Exploring the Environmental Effects of Shale Gas Development in the Chesapeake Bay Watershed

STAC Workshop Report
April 11-12, 2012
State College, Pennsylvania

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Steering Committee:
Kurt Gottschalk, USDA Forest Service
Charles Abdalla, Pennsylvania State University
Brian Benham, Virginia Tech
Randy Chambers, College of William and Mary
Natalie Gardner, Chesapeake Research Consortium
Robert Howarth, Cornell University
Matthew Johnston, Chesapeake Research Consortium
Kelly Maloney, U.S. Geological Survey
Denice Wardrop, Pennsylvania State University

About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay Watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the Watershed. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

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STAC Administrative Support Provided by:
Chesapeake Research Consortium, Inc.
645 Contees Wharf Road
Edgewater, MD 21037
Telephone: 410-798-1283; 301-261-4500
Fax: 410-798-0816
http://www.chesapeake.org

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Executive Summary

On April 11-12, 2012, the Chesapeake Bay Program's Scientific and Technical Advisory Committee (STAC) convened an expert workshop to investigate the environmental effects of shale gas development in the Chesapeake Bay Watershed. The purpose of this workshop was to engage scientists from across the nation in a review of the state-of-the-science regarding shale gas development effects on the Chesapeake Bay.

To date, many researchers have completed studies of various environmental effects, but a collective state-of-the-science review of these studies has not been conducted. Without fully understanding the breadth of available scientific knowledge, the scientific community cannot adequately identify and prioritize future research needs. This workshop represents the first effort within the Chesapeake Bay Watershed to 1) synthesize the collective research results available regarding shale gas development and 2) identify the potential effects associated with shale gas development (e.g., water quality and quantity, land cover change) may pose to the Chesapeake Bay Watershed. To accomplish those objectives, presentations summarizing previous research studies regarding shale gas development were provided.

Presentations from the workshop pointed out that there are some things known regarding shale gas development, but more importantly that there are many more things unknown. A number of research studies have been started but only a few have been completed and published. Workshop participants identified research needs that will help a number of government agencies, industry, and the non-profit sectors prioritize their efforts to gain more information about the environmental effects of shale gas development relative to water quality issues. Additionally, workshop participants produced a list of recommendations. Those recommendations have been divided into two groups: 1) recommendations for the CBP and its partners and 2) to more general scientific, industry, and policy-making audiences. Bullets of those recommendations follow.

Recommendations to the Chesapeake Bay Program and its partners:

- Evaluate existing monitoring data to begin to assess the impact that Marcellus Shale drilling, production, and transport activities may have on sediment loading to the Bay.

- Implement monitoring of nitrogen deposition which may be very high locally near gas rigs, compressor stations, and processing plants.

- Add infrastructure associated with Marcellus Shale gas drilling, production, and transport into Chesapeake Bay land cover/land use maps.

- Investigate if any existing CBWM land uses may be appropriate for simulating the land uses associated with these Marcellus Shale gas play activities by undertaking simulations with a range of parameter values.

- Investigate if the sediment loss from dirt and gravel roads used for gas development and production are effectively simulated in the CBWM.

- ❖ Provide a framework to centralize the data for well pads, pipelines, road ways, and rapid land use/cover changes.
- ❖ Investigate any scale-effects (cumulative effects) associated with using the CBWM to effectively simulate the sediment loading from Marcellus Shale drilling, production, and transport activities.
- ❖ Investigate how the Marcellus Shale gas play may affect land use/land cover future projections, and in turn, how those adjusted projections affect nutrient and sediment loads to the Bay.
- ❖ Implement real-time monitoring at headwaters where shale gas development is taking place or proposed.

Recommendations to Industry, Scientific, and Policy-Making Communities

- ❖ Federal agencies should take the initiative to monitor and conduct research on shale gas development, recognizing that funding and coordinating such activities will be a challenge.
- ❖ A more local focus for monitoring and research should be taken because the Partnership cannot wait for the lag time to observe a larger Bay-wide impact.
- ❖ More research should be done on metals and other pollutants that are not included in the TMDL.
- ❖ Data on pad and pipeline locations and installation and operation periods need to be centralized.
- ❖ The industry should implement set back distances for pads from water bodies, maintain riparian buffers, and implement all mandatory and voluntary BMPs in order to lessen the cumulative impact to the Chesapeake Bay.
- ❖ Does Pennsylvania (PA) regulation for oil and gas activity include BMPs? If not, the PA Department of Environmental Protection (DEP) should encourage that BMPs are used or are amended and developed as necessary.
- ❖ States should change the permitting process to be project-based rather than individual site-based and to require that permits provide potential build-out scenarios to provide better potential cumulative effects information.
- ❖ Industry personnel and state regulators signing permits must be required to have BMP implementation/certification training.

- ❖ Better state-to-state sharing of information via an *ad-hoc* group and that the information gathered (data and research results) be synthesized, centralized, and shared with the public.

Introduction

The 2-day expert workshop to investigate the environmental effects of shale gas development in the Chesapeake Bay Watershed took place in State College, Pennsylvania at the Penn Stater Hotel and Conference Center. The workshop steering committee decided on this location in hopes that committee members, as well as presenters and attendees already participating in a Pennsylvania State University/US Forest Service (PSU/USFS) conference entitled "Ecological Stewardship of Gas and Oil Development," would remain for the following two days to participate in the STAC workshop.

Dr. Susan Stout, USDA Forest Service, attended both workshops, and provided a short synopsis of the PSU/USFS conference to STAC participants as an introduction to the workshop. Following Dr. Stout's introduction, presentations were made on a number of topics related to shale gas development. Following the presentations, workshop participants broke into two discussion groups, Land Based Effects and Water Quantity and Quality Effects. Before the workshop, the steering committee formulated thematic questions (see breakout discussion summaries) as the most important issues related to the Marcellus Shale development's effects on the Chesapeake Bay and its watershed. The questions were used in the breakout discussions to arrive at a consensus on the most critical issues to understanding the cumulative effects of gas extraction from Marcellus Shale development on the Chesapeake Bay and its watershed. Discussion of these questions also highlighted the research needed to better understand these effects and provide direction to further scientific inquiry into these issues that would lead to improved resource management. Following the breakout session, each group had a report out and discussion session.

This report summarizes the workshop's presentations and participant discussions, and identifies possible actionable steps for the CBP and STAC.

Presentation Synopses

"The Successful Development of Shale Gas Resources in the United States," presented by Daniel Soeder, US-DOE, National Energy Technology Laboratory.

Mr. Soeder provided an overview of the history of shale gas development that had its roots in the gas crisis of the 1970s when the Yom Kippur War (1973) and the Organization of Petroleum Exporting Coutnries Oil Embargo (1973-4) led to a quadrupling of U.S. gas prices (from $0.40 to $1.60/gallon). On-going unrest in the Middle East further threatened oil supplies, although increased Saudi Arabian oil production lessened the impact on the U.S.

Due in part to this crisis, President Carter created the U.S. Department of Energy (DOE) to explore the development of domestic sources of energy to ease U.S. reliance on imports. Eastern gas shales were among the domestic energy sources that needed to be characterized to asses the potential for development. Between 1976 and 1992, some 44 shale cores in eastern basins were collected by the department. From these initial samples, gas was found to occur in both organic-rich and organic-lean shales, in small fractures, in pores and nanopores, and adsorbed onto organic matter (OM) and clays. Along a ~250-mile W-E transect through the Appalachian Basin from Ohio to Pennsylvania, Devonian-age shales were found shallower to the west, dipping downward to the east. In the Chesapeake Bay watershed, the Marcellus Shale occurred 4000 to 7000 feet below the Earth's surface.

Production from "conventional" oil and gas resources requires having source rock with 1-2% OM, thermal maturity to transform the OM to oil and/or gas, and migration pathways to move the oil and/or gas to porous rocks that possess traps and seals to contain the material in reservoirs. These can be drilled vertically and produced economically. Shale gas development is "unconventional" in the sense that no porous reservoir, no migration, and no trap and seal are present. The gas is continuous throughout the highly-organic, thermally mature source rock. Thermal maturity generally is greater in the eastern parts of the Appalachian Basin, with "dry gas" (methane-rich, free of mobile liquids) to the east, and "wet gas" (methane plus ethane, propane, and other liquid hydrocarbons) to the west.

The method of extraction of gas from the Marcellus Shale involves horizontal drilling and staged hydraulic fracturing of the rock to create fractures that function as high permeability flow paths allowing the gas to reach the well bore. The fracture fluid consists of water, with sand as a proppant to keep fractures open, and various chemicals added to reduce friction and corrosion, clean the downhole entry points, and control bacteria. A typical shale gas well consists of a cased vertical well drilled down to a "kickoff point" approximately 500 feet above the target Marcellus Shale layer. Using directional drilling technology, the borehole builds a 500-foot radius curve that changes it from vertical to horizontal. The horizontal or "lateral" borehole may extend more than 5000 feet. Hydraulic fracture treatments are staged along the length of the lateral wellbore within the shale formation at spacing approximating 500 feet.

Modern shale gas development began in 1997, with the successful completion of a horizontal well with staged hydraulic fracturing in the Barnett Shale of Texas by Mitchell Energy. Shale gas development expanded in 2004, both in the Fayetteville Shale in northern Arkansas and in the Haynesville Shale in the AR-LA-TX region. Range Resources successfully completed a vertical well in the Marcellus Shale in 2005 that encouraged them to apply Mitchell Energy's horizontal drilling technique on this formation. After some trial and error, they derived an effective frac formulation, and the first successful horizontal Marcellus well, Gulla#9, came on-line in 2007, returning an initial gas production rate of 4.9 million cubic feet per day. Between 2008 and January 2012, some 8000 wells were permitted or drilled in the PA and West Virginia (WV) portions of the Marcellus Shale. This "gold rush" of well drilling into relatively dry gas shales has slowed recently due to a glut of natural gas on the U.S. market. Current development is focused on liquid-rich resources in both the Marcellus and underlying Utica Shale in the western parts of the Appalachian Basin as the price for wet gas products remains strong.

With respect to water resources, hydraulic fracturing requires a water supply that may be drawn from local surface waters (streams or rivers), groundwater, or can be trucked in from off-site. Water used in the fracking process is typically stored in temporary basins on-site. Questions related to water use, and contamination associated with fracking, are to some extent unresolved, since EPA does not require reporting of additives, the water treatment process is not closely regulated, and enforcement is minimal with a chronic shortage of inspectors. Potential environmental impacts are associated with water use, treatment and disposal, atmospheric releases (gas-powered equipment operation, inefficient methane recovery), land use change (pad development, infrastructure for roads and distribution pipelines). And importantly, thresholds for some potential environmental impacts are unknown.

"Past Experience in Arkansas," presented by Sally Entrekin, University of Central Arkansas.

Dr. Entrekin discussed the ongoing work in Arkansas examining potential environmental impacts of fracking in the Fayetteville Shale. Drilling in Arkansas began in 2007, with the typical "gold rush" of high-density drilling sites. From GIS analysis, the density of wells is ~1 per 2 km^2 (4000 wells total), with some 82% of those wells within 300 m of stream corridors (perennial + intermittent). A similar analysis of a subset of wells in SW PA suggests at least 70% of Marcellus Shale wells are within 300 m of stream corridors. The threats to streams include: water withdrawal from streams; contaminated water discharges from drill sites; and erosion-derived sedimentation in streams from development with poor attention to Best Management Practice (BMP) installation and maintenance. To date, cited violations have been documented for erosion at the well site, inadequate reserve pit construction and/or maintenance, unauthorized water discharges, and oil spills.

Dr. Entrekin and colleagues have been seeking to identify impacts related to well development density and distance to surface waters. In the absence of small watersheds without shale gas development, however, they have been forced to complete gradient analysis, to look at how variables such as turbidity, suspended sediments, metabolism, and macroinvertebrate community metrics are influenced by gas well activity. In addition to gas development activities, surrounding land use includes pasture, urban, forest, and crops. Catchment size and slope are factored in, as is road density. Gas activity metrics include total wells, pad density, well density, (~8.7 wells/pad), well density prior to one year of sampling, and total flow length from pads. Turbidity increased in streams with greater surrounding well pad density. Principal components analysis has parsed out different land use types fairly cleanly, but lands developed for pasture and for fracking may contribute similarly to stream turbidity since both involve cleared land disturbance. These results, however, vary by storm event, demonstrating that storm intensity, duration, and antecedent conditions may influence the volume and quality of runoff. Well pad density and/or total number of wells during some seasons have been positively correlated with stream chlorophyll-*a* (Chl-*a*) and/or gross primary production, suggesting nutrient runoff may spur algal production. Concomitantly, an increase in stream macro-invertebrates has been observed in streams from watersheds with greater well density, but lower diversity occurs in streams with more inorganic sediment. Wells may influence streams by increasing nutrient and sediment runoff; those conditions decrease overall diversity but may stimulate production and consumption by larger populations of macro-invertebrates adapted to high nutrients and sediment loads.

Research needs are many, since no long-term datasets exist regarding the in-stream impacts of shale gas development. Results to date suggest a link, but many potential confounding variables make it difficult to tease out the impacts associated specifically with shale gas development.

"Unconventional Development of Natural Gas from Shale Formations: Impacts on Water and Climate," presented by A.R. Ingraffea, Cornell University.

Dr. Ingraffea began by noting that methane concentration in the atmosphere has risen ~8% in the last 25 years, with much of that increase probably attributable to human activities. His take-home message was that development of unconventional gas resources will generate issues associated with drinking water supplies, waste disposal, and methane emissions.

Like in the Fayetteville shale gas play, the intensity of development is high in the Marcellus play. The estimated number of wells in the Chesapeake Bay watershed at buildout is 50,000, i.e., shale gas development has just begun. Tracts are leased in clustered rectangles ~250 ha in size that will allow on average eight wells per pad.

Are natural gas emissions an industry problem? Citing a 2003 Oilfield Review (Brufatto et al., 2003) publication, Dr. Ingraffea noted that uncontrolled migration of hydrocarbons to the surface have challenged the oil and gas industry. Five percent of all drilled wells malfunction immediately with respect to casing pressure and uncontrolled gas migration; a majority (>50%) of all wells fail by "maturity" (>20 years), although no one can predict the "lifetime" of a well. Some 6-7% of over 3500 wells drilled in the last three years have been reported to the PA DEP Compliance Database for methane migration from faulty wells. Some of this uncontrolled migration may have led to localized contamination of drinking water supplies. As the intensity of drilling increases, the contaminated drinking water issue could become more regionalized.

Flowback of fracture fluids is also a problem, with volumes of a million gallons or more per well. This fluid must be stored or treated. These highly saline fluids contain fracture fluid additives (e.g., sand, gelling agents, biocides, anti-corrosion agents, and friction reducers), plus some heavy metals (e.g., strontium) and radioactive materials brought up from the shale deposits. Ohio (OH) permits the disposal of fracking fluids in deep injection wells; suitable geology for deep well injection is not present in PA or WV. In PA, the flowback fluids have been treated at publicly operated treatment works and at industrial wastewater facilities, spread on roads, and recycled and re-used. The industry claims nearly 100% fluid recycling, although PA DEP records from 2011 suggest only 38% of waste fluids are actually recycled.

The majority of Dr. Ingraffea's presentation was centered on atmospheric effects of natural gas systems, which currently contribute 39% of total U.S. methane emissions. As cited from the Howarth and Ingraffea *Nature* publication (2012), shale gas has a larger greenhouse gas footprint than does conventional natural gas, oil, or coal when methane emissions are considered (based on total CO_2 equivalents to the atmosphere normalized to heat energy yield). The best current estimates are that shale gas development leads to methane emission rates that are in the range of 3.9 to 5.8% over the life time of a well, according to the EPA and several other studies (Howarth et al. 2012). This is 40% to 50% more than for conventional natural gas. Even far lower emission rates lead to a greenhouse gas footprint for shale gas that is worse than that of coal or oil, if one focuses on the critical time period of the next few decades and not simply time scales of a century or more into the future.

"Impacts of Natural Gas Drilling on Water Quality and Quantity," presented by Jim Richenderfer, Susquehanna River Basin Commission.

Jim Richenderfer began by noting that PA water quantity issues were in the regulatory realm of the Susquehanna River Basin Commission (SRBC), whereas water quality issues were regulated by PA DEP, i.e., SRBC regulates only water quantity and does not regulate the treatment or disposal of wastewater, drilling fluids, flowback, or production fluids. The Susquehanna River Basin (SRB) covers 43% of the Chesapeake Bay Watershed, and the Susquehanna River supplies some 26 billion gallons of water per day to Chesapeake Bay on average, with high variance seasonally and year-to-year. For comparison, water withdrawals associated with unconventional gas extraction from the Marcellus play currently stand at 12 million gallons per day, with 30 million gallons per day expected at full well buildout and operation (i.e., peak demand). These volumes are roughly equivalent to the daily water withdrawals associated with the cooling operations of a single nuclear power plant. Because 85% of the Susquehanna River basin is underlain by exploitable shales (including the Marcellus and Utica formations), concerns have been raised regarding the environmental impact when all leases are developed and wells are initially drilled and eventually fracked. The SRBC regulates the unconventional natural gas industry with the first gallon used, i.e., all water uses by the industry are regulated whether from groundwater withdrawals (nominal), surface withdrawals (80%), or from public water systems (20%).

With respect to the Marcellus Shale, most of the available energy deposits are dry gas (>85% methane). Since the current price of dry gas is much lower than wet gas (greater percentages of ethane, propane, butane, and other hydrocarbons), many of the drilling companies are presently moving their activities westward to OH and WV to focus on wet gas extraction. Many existing wells are being hydraulically fractured in the SRB (over 200 in the last quarter of 2011), but few new wells are being drilled in the basin.

By the end of 2011, 1,163 wells had been hydraulically fractured in the SRB. Each well on average used 4.37 million gallons of water—80-88% of that water was "fresh", the other 12-20% was re-used "flowback" water. Some 8-12% of the water originally injected as part of the fracturing process is recovered as flowback within the first 30 days after release of pressure. In this context of water use, Mr. Richenderfer overlaid the spatial coverage of the Marcellus Shale with exceptional value, high quality, and trout spawning streams in the SRB, demonstrating the high degree of overlap and potential impact of nonconventional gas extraction. To this end, aquatic resource surveys are part of the regulatory requirements for water withdrawals from streams, along with metering plans, maximum daily and instantaneous withdrawal limits, and monitoring and inspection, among other requirements. A "low flow protection policy" has been proposed based on a Nature Conservancy ecosystem study demonstrating the importance of maintaining a natural hydrograph in stream systems. This proposed policy is under review by the SRBC and currently is in the public comment period.

Although the SRBC does not have any regulatory authority with respect to water quality issues, the commission is involved in various ways. In 2010, the SRBC initiated a remote water quality monitoring network in the shale gas region of the SRB. Fifty stations have been installed to date to collect continuous information on depth, pH, temperature, conductivity, turbidity, and oxygen. Additional sampling is completed quarterly for other water quality parameters, along with macro-invertebrate and habitat data collected annually; fish sampling began in 2012. In addition, water sampling has been conducted since the 1990s as “snapshot surveys” in each of the major sub-basins of the SRB, 5 of 6 of which have some level of shale gas development. Also since 2008, the Aquatic Resources Survey Project has focused on characterizing conditions (habitat, water quality, fish, invertebrates, and periphyton) along stream reaches with proposed water withdrawal applications under consideration by SRBC.

Finally, Mr. Richenderfer considered the land use impact associated with infrastructure surrounding each well. Approximately 6.5 acres of land are disturbed by each well pad and associated road development. With 2,000 pads in the SRB, this creates 13,000 acres of disturbed lands. This level of disturbance should be viewed as a minimum, since additional lands must also be cleared for gathering and transmission pipelines.

“Environmental Effects of Shale Gas Development in the Chesapeake Watershed: Forest Impacts,” presented by Nels Johnson, The Nature Conservancy.

Nels Johnson presented on behalf of Tamara Gagnolet, Scott Bearer, and himself. This presentation addressed the following questions with respect to Pennsylvania: *What is the spatial footprint of existing energy development? How much energy infrastructure might be developed by 2030? Where is the energy development more and less likely to occur? And how could future energy development affect forest habitats?* The goal of the study was to develop projections [informed scenarios] of how new energy development could impact natural habitats in Pennsylvania to shape strategies that avoid or minimize those impacts. Study assumptions included a 20 year time horizon, stable and sufficient prices and capital investment for steady development growth, and continued recent trends and patterns of energy development.

The study concluded that the average spatial disturbance (direct and indirect) for a Marcellus Shale gas well pad was 30 acres, and that approximately 60,000 new wells may be drilled by 2030 (27,600 in the SRB). It was noted that one pad can accommodate between 4 to 10 wells. The study also projected that between 10,000 and 25,000 miles of new [raw gas] gathering pipelines may be built by 2030. This pipeline expansion does not include large diameter transportation pipelines. The study found that projected Marcellus Shale gas play pipeline footprint alone will be larger than the cumulative area impacted by all other Marcellus gas infrastructure combined. Based on the study’s projections, the spatial footprint of Marcellus gas development could result in 45,000 to 110,000 acres of forested land cleared by 2030. This level of clearing could impact an additional 220,000 to 520,000 acres of forest by creating edge effects, allowing invasive species to infiltrate, and detrimentally impacting wildlife (e.g., bird, fish) habitat. Johnson concluded with several recommendations for Marcellus development by design, which, if implemented, might lessen adverse forest impacts.

"Environmental Risk Assessment for Shale Gas Development," presented by Daniel J. Soeder, US-DOE, National Energy Technology Laboratory.

Soeder's presentation dealt with the concepts of risk, risk assessment, risk management, and the relative risks associated with shale gas development. Potential shale gas development risks that were discussed included: a containment breach associated with a well, the possibility of an induced seismic event, the unknown effects of multiple multi-well pads in a relatively small area, and the potential for exceeding a development impact threshold in a given watershed (the analogy of impervious area threshold impacting water quality in a watershed was used). Risk management is critical with shale gas development, but there are limitations. Not all environmental impacts associated with shale gas development are regulated, and not all regulations are fully enforced. Mr. Soeder briefly reviewed the contents of a 2009 U.S. Geological Survey report *Water Resources and Natural Gas Production from the Marcellus Shale*. Additionally, he reviewed some of the existing water contamination incident data that have been reported by various state and federal agencies, and published in peer-reviewed literature. Risks to surface water from drill pad runoff and fracking water pond leakage were also discussed. The on-going DOE shale gas environmental risk assessment strategy was presented. The goals of this risk assessment are to: 1) assess the short/long-term cumulative environmental impacts, 2) define the engineering risks, and 3) conduct a data-based, scientific investigation of the impacts and processes associated with shale gas development. The anticipated outcome from this risk assessment is a rigorous study with conclusions supported by well-documented data. The anticipated benefits are: 1) information-based regulations and indicators for regulatory monitoring, 2) improved management practices for shale gas production to mitigate problems, and 3) the creation of a more informed environmental debate about shale gas development.

"Flowback Management Trends and Strategies," presented by Dave Yoxtheimer, Pennsylvania State University.

This talk dealt with how gas companies are dealing with production flowback water. Approximately 90,000 gallons of water are needed for drilling a gas well. Between 3 to 7 million gallons are used when fracking a well. Approximately 8 to 10% of the injected volume returns to the surface as flowback water. While the volume of flowback decreases over time, the total dissolved solids (TDS) of that water increases. Various flowback water management options were discussed: direct reuse in the well (blending with fresh water), on-site treatment and reuse, off-site treatment and reuse, and off-site treatment and disposal. The capacity of off-site, fixed-location, flowback treatment is expanding in Pennsylvania, but treatment capacity limitation is an on-going issue. The use of mobile on-site treatment is increasing. Water quality standards adopted in Pennsylvania in 2010 regulate discharged effluent concentration of TDS, chlorides, strontium, and barium. One method of disposing flowback water is deep well injection. However, the number and capacity of permitted injection wells in Pennsylvania is limited but the use of deep injection wells in the Commonwealth is being actively pursued. The trend in the industry is to increase the reuse of flowback water. Data indicated that approximately 77% of flowback water is currently (spring 2012) reused as compared to 10% in the recent past.

Land Based Effects Discussion Summary

Land Based Effects Questions

1. **How does the natural gas drilling infrastructure affect land cover/use and indirectly water quality and quantity via cumulative effects?**

Spatial Location of pads and infrastructure appears to be essential in shale development effects in both Arkansas and Pennsylvania (Entrekin et al. presentation, Drohan et al. 2012). The distance to streams or flow paths is likely an important factor in determining impact of infrastructure on local water quality as is the density of well pads, access roads, and pipelines.

CBP Model Land Uses – The Chesapeake Bay Watershed Model (CBWM) does not have a land cover class for gas well pad or for pipeline infrastructure. The CBP should consider if an existing land use class (e.g., extractive, pasture, impervious urban) is suitable for modeling nutrient and sediment losses from shale gas-related development and production activities. If not, a new series of land use/land cover classes (and associated unit area loads) should be developed. Further, much of the existing shale gas development infrastructure may not be reflected in Chesapeake Bay land use/land cover maps because of misclassification, or the fact that shale gas development-related land use changes have occurred in recent years. The CBP should take steps to update land use/land cover data, and pursue options that will allow for the CBP to simulate alternative land use change/evolution scenarios associated with differing degrees of shale gas development.

Modeling Access Roads – The CBP should consider how access roads (well pad access roads and other rural roads) are modeled. There is the belief that these types of roads act as ephemeral streams and that they can significantly impact sediment loss. A generic gravel road classification may not be representative of gas well extraction roads.

Small Watershed Testing - The CBP should consider undertaking sensitivity testing of the CBWM within small watersheds with differing levels of gas extraction disturbance to determine if the model is appropriately simulating these effects. The amount or number of gas well pads, roads, and pipelines could be varied to determine if threshold levels of development can be correlated with water quality impacts, especially sedimentation.

2. **How effective are BMPs at reducing those effects?**

BMP Performance – BMP implementation is required by the states. In Pennsylvania, the DEP enforces stormwater and disturbance BMP implementation (through PA Codes 102 and 105 and the Oil and Gas Act) except if a National Pollution Discharge Elimination System (NPDES) permit is required. Given the great variability in soils and topography across Pennsylvania, the specific BMPs needed vary accordingly. If the wrong BMP is applied/implemented, its effectiveness will be reduced or negated and this could result in more erosion than would be the intent with an effective BMP. BMPs from other regions and other types of disturbances can be effective in reducing erosion and sedimentation, but one problem in the Marcellus region is that many projects occur at times of year when vegetative cover cannot be established for months due to the seasonal climate. Also, BMPs may not be implemented at the right time of year (or sometimes not well).

BMP Non-Compliance – The general problem of BMP non-compliance is largely enforcement or lack thereof. It is difficult to ensure companies are not disturbing landscapes during times of year likely to result in accelerated erosion (due to the impossibility of establishing vegetation) or to prevent the high likelihood of erosion occurring during wet-climate periods, especially with limited resources, staffing, and oversight. Penalties may be too low to "encourage" use, DEP may be allowing too much latitude in implementation, Federal budget cuts have made enforcement more difficult, the speed of erosion and sedimentation plan reviews for gas companies may be too quick to catch problems compared to other groups disturbing PA landscapes (others have a longer than the 2 week review period that is granted to the gas industry), or the speed of extraction if needlessly hurried may result in sloppy BMP implementation and thereby poor removals.

BMP Education – Plenty of information is available, and more will soon be available, to educate companies on the best ways to implement erosion and sediment loss BMPs; PA DEP already has many effective BMPs recommended through their stormwater BMP manual (Pennsylvania Stormwater Best Management Practices Manual DEP Policy No. 392-0300-002). There is an "Environmentally Friendly Drilling (EFD)" program which provides guidance on proper BMP implementation (http://www.netl.doe.gov/technologies/oil-gas/publications/EPact/08122-35-final-report.pdf), an upcoming industry guidance document on recommended practices, and an upcoming Nature Conservancy report and website that will describe the science related to BMPs for well pads and infrastructure (http://www.nature.org). Industry associations such as the American Petroleum Institute have extensive manuals with recommended procedures that are updated regularly (http://www.api.org). These education efforts will help to reduce non-compliance and improve the performance of BMPs.

3. What is the potential effect on Chesapeake Bay TMDL pollution reduction efforts?

Land Cover – The answer to question #1 on the previous page shows the various ways that land cover changes and disturbances can decrease water quality. Any decrease in water quality in the Chesapeake Bay watershed will make it more difficult for jurisdictions to meet their TMDL allocations.

Watershed Segment Effects – There are likely to be more effects from sediment loss in local streams and small watersheds than downstream in the Chesapeake Bay. This substantial local effect could impact local water quality and inhibit jurisdictional ability to implement Phase II Watershed Implementation Plans.

Acute Events – There are acute meteorological events (e.g., Tropical Storm Lee) that likely result in significant runoff from well pads, pipelines, and roads. It is unclear if the Chesapeake Bay Program is able to model these acute events, or that even well planned and well implemented BMPs can prevent substantial impact under such extreme conditions.

Cumulative Effects and Thresholds – While the total amount of disturbance as a portion of the Chesapeake Bay, or even the Susquehanna River watersheds, is likely low, the cumulative cover of well pads and associated infrastructure may add up to 5-10 percent of total land cover in SOME watersheds. There is likely a threshold of infrastructure development in each of the sub-watersheds that will lead to lower water quality and species effects. We also need to understand how sensitive modeling segments might be to this level of land use change, i.e., what effect does reducing forest cover by 5-10%, and increasing impervious cover or gravel roads correspondingly, have? Is there a threshold level of land cover change that is important and does that level change with increasing scale? Are there lag times among the various effects?

Offsets – It is unclear whether the Commonwealth of Pennsylvania, the Chesapeake Bay Program, and other jurisdictions in the future will be able to correctly quantify the land use change and correct for this change using offsets. The CBP and individual jurisdictions should consider how to quantify this fast-moving land use change, and how to develop offsets so the sediment goals in the TMDL can still be met.

4. **What are the high priority research needs for natural gas drilling effects on land cover/use for Chesapeake Bay water quality?**

SEDIMENT LOADS! SEDIMENT LOADS! SEDIMENT LOADS! What are the sediment loads coming from well pads, pipelines, and access roads and how do they change through the development of the well and restoration cycle surrounding it?

What is the trend in current BMP use, how effective are the BMPs, and what is the pattern of enforcement for incorrect or non-use of BMPs?

What sediment (and to a lesser extent, P and N) loading rates should be applied to active vs. reclaimed well sites, roads, and pipelines? Length of the period of the disturbance is also important to quantify.

Are there new and innovative practices to reduce erosion and sediment loss (e.g., bio-retention, reusable plastic roadways, etc.) that can be implemented for oil and gas development?

Do oil and gas development reduce the time that a threshold or tipping point in cumulative land disturbance in a watershed will negatively affect water quality?

How will socio-economic issues such as demographics or economic bust-and-boom cycles affect the watershed both positively and negatively?

What are other land use changes likely to be seen over time as a result of gas development?

What is the best reclamation strategy for disturbed lands? Should it be a successional forest habitat?

What are the risks to key indicator species such as brook trout, green salamander, goshawk, etc.?

What is the potential for invasive species migration into disturbed lands?

Are there chemical signatures in the water such as C-13, strontium, strontium isotopes, barium, bromide, boron, or boron isotopes that could identify spills or leaks?
What is the probability of mass wasting events (i.e., large landslides)?

Can we characterize the conditions on the ground by adjusting loading rates in the Chesapeake Bay watershed model?

Water Quality and Water Quantity Effects Discussion Summary

1. How does shale gas development affect water quality and water quantity?

Extraction of gas from unconventional shale in the Marcellus Shale Play has the potential to affect the water quantity and quality in the Chesapeake Bay and its watershed though several mechanisms.

Well Pads/Infrastructure - The well pad and associated infrastructure (including roads and pipelines) are likely to act in a similar fashion as any other surface disturbance and change the hydrology and sediment, nutrient, and organic export to receiving streams. This may lead to altered flow regimes and habitats and increased sedimentation and nutrient input into streams.

Water Extraction - The drilling and hydraulic fracturing stages use large quantities of water (e.g., 4-8 million gallons per well for hydraulic fracturing of a horizontal well). This water is largely taken from surface freshwater sources such as streams and rivers. The withdrawal occurs over a relatively short period (e.g., a week). If taken from small headwaters or during low-flow periods, such withdrawals may strongly affect water quantity and thus alter the flow regime of the system. The use is completely consumptive as most is never returned from the formation after fracking, and what is returned is so salty it must be disposed or treated.

Increased Emissions and Deposition - Nitrogen emissions associated with developing shale gas can be very high, and are likely to lead to increased deposition which locally may also be high. Such hot spots of deposition may lead to increase nitrogen load to the mainstem of the Susquehanna.

Disposal of Flowback Water - A portion (typically 8-20%) of the hydraulic fracturing fluid is returned to the surface following the fracturing process. This fluid is often high in TDS (>250,000 ppm) and many toxic and carcinogenic constituents and therefore must be disposed of appropriately. The practice in 2012 is to recycle and what cannot be recycled is disposed underground.

Five Critical Issues Stemming from the Group Discussion

Workgroup participants group agreed upon five critical issues related to the effects of gas extraction activities on water quantity and quality: a) data quality and sufficiency, b) need for monitoring, c) efficacy of best management practices (BMPs), d) scale of effects, and e) TMDLs and need for offsets.

Data Quality and Sufficiency - The group agreed that there is a general lack of knowledge about what data exist and if these data are sufficient to assess the effects of gas exploration and development activities on the water quantity and quality in the Chesapeake Bay and its watershed. An assessment is needed to identify data sources, and to determine if available data are sufficient and of suitable quality.

Need for Monitoring - Existing monitoring programs (e.g., USGS gage stations) may not be adequate to assess shale gas development effects on surface waters. Few high quality baseline (pre-drilling) water assessment studies have been undertaken. Participants agreed upon the need for more baseline assessment implementation and for long-term monitoring of shale gas development effects.

2. How effective are BMPs at reducing water quality and quantity impacts?

Efficacy of Best Management Practices (BMPs) - Participants agreed that more research is needed to address what types of BMPs are being used, who (if anyone) is regulating the BMPs, and the overall efficacy of BMPs. Workshop participants agreed there needs to be a suite of BMPs for pipelines. Further, decision makers need to know what BMPs are being used. STAC should encourage large project reviews to include citing and identification of BMPs to reduce cumulative basin loads.

Scale of Effects - The group agreed that, in the short term, the effects of gas extraction activities on water quantity and quality were likely to be more pronounced at the local scale (township/county scale) rather than at the landscape/regional scale.

TMDL's and Need for Offsets - Additionally, there is a possibility of TMDL attainment issues at the local scale. The cumulative, landscape effects will be less pronounced and the group believed that there is high uncertainty in measuring an effect given the error limits of detection at this scale. However, the group agreed there is a high probability of a possible long-term landscape effect in Pennsylvania (and maybe all states in the active development area), and each jurisdiction will perhaps need to offset their load allocations.

3. What is the potential effect on Chesapeake Bay TMDL pollutant reduction efforts?

Metals - They are not included in the TMDL but they are extremely important and will eventually become an issue and may or may not only be a local issue. Radionuclides (Naturally Occurring Radioactive Materials -- NORMS) are presumed to classify as “metals” for purposes of this discussion. Accumulation of trace metals such as barium, arsenic, strontium, and zinc, and radionuclides such as radium, thorium, and uranium may occur in stream sediments in local watersheds as a result of gas drilling and hydraulic fracturing. Isotopes of strontium and radium may be potentially useful source tracers locally. There are also high concentrations of some salts that may be present from spills and casing failures. Some of the salts include boron, bromide, chloride, and lithium. Perhaps bromide/chloride ratios could track movement of brine fluid spills.

4. What are the high priority research needs for quantifying shale gas development impacts on Chesapeake Bay water quality?

Workshop participants identified several high priority research needs for each of the five critical issues.

Data Quality and Sufficiency - Who is doing the research? How is the research being funded? Is the research peer reviewed? Is funding available for the critical reviews to be conducted? There is a need for centralization of data, as well as research results. For example, private well pad data are not currently available, which limits ability to conduct analyses. How will the Chesapeake Bay watershed model use the new data?

Monitoring - How adequate are the monitoring systems? For example, USGS gages were not designed for this type of monitoring – are they sufficient? What other monitoring systems (e.g., SRBCs sondes) are in place and are they adequate? Real-time monitoring at headwaters is essential. Monitoring of nutrients is needed in drilling areas – current monitoring was not designed for Marcellus gas extraction activity. Monitoring systems should be added, expanded, or complemented. Monitoring of nitrogen deposition in the vicinity of gas operations, including pipeline compressor stations, is essential.

Efficiency of BMPs - Which BMPs are being used, and what efficiencies are assigned (are these science-based)? How effective are BMPs? What are BMPs' limitations? Are BMPs site-specific, and what are the cumulative effects of BMPs in reducing adverse water quantity or quality effects? Not all BMPs are mandatory in all jurisdictions, so how do we know industry is implementing these practices? Who is monitoring BMPs? Who is monitoring the regulatory effectiveness of BMP implementation? What is the relationship between BMPs and Chesapeake Bay water quality and quantity? Does PA regulation (Chapter 102 specifically) include BMPs? If not, STAC encourages identification of BMPs in Chapter 102, and used thereafter to estimate loads. New BMPs for pipelines need to be developed. Erosion and sediment control BMPs (E&S) for drill pads, and the separate dirt and gravel road BMPs, could be sufficient for pad and gravel access roads, respectively, but this needs to be assessed perhaps by ensuring sufficient State inspections and monitoring. For pipelines (that, unlike roads, can and do go straight up a mountain side), new BMPs need to be developed.

Scale of Effects - Time/Lag Time: How long will it take sediment generated from gas drilling and production activities to get to the Bay? What is the toxic load attached to the sediment load reaching the Bay? Will the timing of pad and pipeline development affect the magnitude of the effect on the Bay? How long are the pads open and when are they reclaimed/revegetated? Time and scale need to be factored into local-regional assessments. Local effects particularly with sediment can be substantial. Cumulative effects are far-field and could affect the Chesapeake Bay and sub-basin or state/basin TMDLs, particularly for TSS. For example, trout is a local issue, not a TMDL issue. There needs to be a better understanding of the landscape with respect to water quality connections. It is also important to examine how other changes in the landscape may affect water quality and water quantity (e.g., shifts in agriculture such as numbers of livestock).

TMDLs and Need for Offsets - State and local decision makers need to be better integrated (TMDLs and the oil and gas industry) and coordination pursued. In PA, each township/county must meet a certain TMDL load. In order to meet that load, these entities must consider local land use. Jurisdictions need to include Marcellus Shale activities effects on the ability of their WIPs to meet the TMDL. The ability of a Decision Support Model to assist in this activity should be explored.

Related Issues/Additional Discussion

The two breakout groups came back together and presented their respective findings to the entire group. One theme from these breakout group presentations was the large degree of overlap between their findings, recommendations, and research needs. The entire group discussed several other topics they felt important for consideration. First, metals are not included in the TMDL but they are extremely important and will become an issue. This may or may not be a local issue. The group also recommended that the Federal agencies take the initiative to monitor and conduct research on shale gas development but that funding and coordinating such activities will be a challenge. Multiple ideas for funding research and monitoring were discussed including industry contributions, use of a portion of impact fees, and requiring research funding as part of the permitting process. The group also realized that there needs to be quick feedback from policy makers. Identification of thresholds and cumulative effects are also needed. The current low gas prices offer an opportunity for research to play “catch-up” (umbrella – linkage of research to practice). Next, the group recommended that all information gathered (data and research results) must be synthesized, centralized, and shared with the public. These data must also be integrated for state and local decision-making purposes. There is also a need for local focus for monitoring and research because we cannot wait to observe a larger Bay-wide impact: cumulative impacts detectable in the tidal bay would suggest many local problems upstream. Local conservation districts and other entities that are funding and conducting on-the-ground activities need to be linked to researchers who can use those areas to monitor and collect data. Gas extraction could override timber, land use, and downstream effects. The breakout groups derived the following recommendations:

Recommendations to the Chesapeake Bay Program and its partners:

- ❖ The CBP and its Partners should evaluate existing monitoring data to begin to assess the impact that Marcellus Shale drilling, production, and transport activities may have on sediment loading to the Bay. Where data do not exist, the CBP should work with Bay Program partners to design and implement monitoring programs that will enable the CBP to assess the Chesapeake Bay Watershed Model’s (CBWM) ability to simulate sediment loads from Marcellus Shale drilling, production, and transport activities and to collect data that will be useful in fostering any needed adjustments to the CBWM.

- ❖ The CBP should implement monitoring of nitrogen deposition which may be very high locally near gas rigs, compressor stations, and processing plants.

- ❖ The CBP should add infrastructure associated with Marcellus Shale gas drilling, production, and transport into Chesapeake Bay land cover/land use maps and should endeavor to modify the CBWM such that nutrient and sediment loads associated with Marcellus Shale gas drilling, production, and transport-related land disturbing activities can be simulated. The CBP should investigate if any existing CBWM land uses may be appropriate for simulating the land uses associated with these Marcellus Shale gas play activities by undertaking simulations with a range of parameter values.

- ❖ The CBP should investigate if the sediment loss from dirt and gravel roads used for gas development and production are effectively simulated in the CBWM. There is some evidence that these roads act as ephemeral streams which impact the hydrology and sediment loads reaching streams and rivers.

- ❖ The CBP should provide a framework to centralize the data for well pads, pipelines, road ways, and rapid land use/cover changes.

- ❖ The CBP should investigate any scale-effects (cumulative effects) associated with using the CBWM to effectively simulate the sediment loading from Marcellus Shale drilling, production, and transport activities. If the CBWM cannot accurately capture the sediment loading from these activities, the CBP should consider developing/using smaller-scale, companion watershed models that are capable of accurately simulating the sediment loading and using output from those models as inputs to the CBWM, as suggested in the use of small scale models in a previous STAC report (Band et al. 2008.)

- ❖ The CBP should investigate how the Marcellus Shale gas play may affect land use/land cover future projections, and in turn, how those adjusted projections affect nutrient and sediment loads to the Bay. Existing projected trends in development, conversion of agricultural land, etc. may be altered by the Marcellus Shale gas play.

- ❖ CBP needs to implement real-time monitoring at headwaters where shale gas development is taking place or proposed. The current USGS gage stations were not designed for this type of monitoring.

Recommendations to Industry, Scientific, and Policy-Making Communities

- ❖ It is recommended that Federal agencies take the initiative to monitor and conduct research on shale gas development but it is also recognized that funding and coordinating such activities will be a challenge. Research and monitoring funding could come from a variety of sources including federal and state agencies, industry contributions, use of a portion of impact fees, and requiring research funding as part of the permitting process. Coordination should be implemented to prevent duplication of effort and gaps.

- ❖ Workshop participants recommended that there be a local focus for monitoring and research because waiting for the lag time to observe a larger Bay-wide impact jeopardizes smaller systems in the upper watershed. Researchers should team up with local conservation districts and other entities that are permitting, funding, and conducting on-the-ground activities so those organizations and capacities can be used to develop ambient baselines and to monitor and collect data for both short- and long-term assessment programs.

- It is strongly recommended that more research be done on metals and other pollutants that are not included in the TMDL as they may have potential chronic effects and will become an issue in the future if they accumulate in sensitive ecosystems and environments facilitating exposure.

- The industry should implement set back distances for pads from water bodies, maintain riparian buffers, and implement all mandatory and voluntary BMPs in order to lessen the cumulative impact to the Chesapeake Bay. State regulators can study and improve the protective aspects of the most adequate protections and work with industry to disperse the most improved and most innovative protections.

- Does Pennsylvania (PA) regulation for oil and gas activity include BMPs? If not, the PA Department of Environmental Protection (DEP) should encourage that BMPs are used or are amended and developed as necessary. There is a need for large project review process within PA DEP to better evaluate the potential cumulative effects within a watershed.

- Location and timing data need to be centralized. Currently, private well pad data are not publically available, data on pipelines and road ways are difficult to obtain, and the land cover is rapidly changing during gas well development. The timing of well drilling, e.g., in wet vs. dry seasons, matters. Even basic data on the development of new pads and the drilling and hydraulic fracturing of wells are often incorrect or missing from PA DEP files.

- Participants recommended that states change the permitting process to be project-based rather than individual site-based and to require that permits provide potential build-out scenarios to provide better potential cumulative effects information.

- Workshop attendees recommended that industry personnel and state regulators signing permits be required to have BMP implementation/certification training. Continuing education credits could be required to maintain certification.

- Participants recommended better state-to-state sharing of information via an *ad hoc* group and that the information gathered (data and research results) be synthesized, centralized, and shared with the public. Participants suggest a regional conference to look at BMPs, lessons learned, etc. be convened, perhaps on a regular basis.

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Appendix 1 - Suggested Resources

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Appendix 2: Workshop Participants

STAC Marcellus Shale Workshop Attendees	Affiliation	Email
Daniel Soeder	DOE-NETL	daniel.soeder@netl.doe.gov
Sally Entrekin	University of Central Arkansas	sentrekin@uca.edu
Tony Ingraffea	Cornell University	ARI1@cornell.edu
Jim Richenderfer	Susquehanna RBC	jrichenderfer@srbc.net
Nels Johnson	The Nature Conservancy	pa_chapter@tnc.org
David Yoxtheimer	Pennsylvania State University	day122@psu.edu
James (Jim) Campbell	USGS Water Science Center	jcampbel@usgs.gov
Carl Kirby	Bucknell University	kirby@bucknell.edu
Zoltan Szabo	USGS	zszabo@usgs.gov
Desiree Plata	Duke University	desiree.plata@duke.edu
Steven Faulkner	USGS - Leestown Science Center	faulkners@usgs.gov
Lewis Linker	US EPA	linker.lewis@epa.gov
Mark Bryer	The Nature Conservancy	mbryer@TNC.org
Margaret Brittingham	Pennsylvania State University	mxb21@psu.edu
Patrick Drohan	Pennsylvania State University	pjd7@psu.edu
Lesley Milheim	USGS	lmilheim@usgs.gov
Paul Roth	PA DCNR Bureau of Forestry	paroth@state.pa.us
Michelle Evans-White	University of Arkansas	mevanswh@uark.edu
David Velinsky	Academy of Natural Science - Drexel	velinsky@ansp.org
Susan Stout	USDA Forest Service	sstout@fs.fed.us
Tom Schuler	USDA Forest Service	tschuler@fs.fed.us
Tim Ziegler	Penn State University - CDGR	tmz115@psu.edu
Bryan Swistock	Pennsylvania State University	brs@psu.edu
Damian Zampogna	ALL Consulting	dzampogna@all-llc.com
Kurt W. Gottschalk	USDA Forest Service	kgottschalk@fs.fed.us
Charlie Abdalla	Pennsylvania State University	cabdalla@psu.edu
Denice Wardrop	Pennsylvania State University	dhw110@psu.edu
Kelly Maloney	USGS	kmaloney@usgs.gov
Randy Chambers	College of William & Mary	rmcham@wm.edu
Robert Howarth	Cornell University	rwh2@cornell.edu
Brian Benham	Virginia Tech University	benham@vt.edu
Matthew Johnston	Chesapeake Research Consortium	JohnstonMa@si.edu
Natalie Gardner	Chesapeake Research Consortium	GardnerN@si.edu
Kathy Brasier	Pennsylvania State University	kbrasier@psu.edu
Dr. Keith Eshleman	UMD/Appalachian Laboratory	Eshleman@al.umces.edu
Kevin Sellner	Chesapeake Research Consortium	sellnerk@si.edu

Karl Blankenship	Bay Journal	bayjournal@earthlink.net
Arthur Rose	Penn State University (retired)	awr1@psu.edu
Carl Zimmermann	UMCES	carlz@umces.edu