Electronic Supplementary Material (ESI) for Environmental Science: Processes & Impacts

Potential Beneficial Uses of Coalbed Natural Gas (CBNG) Water

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Electronic Supplemental Information

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Results and Discussion

Aluminum concentrations exhibited a significant year by basin interaction ($p<0.01$, df=4,71, F=32.54). The PR basin discharge points were found to have a decreasing trend at a rate of 1.0 µg/L per year (data not shown). The BFR and LPR basins discharge points were shown to be decreasing as well but at rates of <1 µg/L per year and therefore were negligible. The CHR and TR basins had increasing trends at rates of 1.3 µg/L and 98.9 µg/L per year, respectively. The trend analyses for the TR captures the marked increase in aluminum concentrations over the last couple of years. This increase in aluminum was attributed to the CBNG producers using sulfuric acid (sulfur burners) as a water amendment for irrigation.[14]

The disposal ponds had no statistically significant trends for aluminum concentrations (data not shown). One of the studies in the PRB recognized that aluminum concentrations lacked a consistent trend across the PRB.[12] This study reported aluminum concentrations decreased from the CHR basin to the BFR basin and then increased to the LPR basin. Another study in the PRB also cited this variability when they observed that aluminum concentrations were higher in the discharge points in the BFR basin, while in the LPR and PR basins the opposite was true.[14] Consequently, aluminum concentrations were more directly related to fluctuations in pH rather than basin trends. In both discharge points and disposal ponds the geochemical modeling indicated the dominant aluminum species was $Al(OH)_4^-$.[12, 14]

A significant trend in iron concentration was observed in the discharge points ($p=0.0056$, df=1,89, F=8.07), but no differences were observed among basins ($P>0.15$). Iron concentrations in discharge points were found to be decreasing across all basins at a rate of 7.5 µg/L per year (Fig. S3 A). Iron concentrations in the disposal ponds showed a significant year by basin interaction ($P<0.0304$, df=4,126, $F=2.76$). No trend in iron was observed in disposal ponds in the LPR and PR basins (Fig. S3 B). Iron in disposal ponds in the BFR, CHR, and TR basins were increasing by rates of 37 µg/L, 39 µg/L, and 70 µg/L per year, respectively (Fig. S3 C). Iron concentrations in the disposal ponds were closely related to the pH and soluble complexes of iron in water. For example, one of the previous studies reported that increase in iron concentrations in disposal ponds to solution complexes such as $Fe(OH)_4^-$.[14]

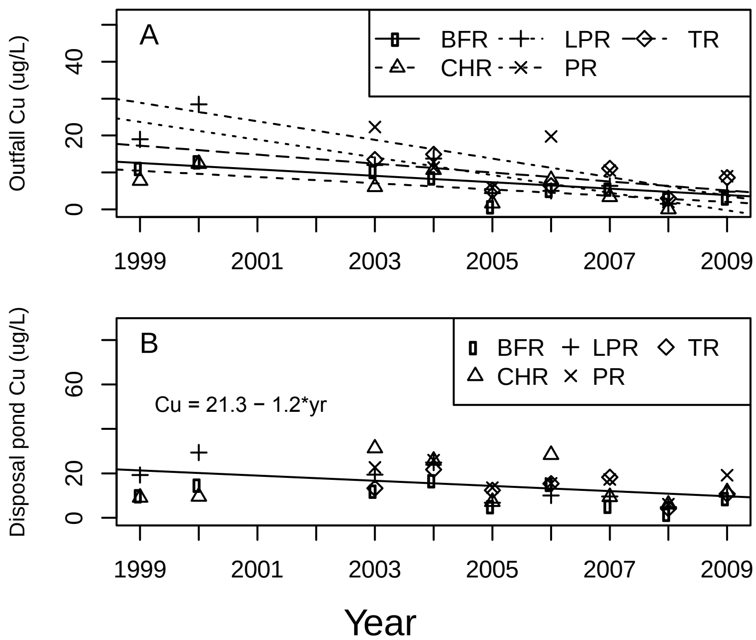

Fig. S1. Mean Cu concentration in CBNG discharge point water (A) and disposal pond water (B) from five basins in Wyoming between 1999 and 2009. Linear regression equations for outfalls: Belle Fourche River (BFR), Cu=12.5-0.9*yr; Cheyenne River (CHR), Cu=10.5-0.8*yr; Little Powder River (LPR), Cu=23.7-2.4*yr; Powder River (PR), Cu=28.9-2.5*yr; Tongue River (TR), Cu=17.2-1.2*yr. An overall trend for decreasing Cu concentration in disposal ponds was observed when averaged over basins ($P<0.0001$).

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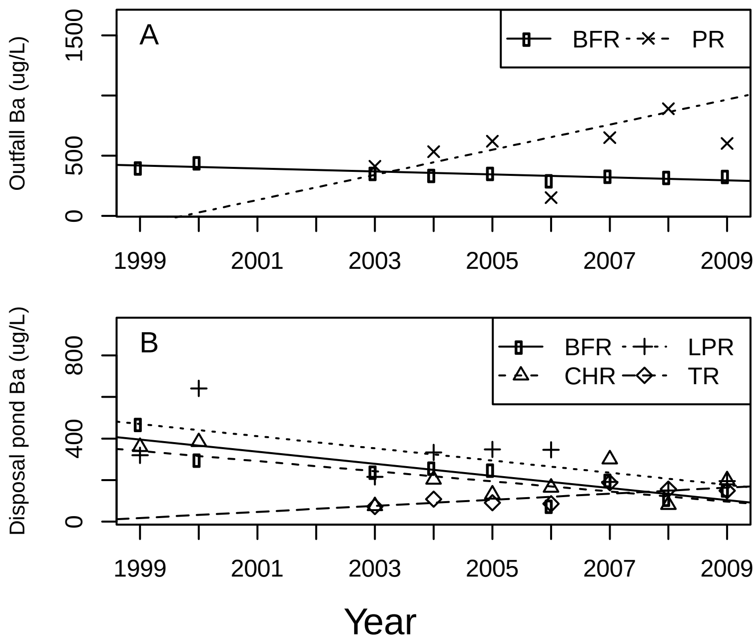

Fig. S2. Mean Ba concentration in CBNG discharge point water (A) and disposal pond water (B) from five basins in Wyoming between 1999 and 2009. No significant trends (P>0.16) were observed in outfalls in the Cheyenne River (CHR), Little Powder River (LPR) or Tongue River (TR) basins. Linear regression equations for outfalls: Belle Fourche River (BFR), Ba=418.7-12.4*yr; Powder River (PR), Ba=-76.0+104.3*yr. No significant trend (P=0.48) was observed in disposal ponds in the PR basin. Linear regression equations for disposal ponds: BFR, Ba=395.1-29.2*yr; CHR, Ba=340.1-24.4*yr; LPR, Ba=469.8-29.3*yr; TR, Ba=17.3-14.6*yr.

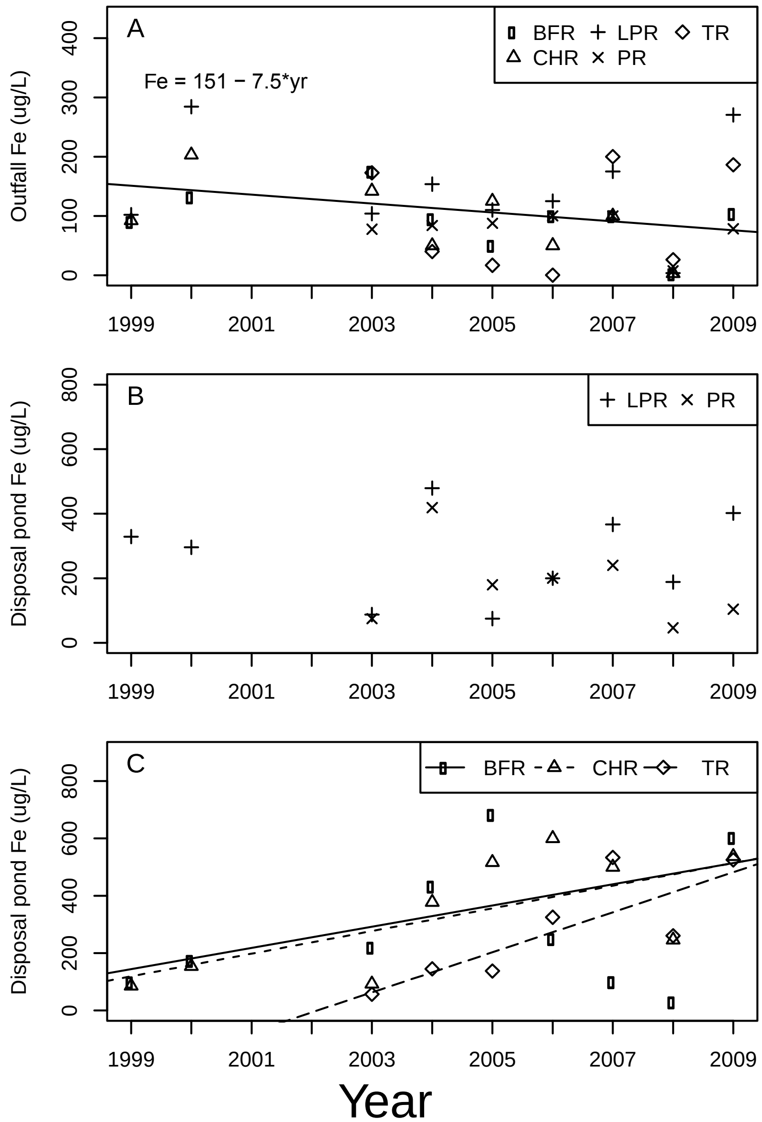

Fig. S3. Mean Fe concentration in CBNG discharge point water (A) and disposal pond water (B and C) from five basins in Wyoming between 1999 and 2009. An overall trend (P=0.0056) for decreasing Fe concentration in outfalls was observed when averaged over the Belle Fourche River (BFR), Cheyene River (CHR), Litter Powder River (LPR), Powder River (PR) and Tongue River (TR) basins (A). No significant trends (P>0.70) in pH were observed from LPR or PR basins (B). Increasing Fe concentrations were observed in the BFR (P=0.0563), CHR, (P=0.0575), and TR (P=0.0017) basins (C). Linear regression equations for Fe in disposal ponds: BFR, Fe=144+37*yr; CHR, Fe=119+39*yr; TR, Fe=-216+70*yr.

Table S1. Comparison of nine-year average of water quality components in CBNG disposal pond water for aquatic life standards. Units are µg/L and pH is S.U.

Basin	Component	Disposal Ponds	Limit	Yes/No
CHR	pH	8.9 ± 0.73	6.5 – 9.0	*
	Arsenic	5.5 ± 3.23	7	Yes
	Cadmium	0.1 ± 0.06	4	Yes
	Chromium	13.2 ± 12.75	100	Yes
	Copper	15.4 ± 9.55	1,000	Yes
	Selenium	0.9 ± 0.33	50	Yes
	Zinc	9.5 ± 5.97	5,000	Yes
BFR	pH	8.5 ± 0.67	6.5 – 9.0	Yes
	Arsenic	3.1 ± 1.79	7	Yes
	Cadmium	0.1 ± 0.08	4	Yes
	Chromium	8.9 ± 10.17	100	Yes
	Copper	10.7 ± 4.75	1,000	Yes
	Selenium	0.8 ± 0.59	50	Yes
	Zinc	6.3 ± 5.09	5,000	Yes
PR	pH	8.6 ± 0.49	6.5 – 9.0	Yes
	Arsenic	5.1 ± 1.69	7	Yes
	Cadmium	0.1 ± 0.12	4	Yes
	Chromium	11.5 ± 7.13	100	Yes
	Copper	17.4 ± 4.91	1,000	Yes
	Selenium	1.7 ± 0.74	50	Yes
	Zinc	9.5 ± 7.15	5,000	Yes
LPR	pH	8.5 ± 0.74	6.5 – 9.0	Yes
	Arsenic	6.5 ± 7.18	7	*
	Cadmium	0.1 ± 0.1	4	Yes
	Chromium	17.2 ± 22.51	100	Yes
	Copper	15.9 ± 8.63	1,000	Yes
	Selenium	1.1 ± 0.54	50	Yes
	Zinc	8.9 ± 7.37	5,000	Yes
TR	pH	8.9 ± 0.26	6.5 – 9.0	*
	Arsenic	2.4 ± 1.57	7	Yes
	Cadmium	1.6 ± 3.31	4	Yes
	Chromium	6.7 ± 3.15	100	Yes
	Copper	15.3 ± 5.16	1,000	Yes
	Selenium	1.2 ± 0.41	50	Yes
	Zinc	13.6 ± 6.65	5,000	Yes

*approaching the limit.

Table S2. The EC and SAR Hazard Classifications.

EC (dS/m)
Class 1, Excellent ≤ 0.25
Class 2, Good 0.25 – 0.75
Class 3, Permissible 0.76 – 2.00
Class 4, Doubtful 2.01 – 3.00
Class 5, Unsuitable ≥ 3.00

SAR
1 – 9 Low Hazard
10 – 17 Medium Hazard
18 – 25 High Hazard
≥ 26 Very High Hazard

Table S3. Comparison of water quality in CBNG discharge point water and disposal pond water to standards for irrigation.

	EC (dS/m) Discharge Points		EC (dS/m) Disposal Ponds	
Basin	Measured Levels	Class	Measured Levels	Class
CHR	0.7 ± .08	Class 2	0.8 ± .29	Class 3
BFR	0.8 ± .25	Class 3	1.0 ± .48	Class 3
PR	2.0 ± .48	Class 4	2.7 ± .21	Class 4
LPR	1.6 ± .26	Class 3	1.7 ± .29	Class 3
TR	1.8 ± .08	Class 3	2.0 ± .20	Class 3/4

	SAR Discharge Points		SAR Disposal Ponds	
Basin	Measured Levels	Hazard	Measured Levels	Hazard
CHR	6.9 ± .96	Low	8.7 ± 3.73	Low
BFR	6.8 ± .65	Low	7.7 ± 2.25	Low
PR	23.6 ± 1.96	High	33.5 ± 6.27	Very High
LPR	10.6 ± 1.09	Medium	12.3 ± 3.19	Medium
TR	41.3 ± 6.51	Very High	37.4 ± 6.71	Very High