Application of ArcGIS Modelbuilder to Airborne Electromagnetic Surveys for the Improvement of Water Management in the Powder River Basin, Wyoming.

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Summary

ArcGIS Modelbuilder was used to create GIS-based decision support model that incorporated digital elevation data and helicopter electromagnetic geophysical results to screen potential sites for coalbed natural gas produced water disposal impoundments. Airborne geophysical surveys were contracted by the National Energy Technology Laboratory at selected study sites within the Powder River Basin of Wyoming and Montana in 2003 and 2004 as part of a hydrologic study of coal bed natural gas production. There were 9 study sites covering approximately 210 km^2 of upland and floodplain areas within the basin. Interpretation of the apparent conductivity maps and inverted conductivity depth sections revealed lithologic heterogeneities and water quality variations that were ultimately used to infer hydrologic processes. However, GIS-based models were used to couple seemingly unrelated spatial datasets in such a manner that may provide industry and environmental agencies with an effective produced water management tool.

Body

The Powder River Basin (PRB) encompasses over 22,000 square miles in Montana and Wyoming and has experienced significant development of coalbed natural gas (CBNG) since 1993 (Figure 1). Estimates of CBNG reserves are variable depending on the calculation method. Conservative reserve estimates of total gas in place for the PRB are up to 90 trillion cubic feet (TCF) in Montana (Arthur et al., 2003) and 38 TCF in Wyoming (De Bruin et al., 2004). In Wyoming, development of CBNG has increased rapidly over the past decade. Since 1993, the annual production of CBNG in the PRB has doubled every year through 2001, with a little over one billion cubic feet (BCF) in 1993 to 256 BCF in 2001 (Figure 2). In early 2004, close to 1 BCF of CBNG was produced each day. By the beginning of 2004, 1.2 TCF of natural gas had been recovered from the PRB. In the 1990's, much of the production of CBNG in the PRB came from the Wyodak-Anderson coalbed near Gillette, WY. More recently, development has occurred west of Gillette in the Big George Coal and northwest of Gillette in multiple coal seams.

CBNG production typically requires removal of large volumes of water from coalbeds. Wells may initially produce 12-25 gallons of water per minute (gpm) (Bryner, 2002; Likwartz, 2002), but will generally produce approximately 4 gpm over an average operating life of 7 to 10 years (Cook, 2002; Bryner, 2002). The rate of water discharge gradually decreases, as does the amount of recovered gas. It is estimated that there will be 1.4 to 5 trillion gallons of produced water in Wyoming over the next 15 years with estimates of up to 3 trillion gallons of produced water in Montana (USDOI-BLM 2002; Darin, 2002). The extracted water is moderately saline and contains elevated levels of sodium relative to other cations (Rice et al., 2000). Produced water is often reused for beneficial purposes, such as irrigation or stock watering, if water quality is suitable. Unused produced water is disposed through direct surface discharge, infiltration impoundments, and evaporation ponds. The potential environmental impacts associated with produced water disposal encompass water resource depletion, water quality degradation in surface and groundwater systems, and altered agricultural lands (Stearns et al., 2005).

In 2003 and 2004, the National Energy Technology Laboratory of the United States Department of Energy in collaboration with the United States Geological Survey, Wyoming Department of Environmental Quality and the Department of Geology and Planetary Science at the University of Pittsburgh completed a Frequency Domain Airborne Electromagnetic (AEM) survey over nine study areas (total of 210 km^2) in the Powder River Basin (Figure 1). The intent of this survey was to evaluate AEM for large-scale mapping of vadose zone electrical conductivity and water quality variation within shallow aquifers to evaluate the effects of produced water disposal. As an example, Figure 3 depicts a near-surface conductivity map and depth section (generated by geophysical inversion of the AEM data) of a field irrigated with produced water. There is a conductive anomaly that is interpreted to be elevated porewater salinity and/or salt accumulation that may have resulted from the moderately saline produced water used to irrigate the field. The anomaly at A (Figure 3) has a mean apparent conductivity value of 143 mS/m which is ~ 2 times above the background conductivity values for the adjacent areas (62 mS/m). AEM data were also useful to elucidate water quality variability of PRB alluvial aquifers. Figure 4 depicts a near surface AEM derived conductivity image for an area south of the Tongue River and Badger Creek confluence. Included on the figure is a conductivity depth section derived from AEM data and from an analogous ground-based system (Geophex GEM 2). There is a shallow alluvial aquifer associated with each stream. However, the Tongue River aquifer contains water with lower total dissolved solids (TDS) concentration (lower electrical conductivity corresponds to TDS levels) than the Badger Creek system as observed on the map and depth sections.

ArcGIS was used to further process the AEM data to be used as a screening tool to identify potential problem areas for new impoundments. ArcGIS was used in all stages of analysis of these data. All AEM apparent conductivities were imported into ArcGIS personal geodatabases. In addition .ers format (ERMAPPER format raster files) was used for some geophysical datasets. These AEM data were then interpreted to determine near surface conductivity. Other raster datasets used in the analysis included topography, remote sensing images and restricted area polygon feature class based data. ArcGIS ModelBuilder technology was perfectly suited to the task of building a decision support model for evaluating the near surface conditions in the siting of CBNG water storage impoundments. Figure 5 shows our model for the screening of site locations of CBNG produced water impoundments. Our CBNG site location model combines digital elevation data, near surface apparent conductivity (which is a proxy for naturally occurring salts in the subsurface) and restricted areas. Using ArcGIS the entire geophysical datasets could quickly and efficiently be incorporated into a regional framework and used to determine a suitability index for potential impoundment sites. Figure 6 shows results from a study area in which an existing CBNG impoundment was built over highly conductive surface materials to store water. A perched aquifer formed in the underlying sediments (~5-9m thick), which had TDS levels up to 2 orders of magnitude higher than the input CBNG water. Locations surrounding the impoundment may have been more suitable based on the results of the GIS model. However, on-site field studies would be necessary to properly evaluate site conditions for any water management plans. Future plans are to add more complexity to the model through incorporating more information used in the decision process for produced water management.

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