Advancing the Next Generation of Environmental Practices for Shale Development:

Workshop Deliberations and Recommendations

The Nature Conservancy & Carnegie Mellon University

Workshop held May 27-29, 2015 | Carnegie Mellon University, Pittsburgh, PA

Carnegie Mellon University

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This report summarizes the content, conclusions, and recommendations from a cross-sector, collaborative workshop organized by The Nature Conservancy and Carnegie Mellon University. Built on the robust and constructive dialogue of workshop participants, the recommendations put forth in this report merit consideration for those seeking to effectively manage shale development in the Appalachian region.

This report represents general agreement achieved during the workshop but does not necessarily reflect the opinions and ideas of each individual participant or the views of their affiliated organizations (listed in Appendix B), The Nature Conservancy, or Carnegie Mellon University. Focused on summarizing workshop discussions, this report also does not purport to describe all complexities associated with each topic.

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WORKSHOP ORGANIZERS AND FUNDER

The Nature Conservancy is the leading conservation organization working around the world to protect ecologically important lands and waters by offering scientific research and tools to decision makers, such as energy developers, land managers, and state and federal agencies, to plan and develop energy resources in a way that keeps our landscapes healthy and productive.

The **Scott Institute for Energy Innovation** works through the academic units of Carnegie Mellon University to find solutions for the nation's and world's energy challenges through research, education, and policymaker and public communication. The Institute focuses on five strategic areas: pathways to a low-carbon future, smart grid, new materials for energy, shale gas, and building energy efficiency.

The **Steinbrenner Institute for Environmental Education and Research** was established in 2004 to change the way the world thinks and acts about the environment.

The **Colcom Foundation**, which provided financial support for the workshop, was established in 1996 by Cordelia S. May, a dedicated conservationist who served as Chairman until her death in 2005. Regionally, the Foundation supports conservation, environmental projects, and cultural assets.

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Steering Committee members are listed in Appendix A.

ACKNOWLEDGEMENTS

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Executive Summary

The Appalachian region faces a tremendous challenge in striking a balance between making the best use of its vast energy resources and safeguarding its abundant ecological resources. The region is a global hotspot for forest and freshwater biodiversity and also a hub of energy development, with plentiful coal, natural gas from shale, and wind energy. All forms of large-scale energy production and delivery require an infrastructure network and construction, operations, and maintenance activities that, to varying degrees, alter our landscapes and communities, challenge the health of our freshwater systems, and strain our air quality. In approaching this challenge, we need to consider what we want our legacy to be not only today but in the future as the mix of energy sources we rely upon continues to evolve.

Underway for less than a decade, unconventional oil and gas development in the Appalachian region involves extraction of natural gas reserves in the Marcellus, Utica, and other shale formations using hydraulic fracturing and horizontal drilling technologies. As research continues to emerge, we are building a scientific understanding of shale development's current and potential future impacts on our lands, waters, and air and also assessing whether existing practices, technologies, and regulations comprehensively address them. Due to the region's landscape diversity, potential impacts vary in scale and severity and need to be understood and managed appropriately to reduce both short-term, local impacts and long-term, cumulative impacts.

Assessing the cumulative impacts of Appalachian shale development is fraught with uncertainty and complexity, particularly given the difficulty in recognizing larger trends within various local impacts or incremental changes. These challenges are exacerbated by the lack of institutions with missions, authority, and capacity to synthesize information, assess patterns at large geographic and temporal scales, and make decisions accordingly. Nevertheless, **we can take collective actions to define and work towards realizing a legacy that we want to leave for future generations after the Marcellus, Utica, and other shales are played out**. Development of Appalachian shale gas reserves is not unlike other industrial and natural resource extraction in our region's recent history. How can we combine lessons learned from the past with modern science and technology to ensure the long-term well-being of our landscapes and communities in the face of today's resource development decisions?

We can begin defining our desired legacy in the Appalachians today. **With this workshop, we propose working toward the goal of maintaining the biodiversity and resilience of Appalachian ecosystems, including protection of its land, air, and water resources.** Before being able to guide development toward our desired legacy or endpoints, however, **we need to better understand the complex challenges related to shale development in the Appalachian region and to educate each other on the ever-evolving state of the science, technology, practice, and regulatory framework.** This cross-sector understanding, as well as ongoing dialogue among stakeholders, is necessary to develop feasible solutions toward addressing the environmental challenges associated with shale development.

WORKSHOP OVERVIEW

To provide a forum for cross-sector dialogue, a collaborative workshop, *Advancing the Next Generation of Environmental Practices for Shale Development*, was held on May 27-29, 2015 on the campus of Carnegie Mellon University (CMU) in Pittsburgh, Pennsylvania, U.S.A. The workshop was designed and implemented by The Nature Conservancy (TNC) and, at CMU, by the Wilton E. Scott Institute for Energy Innovation and the Steinbrenner Institute for Environmental Education and Research. Funding was generously provided by the Colcom Foundation of Pittsburgh.

More than 140 invited participants represented a diverse cross-section of energy and environment experts from academic institutions; local, state, and federal government agencies; non-governmental organizations and foundations; and members of the energy industry. By generating robust **cross-sector dialogue**, the workshop sought to define Challenge Areas related to the environmental risks of Appalachian shale development and produce recommendations for addressing those challenges to meet three overarching **Conservation Goals**: conserving the biodiversity and resilience of Appalachian ecosystems, protecting the quality and availability of water for ecosystems, and minimizing emissions of air pollutants *(see diagram below)*.

While human health, safety, and community impacts are important considerations associated with shale development, they were outside the direct scope of this workshop, although Dr. George Hornberger, chair of the Health Effects Institute's Special Scientific Committee on Unconventional Oil and Gas Development in the Appalachian Basin, provided an overview of the committee's work in a keynote address at the workshop.

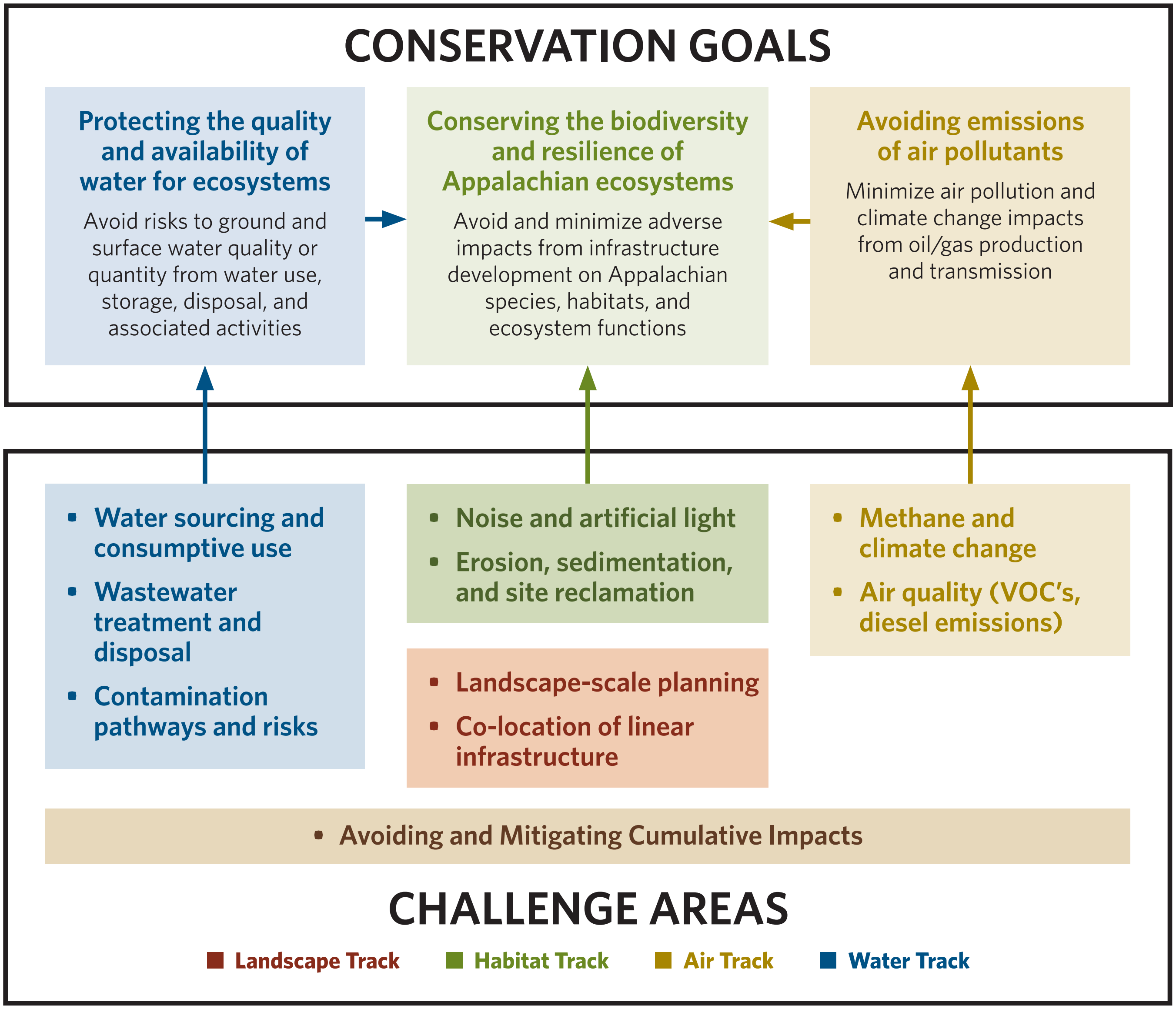
It was clear from Dr. Hornberger's summary of the forthcoming report (since released) that there are strong connections between health and ecological effects, especially in the area of exposure assessment, and that HEI's research should be closely followed and incorporated into future work deliberations.

Framed by the overarching Conservation Goals, working groups explored **Challenge Areas in four tracks: landscape, habitat, air, and water**. During the first two days of the workshop, for each Challenge Area, working groups sought to:

- Reach a common understanding of the **"State of the Challenge,"** based on participants' knowledge of current science, technology, policy, and practice, and
- Identify and prioritize a set of existing or emerging **recommended solutions** that could contribute to addressing the challenge in the short term (one to two years).

On the workshop's last day, for each of the four tracks, working groups developed **implementation strategies for near-term solutions** produced over the first two days of the workshop and discussed long-term strategies necessary to more fully understand and address potential **cumulative impacts**.

This report synthesizes the robust cross-sector dialogue achieved during the working group sessions and does not necessarily reflect the opinions and ideas of each individual participant or the views of their affiliated organizations (listed in Appendix B), The Nature Conservancy, or Carnegie Mellon University. Focused on summarizing workshop discussions, this report also does not purport to describe all complexities associated with each topic.



Framed by the workshop's overarching Conservation Goals, working groups explored Challenge Areas in four different tracks: water, habitat, landscape, and air. Cumulative impacts were discussed as the culmination of the workshop.

OVERVIEW OF CHALLENGE AREAS AND WORKING GROUP RECOMMENDATIONS

Organized by landscape, habitat, air, and water tracks plus "our legacy," this section offers a brief description of each Challenge Area, including the current State of the Challenge covering what we know and what we do not know in the areas of scientific research, technology, practices, and the regulatory framework. **Tables 1 through 5 present the high-level conclusions from the working group sessions and an outline of the priority short-term solutions recommended by the working groups** for moderating adverse impacts to Appalachian ecosystems for that Challenge Area. Groups prioritized recommendations based on their expected combination of effectiveness and feasibility of implementation in one to two years. The working group discussions are summarized more thoroughly in Section 3 (*Challenge Areas and Working Group Recommendations*) and Section 4 (*Our Legacy*) of the full report.

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LANDSCAPE TRACK

Development of any kind, including shale, is made up of many local decisions that cumulatively influence land use patterns and have implications on a larger, landscape scale. Infrastructure development converts land to a mix of natural and non-natural cover, and the cumulative impacts of this conversion can affect the quality of water resources and wildlife habitats on a basin or landscape scale. The discussion of these working groups focused on landscape-scale planning within the context of land-use change from infrastructure development and did not explicitly include air, surface, or ground water quality considerations, as these were discussed in other working groups.

LANDSCAPE-SCALE PLANNING

Landscape-scale planning often seeks to optimize multiple land uses while protecting natural processes and significant cultural and natural resources. In the context of shale infrastructure development, the goal of landscape-scale planning can be characterized as avoiding and minimizing impacts to landscape-scale ecological values — wildlife habitat, water resources, and ecosystem functions — while increasing regulatory predictability and improving operational efficiencies (including potential cost savings).

Horizontal drilling associated with shale development allows for multiple wells to be drilled on a single pad and some flexibility in the location of pads and other infrastructure. As a result, shale operators can more easily plan their infrastructure at a scale larger than a single leasehold. Broad implementation of a landscape-scale planning approach to shale infrastructure development in the Appalachian region, however, is impeded by numerous factors. These barriers include fragmented surface and subsurface ownership, the challenge of coordination among operators, strong personal property rights, and significant gaps in available data. Regulations and requirements for activities associated with shale development differ at every level of jurisdiction, from local to county to state to federal. No single coordinating agency keeps track of development or impacts on the regional or watershed scale.

After brainstorming a lengthy list of recommendations for advancing landscape-scale planning for shale development in the Appalachian region, working group participants identified priority recommendations focused on four areas where greater transparency and cooperation would provide a common knowledge base for future discussions and decisions (Table 1).

CO-LOCATION OF LINEAR INFRASTRUCTURE

The physical footprint of pipelines and other linear infrastructure for natural gas transmission can have significant impacts on soil and water, species habitat, and landscape aesthetics. The goal of co-locating infrastructure is to reduce this footprint by utilizing areas that have already been developed, which can also potentially be economical by lowering construction costs. Operators often seek to co-locate their pipelines near other pipelines, electric power lines, roads, or other existing rights-of-way. Several challenges, however, stand in the way of broad deployment of co-location practices, including legal and safety concerns, competition among operators, landowner preferences, lack of coordination between state and local governments, and differences in the regulatory framework regarding various types of pipelines and other linear infrastructure. In light of this complexity, the working group spent the majority of its time engaged in discussions to better understand these challenges but did produce short-term recommendations outlined in Table 1.

TABLE 1: LANDSCAPE TRACK SUMMARY

CHALLENGE AREA	HIGH-LEVEL CONCLUSIONS	SHORT-TERM RECOMMENDATIONS
Landscape-scale Planning How do we best reconcile the *scales* of decision making with the scales of ecological values? How do we best support ongoing oil and gas development while avoiding, minimizing, and mitigating impacts to *landscape-scale* ecological values?	• The potential efficiencies gained through landscape-scale planning are largely unknown and merit research. • Further discussion is needed to more fully understand the ways in which landscape-scale planning can be integrated into the development process, given differing planning scales and approaches both in industry practices and the current regulatory framework. • Reliable, accessible data on landscape features and a regional governing body are both needed.	• Incentivize collaborative planning and the avoidance of areas of high ecological importance. • Develop a collaborative, centralized, publicly-available data repository. • Develop a collaborative framework that provides objectives and incentives to implement voluntary "leading" practices related to landscape-scale planning. As an additional step, establish a third-party certification program. • Improve expertise and capacity of land managers and regulators to allow for the inclusion of landscape-scale planning principles.
Co-location of Linear Infrastructure How can we reduce the ecological footprint of pipeline corridors by maximizing the *co-location of linear infrastructure*?	• While co-location has the potential to reduce the footprint of shale infrastructure, balancing associated ecological, safety, regulatory, and operational concerns makes implementation complex. • Further discussion is needed (a) to explore the viability of co-location as a standard within the current regulatory and economic environment and (b) to focus on science-driven specific practices aimed at implementing co-location in right-of-way development.	• Create and disseminate information regarding co-location strategies and trade-offs. • Improve and expand existing Best Management Practices for reducing the footprint of linear infrastructure. • Develop transportation corridors for pipelines through "smart planning" with built-in flexibility. • Educate landowners and other stakeholders about the ecological value of co-location. • Enlist inter-agency cooperation. • Develop a "vertical collaboration" pilot for governance of co-location at the sub-state level. • Create a centralized database of key spatial data for safety and planning purposes. • Conduct cumulative impact analyses for gathering lines. • Establish a multi-well approval process for drilling sites to facilitate co-locating infrastructure.

HABITAT TRACK

Infrastructure siting, construction activities, and ongoing operations and maintenance associated with shale development in the Appalachian region can have adverse impacts on wildlife, habitat, and ecosystem function by creating short- and long-term sources of artificial noise and light and increasing risks of erosion and sedimentation from land conversion and maintenance activities.

NOISE AND ARTIFICIAL LIGHT

The daily activities of shale development in the Appalachian region are associated with artificial light and noise, both of which can alter wildlife behavior and reduce habitat quality. Temporary sources of noise from shale development include well pad preparation, road construction, well drilling, and hydraulic fracturing. Operating 24 hours a day for the lifetime of a gas field, gas compressor stations are significant sources of long-term noise. Truck traffic, gas pressure regulators, electric generators, cooling fans, engines, and air conditioners also are long-term noise sources, although they are not in constant operation. Shale development also involves artificial lighting, necessary for security and worker safety, to illuminate work areas at the well pad and near compressor stations.

The impact of noise on wildlife is a relatively new area of scientific study, and consequently only a small body of research is available, especially specific to Appalachian habitats and species. Potential wildlife impacts include disrupted communication, stress, community composition, and reduced fitness. The impact of artificial light on wildlife habitats has been the subject of scientific research for several decades, but has primarily focused on birds and is not well understood in the context of Appalachian shale development. Depending upon the species, wildlife can be attracted to, repulsed by, or disoriented by light, potentially resulting in light entrapment and changes to foraging and circadian rhythms. Many questions still remain regarding the specific attributes of noises that are most disruptive to wildlife, thresholds to behavioral or physiological change, and how different species are affected. Generally, there is little regulation with respect to noise and light and how they relate to wildlife.

Participants overwhelmingly agreed that there are relatively inexpensive and readily available options to mitigate the effects of artificial lighting, including shields and motion sensors, for example. For noise pollution, siting tools, natural and engineered sound barriers, and other methods are available to achieve noise attenuation, but there are opportunities to improve noise-measuring equipment and to explore the cost-effectiveness of various noise attenuation techniques. Table 2 lists the recommended solutions that emerged from the working group discussion.

EROSION, SEDIMENTATION, AND SITE RECLAMATION

Erosion (the mobilization of soil) and sedimentation (the transportation and deposition of that soil) can alter ecosystem functions, damage soil and water organisms, and degrade surface water quality and overall watershed health. Infrastructure development, including for roads, pipelines, stream crossings, and well pads associated with shale development, involves ground clearing and construction that present risks of erosion and sedimentation.

Improperly designed, constructed, and maintained infrastructure, particularly unpaved roads, can be large sources of sediment to streams in forested landscapes. Participants overall agreed that currently used techniques for reducing erosion and sedimentation risks are well known but that they may not be specifically targeted to shale development or implemented comprehensively by operators in the field. Participants mentioned several existing standards and voluntary practices for mitigating erosion and sedimentation, including the Pennsylvania State University Center for Dirt and Gravel Road Studies and state forestry best management practices. Aspects of erosion and sedimentation related to shale development activities are regulated by the Federal Energy Regulatory Commission, the U.S. Army Corps of Engineers, the Pennsylvania Department of Environmental Protection, and other state agencies.

Incorporating reclamation into shale development planning, particularly early in the process, is vital for reducing the risk of damage in the first place and for improving interim and final reclamation outcomes. Reclamation is more likely to be successful if factors such as soils, land use, road design and maintenance, and water quality are adequately considered early in the development planning process. Unlike surface mining, the reclamation of lands developed for oil and gas is not regulated by a specific federal law, and, as a result, the existing regulatory framework is complex and involves a mix of federal, state and local jurisdictions.

TABLE 2: HABITAT TRACK SUMMARY

CHALLENGE AREA	HIGH-LEVEL CONCLUSIONS	SHORT-TERM RECOMMENDATIONS
Noise and Artificial Light How do we reduce ecosystem impacts from *noise and artificial lighting*?	• More research is needed to better understand the ecosystem- and species-specific impacts of noise and light. • There are some relatively simple, inexpensive solutions to cut down on light pollution.	• Create standardized guidelines/rules on lighting. • Implement widespread noise attenuation, both natural and engineered, on well pads and compressors. • Develop a system to create and update a regionally-conscious Best Management Practices manual that can accommodate different communities and ecosystems. • Enhance existing siting tools to include noise-producing facilities.
Erosion, Sedimentation, and Site Reclamation How do we address the impacts/risks of *erosion and sedimentation*, and plan for successful *restoration/ reclamation*?	• The collection of more scientifically sound baseline data is needed to enhance evaluation of erosion and sedimentation management techniques and to inform restoration plans. • Comprehensive training is needed for leaseholders, regulators, operators, service companies, and subcontractors to ensure that proper erosion and sedimentation control measures are implemented on the ground through all phases of development. • Incorporating reclamation into operational planning is vital for successful interim and final reclamation outcomes.	• Collect and make available both baseline and post-construction data to assess land and water impacts and to gauge the effectiveness of best practices to address them. • Provide comprehensive training for leaseholders, operators, service companies, subcontractors, and onsite personnel to avoid improper practices and violations. • Share field-tested practices for interim and final reclamation through a technical cooperative. • Support regulatory agencies to improve oversight in the field. • Create and maintain a comprehensive "one-stop shop" for operator Best Management Practices across jurisdictions. • Provide technical assistance and education to landowners. • Provide flexibility in restoration/reclamation plans.

AIR TRACK

The production, processing, and transmission of oil and gas from shale development in the Appalachian region emit methane and a suite of air pollutants that can have adverse impacts on human communities, wildlife, and habitats and contribute to climate change.

METHANE AND CLIMATE CHANGE

Methane is the primary component of natural gas and the second most prevalent greenhouse gas (GHG) in the United States, according to the U.S. Environmental Protection Agency, contributing to climate change. During shale development operations, methane can be released into the atmosphere during well drilling, fracturing, and completion processes. Releasing methane during initial well drilling and stimulation is largely for safety reasons. The industry also employs a number of required and voluntary engineering and operational controls to reduce both the safety and environmental risks of emissions during completion activities.

Reducing or eliminating methane emissions is a common goal for environmental and industry interests, as minimizing methane leakage both potentially reduces climate change impacts and increases the resource that companies can sell. Practically speaking, however, reducing methane leakage in natural gas systems is a complex challenge. Unreliable data are compounded by regulatory gaps and inconsistencies and a debate about whether methane's global warming potential should be calculated on a 20- or 100-year time horizon, which has serious implications for climate policy.

In light of this complexity, session participants sought to reach agreement on solutions to produce reliable, quality-assured emissions data that could be used for decision making and used by operators to minimize methane leakage and maximize the capture of methane in shale development (Table 3). Participants also recognized that meaningful solutions should address both existing and new facilities, as well as orphaned/abandoned wells and pipelines.

AIR QUALITY

In addition to methane, emissions from shale gas operations can include volatile organic compounds, nitrogen oxides, sulfur dioxide, particulate matter, and various forms of hazardous air toxics, including n-hexane, the BTEX compounds (i.e., benzene, toluene, ethylbenzene, and xylene), and hydrogen sulfide. Currently there are limited directly-measured air emissions data for air toxics and criteria pollutants for several important oil and gas production processes and sources, including well completions and evaporative ponds.

The group discussion concentrated on the absence of credible emissions data, which makes creating appropriate regulation difficult. Participants focused on how best to address these uncertainties by reducing emissions wherever possible and by taking steps to produce an accurate and reliable inventory of emissions that would serve as a baseline from which to take action (Table 3). The group unanimously agreed that addressing the gaps in data, research, and policy is critical to developing effective solutions and that practices may be more effective in the short term than regulations.

TABLE 3: AIR TRACK SUMMARY

CHALLENGE AREA	HIGH-LEVEL CONCLUSIONS	SHORT-TERM RECOMMENDATIONS
Methane and Climate Change How can *methane emissions* be reduced?	• Low-cost monitoring and sensing technologies are needed to provide quality, reliable emissions data in order to more fully understand the issues and optimize control strategies. • Discussions and recommendations related to methane emissions should consider existing and new production facilities, orphaned and abandoned wells, and distribution pipelines. • The level of emissions from natural gas production sites varies greatly, making a reliable prediction of the magnitude of the challenge difficult.	• Improve emissions inventory, for low emitters as well. • Develop rapid screening for super-emitters. • Develop measurable emissions targets.
Air Quality What are the principal threats of shale development to *air quality*? What are the most important practice and policy actions to achieve meaningful reductions?	• Credible, systematic data are needed to identify and quantify specific emissions. An accurate and reliable inventory of emissions is needed to serve as a baseline from which to take action.	• Adopt lowest-emitting equipment across operational sectors. • Monitor emissions and near-source concentrations to identify contributions at local levels (short and long term) during regular operating conditions and equipment failures and address them appropriately. • Develop and disseminate standardized best practices in environmental training replicating the high standards for safety practices and awareness. • Build an ongoing common understanding amongst stakeholders of key variables and common consensus processes to optimize solutions and foster quality, credible research regarding emissions data, concentrations, and public health effects.

WATER TRACK

The management of risks to water resources, including quantity and, in particular, quality, is arguably the most complex environmental and social issue associated with shale gas development. Participants in the water resources sessions explored three Challenge Areas: water sourcing and consumptive use, wastewater treatment and disposal, and contamination pathways and risks to surface and ground water. To unify discussion outcomes for the purposes of this report, the working group discussion on wastewater treatment and disposal was integrated into the session summaries for water use and contamination risk.

WATER SOURCING AND CONSUMPTIVE USE

In the Marcellus shale play, an estimated 4.4 million gallons of water is required to hydraulically fracture a gas well. Over the next 50 years, it is estimated that cumulative demand could reach 264 billion gallons for the region. Water is generally sourced from streams and rivers, transported to gas well pads and stored onsite, and then used for drilling and high-volume hydraulic fracturing. The use is considered "consumptive," meaning it is unavailable for future freshwater uses.

Compared to other consumptive water uses in the region, water demand for Appalachian shale development is relatively small. However, the concern lies not in the total demand but in the location, concentrated timing, and intensity of demand in small streams, in tributary settings, and during seasons with low-flow conditions.

The body of scientific documentation of the ecological risks of surface and ground water withdrawals is significant and demonstrates that alteration of the natural flow regime can reduce habitat and ecosystem services, water supply, and recreation. These impacts can accumulate downstream.

The working group discussed that the general state of standards and practices in the Susquehanna River Basin, established and implemented by the Susquehanna River Basin Commission (SRBC), appear largely appropriate for managing the water quantity risks associated with surface-water withdrawals for shale gas development demands.

SRBC's policy standards are based on basin-wide ecosystem flow recommendations that define limits of alteration to high flows, seasonal flows, and low flows, in order to protect the species and habitat needs in different stream types. It was agreed that a regional-scale science-based vulnerability index would be useful in other parts of the Marcellus Shale play (Table 4). State regulatory agencies responsible for managing water in the Marcellus are outlined in Table 6 in Section 3.4.1.

The working group also described technologies and practices to reduce the risk of surface and ground water withdrawals, including maximizing the use of non-freshwater resources (i.e. re-use of produced water), use of centrally-located water sources, and the development of technologies that minimize water demands. Each of these alternatives has potential trade-offs and risks that need to be considered.

It was recognized that, in addition to avoiding ecological risks of hydrologic alteration from water withdrawals, a potentially greater factor for motivating solutions to reduce freshwater use is to reduce the volume of waste storage, treatment, transportation, and disposal. Participants recommended two related short-term solutions: water lifecycle tracking and pilot programs for use of non-freshwater resources (Table 4).

CONTAMINATION PATHWAYS AND RISKS TO SURFACE AND GROUND WATER RESOURCES

Hydraulic fracturing uses pressurized liquid to fracture rock formations and release gas. Before injection, water is mixed with a combination of hydraulic fracturing fluids (HFFs) including surfactants, gelling agents, and proppant.

Using current technology, 5 to 50% of the fluids injected into a well for fracturing returns to the surface, resulting in an estimated 0.5 million gallons of "flowback" per well, on average. In addition, "produced fluids," including naturally occurring radioactive material (NORM) and dissolved metals mobilized by the fracturing process, are generated along with the oil and gas over the life of a well. It is estimated that development of the Marcellus Shale play could create an estimated 35 billion gallons of waste fluids (flowback and produced fluids).

All of these waste fluids and materials require re-use or safe treatment and disposal. Environmentally-sound and cost-effective management of waste continues to be a challenge without a clear, comprehensive solution. Practices and technologies that are currently used for treatment and disposal include direct re-use (blending), onsite treatment with re-use, disposal in Underground Injection Control (UIC) wells, or desalination treatment.

The body of scientific literature related to surface and ground water contamination pathways and risks is increasing rapidly, both in the Marcellus play and in other plays around the U.S. Although perspectives differed as to the extent and persistence of risk, participants discussed the following contamination mechanisms as confirmed by research: subsurface and surface methane migration, unplanned subsurface fluid migration, and accidental surface release of HFFs and waste fluids. Specifically, both ground and surface water are at risk of contamination from transportation, storage, fracturing, and waste treatment and disposal. At the surface, contamination pathways include accidental spills, overflow of storage ponds in response to storm events, spills during transport and treatment, and disposal of wastewater to surface waters. Surface contaminants include salts (chloride, iodide, bromide), HFFs (sands, benzene, toluene), and NORM (radium), and contamination pathways include migration of gas and drilling fluids, and mobilization of local aquifer contaminants. Subsurface pathways may also include migration of contaminants from surface waste storage — like surface storage pits — or landfills containing drilling cuttings. Subsurface contaminants include salts (chloride and barium), HFFs, NORM (radium), and stray gas (methane).

Several practices and technologies have the potential to reduce the risks of surface and subsurface contamination. The group recommended ten solutions that could be implemented in the short-term (1 to 2 years) to minimize risk in the areas of wastewater treatment and disposal, ground water contamination, and surface contamination (Table 4).

Regulations related to contamination pathways and wastewater treatment and disposal are continually in flux and vary significantly by state. Federal regulations, including the Clean Water Act and Safe Drinking Water Act, include exemptions for hydraulic fracturing or oil and gas development. It was agreed that there is no entity or group of entities that is currently responsible for managing the cumulative risks of surface or ground water contamination. The group discussed long-term solutions related to this issue, summarized in Section 4 of this report (*Our Legacy*).

TABLE 4: WATER TRACK SUMMARY

CHALLENGE AREA	HIGH-LEVEL CONCLUSIONS	SHORT-TERM RECOMMENDATIONS
Water Sourcing and Consumptive Use How do we *source and allocate water* while supporting water availability to support human and ecosystems needs?	• While water availability in the Appalachians is relatively high and O&G demand is relatively small compared to other water demands, unregulated withdrawals can cause localized and/or cumulative stress on water availability in settings that have proportionately high biodiversity and recreation values. • In addition to avoiding ecological risks of hydrologic alteration, an equal and potentially greater motivation to reduce freshwater use is to reduce the volume of water that needs to be stored, transported, treated, and disposed.	• Invest in technologies and practices for tracking lifecycle water use in hydraulic fracturing from withdrawal to treatment and/or disposal. • Structure pilot programs to maximize use of non-freshwater sources, particularly re-use. • Develop a regional scale, science-based vulnerability index to guide siting decisions for water withdrawals.
Contamination Pathways and Risks to Surface and Ground Water Resources How do we define and manage for the risk of *surface and ground water contamination* from shale gas development?	• The development of shale gas in the Marcellus play has resulted in documented ground and surface water contamination pathways. • Water and solid waste associated with production can include contaminants of concern like barium, chloride (high salinity), radium, methane, and hydraulic fracturing fluid additives. • This challenge ranges from acute localized impacts to regional persistent risks. Geology and time scales matter. • Current wastewater treatment options pose risk of contamination to surface and/or ground water. There is a lack of information to determine the viability of any given treatment option in managing contamination risk or to assess and compare the economic, social, and environmental costs or risks among treatment options. • Currently, there is no entity or group of entities responsible for managing these cumulative risks or for taking these factors into consideration *at the scale of development.*	Wastewater treatment and disposal: • Invest in decision support for comprehensive water and wastewater management methods, including storage, transport, and disposal. • Conduct a regional assessment of need for and availability of treatment options. • Reduce demand for disposal capacity and treatment. Ground water pathways: • Implement policies that protect public ground water supplies. • Implement standard casing design, well construction, and monitoring standards. • Mandate geotechnical assessment prior to well siting. • Develop a long-term regional ground water monitoring framework. • Establish demarcation of saltwater/freshwater formations and consistent definitions. Surface water pathways: • Implement siting and design standards for onsite storage and well pads in order to prevent migration. • Implement a wastewater transport tracking system. • Invest in centralized industry-specific waste management methods and technologies.

OUR LEGACY: AVOIDING AND MITIGATING CUMULATIVE IMPACTS

The cumulative risks and impacts of shale gas development in the Appalachian region represent an important challenge characterized by complexity and uncertainty. A compelling way to frame the issue is to consider two questions: what do we want our legacy to be after the Marcellus, Utica, and other shales are played out and what should we do to realize that legacy? We have an opportunity to approach these challenges by learning and drawing from past development in the region and by utilizing emerging science and technology.

The cumulative impacts of incremental changes are often beyond the perception of geopolitical units like townships, counties, and even states. Over time, some indicators of change are sensed, but integrating many local impacts to recognize larger trends is difficult. These challenges are exacerbated by the lack of institutions with missions, authority, and capacity to synthesize information, assess patterns at large geographic and temporal scales, and make decisions accordingly.

We can take collective actions to define and work towards realizing a legacy that we want to leave for future generations. Drawn from workshop discussions, suggested guidance for those actions includes creating a common vision for the "end state," defining indicators of impact and thresholds for action, developing a science-based adaptive management framework, monitoring indicators to inform decision making, and safeguarding for long-term risks.

TABLE 5: OUR LEGACY SUMMARY

CHALLENGE AREA	HIGH-LEVEL CONCLUSIONS & SHORT-TERM RECOMMENDATIONS
Avoiding and Mitigating Cumulative Impacts What do we want *our legacy* to be after the Marcellus, Utica, and other shales are played out? How do we realize that legacy and account for intergenerational needs in our decision making?	• Learn from past development in the region and bring solutions from the present. • Take collective actions to define and work towards realizing a legacy that we want to leave for future generations. – Define the geographic and temporal scales of impact. – Create a common vision for the "end state." – Develop dimensions of impact: indicators, trajectory, and thresholds. – Establish a neutral, accountable, and durable coordinating body at the regional scale. – Develop a science-based monitoring framework and sustained commitment to monitor indicators. – Guide the trajectory to realize the desirable endpoint. – Safeguard for risk.

CROSS-CUTTING THEMES

In this workshop, we focused on the potential impacts to land, water, and air associated with shale development in the Appalachian region. We grappled with questions as varied as how to reduce ecosystem impacts from noise and artificial lighting and how to reconcile the scales of decision making (leaseholds) and ecological values (watersheds and landscapes) through landscape-scale planning. We attempted to unravel the complexities of co-locating surface infrastructure, defining and managing for the risks of surface and ground water contamination, and reducing emissions of methane and other air pollutants. Despite the wide-ranging nature of the topics discussed, some common lessons and cross-cutting themes emerged from the working group sessions.

"Drilling a horizontal shale gas well in Appalachia" by Meredithw, licensed under CC BY-SA 3.0

WHAT DID WE LEARN?

- Most of the challenges we tackled are massive in scale and reach and have solutions that are complicated and depend on multiple stakeholders working in tandem. Although they fostered constructive dialogue and produced some meaningful recommendations, the four-hour working group sessions only scratched the surface of the kind of deep, ongoing dialogue needed to develop a full suite of feasible solutions to address the environmental challenges associated with shale development.
- Working group discussions revealed some knowledge gaps among participating stakeholders in the realms of current research, regulatory changes, and on-the-ground practices. For example, some participants in the non-profit sector were not fully informed about practices currently used by many industry operators and their contractors, and some industry representatives were not aware of recently-published scientific research. There was also some confusion about the complex regulatory framework at the federal level and across states in the region.
- Some of the environmental risks associated with shale development are also relevant to other forms of energy and infrastructure development, and thus we can draw from leading practices in other industries to address those challenges. In the same vein, developing more effective practices in the context of Appalachian shale development can also be useful for industries beyond shale in the region.
- Several solutions toward addressing the environmental challenges associated with shale development already exist, whether through long-standing practices or emerging technologies. Sometimes the problem is about how to achieve widespread adoption of those solutions, and the missing pieces may include improving technology, lowering costs, providing implementation guidance, augmenting regulatory requirements, increasing data availability, or demonstrating effectiveness.
- Many solutions recommended by working groups involve wide-reaching actions through space and time and require cooperation across multiple jurisdictions (federal, state, local), disciplines (e.g., geologists, ecologists, engineers), or stakeholders (e.g., operators, consultants, regulators, landowners, researchers, etc.). Given the complexities of the challenges discussed, it is not surprising that the recommended solutions are equally broad and multifaceted.

WHAT DO WE NEED?

Several needs were identified by participants across all or most sessions during working group discussions. Addressing these needs would allow for a better understanding of the issues and challenges and a more productive, future dialogue targeted at feasible solutions.

- **Stakeholder education for a better understanding of current research, on-the-ground practices, and regulations.** Each sector seemed to have some knowledge gaps in one of these areas, showing a need for further engagement to disseminate information. Part of the reason for this need is the hugely variable and ever-evolving state of research, technology, practices, and policy relevant to all aspects of shale development in the Appalachian region.
- **More research and data.** Every working group cited inadequate or unavailable data as a barrier to fully understanding and addressing their challenge. There is a need for developing standardized metrics and reporting methods so that changes can be more easily detected and consistently monitored through time and space. Information gaps make the development of appropriate policy and practices difficult. Many groups also pointed to the need for more reliable, low-cost monitoring equipment to gather information in the field.
- **Single, comprehensive, regionally-specific BMP manual.** Currently, there is a plethora of Best Management Practice (BMP) and guideline documents relating to or applicable to shale development. Although they are called "best" practices, in general, we lack the research and data to know if this is truly the case under a particular set of circumstances. Workshop participants from the energy industry repeatedly expressed the need for a single, comprehensive regional BMP manual specifically for the Appalachian region. Many companies already implement BMPs and, unless cost-prohibitive, are eager to employ additional voluntary practices to reduce environmental and other risks. The obstacles they face include knowing what practices are most suitable to apply under which circumstances and which of the many disparate sources of material to use as their primary guidance. A "one-stop-shop" for leading practices tailored for the Appalachian region would be a hugely valuable resource.
- **Continued engagement across sectors.** Participants vocalized the benefit of multiple sectors, including government, industry, non-profit organizations, and academic researchers, coming together to talk and share information and ideas. Continuing to provide opportunities for cross-sector dialogue is essential for maintaining a common understanding of the current state of research, technology, practice, and policy and for developing feasible short- and long-term strategies for reducing environmental and other impacts from Appalachian shale development.

Workshop participants agreed on the importance of **cross-sector dialogue** to create a **common understanding and vision** for the "end of life" of shale energy demands and development in the Appalachian region. This workshop helped to build a foundation for continuing to learn from each other, to advance existing techniques and identify new solutions to environmental challenges, and to work towards the legacy that we would like to leave for future generations when Appalachian shale plays have run their course.

Introduction

Section 2

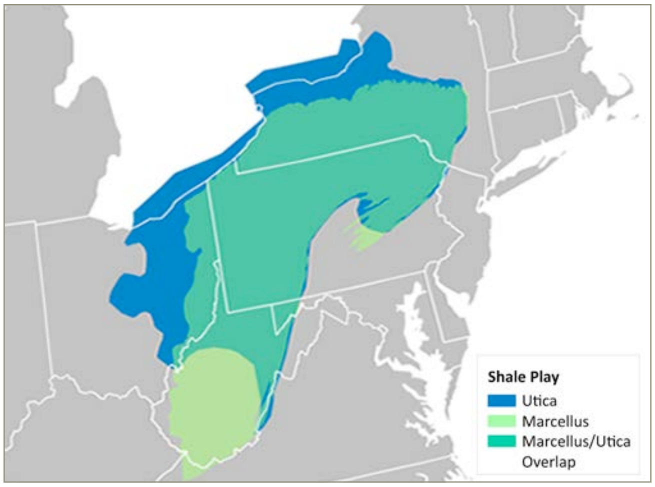
Introduction

Striking a balance between making the best use of energy resources in the Appalachian region and safeguarding its abundant ecological resources is one of our most challenging conservation endeavors. In approaching this challenge, we need to consider what we want our legacy to be not only today but in the future as the mix of energy sources we rely upon continues to evolve.

The Appalachian region is a global hotspot for forest and freshwater diversity, encompassing some of the world's best remaining examples of diverse, intact, and connected temperate forests and freshwater streams.[1,2] The ecological services that flow from these rivers and forests — from clean, reliable water supplies to outdoor recreation — reach tens of millions of people every day.

At the same time, the Appalachian region is an expanding hub of energy development, with abundant coal, natural gas from shale, and wind energy resources. All forms of large-scale energy production and delivery, including shale development, require an infrastructure network and construction, operations, and maintenance activities that can alter natural habitats and wildlife behavior, challenge the health of freshwater systems, create noise and artificial light, and strain our air quality.

Underway for less than a decade, unconventional oil and gas development in the Appalachian region involves extraction of natural gas reserves in the Marcellus, Utica, and other shale formations using hydraulic fracturing and horizontal drilling technologies. As with other types of energy, shale development involves extensive infrastructure, including wells, well pads, access roads, pipelines, storage facilities, and compressor stations. As research continues to emerge, we are building a scientific understanding of the potential impacts on our lands, waters, and air from this infrastructure and associated operations. Due to the region's landscape diversity, potential effects vary in scale and severity and need to be understood and managed appropriately to reduce both short-term, local impacts and long-term, cumulative impacts.



The intersection of important natural habitats, abundant energy resources, and long-standing human communities makes the Appalachian region a significant area of ongoing energy development and research.
Source: U.S. Energy Information Administration

Federal and state regulations and existing voluntary practices related to planning, design, and construction of shale operations address some of the potential environmental impacts associated with shale development. However, horizontal drilling and high-volume hydraulic fracturing are relatively new to the Appalachian region, and existing regulations have not yet been fully updated to cover the distinctive operations and outcomes of shale development. Although a number of oil and gas companies have proactively implemented best practices, they have not yet been adopted by the industry at large, and the degree to which these efforts are successful is largely unknown.

1 Appalachian Landscape Conservation Cooperative (http://applcc.org/cooperative/our-plan/section-1/biodiversity-hotspot)
2 Olson, D. M., Dinerstein, E. 2002. The Global 200: Priority ecoregions for global conservation. *Annals of the Missouri Botanical Garden* 89(2): 199-224.

COLLABORATIVE CONSERVATION: THE NEXT GENERATION

To address these challenges, a collaborative workshop, *Advancing the Next Generation of Environmental Practices for Shale Development*, was held on May 27-29, 2015 on the campus of Carnegie Mellon University (CMU) in Pittsburgh, Pennsylvania. The workshop was designed and implemented by The Nature Conservancy (TNC) and, at CMU, by the Wilton E. Scott Institute for Energy Innovation and the Steinbrenner Institute for Environmental Education and Research. Funding was generously provided by the Colcom Foundation of Pittsburgh.

The workshop had two solution-driven objectives related to Appalachian shale development:

1. **Leverage collaboration** among a variety of actors working to advance conservation practices.
2. Define **Challenge Areas**, increase visibility of available **solutions toward addressing those challenges**, identify barriers in implementation, and generate new, actionable **strategies** toward realizing conservation goals.

WORKSHOP APPROACH AND FORMAT

Over the course of the three-day workshop, more than 140 invited participants worked in groups to identify a shared set of challenges and outstanding questions regarding the ecological risks of shale gas development in the Appalachian region. Once that shared understanding was established, the discussions focused on developing practical solutions within the framework of three key **conservation goals:** conserving the biodiversity and resilience of Appalachian ecosystems, protecting the quality and availability of water for ecosystems, and minimizing emissions of air pollutants *(See Conservation Goals diagram below)*.[3]

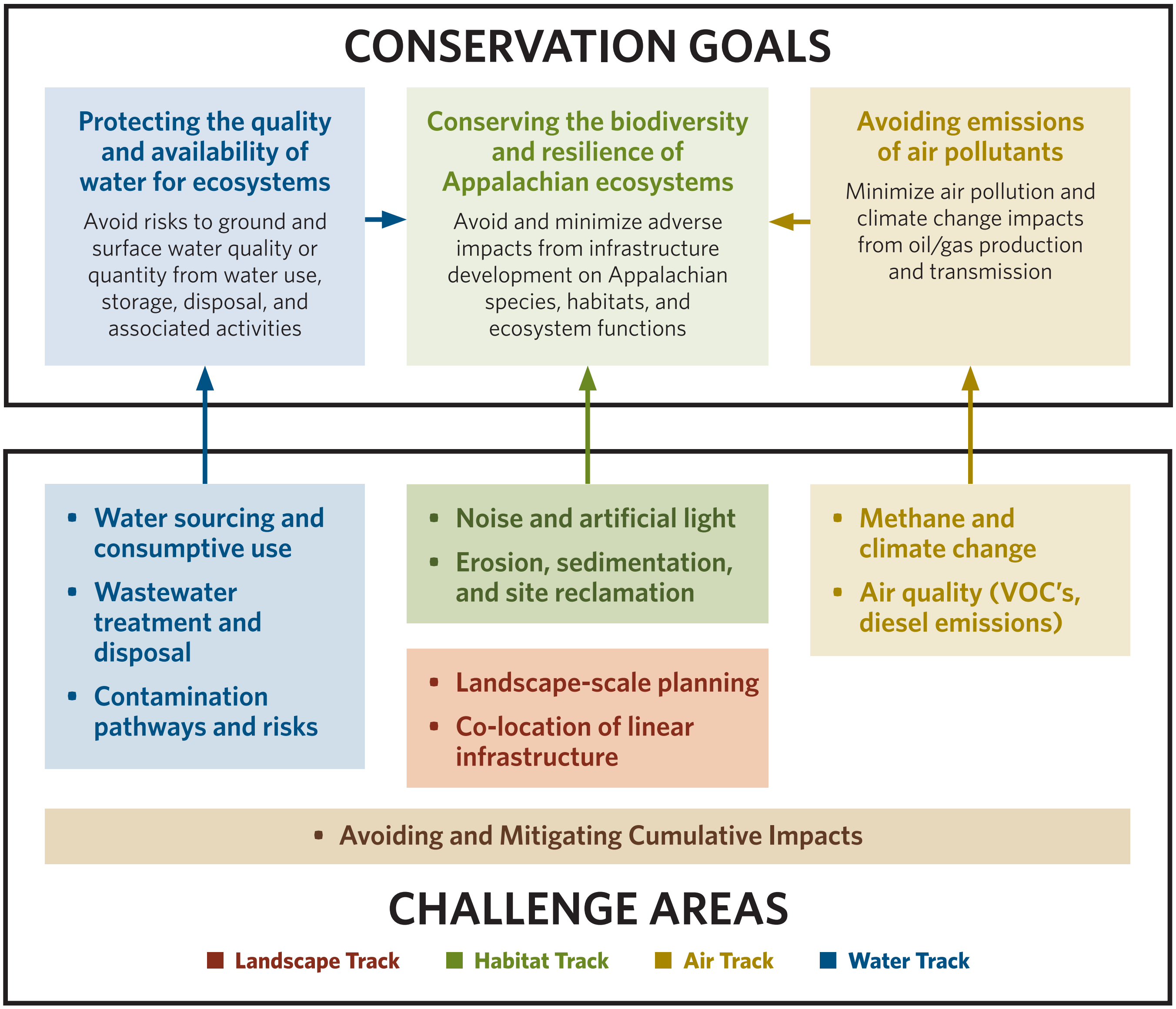
Working groups focused on **four tracks** — **landscape**, **habitat**, **air**, and **water** — geared toward addressing **Challenge Areas** to achieve the conservation goals. Participants included energy and environment experts across several sectors: 15 academic institutions; 16 local, state, and federal government agencies; 22 non-governmental organizations and foundations with interests in shale development; and 25 members of the energy industry. See Appendix B for a list of participating organizations. Participants were assigned to working groups that best fit their expertise, while maintaining a balance of sectors within each group.

Defining the Challenge and Prioritizing Solutions

Over the first two days of the workshop, working groups focused on potential solutions to challenges in the short term (one to two years). These discussions are summarized in the first two portions of each track in the *Challenge Areas and Working Group Recommendations* section of this report. Each session began with a high-level overview of the issue, presented by an "anchor" — an expert in the topic. Following this presentation, facilitators guided the discussion to accomplish the following tasks:

- Reach a common understanding of the **"State of the Challenge,"** based on participants' knowledge of the science, policy, technology, and practice for each topic (i.e., what we know and what we don't know).
- Identify and prioritize a set of existing or emerging **solutions** that could contribute to addressing each challenge and be implemented in the short term.

3 While human health, safety, and community impacts are important considerations associated with shale development, they were outside the direct scope of this workshop, although Dr. George Hornberger, chair of the Health Effects Institute's Special Scientific Committee on Unconventional Oil and Gas Development in the Appalachian Basin, provided an overview of the committee's work in a keynote address at the workshop. It was clear from Dr. Hornberger's summary of the forthcoming report (since released) that there are strong connections between health and ecological effects, especially in the area of exposure assessment, and that HEI's research should be closely followed and incorporated into future work deliberations.



Framed by the workshop's overarching Conservation Goals, working groups explored Challenge Areas in four different tracks: water, habitat, landscape, and air. Cumulative impacts were discussed as the culmination of the workshop.

Achieving Environmental Outcomes: Short- and Long-term Strategies

On the workshop's last day, facilitators guided working groups in the following tasks:

- Develop **implementation strategies for near-term solutions** produced over the first two days of the workshop. These discussions are summarized in the final portion of each track in the *Challenge Areas and Working Group Recommendations* section of the report.
- Discuss **long-term strategies** necessary to more fully understand and address potential cumulative impacts. These discussions are summarized in Section 3.4.3 and Section 4 (*Our Legacy*).

To ensure that participants felt comfortable sharing their expertise and experience openly, members of the news media did not participate, and workshop sessions were not recorded so that statements could not be tied to individuals. Instead, scribes in each session provided the report authors with notes detailing the groups' discussions and outcomes. **Content and conclusions from these working group sessions are summarized in the *Challenge Areas and Working Group Recommendations* section of the report, organized by track (landscape, habitat, air, and water).** All anchors, facilitators, and participants were given the opportunity to review the summary of working group discussions to which they contributed before the report was finalized.

RESULTS OF PARTICIPANT SURVEY

The Nature Conservancy administered a survey of participants the week following the workshop, with almost half of the attendees responding. Overall, responses were very positive. Participants cited the mixture of sectors represented and the opportunity to interact with people from other sectors as the most valuable part of the workshop, suggesting that further opportunities for interaction would be beneficial to relevant stakeholders. In fact, over 80% of respondents said they would be interested in participating in follow-up workshops targeted at specific topics from this workshop.

Respondents thought that the format of the workshop allowed for productive and open discussion that ultimately led to some tangible solutions, although the proposed solutions could benefit from further discussion on strategies for implementation. Respondents also noted that some participants were unaware or misinformed about current regulations, existing practices, and recent scientific research. This highlights the need for ongoing cross-sector dialogue to share information and reach a common understanding on these topics, as a basis for identifying and implementing actionable solutions to environmental challenges associated with shale energy development.

Challenge Areas and Working Group Recommendations

Section 3

Challenge Areas and Working Group Recommendations

The workshop generated robust cross-sector dialogue on a variety of Challenge Areas related to shale development in the Appalachian region. Working groups produced recommendations for addressing those challenges to meet three key conservation goals: conserving the biodiversity and resilience of Appalachian ecosystems, protecting the quality and availability of water for ecosystems, and minimizing emissions of air pollutants.

Organized into landscape, habitat, air, and water tracks, this section summarizes the working group discussions for each Challenge Area. Each summary begins with a description of the current State of the Challenge, covering what we know and what we do not know in the areas of scientific research, technology, practices, and the regulatory framework, based on presentations by expert "anchors" and completed by participants. Next, each summary presents priority short-term solutions recommended by the working groups for moderating adverse impacts to Appalachian ecosystems. Groups prioritized recommendations based on their expected combination of effectiveness and feasibility of implementation in one to two years. For each track, the last subsection summarizes discussions from the workshop's last day, focused on implementation strategies for short-term solutions.

3.1 LANDSCAPE TRACK

3.1.1 LANDSCAPE-SCALE PLANNING

3.1.2 CO-LOCATION OF INFRASTRUCTURE

3.1.3 SHORT-TERM IMPLEMENTATION OF RECOMMENDATIONS

Landscape-scale planning and co-location of linear infrastructure are perhaps the two areas where conservation practices could have the most positive impact on the condition of regional habitats, but may also be the most difficult in developing feasible solutions. In the context of finding both near-term solutions and strategic, long-term approaches to avoid and minimize adverse impacts from infrastructure development on Appalachian wildlife, habitat, and ecosystem functions, participants in the Landscape sessions explored two distinct but related Challenge Areas: (A) landscape-scale planning, and (B) co-location of linear infrastructure.

The summaries for **landscape-scale planning** and **co-location of infrastructure** describe the content of working group discussions during the first two days of the workshop. Each summary begins with an **overview of the challenge** and then presents the **current state of the challenge**, as presented by expert "anchors" and enhanced by participants, covering what we know and what we don't know in the areas of scientific research, mitigation technologies, practices, and regulatory framework.

Because landscape-scale planning and co-location of infrastructure are such complex topics, participants devoted most of the session discussions to defining and understanding them. Participants did brainstorm some **potential solutions** and areas of opportunity in the short term (one to two years), and those ideas are described in the session summaries below and in Appendix C. Insufficient time precluded the working groups from fully vetting and prioritizing proposed ideas. Further discussions are needed to identify and prioritize potential solutions to the challenges associated with landscape-scale planning and co-location of infrastructure in the context of shale development.

The last summary describes the content of working group discussions during the final day of the workshop, when participants focused on the **short-term implementation of recommended solutions** from the previous days' discussions within the landscape track.

3.1.1 LANDSCAPE-SCALE PLANNING

SECTOR REPRESENTATION

Anchors: Academic institution, energy industry
Facilitators: Academic institution, non-governmental organization
Participants: Academic institutions (12), energy industry (10), government (9), non-governmental organizations (16)

CHALLENGE

How do we best reconcile the *scales* of decision making with the scales of ecological values?

How do we best support ongoing oil and gas development while avoiding, minimizing, and mitigating impacts to *landscape-scale* ecological values?

HIGH-LEVEL CONCLUSIONS

- The potential efficiencies gained through landscape-scale planning are largely unknown and merit research.
- Given differing planning scales and approaches both in industry practices and the current regulatory framework, further discussion is needed to more fully understand the ways in which landscape-scale planning can be integrated into the development process.
- Reliable, accessible data on landscape features and a regional coordinating body are both needed.

In working through these challenge statements, participants grappled with determining what defines a landscape (i.e., what is the appropriate scale of landscape-scale planning), which ecological values to focus on, and how landscape-scale planning could be applied to shale development.

OVERVIEW OF THE CHALLENGE

Development of any kind, including shale, is made up of many local decisions that cumulatively influence land use patterns and have implications on a larger, landscape scale. Shale infrastructure relevant to planning includes well pads, wells, compressor stations, roads, pipelines, stream crossings, storage and staging areas, water withdrawal and handling infrastructure, and existing infrastructure.

As development expands, it converts land to a mix of natural and non-natural cover. The cumulative impacts of this conversion can affect the quality of water resources and wildlife habitat on a landscape scale through habitat loss and fragmentation, increased impervious cover, altered hydrology, and increased erosion and sedimentation.[4,5,6,7] The goal of landscape-scale planning is to avoid and minimize impacts to landscape-scale ecological values — wildlife habitat, water resources, and ecosystem functions — while increasing regulatory predictability and improving efficiencies during shale development and operations.

4 Johnson, N., Gagnolet, T., Ralls, R., Zimmerman, E., Eichelberger, B., Tracey, C., Kreitler, G., Orndorff, S., Tomlinson, J., Bearer, S., and Sargent, S. 2010. *The Nature Conservancy*. (http://www.nature.org/media/pa/pa_energy_assessment_report.pdf).

5 Drohan, P. J., Brittingham, M., Bishop, J., and Yoder, K. 2012. Early trends in landcover change and forest fragmentation due to shale-gas development in Pennsylvania: A potential outcome for the northcentral Appalachians. *Environmental Management* 49(5): 1061–1075.

6 Slonecker, E. T., Milheim, L. E., Roig-Silva, C. M., and Malizia, A. R. 2013. *Landscape Consequences of Natural Gas Extraction in Allegheny and Susquehanna Counties, Pennsylvania, 2004-2010*. No. 2013-1025. US Geological Survey.

7 Kiviat, E. 2013. Risks to biodiversity from hydraulic fracturing for natural gas in the Marcellus and Utica shales. *Annals of the New York Academy of Sciences*. 1286: 1–14.

Successfully implementing landscape-scale planning is difficult for many reasons, starting with defining landscape-scale planning, in part because "landscape" is such a generic term.[8] There are various ways to define a "landscape," including using watershed boundaries or other ecological and physical features (e.g., similar vegetation, climate, etc.), and the scale can vary from several to thousands of square miles. In the context of shale development, perhaps it is most useful to think of the landscape's boundaries in terms that are relevant to a company's operations or the scale at which infrastructure placement decisions are made. That could be a medium-sized watershed that largely overlaps with an oil/gas field or it might be two adjacent counties or townships where the company has significant leaseholds. In terms of conservation, landscape-scale planning seeks to optimize competing land uses while protecting natural processes and significant cultural and natural resources.[9]

Applying this framework to infrastructure development is a major challenge — how do we reconcile large-scale ecological values that do not follow political boundaries with state, county, and local decision making? Ecological values are best viewed on a large scale (e.g., watershed, region, or ecosystem) encompassing many thousands of acres, while shale infrastructure is planned on a much smaller scale, often driven by production units or individual leases, which are typically 1,280 acres or less.

STATE OF THE CHALLENGE

STATE OF THE SCIENCE

The consequences of shale development, as with any form of development, are not limited to individual, local effects, but also cumulatively contribute to impacts on a larger, landscape scale. Potential landscape-scale ecological impacts from land use conversion include:[10]

- **Habitat impacts.** Road, pipeline, and well pad development can alter forest and vegetation cover and configuration within a landscape, which affects the region's ability to sustain healthy ecosystems.
- **Watershed impacts.** Watershed health is closely tied to land cover and use. Loss of forest cover and increased impervious surfaces have been linked to increased erosion and sedimentation, altered hydrology and runoff patterns, higher stream temperatures, and changes in the distributions of aquatic species.

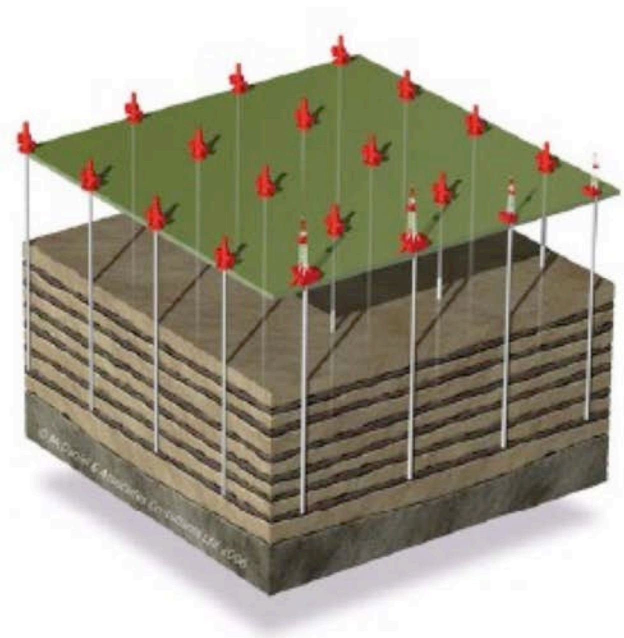
Beyond ecological impacts, participants cited research that points to the efficiencies that can be gained by landscape-scale planning, including preventing or reducing new forest fragmentation and increasing cost-effectiveness. Landscape-scale planning is a relatively new frontier. While there is reason to believe there would be important economic efficiencies, it does not have much by way of example. There are examples with limited applicability, such as infrastructure planning on federal lands and dramatically shortening permitting times for solar because of regional planning and siting.[11]

8 "Landscape may be defined by a combination of geography and resource issues or opportunities, and may be of varying scale and scope." Levitt, J.N. 2004. Landscape-scale Conservation: Grappling with the Green Matrix. *Land Lines*, 16(1): 1-5.

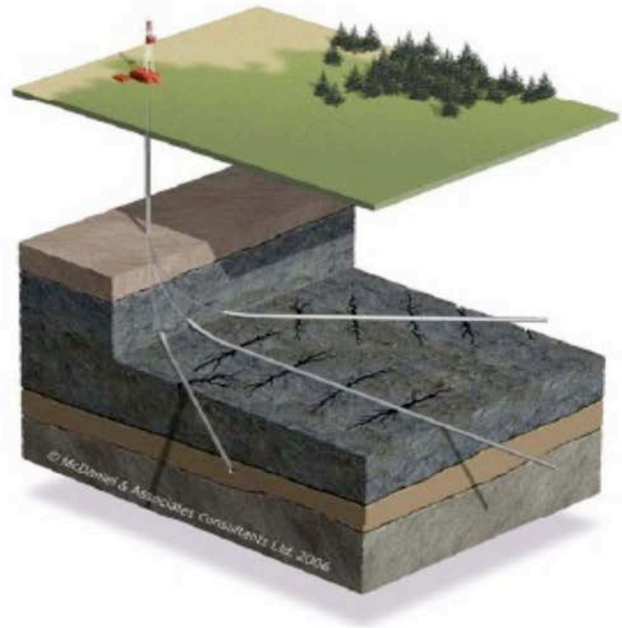
9 Trombulak, S. C., and Baldwin, R. 2010. *Landscape-Scale Conservation Planning*. Springer Science & Business Media.

10 Impacts drawn, in part, from: The Nature Conservancy. 2015. Reducing ecological impacts of shale development: Recommended practices for the Appalachians (nature.org/shale-practices)

11 U.S. Bureau of Land Management. 2015. "Interior Department Approves First Solar Energy Zone Projects." June 1, 2015. Washington, D.C. (http://www.blm.gov/wo/st/en/info/newsroom/2015/June/nr_06_01_2015.html)



Traditional Wells



Horizontal Drilling

As opposed to conventional drilling for oil and gas where infrastructure must be placed directly above the resource to be extracted, horizontal drilling associated with shale development allows for multiple wells to emanate from a single pad and more flexibility in the location of pads and other infrastructure. [Graphic](#) *reproduced courtesy of the American Petroleum Institute*

RESEARCH GAPS

Workshop participants pointed to the following areas where more research could further inform and support landscape-scale planning practices and policies:

- **More specificity related to potential impacts.** More research is needed on what habitats are being affected and how, what areas are most likely to be drilled, and what habitats and resources are there. Answers to these questions and identifying landscape-scale goals will help in developing solutions.
- **Efficiencies of landscape-scale planning.** Documenting potential economic efficiencies due to landscape-scale planning practices (demonstrating the "business case") would be instrumental in demonstrating its value to industry and policy makers.

STATE OF THE TECHNOLOGY

As opposed to conventional drilling for oil and gas where infrastructure must be placed directly above the resource to be extracted, horizontal drilling associated with shale development allows for multiple wells to emanate from a single pad and more flexibility in the location of pads and other infrastructure. As a result, energy companies can more easily incorporate a landscape-scale approach into developing a drilling plan that minimizes the impacts of land use change on habitats.

Mapping and spatial analysis tools have made viewing the landscape, including important habitat features and existing infrastructure, relatively easy. However, as participants discussed (see Technology Gaps), gaps in data can make effective use of these tools more problematic.

- **Siting tools.** Siting tools, like well pad evaluation tools and The Nature Conservancy's LEEP tool, integrate ecological, topographic, cost, and other data to create optimized siting options that can allow operators to reduce ecological impacts and improve operational efficiencies with their siting decisions. Rather than relying on manual analysis, such software tools can facilitate planning of surface infrastructure placement at a larger, landscape level while accounting for a multitude of factors.

TECHNOLOGY GAPS

Participants pointed to inadequate data and limitations on available data as a major challenge in implementing landscape-scale planning.

- **Limited availability of data.** Various stakeholders, including the industry, non-governmental organizations, and members of the public, do not have good datasets available to them that could foster working together to develop solutions and fill data gaps. As helpful as collaborative datasets may be, there are risks and limitations to what data can be made accessible to broad audiences (e.g., social data, proprietary information, such as areas most likely to undergo future development, and data on endangered species).

STATE OF THE PRACTICE

The current state of the practice varies tremendously, with each operator having their own planning process, but all operators must include the following considerations in their siting decisions: geology, regulatory and permitting requirements, landowner preferences, leasehold terms, environmental factors, and operational feasibility. The working group did not have enough time to gain a full understanding of what oil and gas operators are doing in terms of planning.

Several general principles[12] that many agencies and organizations recommend related to landscape-scale planning include:

- **Consolidate infrastructure.** Consolidating and co-locating infrastructure (including with existing roads and other energy transmission infrastructure) can reduce fragmentation and the overall footprint of shale development.
- **Avoid important and sensitive habitat areas.** Avoid ecologically important areas (e.g., large interior forest areas, cave and karst systems, wetlands, etc.) and maintain connectivity between them. State Wildlife Action Plans, or comprehensive wildlife conservation strategies, could be useful resources during planning; they go beyond species and habitats that fall under federal protection to include species of greatest conservation need.
- **Inventory and monitor landscape components.** Identify and assess wildlife concerns, operational constraints, and biological components (e.g., soil, air and water quality, ambient noise levels, and vegetation) of the surrounding landscape to document a complete baseline condition. Continued and regular monitoring can help inform adaptive management and provide data for future research.
- **Plan for restoration.** Planning for restoration at the beginning of the planning process is important and allows for practices such as the re-use of topsoil and the inclusion of wildlife enhancement features.

Participants had varying perspectives on the industry's willingness or ability to adopt voluntary standards for planning and siting. To counteract potentially increased up-front costs (but potentially lower long-term costs and risks), one incentive for industry to adopt more rigorous planning practices is to receive third-party acknowledgement or support for doing so, for example, through a certification program.

12 Practices drawn, in part, from: The Nature Conservancy. 2015. Reducing ecological impacts of shale development: Recommended practices for the Appalachians (nature.org/shale-practices)

GAPS IN PRACTICE AND IMPLEMENTATION

A number of companies participating in the working group indicated that they take steps to minimize landscape disturbances in siting their infrastructure. Broad implementation of a landscape-scale planning approach to infrastructure development in the Appalachian region, however, is impeded by numerous factors.

- **Fragmented surface and subsurface ownership** often precludes planning infrastructure at a scale larger than a single leasehold.
- The **scale of decision making** about infrastructure placement (leasehold-by-leasehold, operator-by-operator) is generally much smaller than the **scale of ecological values** potentially impacted by that development (ecosystem integrity, regional habitat connectivity, etc.).
- **Coordination among operators** with leaseholds in a given area could allow for a larger planning scale but is challenging to execute due to confidentiality, legal, and other constraints.

STATE OF THE REGULATORY FRAMEWORK

Regulations and requirements for activities associated with shale development differ at every level of jurisdiction, from local to county to state to federal. **No single coordinating agency keeps track of development or impacts on the regional or watershed scale.** The exception to this is development that takes place on Pennsylvania State Game Lands and State Forests, where the Pennsylvania Game Commission and the Department of Conservation and Natural Resources, respectively, have a number of administrative policies related to siting and operations.

Some localities/jurisdictions have limited the locations where oil and gas infrastructure can be placed; however, this is often related only to pipelines and compressor stations. Since local/municipal approval does not generally involve a review of all infrastructure types, a comprehensive landscape approach to infrastructure planning is infrequently applied.

Perhaps the most difficult issue, workshop participants noted, is that strong personal property rights can make landscape planning particularly challenging, especially when there are hundreds or even thousands of landowners in the planning area.

GAPS IN REGULATORY FRAMEWORK

Several challenges in the current regulatory framework exist, mainly due to the contrast of small lease holdings within the larger spatial scale inherent in landscape-scale planning. Participants noted that, due to property rights issues, Pennsylvania has more roads, pads, and pipelines than are necessary. Shale infrastructure could be more efficiently built out, but different tools are needed to achieve that efficiency. Participants identified the following challenges to developing effective policy:

- **Antitrust regulations.** Collaborative planning that could be legally interpreted as having the effect of coordinating or controlling oil and gas production so as to influence prices is sometimes cited as a concern that hampers use of landscape planning tools and techniques and sharing of infrastructure such as pipelines and compressor stations.
- **Fragmented leasehold patterns.** Lease holdings on private lands, generally quite small, can be a challenge as not all landholders agree on how their land will be used. For example, one private land holder may be willing for a pipeline to go across their land, while their neighbor may not be willing. This leads to a fragmented leasehold pattern that is not conducive to landscape planning. In addition, multiple operators are often planning infrastructure in the same area, and each is held to varying lease terms, timelines, and royalty agreements creating yet another challenge even if neighboring private land owners agree.
- **Severed surface/subsurface rights.** Severed land and mineral rights make it more difficult for landscape planning to proceed since the same land may have separate surface and subsurface owners with different priorities that cannot be reconciled.

- **Lack of flexibility in production units.** Some parts of the Central Appalachian region have fixed production units (e.g., 640 acres) that are significantly smaller than technology allows. Even without limits, it can be difficult to legally expand or change the configuration of production units once they have been formed.
- **Permitting process.** The permitting process is a partnership between government and industry with non-governmental organizations and the public observing. Both the regulating and the regulated parties must agree on the use of new methods for them to move forward. Industry would need incentives, such as expedited permitting, for implementing advanced landscape planning or meeting third-party certification standards. This would give developers with more responsible planning practices a marketplace advantage in the form of reduced permitting costs.

RECOMMENDED SHORT-TERM SOLUTIONS

Participants brainstormed a lengthy list of recommendations for advancing landscape-scale planning for shale development in the Appalachian region (see Appendix C). Participants then voted to identify priority recommendations, as presented below. These four areas are where greater transparency and cooperation would provide a common knowledge base for future discussions and decisions.

1. **Collaborative planning.** Collaborative planning paired with incentives to avoid areas of identified high importance could help promote landscape-scale planning. Potential incentives include the appropriate regulatory authority offering an expedited permitting process for those who use a landscape-scale planning tool. High importance areas would need to be identified and trade-offs calculated between ecological impacts, industry interests, and landholder factors.

2. **Data repository.** Develop a collaborative, centralized data repository that allows the public to see existing data, via a public-private partnership of state and local governments, industry, academia, and non-governmental organizations. To make this data repository effective, it should:
    - Include data related to infrastructure and ecological values at appropriate scales, taking into account necessary safeguards to protect vulnerable species.
    - Be vetted, accepted, and accessible to all decision makers and the public.

A benefit of the centralized data repository for industry would be a place where their data could be housed, increasing public trust and allowing for use in a dispute between a company and landowner. Challenges associated with creating a centralized data repository would include the different scales and methods at which data are collected and risks of sharing threatened and endangered species information and proprietary information.

3. **Voluntary "leading" practices.** Develop a framework of collaboration (public-private partnership of regulatory agencies, industry, academia, and non-governmental organizations) that provides objectives and incentives to implement practices related to landscape-scale planning. A second step within this recommendation is establishing a third-party certification program for voluntary best practices, starting with broad initial involvement from multiple sectors and with full transparency.

Incentives for industry could include improved public image and trust, the prospect of cost-savings, and potentially expedited permit review by regulatory agencies for certified operators. Challenges include developing and agreeing upon a set of practices, sharing of information, determining who would make up the third party, length of time in creating a third party and certification program, and effective marketing.

4. **Enhancements in expertise and capacity.** Improve expertise and capacity of land managers and regulators to allow for the inclusion of landscape-scale planning principles. Specific goals of this recommendation listed by participants included:
    - Allowing for more effective and efficient permitting processes.
    - Giving government agencies more access to expertise and filling full-time positions in roles needed to adequately carry out roles and responsibilities.
    - Flexibility for innovation.

3.1.2 CO-LOCATION OF LINEAR INFRASTRUCTURE

SECTOR REPRESENTATION

Anchors: Energy industry, non-governmental organization
Facilitators: Energy industry, non-governmental organization
Participants: Academic institutions (9), energy industry (3), government (8), non-governmental organizations (9)

CHALLENGE

How can we reduce the ecological footprint of pipeline corridors by maximizing the *co-location of linear infrastructure*?

HIGH-LEVEL CONCLUSIONS

- While co-location has the potential to reduce the footprint of shale infrastructure, balancing associated ecological, safety, regulatory, and operational concerns makes implementation complex.
- Further discussion is needed (a) to explore the viability of co-location as a standard within the current regulatory and economic environment and (b) to focus on science-driven specific practices aimed at implementing co-location in right-of-way development.

OVERVIEW OF THE CHALLENGE

The physical footprint of pipelines and other linear infrastructure for natural gas transmission can have a significant impact on soil and water, species habitat, and landscape aesthetics. The goal of co-locating infrastructure is to reduce this footprint by utilizing areas that have already been developed. Also, unlike other development sites, pipeline rights-of-way (ROWs) are not subject to final restoration, at least in the short term; they become "fairly permanent aspects of the landscape."[13]

Pipelines are sited based on many factors, including project needs, environmental features, permitting considerations, adjacent infrastructure, cost, and co-location regulations. Operators often seek to co-locate their pipelines near other pipelines, electric power lines, roads, or other existing ROWs. Co-locating infrastructure is said to be both efficient and economical; it also minimizes land use changes and reduces the ecological footprint of pipeline corridors, thus potentially reducing environmental impacts and the cost of laying the pipeline.

Several challenges stand in the way of broad deployment of co-location, including legal, economic, and safety issues;[14] private landowner rights; the relationship among

13 Institute of Politics. 2013. Shale Gas Roundtable: Deliberations, Findings, and Recommendations. University of Pittsburgh, Pittsburgh, PA.

14 Co-location of pipelines within existing energy corridors can sometimes result in interactions between the energy systems, or other hazards due to the physical proximity.

landowners, operators, and regulators; lack of coordination and consultation between state and local governments; differences in the regulatory framework regarding gathering, transmission, distribution, and hazardous liquids pipelines and other linear infrastructure; difficulties with coordinating potential "co-locating" operators; and the absence of a sufficiently comprehensive state authority for intrastate gathering and transmission pipelines.

In light of these complex challenges, the working group spent the majority of its time engaged in discussions to better understand these challenges and frame the problem so that future discussions on this issue can be more targeted toward recommended practices and solutions.

STATE OF THE CHALLENGE

STATE OF THE SCIENCE

Participants discussed the potential environmental impacts of pipeline siting, construction, and maintenance, including:

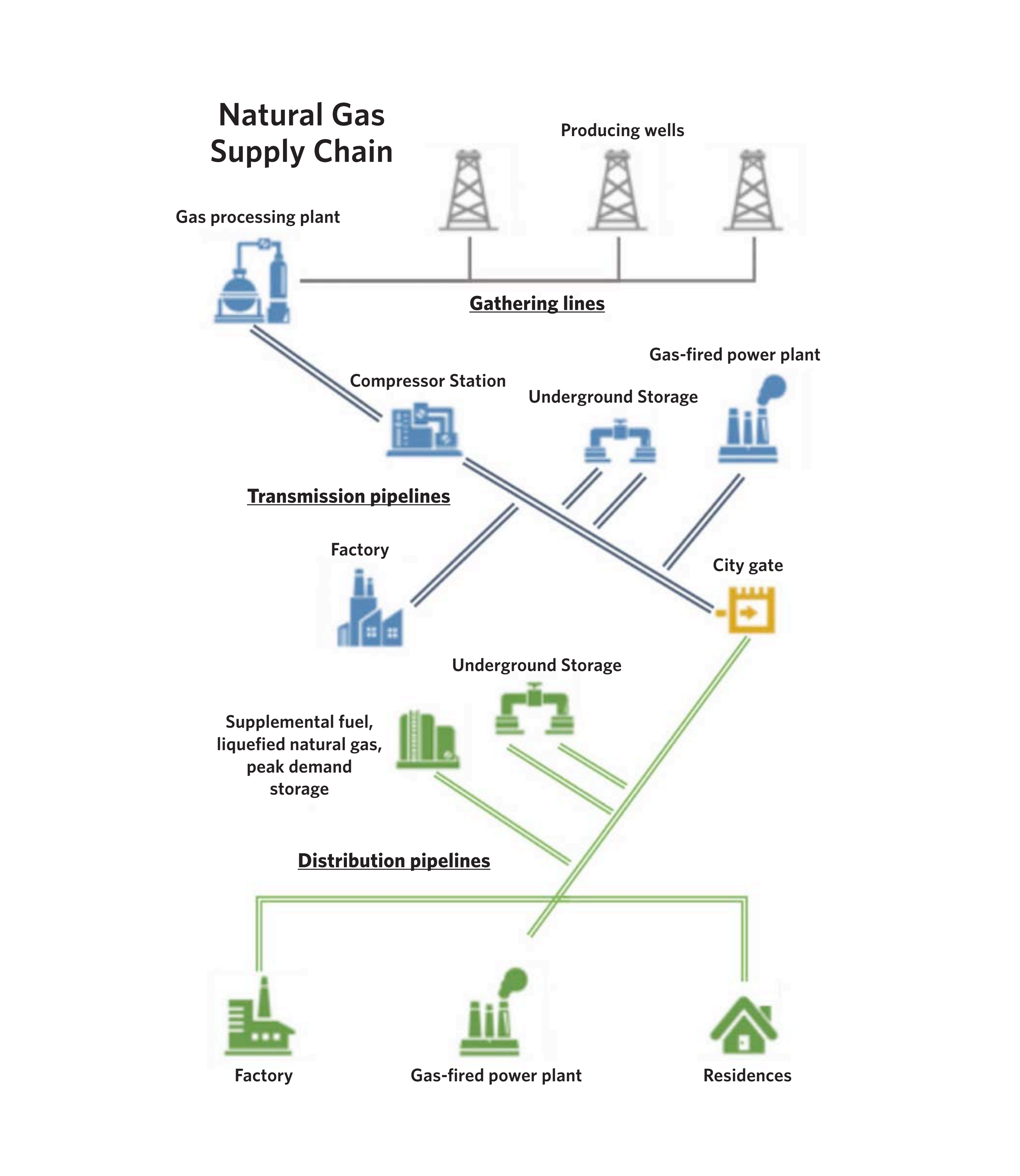
- **Habitat alteration and loss.** Pipeline construction and presence can disrupt habitat and wildlife through forest fragmentation, soil disruption and compaction, stream crossings, and vegetation removal and ongoing maintenance.
- **Watershed impacts.** Pipelines can increase erosion and sedimentation risks, particularly near stream and wetland crossings, and affect hydrology.

While many of these impacts are similar to those discussed in other workshop sessions, the permanence of a pipeline ROW is significant for long-term conservation practices. That is because these corridors continue to be disruptive for decades, since they are subject to ongoing management and maintenance, such as vegetation management, to ensure the integrity of the pipeline.

RESEARCH GAPS

Participants also discussed the disparity of data related to environmental risk and assessment, and noted several areas where additional research could help guide co-location practices and policy:

- **Lack of spatial data.** Some data regarding pipelines are accessible, including all hazardous liquid pipelines (Pipeline and Hazardous Materials Safety Administration (PHMSA) website); however, some data, like those related to gathering and distribution lines, are not effectively documented on this website. State, county, and local governments in Pennsylvania collect only a limited amount of data, and those data are rarely adequate for studies of the issues involved and generally are not available in an easily accessible form (e.g., neither electronic nor shared). Tracking these pipelines with accessible data would allow companies, agencies, and organizations to map linear infrastructure; enhance awareness of the situation for policymakers and the public; and provide the data necessary for researchers to evaluate and develop best practices for reducing local and cumulative impacts.
- **Benefits of co-location.** Research to show the potential cost savings that can be realized by co-locating with other companies could act as an incentive to developers. Participants noted, however, that the main consideration in siting is the partnership with landowners, not economies.
- **Risks of co-location.** Co-location can introduce risk to existing infrastructure. For example, construction of a new pipeline within an existing ROW may introduce risks to the integrity of the existing pipeline.
- **When co-location is appropriate.** Participants noted that determining when co-location would be beneficial, by looking at trade-offs, would be helpful to developers in determining when they should and should not co-locate. For example, is co-location beneficial if it requires the expansion of existing ROWs (width or length)? Would co-location along roadways help or hurt stormwater runoff, habitat disruption, or other environmental considerations? Where would new fragmentation caused by pipelines make a difference to habitat quality and where would it not?
- **Vegetation management.** ROWs can potentially be designed and managed to benefit species of greatest conservation need and other wildlife, but specific



Graphic reproduced courtesy of the American Petroleum Institute practices, such as Integrated Vegetation Management promoted by the Right-of-Way Stewardship Council, were not discussed in the session.

- **Impacts.** More research on how pipeline ROWs impact the landscape would be helpful in developing ways to reduce these impacts. For example, research could enhance our understanding of how ecological impacts from pipelines may differ from other linear infrastructure and how width influences the severity of impacts; it could also help identify potential acute and chronic impacts of multiple stream crossings and forest fragmentation.

STATE OF THE TECHNOLOGY

Technology was not a focus of this group's work, but some methods were mentioned by participants:

- **Corridor inspections.** PHMSA requires operators to patrol ROWs, in order to observe surface conditions and identify factors affecting the safety and integrity of pipelines. There are different methods to carrying out these inspections, such as fly-over inspections, which can result in more aggressive vegetation management. Inspection requirements may inform opportunities for co-locating infrastructure.
- **Decision-support tools.** Industry routinely uses siting and other spatial analysis and planning tools to help in determining areas where co-location is possible, and to avoid impacts to environmental and socioeconomic features early in the process. However, these tools rely on data, which is sometimes inadequate.
- **Pipeline-stream crossings.** Participants discussed several methods used in pipeline-stream crossings, including open trench and horizontal directional drilling (HDD). More information is needed on the frequency, potential extent of impacts, and factors contributing to inadvertent returns from HDD beneath stream beds. Returns/releases can impact aquatic species, habitat, and water quality. The extent of these impacts and factors that may increase or decrease the risk of failure are unknown, as are the criteria used in determining when HDD is the best method for a stream crossing. Participants agreed that this is a strong area for future research and could help inform pipeline co-location practices.

TECHNOLOGY GAPS

The discussion on new technologies was limited; however, the following was identified as an area with high potential for improvement:

- **Technologies to narrow workspace.** New technologies for tunneling and narrowing workspace could reduce the footprint of ROWs. While these technologies have the opportunity to significantly reduce impacts, it was noted that a thorough review of safe construction methods is needed before adoption.

STATE OF THE PRACTICE

There are existing practices related to pipeline siting, construction, and maintenance, some of which are required through existing laws and regulations. Practices identified by participants include:

- **Use existing ROWs.** Coordinate among operators to share existing ROWs and combine pipelines with roads and other ROWs to minimize habitat fragmentation and new stream crossings.
- **Design and construct to minimize impacts.** Examples include combining erosion control with long-term contour and drainage design, using certified forestry practices, preserving canopy cover, minimizing corridor width, and implementing best practices for stream crossings.
- **ROW maintenance and enhancement.** Beyond any required vegetation protocols, examples of best practices include preventing and controlling invasive plants, using an Integrated Vegetation Management[15] approach, minimizing necessary maintenance, and

15 For more information, see IVM Framework and EPA's Fact Sheet.

managing vegetation in a way that provides beneficial wildlife habitat (e.g., native seed mixes that benefit pollinators).

- **Criteria for co-location.** Criteria used to determine when co-location is necessary.[16]

GAPS IN PRACTICE AND IMPLEMENTATION

Implementation of co-location practices is influenced by several factors, including landowner preferences and safety, legal, corporate, and other concerns. While several organizations recommend general principles encouraging co-location, there is a lack of best management practices (BMPs) specific to co-locating linear infrastructure that accounts for safety and the complex permitting process. Participants identified this area as an opportunity to have more science- and engineering-driven best practices and integrate some kind of learning mechanism via literary review and spatial information in order to improve practices over time.

STATE OF THE REGULATORY FRAMEWORK

Carrying gas from the well to consumers requires an array of facilities and pipelines (see figure above). Different types of pipelines fall under different regulations, permitting requirements, and regulatory agencies, making the development process very complex. This complexity also makes identifying where and how to engage in the process to increase the opportunity for co-location difficult. With a focus on pipeline development in Pennsylvania, the following agencies were identified:[17]

- **Federal agencies**
  - **Federal Energy Regulatory Commission (FERC)**. FERC issues approvals and regulates the siting and construction of interstate pipelines, under the Natural Gas Act, which requires a full NEPA process. FERC's alternative analysis considers, among other things, whether pipelines can be placed near or within an existing ROW. Because FERC pipelines are so highly regulated, the group focused mainly on non-FERC pipelines when discussing recommendations.
  - **U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA)**. Sets minimum safety standards for the design, construction, operation, and maintenance of interstate and intrastate pipelines, and some gathering lines, under the Pipeline Safety Act.
  - **U.S. Army Corps of Engineers**. Reviews pipelines that involve waterway or wetland crossings, which may impact the jurisdictional waters of the U.S.

A shared road and pipeline right-of-way on state forest land in Pennsylvania. © *The Nature Conservancy (Tamara Gagnolet)*

- **State agencies**
  - **Pennsylvania Public Utility Commission**. Regulates and inspects intrastate and some gathering lines for safety, under the state Gas and Hazardous Liquids Pipelines Act. A broader scope of responsibilities for additional classes of pipelines may assist in the regulation and tracking of gathering line systems.

16 Participants pointed to Maine's 2011 report on "Issues affecting co-location of energy infrastructure" (http://www.maine.gov/energy/pdf/LD1786%20Co-Location%20Report%20FINAL%20May%202011.pdf)

17 Information supplemented, in part, by the Marcellus Shale Coalition's "Pipeline Oversight: The Role of Government Agencies for Pennsylvania Pipeline Projects" (http://marcelluscoalition.org/wp-content/uploads/2015/10/Pipeline-Oversight-Fact-Sheet.pdf)

  - **Pennsylvania Department of Environmental Protection (PA DEP)**. Responsible for administering various permitting and plan approval requirements involving the siting of natural gas facilities, such as those related to erosion and sedimentation, special-designation species and habitats, and wetlands and waterways, in conjunction with other state and federal agencies.
- **Local agencies**
  - **Municipal Governments.** Those that choose to enact zoning or related ordinances can determine in which zoning districts certain natural gas facilities may be located.
  - **County Conservation Districts.** The PA DEP can delegate certain responsibilities to county conservation districts, related to environmental permits for transmission pipelines and compressor locations.

FERC and non-FERC pipelines are subject to some of the same approvals, such as cultural resource clearance, RTE approval, Chapters 102 and 105 of the PA Code approvals, and 401 water quality certification. The main difference is the applicability of NEPA to the various studies and requirements for FERC pipelines.

REGULATORY GAPS

Participants also identified an important set of legal, economic, and organizational challenges for operators:

- **Antitrust implications and perception of collusion** if energy companies meet to work together to identify optimal locations for pipelines to reduce the potential ecological impact.
- **Competition concerns** that might result due to the need to share what may be proprietary information about their well development and permitting activities.
- **Existing regulations.** Some existing regulations can actually impede opportunities for co-locating infrastructure, such as state prohibitions on co-location in existing corridors. An example is a "limited access right-of-way" (e.g., the Pennsylvania Turnpike) in which the agency that owns the right-of-way may prohibit direct access to the highway by driveways or new side roads.
- **Allocation of responsibility** for ongoing management and liability at co-location sites.
  - Conflicting safety and permitting requirements between state and federal agencies may hold individual operators at a co-location site to different standards.
  - New development may impact existing uses, including new construction risks to existing infrastructure.
  - Response in the event of a problem or accident.
- **Absence of a single coordinating agency.** Permitting requirements and regulatory agencies vary depending upon the classification of pipeline, and there is sometimes a disconnect between companies applying for permits and regulators.

RECOMMENDED SHORT-TERM SOLUTIONS

Below are the recommendations presented to the workshop as priority solutions to reduce the footprint of pipeline development and to encourage co-location of linear infrastructure. These recommendations warrant further discussion, as the working group was not able to discuss them more thoroughly.

1. **Create and disseminate information.** This recommendation is two-fold, suggesting:
    - Research what other operators have done, recording what co-location strategies have worked and not worked, around the U.S.
    - Research the trade-offs between co-location and new alignments and provide guidance to suggest when co-location is the best decision. (For example, if two fragmenting features appear to have less impact than one large fragmenting feature, then co-location would not be beneficial.)
2. **Build on existing BMPs and provide incentives.** Improve and expand BMPs for reducing the footprint of linear infrastructure, as there is no authoritative list on the topic. The CSSD working with industry to create BMPs for pipelines was suggested as a possibility for accomplishing this. Incentives for industry to both implement these BMPs and co-locate, in general, would be helpful in increasing co-location of linear infrastructure. Some suggestions for incentives included faster or reduced-price permitting.
3. **Develop transportation corridors for pipelines** through flexible "smart planning."
4. **Education.** Educate stakeholders, those outside of the industry and regulatory agencies, about existing federal statutes and methods of reducing ecological impacts, and educate landowners about the ecological value of co-location. One of the main factors in determining pipeline siting is landowner preference. Landowners may be concerned with the impacts of co-location in relation to their property value and perceived safety; however, education on the benefits of co-location could help inform that decision.
5. **Enlist inter-agency cooperation.** Convene a single meeting and discuss economic, efficiency, and environmental benefits, and ask for assistance in addressing non-safety issues.
6. **Develop a "vertical collaboration" pilot for governance of co-location** at the sub-state level, among willing developers, to help develop municipal consensus.
7. **Create a centralized database of key spatial data for safety and planning purposes.** This would allow mapping of existing linear infrastructure (electric power lines, gathering and transmission lines, etc.), encourage information sharing between stakeholders (regulatory agencies, companies, consultants, environmental organizations), and increase opportunities to co-locate infrastructure. Some specific actions to accomplish this include:
    - Map "as built" gathering lines, owned and managed by the Public Utilities Commission for a region (for example, Bradford County).
    - Digitize available information (state DEP and Conservation District Offices). Participants noted this would be very time-consuming.
    - Investigate mapping program managed by PHMSA.
8. **Conduct cumulative impact analyses.** This recommendation was made specifically for gathering lines, perhaps from a programmatic environmental impact statement by FERC through 404 permits. States could request that FERC expand their analysis to include gathering lines upstream or establish a statewide NEPA analysis. One issue is that this is not done for other impacts.
9. **Establish a multi-well approval process for drilling sites** to facilitate co-locating gathering lines and other infrastructure. This would essentially "modularize" the permit process to allow separate submissions for siting and well development, provide incentives and a longer shelf life for permits, and potentially allow selling or trading to others to accumulate contiguous or near-contiguous sites. Participants suggested referring to Comprehensive Drilling Plans in Colorado.

3.1.3 SHORT-TERM IMPLEMENTATION OF RECOMMENDATIONS

On the final day of the workshop, participants in each of the four main tracks — landscape, air, habitat, and water — were asked to choose one or two of their recommended short-term solutions aimed at achieving the workshop's overall conservation goals. They were asked to put forward only solutions that were economically and politically feasible, and that could be implemented and reasonably effective within one or two years within the geographic scope of the Appalachian region. The selected solutions were not necessarily expected to be the most important on the list of priorities recorded by the groups during the workshop — only to be the most responsive in the short term.

The working group for the landscape track produced the following two recommended solutions:

1. **Regional repositories for shale-related data.** Collect best available data on landscape impacts across the shale gas play in the Appalachian region; provide broad public access to these collections.
2. **"Toolbox" of best management practices (BMPs).** Based on (1), develop a suite of BMPs, designed for specific situations or site types, and ensure that they are publicly available to all interested parties (e.g., landowners and developers).

Participants agreed that broader access to accurate information about impacts and practices was necessary both for shale developers and for preserving the health of the Appalachian region. The types of information they discussed included:

- "Avoidance areas," or habitats deemed too sensitive to disturb
- Documented impacts or consequences of regulatory violations
- Location of gathering and transmission pipelines
- Pennsylvania Natural Diversity Inventory (PNDI) information
- Stream-crossing techniques
- Case studies and other best practices (including for air, habitat, and water)

A short term approach to making such information more broadly available would be to assemble an index of existing data repositories, case studies, and a catalog of environmental BMPs that are already available online. In the long term, this "toolbox" could reside at one or several universities; suggestions included the Marcellus Center for Outreach and Research (MCOR) at Penn State University; West Virginia University; and Ohio State University.

In addition to providing access to comprehensive data on shale-related topics, participants envisioned the toolbox would include a set of scaled options for users, e.g., from government planners to individual landowners, that could answer such questions as, "What do I want this habitat or corridor to look like after restoration?"

Participants cited two concerns that might affect how quickly such a repository could be assembled. One was the need to screen each entry for relevance and scientific accuracy. The other was strong developer resistance; operators expressed safety, security, and competitive concerns about releasing some types of data, such as the specific location of gathering lines.

To preempt such issues, participants proposed establishing a new stakeholder consortium, comprised of members from industry, conservation groups, academics, leaseholders, and other affected parties. A stakeholder consortium could provide several critical functions:

- Identify which data are needed to develop effective BMPs, including dissemination of sensitive data.
- Develop strategies for making repositories available and ensuring their accuracy.
- Partner with an independent organization or use public lands to build and run demonstration sites using BMPs.
- Establish links with BMP certification bodies, or create a commission that could determine and assemble the best BMPs into a single entity or collection.

3.2 HABITAT TRACK

3.2.1 NOISE AND ARTIFICIAL LIGHT

3.2.2 EROSION, SEDIMENTATION, AND SITE RECLAMATION

3.2.3 SHORT-TERM IMPLEMENTATION OF RECOMMENDATIONS

The construction and daily activities of shale development in the Appalachian region can have adverse impacts on wildlife, habitat, and ecosystem function. In the context of finding both near-term solutions and strategic, long-term approaches to conserve the biodiversity and resilience of Appalachian ecosystems, participants in the Habitat sessions explored two distinct Challenge Areas: (A) noise and artificial light, and (B) erosion, sedimentation, and site reclamation.

The summaries below describe the content of working group discussions during the first two days of the workshop related to **noise and artificial light** and **erosion, sedimentation, and site reclamation**. Each summary begins with an **overview of the challenge** and then presents the **current state of the challenge**, as presented by expert "anchors" and enhanced by participants, covering what we know and what we don't know in the areas of scientific research, mitigation technologies, practices, and the regulatory framework.

After establishing the state of the challenge, session participants proposed potential solutions for moderating adverse impacts to Appalachian ecosystems in each of the Challenge Areas. Participants selected as priorities a small number of **recommended solutions** that consider feasibility and effectiveness in the short term (one to two years). These prioritized recommendations are described below, and all recommendations from participant brainstorming are included in Appendix C.

The last summary describes the content of working group discussions during the final day of the workshop, when participants focused on the **short-term implementation of recommended solutions** from the previous days' discussions within the habitat track.

3.2.1 NOISE AND ARTIFICIAL LIGHT

SECTOR REPRESENTATION

Anchors: Academic institution, state government

Facilitators: Academic institution, non-governmental organization

Participants: Academic institutions (3), energy industry (5), government (7), non-governmental organizations (3)

CHALLENGE

How do we reduce ecosystem impacts from *noise and artificial lighting*?

HIGH-LEVEL CONCLUSIONS

- More research is needed to better understand the ecosystem- and species- specific impacts of noise and light.
- There are some relatively simple, inexpensive solutions to cut down on light pollution.

OVERVIEW OF THE CHALLENGE

The daily activities of shale development in the Appalachian region are associated with artificial light and noise, both of which can alter wildlife behavior and reduce habitat quality.[18,19,20] These impacts vary widely depending upon the species, timing, duration of disturbance, landscape context, and other factors.

Temporary sources of noise from shale development include well pad preparation, road construction, well drilling, and hydraulic fracturing. Operating 24 hours a day for the lifetime of a gas field, gas compressor stations are significant sources of long-term noise. Truck traffic, gas pressure regulators, electric generators, cooling fans, engines, and air conditioners also are long-term noise sources, although they are not in constant operation. Shale development also involves artificial lighting, necessary for security and worker safety, to illuminate work areas at the well pad and near compressor stations. Gas flaring, a practice that produces flames that vary in size, brightness, and duration, is becoming less common, but can also contribute to light pollution.

Whatever the source, studies have demonstrated that noise can change wildlife behavior and use of habitat, interfere with communication, and ultimately reduce rates of both reproduction and survival.[21,22] These impacts can be compounded when combined with other shale-related environmental stressors, such as habitat fragmentation and artificial lighting.[23]

Like noise, artificial lighting can adversely affect the inhabitants of the surrounding ecosystem. In the presence of artificial lighting, wildlife may become disoriented or distracted from other essential behaviors, such as foraging,

18 The Nature Conservancy. 2015. Reducing ecological impacts of shale development: Recommended practices for the Appalachians (nature.org/shale-practices)

19 Rich, C. and Longcore, T. 2005. *Ecological Consequences of artificial night lighting*. Island Press.

20 Barber, J. R., Crooks, K. R., and Fristrup, K. M. 2009. The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology & Evolution* 25(3): 180-189.

21 Francis, C. D., and Barber, J. R. 2013. A framework for understanding noise impacts on wildlife: an urgent conservation priority. *Frontiers in Ecology and the Environment* 11(6): 305–313.

22 Brown, L. 2001. Overview of research on the effects of noise on wildlife. Pages 14–18 *Proceedings of the Effects of Noise on Wildlife Conference*. Happy Valley-Goose Bay, Labrador.

23 Barber, J. R., Crooks, K. R., and Fristrup, K. M. 2009. The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology & Evolution* 25(3): 180-189.

mating, and migrating. Lights can temporarily or permanently blind some animals, leading to injury or death; reduce foraging success; and increase their vulnerability to road mortality.[24]

STATE OF THE CHALLENGE

STATE OF THE SCIENCE

The impact of noise on wildlife is a relatively new area of scientific study, and consequently only a small body of research is available for consideration, especially specific to Appalachian habitats and species.

Potential wildlife impacts identified by participants from noise and vibrations associated with shale development include:

- **Disrupted communication.** Noise can mask or interfere with calls within and among species, reducing the effective distance for communication. The reduced ability to hear calls can affect pairing success (the ability to find a mate), and the ability to locate suitable habitat. Studies also demonstrate changes in species vocalizations to avoid masking. A reduced ability to detect natural sounds can also affect species' ability to find prey, or avoid predation.
- **Stress.** A common wildlife response to sudden or ongoing habitat noise is increased stress levels that trigger the fight-or-flight response and can affect hormone levels.
- **Community composition.** As some species adapt and others avoid noisy areas, the structure and stability of ecological communities may shift, potentially affecting competition and relationships within and among species.
- **Reduced fitness.** For some species, noise may lead to reduced fitness (i.e., the ability to survive to reproductive age and to successfully find mates and produce offspring) as a result of these impacts.

Artificial noise can mask or interfere with calls within and among species, reducing the effective distance for communication, such as for this small chorus frog (spring peeper). © *Kent Mason*

The impact of artificial light on wildlife habitats has been the subject of scientific research for several decades, but has primarily focused on birds. Impacts to other species and widespread effects on population dynamics are not well understood, particularly in the context of Appalachian shale development. Depending upon the species, wildlife can be attracted to, repulsed by, or disoriented by light. Studies have identified three significant categories of potential impact:

- **Light entrapment.** Some species are drawn to light and are reluctant to leave. This is easily observed in insects and has been documented in birds around off-shore rigs, leading to high mortality rates, especially along migratory routes and in foggy weather.
- **Changes in foraging behavior.** Artificial light can affect how and when animals forage for food. For example, nocturnal animals often avoid moonlit open areas to avoid predators, which also restricts where they forage and the amount of food they find.
- **Changes in circadian rhythms.** Artificial light can disrupt circadian rhythms, affecting how an animal eats, sleeps, reproduces, and interacts with other wildlife.

24 Rich, C. and Longcore, T. 2005. *Ecological Consequences of artificial night lighting*. Island Press.

Participants also briefly discussed the timing of shale development operations, primarily in relation to noise and light. Participants noted in particular that operations during critical life stages (e.g., breeding and dispersal periods) and weather conditions can affect the severity of impacts on wildlife.

RESEARCH GAPS

Participants noted several gaps in existing research on noise and light that, if bridged, could help operators to mitigate the impact of shale development on habitat and wildlife. The discussion focused on identifying indicators or triggers of adverse effects on wildlife that could be used in design and operational planning for well sites. These knowledge gaps included:

- **Attributes of noise disruptors.** Little is known about the specific attributes of noises that are disruptive to habitats, and difficulty measuring these attributes compounds the problem (see Technology Gaps on next page). The two most common measures of sound intensity — decibels (volume) and frequency (pitch) — are likely to invoke different responses and affect different species. For example, knowledge is limited about sounds that are pitched both below and above the range of human hearing. In some cases, even though humans might not hear them, these noises can be very disruptive to wildlife, even from a long distance. Another unknown is how potential impacts differ between centralized and distributed gas compressor stations.
- **Brightness thresholds to behavior or physiological change.** Studies are needed that indicate what levels of brightness (quantity and quality), at what duration, will trigger behavioral or physiological changes in wildlife.
- **Effects of different light types on wildlife.** Studies are needed to determine whether (or which) different types of light — direct or reflected, warm or cool — have different effects on wildlife.
- **Effects of timing of lighting on behavior.** While some studies point to changes in circadian rhythms as a result of lighting, an understanding of the impacts of duration (seconds, hours, days) and timing (day or night) of artificial light on wildlife habitat would be useful.
- **Species-specific responses.** Responses to noise and light vary widely among species, suggesting that tolerance may be specific to each. Some species are known to adapt to noise, for example, by modifying their vocalization behaviors. However, the responses and consequences for each species in a habitat are largely unknown. If serious impacts to any threatened or endangered species were found, specific practices or policies could be put in place to mitigate those impacts.
- **Thresholds and attenuation.** There is a need to quantify, or at least better understand, the relationship between anthropogenic noise and habitat stability, and the thresholds for behavioral or physiological changes caused by anthropogenic noise.

STATE OF THE TECHNOLOGY

Participants discussed several existing technological approaches to mitigate the impact of noise and light associated with shale development, including:

- **Siting tools.** The placement of noise-producing facilities is an important factor in noise propagation because landscape attributes, such as topography, vegetation, and prevailing wind direction, influence how noise travels. Siting tools, including acoustic propagation models, are used for design and simulation of how sound will travel from various sources (e.g., air traffic, engines, etc.) and in different environments. The design of a compressor station, for example, greatly influences the amount of sound it will produce.
- **Noise attenuation.** Sound or noise attenuation is not technology per se, but refers to the many existing approaches to block or slow sound waves. These approaches may be temporary or permanent, depending on need. Constructing sound barrier walls, mufflers, enclosing compressor stations, or planting a natural barrier (i.e., vegetation around a noise source) can help to permanently suppress the noise. Temporary buffers also may be rolled into place during high-noise events, like the hydraulic fracturing process, or during times critical to wildlife, such as mating season, to reduce impacts to surrounding habitats.

Shale development involves artificial lighting, necessary for security and worker safety, to illuminate work areas at the well pad and near compressor stations. *"Shale Gas Drilling Rig" by Kelly Maloney, USGS*

- **Minimize duration of lighting.** Using motion detectors to turn on lights only when needed, reducing the amount of time light is impacting the surrounding environment.
- **Types of lighting.** Different types of bulbs emit different wavelengths, which can affect the impact and severity of artificial lighting on wildlife.

TECHNOLOGY GAPS

Participants discussed the gaps in the existing suite of tools for site planning and operations, and how these gaps might best be addressed:

- **Acoustic and attenuation models.** Acoustic propagation tools are not equipped to include the complexities of modeling individual habitats in their calculations. A tool that would manage ecosystem complexity could provide valuable data about the noise impacts on specific sites, in advance of construction. Similarly, developing sound attenuation models can calculate the most effective media or materials for blocking or slowing sound waves.
- **Cost-benefit analysis of alternative technologies.** Determining the effectiveness and costs of various methods would tell us what methods are most cost-effective. For example, enclosing a compressor station is much more expensive than planting a vegetative barrier, but is also more effective. A specialized model for analyzing costs and benefits of noise attenuation technologies would provide the means for more nuanced decisions about how best to attenuate the noise at a given site.
- **Better tools for measuring noise intensity.** Reducing noise intensity must strike a balance among three important aspects: effectively reducing impacts on wildlife, being measurable, and being feasible to implement in the field. The most common metric for noise intensity, decibels, does not provide the information necessary to understand wildlife impacts. Decibels are easy to measure in the field, but streams and wind can produce high dB levels and not annoy or disrupt wildlife. Sound frequencies are likely more important when considering impacts to wildlife, but these are much more difficult to measure in the field.

STATE OF THE PRACTICE

Existing standards and voluntary practices noted by participants included the following:[25]

- **Reduce noise.** Recommendations include considering design and siting of noise-producing facilities and using sound attenuation methods.
- **Monitor dB levels.** Monitoring decibel levels is a fairly common practice, although decibel levels alone do not provide a full picture of noise produced.
- **Reduce light use and spillage.** Downward-facing lights, shielding lights, and motion sensors are commonly recommended practices to use light only when it is needed and to direct light only where it is needed, thus reducing unnecessary light spillage into the surrounding environment.

Participants also commented that, considering the relative lack of knowledge on noise and light impacts to wildlife, there may be additional practices associated with other industries/activities that we could learn from or apply to shale development practices.

GAPS IN PRACTICE AND IMPLEMENTATION

- **Siting.** Siting practices are not consistently used.
- **Need for monitoring.** Monitoring noise and light levels to establish a baseline, understand potential impacts, and help develop relevant practices.
- **Facilities different than designed.** Facilities may not be constructed or operate as designed.
- **Limitations.** Current standards/guidelines are focused primarily on reducing social/human impacts and do not fully consider the ecological effects of artificial noise and light. Practices should also be practical to comply with, measure, and enforce.

STATE OF THE REGULATORY FRAMEWORK

Most of the group's focus was on research and technology gaps, with little discussion about policy. Discussion was centered on Pennsylvania policies, with acknowledgement that regulations vary by state, type of infrastructure, lease, and land ownership (federal government, state government, and private). Applicable policies noted by participants included the following:

- **Federal Energy Regulatory Commission (FERC)**
- **PA Bureau of Forestry.** Guidelines are only applicable on Pennsylvania state forest lands and are specific to compressor stations. There are guidelines for reducing artificial light (including motion sensors and downward-facing lights) related to other activities but nothing specific to shale development.
- **Local government ordinances and leases.** When not on public land, practices related to artificial noise and light depend on local government policies and leasehold terms. Although practices and conditions vary greatly, local ordinances and leases may hold important opportunities for requiring practices to mitigate sources of noise and light.

REGULATORY GAPS

Participants also discussed the limitations and lack of existing policy in some areas.

- **Limitations of existing policies.** FERC only applies to federally regulated facilities and is not applicable to state lands or private lands, and Chapter 78 of the Pennsylvania code lacks specificity for noise. No existing policies specific to lighting were presented or discussed.
- **Lack of focus on ecological impacts.** The driving force behind regulations related to noise and light is social impacts (i.e., the effects on human populations). A focus on ecological/wildlife impacts, and therefore areas with low human population (e.g., natural areas), is absent.

25 Existing practices were drawn, in part, from: The Nature Conservancy. 2015. Reducing ecological impacts of shale development: Recommended practices for the Appalachians (nature.org/shale-practices)

RECOMMENDED SHORT-TERM SOLUTIONS

Session participants selected the recommendations described below as top priorities, based on short-term feasibility and effectiveness (one to two years), for addressing potential adverse impacts of noise and light on wildlife from Appalachian shale development.

1. **Create standardized guidelines/rules on lighting.** Several technological options are relatively cheap and readily available to mitigate the effects of artificial lighting, including shields, wavelengths, motion detectors, and directional LEDs. Guidelines related to utilizing these technologies already exist and could be compiled using best management practice (BMP) manuals and other guidance documents from various agencies.

   Challenges associated with implementing this solution are (a) identifying who is best suited to create the set of standardized guidelines and (b) the dearth of information about impacts on individual species and site-specific situations. Even with these research gaps, this recommendation is "low-hanging fruit" in that it has the potential to drastically reduce light pollution at a very low cost.

   Metrics for success could be the reduction in light levels or potentially the number of complaints about lighting disturbances beyond the work area, using people as a proxy; this would only be effective, however, in areas where people are present (e.g., not interior forest areas).

2. **Implement widespread noise attenuation, both natural and engineered, on well pads and compressors.** Implementing sound attenuation could be led by industry groups (e.g., American Petroleum Institute, Marcellus Shale Coalition, Society of Petroleum Engineers) and secondarily by regulators and/or local communities. Conservation agencies or county agricultural extension offices could provide recommendations related to wildlife, vegetation options (e.g., natural sound barriers), and surrounding land use. To address some research gaps and cost-effectiveness, a pilot program would be ideal before widespread implementation.

   A major challenge is how to incentivize broad adoption outside of urban (i.e., populated) areas, considering the lack of regulation related to noise and the potential high cost of some sound attenuation methods. The primary metric for success would be reduced noise level (dB, frequency, or otherwise).

   Some potential methods of sound attenuation are:

   - **Creating temporary barriers** during loudest operational activities (e.g., certain phases of pad and compressor construction, hydraulic fracturing process).
   - **Widespread use of permanent attenuation** for compressors.
   - **Native tree/shrub planting as an alternative option to engineered sound barriers.** Appropriate vegetation would be based on local guidelines. Research suggests that this is a less effective but more affordable and visually appealing option. Challenges include timing (e.g., trees may not reach optimal height/density for years), ongoing vegetation maintenance, loss of effectiveness (e.g., loss of vegetation through disease or herbivory), and a potential increase in area of disturbance (i.e., footprint) to allow for planting area(s).

3. **Regional Best Management Practices (BMP) manual.** Develop a system to create and update regionally-conscious BMP manuals that can accommodate different communities and ecosystems. Tasks involved in such an undertaking would likely include the following:

   - **Ensure that existing BMPs and guidance documents include all relevant conservation practices and are regionally appropriate.** This would entail assessing each practice and document individually and identifying unique ecosystem indicators and their local and regional triggers.

- **Develop a system for evaluating and updating BMPs.** Metrics for successful BMPs would be based on the improvement of unique indicators related to noise and light impacts. Potential metrics include a decrease in noise level (dB) and mortalities near lighted structures. Likely challenges include the ongoing maintenance of the BMP manual to update practices based on new information (e.g., who could take this on); continual monitoring of practices to evaluate effectiveness; and achieving a consensus on BMPs, given the interest gaps between sectors.
- **Convene an annual forum for stakeholders.** A state-wide leader (for example, a land grant university or cooperative extensions) could act as host and facilitator, tapping regional agencies for regional issues and content. This would allow for dialogue among different sectors and help achieve consensus on what is and is not working and what is needed.

4. **Enhance existing siting tools to include noise-producing facilities.** Commonly used by the oil and gas industry, siting tools help determine suitable locations for different types of infrastructure, depending on a variety of inputs (e.g., operator constraints, topography, land use, homes and schools, and threatened and endangered species). The working group suggested adding additional components to produce a sound attenuation model to compare with threshold guidelines. Inputs would include compressor design and attenuation, local topography and wind patterns, operator constraints, and ecologically and socially sensitive areas. To measure effectiveness, compare expected (by model) and observed (on the ground) noise levels and compressors sited using the tool versus those that were not. Steps to achieve this include:
   - **Research.** Determine noise thresholds based on ecological impacts (research is already available for social impacts), noise produced by various types and designs of infrastructure, and effectiveness of different sound attenuation techniques.
   - **Tool development.** Research/academic institution could develop a tool with industry input. Challenges include time and cost of production.
   - **Tool use.** Once the tool is developed, there would need to be use of it by industry for it to have an impact. Many oil and gas operators, as well as The Nature Conservancy, have siting tools that could potentially be revised to include these additional parameters; however, participants disagreed on the feasibility of incorporating a tool like this into existing planning tools.

Enclosing compressor stations is a permanent method of noise attenuation. *"Gas compressors" by Gerry Dincher, licensed under CC BY-SA 2.0, cropped from original.*

3.2.2 EROSION, SEDIMENTATION, AND SITE RECLAMATION

SECTOR REPRESENTATION

Anchors: Federal government, local government
Facilitators: Federal government, non-governmental organization
Participants: Academic institutions (4), energy industry (6), government (10), non-governmental organizations (4)

CHALLENGE

How do we address the impacts/risk of *erosion and sedimentation* from shale gas development and plan for successful *restoration/reclamation/stabilization*?

HIGH-LEVEL CONCLUSIONS

- The collection of more scientifically sound baseline data is needed to enhance evaluation of erosion and sedimentation management techniques and to inform restoration plans.
- Comprehensive training is needed for leaseholders, regulators, operators, service companies, and subcontractors to ensure that proper erosion and sedimentation control measures are implemented on the ground through all phases of development.
- Incorporating reclamation into operational planning is vital for successful interim and final reclamation outcomes.

OVERVIEW OF THE CHALLENGE

Erosion (the mobilization of soil) and sedimentation (the transportation and deposition of that soil) can alter ecosystem functions, impair soil and water organisms, and degrade surface water quality.[26] Activities associated with all forms of infrastructure development, including shale gas, such as ground clearing and construction for roads, pipelines, stream crossings, and well pads, present risks of erosion and sedimentation. Erosion and sedimentation rates and the severity of associated impacts to surrounding ecosystems can vary depending upon the local habitat types and species, soil characteristics, topography and slope, rainfall, infrastructure surface material, drainage management, and construction and maintenance methods.

Surface infrastructure associated with shale development, including well pads, access roads, pipelines, and stream crossings, can affect runoff patterns and overall watershed health. Improperly designed, constructed, and maintained infrastructure, particularly unpaved roads, can be large sources of sediment to streams in forested landscapes.[27,28,29] Construction on steep hillsides increases the risk of erosion and sedimentation. Stream crossings, which are

26 Henley, W., Patterson, M. A., Neves, R. J., and Lemly, A. D. 2010. Effects of sedimentation and turbidity on lotic food webs: A concise review for natural resource managers. *Reviews in Fisheries Science* 8(2).

27 Aust, W.M., and Blinn, C. R. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982–2002). *Water Air, Soil Pollution: Focus:* 4(1): 5-36.

28 Bloser, S.M., and Scheetz, B.E. 2012. Sediment Production from Unpaved Oil Well Access Roads in the Allegheny National Forest. Penn State University.

29 Daniels, B., McAvoy, D., Kuhns, M., and Gropp, R. 2004. Managing Forests for Water Quality: Forest Roads. Extension Utah State University.

needed where roads and pipelines cross streams, can degrade and destabilize aquatic habitats through erosion and sedimentation, soil compaction, and the effects of altering the flow, distribution, and quality of water.[30] While some impacts associated with construction can be relatively short-term, improper infrastructure siting and maintenance can cause long-term impacts.

Because shale development involves disturbance of the land surface, reclamation or restoration should be part of the planning process from the beginning. Reclamation is returning a site to useable or useful purposes after the disturbance is complete. Restoration is usually defined as restoring to a particular goal — often that of pre-disturbance conditions. Decisions made during planning and before ground-disturbing activities take place can make restoration or reclamation easier or sometimes more difficult. Including reclamation goals in planning is essential to help minimize disturbance, enhance opportunities to alleviate damage after construction, and ensure that a suitable post-disturbance land use is identified. Reclamation is more likely to be successful if factors such as soils, land use, road design and maintenance, and water quality are adequately considered and if mitigating activities are implemented, for example reducing the footprint of disturbance (including wells pads, holding tanks or ponds, other staging areas) to as small an area as possible and using native vegetation for erosion control. One of the issues in shale development is that single wells can be hydraulically fractured more than once and an individual well pad may be used to access multiple wells. Therefore, it may be many years before a site is fully restored or reclaimed.

STATE OF THE CHALLENGE

STATE OF THE SCIENCE

Participants discussed the potential impacts of erosion and sedimentation on stream beds and adjacent habitat from the construction of roads, pipelines, and stream crossings for developing well sites. These impacts are not unique to shale development and also occur with land use change caused by other forms of development.

- **Sedimentation effects on water quality and stream biota** have been well documented in research from a variety of other land uses, and have been related to the areal extent of disturbance, distance to stream channels, and the best management practices and care used by the operators.
- **Destabilization of aquatic habitats** is possible to probable, depending on the care taken by the operators. Particular concerns include:
  - Eroding stream banks and unstable stream beds.
  - Eroding roadway ditches and unstable stream crossings.
  - Unstable pipeline rights of way.
- **Loss of crop and forest production.** Participants disagreed on the validity of this point, partly because of the lack of adequate documentation on this. Generally, the loss of production parallels the loss of land area in gas well and pipeline infrastructure, but the extent and timing are not well documented.
- **Invasive species.** Site restoration can be significantly impeded by invasive species, introduced by way of vehicles, fauna, mulch, and seeds from other areas.

RESEARCH GAPS

Participants noted several gaps in existing knowledge that have practical implications for both development and site reclamation:

- **Baseline data.** Sound baseline data would be useful in determining impacts, evaluating practices, and informing restoration plans.

30 Levesque, L., and Dube, M. 2007. Review of the effects of in-stream pipeline crossing construction on aquatic ecosystems and examination of Canadian methodologies for impact assessment. *Environmental Monitoring and Assessment* 132(1): 395-409; Jackson, S. D. 2003. Design and construction of aquatic organism passage at road-stream crossings: Ecological considerations in the design of river and stream crossings. Pages 20-29 Proceedings of the 2003 International Conference on Ecology and Transportation.

- **Where water and sediment goes, during and after development.** More data on a case-by-case basis would help inform mitigation decisions. For example, was a stream rerouted because of a road, site, or pad installation? Has natural drainage been changed? Is the road (pad, site) built on already-steep topography, increasing an established erosion process?
- **The tipping point for erosion or sediment.** Little is known about how much erosion or sedimentation into nearby streams is too much, and the timing of inputs and tipping points.

Due to these gaps in research, some participants expressed concerns that conclusions are being drawn from insufficient or at least ambiguous data, while others contended that there are good resources in forestry and agricultural journals relative to other land uses and disturbance.

STATE OF THE TECHNOLOGY

Participants overall agreed that most erosion and sedimentation issues are not technical in nature.

- **Mitigation processes.** Currently used techniques for reducing erosion and sedimentation are well known and well described. They include replanting trees at stream crossings, minimizing impacts with conservation-based designs for roadways and stream crossings, and using siting tools, including spatial analysis and GIS, to avoid sensitive areas.
- **Stream crossing techniques.** Horizontal-Directional Drilling is a method of installing pipelines underneath streams without creating a trench and may only be appropriate in certain circumstances, depending on geology, stream type, and other factors.

TECHNOLOGY GAPS

No technological gaps were discussed by participants, but this does not imply that none exist — only that the discussion focused elsewhere.

Activities associated with all forms of infrastructure development, including shale gas, such as ground clearing and construction for roads and pipelines (as pictured above), present risks of erosion and sedimentation. © *The Nature Conservancy (Mark Godfrey)*

STATE OF THE PRACTICE

Participants mentioned several existing standards and voluntary practices for mitigating erosion and sedimentation and supporting site reclamation.

- **Pennsylvania State University, Center for Dirt and Gravel Road Studies.** Provides guidelines to maintain roads in a more cost-efficient and environmentally sensitive manner.
- **Pennsylvania Wilds Design Guide Supplement for Oil and Gas Best Practices.** These guidelines promote environmental stewardship and cooperation among stakeholders across north central Pennsylvania.
- **Marcellus Shale Coalition Recommended Practices for Site Planning, Development, and Restoration.** These recommendations include steps for reducing impacts during planning and restoration phases and for improving outcomes of interim and final restoration.
- **State Forestry Best Management Practices.** Regional examples applicable to shale development in the Appalachian region include:
  - West Virginia Silvicultural Best Management Practices for Controlling Soil Erosion and Sedimentation from Logging Operations, West Virginia Division of Forestry.

  - Timber Harvest Operations Field Guide for Waterways, Wetlands, and Erosion Control, Pennsylvania Department of Environmental Protection.
- **WINGS Project.** Focuses on interim reclamation through vegetation management that aims to return wildlife habitat to pipeline rights-of-way.
- **Native plants.** Using native grass seed, trees, and shrubs to stabilize soil and during reclamation.

GAPS IN PRACTICE AND IMPLEMENTATION

Participants agreed that there are many good resources available regarding best practices, but they are not available in a centralized place and specifically targeted to shale development. As a result, all relevant practices may not be implemented comprehensively by operators in the field.

- **Incorporate reclamation into operational planning.** For many major land disturbing activities, such as hard rock mining, a reclamation plan must be filed at the time of permit application, but reclamation is not currently part of operational planning or permitting for gas well development. Although timeframes and challenges differ, planning for reclamation up-front and minimizing the risk of habitat damage in the first place can improve the efficiency of reclamation.
- **Forestry Reclamation Approach.** Advocated by the Appalachian Regional Reforestation Initiative (ARRI) to reclaim coal mined lands, this approach is not widely implemented on gas lands, and involves creating a suitable rooting medium, loosely grading the rooting medium, using compatible ground covers, planting two types of trees (early successional and commercially valuable crop trees), and using proper tree planting techniques.
- **Increase utilization of existing practices.** There are many good practices out there that should be more widely and consistently implemented.

STATE OF THE REGULATORY FRAMEWORK

Participants focused on Pennsylvania policies and noted that regulations and associated challenges vary by state. Erosion and sedimentation related to shale development activities are covered by the following regulatory agencies:

- **Federal Energy Regulatory Commission (FERC).** Issues approvals and regulates the siting and construction of *interstate* pipelines, under the Natural Gas Act.
- **U.S. Army Corps of Engineers.** Reviews pipelines that involve waterway or wetland crossings, which may impact the jurisdictional waters of the U.S.
- **Pennsylvania Department of Environmental Protection (PA DEP).** Responsible for administering various permitting and plan approval requirements involving the siting of natural gas facilities, including those related to erosion and sedimentation and wetlands and waterways. Under Chapter 102 of the Clean Streams Law of Pennsylvania, PA DEP has delegated erosion and sedimentation control permitting to county Conservation Districts; however, districts are not delegated to do oil and gas permits, only FERC pipelines and development not associated with well pads or gathering lines. Earth disturbance permits are required for constructing well pads, gathering lines, and roadways, if disturbing more than one acre. General permits are required for stream crossings and outfall structures. The following manuals provide guidance for operators:
  - Erosion and Sediment Pollution Control Program Manual
  - Stormwater Best Management Practices Manual

Unlike surface mining, which is regulated under the federal Surface Mining Control and Reclamation Act of 1977, the reclamation of lands developed for oil and gas is not regulated by a specific federal law. As a result, the existing regulatory framework is complex and involves a mix of federal, state, and local jurisdictions.

Reclamation practices include proper retention and redistribution of a development site's original topsoil. © *The Nature Conservancy (Tamara Gagnolet)*

REGULATORY GAPS

Roadway improvements may not reach permit thresholds or may only need a permit for a small portion of the project, which may lead to erosion and sedimentation. As a result, best management practices for erosion control and drainage may not be implemented.

Many participants noted that site reclamation policies can be challenging to navigate due to jurisdictional issues. Once a well has been abandoned, the state of Pennsylvania requires gas operators to restore the site to its approximate original conditions. This requirement, however, is less straightforward than it might seem, sometimes engendering conflicts in several dimensions:

- How to define what "approximate original conditions" means? Sometimes landowners' desired post-development conditions do not align with federal, state, or local restoration guidelines;
- Questions about *what* is expected — restoration, reclamation, or stabilization — and *who* is expected to do the work.

RECOMMENDED SHORT-TERM SOLUTIONS

While there were many disagreements about specific policies or approaches to erosion, sedimentation, and reclamation, the group agreed that the following four concepts were most important to address: (1) data, (2) training, (3) respecting ownership, and (4) finding out what works on the ground. With these in mind, the session participants selected the seven recommendations described below as top priorities (listed in rank order), based on feasibility and effectiveness in the short term.

1. **Baseline and post-construction data.** Collect and make available both baseline and post-construction data to assess land and water impacts. Participants strongly supported the development of scientifically sound baseline data for the following uses:
    - Identifying the source(s) of erosion and sedimentation impacts.
    - Gauging the effectiveness of best practices in avoiding and reducing erosion and sedimentation.
    - Gauging the success of site restoration.
    - Informing the post-construction or site restoration process.
    - Forecasting the impacts of shifting precipitation patterns.

    The working group associated the need for baseline data with several issues, including the ability to identify that oil and gas development is, in fact, responsible for any specific instance of erosion and sedimentation. Participants also noted that a baseline study of multiple soil disturbance types[31] might reveal patterns in erosion and sedimentation dispersal that could differentiate natural causes versus industrial or land management practices.

31 Examples of different types of soil disturbance:
- Natural: drought, treefall, and wind erosion
- Industrial: construction, excavation, and vehicle use
- Land management: compost application, revegetation, and crop rotation

One participant recommended that data from existing studies be evaluated to gauge their usefulness in a baseline. The group did not reach consensus, however, on how much time-based baseline data are needed (one month, six months, one year?), nor who would collect, manage, or pay for it.

2. **Comprehensive training.** Provide comprehensive training for leaseholders, operators, service companies, subcontractors, and onsite personnel to avoid improper practices and violations.
3. **Technical cooperative for reclamation.** Share field-tested practices for interim and final reclamation through a technical cooperative.
4. **Support regulatory oversight**. Support regulatory agencies to improve oversight in the field, based on the fact that more inspections yield fewer problems.
5. **Provide access to operator BMPs.** Create and maintain a comprehensive "one-stop shop" for operator Best Management Practices across jurisdictions so that others can benefit from practical experience.
6. **Educate landowners.** Provide technical assistance and education to landowners on leases so they know their rights and which questions to ask.
7. **Be flexible.** Provide flexibility in restoration/reclamation plans that recognize landowner desires and needs.

3.2.3 SHORT-TERM IMPLEMENTATION OF RECOMMENDATIONS

On the final day of the workshop, participants in each of the four main tracks — landscape, habitat, air, and water — were asked to choose one or two of their recommended solutions aimed at achieving the workshop's overall conservation goals. They were asked to put forward only solutions that were economically and politically feasible, and that could be implemented and reasonably effective within one or two years within the geographic scope of the Appalachian region. The selected solutions were not necessarily expected to be the most important on the list of priorities recorded by the groups during the workshop — only to be the most responsive in the short term.

Participants in the working group for the habitat track focused on a single solution:

"Pilot" sites for best practices. Identify and create field sites in the Appalachian region to demonstrate and disseminate effective habitat conservation practices, from build-out and operation to reclamation after completion.

The group outlined the activities and decisions that would be necessary over the next one to two years to accomplish this, several of which were the subject of debates that are encapsulated below.

> **When to begin?** The qualified consensus was that research could and should begin immediately, in order to address several significant questions participants raised, including whether to site the demonstration on private or public land, if there should be one site or several, using existing sites or starting new, which practice or practices would be demonstrated, and whether the primary activity should be research or demonstration.
>
> **Who should be involved?** The short answer was "everyone at this conference," including local governments and conservation districts, academic researchers, industry, NGOs, the public, private landowners, leaseholders, large public land owners and managers, engineers, contractors, and federal and state agencies such as the Pennsylvania Department of Environmental Protection and the U.S. Department of Agriculture.

Participants suggested the concept of a "cooperative" or "research" extension as an organization framework for the project. The "extension" concept is well known in agriculture, where university extension departments have for many decades helped practitioners learn to apply scientific research and new knowledge to field practices.

How to move from concept to operation? The most important operational issue — who would lead the effort — was discussed at length but not resolved. Calling a local research extension into service was floated as a possibility, but participants were concerned that a small organization would not have sufficient clout to manage a group of stakeholders of such size and influence. Industry would be involved, but would not be appropriate as the organizer. Several participants suggested that an environmental non-profit organization take the lead, or at least lead the effort to find the right entity to take on the role. Funding for the effort was discussed at length, but also was unresolved.

3.3 AIR TRACK

3.3.1 METHANE AND CLIMATE CHANGE

3.3.2 AIR QUALITY

3.3.3 SHORT-TERM IMPLEMENTATION OF RECOMMENDATIONS

The production, processing, and transmission of oil and gas from shale development in the Appalachian region emit methane and a suite of air pollutants that can have adverse impacts on human communities, wildlife, and habitats and contribute to climate change. In the context of finding both near-term solutions and strategic, long-term approaches to minimize air pollution and climate-change impacts, participants in the Air sessions explored two related Challenge Areas: (A) methane and climate change and (B) air quality.

The summaries for **methane and climate change** and **air quality** below describe the content of working group discussions during the first two days of the workshop. Each summary begins with an **overview of the challenge** and then presents the current **state of the challenge**, as presented by expert "anchors" and enhanced by participants, covering what we know and what we don't know in the areas of scientific research, mitigation technologies, practices, and regulatory framework.

After establishing the state of the challenge, session participants proposed potential solutions for moderating adverse impacts to Appalachian ecosystems and communities from methane and air pollutants. Participants selected as priorities a small number of **recommended solutions** that consider feasibility and effectiveness in the short term (one to two years). These prioritized recommendations are described below, and a full list of recommendations from participant brainstorming can be found in Appendix C.

The last summary below describes the content of working group discussions during the final day of the workshop, when participants focused on the **short-term implementation of recommended solutions** from the previous days' discussions within the air track.

3.3.1 METHANE AND CLIMATE CHANGE

SECTOR REPRESENTATION

Anchors: Academic institution, energy industry
Facilitators: Academic institution, energy industry
Participants: Academic institutions (5), energy industry (6), government (0), non-profit organizations (5)

CHALLENGE

How can *methane emissions* be reduced?

HIGH-LEVEL CONCLUSIONS

- Low-cost monitoring and sensing technologies are needed to provide quality, reliable emissions data in order to more fully understand the issues and optimize control strategies.
- Discussions and recommendations related to methane emissions should consider existing and new production facilities, orphaned and abandoned wells, and distribution pipelines.
- The level of emissions from natural gas production sites varies greatly, making a reliable prediction of the magnitude of the challenge difficult.

OVERVIEW OF THE CHALLENGE

Methane is the primary component of natural gas and the second most prevalent greenhouse gas (GHG) in the United States, according to the U.S. Environmental Protection Agency (EPA). While in volume it ranks a distant second and persists in the atmosphere for a much shorter time, per unit mass, it is a more potent GHG than carbon dioxide (CO_2). Methane also oxidizes in the atmosphere to form CO_2, and methane combustion in power generation directly produces CO_2. Methane thus has two roles in climate change: the climate forcing of the CO_2 emissions, whether from combustion or atmospheric oxidation, and the climate forcing of methane that escapes directly into the atmosphere. Broadly, the CO_2 contribution arises mostly from combustion as most methane is successfully extracted and used, whereas the climate forcing from natural gas leakage is mostly associated with the much more potent (per molecule) radiative effect of methane itself.

During shale development operations, methane can be released into the atmosphere during well drilling, fracturing, and completion processes. Releasing methane during initial well drilling and stimulation is largely for safety reasons. The industry also employs a number of required and voluntary engineering and operational controls to reduce both the safety and environmental risks of emissions during completion activities. Legacy wells and pipelines that have been in existence for many decades also contribute to methane emissions.

Reducing or eliminating methane emissions is a common goal for environmental and industry interests, as minimizing methane leakage both potentially reduces climate change impacts and increases the resource that companies can sell. Practically speaking, however, reducing methane leakage in natural gas systems is a complex challenge. Unreliable data are compounded by regulatory gaps and inconsistencies and a debate about how best to measure potential impacts.

In light of this complexity, session participants sought to reach agreement on solutions to produce reliable, quality-assured emissions data that could be used for decision making and used by operators to minimize methane leakage and maximize the capture of methane in upstream (exploration and production) and mid-stream (transportation and storage) activities of shale development. Participants also recognized that meaningful solutions should address both existing and new facilities, as well as orphaned/abandoned wells and pipelines.

STATE OF THE CHALLENGE

STATE OF THE SCIENCE

The most recent (2011) EPA National Emissions Inventory (NEI) reports that methane accounted for 9.7% of total greenhouse gas (GHG) emissions on a CO_2 equivalent basis[32] and that methane from natural gas systems (well site to end use) accounted for 24% of those emissions. Methane from natural gas systems has declined 17% since 1990, while national natural gas production has increased 37%.

Questions have been raised about the accuracy of EPA estimates. The EPA methane inventory is a bottom-up estimate based on equipment-level emissions activity data. Another approach is a top-down study using aircraft to quantify emissions on a basin level. These top-down estimates suggest that the EPA inventory may significantly underestimate methane emissions from natural gas production. Instead of the EPA estimate of a 2.4% overall leak rate, the studies show total methane emissions related to shale development may be as high as 7.9%.

According to session participants, the discrepancy is the result of EPA's methodology, relying on models based on limited emissions and activity datasets. In the case of methane leakage, participants say, the EPA model incorrectly accounts for the distribution of emissions between facilities and outdated activity information.

Participants also noted the following:

- **Variability in emission factors across facilities.** Recent studies have collected a large number of emission measurements that show that emission rates vary widely among facilities (e.g., compressor stations, treatment units, wells, etc.).
- **Contribution of local distribution companies (LDC).** EPA included the entire natural gas "system" in its inventory, from the start of the upstream — breaking ground on a well site — to the end of the downstream: a customer's home stove or heater. It is unknown how leakage from the (old, faulty, cracked) infrastructure of LDCs compares to the rest of the system.

RESEARCH GAPS

Participants discussed the following research and data gaps:

- **Gaps in data reporting.** The EPA has recently implemented a GHG reporting program that collects valuable data. Not all emission sources, however, are required to be reported. The inventory allows for many exemptions and does not account for individual differences between sites, facilities, and other potential sources.
- **Contribution of legacy and abandoned wells.** Relatively little is known about "legacy" energy infrastructure. For example, in Pennsylvania — there are tens of thousands of abandoned or plugged natural gas and traditional oil wells and associated pipelines, and it is unknown how they may be contributing to methane emissions or where they might be located.

32 Equivalent CO_2, or CO_2e, uses carbon dioxide to signify the equivalent global warming impact of other GHGs, such as methane or nitrous oxide, usually on a 100-year scale.

Sources of methane emissions include existing and new production facilities (such as the well heads pictured here), orphaned and abandoned wells, and distribution pipelines. *"Gas wells" by Gerry Dincher, licensed under CC BY-SA 2.0.*

STATE OF THE TECHNOLOGY

Many effective technologies to reduce upstream methane emissions are already used in the field, some of which are required. They include:

- **"Green completions."**[33] Reduced Emissions Completions (RECs) or "green completions" required by both federal and state regulations for upstream operations can effectively capture produced gas during well completions and well workovers following hydraulic fracturing to substantially reduce methane emissions.
- **Leak detection and repair (LDAR).** Required under both federal and state air regulations to identify and repair leaks from specific operations. An LDAR test must be conducted within a specified timeframe after the start of production on key pieces of equipment in up- and mid-stream operations, with leaks repaired within a specified timeframe.
- **Low bleed (6 standard cubic feet per second) or zero bleed pneumatic controllers.** Used to maintain a condition in the production system (such as liquid level, pressure, pressure difference or temperature), low-bleed controllers release only small amounts of natural gas to control line pressure, while zero-bleed controllers release no gas to the atmosphere and instead, release it to a downstream pipeline.
- **Electric/solar pumps and controllers, and compressors.** Replacing pneumatic equipment with solar equipment in the field has increased methane recovery and also has eliminated other problems, including freeze-ups of glycol dehydration systems in the winter. Newer centrifugal compressors have lower emissions than older reciprocating compressors.
- **Site-wide vapor recovery systems.** Vapor recovery systems that aid in EPA NSPS Quad O regulatory compliance capture up to 95% of hydrocarbon vapors that accumulate in tanks in wet gas areas, as well as capture vapors during liquids transfer.

TECHNOLOGY GAPS

Participants discussed the need to develop low-cost technologies for sensing and monitoring equipment that could provide empirical data for an inventory of methane emissions throughout the system.

33 Green completion is an alternate practice that captures the produced gas during well completions and well workovers following hydraulic fracturing. Portable equipment is brought temporarily to the well site to separate the gas from the liquids and solids in the flowback stream, producing a gas stream that is ready or nearly ready for the sales pipeline.

STATE OF THE PRACTICE

Voluntary best practices were discussed as they relate to the economic factors involved in the recovery of methane, which is a valuable component of natural gas. Some high-level best practices were mentioned such as those disseminated by the EPA, American Petroleum Institute, and the Center for Sustainable Shale Development. Participants also discussed ongoing efforts to reduce methane emissions and improve methane recovery for sale. For example, the EPA's Natural Gas Star Methane Challenge Program provides a mechanism through which oil and gas companies can voluntarily make and track ambitious commitments to reduce methane emissions.

STATE OF THE REGULATORY FRAMEWORK

Existing regulations to limit methane emissions at state and federal levels specify performance standards for most of the equipment used in gas production that covers shale hydraulic fracturing processes and equipment, including tanks, compressor stations, and processing plants. Some require green completions and specify emission limits on each. In addition, many segments of an operation require that companies implement a LDAR program. Examples of regulations covering both green completions and LDAR are listed below.

- **Federal: 40 CFR 60 subpart OOOO.** Green completions. Tank emission limits/95% controls.
- **PA Department of Environmental Protection:**
  - GP-5 Compressor stations/processing plants. LDAR, Controllers, engines, etc. Incorporate applicable EPA regulations.
  - Exemption 38 Unconventional well sites. Quad 0 plus. LDAR. Site-wide 2.7 TPY VOC/95% control efficiency.
- **Future state of the regulatory framework.** Participants noted several government actions and recommendations to reduce methane emissions, specifically those that were discussed in *Climate Action Plan: Strategy to Reduce Methane Emissions*, published by the White House in March 2014.

Note that, since the workshop was held, new regulations have been promulgated, including the new methane rule by the EPA.

The radiative impacts of methane emissions can be accurately calculated on different time scales. There is, however, a controversy around the timescale for evaluating methane's Global Warming Potential (GWP) (e.g., 20- or 100-year time horizon) to use for policy assessments. The GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere. GWP is calculated over a specific time interval, usually 20 years or 100 years.

The choice of a 20-year or 100-year interval can greatly affect GWP values and thus the decisions made using them. On the 20-year scale, for example, methane has a GWP of 86, which means that a unit mass of methane emissions is 86 times worse than the same mass of CO_2 emissions. Using 100 years, which EPA used for the above methane calculations, its GWP is 34.[34] Using different time horizons can have a dramatic impact on policy decisions. For example, using a shorter time horizon (e.g., 20-year GWP) would make natural gas much less compelling from the perspective of climate change (compared to coal), increasing the need for mitigation of emissions.

GAPS IN REGULATORY FRAMEWORK

Other policy considerations were raised, including:

- **Uniformity.** Methane leakage is not uniform across the industry, nor across sites. Participants questioned whether government should invest in policies and regulations to gather specific emissions data and provide them with a political "scalpel" to excise bad actors or if they should use an "axe" and regulate the industry as though all emitters are the same.
- **Legacy and abandoned wells**. Time and money are needed to discover the emissions from legacy infrastructure and determine who will pay for the work required to locate and properly plug all abandoned wells.

34 5th assessment report, Intergovernmental Panel on Climate Change.

RECOMMENDED SHORT-TERM SOLUTIONS

Below are the recommendations for reducing methane leakage from shale development voted by participants as top priorities based on short-term feasibility and effectiveness (one to two years). Participants stressed transparency as the key element in their three suggestions:

1. **Improve emissions inventory, for low emitters as well.** Improvements would include:
   - Homogenizing procedures between agencies for consistency.
     - What sources should be included/excluded?
     - What sites should be included/excluded?
     - How should results be calculated?
     - What emission factors should be included?
   - Updating EPA emission factors for improved accuracy.[35]
   - Providing an independent, continuous feedback mechanism to keep the data fresh.

2. **Develop rapid screening for super-emitters.** The group agreed on the need to be able to identify super-emitters, since the data suggests they play a significant role in methane emissions.
   - Develop screening devices that are economically feasible.
   - Protocol for finding the bad actors.
     - Inspection intervals
     - Inspection procedures
     - Reporting
   - Field training for site employees.

3. **Develop measurable emissions targets.** The desired outcome would need to be determined by relevant stakeholders, as well as who would set the targets. Participants did not agree how best to apply this process to operations.

35 Compilation of Air Pollutant Emission Factors AP – 42. U.S. Environmental Protection Agency. (http://www3.epa.gov/ttnchie1/ap42/c00s00.pdf)

3.3.2 AIR QUALITY

SECTOR REPRESENTATION

Anchors: Academic institution, energy industry
Facilitators: Non-governmental organizations
Participants: Academic institutions (2), energy industry (7), government (1), non-governmental organizations (5)

CHALLENGE

What are the principal threats of shale development to *air quality*? What are the most important practice and policy actions to achieve meaningful reductions?

HIGH-LEVEL CONCLUSIONS

- Credible, systematic data are needed to identify and quantify specific emissions. An accurate and reliable inventory of emissions is needed to serve as a baseline from which to take action.

OVERVIEW OF THE CHALLENGE

High levels of growth in the oil and natural gas production sector have highlighted the need for a better understanding of emissions and potential risks from the various operations. Emissions from shale gas operations can include methane, volatile organic compounds, nitrogen oxides, sulfur dioxide, particulate matter, and various forms of hazardous air toxics, including n-hexane, the BTEX compounds (i.e., benzene, toluene, ethylbenzene, and xylene), and hydrogen sulfide. Currently there are limited directly-measured air emissions data for air toxics and criteria pollutants for several important oil and gas production processes and sources, including well completions and evaporative ponds.

Participants wrestled with one basic challenge: scientific uncertainty due to a lack of credible data. Participants focused their work on how best to address these uncertainties by reducing emissions wherever possible, and by taking steps to produce an accurate and reliable inventory of emissions that would serve as a baseline from which to take action.

While the workshop overall did not address human health effects from air pollution, participants acknowledged that they are an issue within this topic area.

STATE OF THE CHALLENGE

STATE OF THE SCIENCE

While a lack of credible data was an overarching theme, participants referenced some studies regarding emissions from shale development:

- **Emissions can be regionally significant.** Since 1999, emissions of ozone precursors and fine particulate matter ($PM_{2.5}$) have decreased dramatically in Allegheny County, Pennsylvania, according to the county's 2014 Air Quality Annual Summary Data. While shale development is not likely to reverse this progress, a study focused on the Marcellus play showed increased emissions of volatile organic compounds (VOCs), and nitrogen oxides (NO_x), mainly due to combustion at the additional compressor engines needed to move the gas. While the increases are manageable, they are significant enough to be regionally significant. By 2020, the study projected, Marcellus activity will account for approximately 12 percent of the region's VOC and NO_x emissions, a figure that does not include VOCs from retainment ponds or end use of the gas in homes, industrial processes, and power generation.

- **Emissions may have local effects.** Further anecdotal evidence shows that levels of speciated hydrocarbons, including methane, hexane, ethylene, benzene, and toluene, are notably higher near shale development sites in Colorado, Utah, South Dakota, Mississippi, and Illinois. Human error and equipment failure can result in above average emissions, and emphasizes the need for monitoring.

RESEARCH GAPS

Participants agreed that efforts to reduce emissions are stymied by the lack of credible data about VOCs, NO_x, and other hazardous air pollutants. More studies to collect high-quality data would allow industry operators and regulators to make evidence-based decisions about preventing and controlling hazardous air pollutants. Some of the existing research and data gaps they listed include:

- **Lack of accessibility to existing data.**
  - **Transparent corporate data.** Participants noted several datasets relevant to emissions, presently considered proprietary by operators, could be released, providing benefit across several stakeholder sectors.
  - **Site-specific gas composition data.** Participants were broadly enthusiastic about operators openly sharing the results of their individual gas composition analyses, which are regularly conducted but generally kept in-house. In addition, researchers noted it would be very helpful if operators could make data accessible to help estimate emissions of VOCs throughout the production process.
- **Lack of data related to:**
  - **Fugitive emission sources.** Local and near-well emissions data from mobile and stationary sources, such as diesel and black carbon from trucks and other engines used during well pad, access roads, compressor stations, gathering and transmission line construction, and data from fracturing, water impoundments, and pipelines is not currently required to be monitored by regulation and thus is not available.
  - **Pipelines and impoundments.** Monitoring pipelines is challenging because of their length and the required manpower. Participants suggested focusing on places along pipelines where there is more infrastructure.
  - **Baseline data.** Baseline data regarding existing ambient air quality are not currently required and therefore are largely absent in many areas where gas wells and associated infrastructure have been constructed.
- **Correlation of data with other factors.**
  - **Correlating concentrations with emissions.** Participants noted the need to correlate measured concentrations to recorded emission levels.
  - **Correlating data with risk, health.** Lack of credible emissions data has effectively quashed researchers' ability to correlate emissions with health effects, which participants considered to be very important. There was also a call to differentiate risk from the amount of emissions.
- **Continuous monitoring.** Continuous monitoring is crucial; averaging emissions across a given timeframe loses important information about activities and impacts that could be associated with certain emissions.

Participants stressed that the availability of quality-assured data is critical for research and to inform voluntary practices and policy.

Emissions from shale gas operations can include methane, volatile organic compounds, nitrogen oxides, sulfur dioxide, particulate matter, and various forms of hazardous air toxics. *"Hydraulic Fracturing Drill Site" by Doug Duncan, USGS*

STATE OF THE TECHNOLOGY

Participants noted that using natural gas to produce electric power is itself an air pollution reduction technology, as it substantially lowers NOx emissions, compared to traditional coal fired plants. In addition, as the methane group discussed, the technologies to capture and re-use methane emissions have improved dramatically.

TECHNOLOGY GAPS

In addition to the well-known gaps in deploying emerging technologies on shale development sites, such as solar and electric engines, participants noted the need for systems technology in two areas plus modeling:

- **Monitoring systems.** Participants agreed that there is room for improving technology related to monitoring emissions to make it more affordable and more accurate, especially in managing distributed sensors for continuous fenceline or specific operations monitoring that can aggregate data on VOCs and other hazardous air pollutants.
- **Reporting systems.** A technology foundation that supports transparency and communication would include records and reports on facilities, adherence to regulations, and more accurate matrices of pollutants.
- **Modeling.** Building air-quality models from emissions data is essential, as raw data points are meaningless on their own without context. Conversely, air-quality models are of limited use without accurate emissions data.

STATE OF THE PRACTICE

Existing practices discussed by the group included:

- **Voluntary certification by the Center for Sustainable Shale Development (CSSD).** A "collaborative" between environmental organizations and energy companies, CSSD certifies Appalachian shale operator practices in two areas, Air & Climate, and Water & Waste. Companies wishing to become certified must demonstrate compliance with the standards in their operations with outside confirmation from a third-party auditing firm, who is qualified and authorized to certify their status. Participants discussed whether the use of certification standards would move more companies toward a more unified standards and practices operational approach.
- **Truck issues.** Issues related to truck traffic (e.g., dust and emissions) were briefly mentioned by participants. Practices including speed restrictions, bonding roads,

and other control methods can be used to control dust. Participants also mentioned the use of pipelines in transporting materials to reduce truck traffic but noted that this brings up a whole different set of issues.

GAPS IN PRACTICE AND IMPLEMENTATION

Participants identified the following areas where practices could be developed or improved:

- **Training practices.** Several aspects of shale operations were suggested as targets for employee and contractor training in competency, hazard response, and best practices, including monitoring and interpreting sensor data.
- **Collaboration and consensus.** There is currently no consensus among stakeholders on popular solutions and preferred operational methods or endorsement for companies that adopt them.
- **Business management practices.** Some participants suggested that, beyond practices to reduce emissions, best management practices should be in place to ensure that environmental initiatives are properly staffed and monitored. One specific area mentioned was accountability and liability for contractors and subcontractors.
- **In-house research.** Participants from several sectors noted the need to establish standards for conducting, reviewing, and communicating results of data collection and/or research conducted by operators. Gathering, assimilation, and distribution of data, assigning a "watchdog" for quality, and peer review were included in the discussion.

STATE OF THE REGULATORY FRAMEWORK

Regulations were not a focus of participant discussion. The group focused more on the absence of credible emissions data, which makes creating appropriate regulation difficult. Although public health was not within the scope of this workshop, participants pointed to human health impacts as a driver for regulation, which includes, but is not limited to, the two U.S. Federal regulations listed below.

- **National Ambient Air Quality Standards (NAAQS)** — The National Ambient Air Quality Standards cover six primary pollutants: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter and sulfur dioxide.
- **HAPs** — National Emission Standards for Hazardous Air Pollutants (NESHAP) apply to specific categories of both new and existing sources, with Maximum Achievable Control Technology required.

REGULATORY GAPS

Participants produced a list of areas where gaps could be filled by regulatory review:

- **Monitoring and reporting of emissions.** Participants generally agreed about the benefits of monitoring and capturing all emission sources in time and space to establish a baseline, produce better estimates of varieties of hydrocarbons emitted, and allow for better speciation of pollutants. This improved knowledge also would help operators identify where equipment failures are causing problems, which could in turn lead to better equipment for source monitoring. Some also noted the practice would provide a way to assess the "super-emitters" that are responsible for a disproportionate percentage of total emissions in shale development. There was, however, much contention about using monitoring data for other purposes, particularly as the first step in identifying and addressing acute incidents. Some participants asserted there were no data to support local health impacts of emissions. Others countered there were such studies.
- **Liability incentives.** At this time, no proportional legal liability is in place for operators, which could leave operators liable for emissions from another site without sufficient monitoring to prove otherwise.
- **Poorly characterized emissions.** The current regulatory framework, both for U.S. Federal and States, does not currently require actual monitoring for fugitive emissions sources. Instead, the U.S. EPA has created emissions factors for specific equipment and operations and this extrapolation methodology is used in reporting to regulatory agencies.

- **Disclosures.** Participants noted that establishing disclosure practices (beyond in-house research, mentioned separately) for some areas would be beneficial, including required neighborhood notification for certain types of planned or unplanned pollutant events. Generally, air permits require notification to the regulatory agency within 24 hours or sooner of an emission exceedance during malfunction events. Other exceedances and permit deviations are periodically reported to regulatory agencies. Environmental emergencies have various immediate reporting requirements to federal, state, and local response agencies/departments. It is often the duty of the regulating agency to notify the public. It was agreed, however, that there are opportunities for better communication with communities.
- **Compliance for legacy infrastructure.** Participants generally agreed on the need to identify and update legacy infrastructure to existing compliance standards, with disagreement about how best to do so or along what timeframe.

RECOMMENDED SHORT-TERM SOLUTIONS

The group unanimously agreed that addressing the gaps in data, research, and policy is critical to developing effective solutions. Participants contended that practices may be more effective in the short term than regulations, because regulations often take a long time to be implemented.

With that in mind, the group voted the following recommendations as top priorities for addressing the principal threats of shale development to air quality, based on feasibility and effectiveness in the short-term.

1. **Adopt lowest-emitting equipment (e.g., tier 4, dual fuel, and electric engines) across operational sectors.** Target areas identified by participants include:
   - Drill rigs, vehicles, diesel engines, and compressors (including legacy transmission and distribution stations and their compressor units).
   - Existing sources must comply with the same standards as newer equipment. Some older systems, which are seeing increased use as a result of Marcellus development, could be upgraded to reduce emissions/increase efficiency.
2. **Monitor emissions and near-source concentrations to identify contributions at local levels (short and long term) during regular operating conditions and equipment failures and address them appropriately.** These data will provide an understanding of the emissions associated with each operation, generate sufficient data to inform voluntary practices and policy, and enable operators to respond to both routine and non-routine emissions exceedances.

   The suggested method for collecting emissions data over time and space was randomized plus constant fenceline/point-of-operations indigenous monitoring around facilities. This could be overseen by industry and regulators and provide tangible data. Some participants claimed that this process has already been effective at refineries in California and Texas and could be implemented immediately.
3. **Develop and disseminate standardized best practices in environmental training, replicating the high standards for safety practices and awareness.** Standardized operational practices would promote consistent replication of the already existing high standards of safety and precaution across the industry, reducing human error. This would include developing standardized environmental training for maintenance, leak detection, reporting, and audit, following the safety protocols that are EHS in scope, for a comprehensive environmental, health, and safety approach. Some participants noted that industry already performs training, and others indicated that, while that may be the case, it is not standardized.
4. **Stakeholder participation.** Among industry, regulators, NGOs, and academia, build an ongoing common understanding of key variables and common consensus processes to optimize solutions and foster quality, credible research regarding emissions data, concentrations, and public health effects.

3.3.3 SHORT-TERM IMPLEMENTATION OF RECOMMENDATIONS

On the final day of the workshop, participants in each of the four main tracks — landscape, habitat, air, and water — were asked to choose one or two of their recommended solutions aimed at achieving the workshop's overall conservation goals. They were asked to put forward only solutions that were economically and politically feasible, and that could be implemented and reasonably effective within one or two years within the geographic scope of the Appalachian region. The selected solutions were not necessarily expected to be the most important on the list of priorities recorded by the groups during the workshop — only to be the most responsive in the short term.

The working group for the air track produced the following two recommended solutions:

1. **Industry partnership for best practices.** Create a partnership among stakeholders (including, for example, the American Petroleum Institute or the Center for Sustainable Shale Development) to produce a "best practices" guidance document for operators, specifically focused on air quality, which could be used nationwide.
2. **Onsite protocol and more accurate mobile equipment for early detection of leaks and fugitive emissions.** An emissions detection protocol, collaboratively developed among stakeholders, would significantly reduce gas leaks and ease the economic burden on both regulators and operators. Participants selected the development of non-regulatory guidance documents as a priority solution because EPA-mandated practices can take years and even decades to finalize. Working with industry associations like the American Petroleum Institute, they noted, could speed the process significantly and make compliance with guidelines "more credible" for operators.

Regular inspections and ongoing monitoring, participants acknowledged, are the most effective measures for reducing or eliminating gas leaks. Because of cost considerations, however, neither measure is being used to its best advantage. For example, regulators have limited resources and, as a result, field visits often can be conducted by people with insufficient knowledge of the site and the chemicals they are inspecting. As for monitoring, many sensors in use today are "cheap" and can detect only large methane leakages of which operators are already aware.

Participants noted that both of their proposals lack a regional entity to "own" the implementations they suggested.

3.4 WATER TRACK

3.4.1 WATER SOURCING AND CONSUMPTIVE USE

3.4.2 CONTAMINATION PATHWAYS AND RISKS TO SURFACE AND GROUND WATER

3.4.3 STRATEGIES TO UNDERSTAND AND ADDRESS CUMULATIVE IMPACTS TO WATER RESOURCES

The management of risks to water resources, including quantity and, in particular, quality, is arguably the most complex environmental and social issue associated with shale gas development.

Participants in the water resources sessions explored three distinct but interrelated Challenge Areas: (A) water sourcing and consumptive use, (B) wastewater treatment and disposal, and (C) contamination pathways and risks to ground and surface water.

The summaries for **water sourcing** and **contamination pathways** describe the content of working group discussions during the first two days of the workshop. Each summarized the **state of the challenge**, as presented by expert "anchors" and enhanced by participants, covering what we know and what we don't know in the areas of scientific research, mitigation technologies, practices, and regulatory framework. Given the limited time, these discussions were not comprehensive and instead focused on areas that define our current state of understanding. These discussions also produced several **recommended short-term solutions** and areas of opportunity, and those ideas are described in the session summaries below and listed in Appendix C.

In an attempt to cover the breadth of the topic, the water sessions were organized slightly differently from the other tracks. On Day 1, the session began with summarized states of the challenge for both *water sourcing* and *wastewater treatment and disposal*, and then the session split into two groups to brainstorm short-term solutions to each challenge. The groups reconvened to report out and discuss the results with all session participants.

Similarly, on Day 2 the session began with a summarized overview of *contamination pathways to ground and surface water*. After a discussion to round out the state of the challenge, participants were divided into two groups — one for ground water risks and one for surface water risks — to brainstorm short-term solutions. The groups then reconvened to report out and discuss the results with all session participants.

As *wastewater treatment and disposal* is related to the topics of *water use* and *contamination risk*, for the purposes of the report, the workgroup discussions for wastewater treatment and disposal were split between the two topics to unify discussion outcomes.

The **long-term impacts** summary describes the content of working group discussions during the final day of the workshop (Day 3), when participants focused on identifying strategies necessary to understand and address the cumulative impacts on water resources.

3.4.1 WATER SOURCING AND CONSUMPTIVE USE

SECTOR REPRESENTATION

Anchors: Academic institutions
Facilitators: Academic institution, non-governmental organization
Participants: Academic institutions (2), energy industry (6), government (10), non-governmental organizations (3)

CHALLENGE

How do we *source and allocate water* while supporting water availability for human and ecosystems needs?

HIGH-LEVEL CONCLUSIONS

- While water availability in the Appalachians is relatively high and O&G demand is relatively small compared to other water demands, unregulated water withdrawals from hydraulic fracturing can cause localized and/or cumulative stress on water availability in smaller streams, streams with low base flow and settings that have proportionately high biodiversity and recreation values.
- In addition to avoiding ecological risks of hydrologic alteration, an equal and potentially greater motivation to reduce freshwater use is to reduce the volume of water that needs to be stored, transported, treated, and disposed.

OVERVIEW OF THE CHALLENGE

In the Marcellus shale play, an estimated 4.4 million gallons of water is required to hydraulically fracture a gas well. It is estimated that more than 14 billion gallons of water have been used to date. Over the next 50 years, it is estimated that cumulative demand could be up to 264 billion gallons for the region.[36] Freshwater is sourced from streams, rivers, ground water, and municipal sources. Most water is used during high-volume hydraulic fracturing, with less being used during drilling. In Pennsylvania, where the highest national rate of development activity occurred in 2015, more than 75 percent of the water used for shale gas production has been diverted from streams and rivers using tanker trucks and subsequently transported to gas-well pads and stored onsite typically for less than one week prior to injection during well stimulation. Development of centralized pipelines and storage is less common.

A recent study shows that peak permitted daily water withdrawals range from 0.01 to 4.7 million gallons.[37] For reference, an Olympic-sized swimming pool holds 0.7 million gallons. While this demand seems high, it is relatively small compared to other water demands in the region. The concern lies in the concentrated timing,

36 Total value was estimated by extrapolating 4.4 million gallons per well by a potential growth scenario of 60,000 wells in the region (Evans and Kiesecker 2014). This is a conservative growth scenario based on recent trajectories.

37 Barth-Naftilan, E., Aloysius, N., and Saiers, J. 2015. Spatial and temporal trends in freshwater appropriations for natural gas development in Pennsylvania's Marcellus Shale Play. *Geophysical Research Letters.* 42(15): 6348-6356.

location, and intensity of this demand for freshwater and the increased likelihood of cumulative impacts to downstream hydrology. Demands often occur in settings with relatively low water availability and high biodiversity and recreation values (e.g., cold-water streams supporting trout, eastern hellbender, and wood turtle; warm-water streams supporting rare darters and freshwater mussels). In addition to relatively low water availability, demands often occur in settings that can have high uncertainty in flow measurements, making it difficult to generate an accurate water budget. This has the potential of leading to overallocation of available water. Lastly, the majority of freshwater (surface and ground water) withdrawn for hydraulic fracturing is consumptively used during the development and disposal process, meaning it will not return to the watershed from which it was withdrawn, nor will it return to the surface water cycle.

STATE OF THE CHALLENGE

STATE OF THE SCIENCE

There is a significant and rapidly growing body of scientific support documenting the ecological risks of surface and ground water withdrawals. Much of this understanding comes from research on dam operations and water withdrawals to meet human demands including public water supply, energy, agriculture, and other industrial needs.

- **Alteration of the natural flow regime can reduce habitat and ecosystem services.** Species in the Appalachian region have evolved to synchronize critical life development stages with the magnitude, timing, and frequency of seasonal and inter-annual flow patterns. Reduced spring high and summer low flows can directly reduce the availability and diversity of habitats, resulting in reduced growth and abundance of fish and macroinvertebrates, and in certain cases, loss of species. Headwaters and small streams are at higher risk of change to the flow regime than larger tributaries. Low flow seasons in these settings present particular risks as do extreme low flow conditions on tributaries. Explicit relationships between ecosystem needs and flow alteration are documented in recent basin-scale studies for the Susquehanna, Delaware, and Upper Ohio basins.
- **Impacts can accumulate downstream.** Water withdrawals for hydraulic fracturing are high volume, occur over a short period of time, and are typically concentrated near well sites to minimize transportation costs. The concentrated timing and location of withdrawals in small stream and tributary settings increase the likelihood of cumulative impacts to downstream hydrology, water supply, aquatic habitat, and recreation.
- **Recent studies support the application of basin-scale water withdrawal policies supported by ecosystem flow recommendations.** Water resource management agencies have applied a science-based approach to water withdrawal management that supports the flow regime by limiting the alteration to seasonal and inter-annual flow conditions. This approach is being monitored in the Susquehanna River basin. Based on monitoring results, two independent research projects found that aquatic biota have not been affected in biomass or diversity by withdrawals administered with protections under this regulatory program.[38,39]

RESEARCH GAPS

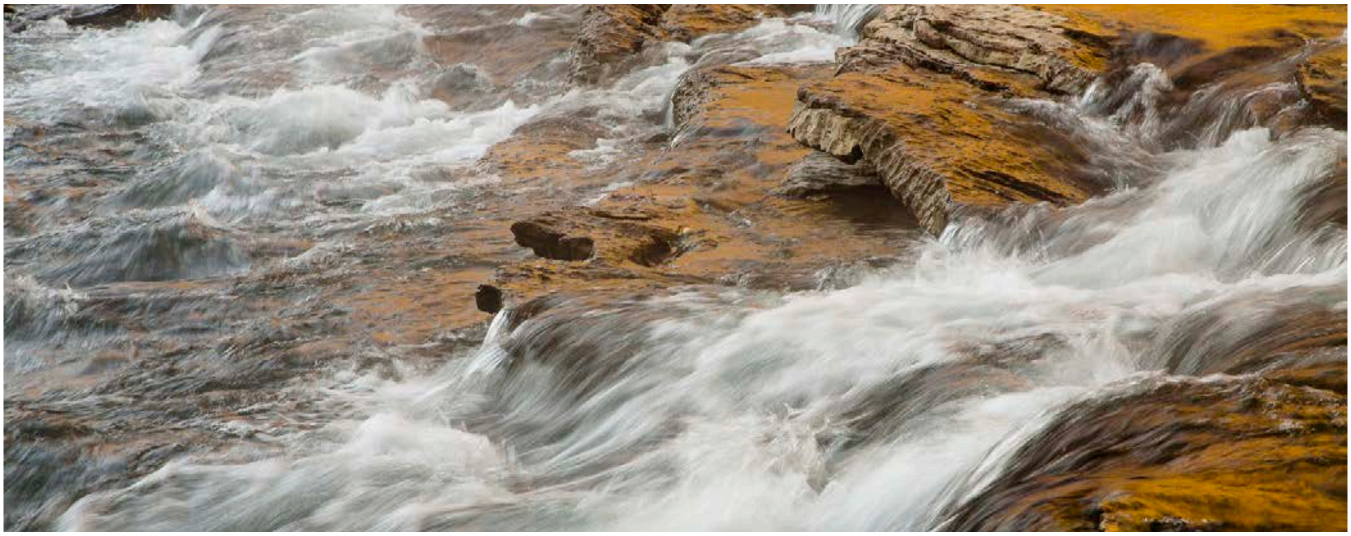
Workshop participants pointed to the following areas where more research could further inform and support water withdrawal planning practices and policies:

- **Baseline data in ungaged settings.** Accuracy of estimating daily flows at ungaged withdrawal sites needs to be increased. There are tools that estimate long-term daily flows for different regions.[40] It was

38 Shank, M. K. and Stauffer Jr, J. R., 2015. Land use and surface water withdrawal effects on fish and macroinvertebrate assemblages in the Susquehanna River basin, USA. *Journal of Freshwater Ecology*, 30(2): 229-248.

39 Barth-Naftilan, E., Aloysius, N., and Saiers, J. 2015. Spatial and temporal trends in freshwater appropriations for natural gas development in Pennsylvania's Marcellus Shale Play. *Geophysical Research Letters*. 42(15): 6348-6356.

40 Stuckey, M. H., Koerkle, E. H., and Ulrich, J. E., 2012. *Estimation of Baseline Daily Mean Streamflows for Ungaged Locations on Pennsylvania Streams, Water Years 1960-2008*. U.S. Geological Survey Scientific Investigations Report 2012-5142: 61.



The individual and cumulative effects of surface and ground water withdrawals for hydraulic fracturing pose a risk to hydrology, water supply, water quality, species abundance and diversity, and recreation. © *Kent Mason*

suggested that these tools should be calibrated, especially in small stream settings. This can be accomplished by investing in new gage locations in under-represented hydro-geologic settings.

- **Temporal characteristics of actual water withdrawals.** While there is specific data about the volume and timing of anticipated use by the industry in those regions where withdrawals are regulated, less is known about the timing, frequency, and volume of actual withdrawals.
- **Cumulative effects of upstream withdrawals.** While participants noted that the relative demand of the shale gas industry is small compared to other water users in the region, it was generally agreed that, due to the concentrated nature of the development, aggregate demands in headwater and small streams could result in measurable cumulative impacts to small and medium-sized tributaries. In addition, the change in water quantity on downstream water quality is unknown. Discharge permit limits for contaminants, based on historic low flows, may result in toxicity to aquatic organisms when upstream withdrawals reduce dilution and increase concentrations during low flow periods.
- **Risks of non-freshwater sourcing to reduce freshwater demands.**

STATE OF TECHNOLOGY AND PRACTICES

Participants noted that several technologies and complementary practices have the potential to minimize the risks of surface and ground water withdrawals to water availability for ecosystems and humans. These include:

- **Re-use and other non-freshwater sources.** Reducing demands on freshwater resources by re-use, and using freshwater alternatives (brackish ground water, treated abandoned mine drainage, waterless gas-well completions). Ninety percent of wastewater produced in the Marcellus play to date is re-used.[41] Flowback and produced water comprise 17% of water used for hydraulic fracturing from 2009-2013.
- **Monitoring withdrawals and responding hydrology.** Technologies for site-specific monitoring and reporting are no longer cost-prohibitive. Pressure

41 Barth-Naftilan, E., N. Aloysius, and J. Saiers. 2015. Spatial and temporal trends in freshwater appropriations for natural gas development in Pennsylvania's Marcellus Shale Play. *Geophysical Research Letters*. 42(15): 6348-6356.

transducers and low-cost gaging stations are being used to track and monitor streamflow in response to withdrawals.

- **Science-based siting and use of centrally located water sources.** A couple of technologies have been implemented to facilitate the shift of industry demand toward locations with lower-risk supplies, like large, main stem rivers. This includes centralized storage facilities or small low-cost temporary water lines to transport water from the source to the well pad. An assessment of trade-offs between these alternatives on transportation of water from source to well pad has not been made.

GAPS IN PRACTICE AND IMPLEMENTATION

Existing technologies to monitor water supply and consumption are not widely deployed. Further, clear assessments of trade-offs between alternative practices for siting and transporting freshwater, including re-use practices and the use of centrally located water infrastructure, have not been made.

STATE OF THE REGULATORY FRAMEWORK

Regulations, specifically a comparison of regulations across the Appalachian region, were a focus of the discussion.

- **Regional governance.** Currently, the federal government does not regulate water withdrawals for natural gas development. Two quasi-federal agencies, the Susquehanna River Basin Commission (SRBC) and the Delaware River Basin Commission (DRBC), have jurisdiction over water withdrawals related to natural gas development in their respective basins. In the Delaware River Basin, there is currently a moratorium on hydraulic fracturing and issuing water withdrawal permits for use in hydraulic fracturing within the basin. Similarly, the state of New York has banned hydraulic fracturing and related water withdrawals. In the working group, it was discussed that the general state of standards and practices in the Susquehanna River Basin, established and implemented by the SRBC, appear largely appropriate for managing the water quantity risks associated with surface-water withdrawals for shale gas development demands.[42] SRBC's policy standards are based on basin-wide ecosystem flow recommendations that define limits of alteration to high flows, seasonal flows, and low flows, in order to protect the species and habitat needs in different stream types. They include informed siting, quantity, and timing of withdrawals and are implemented through pass-by limits, or the flow at which a user is required to cease withdrawals, and daily peak withdrawals limits. The quasi-federal agency for the Ohio River basin (the Ohio River Valley Water Sanitation Commission or ORSANCO) is exploring opportunities to inform water withdrawals related to energy development by working with state agencies and by exploring charter amendments that would expand their regulatory authority.
- **State regulatory agencies** responsible for managing water in the Marcellus play are outlined in Table 6 below. The requirements for state approval vary from providing a report of the withdrawal quantity and timing (West Virginia) to permitting systems that require agency review, approval, and, if necessary, conditions on the permit to assure withdrawals protect ecosystem functions (e.g., Susquehanna River Basin). In those states that require a permit, regulations require that withdrawal applicants generally submit management plans that specify volume, location, safe yield and anticipated impacts of the proposed withdrawal. Delegated agencies then review applications and assign peak daily withdrawals, pass-by flow requirements, and any consumptive use mitigation requirements.

REGULATORY GAPS

Participants created Table 6 to compare state and regional water withdrawal management regulations, including whether the use is regulated and the underlying goals for the regulations (i.e., reporting, drought management, ecosystem protection).

42 Susquehanna River Basin Commission. 2012. Low flow protection related to withdrawal approvals.

Table 6.

An overview of the regulatory framework for allocating water for use in shale gas development as discussed in the Water Sourcing and Consumptive Use working group.

Applicable Agency		Regulates Water Use for Shale Gas Development	Scope of Regulatory Program		
			Reporting only	Permitting-drought protection	Permitting-ecosystem protection
FEDERAL GOVERNMENT	Not applicable (NA)	No	N/A	N/A	N/A
MARYLAND	• Maryland Department of Natural Resources	No	N/A	N/A	N/A
NEW YORK	• Delaware River Basin Commission • New York Department of Environmental Conservation	No	N/A	N/A	N/A
OHIO	• Ohio Environmental Protection Agency	Yes	No	Yes	No
PENNSYLVANIA	• Susquehanna River Basin Commission • Delaware River Basin Commission • Pennsylvania Department of Environmental Protection	Yes *(except Delaware Basin)*	No	Yes	Yes
WEST VIRGINIA	• West Virginia Department of Environmental Protection	Yes	Yes	No	No

RECOMMENDED SHORT-TERM SOLUTIONS

The group developed the following recommendations as top short-term priorities for addressing the principal threats of shale development to surface and ground water hydrology and related resources. These recommended short-term measures were drafted based on their expected combination of effectiveness and feasibility of implementation in one to two years.

- **Lifecycle tracking.** Participants recommended investment in technologies and practices for tracking water use in hydraulic fracturing from withdrawal to treatment and/or disposal. Specifically, a system to track the source and quantity of water withdrawal, the location of use in hydraulic fracturing, the location and quantity of water injected into a production well, the quantity and timing of flowback and produced water, the location and quantity of the fate of flowback and produced water, including re-use, recycling, treatment before discharge to surface waters, and/or deep well injection.
- **Structure pilot programs for non-freshwater sources.** Develop technologies and incentives to maximize use of non-freshwater resources, particularly re-use. Re-use is currently a common practice in Pennsylvania, in part because the cost of disposal is high and in part because development activity is high, when compared with other states in the Appalachian region.[43] Non-freshwater resources also include treated municipal waste, industrial water, and treated abandoned-mine drainage. Participants discussed the inherent connection between development activity and cost-effectiveness of treatment for re-use. One barrier to implementation is developing safe, centrally located storage facilities for re-use water. Participants noted that transport distances more than 5 to 10 miles may be cost-prohibitive, and increase risk of surface spills. It was suggested that the community look toward arid regions for research and development of non-freshwater and non-water technologies.
- **Guide withdrawal siting and allocation through an ecological vulnerability index.** Develop a regional scale, science-based vulnerability index to guide siting decisions for water withdrawals. The vulnerability index would help to identify sites with high risk from alteration by withdrawal or access. Characteristics would include factors like size of stream, quality of existing habitat, ecological value, and stressors (e.g., invasive species, impervious cover).

43 Since the 2015 workshop, shale development rates have decreased significantly, and, therefore, water re-use rates have curtailed.

3.4.2 CONTAMINATION PATHWAYS AND RISKS TO SURFACE AND GROUND WATER

SECTOR REPRESENTATION

Anchors: Academic institutions

Facilitators: Academic institution, non-governmental organization

Participants: Academic institutions (4), energy industry (5), government (7), non-governmental organizations (4)

CHALLENGE

How do we define and manage for the risk of *surface and ground water contamination* from shale gas development?

HIGH-LEVEL CONCLUSIONS

- The development of shale gas in the Marcellus play has resulted in documented ground and surface water contamination pathways.
- Water and solid waste associated with production can include contaminants of concern like barium, chloride (high salinity), radium, methane, and hydraulic fluid additives.
- This challenge ranges from acute localized impacts to regional persistent risks. Geology and time scales matter.
- Current wastewater treatment options pose risk of contamination to surface and/or ground water. There is a lack of information to determine the viability of any given treatment option in managing contamination risk or to assess and compare the economic, social, and environmental costs or risks among treatment options.
- Currently, there is no entity or group of entities responsible for managing these risks or for taking these factors into consideration *at the scale of development.*

STATE OF THE CHALLENGE

OVERVIEW OF THE CHALLENGE[44]

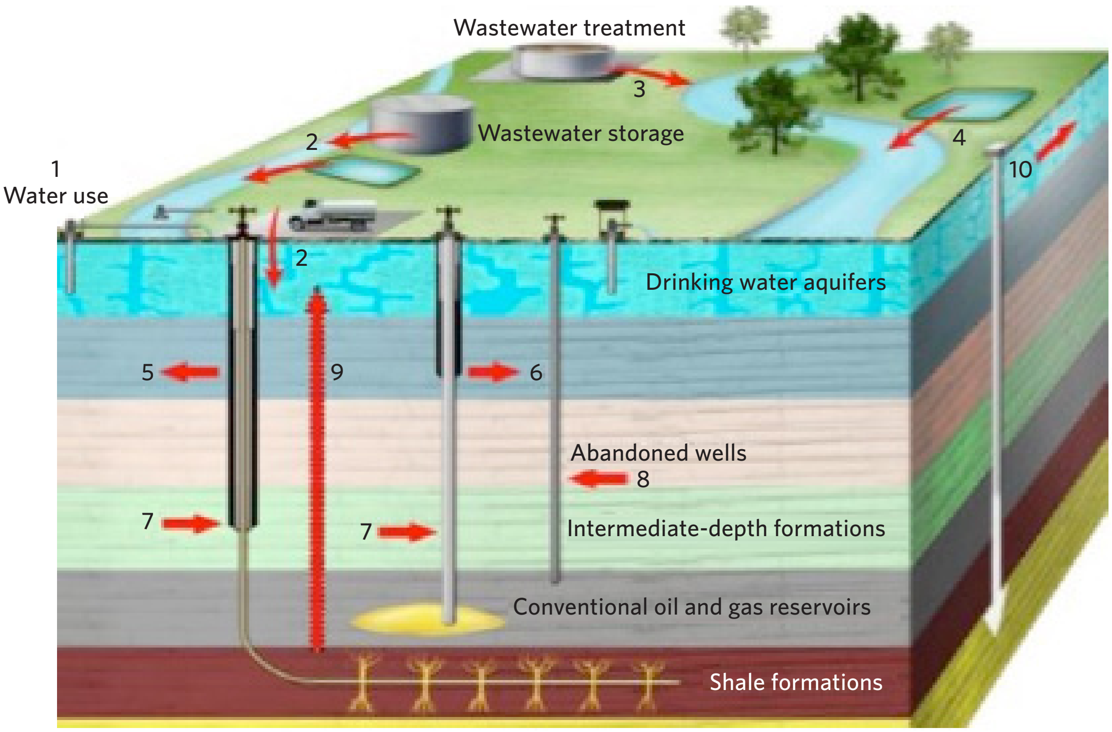
Shale gas development includes the well-stimulation technique known as hydraulic fracturing, which uses pressurized liquid to fracture rock formations and release gas. Before injection, water is mixed with a combination of hydraulic fracturing fluids (HFFs) including surfactants (e.g., methanol), gelling agents (e.g., benzene, toluene) and proppant (e.g., silica sand).

During the hydraulic fracturing process, the water that returns to the surface is referred to as **flowback**. Using current technology, 5 to 50% of the fluids injected into a well for fracturing returns to the surface after fracturing is complete. In the Marcellus Shale play, it is estimated that this percentage is near 10%. Therefore, an estimated 0.5 million gallons of flowback per well requires safe treatment for re-use or disposal. It is estimated that development of the entire Marcellus Shale play will create an estimated 35 billion gallons of waste fluids — enough to put Washington D.C. under an estimated 2 feet of water.[45]

In addition to HFFs returning to the surface, the fracturing process can mobilize naturally occurring radioactive

44 In this working group discussion, participants defined the “Overview of the Challenge” as a component of the “State of the Challenge”.

45 Maloney, K. O. and Yoxtheimer, D.A. 2012. Production and disposal of waste materials from gas and oil extraction from the Marcellus Shale Play in Pennsylvania. *Environmental Practice* 14(4): 278-287.



Ground and surface water risk pathways associated with unconventional shale gas development and hydraulic fracturing.
Vengosh et al. 2014, used with permission.

material (NORM), dissolved metals, and gases. **Produced fluids** refer to the brines generated along with the oil and gas over the life of a well. The rate of brine production is estimated to be 5 to 10 billion barrels per million cubic feet (Mmcf) of gas produced in the Marcellus Shale play. It is estimated that 30 to 50% of the hydraulic fracturing fluids injected into the well will return over the life of the well — and therefore 50 to 70% of the fluids will remain subsurface.

Both ground and surface water are at risk of degradation from activities associated with shale gas development. More than 300 chemicals have been identified in HFFs, flowback, and produced water.[46]

At the **surface, contamination pathways** include accidental spills, overflow of storage ponds in response to storm events, spills during transport and treatment, and disposal of wastewater to surface waters. Surface contaminants of concern include salts (chloride, iodide, bromide) that can be up to five times the salinity of seawater. Surface contaminants can also include HFFs and NORM (radium). Challenges to surface water quality from sedimentation as a result of road, pad, and pipeline construction were discussed previously in Section 3.2.2.

Subsurface contamination pathways include migration of gas and drilling fluids and mobilization of local aquifer contaminants. Subsurface pathways may also include migration of contaminants from surface waste storage — like surface storage pits — or landfills containing drilling cuttings. Subsurface contaminants include salts (chloride and barium), HFFs, and NORM (radium). Different from surface risks, subsurface contaminants also include stray gas, specifically methane.

46 U.S. Environmental Protection Agency. 2011. Draft plan to study the potential impacts of hydraulic fracturing on drinking water resources. Office of Research and Development. Washington, D.C. 140 pp.

In summary, surface and ground water contamination risks occur around the activities of transportation, storage, fracturing, and **waste treatment and disposal**. Workshop facilitators guided a more specific discussion around waste treatment and disposal. Environmentally-sound and cost-effective management of waste continues to be a challenge without clear solutions. Practices and technologies that are currently used for treatment and disposal include direct re-use (blending), onsite treatment with re-use, disposal in Underground Injection Control (UIC) wells, or desalination treatment. In Pennsylvania, 85% of the flowback and produced fluids are currently being re-used.[47] For the remaining waste, 11% is being injected into UIC wells and an estimated 4% is being sent for treatment and surface disposal at wastewater treatment plants.

STATE OF THE SCIENCE

The body of literature around surface and ground water contamination pathways and risks is increasing exponentially, both in the Marcellus play and in plays around the U.S. The following are mechanisms that participants discussed as confirmed by research, although viewpoints differed as to the extent and persistence of risk.

- **Methane migration.** Methane migration has been documented in the Marcellus play — both through the subsurface and to surface waters.[48,49,50,51] While it has been documented as being associated with a small percentage of gas wells, it has impacted homeowners reliant on shallow drinking water wells. In a regional study, methane and ethane were found to be orders of magnitude higher in private drinking water wells within 1 kilometer from gas wells.[49] While there was disagreement among the participants on the methods used to support the specifics of some of the referenced study findings, there was agreement that methane migration has occurred in response to the development of some shale gas wells.
- **Unplanned subsurface fluid migration and accidental surface release of waste fluids.** HFF have been documented migrating from the well and the horizontal fracture into the subsurface, particularly in the case of downhole communication (interaction with orphaned wells). Waste fluids have high concentrations of salinity and radioactivity. NORM is mobilized and brought to the surface in flowback, and produced waters are concentrated as Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) prior to disposal. Increased salinity and radioactivity of surface water and local sediments has been documented in response to disposal or spills of waste fluids.
- **Tracing the contamination path.** Emerging methods and technologies have shown potential for tracking contamination to the source. For example, a recent study demonstrated the potential for using noble gas and hydrocarbon tracers to distinguish natural sources of methane from anthropogenic sources and trace migration mechanisms.[52]

RESEARCH GAPS

Participants noted several gaps in existing research. These knowledge gaps included:

- **Availability of baseline data and a long-term regional ground water quality monitoring program.**

47 The proportion of water being re-used is dependent on the rate of well drilling, with a higher proportion of re-use occurring when rates of well drilling are high. Re-use is not economically efficient when rates of well drilling are low.

48 Osborn, S.G., Vengosh, A., Warner, N. and Jackson, R. 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. PNAS 108(20): 8172-8176

49 Jackson, R.B., Vengosh, A., Darrah, T.H., Warner, N., Down, A., Poreda, R., Osborn, S., Zhao, K. and Karr, J. Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. *Proceedings of the National Academy of Sciences*. 110(28): 11250-11255.

50 Mauter, M., Alvarez, P.J., Burton, A., Cafaro, D., Chen, W., Gregory, K., Jiang, G., Li, Q., PIttock, J., Reible, D. and Schnoor, J. 2013. Regional variation in water-related impacts of shale-gas development and implications for emerging international plays. *Environmental Science & Technology*. 48: 8298-8306.

51 Vengosh, A., Jackson, R.B., Warner, N., Darrah, T.H. and Kondash, A. 2014. A critical review of the risk to water resources from unconventional shale gas development and hydraulic fracturing in the United States. *Environmental Science & Technology*. 48: 8334-8348.

52 Darrah, T.H., Vengosh, A., Jackson, R.B., Warner, N.R., and Poreda, R. 2014. Noble gases identify the mechanisms of fugitive gas contamination in drinking-water wells overlying the Marcellus and Barnett Shales. *PNAS* 111(39): 14076-14081.

- **Clearer determination of mechanisms and probability of gas migration, TENORM exposure, and HFF fingerprints.** Isolating sources (specific well activities) and mechanisms (surface or ground water-related, from casing failure or well construction).
- **Avoiding induced seismicity from wastewater disposal and hydraulic fracturing.** Seismicity has been correlated with some hydraulic fracturing injection operations and from wastewater injections. The majority of wastewater disposal wells used in the region are currently sited in Ohio.
- **Analytical methods to identify specific compounds and cumulative impacts of chemicals.** As some compounds found in flowback and produced water are currently unregulated, standard and/or feasible methods for detection are needed.

STATE OF THE TECHNOLOGY

Participants noted that several technologies have the potential to reduce the risks associated with surface and subsurface contamination pathways. These include:

- **Monitoring well-casing integrity.** Technologies to video-scope well-casings have improved, allowing operators to monitor well-casing integrity at various depths and over time.
- **Use of closed storage with secondary containment.** Closed storage tanks, as opposed to storage pits (closed or open), have been demonstrated to minimize risk of surface spills and migration to ground water resources. One consideration with the use of closed tanks is design to avoid lightning strikes.
- **Onsite waste treatment technologies.** Current technologies support direct re-use (blending) and onsite treatment with re-use. Current re-use technologies include filter socks, chemical precipitation, electrocoagulation, oxidation, and evaporation.
- **Treatment for surface disposal.** Treatment for surface disposal by traditional publicly owned treatment works (POTW's) has resulted in surface water contamination, as wastewater treatment plants are not typically designed to treat the array of constituents associated with flowback and produced water. There are currently two centralized wastewater treatment plants in Pennsylvania designed specifically to handle constituents associated with flowback and produced water. These treatment plants have reduced target contaminants, but an unintended consequence of treatment has been the byproducts of methanol and ammonia. Currently, there are not water quality standards for the majority of target contaminants.

TECHNOLOGY GAPS

Participants discussed the gaps in the existing suite of tools for site planning and operations, and how these gaps might best be addressed:

- **Improvements in casing cement durability.**
- **Cost-effective field re-use treatment technologies.**
- **Low-cost energy technologies for treatment of concentrated brines.**
- **Reducing waste volumes of TENORM.**
- **Safe disposal of sludge/drill cuttings (considering radiation).**
- **Transport of brines that minimizes spill risks.**
- **Rapid fingerprinting of background versus anthropogenic sources.**
- **Long-term wastewater storage.**
- **Long-term monitoring of cumulative impacts.**

STATE OF THE PRACTICE

Participants noted that many practices have the potential to reduce the risks associated with surface and subsurface contamination pathways. These include:

- **Minimizing waste production through re-use.** Currently in Pennsylvania, there is an 85% re-use rate of flowback and produced waters, with the majority of that re-use occurring directly in the field. For most other shale plays, re-use is closer to 50%. The high rates in Pennsylvania are attributed, in part, to the higher expense of disposal in the state.

Storage tanks for produced water. *"Marcellus Shale Storage Tanks" by Doug Duncan, USGS*

- **Disposal wells.** States, like Ohio, have accepted flowback and produced water for injection disposal. Over the past year, this practice has come into question as it has been linked to increased frequency and magnitude of earthquakes. In response, regions within Ohio have begun to limit waste disposal.
- **Onsite waste storage.** While flowback and produced fluid storage is moving to closed system practices, open-air pits are still permitted in some states.[53]

Participants also commented that, considering the relative lack of knowledge on trade-offs between treatment and disposal methods, there may be additional practices associated with other industries/activities that we could learn from or apply to shale practices.

GAPS IN PRACTICE AND IMPLEMENTATION

- **Require flowback and produced fluid re-use to the extent practical.**
- **Storage and transport protocols to minimize and track spill risk.**
- **Disclosure.** Ease of access to publicly available data on waste management methods, volume, and quality.

STATE OF THE REGULATORY FRAMEWORK

As the regulatory framework related to contamination pathways, risk, and wastewater treatment and disposal are diffuse, highly evolving, and vary significantly by state, most of the group's focus was on the state of the science, technology, and practice, with little discussion about specific policies. What was discussed were state, regional, and federal policy components aimed to manage risk.

53 Since the workshop, the Pennsylvania Department of Environmental Protection has issued relevant regulations.

State and regional regulations. Regulations that aim to manage risks of ground and surface water contamination vary by state and regions, including:

- Drilling, casing, and cementing regulations
- Set-back limits and presumed liability
- Permitted waste disposal practices (water and TENORM)
- Local versus state control of zoning regulations
- Statewide moratoriums and local zoning restrictions
- In Pennsylvania, regulations have changed significantly since 2007, including requirements to:
  - Increase the number and depth of video-scoping wells
  - Increase set-back limits and presumed liability
  - Reduce open pond storage
  - Reduce volumes of wastewater sent to disposal facilities
  - Reduced the total number of well pads (co-location)

Federal regulations.

- **Clean Water Act (CWA).** Governs surface disposal and quality of effluent to meet beneficial uses of a receiving stream. In Pennsylvania, treatment of flowback and produced waters through wastewater treatment plants was ceased due to surface water contamination. State law requires that any treatment with surface discharge treat to less than 500 mg/L total dissolved solids (TDS). Produced fluids can have TDS concentrations of 300,000 mg/L. Federal and state laws do not govern thresholds for the majority of the constituents found in waste. The CWA also governs storm water runoff. The Energy Policy Act of 2005 exempts runoff from gas and oil construction activities, if the runoff is composed entirely of stormwater.
- **Safe Drinking Water Act (SDWA).** Flowback and produced fluid disposal wells are regulated under the SDWA as Class II wells, by the Environmental Protection Agency (EPA), but many states have primacy of the program. In the Marcellus region, of the states that presently have hydraulic fracturing operations, Pennsylvania is the only state that does not maintain primacy; therefore, operators planning to store waste in an injection well must receive a permit from the EPA. The Energy Policy Act of 2005 amends the SDWA to exclude from regulation, "the underground injection of fluids or propping agents (other than diesel fuels) pursuant to hydraulic fracturing operations related to oil, gas, or geothermal production activities."

REGULATORY GAPS

In addition to the exclusions described above, participants discussed the limitations and lack of existing policy in some areas.

- **Out of date policies.** Approaches vary by state and gubernatorial control. Regional monitoring programs are inconsistent. There is a significant lack of data from West Virginia and Ohio.
- **Appropriate geologic settings and capacity for siting disposal wells.** Siting of disposal wells is not currently managed on a regional basis, guided by hydrogeologic setting but, rather, is done opportunistically between an injection well operator and a development company.
- **Incentives to minimize waste production.** Re-use of flowback and produced waters is encouraged but not required. In part, this may be due to the risks associated with surface storage required for onsite treatment. Better practices for onsite storage would be a necessary foundation.
- **Drill cuttings.** Disposal of drill cuttings is banned in some places and permitted under certain conditions in others.

RECOMMENDED SHORT-TERM SOLUTIONS

The group developed the following recommendations as top short-term priorities for addressing the principal threats of shale development to surface and ground water quality and related resources. These recommended short-term measures were drafted based on their expected combination of effectiveness and feasibility of implementation in one to two years.

Wastewater treatment and disposal

- **Decision support for comprehensive water and wastewater management methods, including storage, transport and disposal.** Invest in a technology and practice of tracking water use in hydraulic fracturing from withdrawal to treatment and/or disposal. Specifically, a system to track the source and quantity of water withdrawal, the location of use in hydraulic fracturing, the location, quality, and quantity of water injected into a production well, the quantity and timing of flowback and produced water, the location, quality, and quantity of the fate of flowback and produced water, including re-use, recycling, treatment to surface waters, and/or deep well injection.
- **Regional assessment of cumulative need for and availability of treatment options (Treatment for discharge, UIC).** That portion of flowback and produced fluids that cannot be re-used or recycled is either treated by a waste management facility for surface water release ("treatment for discharge") or permanently injected in a deep water well (Underground Injection Control or UIC). It was agreed by the participating stakeholder groups that there is a lack of information to compare the economic, social, and environmental costs or risks of treatment options — or to compare treatment options on timescales equivalent to the duration of the contamination risk. Given the uncertainty around the effectiveness and feasibility of treatment methods using contemporary practices and technologies, participants prioritized a two-part study. The purpose of the study would be to (1) assess the regional need and availability of treatment options (both treatment for discharge and UIC) and (2) compare the effectiveness and feasibility of treatment methods.
- **Reduce demand for disposal capacity and treatment.** In addition to posing one of the most significant conservation challenges, treatment and disposal is also one of the most expensive aspects of development for the industry. Policies and voluntary standards that maximize re-use and recycling to the extent practical would proportionately reduce the volume of produced or flowback water necessary for treatment or long-term disposal. In the short-term, demand reduction would also benefit from research in rapid, low-cost technologies that can treat and reduce the total volume of waste.

Ground water pathways

- **Implement policies that protect public ground water supplies.** In Pennsylvania, over 3 million people rely on private drinking well water supplies, but there are no regulations that govern private drinking water well construction. Since 2004, about 8,000 gas wells have been drilled, and the state has received thousands of complaints of contaminated drinking well water over that timeframe. In Pennsylvania, private drinking water well owners are not currently required to test their wells for contaminants other than fecal coliform, pH, and total dissolved solids. Given the lack of baseline water testing data and the presence of some naturally occurring contaminants in the Appalachian region, water protection policies must be a priority. Currently, there are communities that have contaminated wells and no long-term substitute water supply. Some participants expressed that the incidents of contamination as the result of a well construction failure or leaking impoundment should be zero.

- **Implement standard casing design, well construction, and monitoring standards.** Factors including well construction, casing design, and durability of casing cements have been linked to some incidences of methane migration into ground water. While practices and technologies have reduced this risk, the risk persists. The effectiveness of standards should be monitored and documented using systematic monitoring protocols including baseline water testing, pressure monitoring, cement bonding, and pilot core holes.
- **Mandated geotechnical assessment prior to well siting.** One of the greatest risk factors for ground water contamination is the local geology. Formations with fractures are conducive to migration. Throughout the Marcellus and Utica plays, there has also been a significant amount of historic oil, gas, and coal development. Many of the abandoned wells and exposed seams associated with this development are unmapped and significantly increase the risk of providing a pathway for shallow ground water contamination (downhole communication). Spatial ground water mapping and more robust analytical protocols for test wells could reduce this risk. In addition, significant investments in the identification of abandoned wells through airborne and field surveys and protocols for assessing the local risk of abandoned wells could reduce the risk of downhole communication.
- **Develop a long-term regional ground water monitoring framework.** Currently ground water monitoring is generally focused on private wells with one pre-drill sample and one post-drill sample. Monitoring density is too granular to be useful and, depending on the circumstance, the data from those tests may not be publicly available or may be in analog form. There is a lack of a regional and independent data source (dedicated monitoring wells) to establish baseline conditions and track whether there are trends of localized or dispersed contamination associated with drilling and production activities. Given the remote nature of development, a monitoring framework will likely require a cooperative of organizations that can develop a regional sampling and analysis protocol, install and maintain monitoring wells, collect data, and analyze and respond to trends. This framework would also sustain research into HFF signatures and monitoring techniques.
- **Demarcation of saltwater/freshwater formations and consistent definitions by state.**

Surface water pathways

- **Siting and design standards for onsite storage and well pads in order to prevent migration.** The most effective reduction of spill risk from leaks of temporary onsite storage has been demonstrated by using closed storage technologies with secondary containment. These technologies should address risk of lightning strike and include leak detection methods. Storage ponds pose a higher risk of contamination. Where they are used, clay liners have proven to be an ineffective containment technology given the brine concentrations of produced and flowback waters. Storage should be covered and sited to maintain a buffer between the facility and riparian areas, floodplains, and wetlands, to minimize risk of surface and ground water transport in case of failure.
- **Implement a wastewater transport tracking system.** Tracking wastewater transport, including monitoring transport routes, speeds, and stops, could help increase accountability of surface contamination associated with incidents and illegal dumping. This could be a first step toward lifecycle water resource management. Both incidents and illegal dumping have resulted in surface water contamination events. This is recognized by all stakeholders as an unacceptable practice.
- **Invest in centralized industry-specific waste management methods and technologies.** Contaminants present in flowback, produced water, and drill cuttings include radioactive materials, high saline concentrations (chloride, iodide, bromide), and hydraulic stimulation fluid additives.

- Traditional wastewater treatment plants are not designed to remediate these contaminants for discharge into surface waters. The group prioritized investments in technologies and methods to develop centralized wastewater treatment plants specific for handling flowback and produced water. This investment would include the development of standard detection methodologies to profile waste constituents and similarly, methods to test and monitor effluent. Some constituents may not have current regulations; therefore, a precautionary principle should be applied to protect aquatic and human health standards.
- Similar to municipal wastewater treatment plants, landfills are not typically designed to store solid waste and drill cuttings that include these contaminants. As with wastewater management and treatment, investments in centralized industry-specific waste management methods and practices could reduce risks associated with private and municipal landfill storage. Waste should be profiled before storage and pathways for surface and ground water monitored for contaminants.

- **Address sedimentation from construction of infrastructure** *(see Erosion and Sedimentation discussion in Section 3.2.2)*.

3.4.3 STRATEGIES TO UNDERSTAND AND ADDRESS CUMULATIVE IMPACTS TO WATER RESOURCES

During the workshop's last session, the working group for the water track discussed prioritized strategies to understand and address the cumulative impacts to water resources. Specific to water management, the following three actions were prioritized to begin addressing these concerns.

- **Adoption of lifecycle methods and practices to trace water use and disposal throughout the region.** As a short-term action that is necessary for tracking long-term and cumulative impacts, participants recommended investment in a technology and practice of tracking water use in hydraulic fracturing from withdrawal to treatment and/or disposal. Specifically, a system to track the source and quantity of water withdrawal, the location of use in hydraulic fracturing, the location and quantity of water injected into a production well, the quantity and timing of flowback and produced water, the location and quantity of the fate of flowback and produced water, including re-use, recycling, treatment to surface waters, and/or deep well injection.
- **Implementation and sustainable funding of a regional water quality monitoring and adaptive management cooperative.** As discussed, shale development has the potential to influence surface and subsurface conditions on geologic time scales. Much of the current funding related to monitoring for impact is connected to the development itself. (For example, the Susquehanna River Basin Commission uses funding from water withdrawal permits, and the Pennsylvania Department of Conservation and Natural Resources is funded in part through the Oil & Gas Lease Fund.) Sustained funding sources are necessary to track long-term trajectories.
- **Safeguarding for risk — insurance, bonding mechanisms adequate to ensure remediation.** As we've learned from other extraction industries, companies may not endure for the length of time that risks of contamination persist. This includes companies responsible for developing gas plays and those that are storing waste products over the long-term.

The water working group also had a robust conversation on the legacy we would like to leave for future generations and how to realize that legacy. This was adapted as a framework for all topics and included as the concluding section to the report (Section 4: *Our Legacy*).

Our Legacy: Avoiding and Mitigating Cumulative Impacts

Section 4

Our Legacy: Avoiding and Mitigating Cumulative Impacts

WHAT IS THE LEGACY WE WOULD LIKE TO LEAVE FOR FUTURE GENERATIONS?

The cumulative risks and impacts of shale gas development in the Appalachian region, in addition to all other forms of development, represent an important area of consideration, but one characterized by complexity and uncertainty. One useful and compelling way to frame the issue is: what do we want our legacy to be after the Marcellus, Utica, and other shales are played out? It is a straightforward question to ask, but it is a difficult one to answer. And, even with an answer in hand, it leads to another, equally complex question: What should we do to realize that legacy? Agreeing on a legacy — an endpoint for Appalachian shale development — has many complicating factors.

WHAT IS OUR OPPORTUNITY?

- **Learn from the past.** Development of the Marcellus and Utica shale formations is not unlike other industrial and natural resource extraction in our region's recent past. What did we learn? How do we bring that to bear on today's resource development decisions?
- **Bring solutions from the present.** Our science, technology, and intelligence are better today than they were in the coal and timber industries decades ago. In addition, our motivations have moved from being solely driven by profit margins to also caring deeply about the long-term well-being of ecosystems, people, and communities.

HOW DO WE REALIZE THAT LEGACY AND ACCOUNT FOR INTERGENERATIONAL NEEDS IN OUR DECISION MAKING?

The cumulative impacts of incremental changes are beyond the perception of geopolitical units like townships, counties, and even states. Over time, some indicators of change are sensed, but integrating many local impacts to recognize larger trends is difficult. These challenges are exacerbated by the lack of institutions with missions, authority, and capacity to synthesize information, assess patterns at large geographic and temporal scales, and make decisions accordingly.

We can take collective actions to define and work towards realizing a legacy that we want to leave for future generations. Drawn from workshop discussions (largely from the water resources session on the workshop's last day), suggested guidance for those actions is presented in the call-out box on the next page and described further below.

1. **Define the geographic and temporal scales.** While we understand that the reach of Appalachian shale development is regional, we do not have a common definition of the "region." One place to start would be the "Play-Shed." It is useful to think about a spatial scale that matches the extent of the Marcellus and Utica shale "plays," analogous to a watershed or an air shed. In defining our time horizon, it may be synced with the expected end of the shale play, or the expected duration of impacts after development of the shale play. For planning purposes, this will have to be portioned into discrete and shorter phases of decades to be useful.

Guidance for Collective Thinking and Decision Making about Our Legacy

1. Define the geographic and temporal scales of impact.
2. Create a common vision for the "end state."
3. Develop dimensions of impact: indicators, trajectory, and thresholds.
4. Establish a neutral, accountable, and durable coordinating body at the regional scale.
5. Develop a science-based monitoring framework and sustained commitment to monitor indicators.
6. Guide the trajectory to realize the desirable endpoint.
7. Safeguard for risk.

2. **Create a common vision for the "end state."** While recognizing that the term "cumulative impacts" has various interpretations, workshop participants agreed on the importance of creating a common understanding and vision for the "end of life" of shale energy demands and development in the Appalachians. Futures analysis at a regional scale could include pulling together stakeholders to explore their 50-year community and regional visions — What do you want your town to be then? What are the features you must hold onto to achieve that? Phases of discussion could include:
   a. Post-impact community-level visioning
   b. Adopting a range of scenarios at the community-level
   c. Regional visioning
   d. Making the connection between community and regional visions
3. **Develop dimensions of impact: key indicators, trajectory, and thresholds.** In order to marry a vision for the local and regional end state with the appropriate trajectory of development, we need to define the dimensions of impact in tangible terms. To date, we know these include ecosystems, habitat, biodiversity, endangered species, surface water, ground water, local air quality, climate, public health, and community viability. Challenges exist in detecting long-term trends in the face of short-term fluctuations and attributing impacts to specific sources. The metrics needed for monitoring change include both magnitude and rate. For example, if we see surface water salinity increase by more than X mg/L over Y time, or we see average core forest size reduced by more than Z, these thresholds can be indicators that we are off of a desirable trajectory.
4. **Establish a neutral, accountable, and durable coordinating body at the regional scale.** As direct or indirect consumers of shale gas as a source of energy and other products, we are collectively responsible for its inter-generational footprint. Yet, there is no single body that is accountable for the individual or collective decisions that will influence the cumulative footprint of shale development across space and time. Government agencies at federal, state, and local levels are responsible for monitoring and reducing some dimensions of impact, but their fragmented authorities do not cover the full extent of the challenges. There is a need for a coordinating body that matches the spatial and temporal scales of shale development, provides long-term continuity, and is responsible for decisions that apportion responsibility and risk along the development trajectory.
5. **Develop a science-based adaptive management framework and sustained commitment to monitor indicators.** Robust information is the life blood of good decision making, but many unknowns and uncertainties remain regarding the impacts of shale development on water, air, land, plants, animals, and humans and the most effective methods for addressing those impacts. Ongoing, systematic research is vital for growing our body of knowledge and informing policy and practice, but we lack adequate methodologies to capture cumulative impacts and to make collective decisions in the context of uncertainty and potentially conflicting research outcomes.

Adaptive management is an approach in which impacts are assessed frequently and midcourse corrective actions can be taken as more information becomes available. Although we have little actual experience with it, adaptive management is the only approach that makes sense, in light of the long time horizon and considerable uncertainty associated with shale development impacts. Such an approach will rely on sustained commitment to monitor indicators both during and beyond the life of the shale play. Yet, much of the current funding related to monitoring for impact is connected to the development activity itself. For example, the Susquehanna River Basin Commission uses funding from water withdrawal permits, and the Pennsylvania Department of Conservation and Natural Resources is funded in part through the Oil & Gas Lease Fund. We need to ensure that we have sustained funding to support robust monitoring programs for as long as the science demands it.

6. **Guide the trajectory to realize the desirable endpoint.** Assuming that the complex process of agreeing on a common vision and its measures is successfully negotiated, how would we use this information? There is an infinite number of possible future scenarios; the challenge is to detect which scenario is unfolding at a particular moment in time and to take steps, when necessary, to move from an undesirable pathway to one that is in line with our common vision. Knowing which scenario we are in and choosing the right corrective actions are unavoidably characterized by great uncertainty. Scenario development, large-scale modeling, and risk analyses are all methods of quantifying and understanding that uncertainty. Our task is to take the data we have and make a determination that has an acceptably high probability of being correct. We must then empower a trusted institution, existing or to-be-established, to make decisions on corrective actions that have a high probability of being productive steps to take even if the future unfolds differently than our predictions.

7. **Safeguard for risk.** Companies developing gas plays and storing waste products may not last as long as the risks of contamination or other adverse impacts remain. Ensuring that Appalachian states have appropriate and robust bonding and insurance mechanisms in place for wells and other oil/gas facilities is of utmost importance so that we do not repeat the mistakes made with other extractive industries and hazardous waste disposal. Also, insurance companies should be involved in conversations about assessing and protecting against long-term risks.

"Upper Fairfield Township gas well 2a" by Ruhrfisch, licensed under CC BY-SA 4.0, cropped from original

Appendices

Section 5

Appendices

APPENDIX A: STEERING COMMITTEE

CO-CHAIRS

- **Jared Cohon, Ph.D.,** Co-Director, Wilton E. Scott Institute for Energy Innovation; University Professor of Civil and Environmental Engineering and Engineering and Public Policy; President Emeritus, Carnegie Mellon University
- **Nels Johnson,** Director, North America Energy Program, The Nature Conservancy

COMMITTEE MEMBERS

- **Neil Donahue, Ph.D.,** Director, Steinbrenner Institute for Environmental Education and Research; Lord Professor of Chemistry, Departments of Chemistry, Chemical Engineering, Engineering and Public Policy, and Center for Atmospheric Particle Studies, Carnegie Mellon University
- **Tamara Gagnolet,** Energy Program Manager, The Nature Conservancy
- **Michelle McGregor,** Senior Oil & Gas Development Advisor, The Nature Conservancy
- **Thomas Minney,** State Director, West Virginia; Acting Director, Central Appalachians Program; The Nature Conservancy
- **Emily Posthumus,** Energy Development Research Specialist, The Nature Conservancy
- **Richard Stafford,** Executive Director, Metro21; Distinguished Service Professor, H. John Heinz III College, School of Public Policy and Management, Carnegie Mellon University
- **Deborah Stine, Ph.D.,** Associate Director for Policy Outreach, Wilton E. Scott Institute for Energy Innovation; Professor of the Practice, Engineering and Public Policy, Carnegie Mellon University

APPENDIX B: LIST OF PARTICIPATING ORGANIZATIONS

ACADEMIC INSTITUTIONS

- Academy of Natural Sciences of Drexel University
- Carnegie Mellon University
- Dartmouth College
- Duquesne University
- Pennsylvania State University
- Texas A&M University
- University of Arkansas
- University of Central Arkansas
- University of Pittsburgh
- Vanderbilt University
- Washington and Jefferson College
- West Virginia University
- Wilkes University
- Yale University

ENERGY INDUSTRY

- Air Compliance Consultants
- ALL Consulting
- Anadarko Petroleum Corp.
- Chesapeake Energy
- Chevron
- Clareo Partners
- Consol Energy, Inc.
- Dawood Engineering
- Echelon Applied Geosciences
- Environmental Resource Management
- EQT
- Michael Baker Jr., Inc.
- Montrose Environmental Group
- Range Resources Appalachia, LLC
- RedHorse Environmental
- Shell Appalachia
- Southwestern Energy
- Talisman Energy, Inc.
- TRC Companies, Inc.
- Triana Energy, LLC
- Tug Hill Operating
- Williams
- Woodard & Curran
- WPX Energy

GOVERNMENT (FEDERAL, STATE, AND LOCAL)

- Delaware River Basin Commission
- National Energy Technology Laboratory
- Ohio Department of Natural Resources
- Pennsylvania Department of Conservation and Natural Resources
- Pennsylvania Department of Environmental Protection
- Pennsylvania Department of Transportation
- Pennsylvania Game Commission
- Susquehanna River Basin Commission
- Tioga County Conservation District
- U.S. Army Corps of Engineers
- U.S. Fish and Wildlife Service
- U.S. Forest Service
- West Virginia Department of Environmental Protection
- West Virginia Division of Natural Resources
- Westmoreland County, Pennsylvania

NON-GOVERNMENTAL ORGANIZATIONS AND FOUNDATIONS

- Audubon Pennsylvania
- Carnegie Museum of Natural History
- Center for Sustainable Shale Development
- Clean Air Council
- Colcom Foundation
- Environmental Defense Fund
- Environmental Law Institute
- Equitable Origin
- Foundation for Pennsylvania Watersheds
- FracTracker Alliance
- Group Against Smog & Pollution
- Health Effects Institute
- Hillman Family Foundations
- Marcellus Shale Coalition
- National Academy of Sciences
- Pennsylvania Environmental Council
- Pinchot Institute for Conservation
- Richard King Mellon Foundation
- The Nature Conservancy
- Water and Power Law Group
- Western Pennsylvania Conservancy

APPENDIX C: COMPLETE LIST OF WORKING GROUP RECOMMENDATIONS

Organized by landscape, habitat, air, and water tracks, this appendix presents the following:

- **Prioritized Recommended Solutions:** Working group recommendations for moderating adverse impacts to Appalachian ecosystems are listed below for each Challenge Area, prioritized based on their expected combination of effectiveness and feasibility of implementation in one to two years. These priority recommendations are described in Section 3 (*Challenge Areas and Working Group Recommendations*). Some working groups did not complete the prioritization process, and the "prioritized recommended solutions" listed here for those topics are those presented in the plenary debrief sessions during the workshop.
- **Additional Suggested Solutions:** Other solutions were suggested by participants while brainstorming and were not necessarily further discussed or evaluated by the working groups.

LANDSCAPE PLANNING TRACK

LANDSCAPE-SCALE PLANNING

Prioritized Recommended Solutions

1. **Collaborative planning**
2. **Data repository**
3. **Voluntary "leading" practices**
4. **Enhancements in expertise and capacity**

Additional Suggested Solutions

- **Transferable development rights (TDR).** Use (TDR) as an avoidance tool to define landscape mineral/surface rights. TDR is a zoning technique used to permanently protect farmland and other natural and cultural resources by redirecting development that would otherwise occur on these resource lands to areas planned to accommodate growth and development. As of 2015, under Pennsylvania law, use of TDRs must be voluntary.[54]
- **New components within the permitting process.** Participants suggested various ideas to allow for the permitting process to address landscape-scale issues.
  - **Cumulative impact analysis.** PA DEP should require cumulative impact analysis as part of the permitting process; however, some participants noted this would be difficult.
  - **Demonstrate at watershed scale.** Pennsylvania DEP and one company would demonstrate permitting at a watershed scale to see how it works, identify problems, and define the most appropriate scale of the watershed.
  - **Defined planning area.** Add a component to state the permitting process that defines the planning area or establishes a mechanism that encourages stakeholders to define their own planning areas.
  - **Incentives,** such as expedited permitting, can encourage industry to implement voluntary practices, such as partnering with and using tools created by non-regulatory, outside organizations (e.g., TNC's planning tool LEEP, CSSD certification).
- **Collaborative roadway maintenance plan.** A proactive partnership that identifies and funds roadway improvements and ongoing maintenance. This partnership could also develop and implement driver education and public service campaigns in areas of expected high traffic.
- **Conservation fund.** A conservation fund developed by an NGO, which industry would pay into, that focuses on priority area identification and communication to industry for combined mitigation plans. This could be appealing to industry if it allowed for expedited permitting.
- **Technology sharing.** The industry doesn't share enough information because of the competitive advantage needed. Industry does stringent checks on setbacks with cross checks and balances. State rules for Utica require surface setbacks from unleased acreage but need to revisit that and see if it hinders efficiency at larger scale. (No such requirements for Marcellus.) Actor there would be DEP.
- **Tool to measure trade-offs.** The tool would need to use vetted and accepted databases that are available to all decision makers.
- **Forced pooling.** This would involve mandatory leasing if the percentage of neighboring land has been leased, which could help minimize the footprint of infrastructure (e.g., ensure that land is available for efficient gathering line routing). However, participants noted that there are significant hurdles in implementing forced pooling in both Pennsylvania and West Virginia.
- **Comprehensive drilling plans.** CDPs require that an operator outlines all aspects of any development over a minimum of five years in a given geographic region

54 Pennsylvania Land Trust Association, http://conservationtools.org/guides/12-transfer-of-development-rights, accessed 9-11-15.

before getting permits and being allowed to drill. Sharing these plans would encourage collaboration between operators.

- **Reduce obstacles to developing the largest production units.** Unitization rules by state legislature and DEP can be a barrier to efficiency.
- **Regulatory protection for use of acid mine drainage (AMD).** While the Pennsylvania legislature has adopted some language that provides some liability protection for operators using AMD for completions, there is no federal regulatory protection, resulting in many operators not using AMD due to liability exposure.
- **Enhance database management and transparency.** Develop a centralized data repository — housing information across industry, NGOs, and government — to encourage trust and collaboration. Databases should be accessible to the public, to increase public trust. The scale at which this should happen was undecided.
- **Broaden current standards.** Build from the CSSD and EPA gold standard, with the goal of creating something more similar to LEED certification.
- **Improve regulatory framework.** Account for readily foreseeable future development when evaluating leases and infrastructure. Modernize legal framework (oil and gas act to obtain multi-pad planning, rights-of-way planning). Review of drilling units.
- **Public outreach and education.** Share information on trade-offs and understand cumulative effects.
- **Integrated vegetation management in rights-of-way.**

CO-LOCATION OF LINEAR INFRASTRUCTURE

Recommended Solutions

1. **Create and disseminate information**
2. **Build on existing Best Management Practices and provide incentives**
3. **Develop transportation corridors for pipelines**
4. **Education**
5. **Enlist inter-agency cooperation**
6. **Develop a "vertical collaboration" pilot for governance of co-location**
7. **Create a centralized database of key spatial data for safety and planning purposes**
8. **Cumulative impact analysis**
9. **Establish multi-well approval process for drilling sites**

Additional Suggested Solutions

- **Packaged permitting.** Have a permit structure that allows for pre-approval for drilling sites before development and then plan out sites in a more efficient way.
- **Decision-support tool for siting.**
- **Pilot program.** Run a pilot program in which state decision makers and local governments collaborate to have input in projects and development. Perhaps modify permits to allow public comments.
- **Enhance agency coordination.** All in room at once, at beginning of process. May result in economic and efficiency benefits.
- **Mitigation.** Mitigation is either poorly managed (wetlands), non-existent (upland and riparian area), or not focused and implemented through other mechanisms (streams). Although participants all agreed that there are problems, they had very different views on how best to implement mitigation. Suggestions included building from what other states

have done, having a watershed-scale means of directing mitigation actions that would have greater benefit, creating mitigation options based on ecological criteria that determine credits required and directing mitigation efforts to areas that yield the highest benefit, and developing pre-mitigation programs.

- **No-net-loss of critical habitats.** Study the merits and feasibility of establishing a framework for upland and riparian habitat mitigation. Evaluate establishing a standard for no-net-loss for critical habitats. Should this be required, an incentive, or a standard?
- **Criteria for co-location.** Develop criteria to determine when co-location is necessary. See Maine's criteria as an example.
- **Stream crossing data.** Spatially explicit information on which techniques have been used for stream crossings and how they worked relative to one another.
- **Map.** Map already modified vs. ecologically sensitive areas. This was also a recommendation of the Shale Gas Task Force.

HABITAT TRACK

NOISE AND ARTIFICIAL LIGHT

Recommended Solutions

1. **Create standardized guidelines/rules on lighting**
2. **Implement widespread noise attenuation, both natural and engineered, on well pads and compressors**
3. **Regional Best Management Practice manual**
4. **Enhance existing siting tools to include noise-producing facilities**

Additional Suggested Solutions

NOISE

- **Study operating compressors** to fill research gaps.
- **Set meaningful (non-dB) thresholds in regulation.**
- **Move more materials (e.g., water) with pipelines** to reduce traffic noise. Participants questioned whether or not the trade-offs would be beneficial.
- **Adjusting equipment to reduce noise and directing noise to less sensitive areas** (e.g., directing upwards).

ARTIFICIAL LIGHT

- **Optimum amount of operational light for drilling.**
- **Motion detectors or timers for lights.**
- **Different wavelength bulbs.**
- **Security systems that aren't light based.**

SHARED NOISE AND LIGHT

- **Checklist of available BMPs with signoff by operator.**
- **Local/regional working groups for public dialogue.**
- **Citizen science + shared data in usable formats.**
- **Implementation of training plans** to build successful culture.
- **Long-term guidelines** that are similar across land ownership/leasing situations.
- **Documenting community issues,** sharing with ecological researchers.
- **Highlight financial incentives and PR benefits for implementing BMPS.**
- **Publish case studies** on existing success stories for noise and light impact reduction.

OPERATIONAL TIMING

- **Limit vehicular traffic and post signs during breeding and dispersal periods of amphibians and reptiles,** particularly near and between wetland habitats. Recommendation focused on salamanders and wood frogs because they are known to be heavily impacted. Challenge is determining time and place to restrict/delay traffic.
- **Educate truck drivers** on seasonal periods when wildlife is more vulnerable.

EROSION, SEDIMENTATION, AND SITE RECLAMATION

Recommended Solutions

1. **Baseline and post-construction data**
2. **Comprehensive training**
3. **Technical cooperative for reclamation**
4. **Support regulatory oversight**
5. **Provide access to operator BMPs**
6. **Educate landowners**
7. **Be flexible**

Additional Suggested Solutions

- **Recognize landowner rights and have flexibility to innovate in individual circumstances in regulations** (e.g., the case of a landowner who expressed desire to use well pad as foundation for a barn), including technical assistance on contracts, leases, restoration and education to recognize problems if they arise.

- **Create a venue for regular communication between stakeholders,** to encourage voluntary solutions.
- **Develop an interactive map that highlights sensitive areas** (e.g., soil, species, slope).
- **Develop baseline data on multiple types of soil disturbance** to quantify mechanisms, timing, and quantity for erosion and sedimentation.
- **Create a web-based repository** to share positive results and lessons learned.
- **Create a comprehensive "one-stop shop" for BMPs across jurisdictions,** rather than several through different organizations and agencies.
- **Certification process for multiple levels for erosion control,** including training for the equipment operator.
- **Support funding and training for regulatory agencies** to improve oversight.
- **Engage local regulatory agencies in comprehensive in-house training** on erosion and sedimentation control.
- **Planning to reduce stream crossings.**
- **Prepare cost evaluations** to gauge resources and inform decisions.
- **Make data sets catalog available** to establish baselines and use in monitoring.
- **Conduct research to evaluate existing erosion and sedimentation controls in the field,** and in shifting precipitation patterns.
- **Devise ways to incorporate and standardize data from volunteer watershed groups.**
- **Follow specific, field-tested design guidelines for revegetating temporary or unused spaces during reclamation.**
- **Ensure that information is used in a strategic way;** i.e., a gap analysis of factors causing chronic systemic types of impacts (e.g., administrative issue, technology issue, oversight issue).
- **Increase demand for native seed and vegetation** to reduce costs and increase supplies.
- **Provide technical and educational assistance for landowners** on lease and restoration education to identify problem and what to ask for.
- **Increase inspections** — frequent inspections are correlated with higher compliance — and develop a method to deal with discrepancies.

AIR TRACK

METHANE AND CLIMATE CHANGE

Recommended Solutions

1. **Improve emissions inventory**
2. **Develop rapid screening for super-emitters**
3. **Develop measurable emissions targets**

Additional Suggested Solutions

- **Track methane emissions by improving GHGRP**
  - Site consensus information
  - More direct measurement of emissions
  - Eliminating reporting threshold to target methane
- **Credible studies of emissions** (HEI-like studies)
  - Debate: Monitoring (business) vs Inventory
  - Suggestion: Simultaneous multi-method, multi-scale
- **Market-based** (e.g., carbon tax). Start from climate goals
  - Carbon tax implementation (successful in Vancouver)
  - Suggestion: Different tax level for different objectives
- **Tax on current production for remediating abandoned wells**
  - Suggestion: severance tax
  - Many fees/fines go into general fund
- **Public information** to pressure voluntary practices (e.g., TRI, CEMS)
  - Break down by facility. DEP collects the data, and though the data is available to the public through FOI (Freedom of Information) requests, it is not easily accessible
  - Someone designs public communication (e.g., drinking water report)
- **A comprehensive program** to identify the routine emissions, and also incorporate a plan for remediation

AIR QUALITY

Recommended Solutions

1. **Adopt lowest-emitting equipment across operational sectors**
2. **Monitor emissions and near-source concentrations to identify contributions at local levels, during regular operating conditions and equipment failures, and address them appropriately**
3. **Develop and disseminate standardized best practices in environmental training replicating the high standards for safety practices and awareness**
4. **Stakeholder participation**

Additional Suggested Solutions

- **Consolidation of best practice recommendations** from industry, NGO, government, and academia. This would give more credibility to social corporate responsibility reports, which some organizations already do. An ongoing survey would also be helpful in identifying leading practices and areas to focus.
- **Required neighbor notification** for some pollution events.
- **Liability regime** that incentivizes drillers to do thorough baseline air monitoring. Right now this is a major legal gap, i.e., there is no proportional liability in place for increases in air emissions beyond a baseline. Sufficient monitoring could prove relative liability regarding any increases in air emissions over baseline.
- **Enforcement of planning zones** to reduce risk.
- **Training for monitoring and interpreting emissions data** is needed for many facets of operations, from the maintenance personnel, those tasked with day-to-day operations, as well as the environmental, health and safety monitoring teams. This training could be taken on by third-party consultants, which would give the training and associated data fantastic credibility.

WATER TRACK

WATER SOURCING AND USE

Recommended Solutions

1. **Lifecycle tracking**
2. **Structure pilot programs for non-freshwater sources**
3. **Guide withdrawal siting and allocation through an ecological vulnerability index**

CONTAMINATION PATHWAYS AND RISKS TO SURFACE AND GROUND WATER

Recommended Solutions

WASTEWATER TREATMENT AND DISPOSAL

- Decision support for comprehensive water and wastewater management methods, including storage, transport, and disposal
- Regional assessment of need for and availability of treatment options (Treatment for discharge, UIC)
- Reduce demand for disposal capacity and treatment

GROUND WATER PATHWAYS

- Implement policies that protect public ground water supplies
- Implement standard casing design, well construction, and monitoring standards
- Mandated geotechnical assessment prior to well siting
- Develop a long-term regional ground water monitoring framework
- Demarcation of saltwater/freshwater formations and consistent definitions by state

SURFACE WATER PATHWAYS

- Siting and design standards for onsite storage and well pads in order to prevent migration
- Implement a wastewater transport tracking system
- Investment in centralized industry-specific waste management methods and technologies
- Sedimentation from construction of infrastructure

Carnegie Mellon University

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The Nature Conservancy
Protecting nature. Preserving life.

The Nature Conservancy and Carnegie Mellon University. 2016. Advancing the Next Generation of Environmental Practices for Shale Development: Workshop Deliberations and Recommendations. May 27-29, 2015. Pittsburgh, PA.