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Effects of Development of a Natural Gas Well and Associated Pipeline on the Natural and Scientific Resources of the Fernow Experimental Forest

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Abstract

Development of a natural gas well and pipeline on the Fernow Experimental Forest, WV, was begun in 2007. Concerns were raised about the effects on the natural and scientific resources of the Fernow, set aside in 1934 for long-term research. A case study approach was used to evaluate effects of the development. This report includes results of monitoring projects as well as observations related to unexpected impacts on the resources of the Fernow. Two points are obvious: that some effects can be predicted and mitigated through cooperation between landowner and energy developer, and that unexpected impacts will occur. These unexpected impacts may be most problematic.

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Acronyms and Abbreviations

d.b.h.	diameter at breast height
DEP	Division of Environmental Protection (West Virginia)
DSF	Direct Site Factor
FS	Forest Service
FS701	Forest Service Road #701
MNF	Monongahela National Forest
NTU	Nepholometric turbidity units
PAR	Photosynthetically active radiation
ROW	Right of Way

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INTRODUCTION

Recently, an increased demand for natural gas, coupled with advanced technology for extraction, has led to an increase in mineral exploration and development in many previously unexplored areas. The impacts of this increased development pressure are largely unknown for forest land in the eastern United States. Landowners and land managers are seeking information about these effects to help them make decisions about mineral resource development and associated impacts to surface resources.

In 2001, a natural gas and energy development company leased the privately owned minerals under federally owned U.S. Tract 1, which underlies the Fernow Experimental Forest and about the northern quarter of Otter Creek Wilderness (Fig. 1) in the Monongahela National Forest (MNF) in West Virginia. U.S. Tract 1 was acquired as part of the MNF in 1915, with the mineral rights reserved by the seller. The Fernow, established in 1934, is dedicated to long-term research (Adams et al. 2008) and is part of several national and international research and monitoring networks. In summer 2007, the energy company proposed a gas well within a long-term research compartment (Compartment 16) of the Fernow (B800 well, Fig. 1). When gas was confirmed after the B800 well was drilled, a pipeline was proposed and a right-of-way (ROW) was identified and cleared.

The purpose of this report is to document the impacts of this natural gas development on the natural and scientific resources of the Fernow Experimental Forest. This report describes results from a single case study in a single experimental forest. Although some physical impacts from clearing and construction of the well site and pipeline ROW were predictable, other impacts were not expected or predicted. Because of time and logistical constraints, and because some of the impacts were unforeseen, the data described here generally come from post hoc monitoring, not designed experimentation. In most cases, there is no replication and relatively little pretreatment data. Nor were all the potentially sensitive components of the ecosystem monitored. Information on fauna, in particular, is lacking. The U.S. Fish and Wildlife Service has responsibility for Endangered Species protection and requires biannual counts of Indiana bat[1] and Virginia big-eared bats that overwinter in Big Springs Blowing Cave, located within the Fernow and near the B800 well site[2]. However, effects on other potentially sensitive fauna, such as the endemic Greenbrier Cave isopod, found only in 18 caves including the Big Springs Blowing Cave system, were not evaluated. Finally, many of the impacts were difficult to quantify. As such, this report provides a detailed description of our *observations* of impacts on the resources of the Fernow.

Because of the limitations to the data, it is not appropriate to extrapolate our findings and observations to other mineral development sites across the region. However, such documentation of natural gas development effects on natural resources in central Appalachian hardwood forests is needed and can provide us with useful insights. In addition, this site allows the assessment of impacts from gas well development on a research forest specializing in long-term research. There is a dearth of published research describing the effects of natural gas development on eastern forests. Therefore, the information summarized in this report is novel and useful for future environmental impact analyses and decisionmaking. Such information also will identify avenues for future research.

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[1] See Appendix for scientific names of organisms listed in this text.

[2] Those data are available from the West Virginia Division of Natural Resources, Natural Heritage Program, P.O. Box 67, Ward Road, Elkins, WV 26241, Attn: Barbara Sargent; or through the Web page http://www.wvdnr.gov/wildlife/data.shtm

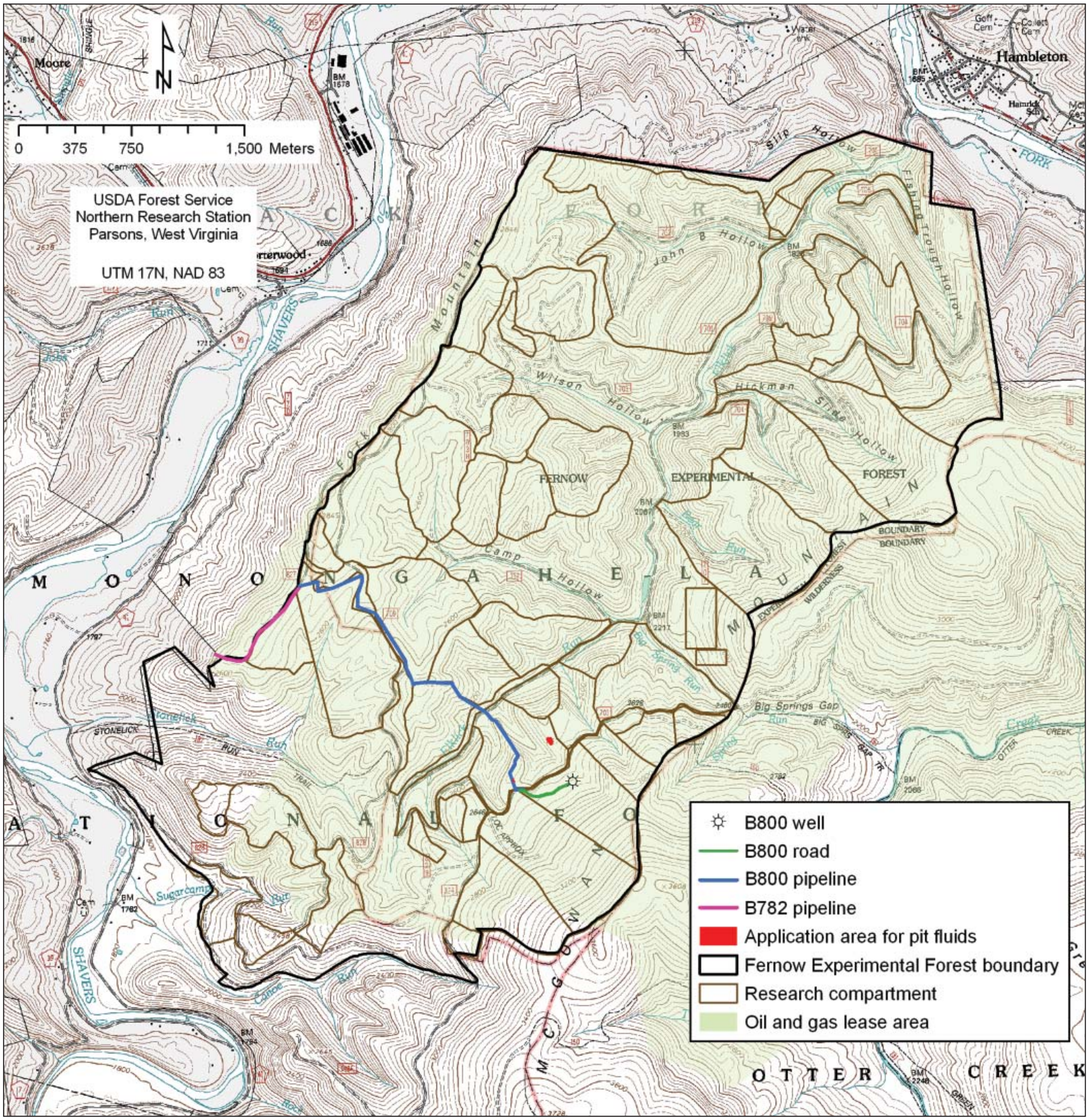

Figure 1.—Map of Fernow Experimental Forest and U.S. Tract 1 lease area, showing locations of B800 well site, pipeline, and significant features.

METHODS

Site Description

The B800 well site is located within the 1,902-ha Fernow Experimental Forest, which is in the Allegheny Mountain section of the mixed mesophytic forest (Braun 1950). 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). Hardwood forest vegetation dominates the area, and the Fernow is managed for research and demonstration. For more information on the history and resources of the Fernow, see Kochenderfer (2006).

The B800 well site is located within a subcompartment of compartment 16 (Fig. 1), which is dedicated to a demonstration of late-rotation crop tree release and two-age management. The demonstration area, established in 1990, has been a frequent destination for many Fernow tours. The subcompartment is 9.8 ha with a northwest aspect and a site index of 77 (base age of 50 years for northern red oak). Such a high site index reflects the influence of the underlying limestone bedrock. About 51 crop trees ha^{-1} were left following crop tree release in 1990. The new age-class of trees established since then consists primarily of black birch, yellow-poplar, and sugar maple. This age-class of trees is undergoing self-thinning and reflects many aspects of an even-aged stand in the early stages of development. The subcompartment is bordered by a Forest Service road (FS701) to the northwest; it contained a skid trail and a small open area that served as a log deck, before replacement by the B800 access road.

The B800 well site and access road are located on karst topography within the Elklick Run watershed, which is part of the Dry Fork subwatershed, a sixth-level HUC (hydrologic unit code) (Seaber et al. 1987). Surficial bedrock geology is the Greenbrier Group, which includes cavernous limestone. Karst features, specifically closed-bottom sinkholes and water disappearance and reappearance within intermittent and ephemeral stream channels, are present within the area of the well site. Groundwater emerges at two major springs located about 1,000 m northeast of and at a lower elevation than the B800 well site. Known underground passageways within the Big Springs Cave are located about 600 m away from, and at a lower elevation, than the B800 site.

Well Site Development

A detailed timeline of the well and pipeline development process is provided in Table 1. Much of the timing of the various activities was controlled by weather conditions and by the availability of equipment required at each stage of well development. Development of the B800 gas well site[3] required about 8 months from the time the West Virginia Division of Environmental Protection (DEP) approved the well work permit application (Table 1). Logging of the site by the Fernow logging crew was completed in slightly less than a month, and site clearing and construction required about 3 months.

It was estimated that 1.4 ha would need to be cleared for the B800 well site: 1.0 ha for the well pad and 0.4 ha for a 335-m-long access road. Trees were cleared from this area, 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.

Drilling required about 3 weeks and was completed to a depth of 2,387 m. After completion of drilling, the rock layer was fractured to release natural gas in the formation (a process known as hydrofracing). Subsequently, the drill pit fluids (about 302,800 liters)

[3] Note this is not the first gas well site within the Fernow. In 2005, about 1.25 acres were logged for the B782 gas well, near the western boundary of the Fernow, but the B782 site was not used.

were land-applied to approximately 0.2 ha within subcompartment 17B (Fig. 1), per the company's drilling permit. Dramatic foliar injury and death of vegetation during this application necessitated a change of application site, and the remaining 75,700 liters were applied within the pipeline ROW on an area of about 0.04 ha (the Discharge Monitoring Report filed with the State indicated that a total of 378,500 liters had been applied to 0.8 ha). The remaining pit contents were then solidified by adding cement and buried in place. A road use permit issued by the MNF allowed use of Fernow roads to move equipment and personnel to and from the site. In addition, about 378,500 liters of water from the reservoir on the Fernow were hauled by tanker trucks to B800 for use during the drilling and hydrofracing process.

Table 1.—The chronology of activities on the B800 well site and associated pipeline (documentation is available in electronic mail or formal correspondence files at the Timber and Watershed Laboratory, Parsons, WV); a list of abbreviations and acronyms can be found on the inside front cover of this report.

Date	Activity
May 11, 2007	Energy company contacts the Forest Service (FS) with project map and requests input.
May 23, 2007	FS sends letter identifying issues with proposed site.
June 21, 2007	Joint energy company and FS review of the site/issues on the ground.
July 20, 2007	FS and energy company review of proposed erosion and sediment control plan.
Sept. 11, 2007	FS receives copy of well work permit application.
Sept. 21, 2007	WV DEP, Office of Oil and Gas approves well work permit application.
Sept 21, 2007	FS Request for Comments on B800, legal notice issued.
Nov. 2, 2007	Decision Memo and Biological Evaluation signed.
Dec. 2007	Appeal period ends – no appeals received.
Jan. 2008	Timber on access road/well site sold, cut by Fernow logging crew.
Feb. - April 2008	Access road/well site constructed.
April 8, 2008	Well drilling begins.
April 30, 2008	B800 well reaches total depth of 2,387 m. Gas confirmed in the Huntersville Chert portion of the Oriskany and associated strata, and possibly the Oriskany sandstone. Drill pipe breaks and sticks in the well bore. Directional drilling around stuck pipe.
May 15, 2008	Drilling completed.
May 16, 2008	Drill rig leaves the site.
May 23, 2008	Hydrofracing begins, completed on May 31.
May 29, 2008	Particulates/aerial spray released from well bore.
June 13, 2008	Road repairs completed.
June 16, 2008	Legal announcement issued for pipeline right of way (ROW).
June 21, 2008	Land application of drill pit fluids completed to Site 1.
July 15-17, 2008	Land application of drill pit fluids completed to Site 2.
July 28, 2008	Pit contents solidified and back-filled.
Aug. 12, 2008	Decision Memo signed for pipeline ROW clearing.
Sept. 9, 2008	Recontouring of the well site begins.
Oct. 2, 2008	Cutting of pipeline ROW begins.
Oct. 7, 2008	Recontouring of well site completed.
Nov.14-15, 2008	Dry trenching completed across Elklick Run.
Dec. 15, 2008	Well pad and access road seeded and mulched.
Dec. 29, 2008	Pipeline installation through small wetland via dry trenching completed.
Dec. 31, 2008	Cutting of pipeline ROW and removal of harvested stems completed.
Jan. 29, 2009	Pipeline installation completed.

Because the mineral rights for this action were privately held, the decisions to be made by the Forest Service were limited. Nonetheless, environmental analyses and decision documents for the B800 well and pipeline were required and are available on the MNF Web page (http://www.fs.fed.us/r9/mnf/environmental/nepa_documents/nepa_index.htm). The WV DEP issued the permit for drilling the B800 well.

Data Collection and Monitoring Methods

Where feasible, we used standard monitoring methods for the anticipated impacts (effects on erosion, water quality, and vegetation loss) and developed measurement techniques to assess the unexpected impacts when additional problems were discovered. Because of limited time, personnel, and resources, and unexpected events, we were unable to monitor as thoroughly as we desired; therefore, many of our observations are simply that—observations.

Erosion and Sediment

Silt fences were used to collect sediment from the well pad site. In addition to perimeter silt fence constructed by the energy company's contractor around the lower and east edges of the well site, more silt fences were later installed by the contractors and by Forest Service employees (Fig. 2). All of the soil collected from behind the supplemental silt fences was oven dried at 100 ºC; the oven-dried masses were determined and then totaled by silt fence segments. The collected material was not combusted to remove the organic matter from the soil, but almost no organic material was visible, so the measured masses were assumed to be almost entirely inorganic material. Particle size analyses also were not conducted because of the very large mass involved, but almost all of the material collected was soil-sized particles (i.e., < 2 mm).

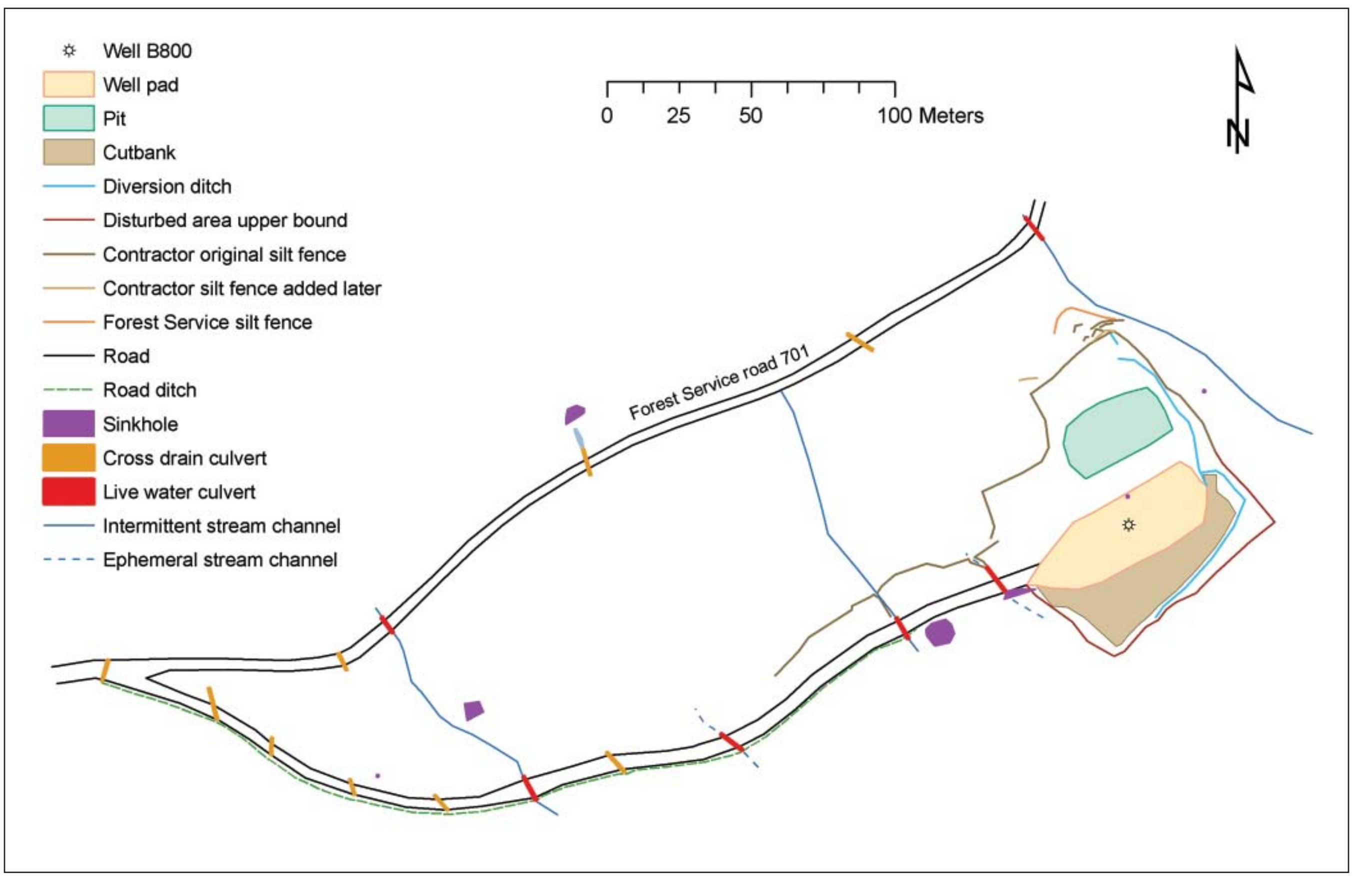

Figure 2.—Diagram of B800 well site, Fernow Experimental Forest, showing locations of water and sediment control devices and of water and sediment areas of concern (from Edwards 2008).

Water was sampled for turbidity analyses at two locations: Big Spring just below FS701 and at the outflow of Big Springs Blowing Cave. This sampling was done out of concern about possible connections between those sites and the well site via subsurface flow through the karst geology. Throughout the monitoring effort, stream samples were collected at preset time intervals using ISCO model 2700 automatic samplers (Teledyne Isco, Inc., Lincoln, NE). At Big Spring, the uptake line for the sampler was positioned in the approach box of the inactive flume that had been built in the early 1990s. At Big Spring Cave, the uptake line was positioned on the stream bottom at about the midpoint of the cross section at the cave mouth.

The frequency of turbidity sample collection depended upon the activities at the well site; thus, sampling frequency was different during different chronological periods of well development. Samples were collected at 6-hour intervals from August 2, 2007, to December 16, 2007, before any ground-disturbing operations. No samples were collected from December 17, 2007, through February 4, 2008, because frozen uptake lines prevented sampling. When sampling began again on February 5, 2008, the frequency was reduced to 2-hour intervals in anticipation of access-road construction expected during the week of February 11. The sample frequency was further intensified to 1-hour intervals on April 8, 2008, the day drilling began. On April 18, sampling was changed back to 2-hour intervals because drilling had passed through the entire limestone layer. Drilling ended May 15, 2008, and the sampling frequency returned to 6-hour intervals on May 27. Recontouring the pit area began September 9, 2008 (+/– 1 day) and was completed on October 7. For 2008, sampling at Big Spring was terminated on September 8, due to low flows; sample collection at Big Spring Cave continued until November 17, when freezing conditions prevented sample collection by the automatic sampler.

The turbidity of each sample was determined in the laboratory using a Hach model 18900 turbidimeter. Results were measured and recorded in Nepholometric turbidity units (NTU). Instrument calibration was performed using stabilized formazin standards. For more details, see Edwards (2008).

Vegetation Condition at Fluid Application Sites

Vegetation injury was observed during the land application of fluids in June 2008. Immediately thereafter, a perimeter of the impacted area was delineated and all trees greater than 2.54 cm diameter at breast height (d.b.h.) that showed symptoms of damage (discolored or damaged foliage, loss of foliage) were marked with flagging, so that their condition could be monitored. Trees were identified to species, and their diameter was measured. Trees greater than 25.4 cm d.b.h. were given individual numbers, and the number of merchantable logs and the grade of the butt log were determined, so that changes in log quality over time could be assessed. This site was revisited in late May 2009, and all the marked trees were reassessed for presence/absence of foliage, percent of full canopy, and presence of any other symptoms such as sprouting, epicormic branching, dwarfed foliage, discolored foliage, or bark sloughing. In addition to trees marked the previous year, any trees within the perimeter that showed symptoms, but were not marked the previous year (those that did not show symptoms in July 2008) were marked and assessed.

Early Leaf Fall and Canopy Openness at Fluid Application Site 1

During fluid application, we observed that trees began dropping leaves early—in late June and early July. We used two methods to estimate the extent of premature foliar loss on fluid application area 1. First, we assessed the mass of freshly fallen (green) leaves within the fluid application site on July 9, 2008 (about 2 weeks after fluid application was halted). Samples were collected using three sampling transects and a sampling template of 668 cm^2 placed at 5-m intervals along the transect. All freshly fallen leaves (indicated by green color on >50 percent of the leaf surface area) within the sampling template were collected, and the mass of the fallen leaves was determined after drying at 70 °C for 2 days.

Second, to assess the amount of solar radiation penetrating through the canopy after leaf fall, we used a Nikon E8400 digital camera, coupled with a Nikon FC-E9 fisheye lens, to take hemispherical canopy images, about 3 weeks after fluid application ceased. Because no images were taken before the premature leaf fall, our analysis was limited to comparing post-impact conditions to similar areas that were not impacted. We conducted canopy analysis using the WinsCANOPY software version 2006b (Regent Instruments Inc., Quebec, Canada). Interactive masks were used to block any ground surface captured in the image due to slope characteristics. We defined the growing season for canopy analysis as May 1 to September 30, and we used standard overcast conditions as defined by Anderson (1971). WinsCANOPY estimates numerous canopy parameters based on calculated solar tracks and canopy characteristics. We report the under-canopy direct site factor (DSF) and openness. Openness is the fraction of the total number of pixels classified as open sky, adjusted for the lens, in the real canopy above the lens. DSF is the ratio of the average daily direct radiation received under the canopy and the average daily direct radiation received over the canopy for the growing season expressed as a percent. Because photosynthetically active radiation (PAR) is a constant percent of total radiation, we used DSF as a surrogate for the amount of PAR penetrating the forest canopy to the height of the lens.

Soil Chemistry at Fluid Application Sites

To evaluate effects of land application of pit fluids on soil chemistry, we ran two or three transects within each of the fluid application sites, depending on size of the area. We also sampled an equivalent number of transects in adjacent forest area with similar aspect and vegetation as controls. For fluid application site 1, three transects were sampled within the fluid application perimeter (Treated) and three transects were run in adjacent forest area with similar aspect and vegetation showing no symptoms (Control). For fluid application area 2, because it was a smaller area, only two transects were run within each Treated/Control area, and it was sampled only once, in August 2008. Soil samples were collected every 5 m along the transect, using a soil pushprobe to a depth of about 10 cm, and composite samples were created by transect. Soil samples were collected from the first fluid application area on July 9 and October 17, 2008, and again on May 18, 2009. Samples were air-dried and analyzed for nutrients and elements at the University of Maine Soils Testing Laboratory, using standard Forest Soil protocols and established QA/QC standards. Means for the control and treatment area were compared for each sampling period for the first fluid application area, using t-tests (p=0.10) (Steel and Torrie 1980).

RESULTS AND DISCUSSION

Expected or Predicted Impacts

An area of approximately 0.63 ha was cleared for the well pad and drill pit; this is slightly less than the area originally estimated. Ninety-four trees (>28 cm d.b.h.) and 126 pulpwood stems (12.7 to 28 cm d.b.h.) were removed, and much reshaping and contouring of the site was required (Fig. 2). All ground vegetation was removed within the perimeter. The road surface and adjacent ditch covered 0.20 ha. The cleared area represents 8.5 percent of subcompartment 16A, less than the originally estimated 14 percent.

The pipeline ROW was located to minimize impacts on active research compartments (Fig. 1), and it runs adjacent to 10 active research and demonstration compartments (totaling 152 ha). The pipeline also required excavating crossings of Elklick Run (Fig. 1) and a small wetland area. The area of the pipeline ROW was estimated to be 2 ha (8 to 9 m wide and 1,798 m long). The trees were felled, and the ROW was cleared using an excavator and bulldozer. Stumps were bulldozed and removed to the side of the ROW. During preparation of the ROW, a total of 714 trees were removed, 310 (43 percent) of those being greater than 28 cm d.b.h.

Initially, the energy company installed silt fences to reduce sediment loss and delivery from the well site, primarily around the perimeter of the well pad site and along the access road (Fig. 2). However, within a relatively short time, the perimeter silt fence was undermined or overtopped along much of its length. The silt fence was least effective in the northern corner of the site because water was rerouted and allowed to concentrate. A relatively large amount of subsurface flow became emergent and remained as concentrated overland flow as the result of the construction of the cutbank around the well pad. This water provided the energy to destabilize, dislodge, and transport exposed soil from the cutbank. Heavy rains on March 4 and 5, 2008, spurred further erosion. During this rainstorm, the concentrated flow and associated sediment initially was routed to a sinkhole (Fig. 2). An unknown amount of eroded soil entered the sinkhole during that storm period. On March 7, 2008, energy company contractors constructed a trench in the upper portion of the cutbank and just inside the perimeter of the silt fence along the eastern side of the well pad and pit area to reroute water and sediment away from the sinkhole.

However, the rerouting of additional water and sediment inside the perimeter fence resulted in the silt fence being overtopped and further undermined in the northern corner. Consequently, five additional short lengths of silt fence (totaling 28.2 m) were installed further downslope to help reduce the water flow and retain sediment. These additional sections of silt fence still did not fully contain sediment coming from the site. The visible evidence suggested that the water infiltrated the soil and the eroded soil settled out before reaching the ditchline on FS701. Also, because of the evidence of extended soil transport and elevated erosion, an additional 27.2-m length of silt fence was installed downslope of the contractor's silt fence by the Forest Service on May 5, 2008 (Fig. 2).

The mass of sediment collected by these non-perimeter silt fence sections during the summer of 2008 is reported by collection date in Table 2. A total of 1,330.12 kg of soil material was collected from the fences. Given a cleared area of 0.63 ha, this would amount to 2.1 metric tons per hectare. This estimate is conservative, however, because it represents only a portion of the soil that moved off the site. Soil eroded from the site before installation of these fences, and soil moved off the well site at other locations, including from the road into the ditch along FS701. In addition, short-term losses to the sinkhole east of the pit were not measured or estimated. Therefore, 2.1 metric tons per hectare likely underestimates total site erosion losses.

Because of the concern about possible subsurface flow connections through the karst geology, water quality was sampled at two locations as described above (see Edwards 2008). More than 99 percent of the turbidity values from both sites were <40 NTU;

Table 2.—Mass of sediment collected from silt fences (excluding the perimeter fence) installed by contractors and the Forest Service on the north side of the well pad and pit, Fernow Experimental Forest, by date of collection (see text for description of methods)

Collection date	Contractor fence sections	Forest Service fence sections	Total
	(kg)		
May 7, 2008	76.30	not installed	76.30
June 26-27, 2008	225.28	618.06	843.34
Sept. 3, 2008	not collected	410.48	410.48
Total	301.58	1028.54	1330.12

only 7 of the 2,035 samples collected from Big Spring and only 12 of the 2,403 samples collected from Big Spring Cave had turbidities exceeding 40 NTU. All of the samples from Big Spring had turbidity values less than 120 NTU as did most of the samples from Big Spring Cave. The two largest turbidity values at Big Spring Cave (252 and 292 NTU) were observed after completion of drilling activities, and both of these measurements were associated with large rainfall events. Approximately 6.4 cm of rain occurred before the first of these was measured, and about 4.7 cm occurred before the second. All of the turbidity values from both sites are within ranges commonly reported in this region; indeed, the preponderance of relatively unvarying low turbidities (< 40 NTU) reflects that most of the flows sampled at these locations originated from groundwater. Streams with larger contributions of surface runoff typically have low turbidities, but they tend to vary more through time, especially during storms or where influences of road runoff would be expected.

The mean turbidity values for the five periods at each site are shown in Table 3. In all five periods for both sites, the mean turbidities were less than 5 NTU (Table 3). Values below 5 NTU are not visible to the human eye (Strausberg 1983), so the flow would have appeared to be clear. Based upon the relatively low and unvarying turbidities observed at either site, and given the reasonably large amount of obviously muddy water flowing into the sinkhole east of the pit, it does not appear that there is a strong or direct connection between that sinkhole and the monitored streams, nor that there were other connections with the karst geology in that area.

The Well Operator's Report (AP1#47-093-00107, available from the WV DEP) describes drilling through three caves (the deepest at 50 m below the surface), and fresh water was encountered at 120 m below the surface. While the well bore was cased in concrete to protect water quality in these sections, these observations reinforce that we have an

Table 3.—Least square mean turbidities and standard error (in parentheses) for stream water collected before, during, and after gas well drilling, collected at two sites on the Fernow Experimental Forest, 2008

Period	Big Spring	Big Spring Cave
	(NTU)	
Pre-disturbance	2.98 (0.24)	2.80 (0.46)
Access road, pad, pit construction	2.16 (0.22)	3.30 (0.42)
Drilling through limestone	1.28 (0.35)	1.50 (0.67)
Drilling below limestone	2.85 (0.24)	3.44 (0.49)
After drilling/before reconstruction	4.80 (0.26)	3.68 (0.39)

incomplete knowledge of the connectiveness within the geologies of this area. A better understanding of karst connections could be obtained by dye tracer studies.

Some damage to roads was expected and was observed during site development and drilling (Fig. 3), despite spot graveling. Ruts of 30 cm or greater developed, roadside drainage ditches were filled or collapsed, and erosion of the road surface subsequently occurred. The problem appeared to be caused by heavy vehicle traffic when the roads were very wet, and insufficient preventive graveling. Conditions were such that FS701 between Big Springs Gap and the McGowan Mountain road (FS324) intersection (about 2 km) was closed to the public for safety reasons. Although some damage was expected, the severity of the impacts was greater than we had expected. After drilling was complete, the roads were repaired by grading and application of stone.

Unexpected Impacts

Probably the most severe, and certainly the most dramatic, of the unexpected impacts are related to the drilling and hydrofracing fluids. Because there was no brine indicated within the geology of the well site, the risk to vegetation was assumed to be minimal. However, obvious and measurable damage to vegetation did occur from these fluids at three different locations.

On June 11, 2008, damage to about two dozen trees was noted immediately adjacent to the well pad on the lower west side by Fernow staff. Browning of foliage and a lack of ground vegetation for several meters into the residual stand were observed (Fig. 4). Many of the trees subsequently dropped their foliage. These symptoms were attributed to a loss of control of the drill bore on May 29, 2008, resulting in an aerial release of materials that drifted over areas immediately

Figure 3.—Damage to road surface and roadside ditch on the Fernow Experimental Forest from gas well construction and drilling equipment. Note that the drainage ditch has been obliterated. Photo taken May 22, 2008. Photo by U.S. Forest Service.

Figure 4.—Foliar injury of trees damaged by aerial release of drilling fluids on May 29, 2008, from the B800 well. Pit containing drilling fluids is shown in the foreground. Photo taken June 11, 2008. Photo by U.S. Forest Service.

adjacent to the well pad and drill pit. These effects were still evident several months later in the autumn, prior to leaf fall. Trees showed no noticeable symptoms in the summer of 2009. Fluids in this release may have had high pH levels from the tallow plug used to hold the fracturing fluids in the formation. Because a major component of the fracturing fluids was hydrochloric acid (15 percent; Well Operator's Report, AP1#47-093-00107, available from the WV DEP), an alternative explanation may be that a low pH solution containing high chloride levels is responsible for the observed symptoms. Clearly, a better knowledge of the chemical makeup of the drilling and hydrofracing fluids is needed in order to understand and predict possible impacts on the resources.

Also, fluids from the drill pit that were land-applied at two locations on the Fernow resulted in dramatic impacts on vegetation. Land application involves spraying the fluid into the air and, in this instance, onto the vegetation (Fig. 5). It was assumed that if the drill pit fluids met the standards specified in the permit, there would be no damage to the vegetation or soil. Levels permitted by WV DEP for this pit were chlorides below 12,500 mg L^{-1} and a pH between 6 and 10. Note that these are concentrations and not loads. An estimated 302,800 L of drill pit fluids were applied to an area of about 0.20 ha in subcompartment 17B (fluid application site 1). Fluid application site 1 represents 2.6 percent of subcompartment 17B. The fluid application area was deliberately kept small in area in order to minimize possible impacts to the ongoing research. This intent obviously backfired. The second fluid application site was located within the pipeline ROW corridor (fluid application site 2) along the boundary of compartments 17 and 19 and received an estimated 75,700 L of drilling pit fluids.

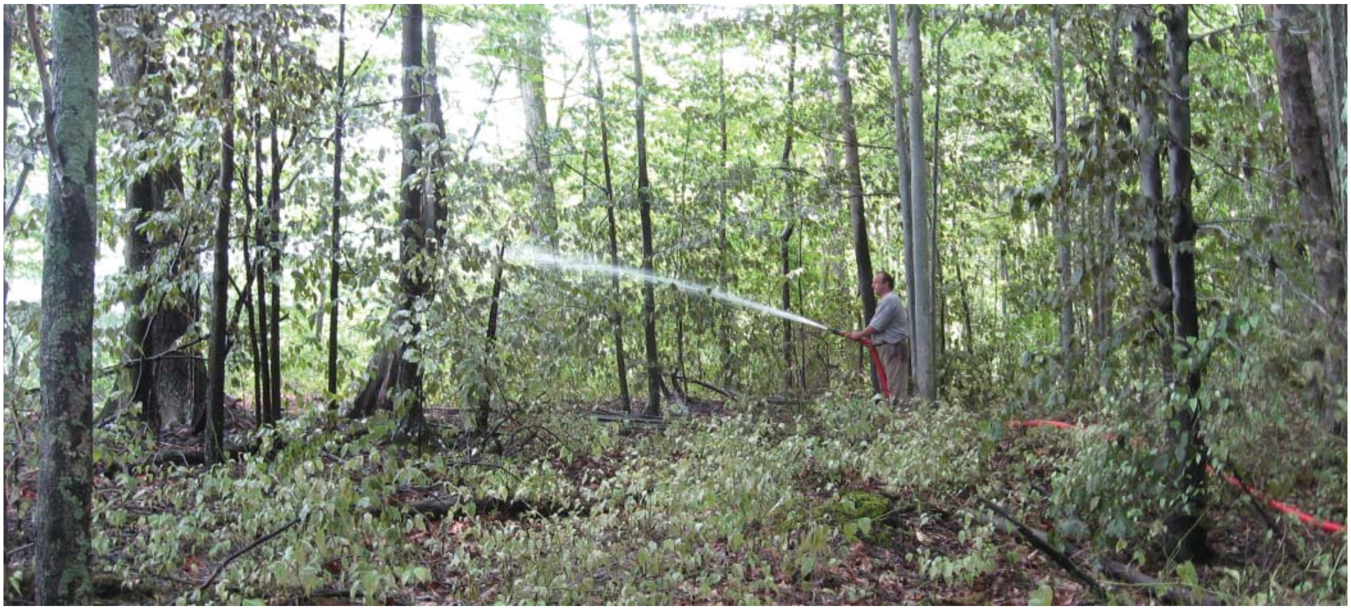

Figure 5.—Land application of drill pit fluids to fluid application site 1, Fernow Experimental Forest, June 2008. Photo by U.S. Forest Service.

On June 19, 2008, severe browning of foliage on the first fluid application site was discovered by Fernow staff (Figs. 6-8; Table 4). Initial effects were immediately visible on shrubs and small trees; however, within about 10 days, leaves of older trees (> 20 m in height), which were unlikely to have been directly contacted by the spray, were showing similar symptoms, and numerous trees began dropping green (fresh) leaves (Fig. 7). Ground vegetation and vines, including greenbrier, were top-killed or killed outright (Fig. 8). The temporal and spatial development of symptoms suggested that the effects were due to both direct contact of foliage with the spray, and to uptake of the solution from the soil by tree roots. A total of 115 trees (10 species), nearly all of those within the perimeter of the application area, exhibited some symptoms of damage (leaf browning, leaf drop, or twig dieback) in 2008.

Almost a year later, in May 2009, the number of trees included in the tally increased to 147, representing 11 species (Table 4). Half of these trees had no live foliage, and two-thirds had less than 35 percent full crown. Although there was some sprouting of tree seedlings and ground vegetation within the perimeter, there were still significant areas of dead ground vegetation in May 2009. Nearby trees outside the application area were nearly fully leafed out and green (Fig. 9). The 2009 tally included trees that had no symptoms in 2008 and a few trees that had shown symptoms in 2008 but were symptom-free in 2009 (mostly understory red maple trees < 12 cm d.b.h.). Symptoms observed in 2009 included dwarfed foliage, discolored foliage, and bark sloughing. Trees with no live foliage in May 2009 were considered dead. We also looked for evidence of basal-stem or root sprouting, but observed very little sprouting.

Table 4.—Trees within fluid application site 1 with damage symptoms due to application of drill pit fluids, July 2008 and May 2009, Fernow Experimental Forest

	July 2008		May 2009
Species	**Number**	**Diameter range**	**Number**
		(cm, d.b.h.)	
American beech	57	2.5 to 15.2	57
Red maple	29	3.8 to 55.9	47
Sassafras	10	2.5 to 10.2	10
Northern red oak	6	2.5 to 68.6	14
Yellow-poplar	5	12.7 to 27.9	6
Sweet birch	4	2.5 to 12.7	5
Chestnut oak	1	40.6	1
Cucumber tree	1	5.1	1
Fraser magnolia	1	5.1	1
Downy serviceberry	1	7.6	3
Sourwood			2
Total	115		147

Figure 6.—Foliage injury of Fraser magnolia on fluid application site 1, Fernow Experimental Forest. Note damaged red maple foliage in background (upper left). Photo taken June 19, 2008. Photo by U.S. Forest Service.

Figure 7.—Fluid application site 1, Fernow Experimental Forest, showing dead and damaged understory vegetation, and freshly fallen green leaves. Red flagging indicates trees showing symptoms. Photo taken July 9, 2008. Photo by U.S. Forest Service.

Figure 8.—Damaged greenbrier vines on fluid application site 1, Fernow Experimental Forest. Photo taken June 19, 2008. Photo by U.S. Forest Service.

American beech was the most common dead tree species in 2009; about 38 percent of the beech trees experienced bark sloughing (Fig. 10), a dramatic visual response, less than 1 year after fluid application. We also noted that the prolific root sprouting, which is well known and documented for beech, is entirely absent within the fluid application area. Auchmoody and Walters (1988) reported that large beech trees were the last of the hardwoods to die after an accidental brine spill from an oil well development in Pennsylvania, although beech were identified as the deciduous trees most sensitive to salt in a Canadian assessment (Environment Canada 2001). While these observations suggest that beech might be a sensitive indicator of excessive salt levels, other species should perhaps be considered because of the presence of beech bark disease in the region. Note, however, that beech bark disease was not observed on beech trees in the area immediately surrounding the application area, so it was ruled out as a causal agent of the symptoms we observed. Other tree species affected on the fluid application areas included northern red oak, chestnut oak, sassafras, yellow-poplar, sweet birch, cucumber tree, Fraser magnolia, red maple, serviceberry, and sourwood. The largest dead tree within the perimeter was a 67.8-cm-d.b.h. northern red oak.

Figure 9.—Fluid application site 1, with non-treated forest in background, Fernow Experimental Forest. Photo taken May 17, 2009. Photo by U.S. Forest Service.

Figure 10.—Bark sloughing by American beech trees, fluid application site 1, Fernow Experimental Forest. Photo taken April 22, 2009. Photo by U.S. Forest Service.

The mass of freshly fallen green leaves in July 2008 on an areal basis (dry weight) ranged from 227 kg ha^{-1} to 1,395 kg ha^{-1} and averaged 714 kg ha^{-1}. For comparison, annual leaf fall from a nearby forested watershed is about 3,060 kg ha^{-1} (Adams 2008). In the control areas, there were insufficient green leaves on the forest floor to sample and the estimated premature leaf fall mass was equivalent to zero. The amount of leaf drop within fluid application site 1 resulted in a much more open canopy, with a significant increase in light penetration to the forest floor (Fig. 9). Canopy openness was 15.0 percent. For comparison, canopy openness of areas that had been treated with prescribed fire twice in recent years was 8.9 percent, and the unburned reference unit was 7.2 percent (T. Schuler, unpublished data). Therefore, the fluid application resulted in almost twice the canopy openness of the prescribed-burned area and untreated references.

DSF, the ratio of the average daily direct radiation under the canopy and above the canopy for the growing season, at fluid application site 1 was 18.5 percent. By comparison, DSF in a nearby prescribed fire site was 17.8 percent for the treated units and 12.0 percent for the untreated reference units. When we used DSF as a surrogate for the amount of PAR penetrating the forest canopy, the PAR penetrating to the forest floor was substantially higher than in an area not receiving drill pit fluids. Because of this increased light to the ground within the affected area, there was a flush of germination of seed from light-sensitive tree species (e.g., sassafras) and some resprouting of top-killed seedlings. Epicormic branching was observed on about 6 percent of trees within the area. The open canopy is expected to continue for some time, because mortality of many of the remaining live overstory and understory trees is expected. Auchmoody and Walters (1988) also reported 100 percent vegetative mortality from an accidental brine spill in Pennsylvania. However, after the brine source was removed, and the site flushed by heavy rainfall, they noted rapid revegetation. We will continue to follow mortality and canopy openness over time on the Fernow fluid application site 1 to gauge recovery.

A much lower volume of fluid was applied to the second fluid application site, and the operator took care not to spray the contents into the air, but to run it out on the ground, and to move the outlet pipe often so as to disperse the fluid over the area. A smaller area was treated (0.04 ha) and the visible effects were not as obvious. Nonetheless, considerable leaf browning and mortality of young northern red oak seedlings was observed (Fig.11), along with some browning of other short vegetation. In general, no symptoms were observed in the overstory trees and there was no obvious increase in leaf drop, as at fluid application site 1. Because the fluids were applied within the future pipeline ROW, further monitoring of the vegetation and soil was not possible after the ROW was cleared for pipeline installation.

For fluid application site 1, analyses of soil chemistry suggest that levels of sodium, chloride, and calcium were substantially higher (by 2-50X) in the area receiving pit fluids than in the adjacent control area in July, shortly after application (Table 5), although only increases in chloride and sodium concentrations were statistically significant. These differences suggest that the drill pit fluids contained elevated salts and chlorides. Levels of nutrient elements in the second fluid application site immediately after application

Figure 11.—Damaged oak seedlings and greenbrier vines on fluid application site 2, Fernow Experimental Forest. Photo taken July 25, 2008. Photo by U.S. Forest Service.

Table 5.—Mean soil analyte concentrations from fluid application site 1, sampled in July and October 2008, Fernow Experimental Forest (standard deviations are shown in parentheses; statistically significant differences within a sampling date and analyte are indicated by * (p=0.10) or ** (p=0.05))

Analyte	July 2008		October 2008		May 2009	
	Control	Treated	Control	Treated	Control	Treated
pH	3.5 (0.25)	3.8 (0.10)	4.5 (0.25)	4.1 (0.0)*	4.1 (0.33)	4.8 (0.24)*
			percent			
Loss on ignition	31.3 (4.31)	30.0 (12.92)	28.3 (6.09)	48.7 (2.96)**	46.4 (14.2)	39.3 (1.42)
Total nitrogen	0.74 (0.12)	0.64 (0.17)	0.68 (0.16)	1.06 (0.08)**	1.15 (0.34)	0.87 (0.05)
Total carbon	15.80 (1.76)	15.43 (5.18)	14.30 (3.48)	24.93 (2.54)**	23.43 (7.89)	19.27 (0.81)
			mg kg^{-1}			
Chloride	15 (3.1)	735 (301.3)**	19 (7.5)	453 (131.8)**	18 (2.9)	35 (4.7)**
Calcium	431 (143)	1,181 (920)	1,226 (515)	1,473 (265)	1,081 (60)	2,414 (1042)*
Potassium	122 (26.7)	135 (81.1)	160 (42.4)	267 (30.0)**	339 (55.4)	365 (45.8)
Magnesium	50 (9.0)	66 (20.1)	77 (17.9)	98 (18.9)	124 (13.9)	165 (44.3)
Phosphorus	14.5 (6.41)	11.8 (7.02)	8.7 (4.68)	17.5 (4.32)*	27.1 (15.56)	12.6 (5.75)
Aluminum	602 (130)	461 (169)	456 (107)	456 (154)	328 (52)	177 (89)*
Iron	159.3 (20.2)	123 (11.8)*	15.2 (15.8)	25 (0.5)	49.1 (32.6)	10.7 (8.5)
Manganese	20 (5.1)	14 (1.0)	66 (14.7)	31 (5.7)**	88 (24.4)	34 (6.3)*
Sodium	15 (3.5)	806 (547.8)*	14 (2.3)	473 (41.9)**	5 (1.7)	105 (5.6)**
Zinc	11.8 (4.10)	7.0 (0.75)	9.5 (4.14)	11.4 (2.92)	13.1 (4.4)	5.9 (0.8)**
Lead	--	--	42 (24.7)	34 (7.1)	35 (3.6)	28 (3.8)*

were similar to those of fluid application site 1 (Table 6), and concentrations of chloride, calcium, potassium, and sodium were elevated within the treated area. Concentrations of iron, magnesium, and lead were also slightly elevated in the treated soil of site 2 relative to the control area.

Although sodium and chloride concentrations at fluid application site 1 decreased by almost 40 percent by October 2008, concentrations in the area treated with drill pit fluids were still significantly elevated relative to the control area. This was observed despite more than 25 cm of precipitation that fell in July, August, and September of 2008; this precipitation should have leached the salts away, as was reported by both DeWalle and Galeone (1990) and Auchmoody and Walters (1988). Chloride, calcium, and sodium levels remained significantly greater in the treated area relative to the control in May 2009.

Table 6.—Mean soil analyte concentrations from fluid application site 2, collected August 2008, Fernow Experimental Forest (n=2)

Analyte	Control	Treated
pH	4.8	4.5
	percent	
Loss on ignition	11.2	17.8
Total nitrogen	0.30	0.46
Total carbon	5.17	8.62
	mg kg^{-1}	
Chloride	16	455
Calcium	96	734
Potassium	84	195
Magnesium	20	32
Phosphorus	2.8	3.3
Aluminum	414	369
Iron	3.6	15.7
Manganese	134	152
Sodium	10	390
Zinc	3.6	3.1
Lead	28	41
	meq 100 g^{-1}	
Acidity	5.4	4.6
Cation exchange capacity	6.2	10.7

Note the increase in soil levels of loss-on-ignition (an indication of organic carbon concentration of soil), total nitrogen, phosphorus, and cation exchange capacity in the treated area from July to October (Table 5). The higher loss-on-ignition may be due to an increase in organic carbon in the soil resulting from rapid decomposition of the premature leaf fall. Indeed, it appears that the increases observed for all of these elements may be due to the pulse of green leaves that fell in July. Because retranslocation of mobile elements, such as nitrogen and potassium, probably did not occur prior to leaf fall, as would happen in the autumn with seasonal senescence, we hypothesize that a flush of nutrients was released from the premature leaf fall, and decomposition occurred relatively more quickly, resulting in a pulse of nutrients to the soil in midsummer. An examination of the site the following spring (2009) revealed relatively little leaf litter, providing some support for the hypothesis of rapid decomposition of the prematurely shed leaves. The relative importance of small-scale changes in nutrient cycling such as these may be minor, but certainly requires further consideration, particularly as natural gas development increases in the eastern U.S. Because carbon sequestration is an important ecosystem service provided by forests, a better understanding of the carbon budgets resulting from these developments is necessary.

The drill pit fluids were sampled and analyzed several times (Table 7) in order to help us understand why we observed the effects that we did, and for compliance reasons. Note that the standards permitted by the General Permit are for a single required sample collected from the end of the hose. There is significant variability in chloride and pH among the samples, and the June 20, 2008, sample did exceed the General Permit standard for chloride. The permit discharge limits were 12,500 mg L^{-1} for chloride, a pH of 6-10, and 6.0 mg L^{-1} for total iron. Based on data provided in the Well Operator's Report (7,500 mg L^{-1} of chlorides), a calculated loading of 11,355 kg of chloride per hectare was applied to the first fluid application site. Such a loading far exceeds load limits established elsewhere, such as in Oklahoma (450 kg ha^{-1}), Wisconsin (275 kg ha^{-1}) (http://www.dnr.state.wi.us/org/water/wm/ww/gpindex/57665_permit.pdf) over a 2-year basis, and Saskatchewan (400 kg ha^{-1}; http://eps.mcgill.ca/~courses/c550/Environmental-impact-of-drilling/Sask_Drilling_Waste_Guidelines.pdf). Thus, while the concentrations may have met the standards of the General Permit, the load (dose) of chloride that was applied was extreme. This points to the desirability of a load-based standard.

The June 19, 2008, sample of pit fluids also was screened by staff at West Virginia University's Department of Forensic and Analytical Chemistry. Their screening showed high levels of sodium, potassium, lead, and palladium; medium to low levels of calcium; and low but detectable levels of rhodium (Dr. Suzanne Bell, pers. communication). Because this was a screening analysis, we do not have concentrations or dosages, but these results raise concerns about the contents of pit fluids that are applied to forest land. DeWalle and Galeone (1990)

Table 7.—Drill pit fluid sampling information and analytical results, Fernow Experimental Forest, 2008

Date sampled	Sampled by	Chloride (mg L^{-1})	pH	Total iron (mg L^{-1})	Other
Unknown	Berry Energy	7,500	7.8	1.0	No settleable solids, oil, grease, or petroleum products
May 24, 2008	MNF staff	10,700	10.51		Pit fluids, immediately below the liquid surface
June 19, 2008	Fernow staff	4,880	11.65		Pit fluids; settleable solids, and some that did not settle for >24 hours
June 20, 2008	Fernow staff	13,500 - 14,250			End of the hose

also reported elevated levels of chloride, barium, lead, selenium, arsenic, and cadmium in soil water as deep as 70 cm from a single brine application to a hardwood forest in Pennsylvania, although levels quickly declined to meet Safe Drinking Water Act limits (except for selenium). Thus, there is some concern about metals in soil and soil solution, and it suggests another area for further research.

Other Unexpected Impacts

The other unexpected impacts of the well development included effects from heavier-than-predicted use, changes in procedures or techniques, and accidents and equipment failures. The extent and severity of these events are unknown; nonetheless, they do represent potential impacts on the resources, natural and scientific, of the Fernow, which would not have occurred had gas well development not taken place. Below, we describe some of these.

As mentioned earlier, substantial damage to roads occurred during site development and drilling. Because loaded log trucks regularly use Fernow roads, we anticipated a similar level of damage. However, the estimated total weight of trucks required for developing the well site was substantially greater than that of logging trucks during a normal year (an estimated 10,218 tons [MNF Road Use Permit] compared to 5,000 tons for logging), which may explain the greater than expected damage. For instance, obliteration of ditches rarely, if ever, occurs on the Fernow main roads due to traffic from logging trucks. We also expected that damage would be repaired as soon as it occurred or was pointed out; instead, the damage was repaired after completion of well site construction and drilling. Some runoff and erosion from roads and loss of road function were observed as a result of this delay in maintenance, but were not quantified.

Unexpected and unknown impacts also occurred from changes in procedures. For example, for the crossing of an unnamed tributary to Stonelick Run, the operating plan and the Decision Memo identified that a buried natural gas pipeline would be installed beneath this wetland by directional boring if water was present at the time of pipeline installation. Otherwise, the pipeline would be installed by excavating and setting the pipeline in an approximately 1-m-deep trench. At the crossing location, the unnamed tributary channel is 0.3 to 0.6 m wide, with a wetland on the west side of the channel containing obligate wetland plant species. Water was present in the channel at the time the pipe was to be laid. Nonetheless, at the energy company's request, permission was granted to install the crossing by excavating a dry trench. Concerns centered around possible elevated turbidity and sedimentation within this tributary to Stonelick Run. Also, trenching through the wetland could produce changes in the hydraulic conductivity of the wetland substrate within the trench, as well as within the wetland for a short distance upslope and downslope of the trench. We have no measurements to support this hypothesis and suggest that these appear as important needs for future research. Risk assessments and plans for mitigation should be prepared before procedural changes are made.

The crossing of Elklick Run was also planned to be accomplished by drilling underneath the streambed. But the dry trenching method was preferred, and it was implemented during a period of low flow. During excavation of the trench, an excavator broke down within the stream channel and remained there for about 18 hours while being repaired. Although no obvious impacts to water quality or sensitive biota were observed, the accidents surrounding this change in procedure point to the potential for unexpected impacts. In another case, the truck carrying pipeline ran off the road in the Biological Control Area, an area considered a reference area for much of the silvicultural research of the Fernow (Fig. 12). Damage to the vegetation from this accident appeared minor, but the potential for significant impacts to such a valuable research resource is not negligible. We suggest conducting risk assessments that consider a variety of scenarios to help prepare for such unexpected effects of natural gas development.

Figure 12.—Biological Control Area, Fernow Experimental Forest, showing damage from truck hauling gas pipeline and from the bulldozer used in an attempt to push the truck back onto the road surface. Photo taken August 13, 2008. Photo by U.S. Forest Service.

Finally, another unexpected impact was the increased presence and activity of white-tailed deer in areas where the pit fluids were land-applied and on the well site in the area of the buried drill pit. The frequency of hoof prints in the ground at these sites remained unusually high throughout the winter, and into the spring and summer of 2009, indicating that B800 had become a readily used mineral source for deer. Such activity is well documented (Campbell et al. 2004). Increased foraging activities by black bears, as evidenced by turned-over logs, heavily disturbed soil, and bear signs such as foot prints and scat, also were observed within fluid application site 1 and hypothesized to be due to high salt concentrations in soil and vegetation.

Two of the seeps (4.5 m^2 and 32 m^2) in the area of the buried pit were covered with slash to discourage deer use of the area and to enhance germination of ground cover seed. This met with mixed success (Fig. 13), because regeneration became well established on the one seep and reasonably well on the second. However, a third, smaller seep (1.7 m^2) was identified in September 2009 and has attracted deer attention. In July 2010, at least two active seep/lick areas still were frequented by deer, and the area disturbed by the deer's activities has increased. Mitigation of increased deer herbivory to establish ground cover may be feasible in these areas, but such mitigation does not deal with the issue of leakage of pit contents through such seeps. High deer numbers could delay or even prevent successful revegetation of an area (Campbell et al. 2006).

Figure 13.—Partially remediated deer lick areas, located near drill pit burial site. Inset photo shows new deer lick area, located to the technician's right (up slope) in the larger photo. Photos taken September 10 and 18, 2009. Photo by U.S. Forest Service.

Impacts on the Research and Research Needs

We have concerns about the impacts of the development of the B800 gas well and associated pipeline on the research mission of the Fernow. These impacts may not be quantifiable and point to additional information gaps and research needs.

The physical impacts expected included the permanent deforestation of the well pad, access road, and pipeline ROW, and the reshaping, ground disturbance, and erosion associated with the construction. Due to coordination and cooperation among all parties, a relatively small area of land was directly affected by the construction of well site, pipeline, and road—less than 0.5 percent of the land area of the Fernow. However, the areas directly impacted were changed permanently, with the possible exception of areas below the pit where silt fences were overrun. Accordingly, these physically impacted areas have been withdrawn from research compartments, decreasing the area available for research and demonstration. For example, fluid application site 1 removed approximately 0.12 ha from an active long-term study of patch-clearcutting, one of the longest term research studies on the Fernow (Schuler 2004). Within these areas, long-term data collection efforts have ended and long-term datasets have been compromised. While research in areas adjacent to the physically impacted areas may proceed, additional possible impacts must be considered: an “edge effect” on tree growth and regeneration (Landenburger and McGraw 2004) due to changes in microclimate in the adjacent open areas, changes in herbivory due to slash piles along the perimeter of the pipeline and adjacent research compartments, increases in variability of data collected subsequently, and truncation of impacted studies. Further work will be needed to assess these effects over time.

The gas well opening and pipeline, although relatively small in comparison with the whole Fernow, may also represent an increase in fragmentation of a relatively intact forest matrix. For example, the pipeline introduced an additional estimated 3,000 m of “hard edge” into the Fernow. Such edge has been demonstrated to have significant implications for nest predation (King et al. 1997, 1998; Gates and Gysel 1978). We also have questions about whether the additional permanent openings, in particular the long, linear pipeline ROW, act as avenues for increased dispersal of invasive exotic plants and animals. Japanese stiltgrass, in particular, is likely to take advantage of the open corridor to invade new territory. However, control of invasive plant species may be easier on the pipeline ROW, due to periodic mowing and improved accessibility. The probability of introduction of invasive exotic plant species through seeds or other propagules may have increased due to markedly greater vehicular traffic for well site and pipeline construction and maintenance, use of hay instead of straw on one occasion on the pipeline ROW, and the truck running off the road in the Biological Control Area. Such introductions could imperil long-term research on the Fernow and negatively affect sensitive plant communities, including communities of running buffalo clover, an endangered species that is the subject of research unique to the Fernow. Such issues will require investigation and monitoring in the future.

We are also concerned about changes in deer movements and effects on browsing in adjacent areas. It is likely that herbivory in the immediate area of the well site and fluid application area will increase in response to elevated salt levels, as reported by Campbell et al. (2004), and we have insufficient information to predict how long such an effect may persist. Based on Campbell’s research, a doe born this year in the area will set up adjacent homerange to her mother but will retain knowledge of this mineral lick and will make sallies from her homerange to visit it (Campbell et al. 2004). This “knowledge” can be passed along the multiple generations from mother to daughter so that deer occupying ranges more than 5 km away may visit these mineral sources in the spring when physiological demand for minerals is high. Incorporating this sort of a shift in herbivory into long-term regeneration research is problematic. We also need to understand how to manage deer in this altered environment.

There were several surprises throughout the development of B800 and the pipeline, which suggest some additional research needs. The response of the vegetation to the land application of fluids is one such surprise and needs further study. We suggest the need for a more reliable means of assessing the chemical content of the drill pit fluids before land application. A single sample clearly did not characterize the contents sufficiently to predict the response that was observed. Also, because we hypothesize a dose effect, rather than just a response to concentration, a better understanding of dose-response relationships for the significant constituents of drill pit fluids would help to predict where land application of drill pit fluids is likely to have deleterious effects. Some vegetation may respond to concentration, while for others dose may be a better predictor of response. Monitoring the fluid application site over time will provide some understanding of the longer term effects on vegetation and regeneration. Research to identify better means to dispose of drill pit fluids is also needed, particularly for karst topography.

Varying season of application (dormant vs. growing season) may be a way to mitigate vegetative effects, but effects on soil, fauna, and other resources should also be studied.

We also posit that a better understanding of fluid movement and connectivity in karst geology is needed. Decisions were made based on relatively limited knowledge about the location of caves and fissures, and how they connect to the Big Springs Blowing Cave housing hibernating Indiana bats, for example. Using dye to trace water movement within the karst would help to identify more conclusively the significant linkages and evaluate the relative safety of drilling in the karst topography for affecting the fragile environment within the caves. While there was some monitoring of sediment in the stream draining Big Springs Blowing Cave, and the U.S. Fish and Wildlife Service and West Virginia Division of Natural Resources did conduct a mid-winter survey of bats, and place temperature probes within the cave, this information about the effects of the drilling on cave environment and biota is far from conclusive or complete.

Finally, we do not know much about how natural gas development affects biota. Vegetation is relatively simple to evaluate, even post-hoc, but other taxa may also be sensitive to changes due to land clearing, drilling, and reclamation activities, and indeed, some may be more sensitive. There is very little information on the effects of these activities on rare, endangered, or threatened species, and relatively little information on effects on salamanders, invertebrates, and cave dwelling organisms.

CONCLUSIONS

This case study identifies some expected and unexpected impacts, which might be used to predict environmental effects of similar developments and to better prepare for monitoring such developments. This case study also helps us examine the information gaps associated with natural gas development in eastern forested landscapes. Finally, our experiences can help inform both public and private land managers as to the range of possible outcomes from the development.

Development of a natural gas well, and associated pipeline, had impacts on the resources, both natural and scientific, of the Fernow Experimental Forest. Due to good coordination and cooperation, some of the expected impacts, mostly physical effects, were minimized. Unexpected impacts, however, were perhaps more important, and because they could not be carefully controlled or planned for, are less likely to be mitigated successfully. It is obvious that unexpected, unpredicted events will occur during such activities, and therefore land managers should consider a wide range of possible effects when analyzing impacts on natural resources. Good communication among all parties becomes even more critical to ensure that unlikely events are not dismissed as unimportant and that appropriate responses to unexpected events can happen in a timely manner.

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APPENDIX

Common and scientific names

Black bear	*Ursus americanus*
Greenbrier isopod	*Stygobromus emarginatus*
Indiana bat	*Myotis sodalis*
Virginia big-eared bat	*Corynorhinus townsendii virginianus*
White-tailed deer	*Odocoileus virginianus*
Greenbrier	*Smilax*
Japanese stiltgrass	*Microstegium viminem*
Running buffalo clover	*Trifolium stoloniferum*

American beech	*Fagus grandifolia*
Chestnut oak	*Quercus prinus*
Cucumbertree	*Magnolia acuminata*
Downy serviceberry	*Amelanchier arborea*
Fraser magnolia	*Magnolia fraserii*
Northern red oak	*Quercus rubra*
Red maple	*Acer rubrum*
Sassafras	*Sassafras albidum*
Sourwood	*Oxydendrum arboretum*
Sugar maple	*Acer saccharum*
Sweet birch	*Betula lenta*
Yellow-poplar	*Liriodendron tulipifera*
Beech bark disease	*Nectria coccinea var. faginata*

Adams, Mary Beth; Edwards, Pamela J.; Ford, W. Mark; Johnson, Joshua B.; Schuler, Thomas M.; Thomas-Van Gundy, Melissa; Wood, Frederica. 2011. **Effects of development of a natural gas well and associated pipeline on the natural and scientific resources of the Fernow Experimental Forest.** Gen. Tech. Rep. NRS-76. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 24 p.

Development of a natural gas well and pipeline on the Fernow Experimental Forest, WV, raised concerns about the effects on the natural and scientific resources of the Fernow, set aside in 1934 for long-term research. A case study approach was used to evaluate effects of the development. This report includes results of monitoring projects as well as observations related to unexpected impacts on the resources of the Fernow. Two points are obvious: that some effects can be predicted and mitigated through cooperation between landowner and energy developer, and that unexpected impacts will occur. These unexpected impacts may be most problematic.

KEY WORDS: natural gas, disturbance, mineral development, fluid application, white-tailed deer, karst topography

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