United States
Environmental Protection
Agency

November 2013 I www.epa.gov/hfstudy

Summary of the Technical Workshop on Case Studies to Assess Potential Impacts of Hydraulic Fracturing on Drinking Water Resources

July 30, 2013

Disclaimer

This report was prepared by EPA with assistance from Eastern Research Group, Inc., an EPA contractor, as a general record of discussions during the July 30, 2013, technical workshop on case studies to assess potential impacts of hydraulic fracturing on drinking water resources. The workshop was held to inform EPA's *Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*. The report summarizes the presentations and facilitated discussions on the workshop topics and is not intended to reflect a complete record of all discussions. All statements and opinions expressed represent individual views of the invited participants; there was no attempt to reach consensus on any of the technical issues being discussed. Except as noted, none of the statements in the report represent analyses or positions of EPA.

Mention of trade names or commercial products does not constitute endorsement or recommendations for use.

Table of Contents

Technical Workshop on Case Studies to Assess Potential Impacts of Hydraulic Fracturing on Drinking Water Resources
July 30, 2013

US EPA Research Triangle Park Campus
"C" Building Auditorium
Research Triangle Park, North Carolina

Final Agenda

8:00 am **Registration/Check-in**

8:30 am **Welcome and Introductions**........ *Ramona Trovato, US EPA*
Glenn Paulson, Science Advisor, US EPA

8:40 am **Opening Remarks**........ *Ramona Trovato, US EPA*

8:45 am **Brief Overview of EPA's Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources**........ *Jeanne Briskin, US EPA*

8:50 am **Purpose of Workshop**........ *Workshop Co-Chairs:*
Cynthia Sonich-Mullin,
US EPA Timothy Fields,
MDB, Inc.

Session 1: Background Assessment and Characterization

9:00 am ***Panel:***

- **Update on EPA's Retrospective Case Studies**........ *Rick Wilkin, US EPA*
- **Baseline Water Quality Characterization At Four US EPA Restrospective Case Study Areas**...... *Tad Fox, Battelle Memorial Institute*
- **Evaluation of Water Quality Monitoring Programs and Statistical Analysis Tools to be Utilized in Shale Development**........ *Uni Blake, Hometown Energy Group*
- **Surface Water and Stray Gas Shallow Aquifer Contamination**........ *Avner Vengosh, Duke University*
- **Designing a Retrospective Hydraulic Fracturing Case Study**........ *George Lukert, Ecology and Environment, Inc.*

Questions of Clarification

Break (10 minutes)

Facilitated discussion among workshop participants focusing on key questions:

– What are the relative strengths of different approaches to assess background conditions?

– What are practical approaches to overcoming the challenges in developing a representative background assessment and characterization for a case study?

12:45 pm **Summary of Session 1**........ *Workshop Co-Chairs*

1:00 pm **Lunch**

Session 2: Prospective Case Studies

2:00 pm **_Panel:_**

- **Update on EPA's Prospective Case Studies**... *Jeanne Briskin, US EPA*
- **Geophysical Characterization and Borehole Geophysical Logging Tools to Aid Monitoring Well Placement and Completion**.. *Ron Sloto, USGS*
- **Groundwater Monitoring for EPA Prospective Study Site**........................... *Daniel Soeder, NETL*

Questions of Clarification Break (10 minutes)

Facilitated discussion among workshop participants focusing on key questions:

– What types of conditions, tests, monitoring, sampling, and analysis are needed to assess impacts from hydraulic fracturing processes on drinking water in a prospective case study, and why?

– What approaches can be used in situations where historic and/or ongoing industrial practices (e.g., mining, oil, gas, agriculture, etc.) may confound assessment of impacts of hydraulic fracturing processes on drinking water resources?

4:45 pm **Summary of Session 2** .... *Workshop Co-Chairs*

4:50 pm **Closing Remarks**... *Ramona Trovato, US EPA*

5:00 pm **Adjourn**

Technical Workshop on Case Studies to Assess Potential Impacts of Hydraulic Fracturing on Drinking Water Resources July 30, 2013

Attendees List

Greg Appleton
Devon Energy

Sina Arjmand
University of Pittsburgh

Bruce Baizel
Earthworks

Ronald Bishop
SUNY College at Oneonta

Uni Blake *
Hometown Energy Group

John Bolakas
Stantec Consulting Services, Inc.

Jeanne Briskin *
US EPA Office of Research and Development

Barbara Butler
US EPA ORD/National Risk Management Research Laboratory

Craig Cipolla
HESS Corporation

Isabelle Cozzarelli US Geological Survey

Timothy Fields (co-chair)
MDB, Inc.

Robert Ford
US EPA ORD/National Risk Management Research Laboratory

Tad Fox *
Battelle Memorial Institute

Lloyd Hetrick
Newfield Exploration

Christopher Hill
Chesapeake Energy Corporation

Anthony Ingraffea
Cornell University

George King
Apache Corporation

Holly Kneeshaw
New York State Department of Environmental Conservation

Thomas Kropatsch
Wyoming Oil and Gas Conservation Commission

George Lukert *
Ecology and Environment, Inc.

Greg Manuel
Pioneer Natural Resources

Lisa Matthews
US EPA Office of Research and Development

Mike Nickolaus
Ground Water Protection Council

Kathleen Nolan
Catskill Mountainkeeper

*Presenter

Kris Nygaard
ExxonMobil Production Company

Jennifer Orme-Zavaleta
US EPA National Exposure Research Laboratory

Michael Overbay
US EPA Region 6

Glenn Paulson
US EPA, Science Advisor

M. Seth Pelepko
Pennsylvania Department of Environmental Protection

Pete Penoyer
National Park Service

Peter Pope
Railroad Commission of Texas

James Richenderfer
Susquehanna River Basin Commission

John Robinson
Dewberry Engineers, Inc.

David Russell
QEP Resources

Steve Shost
New York State Department of Health

Ron Sloto *
US Geological Survey

Bert Smith
Chesapeake Energy Corporation

Kelly Smith
US EPA ORD/National Risk Management Research Laboratory

Daniel Soeder *
US Department of Energy National Energy Technology Laboratory

Cynthia Sonich-Mullin (co-chair)
US EPA ORD/National Risk Management Research Laboratory

Daniel Stephens
Daniel B. Stephens and Associates, Inc.

Ramona Trovato
US EPA Office of Research and Development

Mindy Vanderford
GSI Environmental, Inc.

Avner Vengosh *
Duke University

Norman Warpinski
Pinnacle - A Halliburton Service

Rick Wilkin *
US EPA/National Risk Management Research Laboratory

Ming Zhu
US Department of Energy

*Presenter

Introduction

At the request of Congress, the U.S. Environmental Protection Agency (EPA) is conducting a study to better understand the potential impacts of hydraulic fracturing on drinking water resources. The scope of the research includes the full cycle of water associated with hydraulic fracturing activities. In the study, each stage of the water cycle is associated with a primary research question:

- **Water acquisition:** What are the possible impacts of large volume water withdrawals from ground and surface waters on drinking water resources?
- **Chemical mixing:** What are the possible impacts of hydraulic fracturing fluid surface spills on or near well pads on drinking water resources?
- **Well injection:** What are the possible impacts of the injection and fracturing process on drinking water resources?
- **Flowback and produced water:** What are the possible impacts of surface spills on or near well pads of flowback and produced water on drinking water resources?
- **Wastewater treatment and waste disposal:** What are the possible impacts of inadequate treatment of hydraulic fracturing wastewaters on drinking water resources?

In 2013, EPA hosted a series of five technical workshops related to its *Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*. The workshops included Analytical Chemical Methods (February 25, 2013), Well Construction/Operation and Subsurface Modeling (April 16–17, 2013), Wastewater Treatment and Related Modeling (April 18, 2013), Water Acquisition Modeling (June 4, 2013), and Case Studies (July 30, 2013). The workshops were intended to inform EPA on subjects integral to enhancing the overall hydraulic fracturing study, increasing collaborative opportunities and identifying additional possible future research areas. Each workshop addressed subject matter directly related to the primary research questions.

For each workshop, EPA invited experts with significant relevant and current technical experience. Each workshop consisted of invited presentations followed by facilitated discussion among all invited experts. Participants were chosen with the goal of maintaining balanced viewpoints from a diverse set of stakeholder groups, including industry; nongovernmental organizations; other federal, state and local governments; tribes; and the academic community.

The Case Studies workshop was co-chaired by Cynthia Sonich-Mullin (EPA) and Timothy Fields (MDB, Inc.). A morning session addressed *Background Assessment and Characterization,* while the afternoon session focused on *Prospective Case Studies*.

Summary of Presentations for Session 1: Background Assessment and Characterization

Susan Hazen, Hazen Consulting and Support Services, opened the workshop. She noted that EPA was looking for individual participants' frank input and opinion and was not trying to reach consensus on the topics; the workshop was not held under the rules of the Federal Advisory Committee Act (FACA). **Dr. Glenn Paulson,** Science Advisor to the EPA Administrator, and **Ramona Trovato,** Associate Assistant Administrator of EPA's Office of Research and Development (ORD), welcomed the participants and thanked them for contributing their knowledge and experience. Ms. Trovato stated that the case studies, which will inform EPA's Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, will be peer reviewed. EPA expects to complete the prospective case studies[1] after its draft report is issued in December 2014. Ms. Trovato noted that EPA did not have conclusions to share at this workshop; the data are undergoing quality assurance and will be posted on the study website.[2]

Workshop Co-Chairs **Cynthia Sonich-Mullin,** Director of EPA's National Risk Management Research Laboratory, and **Timothy Fields** (MDB, Inc.) also welcomed the participants and then described the three goals of the workshop: enhance EPA's study, foster collaboration and inform future research needs.

Jeanne Briskin, Coordinator of Hydraulic Fracturing Research, EPA Office of Research and Development, presented an overview of EPA's drinking water study to provide context for discussion of the case studies. Ms. Briskin noted that the overall goals of EPA's study are to assess whether hydraulic fracturing may impact drinking water resources, and to identify any driving factors that may influence the severity and frequency of any potential impacts. She discussed the primary research questions associated with each stage of the hydraulic fracturing water cycle, the secondary research questions and the associated research activities, including case studies. She presented EPA's timeline for the study, noting that the technical roundtables will reconvene in fall 2013. Ms. Briskin stated that EPA is interested in receiving additional data to inform the study; the deadline for submitting data and scientific literature has been extended to November 15, 2013.

Dr. Richard Wilkin, EPA National Risk Management Research Laboratory, presented an update on EPA's retrospective case studies. The purpose of the case studies is to determine if

[1] **Prospective** case studies involve sites where hydraulic fracturing will be implemented after the research begins, which allows sampling and characterization of the site before, during, and after drilling, injection of the fracturing fluid, flowback, and production. **Retrospective** case studies focus on investigating reported instances of drinking water resource contamination in areas where hydraulic fracturing events have already occurred.

[2] http://www.epa.gov/hfstudy

drinking water contamination has occurred at the study location, and, if so, identify possible sources of contamination. He described the process for identifying and selecting case study locations. EPA considered more than 40 sites and chose five based on a set of criteria outlined in the Study Plan (proximity of population and drinking water supplies, evidence of impaired water quality, health and environmental concerns, and knowledge gaps that the case study could fill). Dr. Wilkin described the characteristics, research focus and progress to date for each of the case studies: Las Animas/Huerfano Counties (Raton Basin), Colorado; Bradford County, Pennsylvania; Washington County, Pennsylvania; Wise County, Texas; and Dunn County (Killdeer), North Dakota. The most recent samples were collected in spring 2013; the next major activities are data analysis, comparison of new data with historical data, temporal and spatial evaluation, geochemical modeling and evaluation, and environmental record searches.

Tad Fox, Battelle Memorial Institute, discussed Battelle's work to characterize baseline water quality at EPA retrospective case study areas—specifically, to characterize historical water quality of springs, ground water wells and surface water sources, and to identify the potential for adverse impacts from land use activities before the beginning of unconventional oil and gas development. Battelle offered this work to help EPA evaluate the site-specific data collected for the retrospective case studies, by helping determine whether those data fall within the observed baseline range and what other potential sources should be considered if a water quality impact is detected. Battelle used readily available water quality data and land use information for this effort. The data characterize water resource quality characteristics at a regional level; data were not available on a smaller scale. Mr. Fox presented summary findings for four case study locations (data for the fifth, Raton Basin, were not available within Battelle's study time frame). He stated that the data show extensive prior industrial and agricultural use within the EPA study areas, and historical background water quality data are absent or limited for some parameters (particularly organic chemicals). For these reasons, Battelle believes that rigorous, site-specific analysis and multiple lines of evidence would be needed to differentiate impacts from pre-existing conditions and impacts from other potential sources of contamination, including hydraulic fracturing.

Uni Blake, Hometown Energy Group, discussed the evaluation of water quality monitoring programs and statistical analysis tools to be used in shale development. She stated that natural spatial variations in the hydrogeology of domestic wells present difficulties when creating a pooled background database for inter-well analysis. She said that current monitoring programs with one pre-sampling data point per well cannot determine prior contamination, provide insufficient data for statistical analysis, and do not take into account variability in parameters or long-term changes that may occur. She provided recommendations for trend monitoring sampling to augment the baseline monitoring program. Recommendations include sampling at ground water wells and surface water locations downgradient from the well pad, monthly data collection two years before and two years after shale activities commence, and the use of statistical methods that can identify non-parametric trends.

Dr. Avner Vengosh, Duke University, discussed surface water and stray gas shallow aquifer contamination. The approach of his study was to define the major geochemical features that characterize ground water and surface water before shale gas development, and link possible water contamination to changes in water chemistry using multiple, novel geochemical and isotopic tracers as proxies for sources and mechanisms of contamination. He stated that looking at exceedances of drinking water parameters as evidence, or lack thereof, of contamination is insufficient. He described two parallel investigations: 1) sampling of surface waters and river sediments downstream from wastewater disposal sites, and evaluation of aquatic geochemistry, isotopes and radionuclides; and 2) for ground water, sampling of shallow private wells and analysis of hydrocarbon, aqueous and noble gas geochemistry. He presented the following conclusions: 1) evidence exists for stray gas contamination in a subset of shallow wells near shale gas wells in northeastern Pennsylvania; 2) in contrast, no evidence exists for methane contamination of shallow ground water in north central Arkansas, indicating a possible role of local geology and/or drilling practices in stray gas contamination; 3) evidence exists for hydraulic connectivity between the Marcellus and shallow aquifers in Pennsylvania, but no evidence has shown direct ground water contamination from produced/flowback water; and 4) in Pennsylvania, evidence exists for surface water contamination from wastewater disposal sites and accumulation of radium in river sediments. Dr. Vengosh recommended a zero-discharge policy for wastewater.

George Lukert, Ecology and Environment, Inc., discussed an approach for evaluating case study data for causal assessment. He presented a decision support system using a tiered approach for analyzing retrospective sites. Tier 1 involves identification of candidate causes of contamination, evaluating these potential causes using a conceptual site model, and analyzing existing data to eliminate candidate causes not related to the potential sources. Tier 2 includes a preliminary screening to determine if candidate causes can be linked to an effect, initial sampling, data evaluation, initial causal analysis and identification of data gaps. Tier 3 includes site-specific studies to fill data gaps and produce valid evidence. Finally, in Tier 4, probable candidate causes are determined and designated as principal or secondary causes, and the data undergo quality assurance evaluation. Mr. Lukert noted that multiple causes may be responsible for the environmental impairment, and studies to determine a unique principal cause may be technically or financially impractical.

Summary of Discussions Following Session 1: Background Assessment and Characterization

Following some clarifying questions, participants were asked to consider the following questions during the discussion:

- What are the relative strengths of different approaches to assess background conditions?
- What are practical approaches to overcoming the challenges in developing a representative background assessment and characterization for a case study?

Key themes from Session 1 discussion:

What data to collect/use in the assessment and characterization

Several participants discussed the importance of understanding site-specific geochemistry as well as gathering background data, and noted that many issues complicate a retrospective analysis (e.g., past hydrocarbon production). Several participants noted the importance of optimizing a conceptual site model to help guide an initial causal analysis at a site. A participant recommended an introductory paragraph in the case studies describing the site-specific geology. A participant noted that there are many things that we do not understand about the shales being studied, such as the origin of brines, or where injected water goes, and the help of industry is key to better understanding these issues.

A participant noted that site characterization is key to identifying appropriate tracers and indicators. Another participant suggested using studies led by researcher Brian Fontenot[3] to identify unique parameters that may be present, but not in high concentrations, and then looking at data for quantitative "cut points," rather than absolute values. She also noted that the presence of parameters not present in the background could be helpful in identifying pathways (e.g., surface release).

A participant said that monitoring should focus on methane, rather than rarely detected fracturing fluid components, and that the borehole, rather than induced fractures, is the main pathway of migration. The participant suggested a focused approach to differentiate surface release and gravity flow.

[3] Fontenot, B.E., Hunt, L.R., Hildenbrand, Z.L., Carlton, D.D., Jr., Oka, H., Walton, J.L., Hopkins, D., Osorio, A., Bjorndal, B., Hu, Q.H., & Schug, K.A. (2013). An evaluation of water quality in private drinking water wells near natural gas extraction sites in the Barnett Shale formation. *Environmental Science & Technology 47*(17), 10032-10040. http://pubs.acs.org/doi/abs/10.1021/es4011724?prevSearch=Fontenot&searchHistoryKey

Several participants stated that it is important to have a monitoring plan with defined objectives, specifying representative locations within an aquifer, sampling frequency and parameters. A participant noted that the industry is growing and needs a long-term monitoring plan.

A participant said that industry does not try to study every detail of every well. He said that oil and gas wells contribute a very small percentage of ground water pollution incidents, and that it is more productive to focus on proven causes of ground water contamination (e.g., gasoline, sewage, animal feedlots). Another participant said that it was important not to minimize the possibility of ground water contamination, citing a May 2013 *Science* article[4] concluding that 1 to 3 percent of new wells show casing failure, which can lead to problems with shallow ground water quality.

Issues regarding background data

Several participants raised potential problems with using background information from databases: sampling may have been targeted at sites with anthropogenic, not background, contamination (industrial site, landfills, salt storage); there may be geology-specific issues (such as elevated radium in the Chickies formation); and sample collection methods and quality may be unknown. A participant stated that anthropogenic sources of contamination should be considered as part of the background. Several participants questioned the value of a retrospective study if the data are not adequate, and stated that more might be learned from the prospective studies. Another participant expressed the view that starting from a known incident is very valuable, and that the challenges in defining background are not unique to hydraulic fracturing, but apply to any environmental investigation.

Several participants noted that guidance for RCRA and CERCLA sites has been available for many years, and asked how collecting data for a hydraulic fracturing retrospective study is different. A participant noted that the guidance documents typically address a specific site (such as a landfill or underground storage tank), while the investigation area for hydraulic fracturing may be much larger. The participant stated that the temporal scale was also different, noting potential temporal variability when studying potential effects of hydraulic fracturing (seasonal variation, use of road salt, etc.).

Several participants noted that, in addition to areal distribution evaluations (i.e., county-wide evaluations), an important approach for background evaluations is to examine aquifer-specific (depth-related) background and water quality trends.

[4] Vidic, R.D., Brantley, S.L., Vandenbossche, J.M., Yoxtheimer, D., & Abad, J.D. (2013). Impact of shale gas development on regional water quality. *Science* 340(6134): 1235009. http://www.sciencemag.org/content/340/6134/1235009.abstract

A participant noted that county- or state-wide background data would not be used for a RCRA or CERCLA study. The participant stated that some of the wells sampled to study potential effects of hydraulic fracturing may be too far away to see impacts; instead, wells without alleged impacts in the same area should be sampled. Another participant expressed the view that background levels can best be established at a regional scale, and that regional data are useful for identifying trends.

A participant clarified that EPA's retrospective case studies do not present background levels for a case study area (i.e., levels present at the sampling locations prior to gas development); rather, they use available historical data to identify a range of levels present in the region around the area, to help determine whether there may be an impact and whether further study is warranted.

Statistical approaches

A participant stated that when data are averaged and pooled, there is a risk of diluting the signal. The participant said that the key is aquifer-based analysis, and that the focus should be on individual cases using a match case-control design (rather than comparing to background).

A participant noted that there are many opportunities to improve statistical analyses, including analyzing geochemistry using principal component analysis and cluster analysis. The participant noted that Stiff diagrams and Piper diagrams could be useful for graphical presentation of data.

Ground water contamination occurrence and exposure

A participant said that public health data could be important for the case studies. She stated that health impacts could be early indicators of water contamination; if these impacts resolve over time after water quality has improved or alternate water provided, that could provide helpful information.

A participant noted that it is not enough to detect a contaminant in ground water: exposure also has to occur, at sufficient quantities, for there to be toxic effects. The participant also stated that exposure to a single chemical is unlikely, so cumulative exposure and exposure to mixtures of multiple contaminants should be considered.

A participant stated that it is important to clearly define "impact" and how it relates to risk. Another participant emphasized the importance of tracing contamination to its source and continuing to provide context to the public (e.g., comparing the risks from hydraulic fracturing to familiar risks).

Practical approaches for overcoming challenges

Individual participants offered a wide range of suggestions for overcoming challenges:

- Involve high-level scientists from the nation's world-class academic institutions to overcome limitations of these studies.
- Work with preliminary results from the U.S. Department of Energy (DOE) National Energy Technology Laboratory studies with tracers identifying some quantitative benchmarks (e.g., levels of ethane or propane).
- Use statistical techniques and other appropriate techniques to analyze geochemistry (e.g., Stiff diagrams, stable isotope evaluation).
- Ensure that both industry and universities make their data available, to the extent possible.
- Instead of relying on information from agency databases, collect distributed samples using approved methods.
- Use a case control design (comparing to uncontaminated wells rather than to background).
- Look at case studies individually to consider how useful the background data might be.
- Use a probability density function with very large, regional data sets collected over a significant period to identify anomalies; then focus on a site if something stands out.
- Because drilling often takes place in sites that are already contaminated, making it difficult to identify causal mechanisms, consider requiring cleanup to a certain level before any hydraulic fracturing activities begin. (Such a policy choice would also have environmental justice implications.)
- Consider modifying the goals of the retrospective studies so they are in line with what the available data can answer.

Summary of Presentations for Session 2: Prospective Case Studies

Jeanne Briskin, EPA, presented an overview of EPA's prospective case study approach. The study goals are to understand how site-specific hydraulic fracturing practices prevent impacts to drinking water resources, and to evaluate any changes in water quality over time. Ms. Briskin presented examples of environmental management practices by well operators throughout the life cycle of a production well (site selection, baseline monitoring, pad installation/well drilling and completion, hydraulic fracturing and flowback management, and oil/gas production) and case study research goals and implementation tasks at each stage of well development and operation. She noted that collaboration among partners (e.g., EPA, DOE, U.S. Geological Survey [USGS], well owners/operators, state agencies, landowners) is important for case study design, implementation and interpretation. She stated that water quality monitoring for the case studies is expected to involve both use of pre-existing monitoring points and installation of additional targeted monitoring wells. At a minimum, one year would be required for baseline sampling and one year or more for post-fracture sampling. Ms. Briskin described potential technical challenges in the case studies (such as existing or legacy fossil fuel extraction or other land use, site-specific aquifer properties) and implementation challenges (e.g., access to the well pad, alignment of research and commercial timelines).

Ron Sloto, USGS, discussed geophysical characterization and borehole geophysical tools to aid monitoring well placement and completion. He defined borehole geophysics as the collection of geologic and hydrologic information in wells by lowering and raising probes on a wire. He said that much more can be learned by analyzing a suite of geophysical logs as a group than by analyzing the same logs individually. For new wells, borehole geophysics can be used to determine where to set the well screen, aquifer characteristics, and hydraulic connections between monitoring wells. For existing wells, it can be used to obtain information on well construction characteristics, aquifer hydraulic characteristics, and water quality. Mr. Sloto described each of the standard borehole geophysics logs: caliper, gamma, single-point resistance, fluid temperature, fluid resistivity, heat pulse flowmeter, borehole television and acoustic televiewer. He also described the use of a wire-line sampler to capture borehole fluid from a discrete depth, and the use of aquifer-isolation tests to define hydraulic and chemical characteristics of discrete water-bearing fractures in a borehole. Finally, he presented an example of how analysis of a suite of borehole geophysical logs helped identify the source of trichloroethylene in two water supply wells in Montgomery County, Pennsylvania.

Daniel Soeder, DOE National Energy Technology Laboratory, discussed ground water monitoring for an EPA prospective case study site. He stated that ground water monitoring is needed because drilling through shallow aquifers and hydraulic fracture pressure pulses can affect ground water, and data are needed on stray gas mobilization, fluid infiltration and water quality effects. Surface leaks and spills, he said, are the primary risk to ground water from shale gas operations. He discussed ground water risks during each phase of production (initial spud-in through long-term gas production), noting that the risks are highly phase- and time-dependent. He then described plans for ground water monitoring at a prospective case study site (once a site is identified). Three monitoring wells would be installed off the pad, one up-gradient and two or three down-gradient. Mr. Soeder described the well design standards that would be met and the drilling procedures that would be followed. Sampling would use a multilevel insert in the well to collect ground water from various depths to characterize the aquifer. Next steps would include identifying an industry cooperator and landowners who would allow placement of the wells in the vicinity of the shale gas well site; decision-making by the DOE-EPA-USGS team about well locations, depth, aquifer zones and water sampling; and contact with other shale gas drillers in other areas for similar access, for comparison studies.

Summary of Discussions Following Session 2: Prospective Case Studies

Following clarifying questions, participants were asked to consider the following questions during the discussion:

- What types of conditions, tests, monitoring, sampling and analysis are needed to assess impacts from hydraulic fracturing processes on drinking water in a prospective case study, and why?
- What approaches can be used in situations where historical and/or ongoing industrial practices (e.g., mining, oil, gas, agriculture, etc.) may confound assessment of impacts of hydraulic fracturing processes on drinking water resources?

Key themes from Session 2 discussion:

A participant recommended selecting sites for the prospective case studies where the geology is well characterized. He suggested two sites in the Marcellus formation.

A participant recommended refining the objectives of the case studies to better select and design the measurement system (e.g., what is the next level after measurement of ground water contamination—methane migration, fracturing fluid, etc.?). An EPA participant noted that EPA intends to clarify objectives once the specific sites for the case studies are located.

Another participant noted that most immediate impacts (within one year) are from stray gas migration; a longer-term study would add value. The participant suggested studying how hydraulic fracturing might affect the ability of production string cement to maintain zonal isolation, and also suggested monitoring for more subtle changes in dissolved methane at water supplies over the longer term.

A participant stated that ground water is important, but he questioned the lack of attention to impacts to surface water from wastewater disposal. An EPA participant stated that Congress asked EPA to look at drinking water resources; EPA's National Pollutant Discharge Elimination System permit program is working on effluent limits for disposal, but the issue of disposal of wastewaters into surface water is beyond the scope of the drinking water study (Chapter 13 of the study plan,[5] she noted, discusses this and other research needs). Another participant stated that returning produced water to surface water is a regional, not a national, issue.

A participant stated that much of the discussion about the prospective studies could inform the retrospective studies, and vice versa. She encouraged EPA to look for rich data about

[5] http://www2.epa.gov/sites/production/files/documents/hf_study_plan_110211_final_508.pdf

hydrogeology (e.g., understanding how a pressure wave could cause high total dissolved solids in a homeowner's well).

A participant raised the idea of horizontal monitoring wells. Another participant stated that horizontal wells are typically used in the shallow subsurface for remediation technology, but could be used for monitoring. Several participants described the use of tool stabilizers and ways to pull the logging tool to the end of the well.

A participant stated his view that having an onsite monitor should be a condition for establishing effective monitoring. Another participant disagreed, stating that operators work with regard for public safety and the environment, and their license to operate is contingent on following rules and reporting.

A participant described the Interagency Steering Committee on Multimedia Environmental Modeling (ISCMEM), which has six working groups: 1) software systems design and implementation for environmental modeling, 2) uncertainty analysis and parameter estimation, 3) subsurface reactive solute transport modeling, 4) distributed watershed/water quality modeling, 5) environmental forecasting (ecosystem services), and 6) integrated monitoring and modeling. He noted that the ISCMEM's work to advance environmental modeling could be useful for the case study effort.

A participant stated that sampling for microbial indicators could be considered.

Another participant said that conceptual model building for the prospective studies, using lessons from the retrospective studies, is very important and will increase the chances that the case studies will yield useful information.

Concluding Remarks

Ms. Trovato and Dr. Glenn Paulson, EPA, thanked the participants for attending and sharing their knowledge and experience. Ms. Trovato reminded the participants that once the technical workshops are completed, the technical roundtables will be reconvened to further inform the drinking water study. She noted that the cooperation represented in these workshops will help advance the nation's economy, jobs, the environment, health and drinking water resources. She stated that other nations are watching to understand how best to conduct hydraulic fracturing, so this effort will benefit the world.

Appendix A.

Extended Abstracts from Session 1: Background Assessment and Characterization

Update on EPA's Retrospective Case Studies

Richard Wilkin
United States Environmental Protection Agency
Office of Research and Development

Information presented in this abstract is part of the EPA's ongoing study. EPA intends to use this, combined with other information, to inform its assessment of the potential impacts to drinking water resources from hydraulic fracturing. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Introduction

As part of the United States Environmental Protection Agency's (EPA) study on the potential impacts of hydraulic fracturing on drinking water resources, scientists are conducting case studies at different locations throughout the United States. The purpose of conducting retrospective case studies is to investigate if drinking water contamination has occurred at the case study locations and, if so, to investigate possible sources of contamination.

EPA's scientific approach to these case studies leverages over 30 years of experience identifying potential sources and pathways of contamination at sites with limited background information. Case studies are widely used to conduct in-depth investigations of complex topics and provide a systematic framework for investigating relationships among relevant factors. In conjunction with other elements of the research program, they help determine if hydraulic fracturing can impact drinking water resources and, if so, the extent and possible causes of any impacts. Case studies may also provide opportunities to assess the fate and transport of fluids and contaminants in different regions and geologic settings. Depending on the findings, results from the case studies may help answer the secondary research questions listed in Table 1.

Table 1. Secondary research questions addressed by conducting case studies.

Water Cycle Stage	Applicable Secondary Research Questions
Chemical mixing	• If spills occur, how might hydraulic fracturing chemical additives contaminate drinking water resources?
Well injection	• How effective are current well construction practices at containing gases and fluids before, during, and after hydraulic fracturing? • Can subsurface migration of fluids or gases to drinking water resources occur, and what local geologic or man-made features might allow this?
Flowback and produced water	• If spills occur, how might hydraulic fracturing wastewaters contaminate drinking water resources?

Two types of case studies are being conducted as part of this study. Retrospective case studies focus on investigating reported instances of drinking water resource contamination in areas where hydraulic fracturing events have already occurred. Prospective case studies involve sites where hydraulic fracturing would be implemented after the research begins, to allow sampling and characterization of the site before, during, and after drilling, injection of the fracturing fluid, flowback, and production. This presentation will focus on the progress of retrospective case studies only.

Selection of Case Study Locations

To select the retrospective case study sites, the EPA invited stakeholders from across the country to participate in the identification of locations for potential case studies through informational public meetings and the submission of electronic or written comments. Following thousands of comments, over 40 locations were nominated for inclusion in the study. These locations were prioritized and chosen based on a rigorous set of criteria, including proximity of population and drinking water supplies, evidence of impaired water quality, health and environmental concerns, and knowledge gaps that could be filled by a case study at each potential location. Sites were prioritized based on geographic and geologic diversity, population at risk, geologic and hydrologic features, characteristics of water resources, and land use (US EPA, 2011).

Five retrospective case study locations were ultimately chosen for inclusion in this study and are shown in Figure 1.

1. **Southwest Pennsylvania:** Washington County
2. **Wise County,** Texas
3. **Raton Basin:** Las Animas and Huerfano counties, Colorado
4. **Northeast Pennsylvania:** Bradford County
5. **Killdeer:** Dunn County, North Dakota

The status of these studies is documented in the EPA's "*Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources Progress Report*" (EPA 2012).

General Research Approach

Each retrospective case study differs in geologic and hydrologic characteristics, hydraulic fracturing techniques, and the oil and gas exploration and production history of the area. However, the overall study approach used to assess potential drinking water impacts was applied to all of the study sites. By coordinating the case study approach and chemical analyses, it will be possible to compare the results of each study.

EPA developed a Quality Assurance Project Plan (QAPP) for each retrospective case that describes the detailed plan for the research at that location. The QAPP integrates the technical and quality aspects of the case study in order to provide a guide for obtaining the type and quality of environmental data required for the research. Before each new tier of sampling begins, the QAPPs are revised to include any additional work. QAPPs also revised if the approach needs to be revised within a tier.

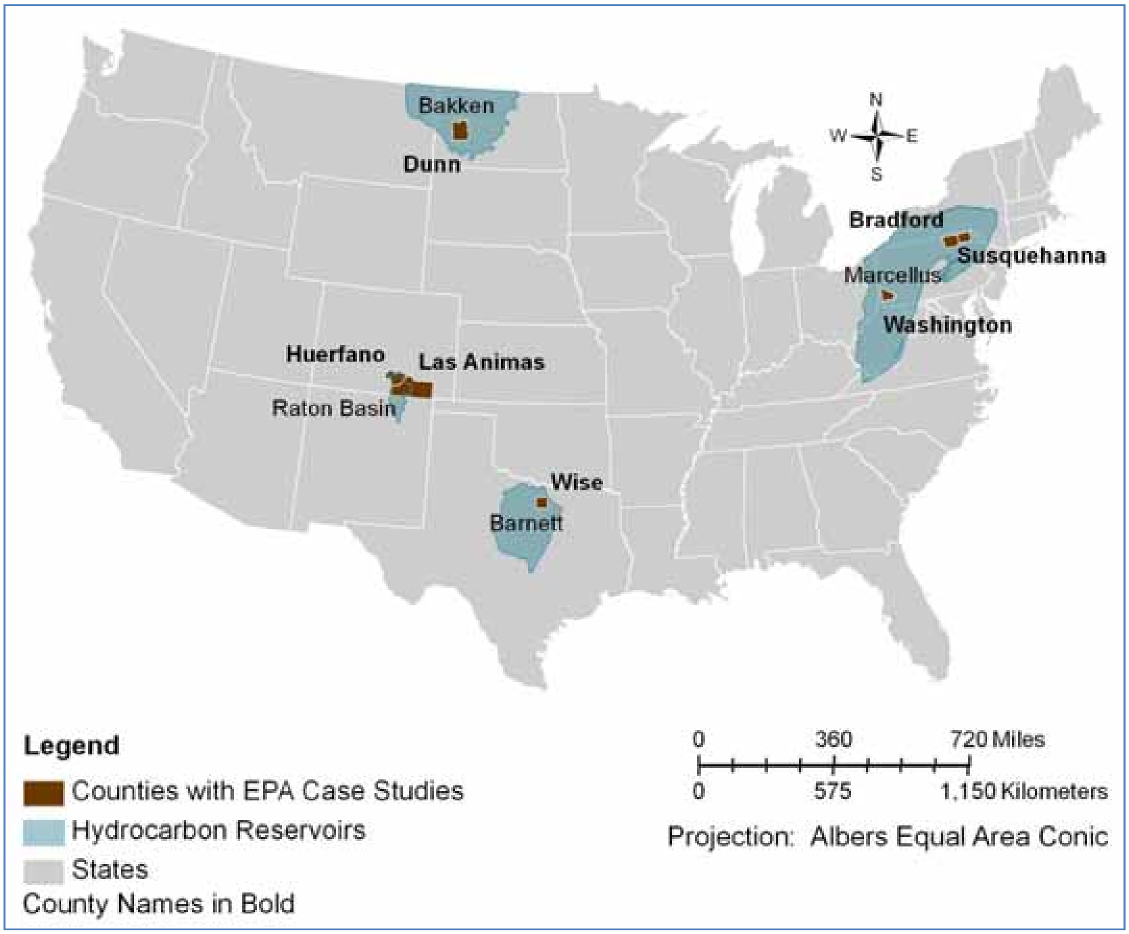

Figure 1. Locations of the five retrospective case studies chosen for inclusion in the EPA's Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources.

Ground water samples have been collected at all retrospective case study locations. The samples come from a variety of available sources, such as existing monitoring wells, domestic and municipal water wells, production wells, and springs. Surface water, if present, has also been sampled. During sample collection, the following water quality parameters were monitored and recorded:

- Temperature
- pH
- TDS
- Specific conductance
- Alkalinity
- Turbidity
- Dissolved oxygen
- Oxidation/reduction potential
- Ferrous iron
- Hydrogen sulfide

Each water sample has been analyzed for a suite of chemicals. Groups of analytes and examples of specific chemicals of interest are listed in Table 2. These chemicals include major anions, reported components of hydraulic fracturing fluids (e.g., glycols), and potentially mobilized naturally occurring substances (e.g., metals); these chemicals are thought to be present frequently in hydraulic fracturing fluids or wastewater. As indicated in Table 2, stable isotope analyses are also being conducted. Stable isotope ratios can provide information about biogeochemical processes that impact the behavior of certain elements in the environment.

Table 2. Analyte groupings and examples of chemicals measured in water samples collected at the retrospective case study locations.

Analyte Groups	Examples
Anions	Bromide, chloride, sulfate
Carbon group	Dissolved organic carbon, dissolved inorganic carbon†
Dissolved gases	Methane, ethane, propane
Extractable petroleum hydrocarbons	Gasoline range organics,§ diesel range organics‡
Glycols	Diethylene glycol, triethylene glycol, tetraethylene glycol
Isotopes	Isotopes of oxygen and hydrogen in water, carbon and hydrogen in methane, strontium
Low molecular weight acids	Formate, acetate, butyrate
Measures of radioactivity	Radium, gross α, gross β
Metals	Arsenic, manganese, iron
Semivolatile organic compounds	Benzoic acid; 1,2,4-trichlorobenzene; 4-nitrophenol
Surfactants	Octylphenol ethoxylate, nonylphenol
Volatile organic compounds	Benzene, toluene, styrene

† Dissolved inorganic carbon is the sum of the carbonate species (e.g., carbonate, bicarbonate) dissolved in water.
§ Gasoline range organics include hydrocarbon molecules containing 5–12 carbon atoms.
‡ Diesel range organics include hydrocarbon molecules containing 15–18 carbon atoms.

Case Study Summaries

EPA has collected water samples from five retrospective case study locations (Colorado, North Dakota, Pennsylvania, and Texas) during Tier 2 of the study. Samples were collected during multiple sampling trips beginning in fall 2010 and ending in spring 2013. Water samples have been collected from domestic water wells, monitoring wells, and surface water sources, among others.

Las Animas & Huerfano Counties, Colorado – Raton Basin

Through the stakeholder process, concerns about local drinking water have been reported in areas located within the Raton Basin. After evaluating the sites, the EPA determined that several areas within the Raton Basin would be good candidates for the study. In the Raton Basin, several areas in Las Animas County and Huerfano County were targeted for ground water and surface water sampling several geographic locations. The hydraulic fracturing in this area is focused on recovering coal bed methane from the Raton Basin.

The case study focuses on two areas: "North Fork Ranch" in Las Animas County and "Little Creek" in Huerfano County. Study sites were selected in response to ongoing complaints about changes in appearance, odor, and taste associated with drinking water in domestic wells. Samples were collected from domestic wells, production wells, monitoring wells, and surface water (streams) from Las Animas and Huerfano counties. The following is a summary of each event:

- **Round 1 (October 2011 sampling event) –** Samples were collected from 12 domestic wells, two production wells, five monitoring wells, and one surface water location.
- **Round 2 (May 2012 sampling event) –** Samples were collected from 12 domestic wells, two production wells, three monitoring wells, and three surface water locations.
- **Round 3 (November 2012 sampling event) –** Similar locations from Round 2 were sampled and the same analytes were tested.
- **Round 4 (May 2013 sampling event) –** Similar locations from Round 3 were sampled and the same analytes were tested.

Bradford County, PA

Northeast PA (NE PA) was selected as a case study site because it is an area of extensive hydraulic fracturing activity, and has received considerable media attention due to citizen concerns over the potential impacts to drinking water resources. The locations were selected due to the large number of homeowner complaints about changes in water appearance (turbidity and bubbling) and odor; reported surface water contamination; and reported methane contamination of multiple drinking water wells. Hydraulic fracturing in this area focuses on recovering natural gas from the Marcellus Shale.

In NE PA, several areas in Bradford County and Susquehanna County were targeted for ground water/surface water sampling. Initial sampling locations were selected during a reconnaissance trip to the area conducted in August 2011. Water samples were collected for analysis from different locations within the two counties, during three rounds of sampling events. The following is a summary of each event:

- **Round 1 (October/November 2011 sampling event) –** Only four water samples were collected in Susquehanna County from three homeowner locations. In Bradford County, water samples were collected from 30 domestic wells and two springs.
- **Round 2 (April/May 2012 sampling event) –** In Bradford County, samples were collected from 22 domestic wells, one spring, one pond (two samples), and one stream (two samples).
- **Round 3 (May 2013 sampling event) –** Some of the locations sampled in Round 1 but excluded in Round 2 were sampled again.

Washington County, PA

Sampling locations in Washington County, PA were based primarily on homeowner concerns/complaints regarding potential impacts to their well water following drilling or hydraulic fracturing activities in the vicinity of their homes. After evaluating the sites, the EPA determined that several of the homes within the county would be good candidates for the study. Several areas in Washington County were targeted for ground water/surface water sampling, including Amwell, Mount Pleasant, and Hopewell townships. These were divided into two areas: Northern Area and Southern Area. Hydraulic fracturing activities in these areas are focused on recovering natural gas from the Marcellus Shale.

In the Northern Area, homeowner complaints alleged recent changes in water quality, including turbidity, stains, and odors, associated with the drinking water in their homes. In the Southern Area, homeowner complaints included concerns over the collection/storage of flowback and other water in an impoundment and cuttings in a reserve pit on a nearby well pad.

The domestic well and surface water samples were collected from the Northern and Southern case study areas. The following is a summary of each event:

- **Round 1 (July 2011 sampling event)** – Water samples were collected from thirteen domestic wells/springs and three surface water locations.
- **Round 2 (March 2012 sampling event)** – Water samples were collected from 13 domestic wells/springs and two surface water locations.
- **Round 3 (May 2013 sampling event)** – Water samples were collected from 13 domestic wells/springs and two surface water locations.

Wise County, TX

Through the stakeholder process, concerns about local drinking water have been reported in three distinct locations within Wise County, TX. After evaluating the sites, the EPA determined that several of the homes within the county would be good candidates for the study.

The reported drinking water concerns are clustered in three distinct locations within Wise County: (1) Location A, approximately 10 miles east of Decatur (2) Location B, approximately 4 miles southwest of Decatur, and (3) Location C, approximately 6 miles northeast of Alvord. Each area was selected in response to homeowner complaints about changes in water quality following hydraulic fracturing activities in the vicinity of their homes. The hydraulic fracturing in this area is focused on recovering natural gas from the Barnett Shale.

- In Location A, homeowner complaints included changes in the smell and taste of the drinking water in their homes.
- In Location B, homeowner complaints included increased saltiness of drinking water.
- In Location C, homeowner complaints included changes in the smell of the drinking water in their homes.

The water samples from domestic wells, industrial wells, and surface water were collected for analysis from the three locations within the Wise County site. The following is a summary of each event:

- **Round 1 (September 2011 sampling event) –** Water samples were collected from four domestic wells and three surface water locations in Location A; five domestic wells and one industrial well in Location B; and two domestic wells in Location C.
- **Round 2 (March 2012 sampling event) –** Water samples were collected from three domestic wells and three surface water locations in Location A; ten domestic wells and one industrial well were sampled in Location B; and two domestic wells were sampled in Location C. EPA was not granted access to one domestic well during the March 2012 sampling event in Location A.
- **Round 3 (September 2012 sampling event) –** This was a limited sampling event in which two domestic wells were sampled along with the produced water from an adjacent gas well in Location B.
- **Round 4 (December 2012 sampling event) –** Water samples were collected from ten domestic wells in location B, as well as a pond adjacent to a gas production well and its abandoned impoundment. The industrial well was not be sampled during this sampling event due to access not being given by the owner.
- **Round 5 (May 2013 sampling event) –** Water samples were collected from eight domestic wells, one surface water location, and two production wells.

Dunn County, (Killdeer), ND

The Killdeer site in Dunn County differs from the other retrospective case studies because the source of potential contamination to drinking water is known. The EPA determined that the Dunn County was a good candidate for an investigation because of an accidental release of hydraulic fracturing fluids and flowback water that occurred during the hydraulic fracturing of a well. The North Dakota Industrial Commission's Oil and Gas Division and the North Dakota Department of Health's Division of Water Quality invited EPA to use the City of Killdeer as the case study location. The hydraulic fracturing in this area is focused on recovering oil from the Bakken Shale.

In September 2010, a blowout occurred in the Franchuk well when Denbury Resources was hydraulically fracturing a well in Dunn County, North Dakota. This resulted in an accidental release of hydraulic fracturing fluids, oil and flowback water, prompting a state action which led to the installation of monitoring wells, removal of contaminated soil, and installation of a liner. The release occurred when an inner string of casing burst due to the accidental over pressurization that occurred during hydraulic fracturing. Two possible pathways for contamination are being investigated: direct release from the wellbore into the aquifer and indirect contamination from fluid on the surface infiltrating the aquifer.

Water samples from monitoring wells, domestic wells, supply wells, and municipal wells were collected for analysis from different locations within the Killdeer site. The following is a summary of each event:

- **Round 1 (July 2011 Sampling Event) –** Water samples were collected from nine monitoring wells located on the well pad, one municipal water supply well, two water depot wells, one state observation well, and three domestic wells.
- **Round 2 (October 2011 Sampling Event) –** Water samples were collected from the same wells that were sampled in Round 1.
- **Round 3 (October 2012 Sampling Event) –** Water samples were collected from some of the same wells that were sampled in Rounds 1 and 2: the nine monitoring wells and the state observation well.

Next Steps

A large quantity of analytical data has been collected from the five retrospective case studies. The next major activity for the retrospective case studies will be analysis of these data. Data evaluation will consist of statistics, comparison with existing data (background, land-use, etc.), temporal and spatial evaluation, geochemical modeling & evaluation, and environmental record searches.

References

United States Environmental Protection Agency (EPA) (2011) Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources. Office of Research and Development. EPA/600/R-11/122.

United States Environmental Protection Agency (EPA) (2012) Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources. Progress Report. Office of Research and Development. December 2012.

Baseline Water Quality Characterization at Four EPA Retrospective Case Study Areas

Tad Fox[1], Andrew Barton[1], Alan Tilstone[1] and Bernhard Metzger[1],
[1]Battelle Memorial Institute

The statements made during the workshop do not represent the views or opinions of EPA. The claims made by participants have not been verified or endorsed by EPA

Introduction

The process of injecting fluids into the subsurface under high pressure to fracture oil and gas bearing formations and enhance the recovery of hydrocarbons has been in use in the US since 1948. Although early application of hydraulic fracturing were typically on vertical wells with a single "stage", recent advances in drilling techniques have allowed for deeper exploration and directional drilling, making recovery of oil and gas from unconventional tight formations possible through horizontal wells and multiple sequential "stage" completion activities within a single well.

EPA has initiated five retrospective case studies as part of the Agency's evaluation of the potential relationship between hydraulic fracturing of unconventional oil and gas formations and drinking water (USEPA, 2011). The EPA retrospective case studies focus on locations with claims of possible drinking water impact within proximity to hydraulic fracturing operations and one location where a casing failure occurred during well stimulation. EPA is investigating the potential presence and extent of drinking water resource contamination and whether hydraulic fracturing caused or contributed to the alleged contamination. In addition, the Agency intends these case studies to provide information to determine the extent to which conclusions on the impact of hydraulic fracturing can be generalized on local, regional and national scales. EPA has stated the agency selected the retrospective case study sites to be representative of the types of concerns that have been reported during stakeholder meetings. The five areas EPA selected are:

- Marcellus Shale, Washington County, Pennsylvania
- Barnett Shale, Wise-Denton Counties, Texas
- Bakken Shale, Dunn County, North Dakota
- Marcellus Shale, Bradford-Susquehanna Counties, Pennsylvania
- Raton Basin, Colorado

As part of these retrospective studies, EPA is collecting and analyzing water samples for a wide range (between 188 and 237 different parameters) of water quality parameters in accordance with a Quality Assurance Project Plan (QAPP) that EPA has prepared for each case study location.

The American Petroleum Institute (API) and America's Natural Gas Alliance (ANGA) requested Battelle to perform initial site characterizations for the retrospective case study areas. Battelle had previously identified the lack of baseline or background water quality prior to unconventional resource development as a data gap (Battelle 2012). To address this data gap, research on baseline regional water resource quality characteristics was conducted using readily available historical data to serve as a comparison with the results to be generated by EPA and industry for each retrospective case study area. Background or baseline water quality is defined in this study as water quality in a defined area prior to development of unconventional oil and gas resources through directional drilling and hydraulic fracturing. An initial characterization of regional baseline water quality conditions has been developed for all but the Raton Basin retrospective case study area (Battelle 2013). The Raton Basin was not included because a large body of data and information exists that was not readily accessible within the timeframe of the Battelle study.

Technical Approach

The primary objectives of the work performed by Battelle for each study area were to characterize historical water quality of springs, groundwater wells and surface water sources, and to highlight the potential for adverse impacts that resulted from previous land use activities prior to the onset of unconventional oil and gas development. The resulting characterization is intended to assist in evaluating the site specific data collected by EPA's retrospective case study program, help determine whether these water quality data fall within the observed baseline range and assist in the identification of other potential sources for consideration in the event of a detected water quality impact. Battelle accomplished these objectives by:

- Defining the spatial and temporal boundaries and attributes of each study area.
- Identifying land use, known potential sources of contamination and water quality data that could be used to provide historical context for characterizing water resources, along with identifying associated analytical parameters that could be used to evaluate potential impact on drinking water resources.
- Developing a list of available analytes and water quality parameters monitored in the study area and comparing them to EPA QAPP requirements.
- Developing and applying quality assurance (QA) criteria to assess the quality of the historical water quality data.
- Conducting summary statistical analyses on the water quality data and comparing the results to relevant state and federal water quality screening criteria. (A value above water quality criteria may simply reflect natural conditions and was not interpreted as indicative of an impact. In order to assess whether an impact occurred, or corrective action is suggested, a thorough investigation would have to be performed which is beyond the scope of this desktop study.)

Battelle utilized EPA's data quality objective (DQO) process to help ensure that an appropriate type and quantity of pre-existing data needed to meet the primary objective were collected (EPA, 2006). For the purpose of this study, a minimum of eight unique sample locations were required to constitute a representative sample for a specific parameter. Water quality data sources included the United States Geologic Survey (USGS) (i.e., National Uranium Resource Evaluation [NURE], National Water Information System [NWIS]), state agencies, and EPA STOrage and RETrieval Data Warehouse. (STORET)

The parameters available for incorporation into the Battelle water-quality databases are limited primarily to general inorganic water quality parameters, major ions, metals and nutrients. For many of the other parameters on the EPA retrospective case study analytical list (e.g., organic parameters) there are insufficient available data to adequately characterize baseline water quality and permit statistical comparisons against site specific data as indicated in Table 1. Methane is commonly detected in the environment (COGCC, 2003; Molofsky et al., 2011; EPA 2012; Weston 2012), although pre-oil and gas development data for methane were not available from the data sources used by Battelle to develop the baseline water quality characteristics.

Table 1. Number of parameters included in EPA study and number of parameters in groundwater, spring and surface water with results from at least eight locations for each retrospective study area

Location	Date[1]	No. of EPA Parameters	Baseline Groundwater Parameters	Baseline Spring Parameters	Baseline Surface Water Parameters
Washington County, PA	2005	196	29	11	21
Bradford/Susquehanna Counties, PA	2007	192	29	11	23
Wise and Denton Counties, TX	1998	188	71[2]	0	24
Dunn County, ND	2005	237	27	16	28

[1]Cut off date for data inclusion (for example, data prior to 2005 were included for Washington County, PA)
[2]Includes 28 organic and 2 inorganic constituents where all results were non-detect.

Because water quality data from the EPA STOrage and RETrieval Data Warehouse (STORET) database is associated with environmental impact monitoring that could potentially skew baseline water quality results, separate evaluations were performed using the complete water quality dataset and a dataset excluding the EPA STORET data.

Results

Water quality data were evaluated by Battelle for the timeframe prior to unconventional oil and gas development via directional drilling and hydraulic fracturing. The water quality data acquired provide an observed range in parameter concentrations prior to the onset of unconventional oil and gas development in each study area.

Sampling locations where groundwater and surface water quality parameters in the database were found to be higher than applicable federal and state water quality standards, criteria and guidance values are shown in Figures 1 through 4. At many sampling locations, the available data indicate pre-unconventional oil and gas development water quality does not meet federal and state water quality standards, criteria or guidance values for several inorganic parameters including pH, total dissolved solids (TDS), chloride, fluoride, sulfate, aluminum, arsenic, barium, beryllium, boron, cobalt, copper, nickel, chromium, manganese, mercury, iron, lead, nitrate, phosphorus, sodium, strontium, turbidity, uranium, vanadium and zinc among others. Insufficient data are available on organic chemical constituents to allow comparison with federal and state water-quality standards.

As reflected in the information acquired by Battelle, natural variability (e.g., spatial and temporal changes and aquifer composition), land use patterns and other anthropogenic factors can affect water quality. Historical activities such as agriculture, mining, steel production, manufacturing, conventional oil and gas extraction, urban runoff, road salts and sewer overflows are known to have impaired streams, rivers and groundwater in many cases. All know potential sources of contamination should be considered as part of the evaluation of data from retrospective case study areas. An array of government programs are in place to regulate oil and gas extraction industrial activities and protect the environment. No instances of adverse impact to water resources caused by injecting hydraulic fracturing fluids into the subsurface have been documented in two recent studies in Pennsylvania and Texas (GWPC, 2011; MSAC, 2011).

Each detailed report characterizes conditions based upon readily available information on land use, known surface water impairments and water quality data from the USGS, EPA, state and local sources. The regional characterization can be used to compare EPA or industry-obtained water quality data at each retrospective case study location.

Conclusions

The initial baseline water quality characterization developed for this study provides a summary of the range and distribution of results for a number of general water quality and inorganic parameters at each study area. This information permits comparison of more recent data collected by EPA and industry within the context of observed water quality prior to unconventional oil and gas resource development. Conclusively determining whether a relationship exists between hydraulic fracturing and drinking water resources will be challenging given the large number of sampling locations in each region where baseline water quality does not meet federal and state water quality standards, criteria or guidance values for some inorganic parameters, and the lack of organic chemical data to characterize background water quality conditions. However, the available area specific historical water-quality data, land use information, and the application of sound hydrogeochemical principles can and should be used to inform EPA's research. Observations of impaired water quality would require rigorous scientific, site-specific analysis to differentiate impacts from pre-existing conditions and impacts due to other potential sources of contamination, including activities associated with hydraulic fracturing operations.

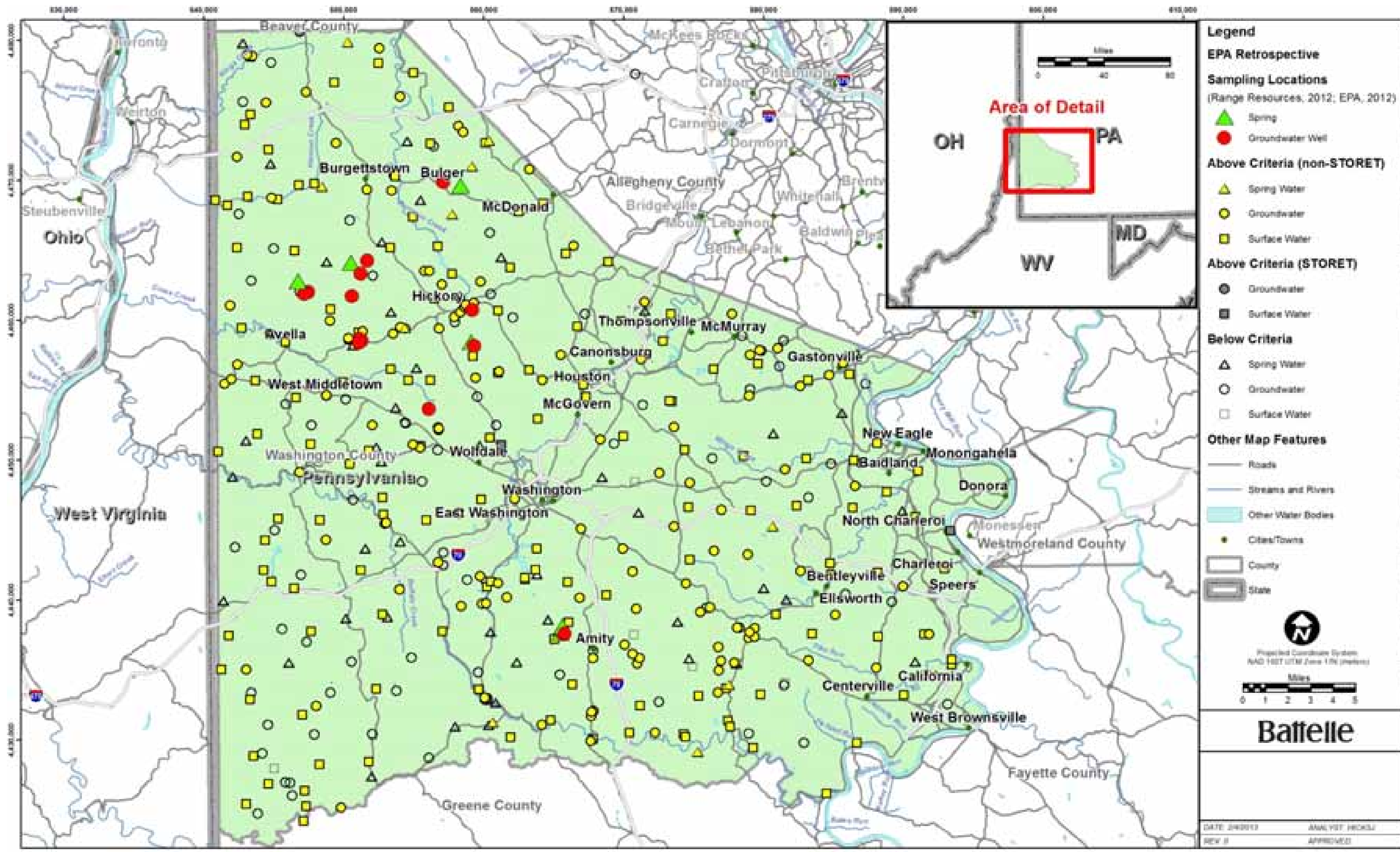

Figure 1. Locations where at least one parameter was detected in groundwater (water wells), spring water, or surface water above one or more screening criteria in Washington County

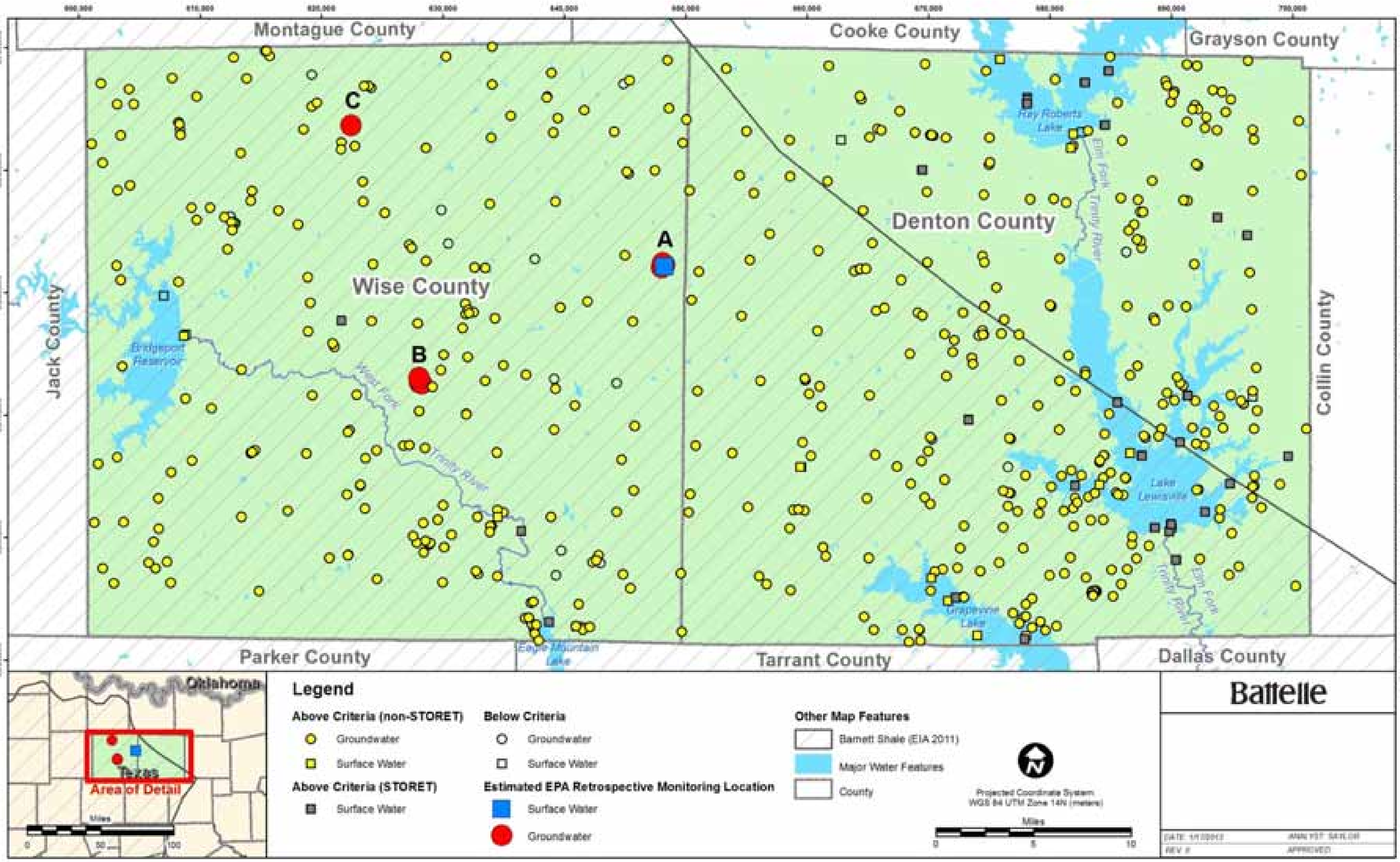

Figure 2. Locations where at least one parameter was detected above one or more screening criteria from groundwater (water wells) or surface water in Wise and Denton Counties

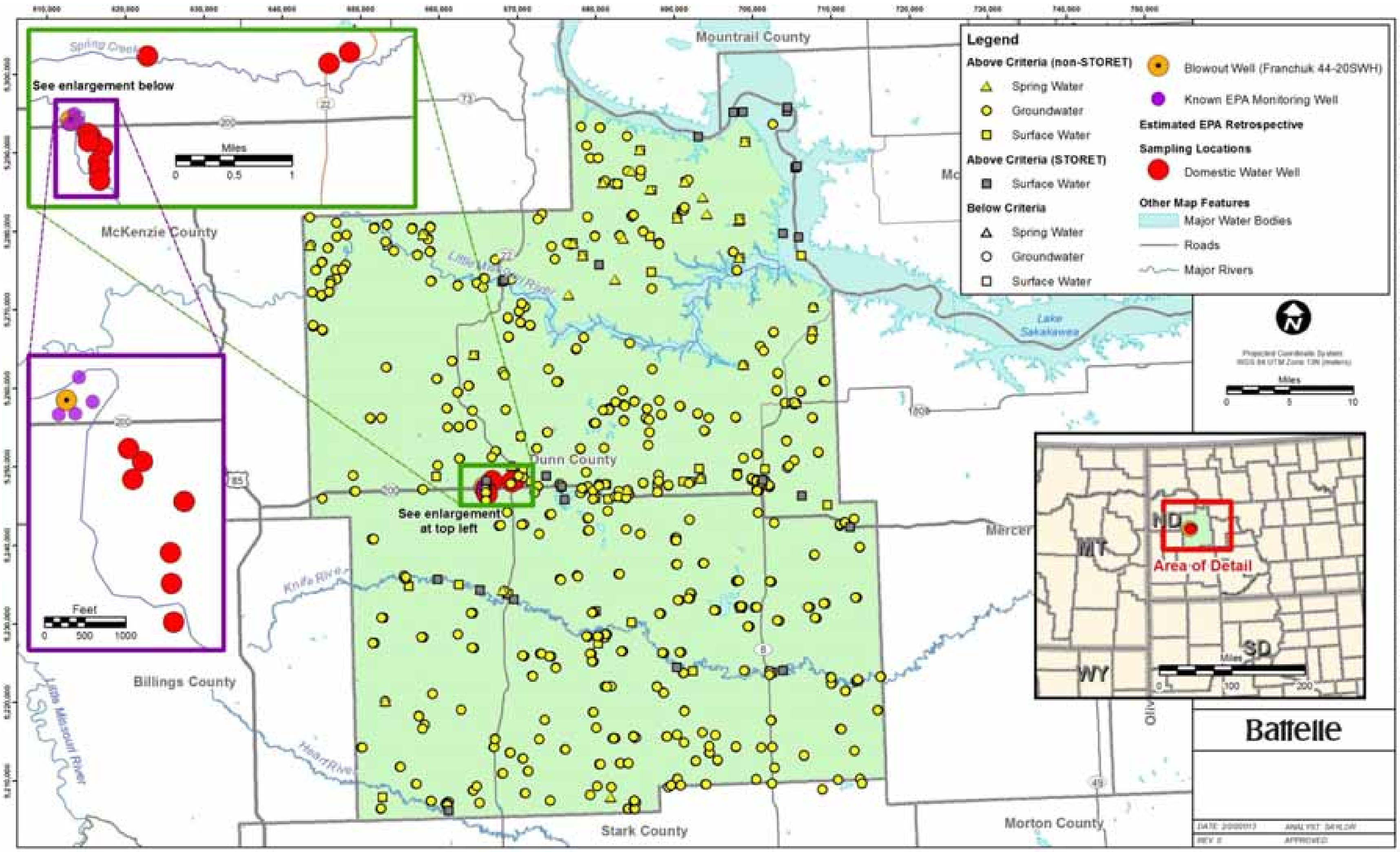

Figure 3. Locations where at least one parameter was detected in groundwater (water wells), surface water, or spring water above one or more screening criteria in Dunn County

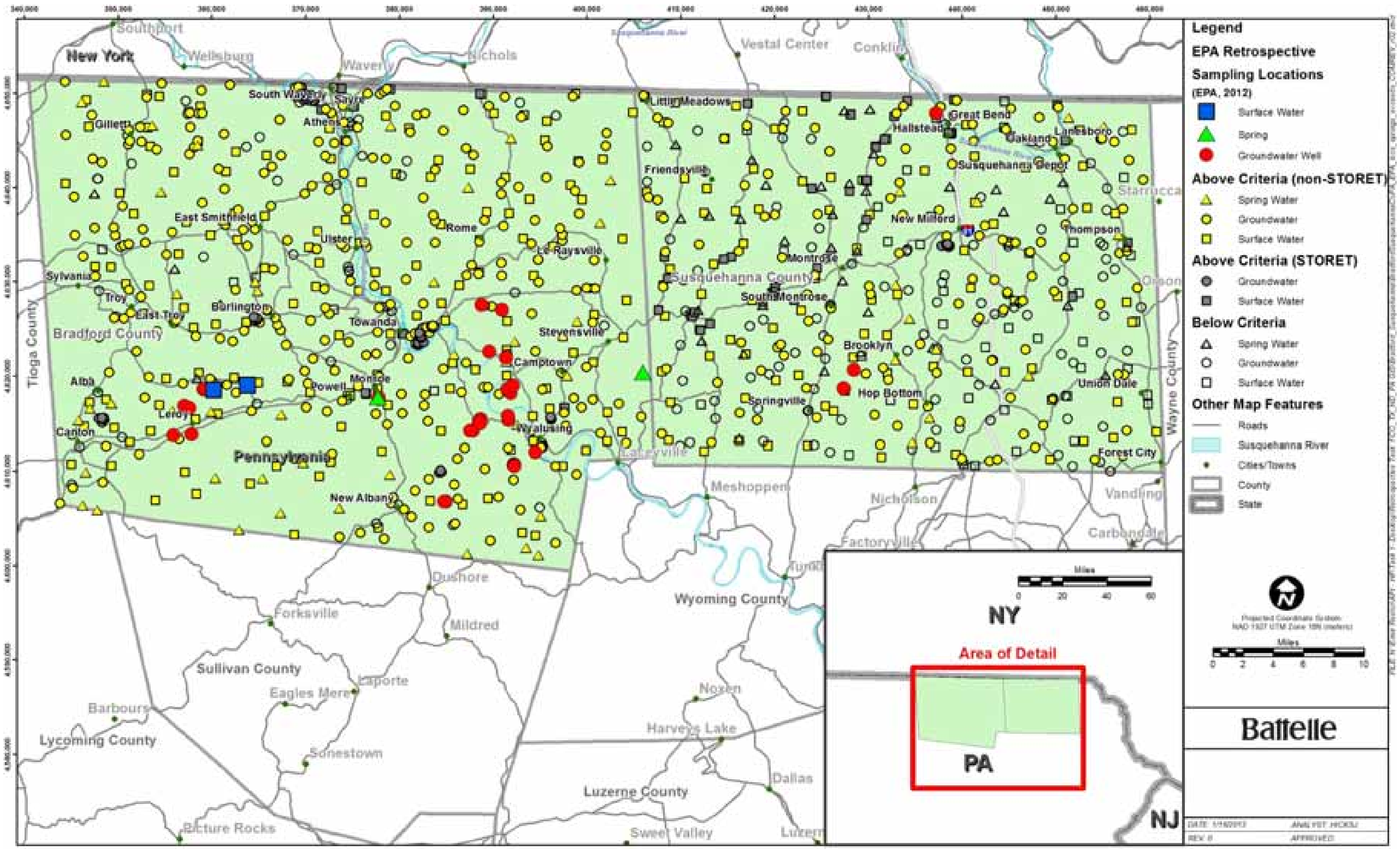

Figure 4. Locations where at least one parameter was detected in groundwater (water wells), spring water, or surface water above one or more screening criteria in Bradford-Susquehanna Counties

Acknowledgements

API and ANGA provided funding to conduct the project. Various industry representatives from each case study area contributed insights on the process of hydraulic fracturing, draft manuscript reviews, and thoughtful comments and suggestions. Pennsylvania Department of Environmental Protection, Texas Rail Road Commission and North Dakota Industrial Commission provided access to pertinent information relative to each case study area. The project was conducted through the dedicated work of a multidisciplinary team of scientists and engineers at Battelle.

References

Battelle 2012. Review of EPA Hydraulic Fracturing Study Plan. Available at: http://www.api.org/news-and-media/news/newsitems/2012/jul-2012/~/media/Files/Policy/Hydraulic_Fracturing/Battelle-Studies/Battelle-EPA-study-plan-review-071012.ashx

Battelle 2013. Site Characterization Reports for Four Study Areas; Available at: http://www.api.org/policy-and-issues/policy-items/hf/comments-api-anga-to-epa

Colorado Oil and Gas Conservation Commission (COGCC). 2003. COGCC Raton Basin Baseline Study Staff Report Rep., Colorado Oil and Gas Conservation Commission.

EPA 2012. Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources: Progress Report. Available at: http://www2.epa.gov/hfstudy/study-potential-impacts-hydraulic-fracturing-drinking-water-resources-progress-report-0

Groundwater Protection Council (GWPC). 2011. State Oil and Gas Agency Groundwater Investigations and Their Role in Advancing Regulatory Reforms A Two-State Review: Ohio and Texas. Available at: http://fracfocus.org/sites/default/files/publications/state_oil__gas_agency_groundwater_investigations_optimized.pdf

Marcellus Shale Advisory Commission (MSAC). 2011. Governor's Marcellus Shale Advisory Commission Report. July 22, 2011.

Molofsky, L.J., J.A. Connor, S.K. Farhat, A.S. Wylie, and T. Wagner, 2011. "Methane In Pennsylvania Water Wells Unrelated To Marcellus Shale Fracturing", *Oil & Gas Journal*, December 5.

United States Environmental Protection Agency (EPA). 2011. "Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources," EPA/600/R-11/122, November.

Weston Solutions, Inc. (Weston). 2012. Evaluation of Geology and Water Well Data Associated with the EPA Hydraulic Fracturing Retrospective Case Study, Bradford County, Pennsylvania. Prepared for Chesapeake Energy, Oklahoma City, Oklahoma. April.

Evaluation of Water Quality Monitoring Programs and Statistical Analysis Tools to be Utilized in Shale Development

Uni Blake
Hometown Energy Group, Oneonta, NY

The statements made during the workshop do not represent the views or opinions of EPA. The claims made by participants have not been verified or endorsed by EPA.

Groundwater monitoring around natural gas development sites is a complex task. There are statistically significant natural spatial variations in the hydrogeology of domestic wells. This presents difficulties when creating a pooled background database for inter well analysis. Current industry water quality baseline strategies involve collecting one pre-sampling data point per domestic well before development starts. Post drilling/HVHF sampling for comparison is routinely optional and is only conducted at the request of a private well owner or if a problem in water quality is suspected. It is assumed that the baseline sample is representative of the general water quality. However, there is growing concern that more and more domestic water supplies are presenting existing contamination. It is anticipated that by modifying the water sampling protocols to include a trend monitoring program, prior contamination or trends can be identified. One-sample point baselines;

- Cannot determine prior contamination or distinguish trends associated with prior contamination.
- Present insufficient data for statistical analysis.
- Do not take into account,
    - Variability in parameters (Coleman, 2012)
    - Long-term changes that may occur (surface spills, seeps, blowouts)

A literature review of strategies utilized to monitor surface and groundwater resources was conducted. Also reviewed were various state and federal guidance documents related to statistical applications for groundwater monitoring. Current natural gas baseline monitoring practices were examined and the best strategies to analyze and assess data were selected.

Summary of a Shale Water Quality Trends Monitoring Program

The program should contain all the elements of a well-designed Monitoring Program designed to fit within the goals of the Clean Water Act. The program should include the following elements:

- Data Objectives: Generate water quality monitoring data that can be analyzed to represent the water quality before, during and after shale gas development. Potential changes targeted include short term (abrupt changes) and/or long-term changes.

- Monitoring Plan Design: The time-frame and the number of samples collected should be adequate to protect human health standards and to also to identify trends if any.
- Data Collection: Utilize consistent methods to minimize assumptions (QAPP/QMP) to create data that is representative and legally defensible.
- Data Management: Date should be stored properly and easily accessible.
- Data Assessment: Utilize easily understood and commonly used statistical methods.

Conclusion

It is recommended that the trend monitoring sampling should be conducted at one or two groundwater wells and one surface water location that are hydrogeologically downstream from the well pad. This trend monitoring program should augment and not replace the regular baseline monitoring program. Background data from multiple-wells should not be pooled for the trend analysis; instead, assessments should be focused on targeted intra-well analysis.
The program should include the following considerations:

- Suggested sampling time frame should consist of two years of data collected monthly prior to shale activities (before) and 2 years after activities commence (after). This four-year database, if collected consistently, can be utilized in trend analysis (Hirsch, 1982).

- Since most water quality data is non-parametric, it is recommended that the statistical methods that can be utilized to monitor for trends include Theil-sen slope or the Mann-Kendall Test, the seasonal Kendall test or the Wilcoxon-Mann-Whitney Step Trend.

- The program should also take into consideration the added cost burden and the attached inconvenience to the landowner that goes with the multiple sampling events.

References

Hirsch R.M., J.R. Slack and R.A. Smith, 1982. Techniques of Trend Analysis for Monthly Water Quality Data. *Water Resources Research,* Vol. 18 (1) pp. 107-121 February.

Coleman, Nancy P., and Debby McElreath. "Short-term Intra-Well Variability in Methane Concentrations from Domestic Well Waters in Northeastern Pennsylvania." (April 2011)

Hirsch R.M., R.B. Alexander, and R.A. Smith 1991. Selection of Methods for the Detection and Estimation of Trends in Water Quality. *Water Resources Research,* Vol. 27(5), pp. 803-813 May.

Surface Water and Stray Gas Shallow Aquifer Contamination

Avner Vengosh*, Robert B. Jackson, Nathaniel Warner, Thomas H. Darrah
Nicholas School of the Environment, Duke University
(*vengosh@duke.edu)

Exploration of unconventional natural gas reservoirs such as low-permeability organic shale formations through horizontal drilling and hydraulic fracturing has changed the energy landscape in the Unites States, providing a vast new energy source. Since the mid-2000s, drilling and production of natural gas has accelerated, also triggering a public debate over the safety and environmental impacts of these operations (1). Here we review the potential short- and long-term risks to the quality water resources associated with shale gas development.

We highlight two key issues related to shorter-term risks. The first is stray gas contamination – the occurrence of elevated levels of methane and other gases in some shallow drinking water wells, which can pose a potential flammability or explosion hazard to homes near shale gas drilling sites. Evidence for stray gas contamination has been suggested in northeastern Pennsylvania overlying the Marcellus Shale (2-4). In these areas, elevated methane levels in shallow groundwater less than 1 km from shale gas wells were characterized by a thermogenic carbon isotope fingerprint, distinctive hydrocarbon ratios with presence of ethane, and noble gas geochemical fingerprints (2-4). Combined, these studies suggest stray gas contamination results from the leaking of natural gas along the well annulus from the shale production formations or shallower formations and/or the release of natural gas from the target formation through poorly constructed or failing well casings. In contrast, shallow groundwater associated with the Fayetteville Shale in north-central Arkansas showed no evidence for methane contamination (5,6), indicating that the local geology and/or drilling practices may play a role in stray gas contamination.

The second short-term risk is the disposal and/or accidental release (spill) of the flowback and produced waters that are generated during well completion, hydraulic fracturing, and gas production from unconventional wells (7,8). Shale gas wastewater is often highly saline and toxic and can contain high levels of naturally occurring radioactivity (8-13). In spite of treatment, discharge of shale gas wastewater to surface waters causes direct contamination of the river systems (12-14). The magnitude of contamination depends on the volume of the disposed wastewater and the local hydrological system (i.e., flow rate and dilution). Disposal of treated wastewater originated from shale gas can also generate bromide levels above baseline levels (13) that can trigger formation of brominated trihalomethanes compounds (e.g., bromodichloromethane) in downstream drinking waters upon water chlorination (15).

As for long-term risks, we have identified four key issues. The first is potential water shortage in areas where water scarcity induces competition over limited or diminishing water availability. In spite of the overall low volume of water that is needed for drilling and hydraulic fracturing relative to other water utilization (16), large-scale unconventional development in water-scare areas such as the Eagle Ford play in Texas could require additional groundwater exploitation and depletion of aquifers that are being utilized for agricultural and domestic uses. Over-exploitation of these aquifers is often associated with water quality deterioration.

The second risk is the potential for natural pathways and hydraulic connection between deep underlying formations and shallow drinking water aquifers, such as faults and/or the natural fracture network, in which pressurized gas and brine can flow to shallow aquifers (17). In spite of thick geological barriers between shallow and deep formations, evidence for possible pathways has been shown in the northeastern Appalachian Basin where shallow groundwater had high salinity combined with geochemical and isotopic fingerprints similar to waters produced from the Marcellus formation during drilling and production (18).

The third risk is the accumulation of residual contaminants in areas of oil and gas wastewater disposal, spills, and leaks. Field evidence shows that long-term disposal of treated wastewater originating from shale gas production can cause reactive radioactive elements (radium and daughter isotopes) to accumulate in the river sediments downstream of disposal sites (13). Likewise, treatment of shale gas wastewater generates solid waste with potentially high levels of radioactivity (13). Improper disposal of these solid wastes to unregulated landfills could in some cases contaminate associated water resources.

1. Howarth R.W., Santoro R., Ingraffea A. (2011) Methane and the greenhouse-gas footprint of natural gas from shale formations. *Climatic Change*; 106: 679-690.

2. Osborn S.G., Vengosh A., Warner N.R., Jackson R.B. (2011) Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *PNAS*; 108: 8172-8176.

3. Darrah, T, Vengosh A, Jackson RB, Warner N. (2012) Constraining the source and migration of natural gas in shallow aquifers within active shale gas production zone: insights from integrating noble gas and hydrocarbon isotope geochemistry. GSA meeting, Charlotte, NC.

4. Jackson, R.B., Vengosh, A., Darrah, T.H., Warner, N.R., Down, A., Poreda, R.J., Osborn, S.G., Zhao, K., and Karr, J.D. (2013) Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. *PNAS* (in press, June, 2013).

5. Kresse, T.M., Warner, N.R., Hays, P.D., Down, A., Vengosh, A., and Jackson, R.B., 2012, Shallow groundwater quality and geochemistry in the Fayetteville Shale gas-production area, north-central Arkansas, 2011: USGS Scientific Investigations Report 2012–5273, 31 p.

6. Warner N.R., Kresse, T.M., Hays, P.D., Down, A., Karr, J.D., Jackson, R.B., Vengosh, A. (2013) Goechemical and isotopic variations in shallow groundwater in areas of Fayetteville Shale development, north central Arkansas. *Applied Geochemistry* (http://dx.doi.org/10.1016/j.apgeochem.2013.04.013).

7. Maloney, K.O. and Yoxtheimer, D. A. (2012) Production and Disposal of Waste Materials from Gas and Oil Extraction from the Marcellus Shale Play in Pennsylvania. *Environ. Pract*. 14, 278 (2012). doi: 10.1017/S146604661200035X7. Lutz, B.D., Lewis, A.N., Doyle, M. W. (2013) Generation, transport, and disposal of wastewater associated with Marcellus Shale gas development. *Water Resour. Res.* 49, 647 (2013). doi: 10.1002/wrcr.20096.

8. Haluszczak L.O., Rose R.W., Kump L.R. (2013) Geochemical evaluation of flowback brine from Marcellus gas wells in Pennsylvania, USA. *App Geoch.,* 28, 55-61.

9. Rowan, E., Engle, M., Kirby, C., Kraemer, T. (2011) Radium content of oil- and gas-field produced waters in the northern Appalachian Basin (USA)—Summary and discussion of data. U.S. Geological Survey Scientific Investigations Report 2011; 513: 31 pp.

10. Entrekin, S. Evans-White, M. , Johnson, B., Hagenbuch, E. (2011) Rapid expansion of natural gas development poses a threat to surface waters. Front. *Ecol. Environ*. **9**, 503 doi: 10.1890/110053.

11. Barbot, E., Vidic, N.S. , Gregory, K.B., Vidic, R. D. (2013) Spatial and temporal correlation of water quality parameters of produced waters from Devonian-Age shale following Hydraulic Fracturing. *ES&T.* 47, 2562 (2013).

12.Ferrar, K. J., Michanowicz, D. R., Christen, C. L., Mulcahy, N., Malone, S. L., Sharma, R. K., (2013) Assessments of effluent contaminants from three wastewater treatment plants discharging Marcellus Shale wastewater to surface waters in Pennsylvania. *ES&T*, 47, (7), 3472–3481.

13. Warner, N.R. (2013) Tracing hydraulic fracturing fluids and formation brines using boron, radium, and strontium isotopes. PhD Thesis, Duke University, Durham, NC.

14. Olmstead, S.M. , Muehlenbachs, L.A. Shih, J.-S., Chu, Z., Krupnick, A. J. (2013) Shale gas development impacts on surface water quality in Pennsylvania. PNAS, doi: 10.1073/pnas.1213871110

15. Wilson, J.M., and VanBriesen, J.M. (2012) Oil and gas produced water management effects on surface drinking water sources in Pennsylvania. *Environmental Practice*, 14, 1-13.

16. Nicot, J.P. and Scanlon, B.R. (2012). Water Use for Shale-Gas Production in Texas, U.S. *ES&T,* 46, 3580-3586.

17. Myers, T. (2012) Potential contaminant pathways from hydraulically fractured shale to aquifers. *Ground Water* 50, 872.

18. Warner, N.R., Jackson, R.B., Darrah, T.H., Osborn, S.G., Down, A., Zhao, K., White, A. Vengosh, A. (2012). Geochemical evidence for possible natural migration of Marcellus formation brine to shallow aquifers in Pennsylvania. *PNAS.*, doi: 10.1073/pnas.1121181109.

Designing a Hydraulic Fracturing Case Study

Gene Florentino
George Lukert
Ecology and Environment, Inc.

The statements made during the workshop do not represent the views or opinions of the EPA. The claims made by participants have not been verified or endorsed by the EPA.

1. Introduction and Purpose

In an effort to aid in developing a documented, consistent, rigorous approach for evaluating retrospective case study data for causal assessment, a Decision Support System (DSS) has been developed. The decision support system is outlined in Figures 1 and 2 and provides a tiered approach to analyzing retrospective sites. This approach documents the entire retrospective case study process, including site characterization, data collection, data evaluation, identification of potential sources, determination of the strength of evidence, determination of additional information needed for causal assessment, identification/evaluation of probable cause(s), sufficient confidence, and criteria used for each step in the causal assessment process. The DSS provides the tools to document the steps taken to evaluate causal links and the level of confidence in the causal links.

The following is a summary of each step of the process.

Purpose of Study

After defining the purpose of the study by identifying the site conditions; the reported problem(s)/issues(s) that warrant the study; the series of events that led to the impairment; and the potential impact(s) on human health and the environment from the site activity, the following steps can be used as a guide during the evaluation process.

2. DSS Tier 1 Steps

Candidate Causes

A candidate cause can be defined as a hypothesized cause of an environmental impairment that is sufficiently credible to be analyzed (EPA 2000). For the purpose of this study, candidate causes include all potential sources that could stress the environment and, therefore, contribute to surface or groundwater contamination.

Once an exhaustive list of candidate causes is developed, each potential cause is evaluated by examining the relationship between the cause and the observed effects. This process is facilitated by developing a preliminary conceptual site model (CSM). The CSM uses a map of the site's physical features and underlying stratigraphy and hydrologic properties to identify possible locations of sources and potential pathways between these sources and the observed impacts. For this study, potential candidate causes include: industrial/commercial use; historical land use; current drilling processes/practices; historical drilling practices; and naturally occurring sources.

Existing Data Collection

After a list of candidate causes is completed for potential sources, existing data are compiled in an effort to infer causality and eliminate candidate causes that are not related to the potential sources.

Existing data may be found in studies conducted to date, including federal and state studies, and stakeholder studies. These studies can be found by performing a detailed background assessment (see Figure 2).

Some data related to the hydraulic fracturing water cycle has already been compiled and reviewed and may include the following:

- Chemicals and practices used by existing producers in the hydraulic fracturing process.
- Chemicals and water use for hydraulic fracturing from the FracFocus database.
- Well construction and hydraulic fracturing records provided by well operators to assess the effectiveness of current well construction practices at containing gases and liquids before, during, and after hydraulic fracturing.
- Causes and volumes of spills of hydraulic fracturing fluids and wastewater from state spill databases in Colorado, New Mexico, and Pennsylvania, and from the National Response Center database.
- Scientific literature relevant to the research questions posed for retrospective studies of potential impacts of hydraulic fracturing (EPA 2012). A Federal Register notice was published on November 9, 2012, requesting relevant, peer-reviewed data and published reports, including information on advances in industry practices and technologies. This body of literature will be synthesized with results from the other research projects to create a report of results.

Evaluation of Data

Analyze Evidence

The existing information is analyzed to determine if the data are related to one or more of the candidate causes. It is expected that most existing information about a site and the candidate causes may be useful for inferring causality and determining impacts. However, data quality objectives (DQOs) should be established to evaluate the data usability.

Data Usability

Potentially useful data should be used to prepare the preliminary Conceptual Site Model (CSM) for each study area and may include information on the hydrology and geology; operator data; information on the sampling and analysis methods; and information on site history. Actual measurement data from the site are needed as evidence of association between potential causes and known impacts. Data should be organized or analyzed in terms of associations that support or refute the potential causes by addressing the nature and extent of potential contamination and contaminant fate and transport.

The DQO process is a component of systematic planning for the project designed to generate performance acceptance criteria for the collection of new data. The process is a series of steps from problem statement through the data collection design. The DQO process is discussed as part of the development of Quality Assurance Project Plans (QAPP). Analysis of existing data and information is incorporated into the DQO process and can help identify data gaps.

A wide variety of data may be collected about the candidate causes and environmental impairment. The usability of data collected are assessed against acceptance and performance criteria often specified in terms of precision, accuracy, representativeness, completeness, and comparability (PARCC) parameters. Numerical acceptance criteria cannot be assigned to all PARCC parameters, but general performance goals can be established for most data collection activities.

3. DSS Tier 2 Steps

Screening of Potential Causes

This step is a preliminary screening (based on the evaluation of existing data) that determines whether a candidate cause can be linked with the effect. The preliminary CSM will aid in establishing the link between the candidate causes and the effect. For this step, a candidate cause will be evaluated and a determination will be made to eliminate the candidate cause or to retain the candidate cause of a potential contributor to the identified contamination. Factors to be considered include the following:

- Are the candidate cause and the observed impact consistent temporally and spatially?
- Is the impact observed if the cause is not present or is the cause present if the impact is not observed?
- Does the intensity of the impact increase or decrease proportional to the evaluation of individual candidate causes?

If direct measurement data are not available for the site, then data from similar sites could be used as evidence to retain a potential cause. In addition, intermediate pathways can be examined to infer an association between a candidate cause and an observed impact based on the known physical, hydrological, or chemical characteristics.

Conduct Initial Sampling

If no site-specific measurement data are available, a limited initial sampling is performed at existing wells, taps, surface water bodies, or surrounding surface soils. Some of this measurement data is needed to develop the CSM and perform the initial causal analysis. Existing data can be used to determine the measurement parameters. At the initial sampling, simple measurement parameters, such as pH, conductivity, and turbidity, can be used as indicators of potential cause and effect associations. The initial sampling is designed to support planning for more detailed investigations.

Issues Associated with Designing and Conducting Field Investigations

One of the main factors in designing a monitoring well network is determining the optimal location of monitoring wells to capture potential methane migration and/or hydraulic fracturing fluid migration. These challenges include determining the proper distance from the production well. If the monitoring wells are too far away from the production well, the travel times for hydraulic fracturing fluid migration may be too great for the wells to be effective. If the monitoring wells are too close to the production well (e.g., on the well pad), the wells may become direct conduits for surface contamination (spills) to the underlying aquifers, or they may be damaged by the drilling process (struck by the production well bit). Production well air rotary drilling methods may also impact monitoring well water quality. Another challenge is that the screens could be grout contaminated when the production well surface casing is installed. Other challenges include design and installation of angled monitoring wells or horizontal monitoring wells as an alternative to monitoring the freshwater zone immediately adjacent to or beneath the production well pad without drilling the monitoring well through the pad. Drilling monitoring wells through the well pad is viewed as unacceptable by some operators. Lastly, there is peer review and public perception that should be considered in the study design. While it may not make technical sense to drill monitoring wells along the production well lateral (which could be over a mile long), it cannot be ignored, since there is a possibility of upward methane migration or hydraulic fracturing fluid migration along natural fractures. Other issues and concerns include influence by other nearby oil and gas drilling, whether it be historical or recent, or near future proposed drilling; site access (reaching agreements with land owners to allow the installation of monitoring wells that are critical to the study); and insurance requirements (operators see the installation of nearby monitoring wells as high risk because of the potential for creating downward migration pathways of contaminants to freshwater aquifers), therefore, liability insurance requirements may impact the solicitation of consultants and subcontractors to implement the study.

Data Evaluation

This step is used to evaluate the quality of the initial sampling data, which would include data validation and other quality assurance/quality control (QA/QC) procedures (e.g., sample collection methods). Additionally, the strength of the data collected must be evaluated relative to potential causes. For example, a detection of methane does not necessarily indicate methane contamination from a particular source or activity. However, isotopic analysis may provide insight into the methane signature as to whether it is biogenic or thermogenic, with the latter possibly being associated with drilling activities or with particular target formations. Sampling data must also be compared against natural or background conditions as much as possible in order to identify anomalies possibly associated with suspected source areas.

Initial Causal Analysis

After available evidence and initial sampling has been compiled and evaluated, the cause(s) of the impact may be obvious. In other cases, a more detailed analysis is needed to reach a conclusion or determine if sufficient data are available for decision making. The methods listed below can be used to develop a clear logical association between the candidate causes and the impacts and to weigh the strength of evidence supporting each candidate cause.

Develop the Conceptual Site Model

The CSM is developed and refined throughout the investigative process to identify sources, receptors, and pathways associated with the site. The CSM is an important part of the analysis of evidence from candidate causes because it identifies links between sources and potential impacts by representing the physical, chemical, and biological processes that control the transport, migration, and potential impacts of potential sources on receptors. A CSM identifies the potential sources of contamination; shows how chemicals at the original point of release might move in the environment; identifies the different types of receptors/human populations; and lists the potential exposure pathways.

Implement Groundwater Model

An initial groundwater model must be established to assess the potential for source contaminants to reach potential receptors. Groundwater data, such as depth to aquifer, regional groundwater flow direction and gradient, aquifer materials and formations, and screened intervals for potential groundwater receptors are needed. This information can be obtained from agency studies and existing data collected as part of Tier 1.

Assess the Nature and Extent of Contamination

The nature and extent of contamination can be evaluated using existing data and the CSM to look for evidence of contamination along potential pathways or at receptors. The data can be used to evaluate the association between the potential causes and observed effects.

Assess Fate and Transport

In order to establish potential causes of contamination there must be a viable pathway from the source to receptor. Assessing the fate and transport mechanisms at a site uses scientific evidence of physical, chemical, and biological processes to evaluate whether contamination can originate from a potential cause.

Identification of Data Gaps

Once potential causes have been screened and/or eliminated during review of existing data, acquiring and assessing additional data is the next step. Typically, sufficient data or evidence will not be available to determine a probable causal candidate. As a result, site-specific studies will likely have to be conducted in order to fill in data gaps. Typical data gaps may include, but are not limited to, site-specific geology and hydrogeologic data, groundwater sampling analysis, historical information, drilling and well completion records, and personal interviews.

4. DSS Tier 3 Steps

Execute Site-Specific Studies

The list of candidate causes can be pared down after screening is completed. Based on the need for additional data and/or the strength of existing data for the remaining candidate causes, a partial or one or more site-specific studies would be necessary to fill in the data gaps and produce valid evidence. Types of site-specific studies include geological assessment, hydrological assessment, and surface impact assessment (see Figure 2).

Re-evaluation of Data

After data gaps have been completed through additional database searches and site-specific studies, the study tools (CSM; groundwater model; nature and extent; and fate and transport) should be updated. Candidate causes can then be re-evaluated to determine which should be eliminated from further consideration. If the data is not sufficient, additional site studies should be completed and along with another re-evaluation step. If there is sufficient data, the probable candidate causes are then identified and designated as principle cause(s) or secondary cause(s).

5. DSS Tier 4 Steps

Probable Candidate Causes

Once sufficient data are obtained, probable candidate causes should be determined and designated as a principle cause(s) or a secondary cause(s). A principle cause is a cause that makes the largest contribution to the effect. A secondary cause is a cause that makes some contribution to the effect but on a smaller scale than a principal cause.

QA Evaluation

All research projects that generate or use environmental data to make conclusions or recommendations must comply with the appropriate QA program requirements. The QA program requirements include developing a QAPP and peer review. The final QA evaluation should verify that the study and decisions or recommendations resulting from the study were completed under an acceptable QA program. Activities include verification that a QAPP was implemented; data quality audits were conducted; work products were subject to peer review; and that the QA procedures were documented in the final reports. If the QA process was properly implemented, conclusions that determine principle and secondary cause(s) are valid and can be released to policy makers and stakeholders.

Conclusions

Final identification of probable candidate causes may not identify a single principle cause, thus multiple principle causes and secondary causes may be responsible for the impairment identified at each case study area. The magnitude of the studies necessary to determine the principle cause(s) of the impairment may be technically impracticable, and thus beyond the scope of this study.

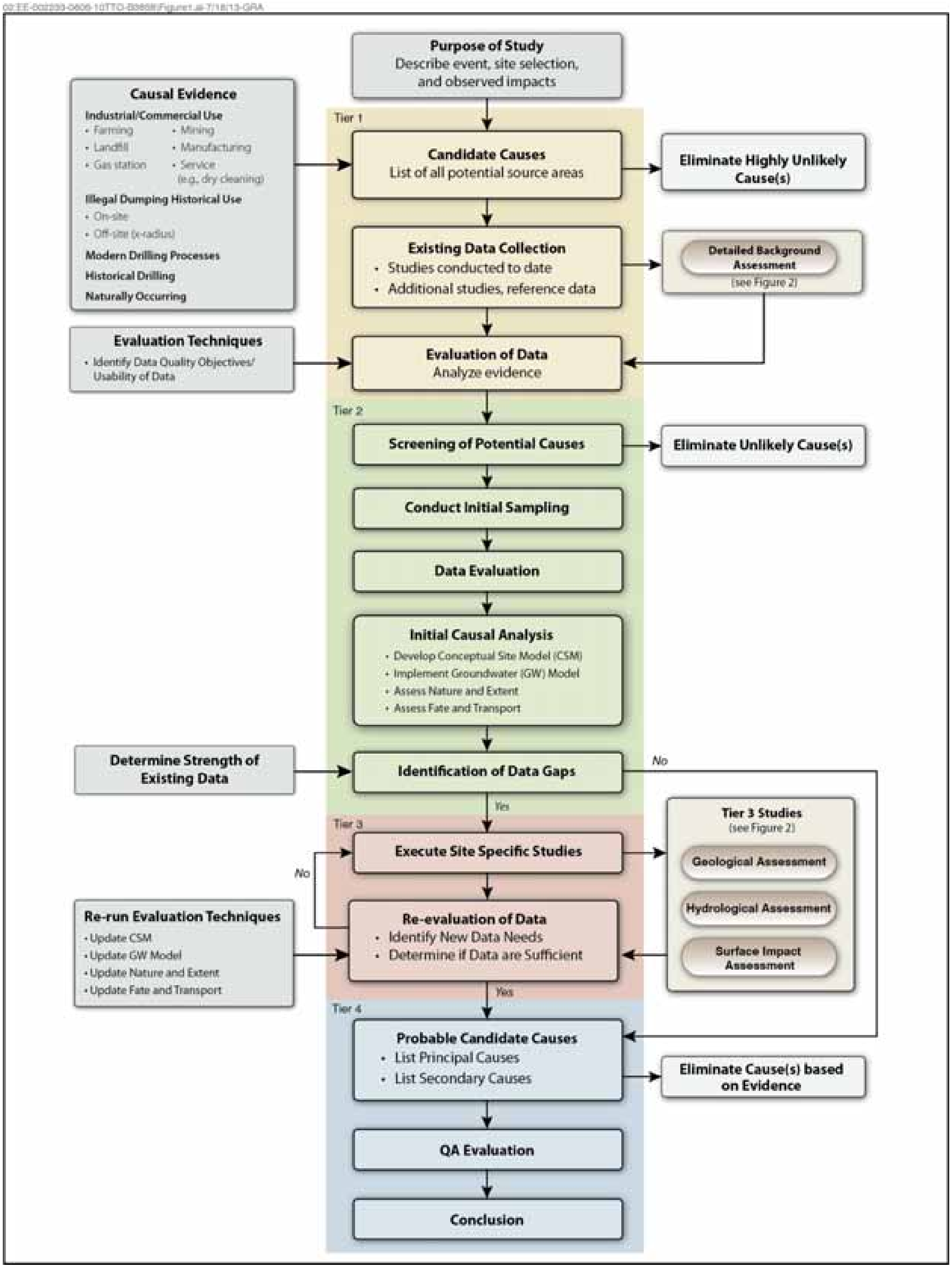

Figure 1. Decision Support System Flow Chart

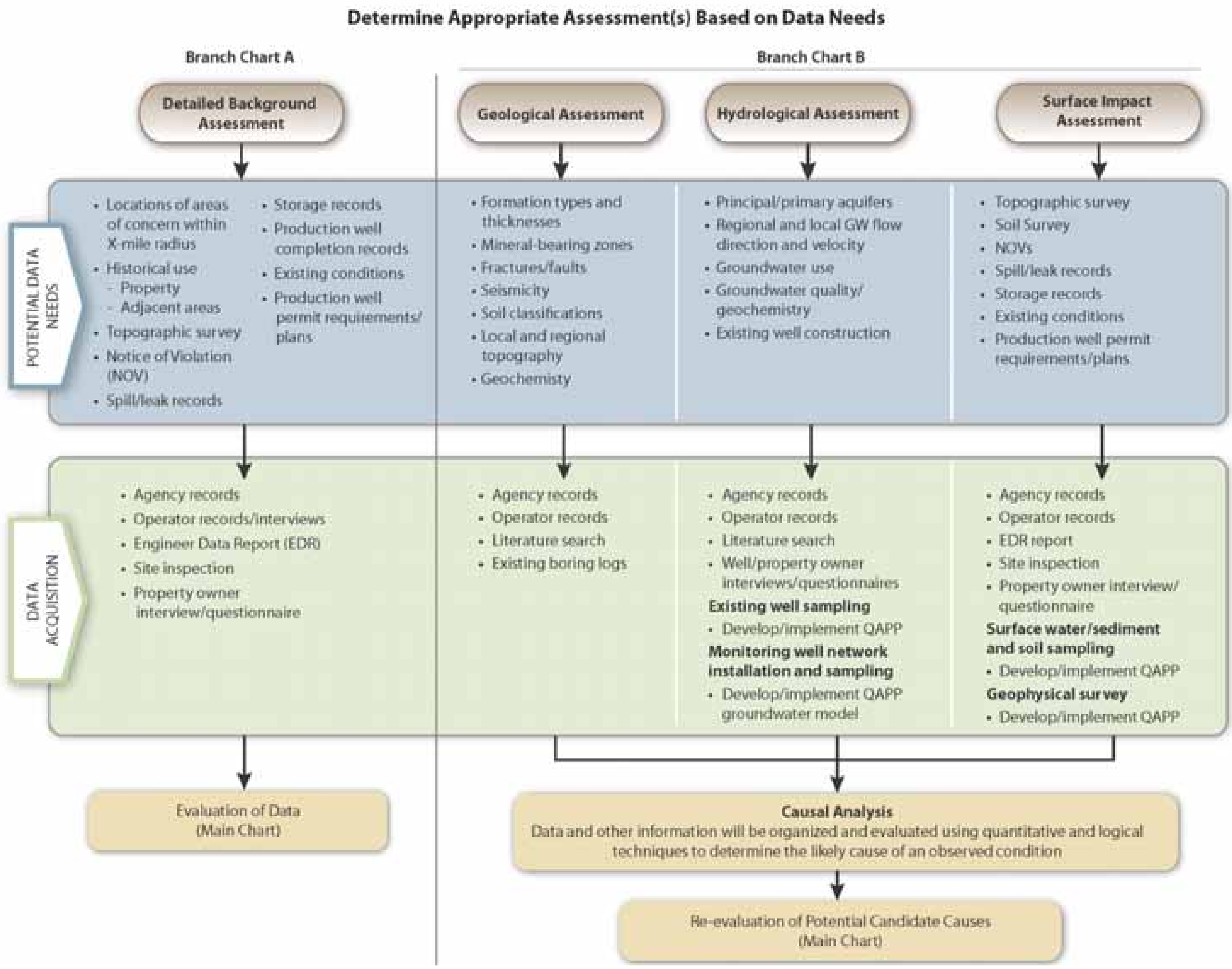

Figure 2. Decision Support System Additional Studies Branch Chart

References

United States Environmental Protection Agency (EPA). 2012. *Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources.* Progress Report. Office of Research and Development.

______. 2000. Stressor Identification Guidance Document. Office of Water. Office of Research and Development. National Exposure Research Laboratory.

Appendix B.

Extended Abstracts from Session 2: Prospective Case Studies

Overview of EPA's Approach to Developing Prospective Case Studies
Technical Workshop: Case Studies to Assess Potential Impacts of Hydraulic Fracturing on Drinking Water Resources

Robert Ford and Jeanne Briskin
United States Environmental Protection Agency
Office of Research and Development
July 30, 2013

Information presented in this abstract is part of the EPA's ongoing study. EPA intends to use this, combined with other information, to inform its assessment of the potential impacts to drinking water resources from hydraulic fracturing. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Introduction

One component of the United States Environmental Protection Agency's (EPA) study of the potential impacts of hydraulic fracturing on drinking water resources is prospective case studies, the purpose of which is to more fully understand and assess if and how site specific hydraulic fracturing practices may impact drinking water resources.[6] The retrospective case studies, addressed in a separate EPA presentation for this workshop, focus on investigating and assessing reported instances of drinking water contamination in areas where hydraulic fracturing activities have already occurred. The prospective case studies are designed to be forward looking and allow for the collaborative design and development of a research program that will include sampling and characterization of the site before, during and after drilling, injection of the fracturing fluid, flowback and production.

Prospective Case Study Goals

Prospective case studies are being designed to contribute to the information base that will allow stakeholders, including other federal partners, States, Congress, industry and the public to better understand hydraulic fracturing, its importance to our nation's energy policies, and factors that may correlate with the conduct of hydraulic fracturing in a manner that protects human health and the environment. Along with other relevant work, these case studies will allow EPA and others to evaluate any changes in water quality over time and will focus on understanding how site specific hydraulic fracturing practices prevent impacts to drinking water resources. Of the five fundamental questions to be addressed, which are linked to the hydraulic fracturing water lifecycle, the three most applicable to the prospective case studies are:

1. Chemical Mixing: What are the possible impacts of surface spills on or near well pads of hydraulic fracturing fluids on drinking water resources?
2. Well Injection: What are the possible impacts of the injection and fracturing process on drinking water resources?
3. Flowback and Produced Waters: What are the possible impacts of surface spills on or near well pads of flowback and produced water on drinking water resources?

[6] EPA, The Potential Impacts of Hydraulic Fracturing on Drinking Water Resources: Progress Report (December 2012)

Study Approach

EPA plans to use the study approach described below, which follows the development phases of a production well (Figure 1).

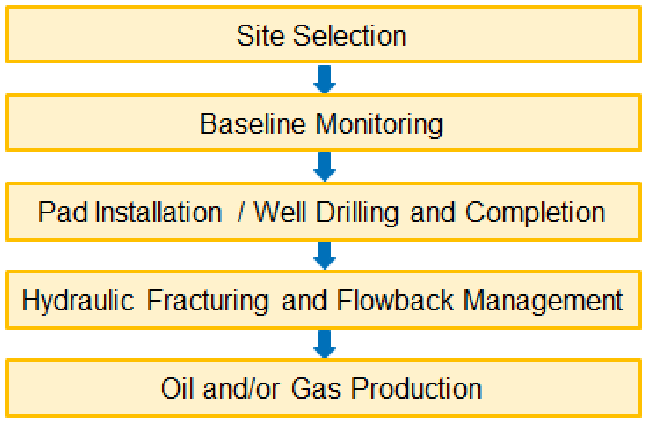

Figure 1: Development Phases of a Production Well

Site Selection: includes considering such factors as proximity to water resources, current ground water quality, site topography, willingness of landowners to participate, proximity and age of existing hydraulic fracturing sites, etc.

Baseline Monitoring: includes selecting locations considering such conditions as depth, direction and rate of groundwater flow; establishing surface water monitoring locations and scheduling at least four, quarterly, water quality and flow monitoring events; conducting baseline monitoring and documenting the baseline water quality.

Pad Installation / Well Drilling and Completion: includes documenting well construction details, well integrity, and assessing any impacts to water quality. Examples of practices that could be evaluated include well pad liner installation and berm construction, well casing and cement installation, and the construction of secondary containment for tanks and impoundments, followed up by observing pad construction, drilling and completion of the production well, and monitoring for ground and surface water.

Hydraulic Fracturing Flowback Management: includes documenting the hydraulic fracturing and flowback process; examples of the types of practices to be observed and documented include site-specific reports of geology, production well drilling records including driller logs (e.g. fluid volumes, cuttings descriptions) and wire-line geophysical logging records, production well construction records including casing design and cementing records, mechanical integrity testing reports (e.g., pre and post fracturing), cement bond logs, pressure monitoring records for the production well, and microseismic test reports including monitoring of fracture propagation. Ideally, tracers would be used to assist assessment of the ultimate fate and transport of hydraulic fracturing fluids; follow up includes sampling flowback at intervals, and also monitoring the conditions in ground water and surface water through use of in-situ devices installed within monitoring wells and surface water monitoring stations and periodic acquisition of water samples for laboratory analysis.

Oil and/or Gas Production: includes documenting flowback and produced water management practices, confirming with the operators the volumes of produced water that result from the process and the treatment and /or disposal methods employed, monitoring surface water and ground water for at least a year following the start of the production phase, and obtaining water quality samples at least quarterly.

Water Quality Monitoring

Water quality monitoring can help inform answers to the five fundamental questions related to the hydraulic fracturing water lifecycle. EPA plans to use pre-existing monitoring points where possible. Options here would include private, public, industrial and agricultural wells as well as springs and surface water bodies within the local drainage system. EPA also plans to install targeted monitoring wells. The locations, depths and numbers of wells will depend on the local ground water depth, flow rate and flow direction. Monitoring wells would be placed in locations that would intercept anticipated flow pathways within aquifers. The conceptual framework for monitoring is displayed in Figure 2:

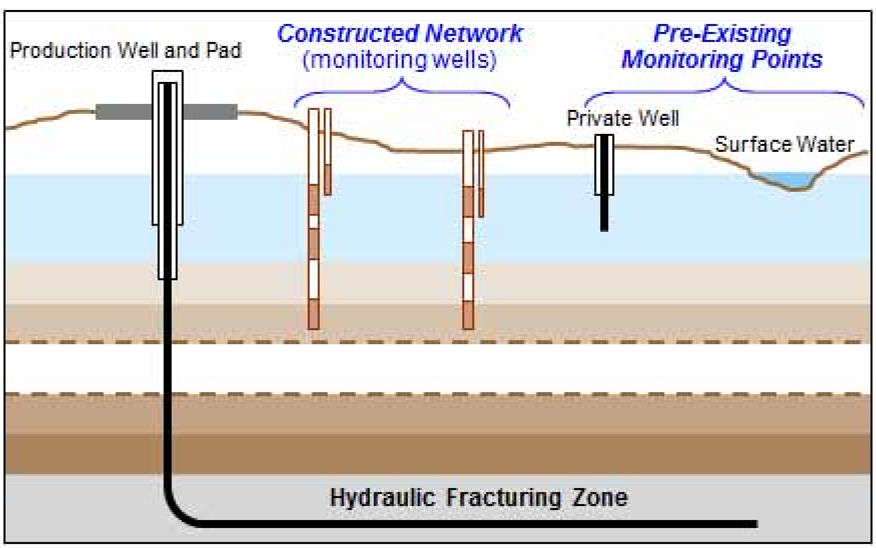

Figure 2: Conceptual Framework for Monitoring

Anticipated Timeline

EPA has not yet selected the sites for these prospective case studies. We are working closely with oil and gas well owners / operators, the hydraulic fracturing industry, other federal partners and landowners to assure that site selection for these prospective studies will yield scientifically robust and reliable results. Once the sites have been selected the timeline is expected to proceed as shown in Figure 3.

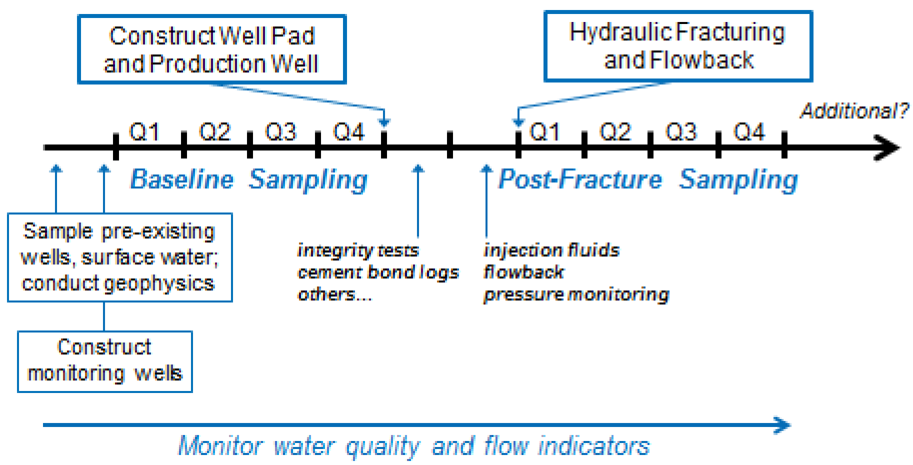

Figure 3: Anticipated Timeline

The Role of Borehole Geophysics in Groundwater Investigations

Ronald A Sloto
U.S. Geological Survey

The statements made during the workshop do not represent the view or opinions of EPA. The comments made by participants have not been verified or endorsed by EPA.

Introduction

Borehole-geophysical logging provides a wealth of information that is critical in gaining an understanding of subsurface conditions needed for groundwater and environmental studies. Multiple logs typically are collected to take advantage of their synergistic nature--much more can be learned by the analysis of a suite of logs as a group than by the analysis of the same logs individually. Borehole geophysics is used to obtain information on well construction, rock lithology and fractures, permeability, and water quality. They provide information on the borehole and aquifer than cannot be obtained in any other way.

Borehole Geophysical Logs

Common geophysical logs include caliper, gamma, single-point resistance, electromagnetic induction, fluid resistivity, fluid temperature, flowmeter, television, and acoustic televiewer.

Caliper logs provide a continuous record of average borehole diameter, which is related to fractures, lithology, and drilling technique. Caliper logs are used to identify fractures, water-bearing openings, and sometimes lithology. Because borehole diameter commonly affects log response, the caliper log is useful in the analysis of other geophysical logs, including interpretation of flowmeter logs.

Natural-gamma logs record the natural-gamma radiation emitted from rocks penetrated by the borehole. Uranium-238, thorium-232, and the progeny of their decay series and potassium-40 are the most common emitters of natural-gamma radiation. These radioactive elements are concentrated in clay and shale by adsorption, precipitation, and ion exchange. Fine-grained sediments, such as mudstone or siltstone, usually emit more gamma radiation than sandstone. The gamma log often is used to interpret lithology and to correlate geologic units between boreholes.

Single-point-resistance logs record the electrical resistance between the borehole and an electrical ground at land surface. In general, resistance increases with grain size and decreases with borehole diameter, density of water-bearing fractures, and increasing dissolved-solids concentration of borehole water. Single-point-resistance logs are used to correlate lithology between boreholes and may help identify water-bearing fractures.

Electromagnetic-induction logs record the electrical conductivity or resistivity of the rocks and water surrounding the borehole. Electrical conductivity and resistivity are affected by the porosity, permeability, and clay content of the rocks and by the dissolved-solids concentration of the water within the rocks. The electromagnetic-induction log can work through plastic casing.

Fluid-temperature logs provide a continuous record of the vertical water-temperature variation in the borehole. They are used to identify water-bearing fractures and to determine intervals of vertical borehole between zones of differing hydraulic head penetrated by the borehole. Water-producing and water-receiving zones usually are identified by sharp changes in temperature, and borehole flow between those zones is indicated by temperature gradients that are less than the regional geothermal gradient.

Fluid-resistivity logs measure the electrical resistance of the water in the borehole. Changes in fluid-resistivity reflect changes in the dissolved-solids concentration of the borehole water. Fluid-resistivity logs are used to identify water-bearing fractures and intervals of vertical borehole flow. Water-producing and water-receiving fractures usually are identified by sharp changes in resistivity. Intervals of vertical borehole flow usually are identified by a low-resistivity gradient between a water-producing and a water-receiving zone.

Flowmeter logs record the direction and rate of vertical flow in the borehole. Flowmeter logs can be collected under non-pumping (ambient) and/or pumping conditions. The direction and rate of borehole-fluid movement is generally measured with a high-resolution heatpulse flowmeter. The range of flow measurement is about 0.01 to 1.5 gallons per minute in a 2- to 10-inch diameter borehole. Flow from fractures can be induced by pumping the borehole at a low rate and maintaining a constant drawdown (pumping conditions).

Borehole television surveys are conducted by lowering a waterproof video camera down the borehole and recording the image on DVD. The optical image can be viewed in real time on a monitor. Well construction, lithology and fractures, water level, cascading water from above the water level, and changes in borehole water quality (chemical precipitates, suspended particles, and gas) can be viewed directly with the camera.

Acoustic-televiewer logs record a magnetically oriented, photographic image of the acoustic reflectivity of the borehole wall. Televiewer logs indicate the location and strike and dip of each fracture and lithologic contact. The televiewer tool also includes a borehole dipmeter.

Water quality samples can be collected at a discrete depth using a wire-line sampler. The sampler is lowered to a desired depth, opened, allowed to fill with water, and closed. Up tp a liter of water can be collected.

Aquifer-isolation (packer) tests, although not a borehole geophysical technique, are often used in conjunction with borehole geophysics to define the hydraulic and chemical characteristics of discrete water-bearing fractures in a borehole. This characterization only can be performed by isolating each water-bearing fracture with straddle packers so that its properties can be separated from the other water-bearing fractures in the borehole. Selection of fractures to isolated and depth of packer placement is determined by analysis of borehole geophysical logs. The packer assembly is lowered to the selected depth in the borehole, and the packers are inflated against the borehole wall, isolating the selected interval. The isolated interval is pumped to measure hydraulic characteristics and collect a discrete-depth water sample. Hydraulic head response to pumping can be measured in the isolated interval and in the aquifer above and below the isolated interval.

Example for how to use geophysics to design a water-monitoring network

The two wells supplying water to the Willow Grove Naval Air Station/Joint Reserve Base in Horsham Township, Montgomery County, Pennsylvania, were contaminated with tetrachloroethylene (PCE). Several investigations of nearby suspected sources were investigated, and numerous monitor wells were drilled. However, the source of the PCE could not be identified. In support of the Navy investigation, the U.S. Geological Survey conducted borehole geophysical logging and aquifer-isolation tests in the two supply wells. The ground-water-flow system for the supply wells was characterized by use of borehole geophysical logs and heatpulse-flowmeter measurements. The hydraulic and chemical properties of discrete water-bearing fractures in the supply wells were characterized by isolating each water-bearing fracture with straddle packers (Sloto and others, 2002).

First, the caliper log was used to determine the location of fractures in the supply wells. The fluid-temperature and fluid-resistivity logs were used to determine which fractures identified by the caliper logs potentially provided water to the wells. Heatpulse-flowmeter measurements made above and below each potential water-producing fracture confirmed the water-bearing fractures (Figure 1). The natural gamma and electric logs were used to correlate lithology between the supply wells and each individual bed was labeled. The caliper logs and borehole television surveys were used to locate smooth sections of borehole to set straddle packers. Each identified water-producing fracture was isolated with straddle packers, and a sample of water produced by the fracture was pumped and analyzed for volatile organic compounds.

Lithologic unit H, which was identified using the natural gamma and electric logs, was the major source of PCE contamination for both supply wells. Using the strike and dip of lithologic unit H, the outcrop area was projected to be approximately 2,300–2,450 feet southeast of supply well 1. The projected outcrop is updip and hydraulically upgradient from the supply wells. A subsequent investigation by the U.S. Environmental Protection Agency showed that an aircraft plant was formerly located in the outcrop area of lithologic unit H, and the shallow groundwater and nearby wells contained highly elevated concentrations of PCE.

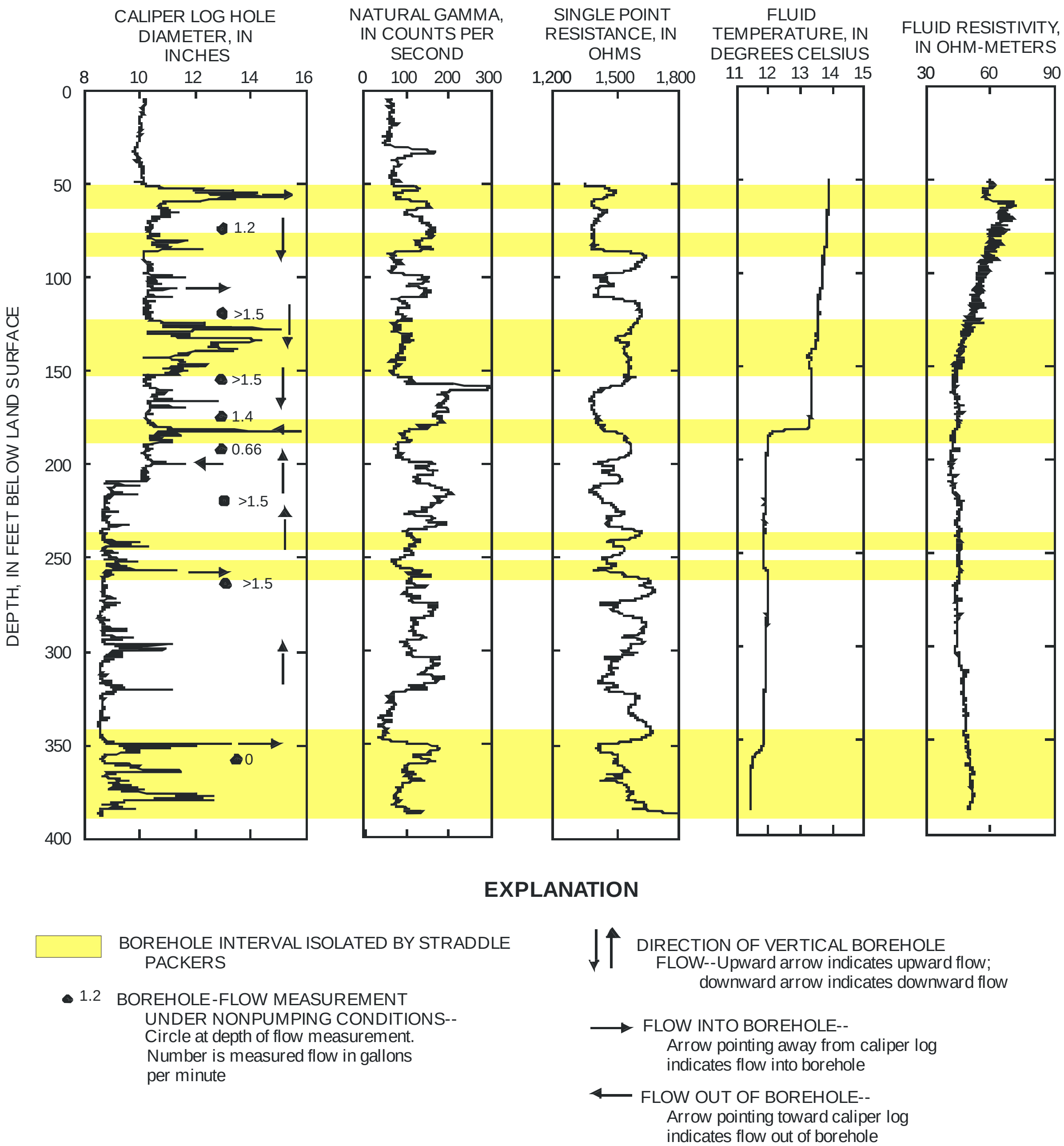

Figure 1. Borehole geophysical logs for supply well 1, Willow Grove Naval Air Station/Joint Reserve Base, Horsham Township, Montgomery County, Pennsylvania.

Reference

Sloto, R.A., Goode, D.J., and Frasch, S.M. (2002) Interpretation of borehole geophysical logs, aquifer-isolation tests, and water quality, supply wells 1 and 2, Willow Grove Naval Air Station/Joint Reserve Base, Horsham Township, Montgomery County, Pennsylvania. U.S. Geological Survey Water-Resources Investigations Report 2001-4264, 64 p.

Groundwater Monitoring for EPA Prospective Case Study Site

Daniel J. Soeder, U.S. Department of Energy, National Energy Technology Laboratory, Morgantown, WV

The statements made during the workshop do not represent the view or opinions of EPA. The comments made by participants have not been verified or endorsed by EPA.

Monitoring of groundwater at shale gas development locations before, during and after the drilling, hydraulic fracturing and completion process is important for a number of reasons. Drilling through shallow aquifers can affect groundwater if compressed air infiltrates into the aquifer, potentially causing a groundwater flow surge. Drilling overbalanced may also allow drilling mud or chemicals to get into the groundwater. The hydraulic fracture process creates pressure pulses at depth that reach the surface, and can affect groundwater, potentially changing the solubility of naturally-occurring methane gas in aquifers and causing it to mobilize. Data on stray gas mobilization, fluid infiltration, and water quality effects related to wellbore integrity, the reliability of casing and cement, and surface spills of frac chemicals or produced water can only be obtained through groundwater monitoring. Ancillary questions, such as soil gas composition and migration, and the rates at which natural attenuation processes might break down organic chemicals and produced hydrocarbons can also be addressed by monitoring groundwater.

Surface spills are the primary risk to groundwater from shale gas operations. Monitoring shallow groundwater and streams in small watersheds will help with early detection, but indicators are needed for drilling mud, hydraulic fracture chemicals, and produced fluids. Sr isotopes appear to be a good indicator for Marcellus shale produced water, but others are also needed. Longer-term concerns include leachate from sulfide-rich drill cuttings as a possible risk to groundwater.

Current plans call for at least three and possibly more groundwater monitoring wells to be installed off the pad at an EPA prospective case study site. One well will be installed up-gradient, with two or potentially three wells down-gradient. The wells will be drilled to a nominal depth of 100 meters (300 feet), and completed open hole with surface casing set at least five feet below the base of the soil.

Installation costs will be funded by DOE-NETL through the site support contractor, and a commercial monitoring well driller will be used. The driller must possess a well drillers license for the State of Pennsylvania and the State of West Virginia, have air and mud rotary and/or air hammer capability, and demonstrate the successful completion of at least 10 monitor or water wells that are at least 300 feet deep within the last five years in Pennsylvania and/or West Virginia. The driller must also show documented experience with groundwater sampling during drilling, and provide resumes for on-site personnel to prove that the crew has the proper training and sufficient work experience to successfully carry out the operation.

All drilling and earthmoving equipment must be washed and decontaminated prior to arrival on the site, and all equipment will be inspected for safe operations. Wells are to be drilled using the hydraulic air-rotary or air-hammer method, unless hole conditions do not allow. Foam or fresh water may be used if wet or saturated zones are encountered that make air drilling impractical. Lubricants used for drill pipe and casing shall be Teflon-based; no additives are allowed without authorization. Surface casing and cement shall meet WV or PA DEP monitor well standards and EPA standards in SESDGUID-101-R1, Design and Installation of Monitoring Wells.

A nominal 10 ½-inch hole will be drilled at least 20 feet deep to allow surface casing to be set to a depth of at least 5 feet below the base of alluvium and soils. The surface casing will be cemented in place and cement run to the surface to seal the annulus. The well will then be drilled open hole to a depth of 200 feet. The deviation angle of the well will be measured and corrected back to vertical if greater than half a degree. The total depth of the hole will nominally be 300 feet.

At each water-bearing zone encountered during drilling, operations will be paused to measure water levels and collect samples. Inflow rates shall be noted. Drill cuttings will be sampled at nominal intervals, and containerized for disposal. Core will be cut as directed. The driller will then develop the completed well, ensuring an inflow of at least ten gallons per minute through the completion zone. After site cleanup, wireline logs will be run as directed, possibly including gamma, density, neutron porosity and saturation, resistivity and others. The well will then be turned over to DOE/EPA/USGS for sampling.

Sampling will use a multilevel insert in the well to collect groundwater from various depths defined from the inflow tests and a geologic evaluation of the aquifer. These multilevel samplers typically allow access to several dozen distinct zones isolated by inflatable packers. Prior to employing these at the prospective case site, an existing USGS monitoring well will be used to field test one or more of these systems to ensure that pump and purge rates suitable for EPA groundwater sampling protocols can be achieved.

Current plans call for identifying an industry cooperator and adjacent landowners who will allow the proposed groundwater monitoring wells to be placed in the vicinity of shale gas well site. This process is currently underway and in discussions. The DOE-EPA-USGS team will make joint decisions about well locations, depth, aquifer zones, and water sampling once a site is positively identified and selected. In addition to periodic, synoptic groundwater sampling, the wells will be outfitted with real-time monitors for water levels, pH, conductivity (TDS), turbidity, DO, temperature, and possibly headspace gas.

Future efforts will include making contacts with other shale gas drillers in other areas for similar access. Comparison studies on other shale plays are needed to more fully understand the possible effects of shale gas development on underground sources of drinking water.