Dr. William H. Clements Comments on BLM's Draft EIS

Final Comments on Draft Environmental Impact Statement Related to Water Quality

William H. Clements, Ph.D.

Background

This review of the Wyoming Draft Environmental Impact Statement (DEIS) will focus on the anticipated effects of coal bed methane (CBM) effluents on water quality and ecological integrity of watersheds in the Powder River project area. My analysis assumes that a significant volume of CBM produced effluents will be discharged into aquatic receiving systems in the area. This assumption is supported by analyses conduced by expert hydrologists that also reviewed the Wyoming DEIS. This review is based on: 1) an analysis of the toxicity of major constituents in CBM produced effluents; 2) an evaluation of the effects of increased sedimentation; and 3) consideration of potential interactions among these stressors.

The Wyoming DEIS reports water quality data for existing CBM produced effluents in the project area. CBM produced waters typically contain a complex mixture of contaminants, several of which are highly toxic to fish and other aquatic organisms. The Wyoming DEIS did not evaluate potential toxicological impacts of these effluents, presumably because of the unsupported assumption that only small volumes of these materials will be discharged to receiving systems in the project area. Assuming that CBM effluents will be released to surface waters, there is a potential for adverse effects on aquatic organisms. Stressors of primary concern associated with CBM effluents include metals (manganese, iron, arsenic and selenium), increased sedimentation, and total dissolved solids (TDS). Of these stressors, sedimentation and TDS will likely have the most widespread impacts on watersheds in the Powder River basin. However, elevated selenium concentrations, which occur naturally in some areas, are a significant source of concern in these watersheds.

Effects of elevated concentrations of major ions on aquatic organisms

The DEIS indicates that CBM produced effluents have high levels of salinity, resulting primarily from elevated concentrations of several major ions. Discharge of high salinity and TDS effluents into receiving systems may result in physiologically stressful conditions for some species due to alterations in osmotic conditions. Even some marine species are negatively impacted by changes in TDS if these effluents alter the specific ionic composition of receiving waters. Thus, reductions of major ions due to dilution by CBM waters in systems with naturally high TDS (e.g., the Upper Belle Fourche River) can impact aquatic organisms.

Aquatic organisms are highly sensitive to changes in ion concentrations in the environment. It is well established that elevated concentrations of major ions can reduce water quality and significantly impact fish and wildlife (Goetsch and Palmer 1997; Pillard et al. 1999; Dickerson and Vinyard 1999; Chapman et al. 2000). In particular, increased levels of Cl^-, HCO_3^-, SO_4^-, Na^+, Ca^{2+}, Mg^{2+}, and K^+, major constituents of CBM produced effluents, are toxic to many aquatic species (see review by Goodfellow et al. 2000). In an analysis of the toxicity of >2900 ionic solutions, Mount et al. (1997) reported that the relative toxicity of major ions in high TDS effluents was: $K^+ > HCO_3^- = Mg^{2+} > Cl^- > SO_4^-$. In general, if conductivity exceeds 2000 _C/cm, concentrations of dissolved solids may be sufficient to cause acute toxicity (Goodfellow et al. 2000). Conductivity values for most CBM produced effluents reported in Table 4-6 of the Wyoming DEIS exceed these threshold levels.

Conductivity, TDS, and toxicity

Conductivity and TDS are common integrated measures of the concentrations of ions in aquatic ecosystems. Although these measures are often used as surrogates for estimating effects, predicting toxicological impacts of high TDS effluents is very complicated. Recent studies have shown considerable variation in the toxicity of TDS. This variation is a result of differences in the concentrations of specific ions, which will change seasonally and among watersheds (Pillard et al. 1999). Dwyer et al. (1992) reported that toxicity of high TDS effluents was more dependent on the specific ionic composition than on the total concentration of TDS. Mount et al. (1997) recently developed statistical models based on specific concentrations of major ions to predict toxicity to fish and invertebrates. The linear logistic regression model used in these analyses was given as

$$\mathbf{logit\ (P) = ln\ [P/(1-P)] = \_{0} + \_{1}X_{1} + \_{2}X_{2} + \_{3}X_{3}\ .... + \_{n}X_{n}}$$

where P = the proportion surviving, _ = regression coefficient, and X = specific ion concentration. Based on these models, CBM produced effluents from most sites within the project area are expected to be highly toxic to aquatic organisms. For example, predicted mortality of fathead minnows (*Pimephales promelas*) exposed to CBM produced effluent from the Upper Powder, Middle Powder, Little Powder, and Upper Belle Fourche drainages ranged from 30-70% (Table 1). These values were based on mean concentrations of the five major ions (K^+, HCO_3^-, Mg^{2+}, Cl^-, SO_4^-) included in the Mount et al. (1997) model. The greatest potential effects of CBM produced effluents are expected to occur in the Upper Tongue River Sub-Watershed because of the naturally low levels of most ions in this stream.

The Wyoming DEIS predicts potential increases in salinity (expressed as conductivity, _C/cm) within each of the watersheds based on mass balance equations. As shown above, estimating potential toxicological impacts in the project area based on TDS or conductivity is overly simplistic. Furthermore, the Wyoming DEIS calculates potential discharge of CBM effluents to surface waters based on mean annual discharge of these watersheds. However, because of large seasonal variation in stream flow, CBM effluents may comprise a significant portion of total stream discharge during periods of low summer flow and concentrations of major ions are likely to be much greater. If the Mount et al. (1997) models are run using maximum ion concentrations measured in CBM effluents, predicted mortality to fish ranged from 90-100% (Table 1). Thus, estimating potential toxicological impacts of CBM produced effluents requires that each watershed in the project area be evaluated separately and that seasonal changes in stream discharge be considered. Weight-of-evidence approaches are necessary to demonstrate effects of ionic imbalance and toxicity identification and evaluation (TIE) procedures are necessary to identify specific constituents responsible for toxicity.

Although there is recent debate in the scientific literature concerning how to regulate high TDS effluents (Goodfellow et al. 2000), numerous studies have shown that ionic imbalance significantly impacts aquatic organisms. Unfortunately, most of the research investigating toxicity of TDS has focused on traditional test species (e.g., fathead minnows, *Ceriodaphnia*, *Daphnia*) and relatively few studies have been conducted with species relevant to the Powder River Basin. Chapman et al. (2000) measured toxic effects of TDS on chironomids and rainbow trout at concentrations similar to those in CBM produced effluents. Although trout showed tolerance to TDS at concentrations greater than 2000 mg/L, benthic macroinvertebrates (chironomids) were significantly affected at 1100 mg/L. Similar findings were reported by Goetsch and Palmer (1997) for benthic macroinvertebrates in the Sabie River (South Africa). Mayflies were highly sensitive to increased concentrations of Na, with LC_{50} values approximately 900 mg/L TDS. These authors also noted that the ionic composition of the water was a major factor influencing acute toxicity, with NaCl showing much less toxicity than $NaSO_4$.

Maximum concentrations of TDS in CBM effluents reported in the Wyoming DEIS exceed 8800 mg/L (Table 3-2). Results of laboratory and field studies indicate that these effluents will be toxic to aquatic organisms in watersheds of the Powder River Basin. Chapman et al. (2000) reported that aquatic organisms should be able to tolerate TDS concentrations of at least 1000 mg/L. This concentration is consistent with the National Pollutant Discharge Elimination System (NPDES) issued in Alaska, which specified a TDS concentration limit of 1000 mg/L. Unless data are available showing no effects on native organisms to this level of TDS, a similar restriction should be placed on CBM effluents released into streams in the Powder River Basin.

Limitations of using mean concentrations for predicting impacts

The DEIS employs mass balance equations to predict effects of CBM effluents on existing water quality in the project area. These estimates are based on minimum discharges of CBM effluents to these watersheds using mean values of various toxic constituents. Because these values significantly underestimate potential discharge to surface waters and do not consider seasonal variation in stream flow, the actual changes in water quality and ionic composition are likely to be much greater. In addition, there are likely to be significant changes in water quality characteristics before these effluents reach adjacent surface waters as a result of leaching materials from surrounding soils. Finally, the use of mean concentrations for predicting effluent toxicity is highly misleading. Because of seasonal changes in stream discharge and CBM effluent quality, organisms inhabiting Powder River watersheds will be subjected to highly variable concentrations of toxic constituents. It is the maximum concentrations of these constituents that cause mortality in aquatic organisms, not the mean values. When maximum concentrations of major ions in CBM effluents are used in logistic regression models, predicted mortality to fish increases dramatically (Table 1).

Limitations of laboratory studies for predicting impacts of TDS

Most of the available research on sensitivity to TDS and salinity has employed laboratory toxicity tests to predict responses of fish and macroinvertebrates. In addition, our understanding of toxicological effects of elevated TDS is based on acute responses (e.g., lethality). There is relatively little information on sublethal, chronic responses to these effluents. While laboratory approaches may provide an approximation of potential effects, toxicity tests are limited in their ability to predict effects on natural communities. These simplistic tests are conducted under unrealistic laboratory conditions and have been routinely criticized because they do not consider potential indirect effects of contaminants or alterations in functional characteristics of ecosystems. Predicting indirect effects of effluents requires information on relative sensitivities of interacting species that is not available in the project area. For example, Leland and Fend (1998) analyzed benthic macroinvertebrate communities along a gradient of TDS (55-1700 mg/L) and reported species-specific variation in response to concentrations of sulfates and bicarbonates. These finding were not consistent with results of laboratory toxicity tests, indicating the difficulty predicting responses of natural communities in the field.

Interactions between elevated TDS and other stressors

The Wyoming DEIS failed to consider potential interactions between toxic constituents in CBM produced water and other stressors in the Powder River Basin. A large body of literature exists showing that exposure to one stressor may increase susceptibility of aquatic species to other stressors (e.g., Clements 1999; Courtney and Clements 2001). In particular, previous research has shown that some contaminants are more toxic under conditions of high TDS. Dickerson and Vinyard (1999) speculated that exposure to other chemical stressors increased the toxicity of TDS to cutthroat trout. Anderson et al. (1994) reported that toxicity of polycyclic aromatic hydrocarbons (PAHs) to fish increased when organisms were simultaneously exposed to elevated TDS. Similarly, salinity increased the toxicity of atrazine, a commonly used herbicide, to sheepshead minnows (1995). Because watersheds in the project area will be subjected to a variety of physical and chemical stressors during CBM exploration and development, potential interactions between high TDS effluents and these other stressors must be considered (Pillard et al. 1999).

Increased Sedimentation

In my opinion, the Wyoming DEIS has not given sufficient attention to the impacts of increased sedimentation on aquatic ecosystems in the project area. Input of sediments to aquatic ecosystems is widely regarded as a major source of stream degradation in North America (Waters 1995). In particular, fine sediments fill interstitial spaces and reduce available habitat for fish and macroinvertebrates. Many species of aquatic insects are highly sensitive to modifications in substrate characteristics, and increased sedimentation will likely alter species diversity and trophic structure. Previous studies have shown major changes in community composition as a result of relatively modest inputs of fine sediments (Zweig and Rabeni 2001), and dose-response relationships between sediment levels and benthic communities have been established (Angradi 1999).

Increased sedimentation resulting from erosion of stream banks, overland flow, and road construction will likely impact aquatic organisms in Powder River watersheds. Because of the natural geologic setting of the project area (e.g., unconsolidated quaternary deposits, sandstone), soils in the Powder River basin are highly erodible. The Wyoming DEIS correctly notes that increased sedimentation will occur in the project area and that these materials will likely degrade habitat quality for aquatic organisms. Expected shifts in community composition in Powder River watersheds include reduced abundance of mayflies, stoneflies and caddisflies with a concomitant increase in abundance of organisms tolerant of sediment deposition (chironomids and other dipterans). These changes in abundance and distribution of macroinvertebrates resulting from sedimentation will likely have significant consequences for fish populations in Powder River watersheds. In addition to the reduction in food resources, loss of fish habitat and degradation of spawning areas will impact fisheries. The potential impacts of fine sediment deposition in the Powder River basin should be quantified. Although the Wyoming DEIS correctly notes these impacts may occur, relatively little information is provided indicating how they will be mitigated.

Toxicity and bioaccumulation of selenium

In my opinion, the Wyoming DEIS has not provided sufficient information to evaluate the potential effects of toxic materials associated with CBM produced effluents in the project area. The DEIS concludes that there will be no impacts of increased metals or metalloids on aquatic organisms in the Powder River Basin. This conclusion is based on the observation that metal levels in CBM effluents are below those considered toxic to macroinvertebrates and fish. However, some metals in CBM produced waters have been measured at levels considered toxic to aquatic organisms. For example, selenium (Se) was detected in several watersheds in the project area, and levels of Se are especially elevated in the South Fork of the Powder River. The Wyoming DEIS correctly notes that Se levels will vary with stream discharge, indicating the need to account for seasonal changes in CBM inputs. The DEIS also states that Se in the South Fork of the Powder River originates from geologic sources, suggesting that elevated levels of Se may occur naturally within the project area.

Therefore, I have serious concerns that increased concentrations of Se may occur in CBM produced waters as a result of interactions with naturally Se-enriched soils. Because of the potential to bioaccumulate up aquatic food chains, concentrations of Se that are below criterion levels may cause significant harm to top predators in Powder River watersheds.

Summary

In summary, the Wyoming DEIS does not provide sufficient information to evaluate the potential risk of changes in concentrations of major ions, selenium bioaccumulation and food chain transfer, increased sedimentation, and interactions among these stressors. Based on my analysis of information presented in the DEIS and my best professional judgement, I expect that CBM produced effluents and associated sediments released into watersheds of the Powder River basin will have deleterious impacts on benthic macroinvertebrates and fish.

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Table 1. Estimated mortality to fish resulting from exposure to CBM produced effluents in the Powder River Basin. Results are based on a multiple logistical regression model using mean and maximum concentrations of major ions. The model is given as

$$\text{logit}(P) = \ln[P/(1-P)] = {}_{0} + {}_{1}X_{1} + {}_{2}X_{2} + {}_{3}X_{3} \ldots\ldots\ldots + {}_{n}X_{n}$$

where P = the proportion surviving, _ = regression coefficient, and X = specific ion concentration. Note these models do not include concentrations of Na and Ca. See Mount et al. (1997) for details. TDS = total dissolved solids.

	Major Ions (mg/L)	Middle	Little	Upper	Upper Belle
Mean Concentration		**Powder**	**Powder**	**Powder**	**Fourche**
	K	11	10	13	8
	Mg	199	88	89	16
	Cl	21	18	19	14
	SO_4	1745	90	548	18
	HCO_3	597	792	1065	834
	TDS	2977	1170	1884	770
	Mortality (%)	**51**	**33**	**70**	**30**
Maximum Concentration					
	K	14	15	35	20
	Mg	265	1020	528	93
	Cl	37	740	152	36
	SO_4	2410	5660	4260	1080
	HCO_3	934	1370	3080	1400
	TDS	3830	8810	7210	1790
	Mortality (%)	**91**	**100**	**100**	**95**