# Geophysical Investigations for Coal Bed Natural Gas Co-produced Water Management, Powder River Basin, Wyoming

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The Powder River Basin is one of the largest producers of coal-bed natural gas (CBNG) in the United States. An important environmental concern in the Basin is the fate of the large amounts of groundwater extracted during CBNG production. CBNG accounts for 7% of natural gas production in the United States, but coproduced water volume greatly exceeds traditional natural gas development. CBNG waters in the PRB typically have specific conductance of 0.6-3.0 mS $cm^{-1}$, high sodium adsorption ratios (SAR = 20-60), and are $Na\text{-}HCO_3$ dominated. Waters with such compositions can degrade soil structure, thus limiting beneficial use through irrigation to carefully managed applications. Since development began in Wyoming, more than 650 billion liters of water have been produced from approximately 22,000 wells (Wyoming Oil and Gas Conservation Commission, 2007). Disposal of CBNG water has been through a variety of methods including directly to surface drainages, infiltration from impoundments (most common method), and more recently in surface and subsurface irrigation. Beginning in 2003 the Department of Energy National Energy Technology Laboratory (DOE NETL) and U.S. Geological Survey (USGS) began geophysical, geochemical, and hydrologic studies to better understand the hydrogeologic framework of shallow groundwater systems (<100 m) to aid in management of the co-produced waters.

The first geophysical studies from 2003 through 2007 concentrated on shallow groundwater impacts from impoundments. These studies included 2,400 line kilometers of helicopter frequency domain electromagnetic (HFEM) surveys flown over several sites in the central and northern PRB. In addition, ground resistivity and electromagnetic (EM) surveys were conducted at several sites. The USGS undertook a detailed study of the Skewed Reservoir site in the central part of the Basin beginning in 2003. Monitor wells were installed prior to construction. Geophysical ground and airborne surveys as well as borehole induction electrical conductivity and total gamma surveys were done post filling of the impoundment. These surveys demonstrate changes in the subsurface electrical properties of the vadose zone around the impoundment that can be attributed to changes in volume and salinity of the groundwater. At the time development of high subsurface electrical conductivities due to dissolution of soluble salts in the near surface was poorly understood. As a result of the studies, a GIS approach was developed for evaluation of the siting of impoundment ponds that used geophysical, landform, and other data.

Subsurface drip irrigation (SDI) emerged as a means to derive beneficial use from CBNG waters in the PRB around 2005. In 2007 the DOE NETL and USGS began a study to characterize the shallow hydrology and geochemistry of a SDI site near Arvada, Wyoming. A HFEM survey with 25 m line spacing was flown of the site. Ground EM conductivity and direct current resistivity surveys were conducted in 2007 prior to installation of the SDI system. Borehole induction electrical conductivity and total gamma survey data were also collected. The ground surveys have been repeated about three times per year since 2007 giving a record of EM conductivity changes that can be correlated with changes in relative soil saturation and salinity. These changes allow high conductivities due to clays (remain generally constant in time) to be separated from high conductivity due to changing groundwater chemistry and volume.