Spatial and Temporal Characterization of the Radon Distribution in a Region of the Hickory Aquifer in Central Texas: Assessment of Stratigraphy and Groundwater Dynamics on Radon Concentrations

Project Duration: March 2003 through February 2004

Graduate Student Researcher: Leslie Randolph, Geology Department, Texas A&M University, College Station, TX. (979) 862-8107. randolph@tamu.edu

Graduate Faculty Advisor: Dr. Bruce Herbert, Geology Department, Texas A&M University, College Station, TX. (979) 845-2405. beherbert@tamu.edu

Problem Statement:

The Hickory Aquifer is the primary water source for the populations of Mason, Concho, McCulloch, San Saba, Menard, Kimble and Gillespie Counties in central Texas. Unfortunately, groundwater in this aquifer system contains radionuclide concentrations above EPA-designated maximum contaminant levels (MCLs) for the alpha-and beta-particle-emitting radionuclides $^{228}$Ra, $^{226}$Ra, and $^{222}$Rn and thus poses potential health risks (Texas Water Development Board (TWDB) Report 346, 1996; Bluntzer and Derton, 1988; Cech, et al, 1988; Lloyd and Drake, 1989). These radionuclides are products (“daughters”) of the decay of $^{238}$U and $^{232}$Th (“parents”), which naturally occur in the aquifer rocks. $^{238}$U and $^{232}$Th and their decay products become incorporated into groundwater by weathering, desorption, alpha recoil from the aquifer solids and parent decay in the dissolved phase (Tricca et. Al, 2001). Assessing and predicting spatial and temporal variations of radionuclide concentrations requires a quantitative understanding of these interactions and the role of groundwater dynamics.

Lloyd and Drake (1989) measured $^{226}$Ra groundwater concentrations above the MCL of 5 pCi/L (for combined $^{226}$Ra and $^{228}$Ra) in seven Hickory wells. Six of these wells are public supply wells for municipalities in McCulloch County. Average $^{226}$Ra and $^{228}$Ra concentrations in Hickory groundwater reported by the Texas Water Development Board (TWDB) from historic and recent records are 3.9 and 11.0 pCi/L, respectively (TWDB Report 346, 1996). Gross alpha concentrations compiled for the same study exceeded the MCL of 15 pCi/L in some Hickory wells. Cech, et. al. (1988) found $^{222}$Rn concentrations varied in Hickory and Ellenberger-San Saba (aquifer above the Hickory) groundwaters from less than 100 up to 1,400 pCi/L. The current EPA proposal calls for a $^{222}$Rn MCL of 300 pCi/L, or an alternate MCL of 4,000 pCi/L. The alternate MCL would require implementation of an indoor radon mitigation plan.

The Hickory aquifer is a Cambrian-age, quartzose sandstone with interbedded mudstones and was derived from Precambrian metamorphic and igneous rocks. It is a composite aquifer consisting of two aquifers separated by an aquitard associated with the mudstone-rich Middle Hickory (Johnson and Zhurina, 2001). The work by Kim (1995) found that uranium and thorium occur in the Hickory Sandstone predominantly in (1) phosphatic fossil fragments and intraclasts, (2) thin shaly laminae, (3) authigenic minerals including hematite and clay minerals, and (4) detrital accessory minerals. These controlling factors vary with stratigraphic position.

Revisions to the Safe Drinking water Act will require public water systems to meet the MCLs for radium, gross alpha, and uranium by December 2005. The proposed MCL for radon is
still being considered (TNRCC Strategic Plan). To date, groundwater radionuclide assessments of Hickory water have been cursory. No systematic study has been done to develop an understanding of or assess the true degree of the radionuclide problem (Stan Reinhardt, manager, Hickory Underground Water Conservation District #1 (HUWCD#1), pers. comm.).

Nature, Scope, and Objectives of the Research:

Nature:

The research proposed here is considered the most logical and “simple” first step of a larger, longer-term assessment of radionuclides in the groundwater of the Hickory aquifer system. Understanding what controls the observed radon distribution is an important step in understanding concentrations of other radionuclides in a groundwater system. The proposed research involves conducting a systematic assessment of the spatial and temporal distribution of \(^{222}\)Rn in Hickory groundwater in a small, ideally suited field site in the Katemcy Creek watershed in northern Mason and southern McCulloch Counties. Bluntzer and Derton (1988) measured discernible radium, radon’s parent radionuclide, in 30 of 33 Hickory groundwater samples collected in 1987 within the Katemcy Creek basin. Seventy-seven percent exceeded the MCL concentration of 5 pCi/L. The proposed research will be within the region studied by Bluntzer and Derton. The purpose of this study is to establish a high-resolution data set that will be used to explore relationships between observed radon distributions, aquifer stratigraphy and mineralogy, and groundwater dynamics.

Radon in groundwater is from decay of radium both within the aquifer host rock and dissolved in the groundwater. Since it is a noble gas, radon does not react chemically with the host rock or groundwater. Radon concentrations will reflect indirectly that of radium because of their parent-daughter relation. The concentration of radium at a given site reflects interactions between the flowing groundwater and the aquifer rock matrix, as well as chemical processes involving dissolved ions in the groundwater. The complex relationship between radium concentrations and chemical fluid/rock interaction, sorption, alpha-recoil, parent decay, and aqueous chemical constituents continue to challenge researchers studying radionuclides in groundwater (Tricca et. al., 2001). Studies are needed that allow quantitative assessment of the effects of these processes on radionuclide concentrations.

Typically, radon and other radionuclides are measured in water samples collected from wells screened over extensive intervals of the aquifer. Hence, these samples represent weighted averages of a radionuclide concentration in an aquifer, and do not directly permit assessment of vertical variations that may exist, especially if the aquifer exhibits significant variations in it’s stratigraphy. A primary goal of this proposed research is to assess the role of prominent stratigraphic variations on radon concentrations. Previous and on-going work at the proposed field site present a unique and rare opportunity to study the vertical and lateral distribution of radon gas in Hickory groundwater, as well as assess the role of spatial variation of groundwater flow. It is anticipated that results of the proposed study will lead to further investigations of relationships between radon gas and it’s parent radionuclides, aquifer mineralogy and aquifer geochemistry. This is a “seed” study that should lead to further research planned for my Ph.D. dissertation.
The field work and sampling will be at a site with an extensive geological and hydrologic data set. Especially important is an in-place network of multi-level monitoring wells constructed as part of another ongoing groundwater research project (Johnson, industrial and higher education coordinating board funding). For my M.S. research I characterized the groundwater system in the region of the study site and demonstrated that faults cutting the Hickory aquifer impede and even compartmentalize groundwater flow (Randolph, 1991). Delaney (1990) did a similar study in an adjacent region. As part of Johnson’s project, twelve, closely spaced boreholes have been continuously cored through the Hickory to Precambrian granite, with more than 1000m of core acquired. Wilson (2001) provides a detailed geologic characterization of the site based on analysis of this core. Westbay multi-level systems are installed in eight of the boreholes, with two additional installations planned in 2003. Packers in the eight monitoring wells isolate a total of 94 monitoring zones in the Hickory aquifer system that can be sampled for groundwater chemistry. Zhurina (in progress) is determining the hydraulic properties of the system from analyses of quasi-steady state and pump-test hydraulic head data. Thus, this is a uniquely well characterized field site.

Scope:
- Collect groundwater samples from the Westbay multi-level zones in the Hickory aquifer in order to measure spatial and temporal variations of radon. Also collect groundwater samples from water wells and abandoned wells in the study area. This researcher has a good working relationship with landowners in the area. Established and accepted sampling protocols will be used.
- Prepare and analyze samples on-site or at a nearby, temporary field laboratory for radon gas. Rapid analysis of this short-lived radionuclide - half-life of 3.2 days – limits the potential for gas loss due to escape or decay.
- Collect samples both during the major summer (June-Sept.) irrigation season and subsequent recovery interval. This will permit assessment of differing groundwater flow rates on radon concentration, which will provide insight on the role of groundwater dynamics on radon concentration.
- Collect groundwater samples during one or more pump tests for a more controlled assessment of the effect of groundwater dynamics on radon concentration;
- Collect groundwater samples also for analysis of geochemical parameters known to influence dissolved radium concentrations including, but not limited to, pH, dissolved oxygen, carbonate, iron and phosphate;
- Conduct flow-through leaching experiments on stratigraphic intervals of the available rock core for which field data indicate high groundwater radon concentrations. Analyze the leachate for radon gas concentration. Compare the laboratory radon concentrations to measurements collected for the same rock interval in the field. Differences in concentration may be attributed to influences of advection and/or contributions to radon concentration due to decay of dissolved radium in the water versus that solely due to the rock.
- If possible, conduct a gamma spectral analysis of core intervals associated with each multi-level sampling zone in order to measure the relationships of uranium and thorium in the rock cores to the groundwater radon concentrations measured in the lithological zones in the aquifer.
Objectives:

The objectives of this research are to assess the temporal and spatial variations in radon concentrations in an aquifer system known to contain elevated concentrations of radionuclides. The primary objective is to establish a high-resolution data set of radon concentrations, both from field and laboratory measurements, and use that data set to explore relationships between observed radon distributions, aquifer stratigraphy and mineralogy, and groundwater dynamics.

Results Expected from this Project:

This study is expected to reveal temporal and spatial variability in radon gas concentrations in the Hickory aquifer. It is expected that relationships between the radon distributions, aquifer stratigraphy and mineralogy, and groundwater dynamics will be discernable. The data gathered in this study will directly influence plans for additional studies of the geological, hydrological and geochemical reasons for the elevated radionuclide concentrations in the Hickory aquifer. We anticipate requesting funding for future work from the following possible sources: the water conservation districts in charge of the Hickory aquifer, the Texas Commission on Environmental Quality, the Texas Water Development Board, and the U. S. Environmental Protection Agency.
Literature Cited


Zhurina, Elena, on-going, Forward and Inverse Numerical Modeling of Fluid Flow in a Faulted Reservoir: Inference of Spatial Distribution of Fault Transmissibility, [Ph.D. Dissertation], College Station, TX, Texas A&M University.