doi:10.2489/jswc.65.3.72A

FEATURE

# The agriculture–energy–environment nexus in the West

Thomas J. Osborne, William M. Schafer, and Neal E. Fehringer

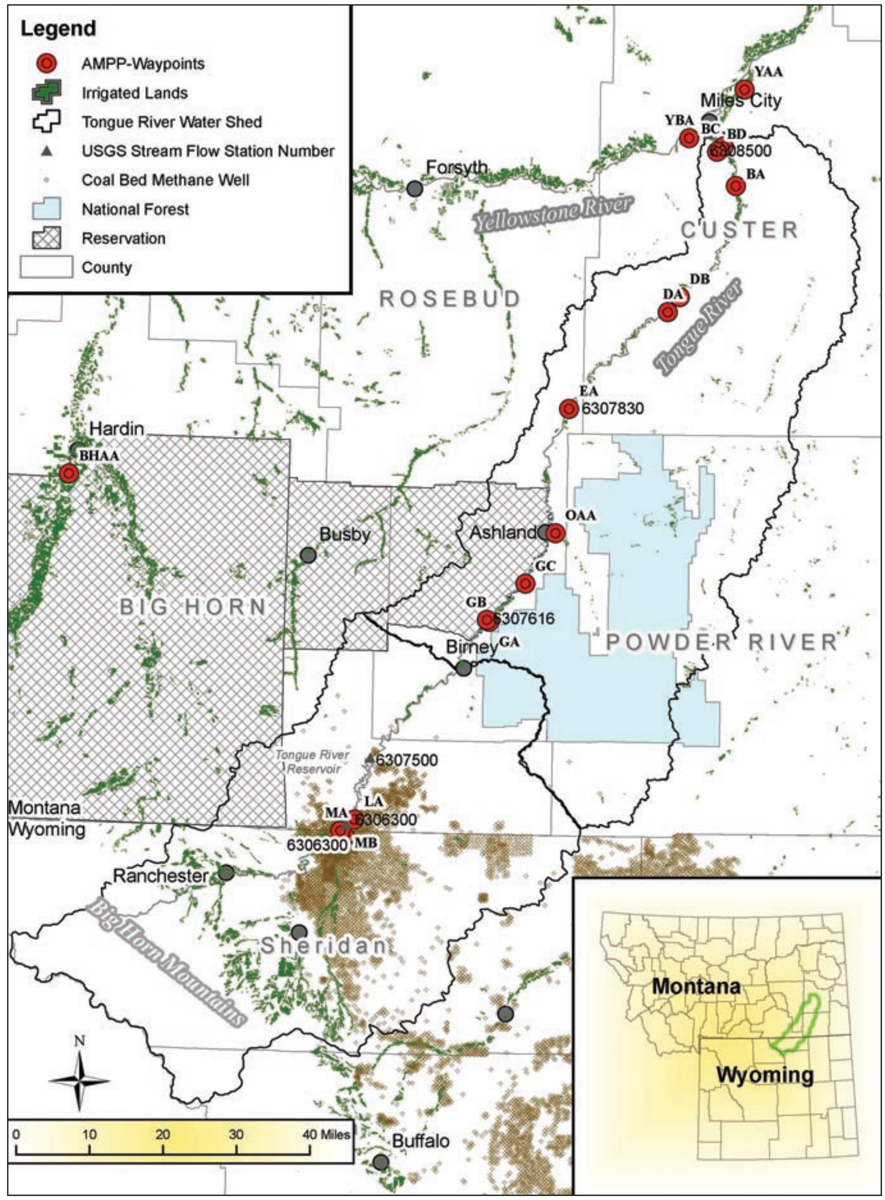
The nexus of the agriculture–energy production–environment triad occurs nowhere in the United States more acutely than on the high plains of Montana and Wyoming. The Tongue River basin (TRB) of Wyoming and Montana has over 27,242 ha (67,317 acres) of irrigated land which has supported cattle ranching and farming operations for more than 120 years. The Tongue River lies over the axis of the coal-rich Powder River geologic basin which has experienced coal bed natural gas (CBNG) development since 1999, along with surface coal mining since 1972. The Tongue River is a principal tributary of the Yellowstone River, with its headwaters in the Bighorn Mountains of northern Wyoming and its confluence with the Yellowstone River in southeastern Montana.

## IRRIGATORS' CONCERNS

Approximately 3,358 CBNG wells were operating in the TRB at the end of 2008, 73% of which are in Wyoming (figure 1) (WOGCC 2009). Production of CBNG requires pumping of water to depressurize coal aquifers and release the adsorbed gas. The quantity of CBNG-produced water within the TRB averaged about 18 $m^3$ $day^{-1}$ (3.3 gal $min^{-1}$) per CBNG well during 2008, for a total of 0.708 $m^3$ $s^{-1}$ (25 $ft^3$ $sec^{-1}$) of produced water, roughly 6% of the median flow of the Tongue River. The water co-produced with CBNG is considered wastewater under the Clean Water Act and must be disposed via an appropriate permit or beneficially used in some way. Most co-produced water is pumped into small ponds where the water evaporates or infiltrates into groundwater. Some is used beneficially under managed irrigation systems employing subsurface drip or center pivot systems. Some is treated to reduce soluble salt and sodium levels and discharged to surface water. About 13% of produced water is discharged to the Tongue River without treatment (HydroSolutions Inc. 2009).

**Figure 1**

**Location map for the Tongue River basin and Tongue River Information Program study fields designated by two- and three-letter codes.**



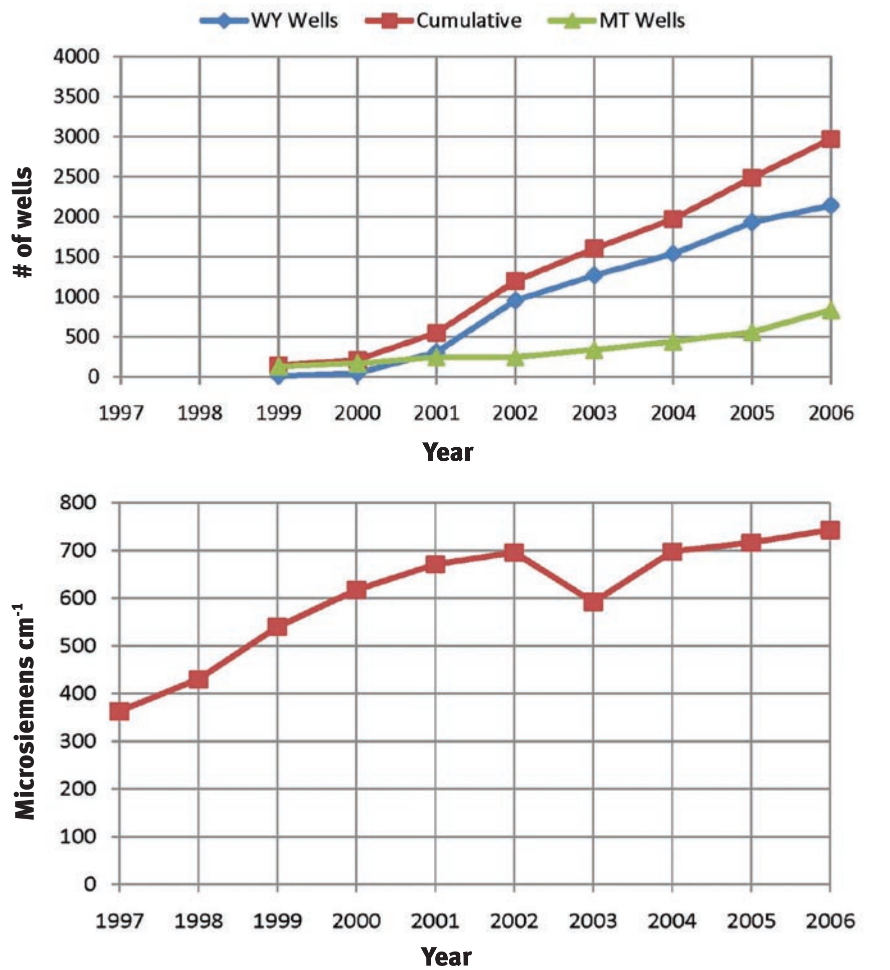

Irrigators in the TRB have expressed concern about the discharge of CBNG-produced water to the Tongue River and its potential effects on water quality and, in turn, soil properties and crop production due to elevated sodium and salinity. CBNG-produced water in the TRB has a salinity of 1000 to 2500 µS $cm^{-1}$ and sodium adsorption ratios (SARs) of 30 to 70, while the Tongue River's median salinity is about 300 to 900 µS $cm^{-1}$ and SAR is <1.5.

A cursory view of temporal salinity trends in the TRB from 1997 through

**Thomas Osborne** is the owner and principal hydrologist with HydroSolutions Inc., Billings, Montana. **William Schafer** is a soil scientist and president of Schafer Ltd, Bozeman, Montana. **Neal Fehringer** is a certified agronomist and owner of Fehringer Agricultural Consulting, Billings, Montana.

**Figure 2**

**The apparent correlation of the number of CBNG wells in the TRB and the salinity of the Tongue River, expressed here as median specific conductance at the USGS State Line station, raised the concerns of some irrigators. Additional time and analysis has shown CBNG discharges to be a small part of river salinity.**




2006 would appear to justify irrigators' concerns. An upward trend of median specific conductance (SC) at the US Geological Survey (USGS) gauging station at the State Line shows a strong correlation with CBNG well drilling (figure 2). More thorough evaluations of the causes of salinity trends show that CBNG discharges, while possibly a contributing source, are not the primary factor responsible for these trends.

The oldest nemesis of the West, namely drought, is the principal factor causing higher salinity and sodium levels since 2000. The years from 2001 to 2006 included the lowest ranked average annual flows since records began in 1961. Our study, called Tongue River Information Program (TRIP), along with other investigations (Clark and Mason 2007), demonstrates the inverse correlation of salinity with stream discharge. This relationship is expressed well by both temporal trends of median discharge and SC, as well as the regression plot (figure 3).

## THE TRIP STUDY

A long-term agricultural and water quality study called the Tongue River Information Program (TRIP) has been sponsored by the Montana Board of Oil and Gas Conservation (MBOGC) since 2006. MBOGC is the permitting authority for CBNG wells and has jurisdiction over the potential environmental impacts of its regulatory actions. TRIP is an outgrowth of the Agronomic Monitoring and Protection Program (AMPP), which preceded it from 2003 to 2006. That initial program was funded by the first CBNG producer in Montana, Fidelity Exploration & Production Company. TRIP includes an agronomy and soils research program and a survey of available hydrology data collected by USGS and others for the Tongue River.

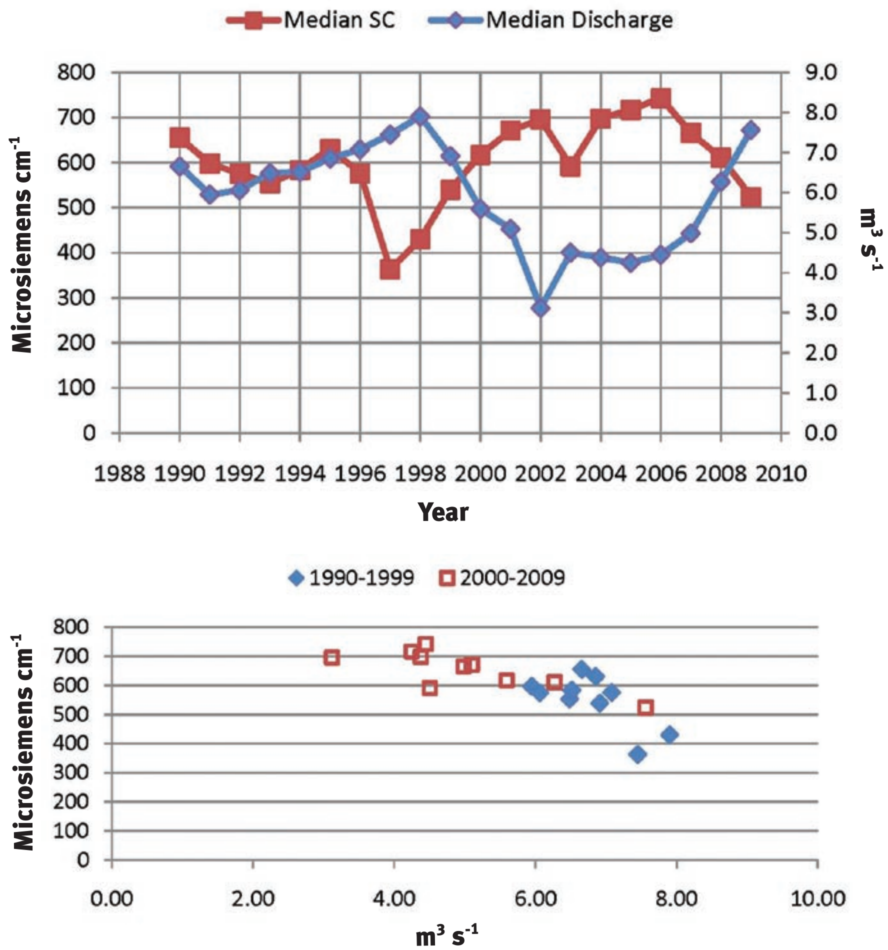
The Tongue River has been the focus of extensive water quality monitoring, but almost no soils or crop data useful to assessing CBNG effects existed. TRIP soils and agronomy components are designed to scientifically address the question of whether CBNG discharges to the Tongue River are having a measurable effect on irrigated soil characteristics, forage quality, and crop yields. Additional benefits of the study include agronomic consultation with participants based on soil and crop testing results, helping irrigators better understand potential effects of CBNG development on their irrigated fields, and documentation of regional trends in irrigated soil characteristics. The program consists of three tiers:

- Tier 1, which assesses crop yield factors, soil fertility, electrical conductivity (EC, a measure of relative salt content), and sodium adsorption ratio (SAR, a ratio measuring sodium abundance relative to calcium and magnesium) in selected fields. Soil sampling is done to a depth of two feet;
- Tier 2, which includes Tier 1 parameters as well as more detailed sampling and measurement of exchangeable sodium percentage (ESP, a measure of relative sodium availability), texture, bulk density, water intake rate, clay mineralogy, and soil classification, as well as determination of crop yields and forage quality (including sodium content) and soil fertility in 14 fields. Soil sampling is done to a depth of eight feet; and
- Tier 3, which consists of replicated crop and forage test plots employing mixtures of Tongue River water and CBNG production water.

Tier 2 soil sampling includes collection of a representative number of composite subsamples from the same depth incre-

**Figure 3**

Discharge and salinity data from the past 20 years demonstrate their inverse relationship. The regression plot of these parameters has an $R^2 = 0.61$.




ments from the largest soil map unit in each field using Global Positioning System technology. Composite samples were collected from seven depth intervals down to 244 cm (96 in). Laboratory analyses included soil texture, EC, SAR, ESP, clay mineralogy, trace metals, plant available nutrients, and other properties. Samples were collected, handled, and analyzed in accordance with a peer-reviewed sampling and analysis plan and a stringent quality assurance program.

Ten fields are irrigated with Tongue River water, two are within the Tongue River drainage but are irrigated with water from tributaries, and two located outside the TRB (reference fields). All were monitored for baseline soil and crop conditions in 2003. The location of the study fields are shown on figure 1, along with features of the TRB. Monitoring has continued each year since 2003 in order to detect any changes in soil chemistry and crop production.

## SOILS COMPONENT AND FINDINGS

Soil samples were collected from the 14 irrigated fields annually from fall 2003 through 2008, as well as spring 2004. Samples were collected from seven depth increments between surface and 2.4 m (8 ft) in depth. Each sample consisted of a composite from 10 to 12 locations within a field. Subsample locations were geo-referenced to facilitate accurate relocation of samples each year. Composite samples were field mixed and were analyzed for a number of physical and chemical properties, including pH, SAR, electrical conductivity (EC), and soluble cations in a saturated paste extract; exchangeable sodium percentage (ESP); cation exchange capacity; texture; and plant available nutrients. Additionally, organic carbon, calcium carbonate, and clay mineralogy were determined on selected samples.

Soil chemical data were compared to commonly used benchmarks for assessing crop suitability and for avoiding sodium-induced permeability problems (Rhoades et al. 1992; Ayers and Westcot 1994; and Hanson et al. 2003), focusing on EC and SAR. Tongue River samples obtained by USGS below the Tongue River Dam (Station 06307500) were compared to Montana irrigation water quality criteria (Montana Department of Environmental Quality 2003), soil extract chemistry, and typical CBNG water. Statistical trends were assessed using analysis of variance (ANOVA) where depth, site, and time were evaluated as factors. Depth/site, site/time, and depth/time factors were evaluated pair-wise since soil samples were not replicated within a particular year.

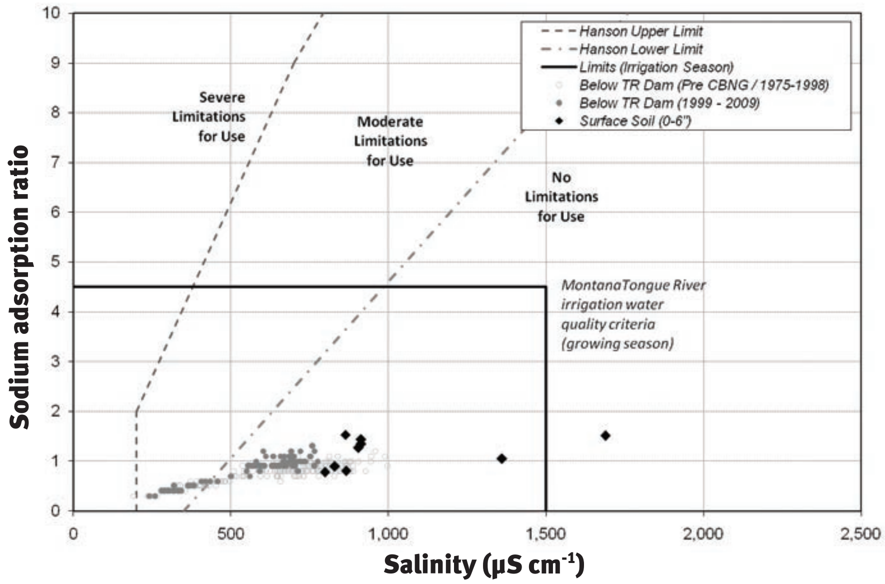
All soils had SAR levels that were below levels that are believed to impair soil permeability (figure 4). Roughly one-half of samples tested had EC values that were marginally above the EC threshold for alfalfa suggesting that alfalfa yields could theoretically be suppressed by 10% to 20%. Two potential causes of increased salinity were considered in the Tongue River soils, namely inputs of CBNG water and evaporation. This study indicates that the primary factor influencing the wide range in soil EC observed (<1000 to 7000 µS $cm^{-1}$) is irrigation management and irrigation water availability (Schafer et al. n.d.).

## AGRONOMIC COMPONENT AND FINDINGS

Crops grown in TRIP fields have been alfalfa, alfalfa/grass mix, grass, spring wheat, corn, sugar beets, malt barley, hay millet, and winter wheat. The agronomic component of the study found, through 2008, that large differences in forage yields were evident between sites, but yield variations showed no systematic changes through time. A myriad of factors have affected forage crop yields, including age of stand, quantity of irrigation water used, fertilizer applied, weed and insect control, climate, and number and timing of cuttings. Although it is difficult using existing data to precisely determine causes of yield

**Figure 4**

Plant uptake weighted EC (0 to 36 in) and SAR (0 to 6 in) in Agricultural Monitoring and Protection Program soils with pre- and post-CBNG EC–SAR data for Tongue River below the Dam. The plot indicates that TRIP soils are well below thresholds believed to impair soil permeability.

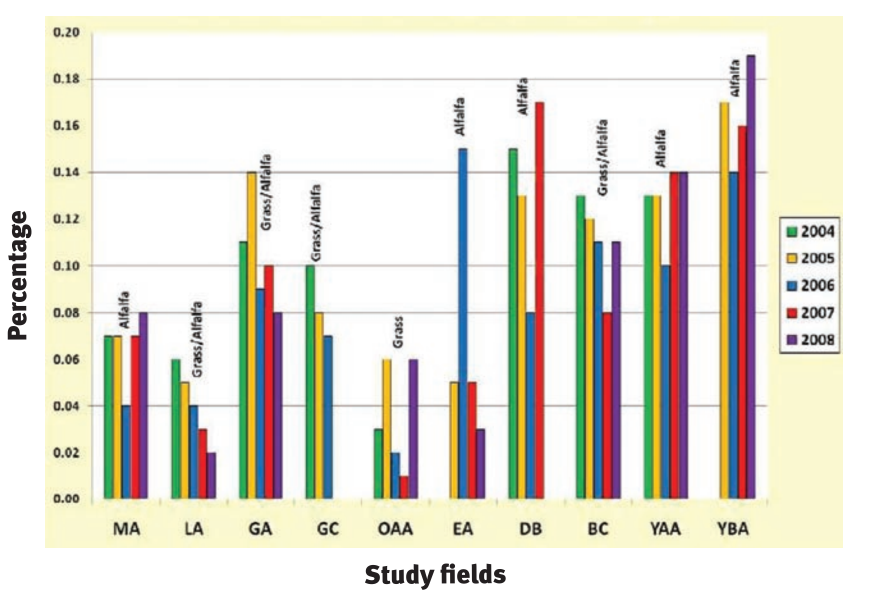



variations among AMPP fields, the following is clear:

- Crop yields are comparable to average irrigated forage production from Big Horn, Custer, and Rosebud Counties in 2003 through 2008.
- Crop yields do not show a decreasing trend between 2003 and 2008.
- Yield differences are not correlated with average salinity or sodium levels.
- Hay yields appear to be limited to around 4.48 t ha$^{-1}$ (2 tn ac$^{-1}$) in fields where less than 20.3 cm (8 in) of irrigation was applied.
- Yields in 2004 were reduced by a late killing freeze on May 12.

**Figure 5**

Comparison of sodium content in forages in fields that have been planted to the same crop for at least two out of three years, 2004 to 2008.




- For certain years at various locations, alfalfa yields have been reduced by severe alfalfa weevil infestations prior to first cutting.
- Other factors, especially crop and irrigation management, appeared to have a greater affect on yields.

Since initial sampling did not begin until fall 2003, 2004 was the first year that crop test and yield evaluations occurred. With elevated sodium levels in CBNG water, increases in sodium content of forage crops should be among the first effects of CBNG activity because plants take up what is applied to the soil. This fact has been observed in forage analyses from Tier 3 test plots. As CBNG water percentage increased from 0% to 50% in the irrigation water, sodium content on a dry matter basis more than doubled for both alfalfa and barley. Plant tissue samples collected from irrigated crops and forages have not shown a trend of increasing sodium levels through 2008 (figure 5). Different crops have had different average sodium levels. Corn has had the least at 0.02%, brome and orchard grass mix have averaged 0.1%, alfalfa 0.12%, hay millet 0.21%, and hay barley 0.53% from 2004 to 2008.

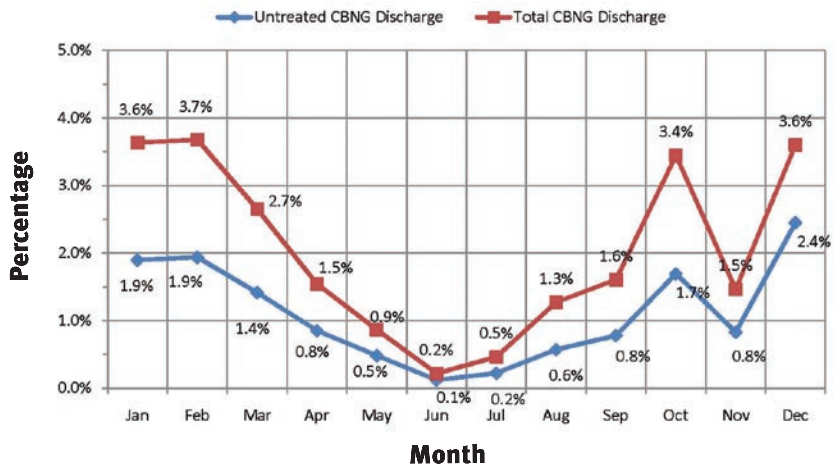
As of 2008, six of the 11 fields shown had sodium levels at or below 2004 levels (figure 6). LA study field is directly below all CBNG discharge locations, and yet its sodium content has steadily decreased from 2004 to 2008. YAA study field, which is irrigated with Tongue River water, and YBA, which is irrigated with Yellowstone River water (reference field), have nearly the same forage sodium content pattern.

## HYDROLOGY COMPONENT

It is difficult to clearly present the salinity and sodicity characteristics of a river basin as diverse as the Tongue River and to distinguish the many causes and effects on its water quality. Serial and continuous monitoring, statistical evaluations, point source and nonpoint source inventories, and water quality modeling have all been used in various studies (Nimick 2004; USGS 2009; Clark and Mason 2007; NRCS 2002; USEPA 2007). CBNG discharges, while elevated in salinity and sodium compared to the river, are a minor component of the hydrologic budget. Of the total 0.708 m$^3$ s$^{-1}$

**Figure 6**

**2008 CBNG direct discharges to the Tongue River in Montana and Wyoming as a percent of flow in the Tongue River below Tongue River Dam.**




(25 ft$^3$ sec$^{-1}$) of CBNG-produced water in the TRB in 2008, approximately 87% was discharged to impoundments, beneficially used, or treated prior to discharge, with the remainder discharged to the river untreated via state-authorized permits. Treatment usually consists of an ionic exchange system that removes most of the sodium and somewhat lowers EC.

There are six permits for discharge of CBNG-produced water to the Tongue River: three are located in Montana and three in Wyoming; however, only two actually discharged in 2008. These permits are authorized for discharge ranging from 0.102 to 0.167 m$^3$ s$^{-1}$ (3.6 to 5.9 ft$^3$ sec$^{-1}$) of untreated CBNG water, and 0.280 m$^3$ s$^{-1}$ (9.9 ft$^3$ sec$^{-1}$) of treated CBNG water. Actual CBNG discharges have been significantly less than the permitted discharges. Discharge rates and/or water quality authorized by permits are seasonally adjusted in order to meet irrigation water standards set by the State of Montana. During the April–September 2008 irrigation season, total CBNG discharges comprised from 0.2% to 1.6% of the flow released from the Tongue River dam, with untreated discharge ranging from 0.1% to 0.8% (figure 6). A theoretical increase in river EC caused by CBNG discharges was computed for the USGS State Line station. For average stream flow of 12.46 m$^3$ s$^{-1}$ (440 ft$^3$ sec$^{-1}$), and average flow-adjusted salinity of 520 µS cm$^{-1}$, discharge of 2% additional flow (0.25 m$^3$ s$^{-1}$ [8.8 ft$^3$ sec$^{-1}$]) at an average EC of 2.000 µS cm$^{-1}$ from CBNG would increase EC by 5.6% to 549 µS cm$^{-1}$.

The US Environmental Protection Agency (USEPA) conducted a water quality assessment of the TRB in support of an ongoing Total Maximum Daily Load (TMDL) study (USEPA 2007) and conducted a modeling study of the sources of salinity within the TRB. They found that river salinity of the "natural scenario" in which the various human sources of salinity were removed was significantly less than the existing scenario, with the difference in mean SC being 176 µS cm$^{-1}$ and 200 µS cm$^{-1}$ at the State Line and Miles City gauging stations, respectively. CBNG sources were found to represent from 4% to 5% and irrigation sources from 20% to 21% of existing salinity (USEPA 2007). The increase from CBNG was similar to theoretical indicated above.

Concerns over irrigation water supplies and water quality in the TRB are sure to linger, indicating that improved accounting of basin-wide point and nonpoint sources of salinity and sodium loading is warranted. It is hoped that the TRIP study can continue to provide a foundation which serves to document forces and trends affecting the water quality, soil productivity, and crop characteristics of the TRB.

TRIP studies may be found at the MBOGC Web site, http://www.bogc.dnrc.mt.gov. Click on Coal Bed Methane link where both the hydrologic and soils and crops studies are available.

## REFERENCES


Ayers, R.S., and D.W. Westcot. 1994. Water quality for agriculture. United Nations Food and Agriculture Organization Irrigation and Drainage Paper 29 Rev. 1. Rome, Italy: United Nations Food and Agriculture Organization.

Clark, M.L., and Mason, J.P. 2007. Water-Quality Characteristics For Sites in the Tongue, Powder, Cheyenne, and Belle Fourche River Drainage Basins, Wyoming and Montana, Water Years 2001–2005, with Temporal Patterns of Selected Long-Term Water-Quality Data. U.S. Geological Survey Scientific Investigations Report 2007–5146. http://pubs.usgs.gov/sir/2007/5146/

Hanson, B., S. Grattan, and A. Fulton. 2004. Agricultural Salinity and Drainage. WaterManagement Handbook Series. Publication3375. Davis, CA: University of California.

HydroSolutions Inc. 2009. 2009 Tongue River Hydrology Report, Tongue River Information Program. Prepared for Montana Board of Oil and Gas Conservation, Billings, MT.

Montana Department of Environmental Quality. 2003. Total Maximum Daily Load (TMDL) Status Report, Tongue River TMDL Planning Area

Nimick, D. 2004. Monitoring Surface-Water Quality in the Tongue River Watershed. Helena, MT: US Geological Survey.

NRCS (Natural Resources Conservation Service). 2002. Tongue River Stream Corridor Assessment. Montana Reaches. Phase II – Physical Habitat Assessment. Bozeman, MT: USDA Natural Resources Conservation Service.

Rhoades, J.D., A. Kandiah, and A.M. Mashali. 1992. The use of saline waters for crop production. United Nations Food and Agriculture Organization Irrigation and Drainage Paper 48. Rome, Italy: United Nations Food and Agriculture Organization.

Schafer, W.M., N.E. Fehringer, and T.J. Osborne. n.d. Irrigated soil chemical trends downstream of coalbed methane development: Tongue River Basin, Montana.

USEPA (US Environmental Protection Agency). 2007. Water Quality Assessment for the Tongue River Watershed, Montana, Final Draft. Prepared by US Environmental Protection Agency, Montana Operations Office, and Tetra Tech. Inc.

USGS (US Geological Survey). 2009. Tongue River Surface-Water-Quality Monitoring Network. Helena, MT: USGS Montana Water Science Center. http://mt.water.usgs.gov/projects/tongueriver/

WOGCC (Wyoming Oil and Gas Conservation Commission). 2009. Casper, WY: WOGCC. http://wogcc.state.wy.us.