WORKSHOP SUMMARY

Assessing the Environmental Effects of Marcellus Shale Gas Development: The State of Science

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PINCHOT INSTITUTE FOR CONSERVATION

Assessing the Environmental Effects of Marcellus Shale Gas Development: The State of the Science

Workshop Summary[1]

1. Introduction

In recent months, public meetings about the development of the Marcellus Shale gas deposit have become almost too numerous to stay abreast of. The pace has quickened with recent articles in the national and international press. Development of the Marcellus Shale is not just a Pennsylvania issue; it has become a proving ground for how deep shale gas deposits will be developed throughout the country.

Momentous decisions are being made that will have long-term implications for the economy and for the environment. The most visible decisions will be those made in law, policy, and regulation, such as the draft regulations proposed by the Delaware River Basin Commission that are available for public review and comment until April 15. Less visible but no less influential decisions are being made in the area of private investment in the development of shale gas resources. Thus far there has been more than $5.5 billion in just foreign investment in unconventional natural gas development in Pennsylvania alone.

By some estimates, the Marcellus Shale is the largest proven reserve of natural gas in North America. Current and projected volumes are so large that they are changing the economics of energy in every other sector, renewable and non-renewable alike. Shale gas is a ready alternative to coal, which has remained the dominant source of energy for electricity largely because it is the cheapest. Shale gas is now challenging coal's supremacy.

The discovery of the Marcellus Shale gas deposit comes at a critical time for states like Pennsylvania, whose economy as well as energy supply have been heavily dependent upon coal. The development of this new energy resource is viewed by many political leaders as the key to both cleaner air and a stronger economy. Natural gas has certain environmental advantages as well. Converting from coal to natural gas immediately reduces greenhouse gas emissions by half, with no decrease in power generation. It is cleaner burning, alleviating many of the air pollution concerns associated with coal, such as emissions of mercury and heavy metals as well as sulfur dioxide. Natural gas is not carbon neutral, and thus it is not a substitute for investing in

[1] Summary of a workshop convened by the Pinchot Institute and hosted by the Academy of Natural Sciences in Philadelphia, Pennsylvania, April 1, 2011.

clean, renewable energy sources like wind and solar, but many of the most vigilant environmental agencies and organizations regard it as a "bridge fuel" during the expansion of renewable energy technologies.

For all these positives, shale gas will have its negatives as well, and they may be significant. The truth is, we don't really know with certainty what these will be.

It is said that it is not what we don't know that will hurt us most; it is what we think we do know, but it turns out to be wrong. There is a great deal of information available from research done on shale gas development even though the technique is relatively new. But much of what we know is from research conducted in places like Texas or Wyoming, in geologic and hydrologic structures that are quite different from those which characterize the region underlain y the Marcellus Shale Formation. As a result, most scientists are wary of extrapolating these research results to shale gas development in the central Appalachians.

But this region too has a long history of oil and gas development. The US oil industry literally started in Pennsylvania. Thousands of gas wells have been drilled on both private and public lands in the region. Managers of federal and state forests have had to learn how to accommodate gas development, subject to appropriate standards intended to protect other natural resources and environmental values. There is extensive experience with this, and a great deal of knowledge has been gained along the way. But most of these are relatively shallow wells, drilled using techniques that are markedly different from those used to tap shale gas. Once again, many scientists are wary of extrapolating what is known about the effects of conventional gas development to unconventional gas development.

So when it comes to shale gas development among the geologic formations and forested watersheds that characterize the region underlain by the Marcellus Shale, what do we know? What do we not know? And what do we think we know that may actually be wrong?

For the region's private landowners, public resource managers, regulatory agencies, citizens, and other stakeholders, these are not academic questions. What are the likely effects on the human and natural environment in the near term? What will be the longer-term ecological, social, and economic legacy of shale gas development once this resource has been exhausted and the energy companies have moved on? What measures can be taken during the development of this energy resource that will be appropriate and effective, and can prevent or largely mitigate the potential negative tradeoffs? What steps need to be taken to prepare for the inevitable unintended consequences, and ensure that the impacts on the human and natural environment are limited?

The answers to at least some of these questions may lie with scientists and technical specialists such as those gathered for this workshop. They may have knowledge of existing science or ongoing research that can help address the critical information needs. Almost as important, they have the knowledge of research methods and scientific collaboration that can help organize and guide new research, to help answer questions we've only recently learned to ask.

Perhaps one of the most important questions to be asked is "at what point do we know enough?" An energy-hungry world is eager to have access to this cheaper, more abundant, and perhaps

cleaner alternative to coal and oil. Chronically challenged state and local economies are eager for the income and employment this energy resource represents. But the cost of error will be high, meaning that even small probabilities deserve thorough consideration before irrevocable decisions are made. More than 15 million people each day get their drinking water from the Delaware River, the headwaters of which sit atop the Marcellus Shale formation. Philadelphia also draws drinking water from the Schuylkill River, whose headwaters still bear the legacy of damage from the unregulated development of an earlier generation of energy resources.

Risk analysis uses algorithms to weigh benefits and costs between developing a high-value energy resource and protecting a high-value environmental resource like clean water. It all comes down to probabilities—the likelihood of human error or accident, and the severity of the likely consequences. This probability is not fixed, but variable; it is adjustable upward or downward, based on what kinds of safeguards society chooses to put in place, and how truly effective those safeguards turn out to be. Where society comes down on the question of an appropriate and effective set of safeguards will be determined largely on the basis of the best available science.

Our task in the days ahead is to assist policymakers, concerned citizens, and other stakeholders by doing the best science we can, and making the knowledge gained from this research as available, accessible, and understandable as possible.

The workshop summarized here was organized around three panel discussions. The first panel addressed the adequacy of available science for estimating the cumulative effects of shale gas development on ecological and environmental resources; to a limited extent, potential human health effects were examined as a function of effects on environmental resources such as water supplies. The second panel addressed the adequacy of currently available science as a basis for the development of appropriate and effective standards or regulations to protect environmental resources during shale gas development. The third panel reviewed the currently available science from the perspectives of several categories of "information users"—regulatory agencies, land managers, and public interest groups.

It is our hope that the information compiled at this workshop will be helpful regulatory agencies, and to the landowners, land managers, and other stakeholders who are submitting comments in ongoing regulatory review processes. Panelist presentations, this summary and other information specific to this workshop are freely available for viewing or download on the Pinchot Institute website at (www.pinchot.org). In cooperation with Wilkes University and the Academy of Natural Sciences, the Pinchot Institute will provide a comprehensive, web-based compilation of scientific and technical information on shale gas development and environmental conservation, in a form that is readily available and accessible to the full range of stakeholders. Over the longer term, we hope that the scientific and technical information compiled through this workshop and any follow-up activities will strengthen the knowledge base of stakeholders of all kinds, and facilitate both citizen monitoring and future academic research.

2. Assessing Cumulative Effects

A central purpose of the meeting was to evaluate the adequacy of existing research results as a basis for assessing the potential cumulative effects of a rapidly expanding number of shale gas wells across the region. Critical to understanding the potential impacts of this expanding industry is better information on how and where it will grow, and what sorts of techniques and activities it will include. A significant additional concern is whether there is the ability to assess effects stretching out over the decades during with development and production will take place on the Marcellus shale, and what the long-term effects will be once this energy resource is exhausted and all the infrastructure remains in place. Information about both near-term and long-term cumulative effects will be essential to determine appropriate siting and mitigation requirements. Developing tan adequate science basis for addressing cumulative effects includes (1) ensuring the availability and comprehensiveness of information, and (2) improving planning and coordination.

Availability and quality of information

Geological features and effects of prior fracturing

Regulators expressed a need for better understanding risks posed by geological features such as faults, natural fractures, and fractures from previous oil and gas development. These irregularities can create preferential pathways that have been known to cause unexpected migration of hydraulic fracturing flowback water (HFFW). USGS presented data on the dispersion of fracking fluids occurring in zones well-beyond where they would be predicted. This data pointed to the need for information on prior existing fractures and faults, sufficient to determine whether these features might need to be accounted for in siting wells. These studies also documented instances in which fracking effects extended beyond the confining layer above the target shale layer. While still well below active water tables or groundwater withdrawal areas, fluids may migrate over time using preferential pathways to which they were not intended to be exposed. Seismic activity could also potentially pose a risk to well-casings and other structures intended to isolate fracking fluids from groundwater.

Chemical composition of flowback and implications for disposal

Much of the public concern over shale gas development is centered on the proper regulation and disposal of hydraulic fracking flowback fluids (HFFW) and potential contamination of groundwater and surface water. These concerns can only be addressed through adequate HFFW handling, treatment, and discharge that is properly tracked and publicly reported.. There are several dimensions: (1) geographic variation in the chemical composition of HFFW; (2) detection capacity and treatment technologies; and (3) duration of flowback..

Geographic/geologic variation. One of the pressing concerns on the regulation and handling of HFFW, is the potential for mobilization and return of compounds which naturally occur in the geological formations that are fracked. The potential toxicity will also vary based on the reactivity of fracking additives with these compounds. This will require more and better integrated information on the geology for particular sections of the Marcellus formation,

mobilization of elements within the shale (especially radioactive trace elements), and reaction and return of toxic chemicals within the frack fluids. Model analyses will need to encompass probable molecular outcomes possible throughout the Marcellus formation, using the broadest suite of chemical additives employed by drilling operators, and at the range of temperatures and pressures at which these reactions could happen.

Detection capacity & treatment technologies. As described, the chemical composition of HFFW can vary in a number of ways, and it is especially troublesome for facilities that are receiving materials from multiple sources. As the first priority, facilities need to have the capacity to detect contaminants in the fluids they accept for treatment. Secondly, they must understand how contaminants in fluids received from different sources may react, and the toxicity of byproducts. Daily variations in water quality also pose problems for treatment facilities—which must as a consequence continually adjust treatment methods. Methods of precipitating materials also leads to hazardous biosolids and this is not always preferable—having social and community considerations, and additional regulatory needs. Even with these difficulties, a host of vendors say that they can treat shale-gas water, yet may not actually be able to do so, lacking the experience or the equipment to make adjustments.

Duration of flowback. Some uncertainties also remain on how long HFFW will continue to emerge at the site, or how far they will eventually migrate subsurface. For the most part experience has shown that the majority of the fluids return in the first 30 days of the active fracking period. Subsurface migration is harder to determine, and is dependent partially on the fracturing and fault issues already discussed—suggesting the need for more experimental and tracking studies.

Potential for failure of approved methods

There are questions even among the scientists themselves on whether the failure rates and associated risks for approved methods are sufficiently understood, and whether existing precautions and mitigation measures are adequate. The Pennsylvania Department of Environmental Protection is including requirements on cement casings for the entire length of the well rather than just the first hundred feet or so, to prevent communication between groundwater and the annulus. There have been several instances in which "open" sections on well-casings were permitted, and have posed risks of groundwater contamination. There is the potential for failure during installation (e.g. testimony related to the BP oil spill in the Gulf revealed that 40 percent of deepwater cementing fails). Specific areas of uncertainty include: (1) proportion of wells that are unsuccessfully cased from the beginning (detectable by pressure loss on fracking); (2) corrosion potential and well failure in Marcellus Shale wells due to brines and other reactive components in flowback water; (3) cement longevity and additives/practices to promote longevity; (4) well susceptibility to seismic activity; and, (5) well integrity and resistance to multiple hydraulic fracturing activities in the well and in adjacent wells.

Similar concerns exist for on-site storage and even transport of hazardous materials and fluids. Based on current regulations and disposal needs, fluids are most frequently stored on-site in enclosed tanks, which pose less risk of leakage than liners of retention ponds. Transitioning to

enclosed tank storage will lead to an increased footprint and attendant site disturbance, as well as traffic to and from the site.

Dissemination of existing information

A key objective of the meeting was to support the process of disseminating information to regulatory agencies and stakeholders, but also how information can better inform guidelines developed within the shale gas industry. The taxonomy of information needs identified prior to the meeting (see Appendix 1) included: (1) relevant scientific and technical information that currently exists, and is available in a form readily accessible to stakeholders and regulatory agencies; (2) relevant information that is in the technical literature, but is in need of a synthesis and/or summary to make it understandable and easily usable by stakeholders and regulatory agencies; and (3), critical information needs that can only be addressed through new research.

There are a number of public concerns for which the information falls in all three of these categories. There seems to be a relatively high level of confidence in the information that supports regulation and guidance on surface and groundwater withdrawals, and the volume of water that can be used for drilling activities. There also seems to be a high level of confidence in the information available for determining minimum setbacks of individual wellpads from water bodies and minimizing erosion and sedimentation. When the cumulative effects of a large number of wells is considered, however, existing guidance may need to be updated and revised.

Planning and coordination

Underpinning many questions on whether there is sufficient information for mitigating the potential impacts of natural gas extraction in the region, is how the play develops. How many wells will be installed? Where will they be and at what density? How extensive will the pipeline network become and where will these corridors be? How good are projections of this kind, and when will they be available to regulators, leaseholders and others who need this information? Better projections related to these questions would enable regulators to use guidelines and requirements to minimize long-term cumulative effects as shale gas development expands.

Anticipated number and density of well sites

The number of wells that will be installed is difficult to estimate. An analysis by The Nature Conservancy of Pennsylvania projects a range of between 60,000 and 120,000 wells will eventually be in place. These buildout scenarios assume a medium density of 6 wells/pad for the low-end estimate, and a high-end estimate based on 10 wells/pad. Presently the average is 3 wells/pad. But at this stage of development, energy companies are focused on occupying and generating yield on an extensive area of leased land, and may return to install additional wells on existing pads.

Another factor influencing where wells can be placed is whether there has been previous oil and gas drilling in the area. There are an estimated 325,000 wells in Pennsylvania, 280,000 of which are abandoned. Many of these old wells were abandoned prior to legal requirements that the wells be capped, and their location registered with state authorities. Methane release from these

abandoned wells have posed problems throughout the state, and are sometimes mistakenly attributed new drilling.

Duration of drilling and production, and post-production restoration

A challenge to understanding the potential effects of this shale gas development is determining how long it will last and how long installed wells will be operating. Industry expectation is that wells in the Marcellus Shale will be in production for the next 20-40 years. Until wells decline to almost no productivity companies have an incentive to keep them open; it is relatively inexpensive to continue operating a well once it is producing. As the long as the well is flowing and does not require re-fracking, site disturbance is minimal once the initial drilling is completed and the well is producing.

During this production phase the level of site disturbance declines, but presently there are no regulations requiring restoration and revegetation of the site. Cumulative impacts will be strongly influenced by what restoration is required once active drilling operations have completed at individual sites.

Leasing, ownership patterns and landscape planning

"Horizontal drilling is a marvel of technology, but mineral laws as they affect use are based on a 19th century model"

Adequate landscape planning can minimize cumulative impacts. While states with portions of the Delaware Basin are generally addressing one well at a time in their regulations, DRBC is encouraging lease area maps and plans for well-pad development (i.e. PNDI plans). This would encourage companies to deal with lease-terms and new pads less sequentially and opportunistically. These plans are to be submitted by the entity responsible for development of the site. However, in some cases—when large leaseholder themselves attempt to improve the plan to minimize disruption of surface resources--they must deal with multiple companies responsible for different phases of the project, and this is a barrier to more holistic planning.

Public land managers working with companies on leases for which they own mineral rights, has been different from where the ownership is split—and where the reality is that ". . . development of the subsurface is going to precede and has primacy." In the case of the Fernow Experimental Forest, the karst geology of the forest is important for drinking water, hosts endangered species, and has cave systems. Managers have found it hard to move forward with certainty--seeking out and understanding the range of information that was appropriate to consider and be holistic about the approach to planning and development. While interested in cumulative effects analysis and using forward-looking strategies to protect surface resources, a planned outcome for "latecomers" with mineral rights may prove unrealistic--i.e. the last person having less opportunity once a cumulative threshold has already been exceeded.

However, where possible, the experience of public land managers has been that planning works. And while it takes time to share and formulate plans, it complements the need of companies to swap leases and tracts in order to make the leases more efficient. At the same time they also

found that some of the needs of companies can be unpredictable, made known only as they better understand the operational area and constraints. Again, making these types of adjustments over time is much easier with large leaseholders.

Industry disincentives for sharing planning information

Discussions at the meeting called for a different way of doing planning, land acquisition and management that is better married with the technologies being deployed. The current reality of opportunistic and competitive leasing among companies, makes efficient infrastructure difficult. Especially concerning is the redundancy and overlap in pipeline infrastructure resulting from multiple operations in the same region. Companies will clearly be limited in the degree to which they can compromise their infrastructure needs in order to better coordinate with the activities of their competitors.

In instances in which leases are with public and private entities with large landholdings, companies have been able to work out the most efficient arrangement to site wellpads and pipeline. Mutually beneficial planning between one leaseholder and one company occurring, and these companies are beginning to trade lands. However, this is more difficult in settings with a greater diversity of operators and leases.

Regulatory agencies are also in a position to influence the density and arrangement of infrastructure on the landscape, but are limited by the bounds of what has already occurred, in terms of current leases of different vintages and existing investments. Most critically, a company's plan for their lease is essential to their business strategy in a highly competitive industry. Sharing their long-range plans may be necessary to some extent to comply with, say PNDI provisions proposed by DRBC, but companies will need to protect information that helps their competition.

3. Development of BMPs, Standards, and Regulations

Restoration and mitigation of impacted areas

As development of the Marcellus Shale Formation expands, the pipeline network will become quite extensive, enough to equal or exceed the land area associated with well-pads and roads. Projections of the eventual development estimate that there will be 10,000 - 20,000 miles of "gathering lines." These are the pipelines that connect individual wells to larger collection lines and ultimately to the main trunk distribution lines. Moreover, the amount of disturbance associated with these lines increases as the size of pipeline; gathering lines are 12 to 34 inches in diameter. When shallow horizontal drilling for pipelines is infeasible open trenches are used. With the extensive dendritic networks for pipes, both forms of disturbance can be problematic. The suspended solid particles entrained in the drill-water and released into streams can pose sedimentation problems. Trenches will result in extensive disturbance, especially for large pipelines. Because of the suspended solids, trenches may be the better alternative when pipelines cross streams. However trenches require staging areas on either side of the stream. Considering the extensive networks of pipeline that will be required, additional analysis is needed to

determine how and when to use different methods to minimize environmental damage,, especially for stream-crossings.

A related concern is how the pipeline corridors will be maintained over time, and whether they necessarily interrupt and degrade forest-habitat on thousands of acres across the landscape. Historically the common practice for energy and power corridors is to maintain the rights-of-way through chemical and mechanical vegetative suppression. However, with buried gas pipelines this does not have to be the case, and many companies are receptive to working with conservation partners on how these areas are maintained to enhance habitat..

Regulatory scope and jurisdiction

"Regulatory agencies constantly have the difficult question of how much is too much, but also must keep in mind that regulations need to be set, and cannot always wait until all the information is in."

"We have a chance to also spur innovations through regulations, and create a competitive playing field."

Performance-based goals

Performance based goals, rather than regulations requiring the use of current technologies, may be prove more durable and effective over the long-term and help spur innovation in the private sector. Regulation recently proposed by the Delaware River Basin Commission (DRBC) are designed to complement regulations, procedures and institutions in New York and Pennsylvania. Existing and proposed regulations focus primarily on siting, installation and operation, and water use and disposal for individual wells. The regulations proposed by DRBC promote performance-based planning at the landscape-level, requiring the submission of development plans for entire leases, not just proposed wells.

Performance-based regulations promote innovation in treatment and control technologies, by giving companies an incentive to develop new ways of meeting performance goals at lower cost. Regulations that lock in on specific current technologies can stifle such innovation. For example, energy companies are developing entirely new approaches to address the problem of treating large volumes of flowback fracking fluids:

Recycling: An increasing number of companies are recycling HFFW, reducing the amount of fresh water and additional fracking chemicals that must be use in new wells. At present, recycled fracking fluids still account for less than a quarter of the total volume, but this proportion is increasing as the technology improves.

Concentration. Water treatment technology providers are developing and testing new methods to both reduce HFFW volume through evaporation. Residual concentrated materials are more easily transported, and in fact can be extracted, or mined, for their chemical constituents. Pilot testing of these methods are now underway.

Some discussion addressed how regulations can help drive the financial incentives helpful to pursue these types of solutions. There is a tradeoff in that new techniques can, for example, create new species of materials for disposal and management that must be tracked. Or say, incentives to reduce the use of liquid chemicals could result in the use of other methods that have some toxicity (e.g. ozone). Overall, the economics of new technologies has to work out, and meet with smart regulations that prod the economics without being unreasonable while not creating incentives which lead to worse outcomes.

An analysis by The Nature Conservancy suggests that there may be less habitat fragmentation from large interstate gas distribution pipelines than from local dendritic networks of gathering lines. Gathering lines owned and installed by each company often access the same area, creating far more disturbance than there would be with a single dendritic network accessed by multiple companies. The interstate pipelines are regulated by the Federal Energy Regulatory Commission (FERC), but intra-state local pipeline networks are not.

Most of the large volume of fresh water used in drilling operations comes from surface water sources rather than through groundwater withdrawals. Nevertheless, there is concern that in dry summers when streamflow drops, companies will be forced to turn to groundwater. The cumulative impact of large-scale groundwater withdrawal, both localized and basin-wide, could be significant if they are poorly timed.

Monitoring and real-time reporting

Any additional shale gas development in Delaware River Basin must be predicated on establishment of an intensive network of monitoring stations in adjacent small tributaries and at individual well sites. DRBC is working with partners to create a comprehensive monitoring framework that will help fill the current gaps. Clearly more resources need to be invested in creating the monitoring system itself. Deployment and operation will require coordination with companies, agencies, and other institutions in the basin.

Performance monitoring should be the priority, but compliance monitoring based on adequate inspection capacity is also essential. A monitoring system needs to be capable of signaling both acute and longer-term changes in water quality for waterways in the basin, evaluated against benchmark measures of water quality. This will rely on a continuously operating monitoring system positioned throughout the basin in subwatersheds where drilling activities occur, and at locations where factors such as depth and dilution do not make it difficult to detect contaminants that may be posing problems upstream. Toxicity parameters that cannot be measured, can also be monitored through biological sampling. However, these methods are less useful for detecting and responding to incidents as they occur.

Cooperation

The complicated array of operators and technical firms in competition with one another creates additional difficulty for regulators who must rely on energy companies for information about their operations. Development plans as well as technical and financial information about current operations, is often proprietary and cannot be shared. Information from energy companies to

regulatory authorities sometimes comes through confidential channels, but it is not systematic or consistent.

Integration of existing capacity

Performance monitoring should be the priority, but compliance monitoring based on adequate inspection capacity is also essential. Presently DRBC, state agencies, and other organizations are evaluating and integrating existing monitoring systems. These systems can address effluent and water bodies throughout the basin, however additional capacity will be needed to meet the increasing number of well-pads and operations. Additional capacity is available in tools being created by universities and other public interest group, which may provide vital information, but are more difficult to interlink with regulatory systems depending on their scope and purpose.

Response and mitigation

Alerts generated by monitoring systems are of little use without an agreed upon protocol for timely and effective actions. Protocols would need to include criteria for triggering actions both for acute site-based incidents, and for cumulative impairments occurring at the subwatershed to basin-scale. Protocols would also need to address methods for rapid containment, mitigation, and remediation suited to nature of the contamination. This challenge will vary by the type of incident, and extent of the area affected. In many cases an incident could potentially involve many types of organizations with different jurisdictions and capacities.

Regulations need to assign the responsibility for bonding requirements and liabilities for clean-up and damage claims. Some of these provisions are already included in EPA NPDES and other requirements of the Clean Water Act. However existing requirements for detection, disclosure, disposal and discharge could still fail in addressing concentrations of potential contaminants (e.g. total ions such as chlorides and sulfate, radionuclides discussed above) introduced by HFFW. This could affect accountability, and the resources and capacity available for remediation.

Conclusions

Overall, the information presented at this workshop suggests that science and policy is struggling to catch up with a rapidly developing industry. The complexity of new technologies, which now enable access to valuable untapped energy resources, is challenging the ability of the scientific community to predict with confidence the likely outcome of a rapid expansion of shale gas development, or guide the development of standards that will provide a reasonable assurance against substantial environmental, economic, or social impacts, especially in the longer term.

The research results presented at the workshop better define the scope of the information is needed to better address the projected impacts of shale-gas development, some of which presently exists in some form, and some of which must be developed through additional research. There is a need for the synthesis and translation of existing information by scientists and technical specialists equipped to accurately interpret research results, and provide policy-relevant information that can be effectively utilized by a variety of stakeholders as well as regulatory agencies. Finally, there is a need for more intensive monitoring of existing and new

shale gas operations, as a basis for rapid detection and response to contamination events, but also to provide a robust body of data for ongoing research into the actual effects of shale gas development, and how best to anticipate, prevent, or mitigate significant environmental impacts.

Additional research.

Some concerns will require additional research, such as those relating to well-siting, disposal and management of HFFW, and setting thresholds for water withdrawals:

- Composition of HFFW as influenced by geology and the composition of additives used in hydrofracture, and the associated potential toxicity of frack additives alone or in combination with naturally occurring compounds in the shales.
- Infrastructure development projections and guidance to identify appropriate locations for the extensive pipelines, and how these corridors are managed;
- Cumulative withdrawal of surface and groundwater resources, considering timing and quantity over the course of the shale play (decades);
- Geochemical information, which is not available in a form to help companies, agencies, and stakeholders better understand how geological features such as faults may introduce design and siting consideration for drilling operations; and,
- Potential for migration of HFFW based on the natural and induced fractures, natural faults, and other subsurface features.

There is a need for a comprehensive compilation and independent analysis of information reflecting results from unconventional natural gas development that has taken place since extraction techniques were developed in 1990s. Some of these data will be of limited relevance because it reflects development of unconventional natural gas resources in regions with geologic formations and water regimes fundamentally different from those found in the region underlain by the Marcellus Shale Formation. Other research results may be of limited relevance because it reflect earlier technologies that have already been superseded in this rapidly evolving technology, such as the types and combination of chemicals used in fracking fluids, or methodologies for the capture, storage, and treatment of HFFW. Nevertheless, the results of this research, and the potential issues identified, can provide guidance in the identification and prioritization of information to be gathered from the growing number of shale gas operations in the Marcellus region.

Synthesis of existing research results

There is an extensive body of scientific and technical information from earlier research, much of which is relevant to the critical information needs identified through this workshop (see Appendix 1). However, much of this information is functionally unavailable to regulatory agencies and public stakeholders because it is contained largely in technical academic and scientific literature that is for the most part inaccessible to the public. Scientists themselves are often unaware of relevant information that is in scientific journals other than those that are specific to their own scientific discipline or technical specialization. Scientists and technical specialists at the workshop identified several areas of critical information needs on which extensive research has already been conducted, and which would benefit from a comprehensive review, compilation, and summarization of existing research results. Among these were:

- Priority water resource areas and ecosystems (i.e. critical watershed protection areas, key wildlife or plant habitats) that have already been identified and mapped and scientifically vetted;
- Seismic data indicating relative risks of failure for wells and other drilling infrastructure;
- Corrosion potential and longevity of wells based on prior experience with conventional or unconventional drilling; and,
- Appropriate reclamation techniques for wellpads, pipeline corridors, and other developed infrastructure.

Research synthesis is as technically demanding as research itself, yet scientific institutions in academia, government, or the private sector offer few incentives for efforts other than original research. Also, in instances where the interpretation of research results is likely to influence the outcome of controversial public issues, questions of objectivity and research funding sources can become a factor. An independent consortium of several public, private, and academic research institutions, with funding directed specifically to research synthesis focused on addressing specifically identified user needs such as those enumerated in Appendix 1, could address both these challenges and contribute significant new and useful information to inform policymaking and regulatory processes.

Differential standards for drinking water resources in the Delaware River Basin

As a primary source for clean drinking water for more than 15 million people, the particular importance of the upper Delaware River watershed has been recognized through its Special Protected Waters status under which regulatory agencies are required to ensure against any impairment of water quality. It is this portion of the Delaware River watershed that is underlain by commercially viable portions of the Marcellus Shale Formation. The high potential impact of even low-probability events on this drinking water supply suggests the need for higher standards in the Delaware Basin. The sensitivity of drinking water resources increases the need to address some uncertainties prior to additional permitting and drilling.

Many of these uncertainties relate to HFFW reuse, storage, transport, and disposal by operators. Similarly, uncertainties in the capacity to detect potential contaminants discharged post-treatment suggests the need for higher and more comprehensive standards for detectable contaminants. The high environmental, economic, and social impacts of even low levels of chemical contamination of drinking water supplies in the Delaware River basin suggest the establishment of a conservative threshold for triggering responses on ceasing drilling operations and remediation.

Establishment of an intensive monitoring network in upper basin, with real-time reporting that is independently monitored

The overall efficacy of policies and regulated practices depends on the capacity and scope of systems to detect as well as prevent impairment. History has shown that, whether through natural events or human error, even the best protective measures are subject to occasional failure. Responsibilities for improving monitoring systems are multi-jurisdictional, and increasingly

necessitate new technologies enabling real-time response. Monitoring must be point-based and systemic, and sufficient to quickly detect both the acute events occurring in small catchments, and gradual impairments evaluated against benchmark water quality standards. The reach and responsiveness of the monitoring system must be proportional in scale and designed to accommodate projected shale-gas activities.

Establishment of an independent scientific review board

Data sharing and scientific research on shale gas development is limited by factors that discourage energy companies themselves from sharing information. Some of this information is held closely by individual energy companies for competitive reasons. Energy companies also must be careful about sharing information that could influence energy supply or prices due to anti-trust concerns. An independent scientific review board is needed for the confidential collection of relevant data, aggregation of the information to protect sources and maintain confidentiality, and provide this information to agencies and stakeholders in a timely and effective manner.

APPENDIX 1.

User information needs[2]

A key objective for the workshop is to identify specific needs for additional scientific or technical information to guide the processes of (1) assessing potential cumulative effects of shale gas development on other resources, and (2) developing standards or regulations that provide adequate assurance the appropriate steps are taken to protect environmental values during shale gas development. To facilitate this process, the following preliminary list of user information needs has been compiled based on input from representatives of regulatory agencies, land management agencies, and public interest organizations.

Please take a moment prior to the workshop to review this list, and consider sources of information that may help to address these needs. If there are additional information needs you would like to identify and add to this list, there will be opportunities to do so in the course of the workshop.

Questions about risks associated with gas development, especially from deep shales

1. What factors influence the short and long term integrity of wells?
    a. Proportion of wells that are unsuccessfully cased from the beginning (detectable by pressure loss on fracking)
    b. Corrosion potential and well failure in Marcellus Shale wells due to brines and geology
    c. Cement longevity and additives/practices to promote longevity
    d. Well susceptibility to seismic activity, is there a risk?
    e. Well integrity and resistance to multiple hydraulic fracturing activities in the well and in adjacent wells.

2. What methods are available to track contaminants from wells/spills.
    a. Is there a chemical signature for fracking and flowback fluids?
    b. What types of tracers available? Purpose and benefits of tracers
    c. Drawbacks of tracers – economic, ecological, and other
    d. Evaluation of benefits to drawbacks

3. What are air pollution effects 1) on humans 2) on forests and secondarily on water quality

[2] Answers may vary for wells drilled when the surface estate and subsurface estate have same owner, vs. wells drilled when estates are owned by different entities.

4. What is the potential toxicity of frack additives alone or in combination with naturally occurring compounds in the shales
    a. Model analysis of probable molecular outcomes given chemistry, temperature and pressures.
    b. 4NQ and other compounds that have been detected in produced water

5. Are there potential "green" alternatives - how should we analyze them and as they emerge how can we encourage their widespread adoption?
    a. Haliburton has a “food-grade” hydraulic fracturing recipe
    b. What is actually being used in most slick water fracs in PA.

6. What are the risks associated with nanoparticles and toxicity to humans?

7. What is the seismic risk and potential for earthquakes in the northeastern US and areas underlying the DRB
    a. Is this risk increased by UIC wells and hydraulic fracturing activities?
    b. Seismicity induced by hydraulic fracturing as compared to earthquakes

8. What are the specific risks associated with radioactivity and how can managers and regulators minimize that risk
    a. Radioactive components in produced waters and equipment that handles produced waters, drilling wastes, and drill cuttings.
    b. Radioactivity in drill cuttings, on-site disposal and landfill disposal

Questions about cumulative effects and methods/regulations for assessing and managing them

9. Should the current well development permit process be split into two parts: one focusing on the assessment of conditions relevant to the siting of well pads and ancillary infrastructure, and a subsequent phase focused on the well development operations?

10. What regulatory process should be used to identify and measure the cumulative impacts of multiple well development projects in a specified area?
    a. By a single well development permittee?
    b. By multiple well development permittees?

11. What is the role, if any, of non-regulatory comprehensive planning processes initiated by landowners’ associations or communities?

12. Who should design and implement cumulative impacts assessments?

13. How should cumulative impacts assessment be funded?

Questions about ecological impacts and monitoring strategies

14. How can managers and regulators translate monitoring data and observations to workable and effective best management practices accepted and implemented by the industry?

15. What is the most cost-effective monitoring strategy and how to organize multiple organizations interested in monitoring to maximize the information return on multiple investments?

16. Understanding short- and long-term effects of oil and gas development on a myriad of forest uses and values:
    a. Ecological resources
        i. Landscape-level forest loss and fragmentation effects
        ii. Plant communities, including species of concern, wetlands, and tree health
        iii. Invasive species
        iv. Wildlife and habitat conditions; winners and losers
        v. Water and soil resources, including surface and groundwater quality and quantity, changes to local hydrology due to compaction and runoff, effects of spills, groundwater withdrawals in headwater areas
    b. Social considerations (primarily in context of the State Forest)
        i. Wild character of the State Forest
        ii. Recreation opportunities, safety, and conflicts
        iii. Noise and aesthetics
        iv. State Forest infrastructure and maintenance
        v. State Forest relationships with local communities
        vi. Documenting and communicating positive social benefits

17. What are the potential secondary impacts by watershed of forest clearing and fragmentation.
    a. What is the risk of invasions associated with increased vehicular traffic? What strategies are cost effective ways to minimize this risk?
    b. How will changes in land value where private lands are developed for oil and natural gas affect land use, access for wood production and public recreation, and other ecosystem services?
    c. How will oil and gas development on public lands affect land use, access for wood production and public recreation, and other ecosystem services.
    d. How will oil and gas development affect the costs and feasibility of sustainable forestry operations (for example, prescribed fires)
    e. What will be effects on wildlife habitat?
    f. What will be the effects on erosion and sedimentation associated with increased right of way clearing and increased road density?

Questions about layout, landscape planning and pattern, and managing landscape/ecological effects

18. What is the appropriate width for buffers along streams and other surface water resources, and how do they vary with type of water body and ecological or community value?
    a. How large should these setbacks be?
    b. Quantifiable justification for setback distances; what constitutes a reasonable, but sufficiently protective setback?
    c. Improved BMP's or BMP upgrades for encroachment inside setback limits

19. What factors should be considered in planning well pad spacing and well pad density
    a. What is the intent of enacting well spacing/unitization regulations or BMPs?
    b. What are the geologic constraints, and how do they vary across the affected region?
    c. What are the political constraints, and how do they vary by region and ownership?
    d. What are the property constraints, and how do they vary by region?
    e. What are the design factors that could/should influence pad spacing and layout
        i. Corridor creation
        ii. Specific micro-habitat avoidance
            1) Unique habitats
            2) Vernal pools
            3) Spring seeps
            4) Scrub oak/pitch pine communities
            5) Scree slopes/talus/boulder fields
            6) Sunny rock outcroppings
            7) Caves
            8) Wetlands
            9) Cliffs
            10) Exposed limestone or shale
            11) Stands of at least 100 trees with diameter at breast height > 30 inches
            12) Herbaceous openings in high-quality forage
            13) Other unusual or ecologically significant features
        iii. PNDI hits
        iv. Recreation and other high public use areas
        v. Cultural resources

20. What factors should be considered in planning layout of pipelines and roads associated with oil and gas development (see above for details)?

21. Are there geographic areas that should be off limits due to issues of rarity, key habitat, geological faults, etc.
    a. How would these be designated?
    b. PA Chapter 78 proposed designating areas such as these. What was the plan for including it in the rule.

Additional questions

22. What are the most promising options for partial and final site reclamation?

23. What is the outlook of other shale plays, such as the Utica; re-use of surface infrastructure and other implications

24. What are the information needs of private landowners and what is the most effective way to meet those needs?

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