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title: **Vulnerability of waters in the area of the Fruitland Formation, southeastern Colorado**

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There remains considerable uncertainty about how coal bed methane (CBM) production from the Fruitland outcrop in Southwestern Colorado USA, may affect the quantity and quality of nearby surface waters, springs, wetlands, and groundwater systems. The Upper Cretaceous Fruitland Formation of the San Juan Basin is presently the second largest gas producing basin in the United States, with total reserves estimated at 1.4×10^9 m^3 (Choate et al., 1984; Kuuskraa and Boyer, 1993; Fassett, 2000). Snyder and Fabryka-Martin (2007) have shown that the basin is also one of the most extensively studied in the world, with a wealth of information available from chemical and isotopic investigations (Scott et al., 1994; Snyder et al., 2003; Riese et al., 2005; Zhou et al., 2005; Zhou and Ballentine, 2006), geophysical logging (Clarkson et al., 1988; McCord et al., 1992), stratigraphic analyses (Ayers and Kaiser, 1994; Fassett, 2000) and well production histories extending over 25 years.

Yet, for all the research activities that have occurred in the area, there remain many controversies regarding the age of formation waters, the extent to which portions of large basins are subject to active hydrologic throughflow or whether they are relatively static, and how CBM production may affect nearby surface—groundwater interactions, particularly at the margins of the gas field. With data collected as part of a basin-wide hydrologic modeling project (3M Project, 2000), Snyder et al. (2003) and Riese et al. (2005) interpreted values of $^{129}I/I$ ratios between 100×10^{-15} and 200×10^{-15} as indicating minimum iodine ages close to 60 Ma. They further suggested that if these ages are corrected for the addition of fissiogenic ^{129}I, they are compatible with the depositional age of the Fruitland Formation (Late Cretaceous) and indicate a static hydrologic system. The implication of these results is that CBM production would have no affect on local hydrologic systems.

However, Zhou and Ballentine (2006) estimated groundwater ages in the Fruitland Formation using ^4He. They report dates on the scale of 30,000 BP. Their ^4He groundwater dates in the center of the underpressured area using average crustal flux rates are consistent with ages of major recharge events (22,000 years BP) reported for the San Juan Basin (Phillips et al., 1986). These dates also agree with the ^{14}C dates and are close to the hydrological modelling dates up to the distance of 20 km from the basin margin recharge area (Mavor et al., 1991). Zhou and Ballentine (2006) state: "*Our results do not support the groundwater ages of ~60 Ma reported by (Snyder et al., 2003) in any sense or form.*"

Based on these new analyses, Snyder and Fabryka-Martin (2007) have re-interpreted the results of Snyder et al. (2003). They show that ^{129}I and ^{36}Cl signatures from the mixing of brine and meteoric waters early in the development of a sedimentary basin are quantitatively different from those imparted by the mixing of old brines with recent meteoric waters. Thus, interpretation of isotopic results is sensitive to the type of hydrologic end-members and the relative mixing of those end-members.

In 2009 a sampling program in Southeastern Colorado near Durango was begun to determine the chemical and isotopic properties of surface and groundwaters near the Fruitland Outcrop coal formation. This data represents a baseline for waters in the area that soon may be perturbed by increased CBM production. Water samples were collected in 2008 and 2009 from existing CBM wells, domestic wells, piezometers, springs and surface waters in neighboring La Plata and Archuleta counties (Figure 1) and analyzed for tritium content.

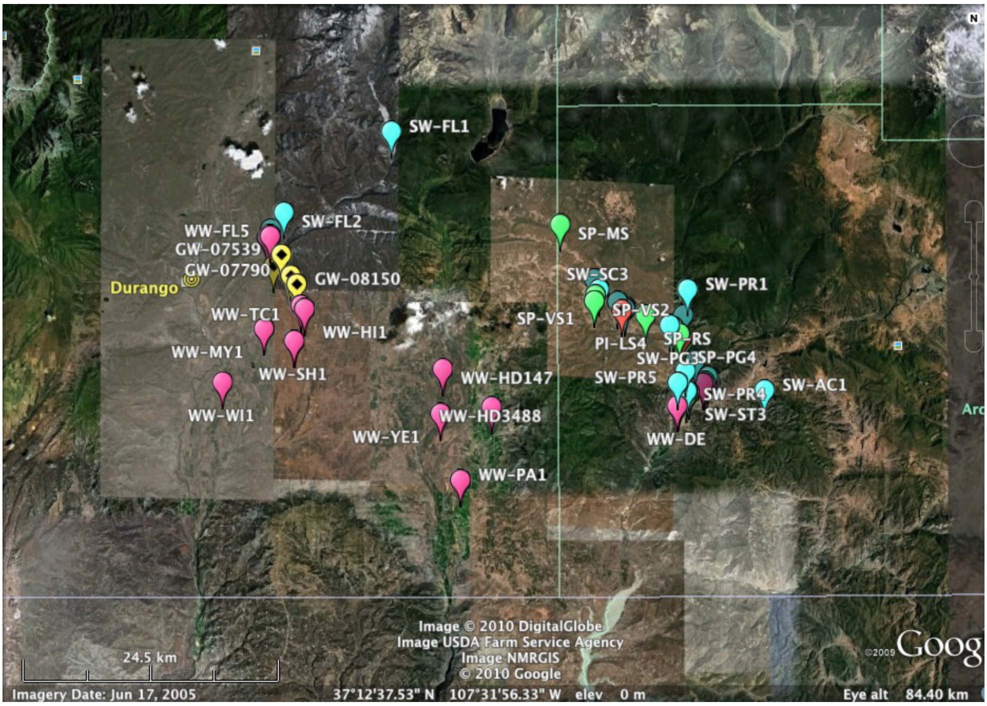

Figure 1. Location of the Fruitland Coal outcrop east of Durango, Colorado. WW = domestic wells, SW = surface water, SP = springs, PI = piezometers, GW = CMB wells.

Approximately 103 samples have been analyzed to this point, and the tritium distributions are bimodal with about 7 percent of the concentrations less than 1.5 TU and about 88% ranging between 4.5-7 TU (Figure 2). Tritium concentrations in all water bodies other than CBM wells approximated post-bomb precipitation levels and showed little seasonal variation. Mean values were as follows: domestic wells, 4.58 TU; piezometers, 5.46 TU; springs, 5.14 TU, and surface waters, 5.85 TU. One-way analyses of variance showed more variance in tritium within water bodies than among them.

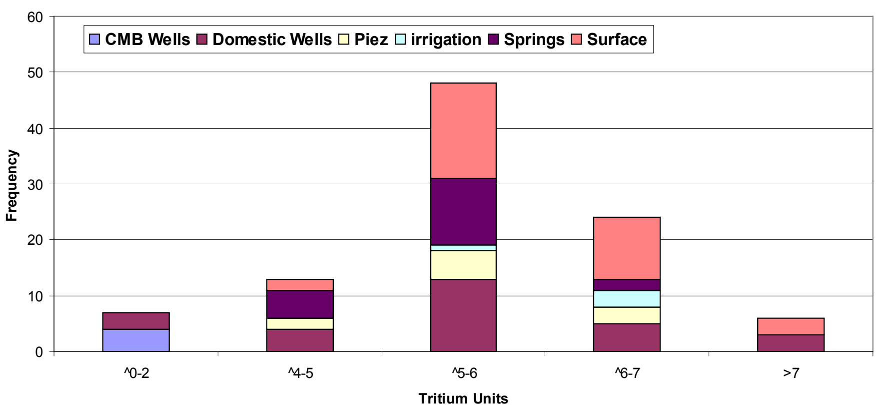

Figure 2. Histogram showing the distribution of tritium in samples measured during this program.

To properly understand the implications of the data, it is necessary to determine the tritium input function. The study area is heavily impacted by moisture moving north from the gulf, especially in summer. As a result, tritium concentrations are lower than those found in northern Colorado as noted in work on the Arkansas River (Michel, 2004). The most representative choice to estimate tritium concentrations in precipitation for this area is a long-term station at Albuquerque, New Mexico. Measured data and concentrations estimated from the Vienna correlation were used from a long term precipitation station at Albuquerque, NM to develop a precipitation input function for tritium. Using the Albuquerque precipitation input function, an exponential model was applied to this data set (Revelle and Suess, 1957; Michel, 2004). Estimates of tritium concentrations for various mean ages of water are shown in Figure 3.

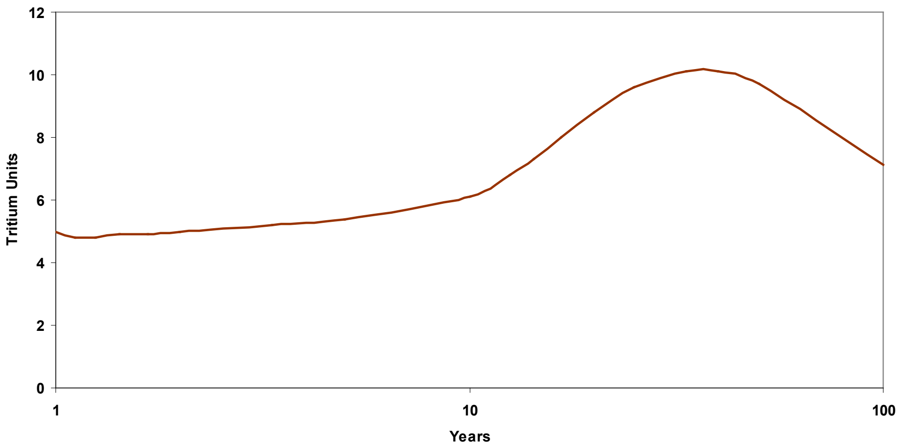

Figure 3. Estimates of tritium concentrations for waters with mean ages between 1–100 years. An input function for precipitation was derived from the Albuquerque, New Mexico precipitation data.

Using the age estimates of mean ages for water in this area derived from Figure 3, it can be seen that the tritium concentration range for this data set falls primarily within an age range of less than 15 years with the vast majority of samples fall in an age range of less than 1 decade. Three samples fall with an age-range of 20–40 years and 7 samples indicate a pre-bomb origin. These results suggest tighter hydrologic connections and more circulation than expected, and may indicate a system that is already over-drafted by existing CBM production and heavy domestic well use.

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