fish; culturally derived salts in concentrations below known lethal concentrations affect growth and survival in chronic exposures. Sublethal concentrations of dissolved solids reduced growth in chinook salmon (*Oncorhynchus tshawytscha*) and striped bass (*Morone saxatilis*) (Saiki and Jennings 1992). Total dissolved solids decreased growth and survival of Lahontan cutthroat trout (*O. clarkii henshawi*) (Dickerson and Vinyard 1999). Survival to hatching of white suckers (*Catostomus commersonii*), walleye (*Sander vitreus*), northern pike (*Esox lucius*), yellow perch (*Perca flavescens*), and common carp (*Cyprinus carpio*) was significantly lower in sodium-sulfate type waters greater than 2400 mg/L TDS than in fresh water of 200 mg/L (Koel and Peterka 1995). Survival rate of newly hatched fathead minnows in CBNG type waters was 89% in the control and only 2.4% in 1400 mg/L NaHCO₃ after 37 days (Skaar et al. 2004). Excessive mortality in 800, 1100, and 1400 mg/L NaHCO₃ tests by day 37 prohibited calculation of a 60-d LC50 (Skaar et al. 2004). Whereas this series of tests by Skaar et al. (2004) provides insight to the effects of sodium bicarbonate on fathead minnows, information on chronic toxicity on other warmwater species in the Powder River Basin is generally lacking, presenting a substantial gap in predicting effects of saline discharges on these ecosystems (Confluence Consulting, Inc. 2003).

Case study of the effects of coalbed natural gas on fish assemblages

Varying levels of water quality alterations of Little Hurricane Creek (O'Neil et al. 1991) and the Big Sandy Creek drainage (Shepard et al. 1993) in the Black Warrior Basin of Alabama, occurred with the direct discharge of CBNG product-water. During low flows, chloride, sodium, bicarbonate, iron, and some heavy metal concentrations were elevated 5-15 times above pre-discharge levels downstream of discharge points. However, bicarbonate levels in product-water discharged into the Big Sandy Creek drainage were lower than those more typical of the Black

Warrior Basin (O'Neil et al. 1991, Shepard et al. 1993). Average annual flow was typically sufficient to dilute the CBNG product-water. However, Little Hurricane Creek discharge dropped to less than 1 cfs for four days of the study, during which instream chloride concentrations exceeded 565 mg/L, the determined threshold safe for fish. However, no significant decline in fish species diversity or biomass occurred after discharge of CBNG product-water began (O'Neil et al. 1991; Shepard et al. 1993). Fish species differed in their response to CBNG discharge. Whereas, the abundance of some fish species, such as the gulf darter, decreased with the presence of product-water, reproduction of the rough shiner was significantly greater downstream of discharge (O'Neil et al. 1991). These subtle patterns of fish species variation observed suggested that the aquatic system was changing and that long periods of CBNG product-water discharge may result in changes in community composition (O'Neil et al. 1991).

Coalbed natural gas product water quality varies among sites depending on the age and origin of the coal seam aquifer. Whereas chloride was the primary cause for toxicity in product-water in the Black Warrior Basin, the major ion compositions of product-water varies among basins limiting the inferences that can be made between basins (Mount et al. 1993). Additionally, in the arid environment of the Powder River Basin, naturally intermittent streams may not provide the same opportunity for dilution as found in Big Sandy Creek, Alabama.

Study Overview

The effects of CBNG development on fish assemblages in intermittent and ephemeral streams in the Powder River Basin may be difficult to assess because they are not well documented. In fact, Wyoming classifies all such streams as fishless. However, large numbers of fish exist in Montana Great Plains streams with intermittent pools (Bramblett et al. 2005). We conducted pilot fish surveys and found a range of 0 to 12 species of fish in such streams of the Powder River Basin.

The role of intermittent streams as unique habitat important to the function of ecosystems is often overlooked (Zale et al. 1989). Smaller intermittent and ephemeral streams are less stable

than perennial streams and would likely be the first to show effects of CBNG development. Therefore, they can be used as predictors of future large scale effects to a drainage.

We will employ four different approaches to assess the local and large scale effects of CBNG on fish assemblages of the Powder River Basin. First, to determine if CBNG development within the drainage area of a stream affects the fish assemblage present, fish surveys will be conducted on streams with CBNG development (treatments) and streams without development (controls). Second, to determine if CBNG development in the middle or lower reach of a stream affects expected longitudinal distribution patterns of fish assemblages, fish surveys will be conducted at multiple points along streams to determine if differences are found in fish assemblages above and below CBNG development. Third, to determine if fish assemblages change immediately after CBNG development in a drainage area, fish surveys will be conducted immediately before and after the initial development of CBNG. Finally, to determine if fish assemblages at specific locations in the Powder River Basin are the same now as they were prior to CBNG development, fish surveys conducted in the mid 1990s in areas with and without CBNG development will be repeated. Using a variety of approaches is necessary because of limited availability of baseline information and study sites, and high levels of variability between study streams.

Study Objectives and Hypotheses

Objective 1: Determine if CBNG development within the drainage area of a stream affects the fish assemblage present.

H1: Fish assemblages do not differ between streams within areas of CBNG development and streams in areas without CBNG development.

Objective 2: Determine if CBNG development in the middle or lower reaches of a stream affects expected longitudinal distribution patterns of fish assemblages.

H2: Streams with CBNG development in a middle or lower reach will have equal or higher species richness and IBI scores in the lower reaches than in the upper reaches.

Objective 3: Determine if fish assemblages change immediately after CBNG development in a drainage area.

H3: Fish assemblages will not change immediately after CBNG development in a drainage area.

Objective 4: Determine if fish assemblages at specific locations in the Powder River Basin are the same now as they were prior to CBNG development.

H4: Fish assemblages are the same now as they were prior to CBNG development.

Study Area

The Powder River geologic basin of southeastern Montana and northeastern Wyoming includes portions of the Tongue and Powder River hydrologic basins. These tributaries to the Yellowstone River are in the Northwestern Great Plains ecoregion (Woods et al. 1999). All study sites are within these basins (Figure 2.).

The Powder River hydrologic basin is 34,300 km² in area (Rehwinkle et al. 1978). Elevation ranges from 3,950 m above sea level at the headwaters in the Bighorn Mountains to 676 m at the confluence with the Yellowstone River. Erosive limestone, shale, sandstone, and siltstone sedimentary material of the high plains have resulted in high plateaus dissected by stream-cut canyons, badlands, and river terraces (Rehwinkle et al. 1978).

The Tongue River basin is 13,931 km² in area (Gustafson 2005). Elevation ranges from 3,059 m above sea level at the headwaters in the Bighorn Mountains to 719 m at the confluence with the Yellowstone River. The Tongue River is dammed by the Tongue River Dam near the Montana-Wyoming border and four additional diversion dams are located downstream. The Tongue River probably had a fish assemblage similar to the Powder River before water development (Smith and Hubert 1989). Now seven species that were present in both rivers, including goldeye (*Hiodon alosoides*), shovelnose sturgeon (*Scaphirhynchus platorhynchus*), and sturgeon chub (*Machrybopsis gelida*), are only found below the farthest downstream diversion dam (Hubert 1993). Species introduced to the reservoir as sport fish, including northern pike and black crappie (*Poxomis nigromaculatus*), are now established in the river. Additionally, some creek residents, including white suckers and black bullheads (*Ameiurus melas*), are now abundant in the river.

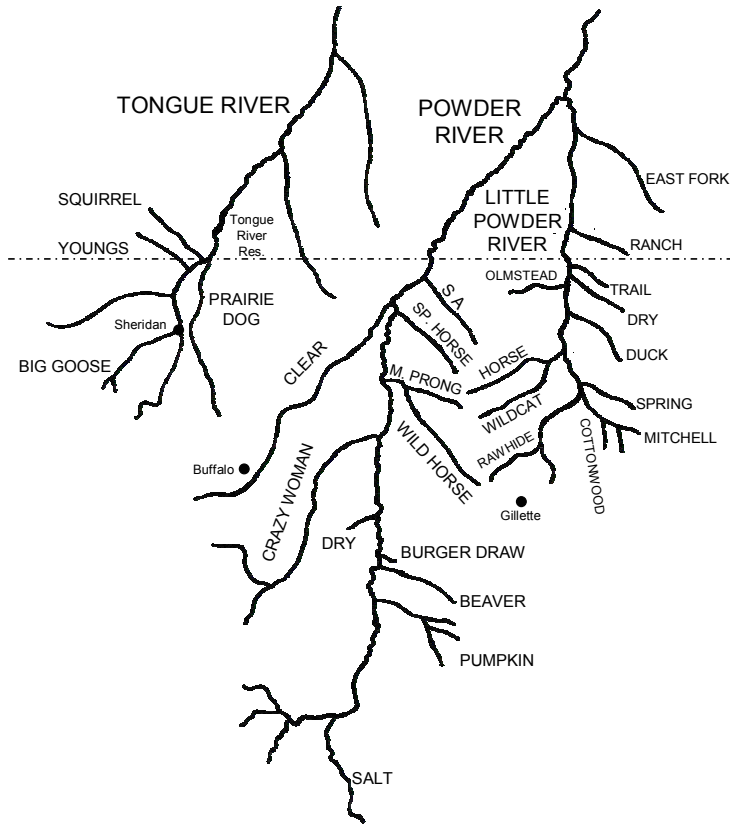


Figure 2. Study area in the Tongue and Powder River drainages of Montana and Wyoming.

Methods

Water quality samples

Surface waters of the Powder River Basin differ from CBNG product-water. Water quality samples will be analyzed to characterize the differences in water quality between areas with and without CBNG development.

Protocol.—Water quality samples will be collected from the lowest survey site on each control and treatment stream and every site on longitudinal streams within a one-week period in August in 2005. Water quality samples will also be collected from all survey sites within a one-week period in August 2006. These samples will be kept on ice and delivered within 48 h to Energy Labs Inc., Billings, Montana, for complete ion analysis (Table 1) in accordance with American Public Health Association (APHA) (1998).

Table 1. Parameters measured in each water sample.

Physical properties	Units
pH	
Conductivity	µmhos/cm
Total dissolved solids	
Alkalinity, total CaCO ₃	mg/L
Bicarbonate as HCO ₃ ⁻	mg/L
Chloride	mg/L
Sulfate	mg/L
Nutrients	
Ammonia	mg/L
Dissolved metals	
Calcium	mg/L
Magnesium	mg/L
Potassium	mg/L
Sodium	mg/L

Treatment versus control stream surveys

The first objective is to determine if CBNG development within the drainage area of a stream affects the fish assemblage present. The mainstems of the Tongue and Powder rivers receive CBNG product-water discharges from direct discharge points and tributaries.

Determining the relationship between past and future changes in fish assemblages in the rivers

with CBNG development would be difficult because the rivers have to be considered fully treated with CBNG product-water. However, small tributaries with and without CBNG development provide an opportunity to determine relationships between fish assemblages and CBNG development.

Site selection.—Sites will be selected to represent stream with and without CBNG development in the Powder and Tongue river basins. Treatment streams are those which have some level of CBNG development within their drainages regardless of the number of producing wells and the method of product-water disposal. Control streams are those without CBNG development in their drainage area. We identified a total of twelve treatment and twelve control streams in the study area. However, all sites are located on private land and access was limited to nine treatment and eight control streams (Table 2).

The uppermost reach that holds water in the stream will be determined from high resolution infrared aerial photos taken in July 2003. The stream will then be divided into three sections of equal length between the confluence with a higher order stream and the uppermost reach of water (Sections A, B, C moving from confluence upstream). A proportion (0.0 – 1.0) will be randomly assigned to each section of the stream and the distance of that proportion from the lower margin of the section will be estimated and plotted on a map. Control and treatment streams will be randomly assigned an alternating order in which they will be sampled to preclude the influence of temporal variations within the sampling period.

Table 2. Treatment and control streams in the Powder and Tongue river basins of Montana and Wyoming.

Treatment	Control
SA Creek	Ranch Creek
Spotted Horse Creek	Trail Creek
Middle Prong Wildhorse Creek	Olmstead Creek
Wildhorse Creek	Dry Creek (Little Powder drainage)
Wildcat Creek	Mitchell Creek
Horse Creek	Cottonwood Creek
Dry Creek (Powder drainage)	Spring Creek
Burger Draw	East Fork Little Powder
Squirrel Creek	

Protocol.—Sites will be located by finding the access closest to the assigned point. A coin will be flipped to determine if the reach will be surveyed upstream (heads) or downstream (tails) from this access point. A random number between 150 and 300 will be generated to determine the number of meters paced out from the access point to set the center point of the study reach. In the event that the assigned study reach has no water present, a coin will be flipped to determine if the site will be moved upstream (heads) or downstream (tails) to the nearest reach holding water within the land for which access has been granted.

Fish assemblages will be sampled in a 300-m reach of stream. The reach will be delineated using flags and fish will be collected by seining according to the Fish and Habitat Prairie Stream Survey Protocol (Bramblett 2003, attached in Appendix A). Species of each fish will be recorded and total lengths (mm) of fish of each species will be taken (up to 100 individuals per species). Up to 10 voucher specimens per species will be collected and preserved from each stream for laboratory verification and for placement into permanent collections. Visual estimates of proximity of roads, grazing, row crops, buildings, CBNG wells, CBNG holding ponds, and CBNG compressor stations (m), percent riparian vegetation cover, and

percent in-stream fish cover will be recorded at each site. Stream temperature (°C), specific conductivity ($\mu\text{mhos/cm}$), and dissolved oxygen (mg/L) will be measured using a Yellowstone Springs Institute (YSI) meter. Turbidity (NTU) will be measured using a LaMotte turbidimeter. Finally, pH will be measured using an Oakton pH Tester 2.

Analysis.—Multimetric indices of biological condition have been used successfully for biological assessment of waters worldwide (Karr and Chu 2000). Indices of biotic integrity (IBI) are designed to respond only to anthropogenic stressors (Bramblett et al. 2005). Multimetric indices are more robust than single biological indicators (Karr 1981). Slight modifications of the recently developed IBI for northwestern Great Plains streams (Bramblett et al. 2005) may provide a useful tool for assessing the effects of CBNG development on fish assemblages. An IBI score for northwestern Great Plains streams will be computed for each site. Whereas species richness and the presence-absence of sensitive species are used in the calculation of IBI scores, we will also consider these measures separately. Sites will be blocked by basin and treatments and controls will be compared using analysis of variance (ANOVA). Formerly ephemeral streams that have been perennialized by CBNG product-water will be considered separately because the control for these cases would be a dry streambed. Linear regression will be used to determine relationships of IBI scores, species richness, and presence of sensitive species with concentrations of major ions associated with CBNG product-water.

Length-frequency distributions will be developed for each species at each site. Modal lengths-at-age and annual survival will be compared among populations of a species (e.g., treatments vs. control). This will also provide insight into regularity of recruitment by identifying missing year classes.

Longitudinal stream surveys

This objective is to determine if CBNG development in the middle or lower reach of a stream affects expected longitudinal distribution patterns of fish assemblages. Species richness typically will increase moving downstream from the headwaters to the confluence with a higher order stream (Vannote et al. 1980). Species richness may decline in lower reaches if fish are unable to persist under the environmental conditions resulting from CBNG development.

Site selection.—Typically the upper reaches of streams are the first developed for CBNG because permitting is generally easier in upland areas where stream water is not being used for irrigation. Streams with the upper reaches developed are considered treatment streams. However, only a middle or lower reach has been developed in Squirrel, Youngs, and Crazy Woman Creeks. All of these will be profiled longitudinally. Squirrel Creek is a small intermittent tributary to the Tongue River, Montana, with about 200 CBNG wells in the lower portion of the drainage. Squirrel Creek does not receive direct discharge of the CBNG product-water. Product-water is either piped to the permitted outfalls on the Tongue River, or stored in either in-channel or off-channel impoundments. The upper reaches of Squirrel Creek have not yet been developed by CBNG; however, proposals exist to expand development up the drainage. Youngs Creek is a small perennial tributary of the Tongue River with headwaters in Montana and its lower reaches in Wyoming. Currently, no CBNG development has occurred on Youngs Creek in Montana and relatively limited development has occurred on the lower reach in Wyoming. To assess the longitudinal distribution of the fish assemblages, Squirrel and Youngs creeks were stratified into five sections between the confluence with the Tongue River and the uppermost reach of water (Sections A, B, C, D, E, moving from confluence upstream). Crazy Woman Creek is a perennial tributary to the Powder River. Its confluence is located about 20 km south of Arvada, Wyoming. Whereas its headwaters are in the Bighorn Mountains and support salmonids, the study sites are lower in the drainage and have fish assemblages typical of a Great Plains stream. Crazy Woman Creek is used for spawning by several migratory fish species including channel catfish (*Ictalurus punctatus*) and shovelnose sturgeon (Smith and Hubert 1989). About 300 permitted CBNG wells are in the area of the middle survey sites of the stream. Crazy Woman Creek will be surveyed at five locations that were the locations of historic surveys (Patton 1997) and represent a longitudinal profile of the stream.

Protocol.—Sites on Squirrel and Crazy Woman creeks will be surveyed using the standard seining protocol. Youngs Creek has a significant amount of woody debris in the stream making seining inefficient. Single-pass electrofishing using a Smith Root backpack shocking unit and one netter will be used as an alternative to seining in this stream.

Analysis.—An index of biotic integrity (IBI) score will be computed for each site (Bramblett et al. 2005). These scores for individual sites will be compared using analysis of variance (ANOVA). The relationship between species richness and longitudinal position along the stream will be determined using regression.

Before and after stream surveys

The objective is to determine if fish assemblages change immediately after CBNG development in a drainage area.

Site selection.—Currently, the upper reach of Squirrel Creek is within the drainage area of CBNG development; however, development is projected to be in place by the end of 2005. The two upper sites of Squirrel Creek that are being used for the longitudinal profile study will also be used for the before and after study.

Protocol.—Sites will be surveyed using the standard seining protocol.

Analysis.—An index of biotic integrity (IBI) score will be computed for each survey using the methods of Bramblett et al. (2005). Pre-CBNG and post-CBNG scores and relative abundance of various species will be compared.

Historical surveys

The fourth objective is to determine if fish assemblages at specific locations in the Powder River Basin are the same now as they were prior to CBNG development. Revisiting sample sites in areas of CBNG development and areas without CBNG development will allow us to determine if differences in the fish fauna are related to CBNG development. To account for differences in sampling efficiency and lack of historical abundance data, presence-absence data were used to determine patterns of species decline between the 1960s and the 1990s (Patton et al. 1998b). Resampling historic sites using similar field methods will allow us to determine site-specific species declines and infer trends within the drainage. However, historic data may be more useful than recent data for detecting population declines (Patton et al. 1998b). Therefore, we can also compare presence-absence data from both 1960s surveys and 1990s surveys to determine species decline on the drainage scale.

Site selection.—Surveys conducted by Patton in 1993-1995, prior to CBNG production will be repeated in several streams in the Wyoming portion of the Powder River Basin (Table 3).

Table 3. Fish surveys conducted by Patton et al. (1998b) to be repeated in 2005-2006 field study.

Historical stream	CBNG present	CBNG absent
Crazy Woman Creek	3 sites	2 sites
Salt Creek		2 sites
Clear Creek		5 sites
Prairie Dog Creek	2 sites	1 site
Little Goose Creek	1 site	
Big Goose Creek	1 site	
Little Powder River	5 sites	
Total: 22 sites	12 sites	10 sites

Protocol.—Sites will be located using a GPS unit with the assigned coordinates representing the center point of the study reach. Sites will be surveyed using the same protocol as the control and treatment surveys. Although the methods of Patton et al. (1998b) and Bramblett (2003) differ slightly in reach length, both protocols are designed to capture 100% of the species present.

Analysis.—Index of biotic integrity scores will be calculated for surveys conducted in the 1990s and for surveys to be conducted during this study. Scores will be blocked by CBNG status and compared using ANOVA. Relative abundance between the historic (1990s) and present surveys allow for direct comparisons using ANOVA. Additionally, species richness and presence-absence data will be compared from the 1960s, 1990s, and our surveys to determine changes in fish distributions within and outside areas of CBNG development.

Projected Schedule

Field Season 1: June – August 2005 (Work Completed)

- Control and Treatment Stream Surveys
- Longitudinal Stream Surveys
- Before Stream Surveys
- Historical Survey of Crazy Woman Creek

Off season: (Fall and Spring Semester 2005-2006)

- Complete preliminary data analysis.
- Contact landowners for remaining historical surveys.

Field Season 2: June – August 2006

- Repeat control and treatment stream surveys.
- Complete before and after stream surveys.
- Complete remaining historical surveys.

Off season: (Fall and Spring Semester 2006-2007)

- Complete data analysis
- Prepare thesis and final reports

References

- ALL Consulting. 2003. Handbook on Coal Bed Methane Produced Water: Management and Beneficial Use Alternative. Report of ALL Consulting to Ground Water Resource Protection Foundation, U.S. Department of Energy, National Petroleum Technology Office, and the Bureau of Land Management.
- Andreasen, J., and R. Spears. 1983. Toxicity of Texan petroleum well brine to the sheepshead minnow (*Cyprinodon variegatus*), a common estuarine fish. *Bulletin of Environmental Contamination and Toxicology* 30: 277-283.
- APHA (American Public Health Association). 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th Edition. APHA, Washington, D.C.
- Barclay, M.C., and R.C. Harrel. 1985. Effects of pollution effluents on two successive tributaries and Village Creek in southeastern Texas. *The Texas Journal of Science* 37:175-188.
- Bierhuizen, J. F. H., and E. E. Prepas. 1985. Relationships between nutrients, dominant ions, and phytoplankton standing crop in prairie saline lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 42:1588-1594.
- Bramblett, R. G., T.R. Johnson, A. V. Zale, and D. G. Heggem. 2005. Development and evaluation of a fish assemblage index of biotic integrity for northwestern Great Plains streams. *Transactions of the American Fisheries Society* 134:624-640.
- Clark, M. L., K. A. Miller, and M. H. Brooks. 2001. U.S. Geological Survey monitoring of Powder River Basin stream-water quantity and quality. Water-resources investigation report 01-4279. Cheyenne, Wyoming.

- Clearwater, S. J., B. A. Morris, and J. S. Meyer. 2002. A comparison of coalbed methane product-water quality versus surface water quality in the Powder River Basin of Wyoming, and an assessment of the use of standard aquatic toxicity testing organisms for evaluating the potential effects of coalbed methane product-waters. Report to University of Wyoming, Laramie, Wyoming.
- Confluence Consulting, Inc. 2003. Biological, physical, and chemical integrity of select streams in the Tongue River Basin. Report to Bureau of Land Management, Miles City, Montana.
- Confluence Consulting, Inc. 2004. Powder River biological survey and implications for coalbed methane development. Report to Powder River Basin Resource Council, Sheridan, Wyoming.
- Dickerson, B. R., and G. L. Vineyard. 1999. Effects of high levels of total dissolved solids in Walker Lake, Nevada, on survival and growth of Lahontan cutthroat trout. *Transactions of the American Fisheries Society* 128:507-515.
- Forbes, M. B. 2003. Toxicity of coalbed methane product-waters and receiving waters in the Powder River Basin, Wyoming. Master's thesis. University of Wyoming. Laramie, Wyoming.
- Gustafson, D. 2005. Graphical Locator On-line Database. Environmental Statistics Group, Montana State University, Bozeman, Montana. Available: <http://www.esg.montana.edu>. (October 2005).
- Higgins, C. L., and G. R. Wilde. 2005. The role of salinity in structuring fish assemblages in a prairie stream system. *Hydrobiologia* 549: 197-203.

- Hubert, W. A. 1993. The Powder River: a relatively pristine stream on the Great Plains. Pages 387-395 in Restoration Planning for the Rivers of the Mississippi River Ecosystem. U.S. National Biological Survey, Biological Report 19, Washington, D.C.
- Ingersoll, C. G., F. J. Dwyer, S. A. Burch, M. K. Nelson, D. R. Buckler, and J. B. Hunn. 1992. The use of freshwater and saltwater animals to distinguish between toxic effects of salinity and contaminants in irrigation drain water. *Environmental Toxicology and Chemistry* 11:503-511.
- Karr, J. R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6(6):21-27.
- Karr, J. R., and E.W. Chu. 2000. Sustaining living rivers. *Hydrobiologia* 422/423:1-14.
- Kochsiek, K. A., and R. A. Tubb. 1967. Salinity tolerance of *Fundulus diaphanous*, *Culaea inconstans*, and *Pimephales promelas*. *Proceedings of South Dakota Academy of Science* 46:97-100.
- Koel, T., and J. Peterka. 1995. Survival to hatching of fishes in sulfate-saline waters, Devils Lake, North Dakota. *Canadian Journal of Fisheries and Aquatic Science* 52:464-469.
- McBeth, I., K. Reddy, and Q. Skinner. 2003. Coalbed methane product-water chemistry in three Wyoming watersheds. *Journal of the American Water Resources Association* 39(3):575-585.
- Mount, D. R., D. D. Gulley, J. R. Hockett, T. D. Garrison, and J. M. Evans. 1997. Statistical models to predict the toxicity of major ions to *Ceriodaphnia dubia*, *Daphnia magna*, and *Pimephales promelas*. *Environmental Toxicology and Chemistry* 16:2009-2019.
- Mount, D. R., P. E. O'Neil, and J. M. Evans. 1993. Discharge of coalbed produced water to surface waters- Assessing, predicting, and preventing ecological effects. *Quarterly Review of Methane from Coal Seams Technology* 11(2): 18-25.

- O'Neil, P. E., S. C. Harris, M. F. Mettee, S. W. McGregor, and T. E. Shepard. 1991. Long-term biomonitoring of a produced water discharge from the Cedar Cove degasification field, Alabama. Geological Survey of Alabama, Bulletin 141, Tuscaloosa, Alabama.
- Patton, T. M. 1997. Distribution and status of fishes in the Missouri River drainage in Wyoming: implications for identifying conservation areas. Doctoral dissertation. University of Wyoming, Laramie, Wyoming.
- Patton, T. M., W. A. Hubert, and F. J. Rahel. 1998a. Ichthyofauna in streams of the Missouri River drainage, Wyoming. *The Prairie Naturalist* 30:9-21.
- Patton, T. M., F. J. Rahel, and W. A. Hubert. 1998b. Using historical data to assess changes in Wyoming's fish fauna. *Conservation Biology* 12(5):1120-1128.
- Patz, M., K. Reddy, and Q. Skinner. 2004. Chemistry of coalbed methane discharge water interacting with semi-arid ephemeral stream channels. *Journal of the American Water Resources Association* 4:1247-1255.
- Peterka, J. J. 1972. Effects of saline waters upon survival of fish eggs and larvae and upon the ecology of the fathead minnow. North Dakota State University, Research project technical completion report, Fargo, North Dakota.
- Rehwinkle, B. J., M. Gorges, and J. Wells. 1978. Powder River aquatic ecology project. Montana Department of Fish and Game, Final Report, Helena.
- Rice, C. A., M. S. Ellis, and J. H. Bullock, Jr. 2000. Water co-produced with coalbed methane in the Powder River Basin, Wyoming, preliminary compositional data. U.S. Geological Survey, Open-file Report 00-372, Denver, Colorado.
- Saiki, M. K., and M. R. Jennings. 1992. Toxicity of agricultural subsurface drainwater from the San Joaquin Valley, California to juvenile chinook salmon and striped bass. *Transactions of the American Fisheries Society* 121:78-93.

- Shepard, T. E., P. E. O'Neil, S. C. Harris, and S. W. McGregor. 1993. Effects of coalbed methane development on the water-quality and fish and benthic invertebrate communities of the Big Sandy Creek Drainage System, Alabama. Geological Survey of Alabama, Circular 171, Tuscaloosa, Alabama.
- Shiple, F. 1991. Oil field-produced brines in a coastal stream: water quality and fish community recovery following long term impacts. Texas Journal of Science 43:51-64.
- Skaar, D., B. Morris, and A. Farag. 2004. National pollution discharge elimination system. Toxicity of the major salt (sodium bicarbonate) from coalbed methane production on fish in the Tongue and Powder river drainages in Montana. U.S. Environmental Protection Agency, Semi-annual progress report, Washington, D.C.
- Smith, J. B., and W. A. Hubert. 1989. Use of a tributary by fishes in a Great Plains river system. Prairie Naturalist 21:27-38.
- Spears, R. 1971. An evaluation of the effects of oil, oilfield brine and removing compounds. American Institute of Mining, Metallurgical and Petroleum Engineers, Report EQC 43, Washington, D.C.
- Swanson, R. B., J. P. Mason, and D. T. Miller. 2000. Water resources data, Wyoming, Water Year 1999; volume 2, ground water. U.S. Geological Survey, Report WY-99-2, Washington, D.C.
- Toepfer, C., and M. Barton. 1992. Influence of salinity on the rates of oxygen consumption in two species of freshwater fishes, *Phoxinus erythrogaster* (family Cyprinidae), and *Fundulus catenatus* (family Fundulidae). Hydrobiologia 242: 149-154.
- Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Science 37:130-137.

- Wilde, E. W., and A. B. Parrott. 1984. A simple and inexpensive *in situ* method for assessing acute toxicity of effluents to fish. *Water Research* 18:783-785.
- Williams, W.D. 2001. Anthropogenic salinization of inland waters. *Hydrobiologia* 466:329-337.
- WOGCC (Wyoming Oil and Gas Conservation Commission). 2005. On-line oil and gas database. WOGCC. Available: <http://wogcc.state.wy.us>. (November 2005).
- Woods, A. J., J. M. Omernik, J. A. Nesser, J. Sheldon, and S. H. Azevedo. 1999. Ecoregions of Montana (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U. S. Geological Survey (map scale 1:1,500,000).
- Zale, A. V., D. M. Leslie Jr., W. L. Fisher, and S. G. Merrifield. 1989. The physicochemistry, flora, and fauna of intermittent prairie streams: a review of the literature. U.S. Fish and Wildlife Service, Biological Report 89(5), Washington, D.C.

Appendix A

Fish and Habitat Sampling Protocol for Prairie Streams

Bob Bramblett

Montana Cooperative Fisheries Research Unit

January, 2003

1. **Site location.**-Locate the sampling site using GPS for random sites, or by convenience for non-random sites. The GPS location will be the center of the reach, this is where you place the “F” flag (see Step 2). If the site is dry, shift the reach up or downstream to capture the most wetted channel possible on the parcel of land where you have permission for sampling.
2. **Laying out the sample reach.**-Lay out a 300 m sample reach using a measuring tape and a set of 11 pin flags (labeled A-K). Follow the curves in the stream channel with the measuring tape; do not cut across curves. To avoid spooking fish, walk along the bank, not in the stream. Place a flag every 30 m. The “A” flag will be at the downstream end, the “K” flag will be at the upstream end of the reach. The “F” flag will go in the center of the reach.
3. **Block nets.**-Place block nets (these can be old seines, 1/4” mesh) at the upstream (K flag) and downstream (A flag) ends of the sample reach if the water in the channel is continuous, deeper than 25 cm, and relatively clear. This prevents fish from leaving the sample reach.
4. **Seining.**-Select the seine based on the size of the stream to be sampled. The seine length to be used should be approximately equal to or slightly greater than the stream width, and the seine height should be about 1.5 to 2 times greater than the depth of the stream. Dip nets can be used in very shallow, small habitats. Seining begins at the upstream end (K flag) and proceeds downstream to the A flag. Seining is performed by two people, one on each end of the seine. In pools, the seine is pulled down the stream channel, using the shore and other natural habitat features as barriers. Begin with the seine rolled up on each seine braille. The seine is typically set perpendicular to shore and hauled downstream parallel to shore. As you proceed, let out enough seine so that the seine forms a “U” shape, but not so much that the net is hard to control. Adjust the length of the seine by rolling or un-rolling net on the seine braille. The speed of seining should be fast enough to maintain the “U” shape, but not so fast that the floats become submerged, or that the seine’s lead line come way up off the bottom of

the stream. If rocks or other snags are on the bottom, the seine can be lifted off the bottom for a moment to avoid the snag, or one of the netters can bring the seine around the snag to avoid it, all the while maintaining the forward progress of the seine. Similarly, areas of dense aquatic vegetation can be avoided. It is important not to stop the forward progress, because fish will swim out of the seine. It is better to avoid a snag while keeping moving than to become snagged, which will allow fish to escape. In “snaggy” waters, keep more of your seine rolled up for better control.

Proceed downstream while seining. In narrow streams, the entire channel width is spanned with the seine. In wider streams, one person walks along the shore, while the other wades through the channel. The length of each seine haul will depend on the natural features of the stream channel and shoreline, but seine hauls should not normally be more than 60 or 90 m long. Side channel bars or the end of a standing pool are good areas to haul out or “beach” the seine. Where a large bar or end of a standing pool is present both netters can simply run the net up on the shore. In streams with steep banks or lack of obvious seine beaching areas the “snap” technique can be used. At the end of the haul, the person near shore stops, while the person farthest out turns into shore, quickly, until the seine is up against the bank. The two netters then walk away from each other, taking the slack out of the seine, and keeping the seine’s lead line up against the bank.

In riffles, with moderate to fast current, the “kick seine” technique can be used. The seine is held stationary in a “U” shape, while the other team member disturbs the substrate immediately upstream of the net. Then the net is quickly “snapped” out of the water by both team members using an upstream scooping motion.

Seine the entire 300 m reach, covering the linear distance at least once. If part of the 300 m is dry, just skip it. If the stream is much wider than your seine, do extra seine hauls in the large pools to cover the extra width. Sample all habitat types (shoreline, thalweg, side channels, backwaters).

After each seine haul, place fish in a bucket. If the water is warm, or you have captured many fish, place fish in a fish bag to keep them alive until seining is completed, or use an aerator. If you have to work up fish before seining is completed, release processed fish in an area that has already been seined, as far away from the area remaining to be seined as possible (or outside of the block nets). Large fish such as northern pike, common carp, white sucker, shorthead redhorse, or channel catfish, can be measured, given a small clip to the lower caudal fin and released immediately. Marking fish will prevent them from being counted more than once if they are captured again.

5. ***Processing captured fish.***-Record the species of each fish captured, and measure 20 “randomly” selected fish to the nearest millimeter, total length. If the species of fish is unknown, try to at least record it as Unknown type 1, Unknown type 2, etc. Keep track of and record the minimum and maximum length of each species.

For each species, preserve a subsample of at least 10 individuals per site to serve as voucher specimens. Record a small letter “v” next to the recorded length of the fish that is vouchered to allow for later validation. For *Hybognathus* spp., voucher up to 20 individuals per site. Kill the fish to be vouchered by placing them in a small bucket or 1000 ml nalgene jar with an overdose solution of MS-222. After fish processing is completed, drain the MS-222 solution and place the fish in a 1000 ml nalgene jar with a 10% solution of formalin (in clear water, if possible). For specimens longer than 150 mm, an incision should be made on the right ventral side of the abdomen after death, to allow fixative to enter the body cavity. The volume of formalin solution should be approximately equal to the twice the volume of fish tissue to be preserved, and the fish volume should be considered water when concentrations are determined. For example, if the fish take up 250 ml of the 1000 ml volume, you need about 500 ml of 10 % formalin solution (75 ml formalin and 425 ml water) in the 1000 ml nalgene jar. If necessary, use a second jar to accommodate all of the specimens. Use safety glasses and gloves when pouring formalin. Do not let the fish “cook” in the sun for a while and preserve them later, do it as soon as possible. Label all jars inside and out with Site, Site Number, Lat/Long, Date, Collectors names. Use pencil on Write-In-the-Rain or high rag paper for inside labels (just put the label right in with the fish), use a sticker label on the

outside, cover it with clear (ScotchPad high performance packing tape pad 3750-P). Fish specimens should be left in formalin solution for at least 2-7 days. Fish specimens must have formalin solution soaked out before being handled extensively. Specimens should be soaked in water for at least 2 days, and water should be changed at least four times during this period. After soaking out the formalin, the fish specimens should be placed in either 70% ethanol or 40% isopropanol for long-term storage.

6. **Habitat survey.**-Channel width, depth of water, and substrate will be measured at 11 transects perpendicular to the stream channel (located at Flags A-K), and along the thalweg in 10 thalweg intervals between transects (deepest part of channel). Stream width is measured to the nearest 0.1 m, depth is measured to the nearest cm, and substrate sizes and codes are on the data sheet. One person will be in the stream taking measurements while the other records data. Record the Latitude and Longitude (in digital degrees) of the F flag, the stream name, site number, the date, the flow status (flowing, continuous standing water, or interrupted standing water) and the names of the crew members on the data sheet. Take photographs of the site, capturing as much of the sampling reach as possible. Make sure the date feature on the camera is turned on, to allow for later identification of site photographs.

Transects.-Start on the left bank (facing downstream) at Flag A. Measure and record the wetted width of the channel to the nearest 0.1 m. Measure and record (separated by a comma on the data sheet) five equally spaced depth and substrate measurements across the wetted stream channel:

1. Left Bank-5 cm from the left bank;
2. Left Center-halfway between the Center and the Left Bank;
3. Center-center of the wetted stream;
4. Right Center-halfway between the Center and the Right Bank;
5. Right Bank-5 cm from the right bank

Thalweg.-Begin by recording the depth and substrate 3 m upstream of the transect, in the deepest part of the channel (thalweg). Proceed up the thalweg to Flag B, recording depth and substrate every 3 m along the thalweg. You will record a total of 10 depths and substrates between each pair of transects. If the stream channel is dry, record a 0 for

depth, and record the substrate. The last thalweg measurement point should fall on the next upstream transect. The 3 m interval can be estimated, and it is helpful if the data recorder helps to keep the person in the stream from “squeezing” or “stretching” the thalweg measurements.

Repeat this procedure until all 11 transects and 10 thalweg intervals are completed.

Gear List

- 20', x 6' x ¼" heavy delta seines
- 15' x 4' x ¼" heavy delta
- 30' x 6' x ¼" heavy delta (or delta) with 6' x 6' x 6' bag
- Fish bags: nylon diver's bags, ¼" mesh 18" x 30"
- Mudders – 109.00 at Ben Meadows
- Block nets, Tent stakes
- Stream Conductivity meter
- Thermometer
- Turbidity meter (LaMotte, Ben Meadows 224805, \$795.00-might try the “transparency tube” Ben Meadows 224196, \$52.95)
- Waders (breathable waders are essential for this work-Cabelas has them for about \$100/pair), hip boots are usually too low
- Lug sole wading boots (Cabelas)
- Habitat pole (I make habitat poles out of 1.0" OD PVC pipe. 1.5 m long including caps. Score the pipe every 10 cm with a pipe cutter, then use a Sharpie to mark rings around the pole at the scores, and label the pole 10, 20, 30, etc. 5 cm marks are made between the 10 cm rings, you can visually estimate between the 5 cm marks to get to the nearest cm. Spray or brush a Urethane finish on the pole or your marks will come off fast with sunscreen and bug dope.)
- Metric 30 m tape (Ace Hardware actually carries a tape with metric on one side)
- Measuring boards, one short 300 mm (half a 6" PVC works well for *Hybognathus* “fin flotation”, one long, ~0.5-1 m, or you can just use a meter stick for the odd big fish)

- Hand lens
- Small 1 gallon red bucket from Ace Hardware for doping fish
- 5 gallon buckets
- MS-222
- Labels and tape pads for fish samples
- 1000 ml Nalgene jars
- Formalin (buffered is great, but more expensive-I throw a Roloids in each jar of fish to neutralize the acidity)
- Clip board
- 11 Pin flags labeled A-F

List of expenditures for the “Literature Review and Development of a Study Plan to Assess the Effects of Coalbed Natural Gas Activities on Fish Assemblages”.

Expenditures	Cost
Travel	\$8,400
Rent	\$1,800
Computer	\$4,067
Water quality equipment (meters and buffers)	\$883
Office supplies	\$460
Equipment repair and maintenance	\$212
Photocopies	\$353
Shipping and postage	\$318
Computer software	\$80
Total	\$16,573
