Report for 2003WY10B: Geochemistry of CBM Retention Ponds Across the Powder River Basin, Wyoming

There are no reported publications resulting from this project.

Report Follows

Abstract

The Wyoming Water Research Program (2002) funded the project geochemistry changes of coalbed methane (CBM) disposal pond waters across the Powder River Basin (PRB) in collaboration with the US Geological Survey and the Wyoming Water Development Commission. Objectives of this research were to monitor the geochemical changes and water quality of CBNG disposal ponds in Tongue River Basin (TRB), Powder River Basin (PRB), Little Powder River Basin (LPRB), Belle Fourche River Basin (BFRB), and Cheyenne River Basin (CRB) over a period of 3 years. This report summarizes results from year 1 and year 2 data collected from March 2003 to April 2004. The CBNG product water samples from discharge points and corresponding disposal ponds were collected during the summer months of 2003 and 2004. Samples were analyzed for pH, dissolved oxygen (DO), electrical conductivity (EC), major cations (e.g., Ca, Mg, Na, and K), major anions (e.g., alkalinity, sulfate, chloride, fluoride, nitrate, and phosphate), and trace elements (e.g., Al, As, Ba, B, Fe, Cd, Cu, Cr, Mn, Mo, Se, Pb, and Zn). Sodium adsorption ratio (SAR) was calculated from the measurements of Ca, Mg, and Na. Samples were also analyzed for abundance of macroinvertebrates and vegetation species. The results of year 1 and year 2 data show how quality of CBNG discharge and disposal pond waters change, predominantly salt concentration and SAR as a function of watershed physical and chemical characteristics. Macroinvertebrates were more abundant and have higher taxa richness in CHR, BFR, and LPR watersheds than in PR and TR watersheds. Similarly, there were more vegetation species encountered in and around ponds in CHR, BFR, and LPR watersheds than in PR and TR watersheds. The proposed research helps water users (landowners, agriculture and livestock producers, and ranchers) and water managers (state, federal, and local agencies) with the planning and management of CBNG product water within the Powder River Basin.

Statement of Critical Regional or State Water Problems

Demand for natural gas (methane) is increasing within the United States because of the energy shortage. Further, methane is a clean form of burning fossil fuel. Several states within the United States (e.g., Wyoming, Colorado, Montana, New Mexico, and Utah) are exploring methane extraction from their coal resources. As an example, in the Powder River Basin (PRB) of Wyoming, it is estimated that there are 31.7 trillion cubic feet of recoverable CBM (coalbed methane). Currently, the CBM development in this basin is occurring at a rapid pace as demand for natural gas has increased in the United States (DeBruin et al., 2000).

Methane is formed deep in confined coalbed aquifers through biogeophysical processes and remains trapped by water pressure. Recovery of the methane is facilitated by pumping water from the aquifer (product water). It is estimated that a single CBNG well in the Powder River Basin may produce from 8 to 80 L of product water per minute, but this amount varies with aquifer that is being pumped and the density of the wells. At present, more than 16,000 wells are under production in the PRB and this number is expected to increase to at least 30,000. Based on information provided by the Wyoming Geological Survey, approximately 2 trillion L of product water will eventually be produced from CBNG extraction in Wyoming. Commonly 2 to 10 CBNG extraction wells are placed together in a manifold system discharging to a single point and releasing into constructed unlined disposal ponds. These disposal ponds are constructed with initial well pumping. The Wyoming DEQ considers this water as surface water of the state with Class 4C designation.

Various metals such as Fe, Ba, As, and Se in the CBNG pond waters are expected to go through several geochemical processes including desorption and dissolution, ion complexation (speciation), and adsorption and precipitation. These processes in turn control the quality of product water in disposal ponds as well as the water that is infiltrating into the shallow ground water. Very little information is available on the geochemistry of CBNG product water and associated disposal ponds in the Powder River Basin (Rice et al., 1999; McBeth et al., 2003a and b). The studies conducted by Rice et al. (1999) only examined the chemistry of CBNG discharge water at wellhead. McBeth et al. (2003a and b) studies examined the chemistry changes of product water both at wellhead and in disposal ponds of the Powder River Basin. However, to our knowledge no studies involved the monitoring of the geochemical processes that product water undergoes in disposal ponds across the Powder River Basin. The CBNG product water discharged to the surface is managed and regulated by several state and federal agencies. To effectively manage this water resource there is a need to understand the geochemical changes that occur in CBNG disposal ponds over time.

Objectives

The overall objectives of this research are to:

1. Collect, analyze, and monitor pH, DO, EC, DOC, major cations (e.g., Ca, Mg, Na, and K), major anions (e.g., alkalinity, SO_4^{2-},Cl^-,F^-,NO_3^-, and PO_4^{2-}), and trace elements (e.g., Al, As, Ba, B, Fe, Cd, Cu, Cr, Mn, Mo, Se, Pb, and Zn) from produced water samples at discharge points and disposal ponds over a period of 3 years (2003, 2004, 2005);
2. Identify statistical differences of produced water test parameters between discharge points and associated ponds;
3. Identify statistical differences of produced water test parameters between watersheds of a particular water type (wells and ponds);
4. Predict geochemical changes (speciation, adsorption, and precipitation) for critical metals such as Fe, Ba, As, and Se in the disposal pond from produced water and associated disposal pond sediment;
5. Identify trends in major cation, major anion, and trace element concentrations of produced water at discharge points and associated ponds;
6. Compile a list of aquatic macroinvertebrate and wetland plant species associated with disposal ponds; and
7. Transfer research results to user groups through project demonstrations, workshops, and local meetings.

This final report outlines research progress accomplished for year 1 and 2 from March 2003 to April 2005. This report consists of objectives, methods and procedures, site selection, sample collection and analysis, results, clientele network, presentations, and student education and training.

Methods and Procedures

Site Selection. We selected twenty-six sites within five Wyoming watersheds to obtain CBNG well and associated pond data. Site selection was coordinated with a network of working partners. These working partners include: Wyoming Department of Environmental Quality (WY-DEQ), Wyoming Water Development Commission (WY-WDC), Coalbed Methane Industry, Wyoming Landowners and Citizens, U.S. Geological Survey (USGS), Wyoming State Geological Survey (WYSGS), U.S. Environmental Protection Agency (USEPA), Colorado, and

Montana. We sampled seven sites in each of the Little Powder River (LPR) and Powder River (PR) watersheds. We sampled three sites from Cheyenne River (CHR) watershed and four sites from Belle Fourche River (BFR) watershed, and five sites from Tongue River (TR) watershed (Figure 1).

Sample Collection and Analysis. Before sample collection, a pilot study was conducted to determine sampling location within the CBNG pond waters. Chemical, plant, and aquatic macroinvertebrates were also examined to determine the sampling locations to obtain a representative sample. CBNG water samples from each well and corresponding ponds were collected during the summer of 2003. Before sample collection, field measurements including pH, conductivity, temperature, ORP, and dissolved oxygen were taken in each well and pond.

CBNG water samples from each discharge well and corresponding pond will be collected during the summer of 2003, 2004, and 2005. Collecting samples once a year during the same season may preclude any seasonal fluctuations in pond water quality parameters. Before sample collection, field measurements including pH, conductivity, temperature, ORP (oxidation and reduction potential), and dissolved oxygen will be taken in each well and pond Locations for pond measurements and field samples will be taken directly away from discharge well, and will be chosen upon pH stabilization at different distances from discharge point to avoid interference from the mixing zone. These measurements will be conducted using an Orion Model 1230 Multi-Probe. Duplicate water samples of wells and ponds will be taken from each site as well as 2 trip blanks (112 total water samples). Water samples will be analyzed for: Ca, Na, Mg, K, Fe, Al, Cr, Mn, Pb, Cu, Zn, As, Se, Mo, Cd, Ba and B by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), and SO_4^{2-}, Cl^-, F^-, NO_3^-, and PO_4^{2-} will be analyzed using Ion Chromatography (IC). In addition, these samples will be analyzed for dissolved organic carbon due to the appearance of organic matter in disposal ponds. Dissolved organic carbon will be analyzed using a Tekmar-Dohrmann 8000 Total Organic Carbon analyzer (TOC). The quality control/quality assurances protocols such as duplicate sampling and analysis, trip blanks, and known concentrations of reference standards will be included. Laboratory measurements of pH, electrical conductivity, alkalinity and total dissolved solids will be accomplished using standard laboratory procedures (APHA, 1992). Sodium adsorption ratios will be calculated from Ca, Na and Mg concentrations. All analyses will be performed following CFR 40, Part 1, Chapter 36 procedures (WYDEQ, 2001). In addition, water quality data will be modeled with MINTEQA2 (Brown and Allison, 1992), EPA water quality geochemical model to check data accuracy, predict ion activities, and calculate true SAR (SARt).

Disposal pond sediments will be collected during the summer of 2003, 2004, and 2005 using 4.5cm diameter PVC corer. Sample locations will be located directly away from discharge well and will be chosen upon pH stabilization at different distances from discharge point. Typically, sediment will be collected approximately 3 meters from discharge point and consists of a 20cm core. A sediment core will be taken from every pond, placed in a 1L polypropylene bottle, and then completely filled with pond water. Once at the lab, all samples will be frozen. Two samples from each watershed (10 total samples) will be separated into exchangeable, carbonate bound, Fe/Mn oxide bound, organically bound, and residual mineral fractions to determinate the fate of As, Ba, Fe, and Se. Each fraction will be dissolved in an appropriate solution and extracted. The extract will then be analyzed for As, Ba, Fe, and Se on ICP-MS as described by Tressier et al. (1979).

Since Wyoming and surrounding states do not have sampling protocols for macroinvertebrates in lentic systems, a minimal effort approach for sampling was selected. Four macroinvertebrate samples (collected from the four cardinal directions) will be collected from the water column using a D-net with 1mm mesh and from sediment using an 8cm diameter core sampler. Water column samples will be combined as well as sediment samples to form a composite sample for the water column and sediment column for each pond. Samples will be taken from 2 ponds in each different watershed (20 total samples) and preserved in 95% ethanol. At the laboratory, samples will be sorted from vegetation and debris, and preserved in 75% ethanol (Merrit and Cummins, 1996). Aquatic macroinvertebrate samples will be sent to a certified laboratory specializing in analysis of aquatic macroinvertebrate communities (Aquatic Biology Associates, Inc) for identification to lowest taxonomic level. Laboratory data will include total taxa present and community richness. Vegetation identification will be performed on location for predominant wetland and aquatic plant species in and around ponds. Samples of unknown species will be collected and brought back to the lab for identification.

The primary questions of interest are to identify chemical differences between water types (discharge well vs. pond), between watersheds of a particular water type, and between years with watersheds of a particular water type. Due to a "natural pairing" of the discharge well and associated discharge pond, paired t-tests will be used to identify chemical differences between water types (discharge wells vs. associated ponds) with years as replications (3 years) (alpha = 0.05; SAS, 2000). One-way ANOVAs will be used to identify element differences between watersheds of a particular water type. Tukey mean separation test will be performed if there are significant differences between watersheds to further identify these differences (alpha = 0.05; SAS, 2000). Randomized Complete Block Design Factorial Analysis will be conducted to identify element differences between years within watersheds of a particular water type. Again, a Tukey mean separation test will be performed if there are significant differences between years or watersheds (alpha = 0.05; SAS 2000). A trend analysis will be conducted to identify any changes in element concentrations over 3 year time period for the five watersheds (alpha = 0.05; SPSS, 2001). Results from sediment fractionation will be used in One-way ANOVAs to determine differences between specific element fractions (exchangeable, carbonate bound, Fe/Mn oxide bound, organic matter bound, and residual of As, Se, Ba, and Fe) of an individual watershed. Tukey mean separation test will be performed if there are significant differences between watersheds to further identify these differences (alpha = 0.05; SAS, 2000).

Task Completion List.

2003 Sample Season

- Water chemistry completed for all samples (anions, cations, trace metals, DOC)
- MinteqA2 modeling completed
- Statistical analysis completed for year 1 data (T-tests, ANOVAs)
- Compiled CBNG water quality data and contacted landowners of results
- Aquatic macroinvertebrate samples analyzed
- Vegetation species list completed

2004 Sample Season

- Water chemistry completed for all samples (anions, cations, trace metals, DOC)
- MinteqA2 modeling completed
- Statistical analysis completed for year 2 data (T-tests, ANOVAs)
- Preparing to send CBNG water quality results to participating landowners
- Aquatic macroinvertebrate samples sorted and sent to laboratory
- Vegetation species list near completion
- Sediment fractionation analysis for year 1 and 2 in progress

Results

Chemical results comparing year 1 to year 2 are presented in figures 2, 3 and 4. All error bars represent standard mean error for individual watershed data. Discharge well water pH did not vary much between watersheds and years, but discharge pond pH are higher than associated discharge wells. Alkalinity for both discharge wells and ponds tend to increase as we move geographically from CHR up to PR then slightly decrease at TR. Sodium Adsorption Ratio for both discharge wells and ponds tend to increase as we move geographically from CHR up to TR. Discharge well water SAR tends to increase from year 1 to 2 across watersheds, but this trend does not continue to the ponds. Discharge pond SAR follow a similar pattern as the discharge well SAR except for a substantial decrease at TR discharge pond from year 1 to year 2. This decrease may be due to sulfur burner water amendment process, an acidification process that is commonly done in this area to reduce discharge water SAR for irrigation. Calcium and magnesium vary between watershed and years with calcium decreasing from discharge wells to associated ponds and magnesium not varying much between discharge wells and associated ponds. Sodium is a major cation in both discharge wells and ponds in all watersheds and appears to increase from year 1 to year 2 in LPR, PR, and TR discharge ponds. Trace metals iron, arsenic, and selenium tend to increase from year 1 to year 2 and from discharge wells to associated discharge ponds. Figure 5 identifies year 1 macroinvertebrate data. The CHR, BFR, and LPR watersheds have a much higher percentage of non-insects caught and larger overall abundance of aquatic organisms than the PR and TR watersheds. Collector-gatherers and predators are the most represented functional feeding groups in all watersheds. Table 1 identifies vegetation encountered in and around discharge ponds across all five watersheds. More vegetation species were observed in and around CHR, BFR, and LPR discharge ponds than in PR and TR discharge ponds. This may be a function of pond age.

Clientele Network

Several contacts were made with different clientele groups to obtain access to the sampling sites and permission to collect samples. These contacts or clientele included WY-DEQ, WY-WDC, CBNG Industry, WY Landowners and Citizens, NRCS personnel, Conservation Districts personnel, WY Cooperative Extension Agency, USGS, EPA, Colorado, Montana. Landowners were informed of individual well/pond water quality on their property. Year 2 water quality data will be mailed to individual landowners before year 3 sampling.

Publications

Jackson, R.E., K.J. Reddy, R.E. Olson, and D.E. Legg. 2004. Geochemistry of coalbed methane disposal ponds across the Powder River Basin, Wyoming. In Proceedings of Society of Range Management 2004 Annual Meetings, Salt Lake City, Utah.

Jackson, R.E., and K.J. Reddy. 2004. Water quality of major rivers in reference to CBM product water discharge in the Powder River Basin, Wyoming. Journal of American Water Resources Association. (in preparation)

Presentations

1. Wyoming Water Development Commission Annual Meetings, November 30th 2004, Cheyenne, Wyoming.

2. 1st Annual Coalbed Natural Gas Research, Monitoring, and Applications Conference. Aug 17-19, 2004. Laramie, Wyoming.
3. University of Wyoming 2003 Graduate Student Symposium March 2nd, 2004, Laramie, Wyoming. This presentation won Best Project Presentation Award.
4. USDA-CSREES National Water Quality Conference: Integrating Research, Extension and Education scheduled January 11-14, 2004 in Clearwater, Florida.
5. Wyoming Water Development Commission Annual Meetings, December 4th, 2003, Cheyenne, Wyoming.
6. Rangeland National Annual Meetings, Water Quality Division, scheduled January 24-30, 2004 in Salt Lake City, Utah.
7. American Society of Agronomy (Soil and Water Ecology Section) Meetings, Denver, Colorado. November 5, 2003
8. Wyoming Department of Environmental Quality Meeting, Cheyenne, Wyoming. August 21, 2003.
9. EPA-USGS Meeting for Tongue River and Powder River Long-term Monitoring Network. Sheridan, Wyoming. June 5, 2003
10. Missouri River Basin Natural Resources Meeting, Benedictine, Kansas. June 2-4, 2003 (invited).
11. American Society of Surface Mining and Reclamation Symposium, Billings, Montana. June 5-6, 2003.
12. Wyoming Water Development Commission, River Basin Meeting, Kaycee, Wyoming. June 16, 2003.
13. Wyoming Department of Environmental Quality (Water Quality Division) Meeting, Cheyenne, Wyoming. May 10, 2003. This meeting included representatives from U.S. EPA Region VIII, BLM, CBM Industry, Colorado State University.

References

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Brown, D.S. and J.D. Allison. 1992. MINTEQA2: An equilibrium metal speciation model. Environmental Research Laboratory, Office of Research and Development. U.S. Environmental Protection Agency, Athens, Georgia.

McBeth, I.H., K.J. Reddy, and Q.D. Skinner. 2003a. Chemistry of coalbed methane product water in three Wyoming watersheds. Journal of American Water Resources Association. 39:575-585 .

McBeth, I.H., K.J. Reddy, and Q.D. Skinner. 2003b. Chemistry of trace elements in coalbed methane product water. Journal of Water Research. 37:884-890 .

Merritt, R.W. and K.W. Cummins. 1996. An introduction to the aquatic insects of North America 3rd edition. Kendall/Hunt, Dubuque, Iowa.

Rice, C.A., Ellis, M.S, and Bullock, J.H., Jr. 1999. Water co-produced with coalbed methane in the Powder River Basin, Wyoming: Preliminary compositional data. Open-File Report 00-372. U.S. Geological Survey, Denver, CO.

Tressier, A., Campbell, P.G.C, and Bisson, M. 1979. Sequential extraction procedure for the separation of particulate trace elements. Analytical Chemistry. 51:844-850.

Wyoming Department of Environmental. 2001. SAP: Water Quality Rules and Regulations, Chapter 1. Department of Environmental Quality and Water Quality Division, Cheyenne, Wyoming.

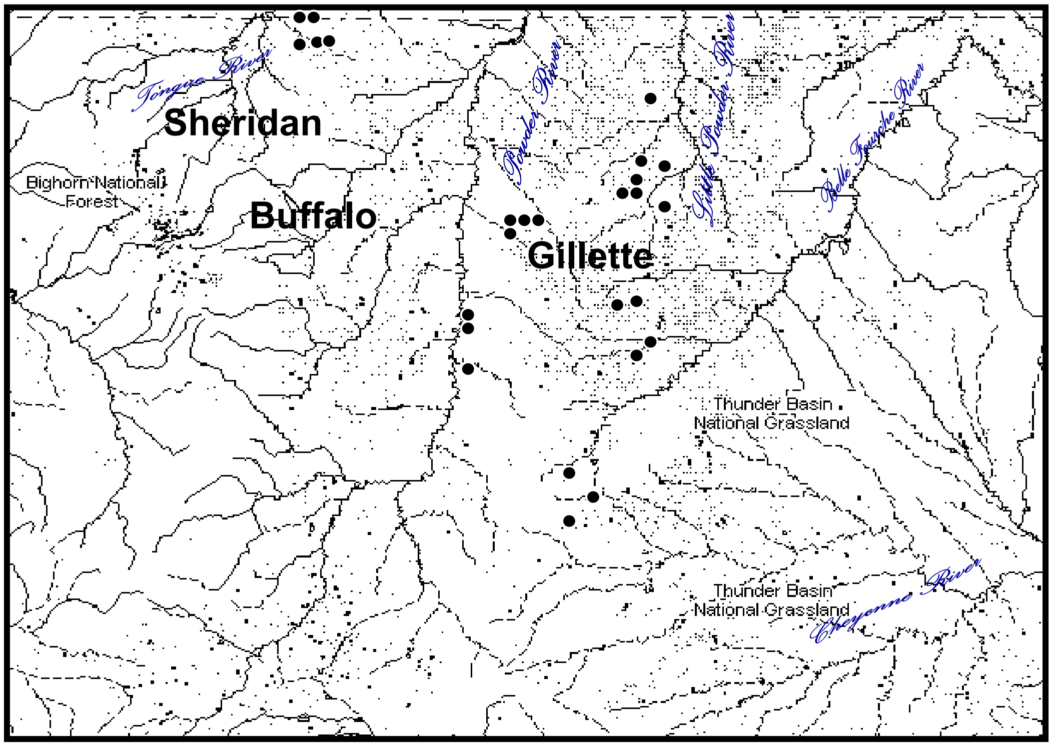


Figure 1. Map of study sites in the Powder River Basin, Wyoming (not to scale).

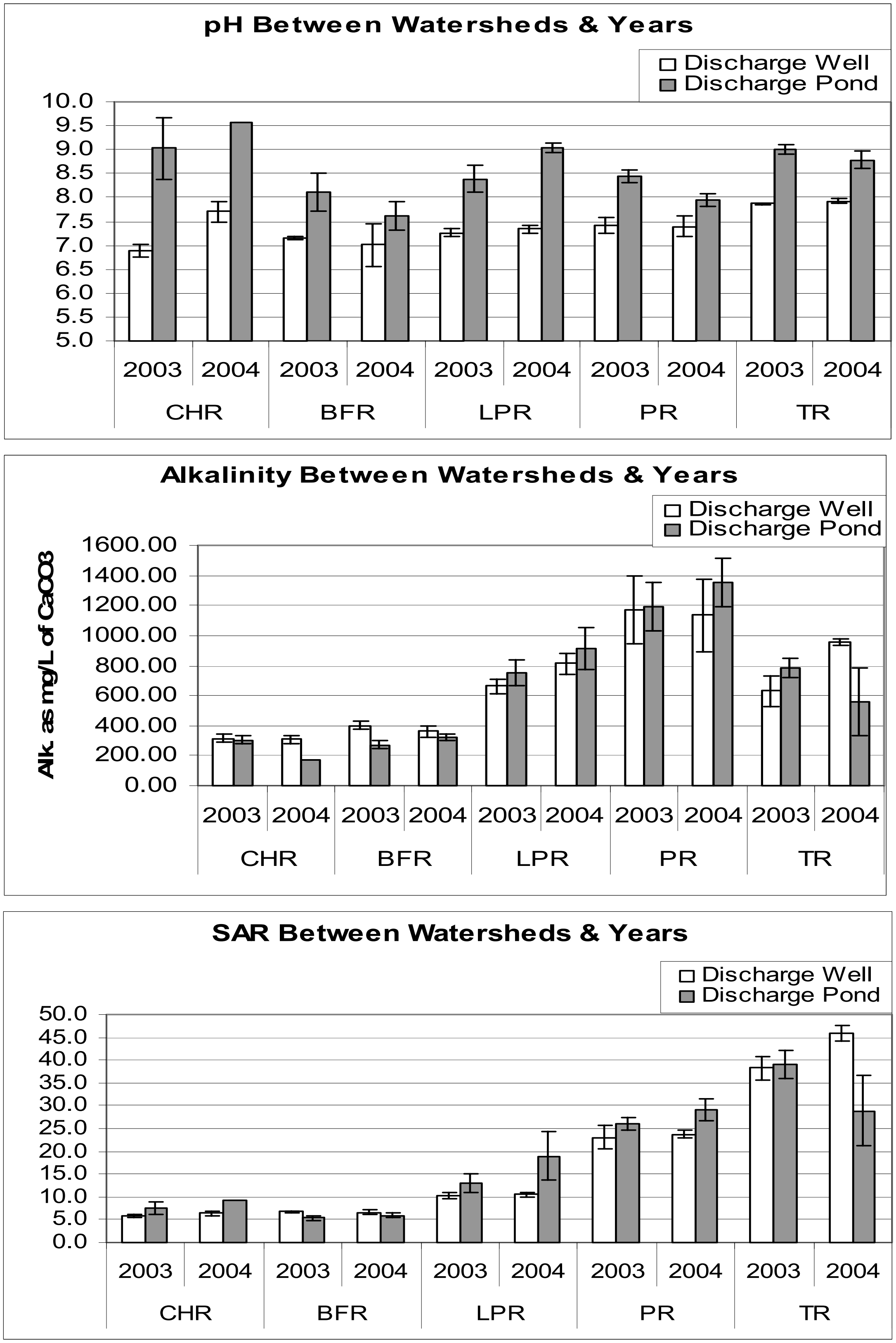
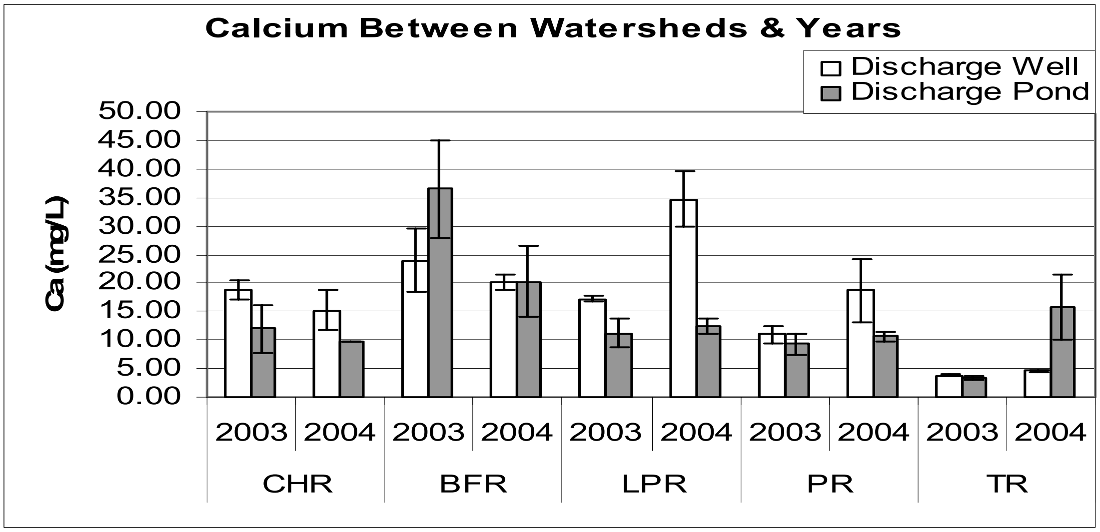
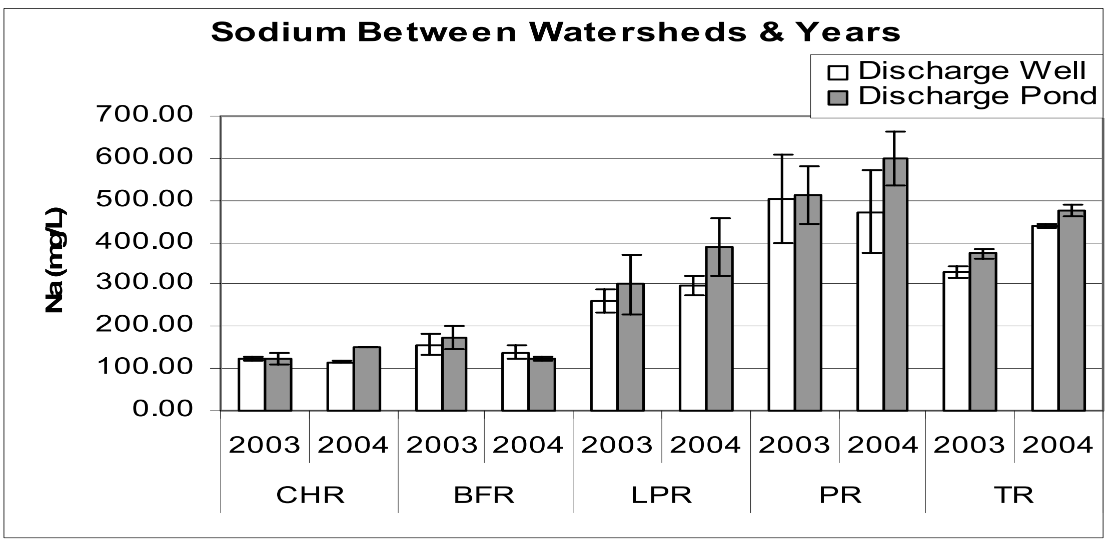


Figure 2. CBNG discharge well and disposal pond water pH (top), Alkalinity (middle), and SAR (bottom) between two sample years as a function of watershed.





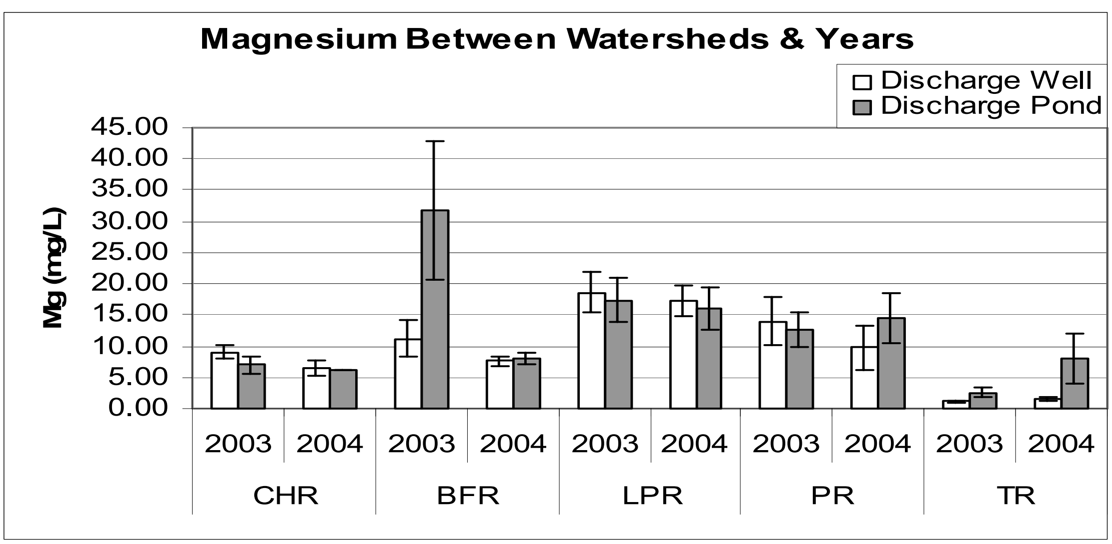


Figure 3. CBNG discharge well and disposal pond water Ca (top), Mg (middle), and Na (bottom) between two sample years as a function of watershed.

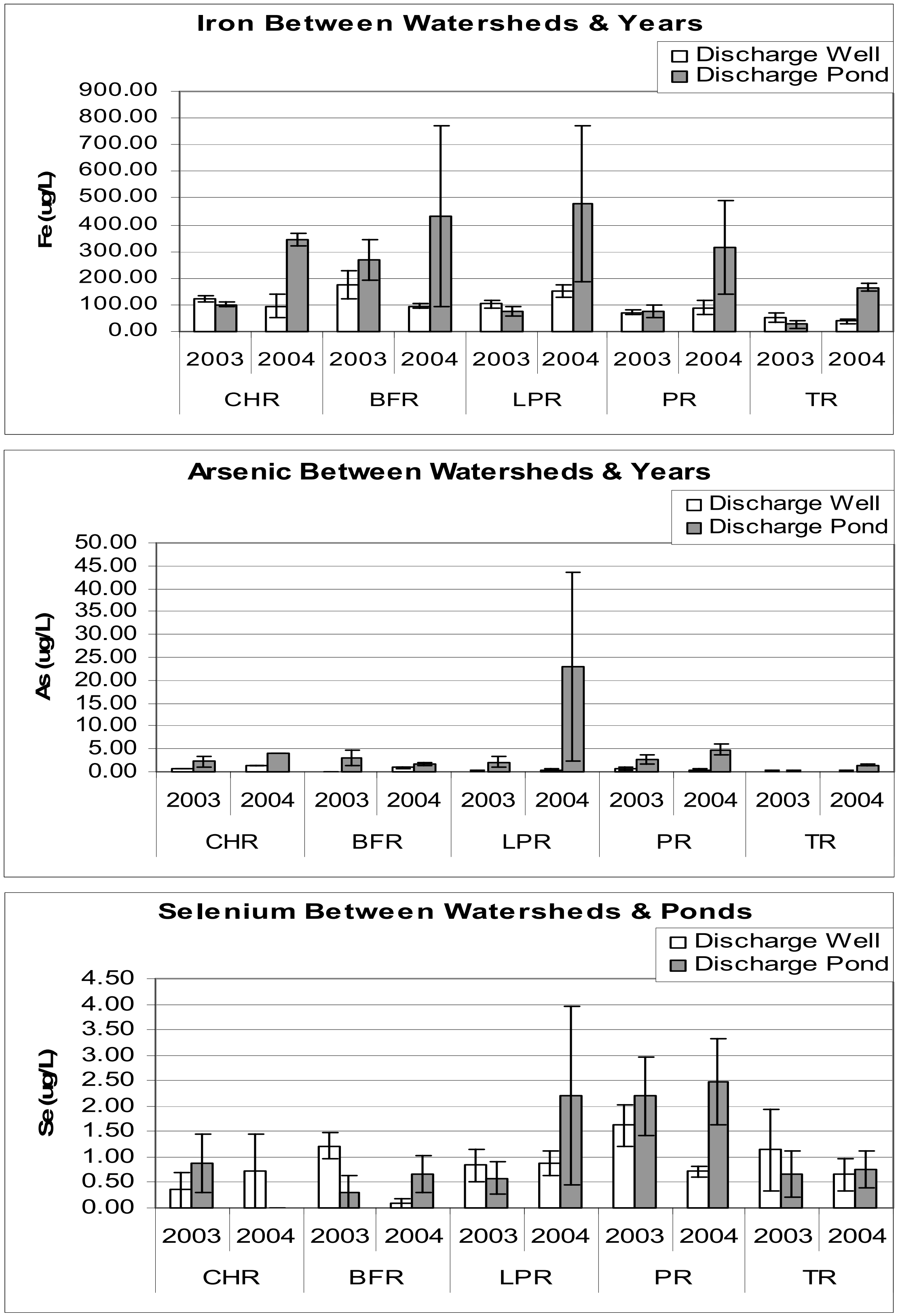


Figure 4. CBNG discharge well and disposal pond water Fe (top), As (middle), and Se (bottom) between two sample years as a function of watershed.

Basin	CHR	CHR	BFR	BFR	LPR	LPR	PR	PR	TR	TR
% Non insects	15.9	59.5	68.9	68.2	43.6	43.6	1.5	12.2	0	1.9
% *Ephemeroptera*	6.8	3.6	9.7	3.5	9.7	4.7	30.8	7.5	0	0
% *Trichoptera*	0	0	0.3	0	0	0	0	0	3.3	0
% *Coleoptera*	0	0.5	2.6	0.7	3.4	0.5	6	3.2	10	9.3
% *Diptera* (non-midge)	0	0.1	0.3	0	0.2	16.3	0	0	0	0
% *Diptera-Chironomidae*	4.8	23.2	1.3	14.6	7.1	2.2	16.5	11.2	6.7	13
Total abundance (m2)	63	390	96	106	149	295	33	47	8	14
Total number of taxa	15	29	19	24	20	30	11	20	7	10
Hilsenhoff Biotic Index (modified)	8.08	7.74	8.03	8.17	7.91	7.77	8.1	8.18	7.71	8.02

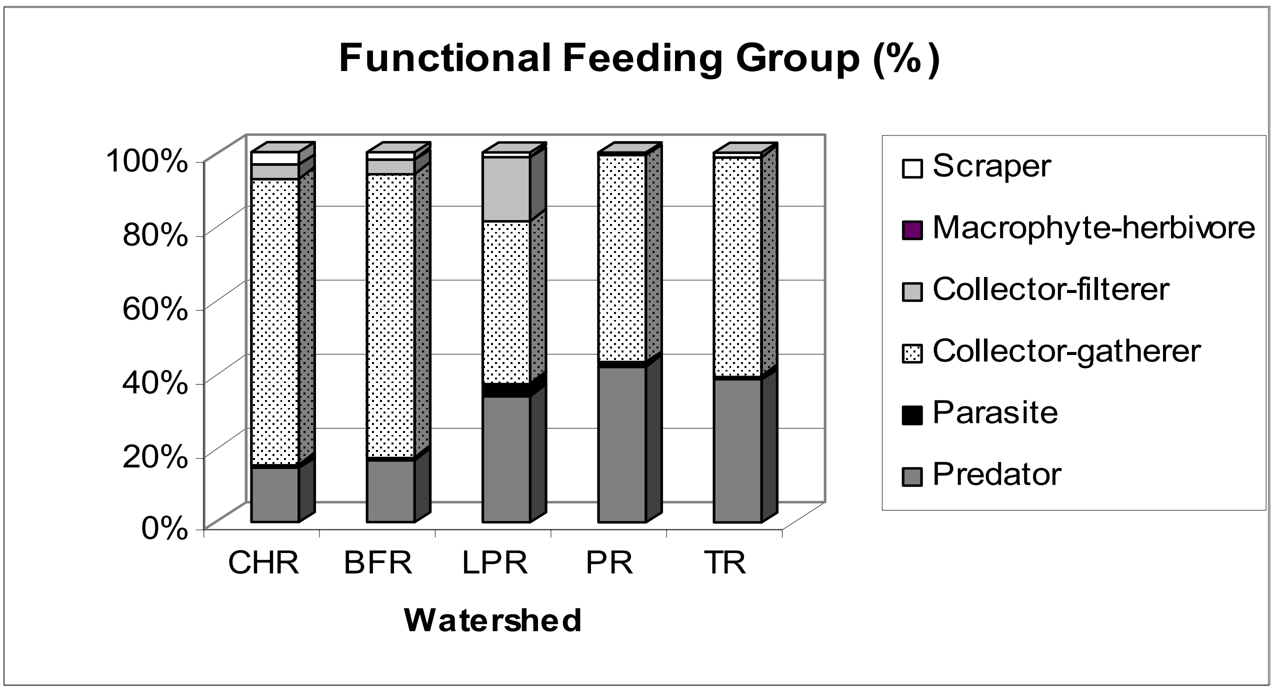


Figure 5. Percent insect taxa, abundance, and HBI (top table) for individual discharge ponds in 2003 and percent functional feeding group per watershed (bottom graph) for 2003.

Table 1. Vegetation commonly encountered in and around CBNG discharge ponds in all watersheds.

Grasses	*Hordeum jubatum*
	Pascopyrum smithii
	Distichlis spicata
	Elytrigia intermedia
	Bromus japanicus
	Bromus tectorum
Grass-Like	*Juncus balticus*
	Scirpus meridimus
	Scipus americanus
	Carex parryana
Macrophytes	
	Polygonium amphibium
	Potomogeton pectanatus
Forbs	*Rupia maritima*
	Solanum rostratum
	Kochia scoparia
	Euphorbia humistata
	Astraglas bisulcatus
	Melilotus officinalis
	Cirsium arvense
	Cleome serrulata
	Grindelia squarrosa
	Xanthium strunarium