Abstract:
Naturally occurring methane is found in the fresh groundwater system of northeastern Pennsylvania. However, in certain instances, natural gas drilling in the region has resulted in increased dissolved-phase methane concentrations in water supplies. The mobilization of thermogenic methane in such instances has largely been attributed to substandard gas well construction and operational practices resulting in the vertical and lateral migration of gas associated with Upper to Middle Devonian strata. This research explores how 3D modeling in the Geographic Information Systems (GIS) environment represents an effective tool for exploring the spatial relationship between water well depths and both introduced and natural occurrences of methane in fresh groundwater systems.

Ultimately, by modeling geologic structure, water and gas well construction attributes, and the distribution of shallow gas-bearing units, it is possible to gain insight regarding factors that contribute to both stray gas migration and the distribution of background methane.

Purpose/Background:
Pennsylvania has a long history of oil and gas operations dating back to 1859 with the completion of the Drake Well in Titusville. For most of that history, extraction activities have focused on tight gas and oil-rich wells predominantly located in the western half of the state. With advances in drilling and stimulation techniques, shale-gas plays have become an important part of the domestic energy profile in Pennsylvania. Shale-gas operations have ramped up due to the widespread occurrence of productive intervals of the Marcellus Shale, one of the largest shale gas plays in the world.

Between 2008 and 2010, marked increases in the number of Marcellus Shale wells drilled in the state were observed (Figure 1). This trend was accompanied by an increase in the number of stray gas migration incidents investigated by DEP (Figure 2). Typically, investigations are conducted in response to a water supply complaint (Figure 3). Current DEP regulations require the operator to take a primary role in investigating if it appears to stray gas migration, although the agency does conduct operations allowing for an independent, technical consultant to be drawn to as to whether the reported impact is attributable to local oil and gas operations or a background condition.

Most of the recent stray gas incidents have taken place in the northeastern area of core development and appear associated with Upper to Middle Devonian gas-bearing units not entirely isolated during Marcellus Shale gas well construction.

Prior to Marcellus Shale development, the affected region had not been exposed to much historical oil and gas exploration and production. The area is geologically distinct in that it is a largely glaciated terrain, and was susceptible to ice-push compression. The environment compared to the other area of core Marcellus Shale development in the southwestern corner of the state. Sedimentary facies associated with the gas-bearing units are also generally more porous in character due to the eastern disposition of clastic sources.

As exploration and production activities in the region progressed into more recent years, much effort has been focused on thorough characterization of the shallow subsurface and groundwater sampling. This has revealed, in some cases, that background thermogenic methane concentrations in the fresh groundwater-bearing zone is not entirely unexpected (Figure 4). Such an observation confirms water supply complaint investigations received following the commencement of nearby gas well drilling, oftentimes raising a number of complexities when attempting to differentiate between the background condition and departures from that baseline. Subsurface complexes, multiple potential sources, and the rapid distribution of alleged receptors all require visualization tools to develop a robust site conceptual model.

Method:
The first part of this project involved assembling and tabulating all relevant data. Most of the data are either analog in nature or received in formats that must be modified for the purposes of modeling (Figure 5). Compiling Microsoft Excel summary tables is a useful intermediate step for ensuring consistent formatting that readily translates to the GIS environment.

The second part of the project involved importing the necessary components into the GIS and developing animations. The ArcScene and Spatial Analysis modules of ESRI’s ArcGIS were critical tools for this aspect of model development.

Results/Conclusion:
Visualization of the distributions of gas shows and water wells in three dimensions yields insight with regard to whether or not spatial correlations between the two datasets exist. By assuming that the used-groundwater interval is generally 500 feet of the surface and that the base of the deepest fresh groundwater is found at approximately 1000 feet below the surface, it is possible to summarize gas show magnitudes and occurrence over the fresh groundwater interval. Above and below, it was found that even though the frequency of gas shows is higher over the shallower subsurface in the study area, gas-bearing zones tend to be less prolific based on gas unit measurements. Finally, through radar analysis in the ArcGIS environment, gas show density values were found to be more closely related to the distribution of naturally occurring methane. No compelling spatial correlations were identified.

A site conceptual model (Figure 6) for the stray gas investigation site in northeastern Pennsylvania under study was also constructed in ArcScene. The model is capable of being reoriented spatially to examine various aspects of the case and different feature classes can be activated to better understand the chronology of events that led to the observed water supply impacts. Bedding orientation as well as the presence of drainage associated lineaments appear to be the major natural controls on gas migration at the site. This conclusion was used to identify other potential source wells. Cement jets of lesser quality and operational practices such as chuting in annular spaces were both identified as contributing to the stray gas migration incident. Further, well construction practices, including the installation of external casing packers at relatively shallow intervals with long open-hole intervals below the packer base, also appear to have been a significant causative factor.

Time-series trends with regard to water quality were also visualized to determine if any responses to remedial activities and the application of different operational practices at the site could be identified. Improvements in water quality were noted in response to the implementation of an annular venting program as well as remedial source work and primary cementing operations at select gas wells.

Tools—Including models—that enable users to instantaneously be made between natural and anthropogenic sources of methane in the fresh groundwater system provide an invaluable resource for the remediation of contaminated groundwater supplies and developing hydrostratigraphic resources responsibly, particularly in areas characterized by known concentrations of pre-existing thermogenic methane. Once constructed, models also enable different stakeholders across state and local government to be readily explored in the context of stray gas migration case investigations. Remediation can be achieved by varying model inputs appropriately.

Although the benefits of modeling complex systems are clear, model construction is time consuming. In this case the process was also hindered by the character of the data sources, which were largely analog and required a significant amount of data input time. Sharing the model with stakeholders has proven valuable. It has at least one case prompted an operator to re-examine how they are meeting well pads to ensure better consistency. In all cases, consistent data reporting formats will allow for more efficient model construction. Moreover, better input data will improve the quality of the model and subsequent interpretations.

Sources:
PADEP Field Reports, 2002 and 2011.