EFFECTS OF NATURAL GAS DEVELOPMENT ON FOREST ECOSYSTEMS

Mary Beth Adams, W. Mark Ford, Thomas M. Schuler, and Melissa Thomas-Van Gundy[1]

Abstract.—In 2004, an energy company leased the privately owned minerals that underlie the Fernow Experimental Forest in West Virginia. The Fernow, established in 1934, is dedicated to long-term research. In 2008, a natural gas well was drilled on the Fernow and a pipeline and supporting infrastructure constructed. We describe the impacts of natural gas development on the natural resources of the Fernow, and develop recommendations for landowners and land managers based on our experiences. Some of the effects (forest clearing, erosion, road damage) were expected and predictable, and some were unexpected (vegetation death from land application of fluids, an apparent increase in white-tailed deer presence). Although this is a case study, and therefore the results and conclusions are not applicable to all hardwood forests, information about gas development impacts is sufficiently rare that forest managers, research scientists, and the concerned public can learn from our experience.

INTRODUCTION

The increased demand for natural gas during recent decades, coupled with advances in extraction technology, has led to an increase in exploration and development in many previously unexplored areas in the United States, most notably areas underlain by Marcellus shales in the eastern part of the nation. The impacts of increased development pressure on other natural resources, including soil water, wildlife, and vegetation, are relatively undocumented for forest ecosystems in the eastern United States. Landowners, land managers, and policy makers require such information about these effects to help them make decisions about mineral resource development.

In 2008, drilling for natural gas and subsequent pipeline construction were implemented to extract the privately owned minerals underneath the Fernow Experimental Forest in West Virginia. The Fernow is well known for long-term silviculture, watershed, and ecological research (Kochenderfer 2006). In this paper, we describe some of the impacts of this natural gas development on the natural and scientific resources of the Fernow, and identify opportunities to mitigate possible impacts based on our experiences. This report describes results from a single case study, and the data described herein generally come from post-hoc monitoring, not designed experimentation. In addition, many of the potentially sensitive components of the ecosystem were not monitored; information on fauna, in particular, is lacking. Nonetheless, conclusions can be drawn which may be useful to other land managers.

[1]Supervisory Soil Scientist (MBA) and Research Foresters (TMS, MT-VG), USDA Forest Service, Timber and Watershed Laboratory, Parsons, WV 26287; Research Wildlife Biologist (WMF), currently Unit Leader, U.S. Geological Survey, Virginia Cooperative Fish and Wildlife Research Unit, Virginia Tech, Blacksburg, VA 24061. MBA is corresponding author: to contact, call (304) 478-2000 or email at mbadams@fs.fed.us.

SITE DESCRIPTION

The well site is located within the 1,902-ha Fernow Experimental Forest, which lies in the Allegheny Mountain section of the mixed mesophytic forest (Kochenderfer 2006). The Fernow was set aside to "make permanently available for forest research and the demonstration of its results a carefully selected area representing forest conditions that are important in Northeastern West Virginia" (Fernow Establishment Order, dated March 23, 1934; on file at the Timber and Watershed Laboratory, Parsons, WV).

The gas well site and access road are located on karst topography within the Elklick Run watershed. Surficial bedrock geology is the Greenbrier Group, which is composed of interbedded limestones and calcareous shales, and includes cavernous limestone. Groundwater emerges at two springs located approximately 1,000 m northeast of and at a lower elevation than the well site. Known underground passageways within the Big Springs Cave are located approximately 600 m away from the well site. Big Springs Cave is the largest hibernaculum on public land in West Virginia for the endangered Indiana Bat.

PROCESS OF DEVELOPMENT OF THE WELL SITE

An abbreviated timeline of the well and pipeline development process is provided in Table 1 (for a detailed timeline and for details of monitoring methods, see Adams and others in process). A similar time frame might be expected for well development on other lands, but the timing of the various activities was controlled by weather conditions by the availability of equipment required at each stage of well development. Trees and all vegetation were cleared from an area of about 1.4 ha, followed by earthwork to construct a 4.6-m-wide road, a level drill pad of about 30 m by 61 m, and a pit 24 m by 37 m by 3 m deep. The purpose of the plastic-lined drilling pit was to hold rock cuttings and drilling residues.

Table 1.—Abbreviated chronology of activities on the natural gas well site and associated pipeline, Fernow Experimental Forest.

Date	Activity
May 11, 2007	Energy company contacts the U.S. Forest Service and requests input.
Sept. 11, 2007	FS receives copy of well work permit application.
Sept. 21, 2007	WV Department of Environmental Protection, Office of Oil and Gas, approves well work permit application.
Jan. 2008	Timber on access road/well site cut by Fernow logging crew.
Feb.-April, 2008	Construction of access road/well site.
April 8, 2008	Well drilling begins.
April 30, 2008	Well reached total depth of 2,387 m. Proved gas in the Huntersville Chert portion of the Oriskany and associated strata, and possibly the Oriskany sandstone. Drill pipe broke off and stuck in the well bore. Directional drilling around stuck pipe.
May 15, 2008	Drilling completed.
May 23, 2008	Hydrofracing begins, completed on 5/31.
June 13, 2008	Road repairs completed.
June 21, 2008	Land application of drill pit fluids completed to Site 1.
July 28, 2008	Pit contents solidified and back-filled.
September 9, 2008	Recontouring of the well site begins.
October 2, 2008	Cutting of pipeline right-of-way begins.
October 7, 2008	Recontouring of well site completed.
December 15, 2008	Well pad and access road seeded and mulched.
December 31, 2008	Cutting of pipeline right-of-way and removal of harvested stems completed.
January 29, 2009	Pipeline installation completed.

Drilling required approximately 3 weeks, and was completed to a depth of 2,387 m in the Oriskany sandstone. After completion of drilling, the rock layer was fractured to release natural gas in the formation —a process known as hydrofracing. Following hydrofracing, the hydrofracing fluids were recovered and temporarily stored in the pit. Subsequently, the majority of the drill pit fluids (302,800 L) were land-applied to an area of about 0.2 ha within a nearby research compartment (Fig. 1). This fairly small area was negotiated in an effort to minimize impacts on ongoing research nearby. Foliar injury and death of vegetation during this application necessitated a change of application site, and the remaining 75,700 L was applied within the pipeline right-of-way to an area of about 0.04 ha. The remaining pit contents were then solidified by adding cement, and buried in place.

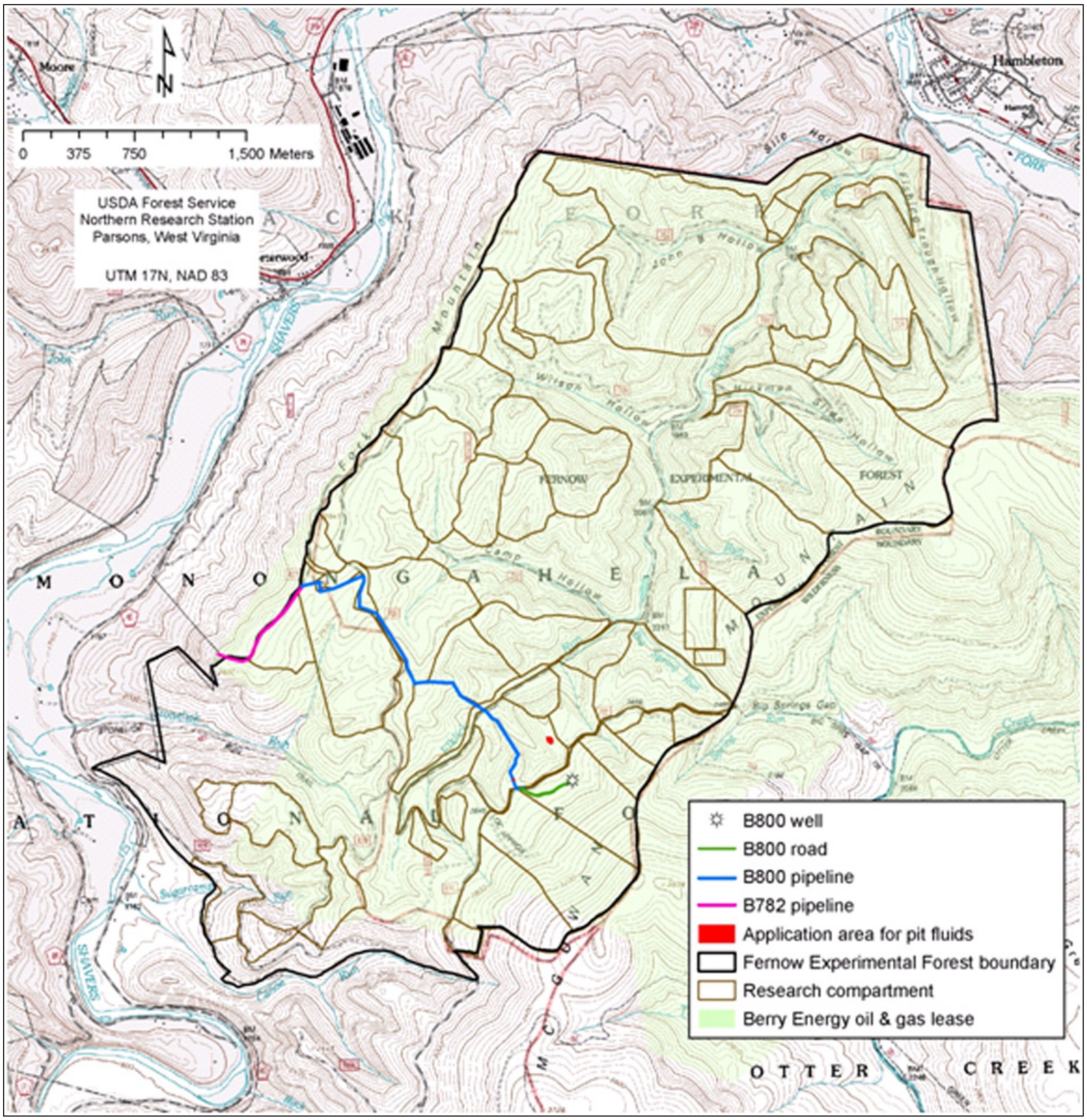

Figure 1.—Fernow Experimental Forest, West Virginia, showing location of features related to natural gas exploration and development project.

OBSERVATIONS

CLEARING AND SITE DEVELOPMENT

An area of about 0.63 ha was cleared for the well-pad and drill pit. All vegetation within the perimeter was removed, including 94 trees (>28 cm diameter at breast height [d.b.h.]) and 126 pulpwood stems (52,200 bd ft, or 123.2 m^3). Most of the well site will remain in herbaceous cover, except for the well-pad itself and the access road, which were graveled.

The pipeline corridor is estimated at 2 ha in extent (8 to 9 m wide, and 1,800 m long). All vegetation was cleared from the area and stumps removed. Brush was piled along the edges of the right-of-way. In total, 714 trees were removed, 310 of them (43 percent) being greater than 28 cm d.b.h. (volume of 84,600 bd ft, or 199.6 m^3). The pipeline is to be maintained as a grassy corridor by mowing, and no trees will be allowed to become established.

EROSION AND SEDIMENT

A total of 1,330.12 kg of soil material was collected behind silt fences located below the well site. This number represents total soil loss during summer 2008, from a cleared area of about 0.63 ha, and equates to a loss rate of 2.1 metric tons per hectare during a 3-month period. This figure likely underestimates total soil erosion losses, however; site soil was also lost prior to silt fence installation, and soil loss occurred off the well site at other locations that were not monitored (Edwards 2008). For comparison, rates of erosion from road surfaces in eastern forests range from 1.9 metric tons per hectare (Dickerson 1975) to 337 metric tons per hectare (Ursic and Douglas 1979). Chen (1974) estimated erosion losses from urban construction sites to range from 11 to 450 metric tons per hectare per year. Given that we measured soil loss from a portion of the site for only a portion of the year, it is apparent that soil erosion from gas well development can be significant.

There is no evidence that soil eroded from the well site reached nearby springs (Edwards 2008). More than 99 percent of the reported turbidity values from the springs were less than 40 NTUs. All of the turbidity values observed during monitoring of these two springs were within ranges commonly reported within this region, and variability was notably low.

ROAD DAMAGE

Damage to the Fernow's graveled roads was anticipated and did occur. Road use was estimated to exceed 9,300 metric tons during the approximately 6-month development phase, compared with about 4,500 metric tons annually for logging on the Fernow. Ruts of 30 cm or more developed, roadside drainage ditches were filled or collapsed, and erosion of the road surface subsequently occurred. Damage was repaired satisfactorily after completion of well site construction and drilling, but temporary repairs during the drilling process were not always sufficient to keep the road open to the general public.

DRILLING AND HYDROFRACING FLUIDS

Fluids from the drill pit were land-applied at two locations on the Fernow in June 2008, with nearly immediate impacts on vegetation. The fluid from the drill pit was sprayed into the air and onto the vegetation, although this application method may not be the standard protocol. The assumption was that if the drill pit fluids met the standards specified in the permit, there would be no damage to the vegetation or soil. Permit levels, as established by the West Virginia Division of Environmental Protection, dictate land-applied drill pit fluids must have chloride concentrations less than 12,500 mg/L and a pH between 6 and 10. State regulations require only one sample of the effluent be taken from the distribution hose during land application. The drill pit fluids met the permit concentration levels, but total vegetation mortality was observed on the first fluid application site almost immediately after land application. Because of this unexpected effect, a second fluid application site was negotiated, and a smaller amount of fluids applied to this site.

At the first fluid application site, many trees, shrubs, and understory plants showed immediate responses to the fluid application, with leaves turning brown, wilting, and subsequent leaf and bud mortality. We also observed that taller trees, whose leaves were not contacted by the fluids, also began showing decline symptoms about 10 days after the ground vegetation; these symptoms included leaf browning, leaf curling, and premature leaf drop. Premature leaf fall ranged from 227 to 1,395 kg ha^{-1}, or about 10 to 45 percent of annual autumn leaf fall biomass (Adams 2008). We inferred from these observations that some of the vegetation was damaged immediately by contact with the drill pit fluids, but most likely many of the larger trees were killed as a result of uptake of the fluid through roots from the soil.

All herbaceous and shrub vegetation within the perimeter of the application area showed damage symptoms in 2008; 115 trees (>2.54 cm d.b.h.) exhibited decline symptoms. In 2009, that number had increased to 147 trees (basal area 3.8 m^2). Some recovery of understory vegetation occurred in 2009. Note, however, that more than 50 percent of the trees had no foliage in 2009, and 65 percent of the trees had less than one-third full crown. Mortality was most evident in American beech, with bark sloughing from the bole and branches on 38 percent of the beech trees within the application area perimeter.

Damage symptoms on the second fluid application site were less dramatic (browning of leaves, particularly of northern red oak seedlings), most likely because a much lower volume of fluids was applied, and the operator took care to apply the fluids onto the ground, rather than spraying it onto the vegetation.

We hypothesized that the vegetation on fluid application site 1 was killed as a result of very high salt loading to the site. Although concentrations of chlorides met the permit criteria, an estimated 302,800 L of fluid were applied to this site, resulting in a load of 11,355 kg chlorides per ha. Such a loading far exceeds load limits established elsewhere, such as Oklahoma (450 kg ha^{-1}), Wisconsin (275 kg ha^{-1} on a 2-year basis; www.dnr.state.wi.us/org/water/wm/ww/gpindex/57665_permit.pdf), and in Saskatchewan (400 kg ha^{-1}; http://eps.mcgill.ca/%7Ecourses/c550/Environmental-impact-of-drilling/Sask_Drilling_Waste_Guidelines.pdf).

Monitoring of soil chemistry over time has confirmed that high levels of chlorides, sodium, and calcium were found in the application areas immediately after the fluids were applied (Fig. 2). Although concentrations have decreased over time, soil chloride and sodium levels were still significantly elevated in May 2009 in the application area relative to the control area.

DEER ACTIVITY

We observed extensive use of the area by white-tailed deer, and to a lesser extent black bear, as represented by high density of hoof prints, browse sign, turned-over logs, and disturbed soil, on the areas adjacent to the gas well, and on the fluid application areas. The levels of wildlife sign greatly exceeded what is normally observed on the Fernow in a localized area. After reclamation of the drill pit, there were several seeps on the lower side of the well pad where the contractor was unable to establish vegetative cover because deer utilized this area as

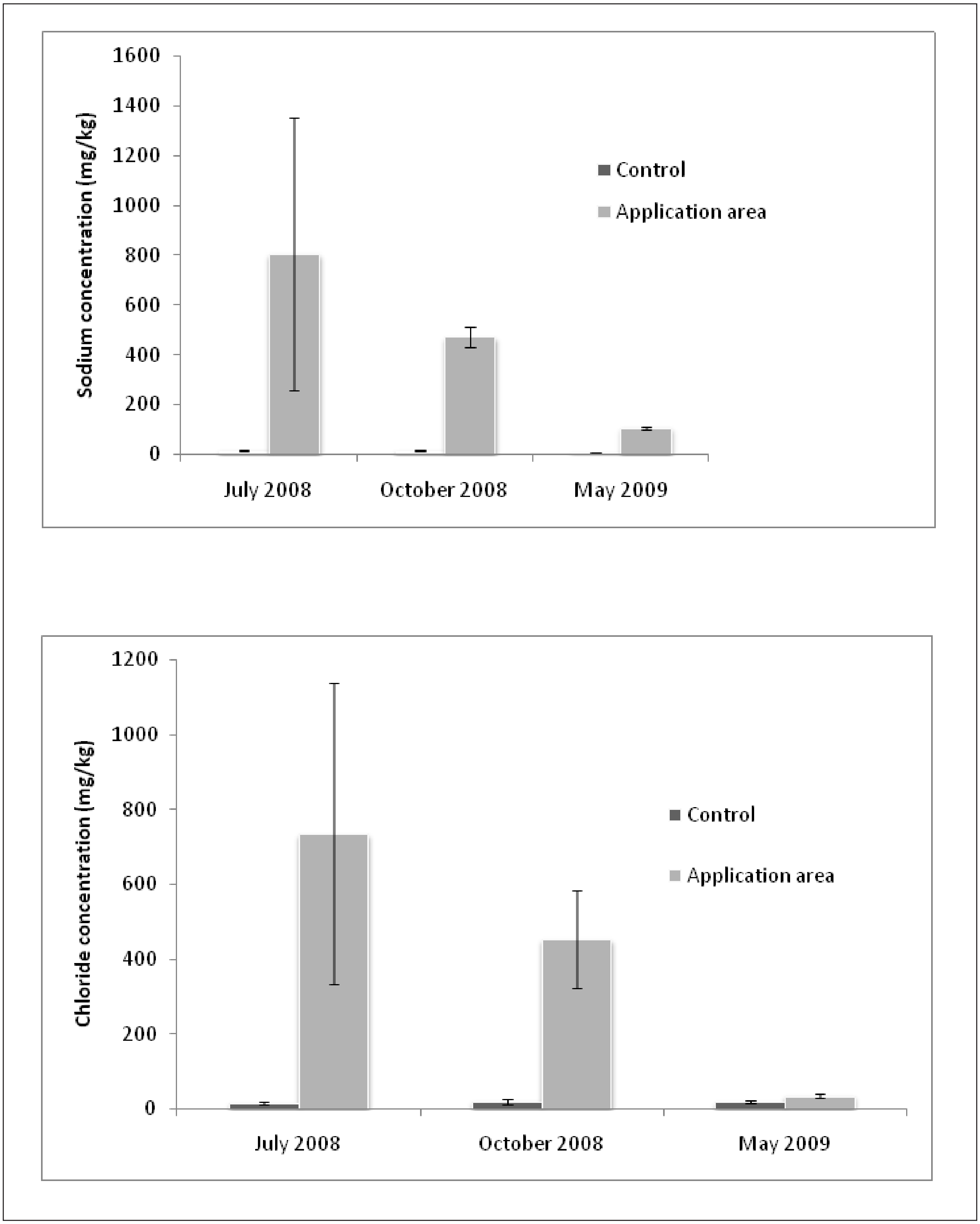

Figure 2.—Sodium and chloride concentrations in soil from fluid application area 1, and an adjacent control area, Fernow Experimental Forest, West Virginia, over time. Fluids were applied in late June 2008. Soil samples were collected from the surface 10 cm from three transects per area.

a mineral source or "lick". Covering of these sites with slash was moderately successful in allowing germination of the seeded ground cover to proceed, but high levels of deer activity around these seeps continued into late summer 2009. Similar deer behavior has been previously documented as an unintended consequence of gas development in the region (Campbell and others 2004).

RECOMMENDATIONS

All discussions about development of energy resources, including natural gas, should include careful consideration of the effects on natural resources. From our experiences on the Fernow Experimental Forest, we present some of the lessons learned that perhaps should be incorporated into these important discussions.

Some of the impacts of natural gas development can be predicted, and these impacts can be lessened through planning and cooperation. For example, the area cleared for the well site, and for the pipeline in particular, was negotiated so as to minimize impacts. Soil loss from construction of the well site was inevitable, but silt fences installed by the contractor and by the U.S. Forest Service minimized transport of that sediment to nearby water sources. These mitigating activities required negotiation and communication by all parties involved.

The unexpected will always happen, and should be part of any planning discussions. The unexpected did occur during the development of the gas well and pipeline on the Fernow. We attribute such occurrences to accidents, equipment failures, and misconceptions about what to expect. Our misconceptions may be similar to those of private landowners with little direct experience with gas well development. Discussions of the process between the energy developer and the landowners/managers should happen early and often to be sure that all parties' expectations are clear. Visits to active development sites can help landowners better understand what to expect, and also help them communicate their wishes to the developer. Landowners who also own the subsurface rights have the authority to require the developer to follow desired procedures. Landowners who do not own the subsurface rights still retain some legal rights during gas well development, and may want to seek council to ensure those rights are respected. Surface owners' organizations (for example, www.wvsoro.org) can help to educate landowners about their rights and what to expect. While we recognize that it is impossible to foresee every eventuality, we suggest that a thorough analysis of risks to natural resources, using alternative "what-if" scenarios, should be conducted.

Much more research is needed immediately to better understand and predict the effects of natural gas exploration and development on forests, particularly in the eastern United States. We were surprised by the paucity of peer-reviewed research evaluating effects of natural gas development on forest lands in the eastern United States. For example, as mentioned above, the permit standard in West Virginia for land application of hydrofracing fluids is based on a concentration rather than a total amount of chemicals applied, which might provide better resource protection. Unfortunately, little research is available to use in developing a dose-based standard, and such research could improve information available to policymakers, regulators, and energy developers. We also know little about the effects of exploration and development on ground water hydrology and water quality, and surprisingly little about effects on downstream surface waters. In general, information about effects on most fauna also is lacking (but see Moseley and others 2009).

Other questions include:

- How can the risks associated with natural gas development in karst geology be evaluated and mitigated?
- What are the effects of elevated chlorides and salts on water quality and biota in the soil, ground water, or stream water?
- Are there significant edge effects from the pipeline corridor—changes in light, temperature, or moisture regimes? Are these similar to effects of roads and other permanent openings?
- How can we evaluate the cumulative effects of natural gas development within a landscape?

LITERATURE CITED

Adams, M.B. 2008. **Long-term leaf fall mass from three watersheds on the Fernow Experimental Forest, West Virginia.** In: Jacobs, D.F.; Michler, C.H., eds. Proceedings, 16th central hardwood forest conference. 2008 April 8-9; West Lafayette, IN. U.S. Department of Agriculture, Forest Service, Northern Research Station. Gen. Tech. Rep. NRS-P-24. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 179-186.

Adams, M.B.; Edwards, P.J.; Ford, W.M.; Johnson, J.B.; Schuler, T.M.; Thomas-Van Gundy, M.; Wood, F. (in process). **Effects of development of a natural gas well and associated pipeline on the natural and scientific resources of the Fernow Experimental Forest.** Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Campbell, T.A.; Laseter, B.R.; Ford, W.M.; Miller, K.V. 2004. **From the field: unusual white-tailed deer movements to a gas well in the central Appalachians.** Wildlife Society Bulletin. 32(3): 983-986.

Chen, C. 1974. **Evaluation and control of soil erosion in urbanizing watersheds.** In: National symposium on urban rainfall and runoff and sediment control; proceedings of a symposium held July 29-31, 1974. Report UKY BU106. Lexington, KY: University of Kentucky: 161-173.

Dickerson, B.P. 1975. **Stormflows and erosion after tree-length skidding on coastal plain soils.** Transactions, American Society of Agricultural Engineers. 18: 867-868, 872.

Edwards, P.J. 2008. **Monitoring report for the Fernow gas well: surface erosion and in-stream turbidity results.** NRS Monitoring Report. Parsons, WV: Timber and Watershed Laboratory. 11 p.

Kochenderfer, J.N. 2006. **Fernow and the Appalachian hardwood region.** In: Adams, M.B.; DeWalle, D.R.; Hom, J.L., eds. 2006. The Fernow Watershed acidification study. Dordrecht, The Netherlands: Springer. 279 p.

Moseley, K.R.; Ford, W.M.; Edwards, J.W. 2009. **Local and landscape scale factors influencing edge effects on woodland salamanders.** Environmental Monitoring and Assessment. 151: 425-435.

Ursic, S.J.; Douglass, J.E. 1979. **Effects of forestry practices on water resources.** In: Proceedings of the W. Kelly Mosely environmental forum. Auburn, AL: Auburn University Press: 33-49.