Workshop to Develop Recommendations for Environmental Monitoring Related to Unconventional Oil & Gas Extraction

December 12 – 13, 2013

Workshop Proceedings

Co-sponsored by:
Center for Health and the Global Environment at Harvard (CHGE)
Mid-Atlantic Center for Children's Health & the Environment (MACCHE)[1]
Health Effects Institute (HEI)
Natural Resources Defense Council (NRDC)

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All materials including this report and links to presentations are available at http://www.nrdc.org/health/14053001.asp

Meeting Overview

On December 12 – 13, 2013, a group of about 40 scientists and technical experts in air and water monitoring met to discuss best practices for conducting air and water monitoring for oil and natural gas production sites that use unconventional oil and gas extraction techniques involving horizontal drilling combined with hydraulic fracturing. The goal of the workshop was to identify consistent expert-vetted procedures for air and water monitoring that can inform federal, local and state discussions and policies, community investigations, and research studies. Pollution concerns range across all stages of the unconventional gas extraction process, including pad construction, drill set-up, drilling, hydraulic fracturing, oil or gas extraction, well decommissioning, and land restoration. Discussions considered all of these potential routes of pollution.

The workshop was co-sponsored by the Harvard Center for Health and the Global Environment, the Mid-Atlantic Center for Children's Health & the Environment (MACCHE)[2], the Health Effects Institute (HEI), and the Natural Resources Defense Council (NRDC). Paul De Morgan and Dana Goodson of RESOLVE facilitated the meeting and developed this summary. For a full list of attendees, see Appendix A. (Attendees' names and affiliations are listed for identification purposes only, and do not constitute an institutional or personal endorsement.)

These Workshop Proceedings are a reporting of the discussions, but do not represent a consensus of recommendations for monitoring. A future document is being drafted that will make recommendations for air and water monitoring.

This document is a product of the steering committee:

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The attendees first met in plenary to hear and discuss a series of presentations. They then moved into two rounds of three breakout groups for more in-depth discussions of monitoring practices and requirements. The first round focused on air monitoring and the second on water monitoring. Each breakout group considered recommendations for monitoring actions designed for one of the following scenarios: 1) a community investigation (i.e., citizens, city, county, state health officials), 2) a state or federal program (i.e., regulatory compliance of surveillance), or 3) a health study (i.e., epidemiological or clinical investigation). For more details, see the agenda (Appendix B) and the discussion guide (Appendix C). On the second day of the meeting, the participants again met in plenary to discuss the key takeaway messages from the breakout discussions and to explore crosscutting themes. Notes from the breakout sessions can be found in Appendix D.

Presentations

To see presentations please visit NRDC's webpage at http://www.nrdc.org/health/14053001.asp

Keynote Address: Role of Monitoring in Addressing the Impact from Oil and Gas Development
Bernard Goldstein, MD, University of Pittsburgh Graduate School of Public Health

In delivering the keynote address, Dr. Goldstein described the process through which shale gas drilling activities can lead to human exposure to toxicologically relevant agents, which may result in health effects. He discussed the challenges of monitoring for these agents, including uncertainty about 1) the time and location of all relevant releases; 2) the intermediate pathways for exposure; and 3) the identity of the chemical and physical agents themselves. He noted that a lack of transparency and accessibility of relevant data poses a major challenge to carrying out exposure studies related to shale gas development.

Observing that occupational and public exposures are likely, given numerous opportunities for exposure to occur, and noting the potential seriousness of health impacts, he espoused Willie Sutton's Law – a robber who targeted banks because "that's where the money is" – i.e., going directly to the problem to measure exposure or effects in receptors of concern. Dr. Goldstein questioned the rush to development and advocated waiting to learn more about potential health effects before drilling.

Overview of Sector and Governance: Current Practices and Future Projections

Sarah Jordaan, PhD, University of Calgary

Dr. Jordaan explored the key questions and challenges arising from its rapidly increasing development, as well as current practices for addressing some of those issues. She pointed out that it is important to be aware of where the emissions come from and referred to a graphic of the natural gas production life cycle, which illustrated the multiple points at which leaks and emissions can occur – including from wells, impoundments, and compression stations – all of which require different monitoring approaches.

With regard to air monitoring, key challenges include measuring fugitive emissions of methane, nitrogen oxides, and volatile organic compounds (VOCs) and accurately attributing these emissions to their source. For water monitoring, water quality challenges include ensuring well-bore integrity; handling chemical spills; managing, treating, and disposing of wastewater; characterizing the fluids used; and preventing leaks from impoundments. The potential for induced seismicity could also pose a threat to groundwater supplies. There is continuing controversy surrounding the source of methane contamination in water wells or direct leaks to the atmosphere, with existing studies indicating the need for baseline monitoring.

Bearing in mind both the potential environmental benefits from the displacement of coal and the potential environmental impacts, Dr. Jordaan suggested that solutions could be found through a combination of adequate monitoring and transparent reporting. In light of the anticipated growth in the sector, she urged that challenges be faced sooner rather than later.

Perspectives on Health Implications and Data Needs: Health Department Perspective

Clifford S. Mitchell, MD, MPH, Maryland Department of Health and Mental Hygiene

Dr. Mitchell described the state of Maryland's approach to developing data on unconventional oil and gas extraction and offered some insights about state needs with regard to oil and gas development. In 2011, Governor O'Malley signed an executive order creating the Marcellus Shale Safe Drilling Initiative, which aims to establish whether or how unconventional gas production can be accomplished in Maryland "without unacceptable risks of adverse impacts." Under this initiative, a multi-stakeholder advisory commission, charged with making recommendations on funding mechanisms, liability standards, and best management practices, will provide its report to the governor by August 2014. Accordingly, the Maryland Department of the Environment and the Department of Health and Mental Hygiene have established a public health project that will provide a baseline public health and impact assessment for the state's population and makes recommendations on monitoring and assessment before, during, and after extraction operations.

With regard to the work to be carried out under the assessment project, Dr. Mitchell stressed the importance of attention to sentinel events (events that signal the need for investigation and response) and the need for the free flow of information related to potential hazards and exposures. He also stressed the need for a robust baseline assessment of groundwater for drinking water, the value of learning from states and communities that are already engaged in extraction operations, and the importance of sharing information between the public health sector and clinicians. On the topic of exposure, he noted that the perception of exposure could be as important as actual exposure.

Perspectives on Health Implications and Data Needs: Community Perspective
Raina Rippel and David Brown, PhD, Southwest Pennsylvania Environmental Health Project (SWPA – EHP)

Ms. Rippel and Dr. Brown spoke from their experience working from a public health perspective with communities in southwest Pennsylvania that have been experiencing natural gas development. Ms. Ripple cautioned that affected communities have little trust in regulatory agencies or the research community, due in part to a lack of transparency. In order to work with communities, she stated that researchers would need to collaborate with on-the-ground groups like EHP that have earned community trust. The two speakers noted that the promise of bottled drinking water provided by the industry and the threat of cessation of provision have been used to inhibit residential complaints or health reports when water wells are contaminated.

Due to his work with local communities, Dr. Brown concluded that regulatory compliance monitoring fails to identify acute exposures and underestimates the health impacts. EHP has gathered reports of acute onset health effects including respiratory, neurologic, and dermal conditions at natural gas development sites in southwest Pennsylvania. Air monitoring reports from the Pennsylvania Department of Environmental Protection (PADEP) and others do not show a link to these health outcomes because the data used are averages and do not capture potentially harmful short-term variable exposures, such as those caused by changing weather patterns. Furthermore, federal and state environmental standards are not helpful for evaluating human health effects because they are designed to capture chronic stable exposures, not the acute, episodic, and variable exposures that are occurring.

To design an effective monitoring program, Dr. Brown recommended using nested protocols with at least one "real time" measure of exposure. For example, he suggested continuous sampling to identify and quantitate peak exposure periods, a quantitative composite sample for periods of 24 hours or more to identify chemical pollutants and a site specific measure of air dilution for periods of 6 hours or less conducted over a period of 1 week. The program should: 1) measure exposure patterns using surrogate chemicals; 2) characterize the components of mixtures; and 3) characterize short-term local air dilution due to weather conditions.

Perspectives on Health Implications and Data Needs: Environmental Health Research Perspective
John Adgate, PhD, University of Colorado

To address public health concerns with regard to unconventional oil and gas extraction, Dr. Adgate observed that researchers would need to monitor both exposures and health effects. Given that the industry is changing quickly, it is hard for researchers to keep pace so that they are examining the impacts of current technologies and practices. Dr. Adgate presented a graphic depicting the range of health effects to consider, correlated with their geographic scale – well site, local, regional, and global. He also gave an overview of the current research on the environmental health effects of oil and gas development for both water and air quality.

Remaining unanswered questions include the spatial and temporal variability in exposures and reported health effects; the variability in non-methane pollutant emissions; and the minimum setback needed between well sites and communities. Public health research is needed on: 1) concentration levels in air and/or water for a range of stressors and/or toxicants; 2) human exposures; 3) health outcomes, including the effects of chemical mixtures and stress; and 4) community impacts, including noise, traffic, and accidents. Dr. Adgate noted that it is important to understand cumulative risk.

Perspectives on Health Implications and Data Needs: Industry Perspective
Dennis Devlin, PhD, Exxon Mobil Corp

Noting that natural gas plays a key role in the U.S. economy, Dr. Devlin pointed out that hydraulic fracturing is an industrial operation and carries the attendant risks and benefits. Issues to consider include the effects of hydraulic fracturing fluids and flowback on water quality; the impacts of VOCs, ozone, and methane on air quality; stress, including that caused by the belief that one's health is being impacted; and occupational hazards such as silica and injuries. There are limited scientific data available on these health issues. In addition to meeting regulations, Dr. Devlin stated that operators have a responsibility to use and share sound practices; to seek improvements to those practices; to work with local communities to minimize impacts; and to encourage research on potential health impacts. He also clarified that service companies like Halliburton do much of the work on site and therefore producers like ExxonMobil's subsidiary XTO must coordinate with them on developing good practices.

Dr. Devlin described industry efforts to address some of the questions on potential health impacts. The industry association, the American Petroleum Institute (API), is currently revising its standards for environmental monitoring, well integrity, and community relations; the updated standards should be available within the next year. API has also formed an Exploration & Production (E & P) Health Issues Group to focus on the potential community health impacts of unconventional gas development. Its current areas of focus are: 1) occupational studies on silica exposure; 2) methods to rate the hazards of chemicals used in hydraulic fracturing, estimate exposures, and communicate risks; and 3) analysis of available data on the impact of unconventional resource development, with a focus on short-term health endpoints. He indicated the need to strike a balance between protecting confidential business information (CBI) and disclosing necessary public health information.

Monitoring Technologies and Approaches: Air Quality
Barbara Zielinska, PhD, Desert Research Institute

Dr. Zielinska gave an overview of air monitoring techniques for unconventional oil and gas operations. She first reviewed the life cycle of shale gas, noting that the lifetime of a single well from exploration to closure and remediation can extend up to several decades. Seventy to ninety percent of produced raw gas is composed of methane, which, despite its relatively short ten-year lifespan in the atmosphere, has a high greenhouse gas impact. Dr. Zielinska reviewed each stage of the natural gas production life cycle and the emissions of concern at each stage. Observing that a significant amount of natural gas is lost annually through leaks, she pointed to a study that found 3,356 methane leaks linked to natural gas over a three-month period in 2011 (Phillips et al, 2012).[3]

Dr. Zielinska then reviewed three types of air monitoring methods – continuous, time-integrated, and fixed-location measurements. In closing, she highlighted the need for baseline air quality measurements; chemical characterizations of emissions during all life cycle stages; more data on the extent of methane leaks; information on emissions from retired and abandoned wells; and measurements of the variation among air emissions from the different oil and gas plays. She concluded with a call for increased collaboration between industry and scientists to allow for the creation of effective emissions monitoring and reduction strategies.

Monitoring Technologies and Approaches: Drinking Water

Alan Roberson, PE, American Water Works Association

Mr. Roberson explained that the American Water Works Association represents community water systems as defined by the Safe Drinking Water Act and does not encompass private wells or small suppliers. From a water quality point of view, potential impacts include groundwater contamination; surface water contamination; land use impacts and storm water quality; induced seismicity from disposal wells; and water use volume and timing.

Mr. Roberson discussed state water monitoring requirements and their limitations. While some states require pre- and post-drill sampling, those requirements are not uniform. Most require that one to three samples be taken, but given day-to-day and seasonal variations, that number is often insufficient to capture water quality accurately. Pointing out that public water systems already monitor for over 90 regulated contaminants, he asked if utilities should monitor for other constituents.

Monitoring challenges include attributing water quality changes to their source and integrating sampling results across a watershed or aquifer. To confront these challenges, Mr. Roberson indicated the need to establish baseline conditions. It will also be necessary to arrive at a better understanding of what to monitor for, how often, when, and how. An example of a good monitoring program is one conducted by a utility in Garrettsville, Ohio that was concerned about the future impacts of drilling.

In closing, Mr. Roberson emphasized that this country should not have to choose between energy development and clean water, but should have both – and that better collaboration between water systems, industry, and scientists is needed to reach that goal.

Monitoring Technologies and Approaches: Exposure Monitoring for Human Health, Workers, and Community

Aubrey Miller, MD, PhD, National Institute of Environmental Health Sciences

Dr. Miller began by cautioning that it is generally difficult to identify exposures, particularly for health outcomes that have long latencies; furthermore, representative exposure data are lacking in areas

[3] N. G. Phillips et al., "Mapping Urban Pipeline Leaks: Methane Leaks across Boston," *Environmental Pollution* (2012), http://dx.doi.org/10.1016/j.envpol.2012.11.003. For more information, see http://www.bu.edu/cas/2012/11/20/thousands-of-natural-gas-leaks-discovered-in-boston/.

where oil and gas development is taking place. In order to have an informed risk assessment process, four components are necessary – hazard identification, exposure assessment, and dose-response assessment, which feed into the fourth component of risk characterization. Dr. Miller then discussed the types of potential health risks posed by oil and gas development, including chemical use, air pollutants, and community health impacts (e.g., noise, road dust, and psychosocial effects associated with boom-and-bust cycles of oil and gas development). With regard to chemicals, he noted that over 1,000 chemicals are used in hydraulic fracturing, but their identification is limited by the nondisclosure of trade secrets, low penalties for failing to report, and varying reporting timelines.

When conducting an exposure assessment, Dr. Miller explained that it is necessary to consider exposure duration; intensity and frequency; route of exposure; mixtures and cumulative effects; sampling; acute vs. chronic effects; and the susceptibility of vulnerable populations. It is very difficult to determine exposure related to unconventional oil and gas development without having baseline exposure data, so it is a key research need in areas where hydraulic fracturing will take place. Other research needs include health studies on both acute and long-term health effects as well as on community impacts and psychosocial stressors; toxicological studies on hydraulic fracturing fluids and mixtures; and research on air emissions, water quality, surface soil contamination, and contaminants in homes. He emphasized the importance of involving communities and citizen scientists in the research. He noted that several government studies on unconventional oil and gas development are underway, including a collaborative effort between the US Environmental Protection Agency (EPA), the US Geological Survey (USGS), and the US Department of Energy (DOE). There are also several health studies taking place under the auspices of the National Institutes of Health (NIH) and National Institute of Environmental Health Sciences (NIEHS).

Plenary Discussions

In the discussions following the panel presentations, participants raised a number of key points:

- Different chemicals may be used in oil development compared with gas development (one participant noted that they had not seen different chemicals in oil versus gas development), so it is worth considering the different potential impacts between drilling for oil versus gas.
- There are many existing data on conventional oil and gas development that could help create monitoring plans.
- Environmental monitoring must be tied to specific activities in unconventional resource development. A strong link between process and emissions is critical to informing sustainable drilling techniques and motivating their implementation.
- Health outcomes should be tied to measured or estimated exposure. To do so, health information needs to be matched to specific physical addresses – county-wide data is not specific enough because exposure can be highly variable. Exposure monitoring could include personal monitors, indoor air monitoring, and biomonitoring.
- It is difficult to achieve enough statistical power in epidemiological studies because hydraulic fracturing often takes place in low population density areas. Cooperative studies across centers can help to attain the necessary statistical power.
- Given the potential for the formation of ultrafine particles, it is important to monitor for this size particulate matter (PM) and determine whether it is due to direct emissions or secondary formation.

- Studies need to consider micrometeorology resulting from topographical characteristics, such as rolling hills, canyons, etc.
- Monitoring should take into account cumulative emissions from multiple well pads and other adjacent/nearby drilling-related activities (compressor stations, truck traffic, processing plants, etc.).
- There is a great need to pool data both within and across states to gain more certainty in determining exposure attribution and establishing links to health effects.
- Due to confidential business information (CBI) concerns, producers are not informed of all the substances that service companies are using onsite. There is an API ad hoc group working on how to share hazard assessment information between companies (without identifying specific chemicals).
- Other methane monitoring studies have reached different conclusions from the Allen et al (2013) study that found methane emissions that were similar to the EPA inventory of natural gas emissions. Petron et al. (2012) found that approximately 4% of produced methane ends up in the atmosphere, and a recent Harvard study (Miller et al, 2013) found that methane emissions might be 1.5 times higher than EPA estimates.[4] Allen et al also reported emissions from pneumatic controllers and equipment leaks were higher than EPA national emission projections.
- To focus monitoring, researchers could first look at wet gas[5] (due to its potentially higher content of VOCs/toxics) by producing a heat map of the location of oil and gas plays.
- The ability of researchers to access sites is an issue that hinders monitoring efforts. Off-site remote monitoring could be done, but it should be linked to the well development process.
- Monitoring surrogates of contamination may be cheaper and easier, but the relationship to contaminants must be characterized. One participant suggested that chloromethane might be a good surrogate of water contamination that could be easily measured.
- The Texas Commission on Environmental Quality has ten years of unpublished monitoring data for ambient air VOCs in the Barnett Shale.[6] These data could be very useful for researchers.

[4] Scot M. Miller et al, "Anthropogenic Emissions of Methane in the United States," Proceedings of the National Academy of Sciences of the United States of America 110, no. 50 (December 2013): 20018-22.

For more information, see http://news.harvard.edu/gazette/story/2013/11/u-s-methane-emissions-far-exceed-government-estimates/.

[5] Wet gas contains compounds like ethane and butane (called natural gas liquids, or NGLs), in addition to methane. Gas extracted from the Marcellus Shale in southwestern Pennsylvania is wet gas. In contrast, dry gas is essentially methane. For more information, see http://stateimpact.npr.org/pennsylvania/tag/natural-gas-prices/.

[6] See http://www.tceq.texas.gov/airquality/barnettshale.

Breakout Group Reports

After meeting in breakout groups to discuss air and water monitoring from the perspective of a community investigation, a state or federal program, or a health study, participants reconvened in plenary to hear and discuss the results from the breakout sessions (see Appendix D for reports from the breakout groups).

Monitoring Approach

Some of the breakout groups' suggestions pertained more broadly to both air and water monitoring. The health study breakout group recommended thinking about designing monitoring programs in a systematic way (see Figure 1) that has both spatial (on the well site, near it, or downstream) and temporal (long and short-term) dimensions for both acute and chronic health effects throughout the stages of development and production. Participants designed this figure as a depiction of the different parameters that monitoring should address.

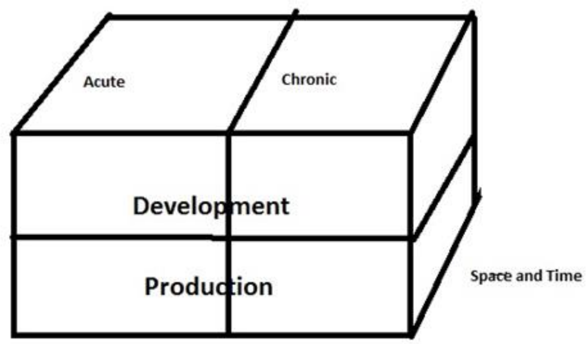

Figure 1. Monitoring Program Framework

Researchers should define the dimensions of the monitoring study by identifying relevant outcomes of interest and the biological plausibility relationship to activities at the well site (or more broadly to several wells across a larger oil or gas field), the timeframe and intensity of those activities, and the proximity of those affected to the well site.

The community investigation group proposed a three-step approach to monitoring that included community engagement, scoping, and a sampling plan. A comprehensive monitoring plan should include a list of potential toxicants identified in the scoping phase, appropriate monitoring equipment for identifying environmental concentrations, and the health-relevant limits of detection. Participants pointed out that a comprehensive list of chemicals used in hydraulic fracturing is necessary, as is an understanding of the constituents contributed by the subsurface geology in the region. This table can help determine the ease of use and cost of each method and aid in decision-making about which approaches and tools are most appropriate to use in monitoring at a specific site. One participant suggested looking at the quantitative limits of the method rather than relying on the detection limits asserted by the equipment vendor.

Common Themes

The following issues and recommendations emerged in both the air and water monitoring discussions across more than one scenario:

- **Baselines:** Developing baselines is essential to both air and water monitoring. For water monitoring, Total Dissolved Solids (TDS) meters could be given to residents to establish a baseline for their tap water and to detect changes in water quality. In some cases, other similar communities without oil and gas development could be used as a baseline. It was suggested that existing data (e.g., USGS data from National Water Quality Assessment Program, the produced water database, and the National Health and Nutrition Examination Survey [NHANES]) could be mined to help establish background information and that researchers and industry could work together in attempting to answer these questions. One participant noted, however, that the retrospective mining of existing databases for baseline is of limited usefulness; the original analyte lists, site locations, scale, scope, and objectives of the existing monitoring data are often inadequate to define baseline for new purposes. Consequently, it is important to establish an *a priori,* rigorously defined monitoring design that addresses the key objectives required to define a baseline. The best use of the existing databases, therefore, may be to inform the design of a new monitoring effort that establishes baseline. Baseline monitoring should begin as soon as possible.

- **Chemical analysis:** All the groups agreed on the need to identify the chemicals used at each stage of the unconventional oil and gas development process as a high priority. In the air monitoring discussion, a comprehensive analysis of the chemicals used at several individual well sites at different geographic locations was suggested. Participants identified several such studies that are underway or in planning stages and agreed that it would be useful to share an inventory of the studies and their results. For water monitoring, it is essential to understand the components of hydraulic fracturing fluids, drilling muds, spills, and flowback/produced[7] water in order to develop a good list of constituents to monitor. An accompanying effort to develop new laboratory methods to detect these analytes (where none exists now) is essential.
- **Community involvement:** Throughout the meeting, participants frequently referenced the need to engage citizens from communities where oil and gas development is taking place. Depending on the monitoring objectives, community involvement might provide useful insight. Of course, whenever community concerns are involved, timely reporting of findings, along with appropriate interpretation in the context of health impact assessment, should be a standard procedure. Community engagement should entail clear communication with residents about monitoring objectives, methodologies, and limitations. New sensor technologies adapted to mobile phones are emerging, which will make citizen participation in time- and location-positioned data and observations feasible. NIEHS, which requires many of its funded projects to have community participation components (community-based participatory research [CBPR]), offers a successful model of community engagement.[8] It is important to involve those in the community who are suffering from worry and anxiety, such community members may be the most heavily impacted and at the highest health risk.
- **Timing:** Given that air emissions associated with hydraulic fracturing operations are often episodic, it is essential that a monitoring strategy include multiple locations and ancillary monitoring to meteorologically resolve incidents above background. In the air quality discussion, participants suggested using both continuous and wind-direction-activated interval sampling methods.
- **Sentinel events:** Pets, livestock, and wildlife may experience exposure patterns different from humans and express adverse outcomes that can serve as sentinel events, signaling the need for

[7] The terms "flowback" and "produced" water are often both poorly defined and misunderstood. "Flowback" usually refers to the first proportion of fluid that flows back to the surface after an oil and/or gas well has been stimulated. "Produced water" is the fluid that comes to the surface for the remainder of the life of the well. Flowback fluid is often predominantly fracturing/stimulation fluid, with some formation water in it as well, and the ratio decreases over time. For this workshop report, unless otherwise specified we are referring to both flowback and produced water.

[8] For more information, see http://www.niehs.nih.gov/research/supported/dert/programs/justice/.

investigation and response. Patterns of human morbidity are often difficult to discern, especially when the suspected source or sources are widely dispersed with periodic or episodic releases. This is especially true for rural operations. It may be possible to discern trends and patterns of aberrant health, however, by analyzing the medical records of health care providers. Health incidents associated with upset conditions such as blowouts, spills, or the installation of particular facilities may provide information as sentinel events.

- **Vulnerable populations:** Monitoring programs need to account for vulnerable populations, such as children and the elderly, by ensuring that monitors are placed in schools, childcare centers, and nursing homes.

Air Monitoring

Community Investigation

As mentioned above, the community investigation breakout group set out the following three-step model for a monitoring approach:

- **Step 1 – Community Engagement:** The group emphasized the importance of academic and government researchers working with the community to engage residents before the research begins. Community members can often be a good resource to help understand where and when potential air pollution exposures are likely to occur. Researchers should work with residents to understand the questions that the community wants addressed, their concerns, and the relevant resources that are available - including funding, skills, and knowledge. A workshop participant pointed out that researchers also should notify state and local health departments early on in the process to avoid frustrating the local community with repeated research requests. Coordinating on a state and regional level can also contribute to the pooling of data within and across states to develop greater statistical power.
- **Step 2 – Scoping:** In the scoping phase, researchers should undertake these activities:
    - Identify any ambient air quality monitoring sites and other pre-existing monitoring resources to determine their availability and relevance for a particular community. Ambient air monitoring systems often, but not always, monitor air quality that is relevant at the regional scale - but not at the local scale, nor near the emission sources where elevated exposures can occur.
    - Perform an initial health assessment that gathers data on affected residents' symptoms, health status, and medical history.
    - Learn about the sources, proximal sources, phases of well development, and known contaminants.
    - Become familiar with the meteorology, geography, and topology of the local landscape.
- **Step 3 – Sampling Plan:** The community investigation breakout group outlined the following aspects of a sampling plan:
    - **What to monitor:** Using a tiered approach to evaluate what to monitor and how, the research team could consider total particulates, fine particulates, hydrogen sulfide, benzene, and other VOCs or semi-volatile organic compounds (SVOCs) for air quality monitoring. Noise monitoring can also be done.
    - **Where and when to do it:** Monitoring should be as comprehensive as possible – at a minimum, it should take place both upwind and downwind from well sites. It is necessary to capture wind speed, wind direction and degree of insolation (solar radiation or cloud cover) to predict periods of air stagnation. Ideally, there would be

monitoring in multiple directions, as well as both indoors and outdoors, in order to get a broader picture. Monitoring should take place at sites with vulnerable demographics such as schools, childcare centers, and nursing homes at appropriate times of day to capture when people are present. Furthermore, the program should be coordinated with local first responders so they will be notified in the event of an emergency.

- **How to do it:** Two methods are needed - integrated sampling, and a method that captures both peak exposure times and the incidence of complaints. The data collected should be geocoded and time-stamped, using security methods to protect privacy. Samples should be archived for future analysis as methods improve over time. Citizens can participate by collecting observations via mobile devices, recording symptoms in diaries, and detecting odors. When citizen scientists are involved, it is important to provide them with training; it is also helpful to check in with them on a weekly basis about their symptoms. There are existing protocols for working with citizen scientists to collect evidence.[9]

During the discussion of this proposed model, some observed that although biomonitoring is often of interest to residents, it is of limited usefulness because the results are difficult to interpret unless researchers are monitoring for a specific chemical and there is a clear connection to an exposure. Other participants indicated there are ongoing biomonitoring efforts and syndromic surveillance tools that could be useful for research. Biomonitoring studies conducted before, during, and after a well system is operating can help inform whether community members are in contact with contaminants. Cortisol and indicators of inflammation were mentioned as possible biomarkers of effect. Researchers could look at emergency department utilization and patterns of complaints, as well as patterns in the lab reports of the tests run by health practitioners. Exposure patterns in animals can also be considered. One issue is the lack of good background data. Researchers need to work with statisticians to gain a better understanding of how to use the population biomonitoring data from the Centers for Disease Control and Prevention's (CDC) National Health and Nutrition Examination Survey (NHANES).

With regard to the related topic of noise, participants observed that the research evidence of adverse health consequences from noise exposure is sufficiently well established to support the standards set by the European Union. Workshop participants thought noise generated from condensers, electrical generators, pumps, drilling, trucks, compressors and other sources associated with oil and gas exploration and production can be of great concern to communities and should be included in monitoring efforts. The volume, tonal quality, frequency and vibration, periodicity, and timing of sound disturbances are relevant to health and can be readily monitored. Mobile phone apps offer a variety of decibel meters that can be used by citizens to develop patterns of sound impact.

Participants also identified the following available resources:

- FrackMap is an open-source GIS platform at Harvard that could be used as a central database.[10] The map provides the GPS coordinates for thousands of active wells in the United States. Users can create a local version of the map and populate it by geographically identifying key

[9] For example, see Texas Commission on Environmental Quality webpage on Gathering and Preserving Information and Evidence Showing a Violation: https://www.tceq.texas.gov/complaints/protocols/evi_proto.html

[10] FrackMap is available here: http://worldmap.harvard.edu/maps/FrackMap.

information, including the location of vulnerable populations, monitoring data, observations and health reports.
- A "researcher response" website by the National Institutes of Environmental Health Sciences (NIEHS) is under development and will soon be hosted by the National Library of Medicine. It will provide a repository for instruments such as surveys, tools, and protocols that the research community can use during emergency events or other emerging threats.
- There is a DOE database called the Energy Data Exchange (EDX) with a focused collection of databases related to unconventional resource development. Examples include formation depth maps, well location data, Class II injection well databases, and other geophysical data.[11]
- The Council of State & Territorial Epidemiologists is working on surveillance for non-infectious diseases and evaluating syndromic surveillance tools on how they might be used.[12]

State/Federal Program

The state and federal program group pointed out that the design of an air monitoring program will depend on its objectives; once those are determined, monitoring tools can be chosen accordingly. If the goal is to understand reactive hydrocarbons and their contribution to regional ozone pollution, researchers can employ integrating monitoring tools like Picarro methane analyzers and air towers. For the general detection of air emissions on a larger scale, flyovers with infrared cameras are one option, albeit an expensive one. Such screening techniques can be used to identify high-priority areas for further monitoring on a finer scale. Then, in order to determine concentrations, researchers can use fixed monitors for a broad range of pollutants and look for peaks that lead to acute exposures as well as chronic concentrations. Comparing these results to short- and long-term action levels will help officials to prioritize enforcement actions.

To identify areas that need more detailed study in a community, tools such as passive monitors, canisters, filters, and mobile monitors are suitable. If the intent is to determine emission rates and develop source signatures, then monitoring in close proximity to equipment and operations is required. To evaluate emissions, researchers should monitor close to the source and characterize chemicals and other temporal and auditory cues in order to match emissions to specific processes. Source signatures can also assist with attribution.

In another approach to tracing emissions back to sources, researchers can use continuous monitoring methods in combination with GIS, meteorology data, and air modeling (note that continuous methods are usually not high-resolution and provide a limited number of species). For example, a Picarro analyzer can measure methane with high sensitivity and time-resolution, but not other hydrocarbons at the same time.[13] Open-path Fourier transform infrared (OP-FTIR) spectroscopy is a speciating measurement (i.e.,

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[11] See https://edx.netl.doe.gov/.

[12] The fundamental objective of *syndromic surveillance* is to identify illness clusters early, before diagnoses are confirmed and reported to public health agencies, and to mobilize a rapid response, thereby reducing morbidity and mortality. See, for example: http://www.cdc.gov/mmwr/preview/mmwrhtml/su5301a3.htm

[13] The Picarro provides precision, real-time carbon isotope information for ambient methane, and can be used to distinguish between various sources of methane. For example, it can be used to identify the origin of methane in groundwater near a hydraulic fracturing well or monitor fugitive methane emissions. For more information, see http://www.picarro.com/products_solutions/isotope_analyzers/13c_for_ch4.

only measures specific compounds); it can provide information on some specific hydrocarbons such as methanol, but not total hydrocarbons in a mixture such as oil and gas emissions.

Decisions on monitoring locations might call for collaboration between industry and community groups and should include the following considerations:

- Wind direction
- Wind speed and cloud cover
- Number of wells
- Population demographics
- Environmental justice issues and community concerns
- Practical issues, such as access to suitable monitoring sites (e.g., electricity)
- Background monitoring to establish "upwind" conditions and/or air quality and water quality prior to well development

It might be necessary to modify or supplement a monitoring program to acquire more finely resolved temporal and spatial data. For a best practice when collecting data, a participant suggested that researchers add a representative subsampling in order to get a picture of actual exposure (not simply using the regulatory standards). It would be interesting, if challenging, the participant added, to test this approach at a number of sites.

Community residents can participate in some monitoring activities using canisters, ultrafine particle monitors, or solid adsorption cartridges and hand pumps. It is often difficult to pinpoint the source of emissions, especially given the temporal nature of the emissions and the fact that there can be multiple pieces of equipment from different companies on one well pad.

The group noted several unresolved issues, including whether VOC ratios can be used for source attribution; whether the monitoring strategy would be replicable across locations; how post-production wells (plugged and abandoned wells) can be monitored; and how to identify and assess important occupational exposures. A participant raised the idea of creating a fund for monitoring activities, suggesting that impact fees be allocated to monitoring the impacts of development.

Health Study

The health study group focused its discussions on the short-term health outcomes or exposures that might occur in closer proximity to the well site. They felt that health assessments should cover the entire production cycle of well sites and associated sources while considering critical nearby facilities such as residences, childcare centers, nursing homes, and schools. An initial objective of a health study is to establish a case description. Group members advised that regulatory standards should not form the basis of a monitoring program because they would not allow for the collection of the necessary range of information. Thus, the group suggested focusing assessment activities on the population's health status, and in particular looking at nosebleeds; respiratory effects and asthma; skin rashes; and birth outcomes, including birth weight. It may be useful to work with school nurses, community health workers, and treating physicians to identify these conditions, which can serve as sentinel events. Worker complaints could also serve as sentinel events; a list of work-related exposures could help identify health impacts.

Pollutants of interest include VOCs, methane, and particulates, including coarse particles; PM2.5 and ultrafine particles; and air toxics. Participants discussed the difficulty of correlating ultrafines with hydraulic fracturing activity because they can come from any combustion source. It was pointed out however, that most hydraulic fracturing sites are in rural areas where high levels of ultrafines are less typical, so ultrafine particles might be about 5,000 particles per cubic centimeter (p/cc), making it relatively easy to identify ultrafine particles coming from combustion sources, such as compressors, generators and trucks. At sites in West Virginia, researchers did look at elemental and organic carbon, but it was not informative as organics tended to correlate with truck traffic rather than the site. With regard to diesel trucks, some pointed out that the technology is changing rapidly and that there should be a dramatic reduction in particulate emissions from post-2007 trucks and trucks retrofitted to comply with EPA 2007 standards.

The group thought there might not be any good surrogates to monitor for, although methane is one possibility. Another suggestion was to measure the ratios of butane and other isomers to use as a fingerprinting tool.

In order to characterize emissions at each stage of well development, the health study group recommended comprehensive assessments of particulates, nitrogen oxides, and VOCs at individual wells. Some participants in the health study group urged monitoring at the site as well as conducting continuous monitoring at a distance. A challenge for air monitoring is being able to attribute health effects to a particular facility. If emissions can be understood in the acute phase, then researchers can do sampling in the home. One participant added that it is important to look at emissions on the scale of the multi-well pad in order to obtain a cumulative emissions profile. Another cautioned that researchers need to pay attention to hourly changes in dilution when monitoring at a particular site.

Additionally, top-down monitoring at the regional scale is important in order to capture emissions from sources that might not be measured in bottom-up studies.[14] For example, emissions of methane and VOCs have been detected during the drilling phase, but many studies have not included drilling emissions because they were assumed negligible.

When it comes to fugitive methane emissions in the natural gas sector, top-down studies (i.e., Miller et al. 2013; Petron et al. 2012; Peischl et al. 2013) have consistently estimated higher emissions of fugitive methane than bottom-up studies (Allen et al. 2013). This is likely due to a number of factors, including missing or unknown emission sources (for example, drilling emissions). Additionally, a limited understanding of the probability distribution function of methane emissions across geographic and corporate space in oil and gas production makes it difficult for researchers conducting bottom-up studies to be sure that they are generating a representative sample of fugitive methane emissions across the United States (Brandt et al. 2014). Top-down monitoring, verified with bottom-up measurements, will enable researchers to be sure to identify all relevant emission sources.

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[14] Top down monitoring is monitoring that occurs often at a regional scale (i.e., flyovers, tall towers) and measures the *ambient concentrations* of pollutants. Often top-down monitoring is combined with other methods to attempt to distinguish the sources from which emissions in the atmosphere originated ("source apportionment"). Bottom-up monitoring involves measuring or modeling *emissions* from specific sources and adding them together to develop an emissions inventory. Different methods (e.g., atmospheric modeling and dispersion modeling) can be used to estimate atmospheric concentrations.

Plenary participants identified the following studies that include monitoring of a well site from the beginning to the end of the development process:

- Michael McCawley at the West Virginia University School of Public Health is conducting a comprehensive study.
- The Fort Worth, TX study was information-rich, if not comprehensive. The study looked at air quality associated with natural gas development in the Barnett Shale.
- Jeff Collett at Colorado State University is doing a study in Garfield County, Colorado and the results will be available in 2015.
- The National Energy Technology Laboratory (NETL) is running a program in Pennsylvania at both wet and dry gas sites.
- The National Institute for Occupational Safety and Health (NIOSH) and NETL are doing a study involving both worker and community exposure monitoring over the next few years.

Participants observed that it would be useful to have an inventory of such studies.[15]

Water Monitoring

Community

Drawing on the three-step model it developed, the community investigation group offered its approach to water monitoring:

- **Step 1 – Community Engagement:** The group reiterated that the first step in a monitoring program should be engaging with the community. The principles for engagement articulated previously should be followed here as well.
- **Step 2 – Scoping:** Researchers should undertake the following activities:
    - Identify the community's water sources and determine routes through which these resources might be impacted. Researchers should consider the water sources people and animals come into contact with through drinking, cooking, and bathing. One difference between air and water monitoring is that there can be ownership of water resources. Researchers have sometimes had difficulty accessing sites, particularly if homeowners have signed nondisclosure agreements. Research teams might therefore need to work with industry and local regulators in order to gain access to certain sites.
    - Identify available, relevant data.
    - Work with citizens to track water characteristics and any health symptoms they might have.
    - Identify contaminants of concern, such as fracking fluid components, drilling mud components, and flowback water.
    - Become familiar with the characteristics of the aquifer and understand local groundwater flow, as well as surface water characteristics. Researchers should also determine how oil and gas development wastewaters are handled and where they go in order to prioritize pathways.
- **Step 3 – Sampling Plan:** The community investigation group recommended the following framework for a sampling plan:

[15] Since the meeting took place, NRDC has hired a consultant scientist to develop and update such an inventory.

- **What to monitor for:** Using a tiered approach[16], a sampling plan could look for specific chemicals (e.g., total dissolved solids [TDS], salts, methane, hydrocarbons, glycols, biocides, disinfection byproducts, and radionuclides) or look for water attributes such as toxicity to indicator organisms (e.g., zebrafish) as a potential indicators of exposure. Comparing the chemicals used in hydraulic fracturing with those regularly subject to monitoring by public water systems could yield a set of untracked chemicals to seek.
- **Where and when to do it:** The monitoring plan should involve sampling in different locations, chosen based on the understanding of the community's water resources and their usage of those resources (this should be developed by researchers in the scoping stage). One participant added that the cement casing around the well-bore is important to consider because it can facilitate gases migrating to the subsurface. The group indicated the questions of when and how long to sample were yet to be answered for drinking water. The timeframe could potentially be very long (months to years) because there can be hundreds of wells across an aquifer and it is not always clear where the water is migrating (data from the migration of other organics leaked underground in other settings may be useful to inform the expected timeframe, extent of migration, and degree of attenuation). That is why a rigorously designed monitoring plan is needed - one in which sentinel wells are strategically located based on groundwater gradients, proximity to sources, and location of drinking water resources.
- **How to do it:** It is important to first understand the background status of the community's water resources by consulting maps of the aquifer and looking to other comparable communities whose water could be used as a baseline. Although isotope ratios of methane can be used as a fingerprinting tool, this method can be costly.

During the discussion, plenary participants discussed the issue of holding pits for wastewater as potential sources of groundwater and surface contamination. State requirements for lining the pits can vary and at times liners can be buried onsite – which indicates a need for long-term monitoring. When the wastewater from the pits is eventually removed, the remaining sediment may be buried onsite or deposited in landfills. Federal law exempts wastes from oil and gas exploration and development from regulation under the Resource Conservation and Recovery Act (RCRA) Subtitle C, but does not preclude these wastes from control under state regulations, under the less stringent RCRA Subtitle D solid waste regulations, or under other federal regulations (EPA, 2002; Konschnik, 2014). Participants also pointed out that some pit sediments can be radioactive; it is not natural for radioactivity to collect at the surface in the pits. Naturally Occurring Radioactive Material (NORM) from oil and gas waste is not regulated by federal law irrespective of the types and levels of radioactivity (USGS, 1999).

Impoundment pits can also contribute to air pollution through evaporation and the use of misters that aerosolize a solution, leading to fallout of particulate matter, petroleum liquids, and dissolved materials. Some participants mentioned that impoundment sites could store a mixture of flowback/produced waters from different sources in a multi-state region. Group members noted that it would be useful to

[16] One proposed tiered approach consisted of continuous sampling to identify and quantitate peak exposure periods, a quantitative composite sample for periods of 24 hours or more to identify chemical pollutants and a site specific measure of air dilution for periods of 6 hours or less conducted over a period of 1 week.

have a database indicating the locations of holding pits similar to that for well sites, as well as a database of spills.

State/Federal Program

The state and federal program group felt that a framework for water monitoring is lacking and that likely pathways of contamination need to be identified in order to prioritize sampling. The EPA is conducting a research study on the potential impacts of hydraulic fracturing for oil and gas on drinking water resources. This study will assess the pathways through which hydraulic fracturing (and other closely related activities, such as water acquisition and wastewater disposal) may affect the quality and quantity of drinking water resources. In order to arrive at the right conceptual model, however, a thorough case study is needed.

To establish background, researchers can draw on existing data such as USGS data from the National Water Quality Assessment program. Some states mandate pre- and post-development project sampling, although specific requirements vary.

In order to track long-term impacts on the aquifer, researchers could monitor for stray gas in groundwater-supplied streams as an indicator of water quality. The fate and transport of gas may differ from the migration of chemicals (synthetic and naturally occurring), however, and other approaches for tracking chemical movement may be needed. When test wells are installed, long-term water monitoring down-gradient of the site could be required. Monitoring with the necessary frequency, however, would likely require resources at the state or federal level.

For a state or federal program to select chemicals (synthetic and naturally occurring) to monitor, the constituents in hydraulic fracturing fluids and the produced water would first need to be identified, as mentioned above. For produced water, researchers can refer to the USGS produced water database to find contaminants to use as fingerprints.[17] The Colorado Oil and Gas Conservation Commission and Pennsylvania State University also have some data on produced water. As a start, the program could then choose indicator chemicals to monitor based on frequency of use, toxicity, and potential for movement to the subsurface.

A state or federal program could also monitor behaviors affecting water quality and prioritize higher-risk sites for follow up. Criteria to consider include:

- Drinking water well setback distances
- Areas with a lot of oil and gas wells
- Treatment practices in place
- Transport distances
- Measures of well bore integrity
- Effectiveness of documentation and response to spills onsite
- Management of wastewater
- History of low-level violations

[17] These fingerprints are for the formation water and might have only limited value as tracers for contaminant migration from flowback/produced wastewaters into water resources, etc.

A participant cautioned, however, that risks must first be identified before high-risk sites can be prioritized. That means researchers must establish baselines, conduct contaminant migration studies, define “risk” in this context, and then assess the factors that allow results to be extrapolated regionally such as to hydro-geologic settings, aquifer parameters, ponds, and well placement and depths.

A history of violations - leaks, spills, safety infractions, improper construction, notification failures, etc. - may be predictive of subsequent violations, including more serious ones. The group suggested that there might be a role for third-party verification of management practices. The contaminants that may be of greatest health and safety concern may not be the ones that are regulated or monitored.

Health Study

Surveillance should be conducted for acute health outcomes that could be indicative of exposure to contaminated water, such as skin rashes, adverse birth outcomes, and eye and respiratory complaints. In terms of monitoring for pollutants, the Colorado statute may offer some guidance. Potential targets include trace metals, dissolved gases, and VOCs. EPA methods 8260 and 8270 offer some guidance on VOC monitoring techniques. For emissions with subterranean origins, isotopic dissolved gases can be used for fingerprinting, although it is an expensive method. Salinity can be used as a cheaper, easier screen. Produced water and holding ponds should be screened for radioactivity. One participant noted that some drinking water facilities screen for radioactivity, and another mentioned that Dr. Michael K. Schultz at the University of Iowa is looking at monitoring for radionuclides. It would be useful to utilize tracers for hydraulic fracturing fluids. A participant noted that a unique DNA-based tracer technology called BaseTrace has been developed for environmental monitoring.

The group recommended that monitoring take place at the wellhead, in and around holding pits, and possibly at areas of water convergence (i.e., where streams come together). Surface waters also need to be considered. There should be groundwater monitoring before a hydraulic fracturing operation takes place. Given that in some locations the industry seems to be moving away from the use of open-air holding pits to storing wastewater in tanks, sometimes at tank farms, those sites should also be monitored. The group also recommended the ground at tank farms should have double coverage with tarps. In the case of a leak, spill or other incident (sentinel event), homes adjacent to the aquifer or that draw water from it need to be monitored. Due to the potentially long life of wastewater disposal sites, in addition to baseline or pre-drilling monitoring, monitoring of wastewater disposal sites may be necessary for decades after hydraulic fracturing activities have taken place. It is important to note that wastewater disposal may not necessarily be located near the well pad where fracturing has taken place.

To determine the best way to conduct monitoring, researchers need to systematically collect information about the hydraulic fracturing process and identify risk factors across sites. Monitoring results, as well as any spill events, should be reported in a publicly searchable database.

The plenary group discussed the roles of federal, state, and local agencies in the event of an emergency. In an event where public exposure is a risk, the state environmental and health agencies will generally work with the local health department to evaluate the potential for human exposure and determine a response. Some participants indicated the levels of involvement and cooperation between health and environmental agencies may vary from state to state. Agency participants clarified that the state has the power to intervene when health impacts are predicted, even if nondisclosure agreements are in place. The EPA and the Occupational Safety and Health Administration (OSHA) are the federal agencies with the regulatory authority to respond to health emergencies with enforcement actions against the sources of contamination. It would be useful to come up with recommendations for a trigger to prospectively follow a surveillance cohort for a given exposure.

Although not a primary focus of this workshop, participants recognize that the psychosocial impact of worry and anxiety needs to be addressed as a public health concern. Loss of social control reduces the capacity of families to function and to seek health assistance.

Next Steps

In the closing session, participants discussed the following potential next steps:

- Producing a peer-reviewed, open-access journal article (or series of articles) to give guidance to those trying to conduct monitoring activities. There could be a section with guidance for homeowners on monitoring techniques.
- Establishing website or wiki where the living guidance document can be posted, along with a collection of Standard Operating Procedures (SOPs), sample analytic plans, EPA methods, detection limits, contaminants of concern, and a list of accredited labs. A mind map of the website could be drafted and shared with the group for feedback. NRDC staff will begin collecting information for this resource.
- Drafting guidance to mineral owners on monitoring provisions to include in their oil or gas leases, potentially developed by the Harvard environmental law clinic. Risk communication experts should be involved with this.
- Collaborating on the design of the FrackMap database and using it to compile data.
- Setting up a listserv for meeting attendees to share information. NRDC staff will create one.

Aubrey Miller, NIEHS, invited participants to let him know if they are conducting environmental monitoring projects that could potentially be paired with complementary health data. USGS indicated an interest in discussions and possible collaborations. It would also be worthwhile for NIEHS to know about projects collecting health data as the Institute could share the information with others to help facilitate opportunities for collaborations. Attendees suggested inviting the Council of State and Territorial Epidemiologists (CSTE), NIOSH, CDC, and additional industry representatives to join the effort.

Participants also flagged the following topics for consideration in the ongoing conversation:

- The effects of light, which can be a stressor
- The effects of noise as a stressor
- The identification of available tools for modelling data gaps
- The costs of different monitoring techniques, perhaps prioritized in a structured way

In closing, the meeting sponsors thanked group members for their time and the valuable conversation that took place over the course of the two-day meeting. They also expressed the hope that members will remain engaged in the continuing activities of this effort to develop recommendations on environmental monitoring for unconventional oil and gas extraction.

Appendix A: Participant List

WORKSHOP TO DEVELOP RECOMMENDATIONS FOR ENVIRONMENTAL MONITORING

RELATED TO UNCONVENTIONAL OIL AND GAS EXTRACTION

Thursday, December 12 – Friday December 13

Participant List

Attendance will not constitute an institutional or personal endorsement of the results of the workshop. There will not be a consensus statement or position from this workshop. The final report that arises from this workshop will be a product solely of the steering committee and any attendees that wish to share authorship.

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Appendix B: Agenda

WORKSHOP TO DEVELOP RECOMMENDATIONS FOR ENVIRONMENTAL MONITORING RELATED TO UNCONVENTIONAL OIL AND GAS EXTRACTION

Thursday, December 12 – Friday December 13
Agenda
One Washington Circle Hotel
One Washington Circle, NW, Washington, DC 20037

<u>*Co-sponsors:*</u>
Harvard Center for Health and the Global Environment
Mid-Atlantic Center for Children's Health & the Environment (MACCHE)[18]
Health Effects Institute (HEI)
Natural Resources Defense Council (NRDC)

The project goal is to issue a final report that identifies best practices for conducting air and water monitoring for oil and natural gas production sites that utilizes unconventional gas extraction. By applying consistent expert-vetted procedures, we hope that final report from this workshop can inform local and state discussions, community investigations, and research studies.

Attendees names and affiliations are listed for identification purposes only, and do not constitute an institutional or personal endorsement. There will not be a consensus statement or position from this workshop. The final report that arises from this workshop will be a product solely of the steering committee and any attendees that wish to share authorship.

The final output is expected to be an open-access published, peer-reviewed article(s) with best practices guidelines for air and/or water monitoring.

<u>Day One – Thursday, December 12</u>

9:00 – 9:15 <u>Welcome, Introductions, and Purpose of Meeting</u>

- Introductions
- Overview of problem statement and framing the opportunity – *Aaron Bernstein, Harvard University and Jack Spengler, Harvard University*
- Agenda review and ground rules – *Facilitator (Resolve)*

9:15 – 9:30 <u>Keynote Address</u>

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[18] MACCHE Disclaimer. This material was developed by the Association of Occupational & Environmental Clinics and funded under the cooperative agreement award number 1U61TS000118-03 from the Agency for Toxic Substances and Disease Registry (ATSDR). Acknowledgement: The U.S. Environmental Protection Agency (EPA) supports the PEHSU by providing funds to ATSDR under Inter-Agency Agreement number DW-75-92301301-0. Neither EPA nor ATSDR endorse the purchase of any commercial products or services mentioned in PEHSU publications.

- Role of Monitoring in Addressing Health Impact from Oil and Gas Development – *Bernard Goldstein, University of Pittsburgh*

9:30 – 9:45 Overview of Sector and Governance

- Current Practices and Future Projections – *Sarah Jordaan, University of Calgary*

9:45 – 10:45 Session I: Perspectives on Health Implications and Data Needs
(10 min talks; 20 min panel discussion)

- Health Department (local/state) – *Cliff Mitchell, Maryland Department of Health and Mental Hygiene*
- Community – *Raina Rippel and/or Dave Brown, SWPA Environmental Health Project*
- Environmental Health Research – *John Adgate, University of Colorado*
- Industry – *Dennis Devlin, Exxon Mobil Corporation*

10:45 – 11:15 Participant Discussion of Health Implications and Data Needs

11:15 – 11:30 **Break**

11:30 – 12:30 Session II: Monitoring Technologies and Approaches
(10 min talks; 30 min panel discussion)

- Air Quality – *Barbara Zielinska, Desert Research Institute*
- Drinking Water – *Alan Roberson, American Water Works Association*
- Exposure monitoring for human health, workers and community – *Aubrey Miller, National Institute of Environmental Health Sciences*

12:30 – 12:45 Intro to Breakout Sessions

- Overview of discussion guide and questions
- Assignments

12:45 – 1:45 **Lunch** (provided)

1:45 – 2:45 Breakout Session A: Air Quality

1. Group 1: Community Investigation: Jerome Paulson (Group Leader)
2. Group 2: State/Federal Program: Jack Spengler (Group Leader)
3. Group 3: Health Study: Aaron Bernstein (Group Leader)

2:45 – 3:00 **Break**

3:00 – 4:00 Breakout Session B: Drinking Water Quality

1. Group 1: Community Investigation: Jerome Paulson (Group Leader)
2. Group 2: State/Federal Program: Jack Spengler (Group Leader)
3. Group 3: Health Study: Aaron Bernstein (Group Leader)

4:00 – 4:15 **Break**

4:15 – 5:00 Breakout Session Report Backs

5:00 – 5:30 Wrap-up and Discuss Plans for Day Two

5:30 Adjourn for the Day (Dinner on your own)

Day Two – Friday, December 13

8:30 – 8:45 Welcome and Agenda Review
- Discussion of day's objectives

8:45 – 9:30 Development of Framework for Best Practices Discussion
- Ideas distilled from breakout sessions – *Jerome Paulson, Mid-Atlantic Center for Children's Health & the Environment*
- Group questions and discussion

9:30 – 11:00 Developing Best Practices for Air Monitoring
- Group discussion of potential best practices
- Discussion of strengths, weaknesses, and alternative approaches

11:00 – 11:15 **Break**

11:15 – 12:45 Developing Best Practices for Drinking Water Monitoring
- Group discussion of potential best practices
- Discussion of strengths, weaknesses, and alternative approaches

12:45 – 1:45 **Lunch** (provided)

1:45 – 3:00 Additional Questions/Unresolved Issues

3:00 – 3:30 Next Steps and Wrap-up
- Present next steps including process for drafting report and soliciting input
- Appreciations

3:30 Adjourn

Appendix C: Discussion Guide

Expert Workshop Discussion Guide

PROJECT GOALS

We are convening a workshop of scientific researchers, policy analysts, environmental health experts, state environmental agencies, and industry experts to identify best practices for conducting air and water monitoring projects or programs to inform public health assessments and protections near oil and natural gas production where unconventional extraction processes are utilized.

Oil and gas development, using hydraulic fracturing, has expanded dramatically in recent years putting, in many cases, facilities in close proximity to communities and raising concerns about pollutant exposures and health impacts. Given the paucity of private or publically supported research on the impact of unconventional extraction processes prior to large-scale implementation of the same, there is a paucity of data on pollutant levels and human exposures. Moreover, the exemption of many oil and gas related practices in general, and unconventional gas extraction processes in particular, from federal or state reporting requirements on the use or release of hazardous substances has also resulted in the absence of data that would be available in other industrial settings. The lack of federal oversight and regulatory consistency has resulted in a patchwork of state and local rules, investigations, and assessments yielding inconsistent, incomplete, and contradictory data.

The workshop will set the foundation for a report that will summarize best practices for gathering meaningful information to evaluate exposures and inform the assessment of public health and environmental threats. These will outline expert-vetted, best practices that can be incorporated into local and state regulations, community investigations, and research studies.

All participants are being asked to contribute their expertise and knowledge to issues relevant to the workshop but attendance will not constitute an institutional or personal endorsement of the overall findings or conclusions of the workshop. Although broad agreement among the participants will be sought, there will not be a consensus statement or position from this workshop. The final report from this workshop will be a product solely of the steering committee and any attendees that wish to share authorship.

The goal of this workshop is to identify best practices for air and drinking water monitoring which will inform public health assessments. Questions that will be addressed include:

- WHAT to monitor for?
- WHERE to monitor?
- WHEN to monitor?
- HOW to conduct the monitoring?
- HOW to interpret and communicate results?
- HOW to consider assessments during upset conditions (e.g., flooding)?

Because unconventional oil and gas development and extraction entails heterogeneous activities and produces exposures to contaminants varying in time and space, monitoring for potential public health threats must be tailored to the specific activities it involves. The following processes and stages should be considered:

- Pad construction
- Drill set-up
- Drilling (including servicing operations with sand, water, etc.)
- Hydraulic Fracturing
- Oil and/or Natural gas extraction
- Disposal of waste water/extraction fluid
- Well decommissioning
- Land restoration

Questions for Discussion of Best Practices for AIR QUALITY Monitoring

Each person will participate in **one** of the following three scenario groups:

1. Community Investigations: You have been asked by a local group to investigate health concerns and complaints from residents living close to oil and gas wells where hydraulic fracturing is being utilized.
2. State/Federal Program: You are consulting with a state agency that is tasked with developing a state-wide monitoring program to evaluate and manage public health concerns from oil and gas facilities where hydraulic fracturing is being utilized. Discuss any differences for a federal program.
3. Health Study: You are collaborating with epidemiologists who have access to geo-referenced health information for a given area and tasked with developing a monitoring study to provide more information on exposures.

Consider the following questions from the perspective of your scenario group (one of the above):

WHAT constituents should be monitored for, relevant to human health impacts?

- What are the key pollutants during each phase of activity?
- Are there indicator pollutants of one or more parts of the processes?
- Are there ecological indicators of potential human exposures?

WHERE should monitoring take place?

- On-site, off-site, indoors, outdoors, distance, up/down wind?
- How to account for topography and meteorological patterns?

WHEN to monitor?

- Timing?
- Frequency?
- Duration?

HOW to monitor?

- Monitoring techniques/equipment selection?
- How should grab versus continuous monitoring methods be utilized?
- How do you measure background?
- How to account for, and capture, intermittent and variable emissions/pollutant levels?
- How to incorporate statistical designs that are likely to give robust results?
- What monitoring is needed to enable source attribution?
- When should human (biomonitoring) be considered? Relationship to environmental monitoring?
- How to involve communities/individuals?

WHAT needs to be considered during and after an “upset” condition either caused by a natural event or an accident?

Questions for Discussion of Best Practices for DRINKING WATER QUALITY Monitoring

Each person will participate in **one** of the following three scenario groups:

1. Community Investigations: You have been asked by a local group to investigate health concerns and complaints from residents living close to oil and gas wells where hydraulic fracturing is being utilized.
2. State/Federal Program: You are consulting with a state agency that is tasked with developing a state-wide monitoring program to evaluate and control public health concerns from oil and gas facilities where hydraulic fracturing is being utilized. Discuss any differences for a federal program.
3. Health Study: You are collaborating with epidemiologists who have access to geo-referenced health information for a given area and tasked with developing a monitoring study to provide more information on exposures.

Consider the following questions from the perspective of your scenario group (one of the above):

WHAT constituents should be monitored?

- Are there key pollutants related to different stages of well development?
- Are there indicator pollutants?

WHERE should monitoring take place?

- How to determine which wells or drinking water systems should be monitored?
- Where in the house/on the property should water be monitored?
- Differences between private wells versus public water systems? How to incorporate environmental (i.e. groundwater or surface water monitoring)?

WHEN to monitor?

- Duration of monitoring?
- How far out after drilling and fracturing should monitoring be continued?
- Frequency of monitoring?
- What events or onsite practices should trigger monitoring? Spills, ponds, contamination events?

HOW to monitor?

- Monitoring techniques/equipment selection?
- How do you measure (or assess) background pollutant levels?
- What monitoring is needed to enable source attribution?
- When should human (biomonitoring) be considered? Relationship to environmental monitoring? Body burden studies in animals?
- How to involve communities/individuals?
- How to account for, and capture, variability?
- How to interpret and communicate results

WHAT needs to be considered during and after an “upset” condition either caused by a natural event or an accident?

Questions for “Developing Best Practices” Discussions (Friday Morning)

- What are essential elements of any air quality/drinking water monitoring program?
- What information must inform monitoring program development?
- What are the common practices across all for three types of air quality monitoring efforts (community investigation, state/federal program, health study)?
- What are the common practices across all for three types of drinking water quality monitoring efforts (community investigation, state/federal program, health study)?
- What practices are more important or different depending on the type of monitoring effort?
- What are the deluxe/Cadillac practices versus the lower-budget (but still good) options for each type of monitoring effort?

Appendix D: Breakout Group Reports

Breakout Session A: Air Quality

Community Investigation Breakout

- Community Engagement
  - Clear communication
  - Communicate expectations about what is achievable
  - Look for opportunities to involve communities in monitoring
  - Reporting back results in a timely manner and describe limitations
- Scoping
  - Look for established ambient air quality monitoring sites and the data
    - evaluate the degree to which sampling sites are relevant for measuring exposure for a specific community or (i.e., location of monitor, prevailing winds, constituents being monitored)
  - Health Survey or Assessment – symptoms, health status, medical history
  - Define the sources and associated pollutants
  - Identify the proximal sources and known contaminants associated with those processes
  - Site evaluation and characteristics
    - Meteorology, geography, landscape characteristics
- Sampling Plan
  - Consider a Tiered Approach
  - What
    - Use a compendium (table) of contaminants, associated monitoring equipment, and limits of detection that are health relevant to cross reference with site specific information and identify what and how to monitor
    - Consider total particulate, fine particulate, H_2S, benzene, VOCs/SVOCs (EPA methods or equivalent)
  - Where
    - As comprehensive as practical (on and off-site, indoor and outdoor, upwind and downwind)
    - Vulnerable populations: schools, childcare centers; nursing homes
    - Need to capture local meteorology – account for local places where contaminants could settle
    - Distance: for health, monitor where people are; for source attribution and validation, do a gradient with distance from source where possible
  - When
    - Measuring different times can get at different parts of the process
    - Different times of day to reflect where people are
    - Need capacity to respond to concerns or events/incidences
  - How
    - Importance of geocoding and time stamps – taking into account privacy concerns
    - Need both integrated sampling and a mechanism to capture peaks
    - Can train community members as odor detectors
    - Archive samples for further analysis (i.e., additional constituents)
    - Use symptom diaries and citizen observations

        - New technologies for mobile and personal monitors (PM, PAHs on backpacks, mobile apps, etc.)
        - Biomonitoring is difficult and may be more problematic than helpful
- Research Needed
    - Need a list of pollutants associated with each process in order to identify indicators and facilitate screening level sampling

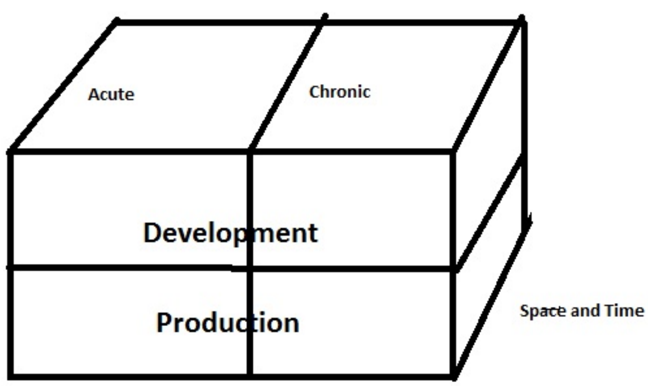
State/Federal Program Breakout

- Air monitoring depends on objective
    - Regional level
        - Large scale monitoring tools (Picarro methane analyzer, air towers)
        - Need to understand reactive hydrocarbons that have implications for regional pollutants like ozone
    - Community level
        - Passive monitors, canisters, filters, mobile monitors
        - Use these approaches to identify areas that need more detailed study
- Evaluating Emissions from Processes
    - Monitor close to the source
        - Characterize chemicals including air toxics to match certain emissions to processes
        - Source signatures help with attribution
    - Can also use high resolution real time chemical analysis, combined with GIS, meteorology data and air modelling to trace back to sources
- Monitoring Sources
    - Choose locations for monitoring stations (with participation from key groups), based on:
        - Wind direction
        - Number of wells
        - Population
        - EJ considerations
        - Practical issues (access to electricity, no buildings nearby to cause downwash)
        - Once monitoring is in place, do ground-truthing with more refined monitoring, also look at monitoring bans
        - Include background monitors – urban background and rural
- What Kind of Monitors?
    - For screening:
        - Can use IR camera with flyovers (expensive) - can see hundreds of facilities this way, also mobile platforms (vans); then confirm high priority areas with more sensitive monitors
        - Note this is for general detection of problems but not measuring concentration
    - For identifying concentrations that exceed standards:
        - Fixed monitors for broad range of pollutants (e.g., continuous GC that sample VOCs (55 VOCs including BTEX) (relevance?) but also can use ethane as an indicator of fracking activity)
        - Identify peaks for acute exposure and chronic concentrations, compare to short and long term action levels (one half RfC)
        - Use to prioritize enforcement actions
        - Use the information collected to associate problems with certain problem behaviors, then create regulations based on these observed problem behaviors to regulate others based on practices
        - Problems can derive from both design and poor practices

- Response to Communities
  - Can rely on complaints of population to trigger investigations (usually based on smell aromatics; or combustion smell)
  - Communities stop reporting when their concerns are ignored
  - Residents can perform some monitoring:
    - canisters
    - ultrafine particle monitors (cheap, easy, can follow gradients)
    - thermal desorption and hand pump
- Unresolved Questions
  - Can we use VOCs ratios for source attribution?
  - How robust would this strategy be across different contexts (e.g., with complicated terrain)?
  - How to monitor even after well finishes current production (e.g., for ongoing well integrity)?
  - What are the important occupational exposures and how can they be assessed?
  - Excessive Noise has the potential to cause stress and disrupt sleep---what standards are relevant? What would be appropriate response for health officials, regulators and industry?
  - We don't know all additives in fracking fluid – a major community concern (air and water)

Health Study Breakout

- What are the key pollutants during each phase of activity? Are there indicator pollutants of one or more parts of the process? Are there ecological indicators of potential human exposures? What constituents, relevant to human health impacts, should be monitored?
  - Monitor population health status – nose bleeds, respiratory/asthma, skin rashes, birth outcomes/weight. Identify complaints from workers. Focus is on the acute/development portion of the schematic below.



  - Monitor for VOCs, particulates (especially ultrafine fraction), methane. Biocides are troubling, because they are sensitizers.
  - Ultrafine particles – combustion vs. other sources. Organic vs inorganic. Diesel truck engines post 2007 cleaner.
  - Comprehensive assessment of particulates, NOx and VOCs of individual wells across development stages to characterize emissions at each stage. – W VA study; Garfield county, study/Colorado St. – available 2015, NETL (Briana)
  - Surrogates – not clear there are any good surrogates. ? Methane. Propane (Lisa) ratio butane:pentane isomers to use as fingerprinting tool.
- Challenges

  - What is the best design to attribute individual exposure to the source? Is that a combination of detailed characterization of the process paired w/ local and/or in home monitoring, or is there something better?
  - How best to address confounders e.g. other sources of particulates, indoor cooking, wood heating.
  - Are there specific risks after well development that may be missed with monitoring recommendations above? E.g., emission from glycol pumps, off-gassing from produced water in open pits, compressors (diesel fuel)
  - Sand/silica exposure.
  - Sound is a common complaint and can be easily measured with mobile applications (apps) – an opportunity to get a lot of data at critical noisy times. This could be a surrogate for truck traffic?
- Where should monitoring take place?
  - Monitor at the most potentially polluting stages of operations: compressor stations; when flowback occurs; producing sites.
  - Monitor at the site of the well, people in their homes, schools, daycares.
  - Work with school nurses, community health workers, treating physicians for sentinel events.
- When to monitor? Frequency/timing/duration?
  - Want continuous monitoring, but also an integrated analyzer to do specific identification of particles if there is a spike. This is particularly useful in the longer-term.
- How to monitor?
  - N/A
- What needs to be considered during and after an "upset" condition?
  - Find out disease patterns within the community. COPD is quickest and most efficient signal. Do continuous particulate monitoring, but should be hourly monitoring.
- Other issues?
  - Are there biomarkers for chronic exposures that are helpful?
  - Health standards should not form the basis of monitoring decisions.
  - In addition to a health study, need to do an exposure characterization for latent health outcomes.

Breakout Session B: Drinking Water Quality

Community Investigation Breakout

- Community Engagement
  - Clear communication
  - Communicate expectations about what is achievable (and meet them)
  - Look for opportunities to involve communities in monitoring
  - Reporting back results in a timely manner and describe limitations
- Scoping
  - Define the water source (private, public, ground, surface)
  - Look for available data
  - evaluate the degree to which it is relevant for measuring exposure for a specific community or (i.e., location of monitor, water flow, constituents being monitored)
  - Identify water sources people are in contact with (oral consumption, bathing, cooking); what are pets and livestock drinking?
  - Utilize citizens to track water characteristics (color, odor, taste, turbidity)
  - Symptom survey; evaluate how the symptoms are consistent; assess which chemicals might be indicative

- Define the sources and associated pollutants
- Identify contaminants of concern based on use and geology: Fracking fluid components, drilling mud components, flow back water (and constituents brought up)
- Site evaluation and characteristics
- Know your aquifer – gradient, flow, permeability, water level

- Sampling Plan
  - Utilize a tiered approach
  - What
    - Crude indicators: TDS, salts, methane
    - Include hydrocarbons – look for potential indicator
    - Quite a few of the chemicals used in fracturing are not on SDWA list; compare lists (chemicals used and associated with oil and gas development and look for what's missing from regular monitoring of public water systems)
    - Additional chemicals could include: glycols, total petroleum hydrocarbons (indicator) biocides, disinfection byproducts
    - Radionuclides could be a tracer
    - Wildlife could be an indicator
  - Where
    - Pull from the home or from the field. Depends on ground vs. surface water systems
    - Use a study design that gives allows a description of the community
    - Measure at the faucet to capture contaminants that result from interactions with the pipes – pull lead out of the pipes
  - When
    - Unanswered questions about "when" and "how long" and degree of importance for drinking water
    - Responding to spill events – very large floods can dilute but tracking spills or other contamination events could be used to indicate the need for sampling
  - How
    - Important to evaluate background
    - Maps of aquifer to understand flow; and also look for other communities that could be used as "baseline"
    - Source attribution
    - Can use isotope ratios of CH_4 as fingerprint – can be costly
    - Equipment/Methods
    - Primarily grab samples; limited real time or continuous monitoring
    - Biomonitoring is difficult and may be more problematic than helpful
- Research Needed
  - Need to understand what's in fluids, spills, and flow back water in order to develop good list of constituents to monitor
  - Consider constituents found in research studies:
    - Yale researchers – using TOF to capture broader list of chemicals – drinking water and water the animals are drinking

FRACKING RECIPE

Example of fracturing fluid composition from a gas well in Beaver, Pa.

INGREDIENT FUNCTION	CHEMICAL	MAXIMUM INGREDIENT CONCENTRATION, % BY MASS
Carrier/base fluid	Freshwater	85.47795%
Proppant	Crystalline silica	12.66106%
Acid	Hydrochloric acid in water	1.29737%
Gelling agent	Petroleum distillate blend	0.14437%
	Polysaccharide blend	0.14437%
Cross-linker	Methanol	0.04811%
	Boric acid	0.01069%
Breaker	Sodium chloride	0.04252%
Friction reducer	Petroleum distillate, hydrotreated light	0.01499%
pH-adjusting agent	Potassium hydroxide	0.01268%
Scale inhibitor	Ethylene glycol	0.00540%
	Diethylene glycol	0.00077%
Iron control agent	Citric acid	0.00360%
Antibacterial agent	Glutaraldehyde	0.00200%
	Dimethyl benzyl ammonium chloride	0.00067%
Corrosion inhibitor	Methanol	0.00142%
	Propargyl alcohol	0.00010%

NOTE: Additional proprietary ingredients not listed in material safety data sheet: acid, alcohol, biocide, copolymer, disinfectant, enzyme, polymer, silica, solvent, surfactant, and weak acid. **SOURCE:** FracFocus

- Overall Framework Lacking
  - Need a framework for evaluating how fracking can affect drinking water resources
  - What are the most likely pathways of contamination (from fracked wells? impoundments? wastewater discharge?)? From this we can figure out where to prioritize sampling.
  - In its water study, EPA is trying to develop a lifecycle approach to look at activities and how they interact with drinking water resources – both quality and quantity impacts
  - Amount of water used
  - The chemicals used in fracking fluids and how they are used
  - Potentials for spills
  - Content of flowback/produced fluids, quality, and how it is treated
  - Flowback/produced water must be considered as a separate site specific pollutant
  - Subsurface processes that could cause flow to groundwater
  - Overall, need a really thorough case study with long term monitoring and hydrology studies

- Establishing Background
  - Mine existing data to get background on a regional level – USGS data from National Water Quality assessment program (correct constituents?)
  - Some states are now requiring monitoring (e.g., Wyoming, Colorado require 1 pre and 2 post samples for wells in a given radius)
    - How can this requirement be improved (design a more cogent monitoring plan, more wells, more frequent samples)?
- Long-term surveillance
  - Track impacts on the aquifer - e.g. stray gas monitoring in streams that receive water from groundwater – will be indicative of water quality
  - Install test wells, require long-term water monitoring down-gradient of the site?
  - Need episodic sampling – but this level of monitoring will require state or federal level support
- Choosing Chemicals to Monitor
  - Great need for indicator contaminants – to do so, need to know what is in produced water and fracking fluid
    - For fracking fluids: need information about constituents
    - For constituents of produced water: look at produced water database, find contaminants to use as fingerprints
  - Based on that information, could choose indicator chemicals based on:
    - Frequency of use
    - Toxicity (or use models to predict toxicology)
    - Potential for movement in the subsurface
  - For wastewater discharged to POTW: high bromides in produced water can form DBP (bromoform, bromamines) in treated water
  - Ultimately, need to put a unique tracer in every fracking fluid to be able to see where it goes, and monitor for that tracer
- Monitor Practices that Affect Water
  - Well water setback distances
  - Prioritize areas that already have a lot of wells
  - Treatment practices in place
  - Transport distances – that could affect probability of spills and leaks
  - Measures of well bore integrity
  - How well people respond to spills onsite and how well they document the response
  - How is wastewater handled (e.g., re-inject, surface reuse)
  - Use a history of low level violations predict more severe violations (industry profiling)
  - Could third party verification of management practices play a role?
- Issues with Monitoring
  - Need a baseline – do we have this for private well water?
  - What values can people compare the results to?
  - Need a set of specific constituents to monitor
  - Frequency of sampling, especially given episodic nature
  - TDS meters maybe be helpful to residents to establish baseline over time and to detect changes in water quality

Health Study Breakout

- ❖ What are the key pollutants during each phase of activity? Are there indicator pollutants of one or more parts of the process? Are there ecological indicators of potential human exposures? What constituents, relevant to human health impacts, should be monitored?
  - ➢ Monitor for acute health outcomes in a population that may reflect contaminated water exposures – skin rashes from washing, adverse birth outcomes (e.g., birth weight and birth defects), eye and respiratory complaints. Also may use pet illness/death as sentinel event.
  - ➢ A comprehensive analysis of produced water from multiple sites in different basins is essential to understand what we should be monitoring.
  - ➢ Consider monitoring for trace metals, dissolved gases, organics. May use Colorado statute as basis but needs more. Also EPA 8260 and 8270 techniques for organics.
  - ➢ Consider livestock as biomonitors for low level exposures to contaminated water.
  - ➢ Isotopic dissolved gas analysis can be used as a fingerprint for emissions with subterranean origins. Dissolved gases require short holding times and require some expertise to obtain. About $1000/sample.
  - ➢ As a cheaper/easier screen, salinity may be used. Ratios of Na, Br, and Cl can be used to assess whether salt is from fracking brines.
  - ➢ Radioactivity should be screened for in produced water and holding pits.
  - ➢ Development of tracers in hydrofracturing fluids would be helpful.
- ❖ Where should monitoring take place?
  - ➢ At well head, in and around holding ponds, in groundwater in regions where fracturing has not yet taken place but will.
  - ➢ Consider monitoring at areas of water convergence (e.g. where streams come together)
  - ➢ Surface waters – flowing of pads, into soils, e.g.
  - ➢ If a sentinel event is identified, water from all homes that take water from that aquifer or are adjacent to it should be assessed
- ❖ When to monitor? Frequency/timing/duration?
  - ➢ Duration of open pits and surrounds as well as groundwater around fracking sites may need monitoring for as long as 50 years after fracturing.
  - ➢ Movement to "tank farms" where brines that are too polluted to be processed are stored, especially in PA where underground injection not occurring. Tanks and surrounds should be monitored, ground should have double coverage w/ tarps.
- ❖ How to monitor?
  - ➢ Looking for risk factors across sites. Need to collect information about process (how is water stored, handled, pit linings, how much flowback/produced fluids are going into tanks vs. pits, etc.) in a systematic way.
  - ➢ Publicly searchable database of monitoring results.
- ❖ What needs to be considered during and after an "upset" condition?
  - ➢ N/A
- ❖ Other issues?
  - ➢ Require all spills of brines/fluids to be reported in a publicly searchable database w/ geographic coordinates
  - ➢ All pond locations should be publicly known
  - ➢ Are there biomarkers of exposure?