Comparative Study of Domestic Water Well Integrity to Coal Mine Blasting Summary Report

Prepared for

Office of Surface Mining
Reclamation and Enforcement
Pittsburgh, Pennsylvania

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1. Introduction

The Appalachian coal region in the southeastern portion of the United States has been an important source of coal since it was first mined in the mid-1800s. Even after extensive mining, this region today still accounts for approximately 40 percent of total U.S. coal production (USGS, 1999). Surface coal mining is an important economic resource for residents of the Appalachian region and an important source of energy for the United States. However, many people living close to active mining operations believe that mining activities, such as blasting to remove overburden, adversely affect their well's yield and water quality.

To date, few studies have been performed looking at the possible effects of mining on domestic well water quality and quantity. Accordingly, the Office of Surface Mining Reclamation and Enforcement (OSMRE) contracted with Daniel B. Stephens & Associates, Inc. (DBS&A) to design and initiate a long-term study to investigate whether coal mining operations located close to domestic wells have caused or will contribute to the loss, diminution, or degradation of groundwater supplies and/or negatively affect domestic wells and their ability to supply water. The scope of work for this study included:

- Selecting suitable sites
- Equipping the selected wells with monitoring instruments
- Collecting data during an initial monitoring period
- Training state employees to collect monitoring data during the study

To ascertain the induced effects of blasting and pumping vibrations from nearby coal mining sites on domestic well integrity, water quality/chemistry, and well yield, DBS&A designed and initiated a quarterly monitoring program for domestic wells located near active mining operations in a tri-state (Virginia, West Virginia, and Kentucky) area. Following a discussion of groundwater conditions in the study areas (Section 2), this report describes the monitoring program, including site selection and descriptions (Section 3) and monitoring methods used (Section 4). The results obtained over the year of monitoring are discussed in Section 5.

2. Occurrence of Groundwater

Groundwater in Appalachian coal country is obtained from sedimentary rocks, glacial deposits, and alluvial fill. Most of the groundwater found in the sedimentary, coal-bearing rocks occurs in nearly vertical fractures and joints and along bedding planes. Some of these fractures are undoubtedly tectonic in origin and exhibit a regional pattern, but most of the fractures are more localized in nature and are the result of lateral stress relief associated with natural topographic development. The fractures tend to form networks that exhibit some of the characteristics of a water table aquifer, including:

- Water levels that respond to rainfall within 24 hours
- Water levels that do not respond to changes in atmospheric pressure
- Pumping rates (during pump tests) that decrease as the drawdown increases even though the power supply remains constant

A fracture system may not have a large lateral extent, but may form small sub-systems. In a study looking at blasting effects on groundwater supplies in Appalachia, Robertson et al. (1980) found that during pump tests, wells located 35 to 65 feet from the pumped wells exhibited more drawdown than observation wells only 10 feet away, while in other wells, no response to pumping was observed.

Coal-bearing strata found throughout the Pennsylvanian and Permian strata are very brittle and have a low tensile strength and, therefore, extensive vertical fracturing. Coal seams may act as conduits through which water from the overlying units can move downward to deeper units (Robertson et al., 1980). Groundwater is often associated with coal seams because (1) the high degree of fracturing in these strata increases the chances that water will move vertically from the surface to depth and (2) coal seams are often underlain by low-permeability plastic clays, causing groundwater to perch in the coal strata.

Wells constructed in Appalachia for industrial and municipal purposes may provide large yields, but domestic wells commonly have yields of 1 gallon per minute or less. This is due to many factors, including:

- Well locations selected based on convenience of access and proximity to the residential dwelling it will serve rather than sound geologic evidence
- Poor design, construction, and completion
- Inadequate formation transmissivity
- Inadequate well maintenance

Wells in the hollow valleys generally produce more water than those located near the tops of the hill. This is because the water table tends to mimic local topography, with recharge areas at the high points and groundwater moving toward discharge points in the valley (Robertson et al., 1980).

Groundwater in Appalachia tends to be high in manganese and iron and often exceeds regulatory limits for turbidity. Often, water in wells has higher dissolved oxygen than formation water, resulting in a reddish tint as ferrous iron is oxidized in the well. Iron-consuming bacteria may also be found in well water and, if so, contribute to the reddish color and unpleasant odor. The pH of the groundwater is relatively neutral, ranging between 6 and 8 (Robertson et al., 1980).

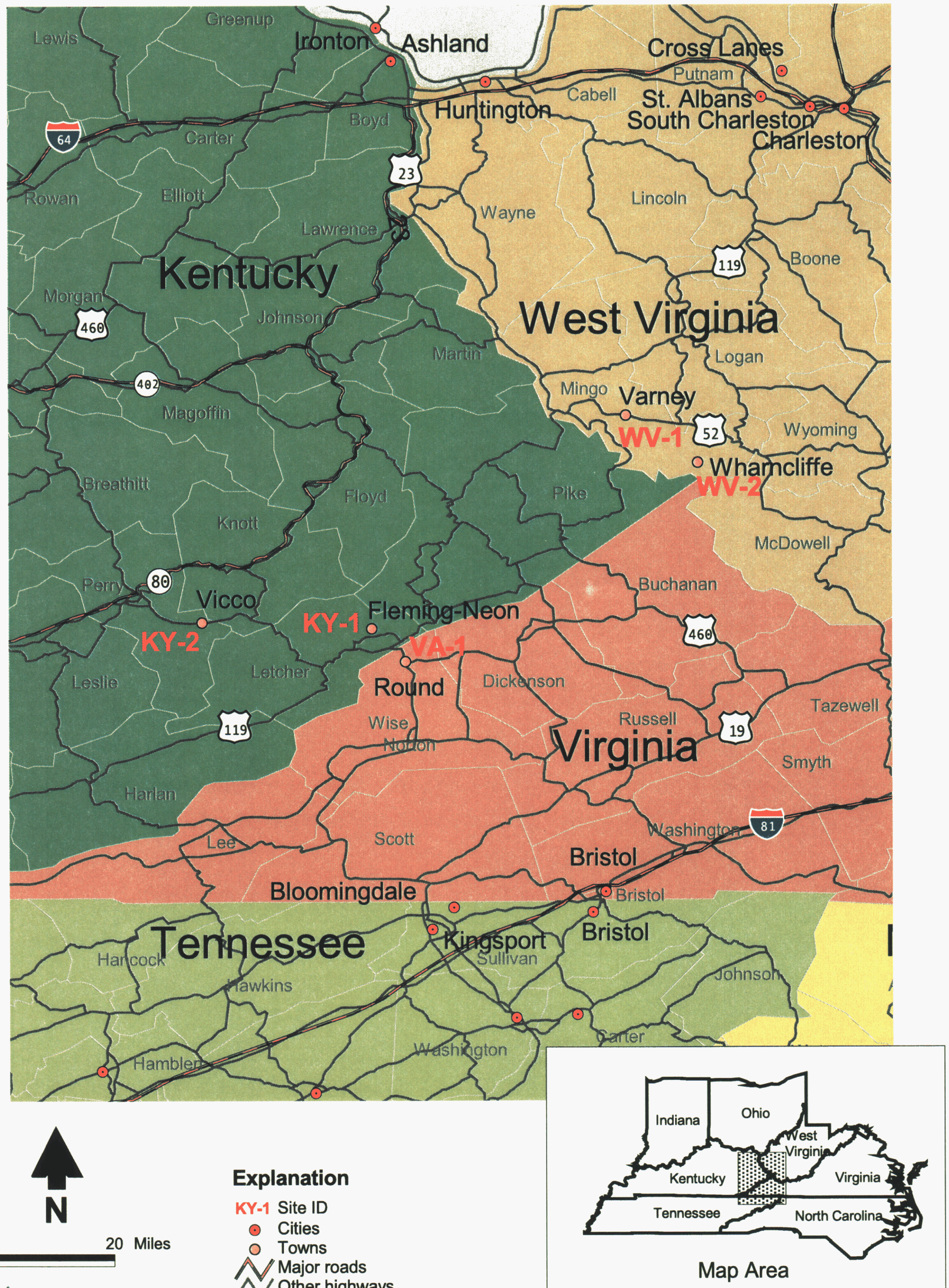
3. Site Selection and Descriptions

The domestic wells used in this study were selected by Office of Surface Mining (OSM) officials, with input by Virginia, West Virginia, and Kentucky state officials based upon current and past complaint information. To identify suitable sites that meet the study criteria, state representatives were to review sites and:

- Identify mine sites that would be blasting at least once a day
- Contact the individual coal mines to determine their blasting schedules.
- Find at least one, and preferably two, domestic well near each mine.
- Contact with the owners of the domestic wells to request and secure their participation in the study.
- Complete a nomination package that provides the location of the well site, the five most recent blast logs with plotted blast locations, pictures of the well installation, any technical reports done on the site, and anticipated dates of blasting near the wells.

Based on the nomination packages provided by the state representatives, five mine sites were selected for this study: one site in Virginia and two sites each in Kentucky and West Virginia (Figure 1, Table 1). At each of the sites in Kentucky and West Virginia, at least two domestic wells were selected for monitoring after OSM officials secured right-of-entry agreements from the individual homeowners. Only one domestic well suitable for this study was identified at the Virginia site. The wells selected represent a range of well construction types and proximity to surface coal mining operations. The ages of the wells were not determined, but it is assumed that the wells were completed when the homes were first occupied.

Blasting had been occurring near all of the sites for a significant time prior to the arrival of monitoring personnel and the installation of monitoring equipment. The data collected represent only a small amount of time compared to the total amount of time the well has been within the range of influence of an active mining/blasting operation.



OSM WELL STUDY

Study Area

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Figure 1

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Table 1. Monitor Well Identifiers

State	County	Site ID	Well ID	Well owner
Virginia	Wise	VA-1	Well-1	Hylton
Kentucky	Letcher	KY-1	Well-1	Banks
			Well-2	Ratliff
	Perry	KY-2	Well-1	G. Hurley
			Well-2	Sumner
			Well-3	A. Hurley
West Virginia	Mingo	WV-1	Well-1	L. Dean Sr.
			Well-2	L. Dean Jr.
		WV-2	Well-1	G. Abbott
			Well-2	D. Abbott

The study sites were typical of Appalachian coal country, where residents live within hollows below coal outcrops, which generally exist where the slopes are steepest. Within the hollows, residential sites are typically founded on valley alluvial fills and glacial deposits comprising cobbles, gravels, and sands with some clay. Wells can penetrate sandstone formations that may be recharged by water moving through naturally occurring fractures in the upper elevation coal seams and porous rock units.

The domestic water wells at all the study sites are drilled within hollows at elevations far below mining activity. The photographs in Figure 2 show the typical terrain at all the sites investigated. Mining activity takes place beyond the ridgeline (shown at the top of each photograph) at the head of the hollow in which the houses are located. The ridgeline between the head of the hollow and the mining operations is formed of overburden fill (waste rock). Blasting activities take place within sandstone and shale formations along mountain contours and across the mountaintop (full mountaintop removal) (Figure 3). Rock blasting along contours produces blasting bench faces directed away from the hollow (Figure 4) or toward the hollow. At the Virginia study site, mountaintop removal has left a pinnacle of rock that rises above the surrounding mining operations upslope and below the waste rock ridgeline (Figure 3a). A typical mining scenario encountered at each site is shown in Figure 4.

2a. View of a hollow in Kentucky.

2b. View of a hollow in West Virginia.

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Typical Terrain at Investigation Sites

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Figure 2

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3a. Final stages of mountain top removal in Virginia.

3b. Contouring overburden blasting in Perry County, Kentucky.

3c. Mountain top blasting in Perry County, Kentucky.

3d. Contour blasting at a mine in Letcher County, Kentucky.

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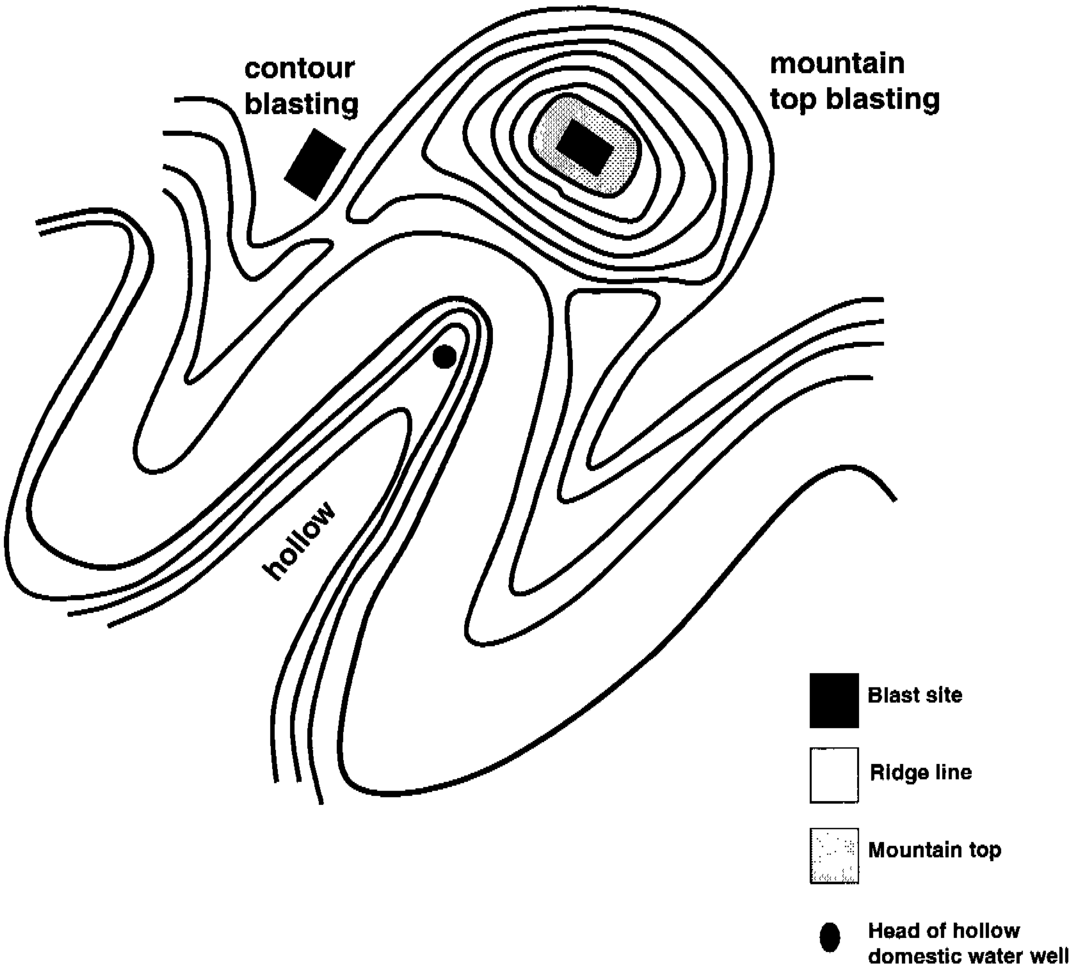
Typical Blasting Activities

Figure 3



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Typical Mining Scenario

Figure 4

4. Monitoring Methods and Training

Upon completion of site selection, collection of field data began. Fieldwork and instrumentation was conducted in two phases. Phase I took place during a three-week period in the Fall-Winter 2000 season and involved an intensive commitment to field instrument installation and data collection over four consecutive days of blasting at each site. Phase II involved the collection of data during the subsequent three seasons.

During Phase I, prior to the start of monitoring at each site, representatives of DBS&A and Aimone-Martin Associates (subcontractor to the project) met with mining operations personnel to obtain blasting information and general information on the anticipated locations of blasting during the monitoring phase. Representatives of DBS&A and Aimone-Martin Associates also visited individual homeowners to assess the nature of complaints regarding well responses to blasts and pumping vibrations (if any), to obtain previous water quality data for the domestic wells (if available), and to obtain well construction details (if available).

Following the initial meetings, a DBS&A hydrogeologist accessed the domestic wells at the sites to equip them with continuous water quality and well yield monitoring instrumentation. All instrumentation (seismic, water quality, and well yield monitoring instruments) was calibrated, tested, and quality-control checked prior to installation and the initiation of monitoring. During the Fall-Winter 2000 four-day monitoring event, DBS&A personnel measured turbidity and well yield, collected groundwater samples for laboratory analysis, and collected and analyzed data from the field instruments. In addition, state personnel were trained in the use of field data acquisition systems and retrieval of data so that they could collect data during subsequent monitoring events.

Each state agency assigned an employee to perform the following activities:

- Contacting mine officials and well owners and coordinating blasting and monitoring efforts at each site

- Field calibrating, testing, and installing the monitoring instruments
- Initiating continuous monitoring at each site (well yield, water quality, and vibration) during the monitoring period
- Collecting pre- and post- blast turbidity readings at a point between the well and the pressure tank of each residence with the use of a portable turbidimeter
- Downloading all water quality, well yield, and vibration data from dataloggers and transferring the data to DBS&A and Aimone-Martin Associates
- Removing all instrumentation from the well sites and preparing them for storage or shipment to DBS&A or the next monitoring site

Specific methods for each of the types of monitoring are described in Sections 4.1 through 4.3. The training conducted for state personnel is described in Section 4.4.

4.1 Domestic Well Water Quality Monitoring

The water quality of the individual domestic wells was evaluated using both field monitoring equipment and laboratory analysis. Field water quality monitoring was conducted prior to, during, and after a series of blasts at the five study sites.

Field water quality monitoring was conducted using electronic sensors (EC-Campbell Scientific CSI-247, pH-Innovative Sensors M11) connected to a Campbell Scientific 21X datalogger. The datalogger allowed for automated measurement at a frequency of the operator's discretion. The sensors (temperature, pH, and electrical conductivity [EC]) were installed in each well below the water level. If it was not possible to place the sensors in a particular well, they were inserted in a flow-through cell extending from a discharge line between the well and the pressure tank at the ground surface. Additionally, the turbidity of the domestic well water was measured at the surface using a Hach 2100P portable turbidimeter.

During the initial monitoring period (Fall-Winter 2000), water quality samples were collected from each of the individual domestic wells for laboratory analysis of total aluminum, iron, manganese, sulfate, total dissolved solids, and total suspended solids (TSS). At each well, samples were collected from faucets connected to the pressure tanks. The water quality samples were collected in laboratory-supplied containers, immediately preserved on ice in an insulated cooler with full chain-of-custody documentation, and shipped to Inter-Mountain Laboratories, Inc. in Farmington, New Mexico for analysis. A duplicate sample analysis was conducted at the KY-1 Well-2 site.

4.2 Domestic Well Yield and Discharge Monitoring

In order to determine the effects of mine blasting on the normal usage of the individual study wells, DBS&A and state personnel monitored variations in well yield by continuously monitoring volumetric flow and water level in the individual domestic wells before, during, and after blasting events. For the purposes of this study, well yield is defined as the volumetric flow rate of water from the well during a pumping cycle. Monitoring of well yield helps determine whether blasting affects the ability of a well to produce water at a reliable rate. A decrease in well yield could be due to blasting or other causes such as compaction of the material surrounding the well, changes in the fracture size or occurrence, deterioration of the well due to age, improper maintenance, and/or biological or mineral fouling. In order for this study to identify changes due to blasting, an acute change would have to be associated to a blast during a monitoring event.

Well yield was monitored using a Controlotron 1010n flow meter installed on the pipe between the well and the pressure tank. The Controlotron is equipped with an internal datalogger that was programmed to record data at approximately the same interval as that of the Campbell equipment (Section 4.1). Wells were also equipped with water level sensors (Druck 150 psi pressure transducers) connected to a Campbell Scientific 21X datalogger to record water levels (pressure head) within the wells at specified time intervals.

Continuous measurements of well yield and water levels were obtained for a period beginning one day prior to blasting and ending approximately one day following the tests. The durations of the pre- and post-blast monitoring periods were adjusted slightly, depending on the degree of water level fluctuations observed in each well.

4.3 Vibration Monitoring

Ground motions adjacent to nine domestic water wells (ten during the initial monitoring period) were recorded during blasting events to determine the ground motion variation with depth below the ground surface. At each well selected for study, one tri-axial transducer was buried 0.42 foot from the surface near each wellhead. A second transducer was buried at depth, as outlined below:

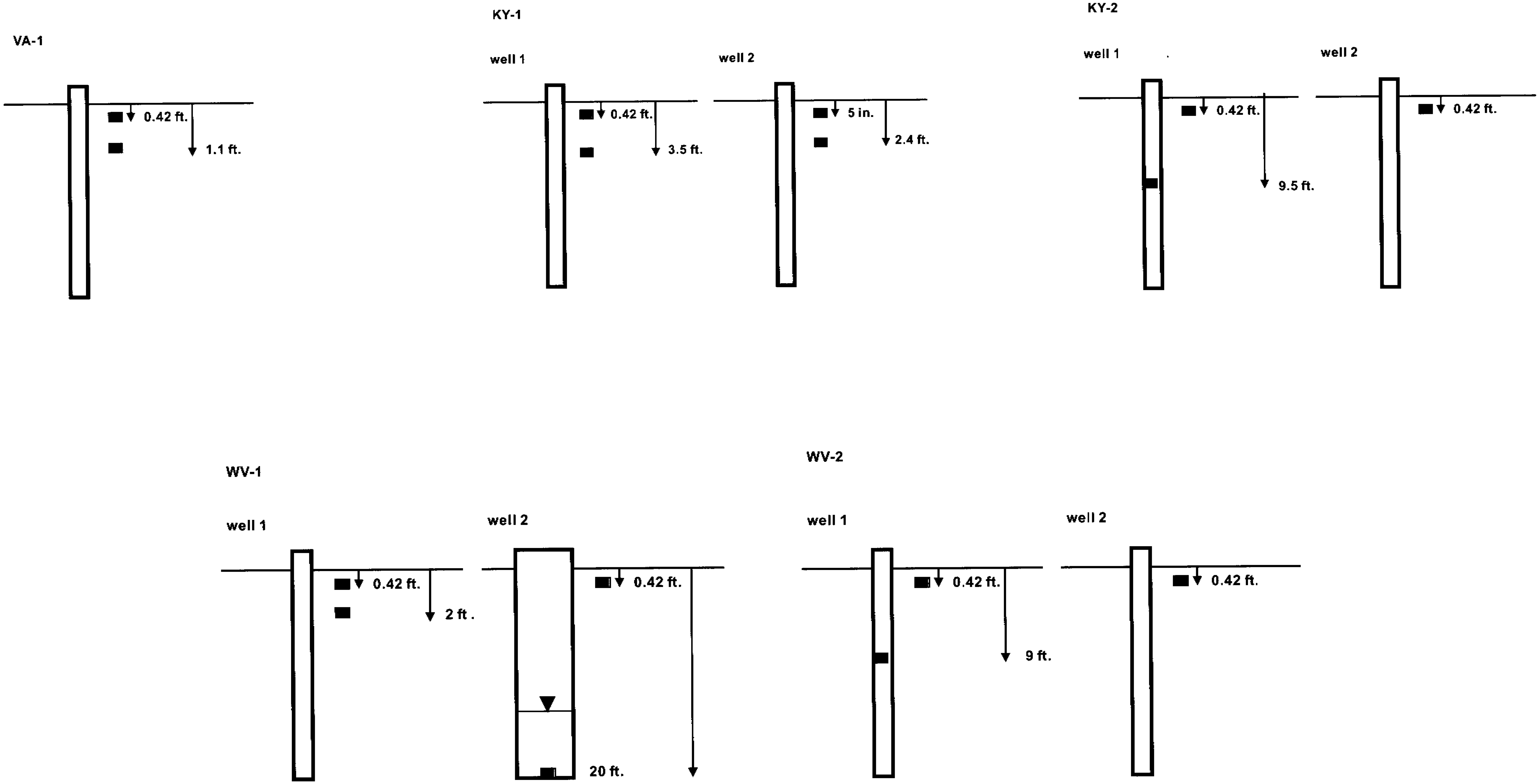
- At three sites the second transducer was placed at depths between 9 and 20 feet in either an abandoned well casings (two sites) or a hand-dug well (one site).

- At four sites, an attempt was made to hand-dig holes as deep as possible to record ground motions. At most of these sites, however, the subsurface soils contained large gravels and cobbles, making it difficult to dig holes deeper than 3.5 feet from the surface.

- At two sites, it was not possible to dig into the ground any deeper than 0.42 foot from the surface. Therefore, no second transducer was used at these sites.

Figure 5 shows the locations of transducers placed in or adjacent to wells. Transducers placed in abandoned wells were either grouted in place or encapsulated in crushed stone. Those placed within the ground adjacent to wells were tamped with pressure to ensure good coupling.

Blasting-type seismographs manufactured by LARCOR of Dallas, Texas were used to monitor ground motions near wells. Sensors were embedded in epoxy within a watertight housing for long-term survivability. The sensors were attached to the housing using 50-foot cables aligned with the vertical transducer for ease of inserting at depth. Airblast was recorded using the surface seismograph.



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Transducer Locations within or Adjacent to Wells

The following settings were used:

- Ground trigger level 0.02 inch per second (ips)
- Air trigger level 125 decibels (dB)
- Sample rate 1248 samples per second
- Record length 5 to 10 seconds
- Range 2.5 ips
- Lowest velocity detected 0.005 ips

4.4 Training

During the initial Fall-Winter 2000 monitoring period, the following state personnel from Kentucky, Virginia, and West Virginia were trained by DBS&A personnel to conduct the remaining three seasons of monitoring for the OSM well study:

- Leslie Bright, a geologist with the Division of Mined Land Reclamation, Department of Mines Mineral and Energy in Virginia
- Darcy White, Assistant Chief with the Office of Explosives and Blasting in West Virginia
- Ralph King, a Staff Scientist III with the Office of Surface Mining in Kentucky

These personnel were trained in the following tasks:

- Programming and data collection using the Campbell Scientific 21X datalogger and a laptop computer
- Wiring, calibrating, installing, and maintaining the Innovative Sensors M11 downhole pH sensor

- Wiring, calibrating, installing, and maintaining the Campbell Scientific CSI-247 downhole EC sensor

- Wiring and placement of the two Druck pressure transducers

- Calibrating and using the HACH 2100p turbidimeter

- Installing, programming, and collecting data from the Controlotron 1010n flow meter

- Using and calibrating the YSI-63 handheld pH, specific conductance, and temperature meter

Where applicable, the personnel were also trained in special procedures required at some of the sites (i.e., flow-through setups at the VA-1 Well-1 and KY-2 Well-2 locations).

5. Results

During each of the monitoring events, field personnel attempted to collect all three categories of data, including vibration/blasting data, water quality data, and well yield data. Throughout the study, wells were dropped from the monitoring program for various reasons. For example, the Kentucky sites were flooded before the second monitoring event, compromising the wells. The West Virginia sites were not monitored during the fourth quarter because blasting activities occurred too far from the well sites, and the Virginia site was dropped prior to the third monitoring event for the same reason, as well as discontinued use of the well due to hookup of the residence to a municipal water supply. Further details regarding the reasons for removing wells from the study are outlined in Table 2.

5.1 Vibration Data from Blasting

Ground motions adjacent to nine domestic water wells were recorded during blasting events to determine the ground motion variation with depth below the ground surface. Full waveform vibration data and summary tables are shown in Appendix A for all blast events that were recorded.

Detailed blasting records were available only during the Fall-Winter 2000 monitoring period. Hence, this data set is the most complete, with 54 shots recorded at nine wells. As the study continued mine blasting was being conducted at farther distances from the wells, and as a result, many mine blasts did not trigger the seismographs.

The maximum ground motion recorded during the study was 0.125 ips. The Fall-Winter 2000 data set shows average near-surface (0.42 foot) and at depth (from 1.1 to 20 feet) peak particle velocities (PPV) of 0.043 ips and 0.033 ips, respectively. In the Spring of 2001 as mining progressed away from the well site, the average PPV values decreased to 0.038 ips and 0.029 ips for the near-surface and at depth locations, respectively. In the Fall of 2001 ground motion was measured at the surface only and averaged 0.026 ips. In no case did the average ground motions at depth exceed those measured at the surface.

Table 2. Quarterly Monitoring Activities in Virginia, Kentucky, and West Virginia

State	Site ID	Well ID	Monitoring Performed				Comments
			Fall-Winter 2000	Spring 2001	Fall 2001	Winter 2001	
Virginia	VA-1	Well-1	FWQ, WY, LWQ, V	FWQ,WY	---	---	Resident on city water (third quarter) and no longer using well; dropped from study
Kentucky	KY-1	Well-1	FWQ, WY, LWQ, V	---	---	---	No access to wells due to flooding from sediment pond overflow (second quarter); site dropped from study
		Well-2	FWQ, WY, LWQ, V	---	---	---	No access to wells due to flooding from sediment pond overflow (second quarter); site dropped from study
	KY-2	Well-1	V	---	---	---	Well used only for vibration monitoring during initial monitoring period (well was dry).
		Well-2	FWQ, WY, LWQ, V	FWQ	V	---	Data not received (third quarter); residents refused access (fourth quarter)
		Well-3	FWQ, WY, LWQ	FWQ	V	---	Data not received (third quarter); residents refused access (fourth quarter)
West Virginia	WV-1	Well-1	FWQ, WY, LWQ, V	FWQ, WY, V	---	FWQ	West Virginia state personnel not on-site to supervise monitoring (third quarter)
		Well-2	FWQ, WY, LWQ, V	FWQ, WY, V	---	FWQ, V	West Virginia state personnel not on-site to supervise monitoring (third quarter)
	WV-2	Well-1	FWQ, WY, LWQ, V	FWQ,V	WY	---	West Virginia state personnel not on-site to supervise monitoring (third quarter); blasting took place too far away from site (fourth quarter)
		Well-2	FWQ, WY, LWQ, V	FWQ, WY,V	---	---	West Virginia state personnel not on-site to supervise monitoring (third quarter); blasting took place too far away from site (fourth quarter)

FWQ = Downhole field water quality parameter monitoring
WY = Well yield monitoring
LWQ = Laboratory water quality monitoring
V = Vibration monitoring
--- = No monitoring conducted; see Comments column for explanation

Frequencies at the PPV also tended to decrease with depth as the degree of confinement increased. Similarly, average frequencies decreased with successive monitoring periods. The average frequencies near the ground surface and at depth in 2000 were 17.5 Hz and 14.8 Hz. In the Spring of 2001, an average surface frequency of 18.8 Hz was measured. The ground motion data at depth fell within the resolution of the instrumentation and frequencies could not be reliably calculated.

The Fast Fourier Transform (FFT) frequency is a measure of the predominant frequency over the entire waveform and indicates the frequency containing most of the ground motion energy. In contrast, the frequency at the PPV (or peak frequency) is the frequency calculated from the zone-crossings for the cycle containing the PPV. Average values for PPV and frequency at the PPV by well site, as well as dominant waveform frequency obtained from the FFT are plotted on Figures 1 through 5 in Appendix A. The decrease in ground motion with depth is shown in Figure 1 (Appendix A) for the Fall-Winter 2000 monitoring season and Figures 2 and 3 (Appendix A) for 2000 and Spring 2001 combined. The linear trend for the averaged combined data is:

$$V\ (\text{average}) = -0.0015\,D + 0.0421 \qquad (1)$$

where V = the average PPV
D = the burial distance

The correlation coefficient (R^2) for the data is 0.38.

The average decrease in ground motion velocity was 0.0015 ips per foot below the ground surface, dependent on geology and coupling. Individual well site rates are provided in Figure 1 in Appendix A. For well-coupled burial depths (2 feet and below), this rate ranges between -0.002 and -0.0026 (the negative indicating a decrease with depth) ips per foot of burial. The best-fit trend line giving the decrease in frequency at the PPV with burial depth, shown in Figure 4 of Appendix A, is:

$$F\ (\text{average}) = -0.232\,D + 16.7 \qquad (2)$$

where F = the average peak frequency

D = the burial distance

Figure 5 of Appendix A shows the relationship between peak particle velocity and frequency at the peak for 2000 data, plotted on the OSM blasting level chart (1986).

It is difficult to distinguish the frequency differences between surface and buried ground motions. All data fell between 5.4 Hz and 34.1 Hz

5.2 Water Quality and Well Yield Data

As was the case with vibration monitoring, the data sets for field and laboratory water quality and well yield were most complete for the initial monitoring period. Analytical reports from water quality sampling and time-series graphs showing the results of downhole and well yield monitoring are included as Appendices B and C, respectively.

During the Fall-Winter 2000 monitoring event, water samples were collected from wells at each of the study sites prior to and after blasting (Table 3), and the results of the analyses are summarized in Table 4. Generally, parameters were stable throughout the monitoring period and showed no effects from blasting, as exemplified by the KY-1 Well-1 site. However, iron and TSS concentrations measured prior to and after blasting differed significantly in many wells (Table 4). It is theorized that these differences were caused by the stirring of sediments and sloughing of scale from both normal well operation and the introduction of monitoring equipment. Laboratory analysis was not performed during any of the subsequent monitoring events.

The dates and times of blasting events were placed on time-series graphs of data collected from field water quality monitoring, allowing identification of any changes in any of the parameters related to blasting (Appendix C). Throughout the study, where data are available, well yield and water level trends remained unchanged due to blasting. For example:

Table 3. Water Quality Sample Inventory

State	Site ID	Well ID	Pre-Test		Post-Test	
			Date	Sample ID	Date	Sample ID
Virginia	VA-1	Well-1	11/06/00	Boggs 1	11/18/00	Boggs 2
Kentucky	KY-1	Well-1	11/09/00	Ratliffe 1	11/18/00	Ratliff 2
		Well-2	11/09/00	Banks 1[a]	11/18/00	Banks 2
	KY-2	Well-1	Well not sampled			
		Well-2	11/18/00	Sumner 1	11/25/00	Sumner-2
		Well-3	11/20/00	Hurley #1	11/25/00	Hurley-2
West Virginia	WV-1	Well-1	11/26/00	Dean 1-1	12/4/00	Dean 1-2
		Well-2	11/26/00	Dean 2-1	12/4/00	Dean 2-2
	WV-2	Well-1	12/04/00	Abbott 1-1	12/7/00	Abbott 1-2
		Well-2	12/04/00	Abbott 2-1	12/7/00	Abbott 2-2

Note: All samples analyzed by Inter-Mountain Laboratories, Inc. of Farmington, New Mexico
[a] Duplicate analysis performed on sample

Table 4. Results of Laboratory Water Quality Analyses, Initial Quarterly Monitoring Event

State	Site ID	Well ID	Date	Concentration (mg/L)					
				General Parameters			Total Metals		
				TDS	TSS	Sulfate	Aluminum	Iron	Manganese
Virginia	VA-1	Well-1	11/06/00	1,740	19	991	<0.05	17.7	1.10
			11/18/00	1,710	9	955	<0.05	0.03	0.88
Kentucky	KY-1	Well-1	11/09/00	274	3	72	<0.05	3.48	0.44
			11/18/00	260	21	72	<0.05	24.8	0.35
		Well-1 Dup	11/09/00	272	10	72	<0.05	3.34	0.42
		Well-2	11/09/00	448	4	109	<0.05	4.17	0.36
			11/18/00	430	14	108	0.07	5.71	0.42
	KY-2	Well-1	Well not sampled						
		Well-2	11/18/00	250	<2	7	<0.05	20.8	0.89
			11/25/00	250	103	5	0.06	67.0	3.86
		Well-3	11/20/00	700	22	36	<0.05	12.9	1.51
			11/25/00	650	26	37	<0.05	14.7	1.46
West Virginia	WV-1	Well-1	11/26/00	400	75	145	0.07	28.4	1.00
			12/04/00	380	<2	144	<0.05	5.42	0.85
		Well-2	11/26/00	320	7	109	<0.05	4.62	0.39
			12/04/00	280	<2	109	<0.05	1.84	0.24
	WV-2	Well-1	12/04/00	180	<2	7	<0.05	0.89	0.10
			12/07/00	140	6	<5	<0.05	0.34	0.03
		Well-2	12/04/00	160	58	15	<0.05	16.4	0.55
			12/07/00	130	35	12	<0.05	5.16	0.07

mg/L = Milligrams per liter   TDS = Total dissolved solids   TSS = Total suspended solids

- The well yield from VA-1 Well-1 remained between 8 and 10 gallons per minute (gpm) during the entire Fall-Winter 2000 monitoring period, unaffected by blast timing. When VA-1 Well-1 was monitored again in Spring 2001 the well yield was in the same range.

- Where well yields were erratic, such as in KY-1 Well-2 during the Fall-Winter 2000 monitoring period, the erratic behavior did not correspond to the blast timing.

- Water level changes in wells, if any, were very regular and predictable and were related to household schedules. During periods of high water use for activities such as bathing and washing dishes, the pump cycles more often, resulting in a short-term lowering of the water level in the well. WV-2 Well-2 is a good example of these types of water level changes.

Field water quality parameters remained in similar ranges throughout the study (Table 5). The data from the downhole sensors fall into three categories:

- *Very little change in measured parameters.* A good example of this result can be seen in the temperature, pH, and EC data for WV-1 Well-1 during the Winter 2001 monitoring period, which remained nearly unchanged throughout the monitoring period.

- *Spikes in measured parameters related to household schedules.* For instance, during the Fall-Winter 2000 monitoring, VA-1 Well-1 showed spikes in temperature related to ground water being brought into the well during high use periods of the day.

- *Sensor drift.* Fouling of the instrument in the well can cause a gradually drifting data trend, or sensor drift. The slowly rising pH in well WV-2 Well-1 over the Spring 2001 monitoring period is a prime example of sensor drift. The continually increasing pH trend in this well is not disrupted by the blasts.

Table 5. Results of Field Turbidity Monitoring
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Site	Date	Time	Turbidity
VA-1 Well-1	11/05/00	15:45	30.9
	11/05/00	15:50	61.1
	11/05/00	15:59	54
	11/06/00	09:20	30.2
	11/06/00	09:40	22.7
	11/07/00	09:40	34.6
	11/07/00	10:00	30.5
	11/07/00	10:15	27.7
	11/07/00	16:01	29.4
	11/08/00	05:49	38.7
	11/08/00	06:04	11.3
	11/09/00	08:30	25.9
	11/09/00	09:00	23.4
	11/09/00	13:58	17.7
	11/09/00	16:14	39.1
	11/09/00	16:30	61
	11/09/00	16:43	61.5
	11/09/00	16:52	46.1
	11/09/00	17:00	40.1
	11/10/00	15:20	26.9
	11/10/00	15:35	25.8
	11/10/00	15:45	39.8
	11/11/00	13:54	30.5
	11/11/00	14:46	68.4
	11/11/00	15:50	18.3
KY-1 Well-1	11/09/00	13:58	17.7
	11/10/00	13:00	>1,000
	11/12/00	16:00	192
	11/13/00	09:53	NA
	11/13/00	10:14	26.3
	11/13/00	16:45	23.9
	11/14/00	12:59	23.2
	11/15/00	11:00	43.8
	11/16/00	09:53	24.2
	11/16/00	11:35	21.2
	11/17/00	11:55	90.9
	11/17/00	12:52	31.9

Table 5. Results of Field Turbidity Monitoring

Site	Date	Time	Turbidity
KY-1 Well-2	11/09/00	11:25	2.59
	11/09/00	11:30	2.34
	11/09/00	13:30	13
	11/10/00	11:38	5.28
	11/12/00	09:03	177
	11/12/00	12:30	170
	11/13/00	10:08	20.3
	11/13/00	16:40	7.59
	11/14/00	13:10	20.9
	11/15/00	10:55	2.64
	11/16/00	09:58	24.2
	11/16/00	11:36	20.1
	11/17/00	12:03	2.78
	11/17/00	12:52	0.99
KY-2 Well-2	11/19/00	14:15	19
	11/20/00	17:10	24
	11/22/00	09:45	56.5
	11/25/00	18:50	101
KY-2 Well-3	11/20/00	14:55	2.82
	11/20/00	17:20	8.1
	11/22/00	09:25	4.22
	11/25/00	17:50	60.6
WV-1 Well-1	11/26/00	16:00	29.80
	11/27/00	12:57	54.1
	11/27/00	13:30	30.2
	11/28/00	12:54	67.9
	11/28/00	13:29	58.2
	11/29/00	11:24	54.8
	11/29/00	12:40	45.2
	12/02/00	10:40	17.9
	12/02/00	12:10	25.8
WV-1 Well-2	11/26/00	16:00	58
	11/27/00	12:58	29.2
	11/27/00	13:32	60.2
	11/28/00	12:50	35.6
	11/28/00	13:24	37.8
	11/29/00	11:22	6.48

Table 5. Results of Field Turbidity Monitoring
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Site	Date	Time	Turbidity
WV-1 Well-2 (cont.)	11/29/00	12:30	9.3
	12/02/00	10:40	9.22
	12/02/00	12:10	11.1
WV-2 Well-1	12/03/00	12:40	2.28
	12/04/00	11:50	3.45
	12/05/00	11:30	9.69
WV-2 Well-2	12/03/00	12:45	81.6
	12/04/00	11:50	39.9
	12/05/00	11:30	45.2

6. Summary and Conclusions

DBS&A was contracted by the OSMRE to design and initiate a long-term study to investigate possible effects of mining operations on groundwater quality and supply in domestic wells. The study was conducted between November 2000 and December 2001 and consisted of four field data collection periods and subsequent data analysis.

During each of the monitoring periods, field personnel attempted to collect data deemed necessary to determine effects of mining operations on nearby domestic wells, including vibration/blasting, water quality, and well yield data. Data from the initial monitoring period are the most complete. Unforeseen issues in data collection and removal of sites from the study for various reasons resulted in progressively less complete data sets in each of the remaining data collection periods, and during the final period, only one site of the original nine selected could be monitored.

Vibration data became more sparse as the study progressed because mine blasting was conducted at increasingly larger distances from the study sites. Ground movements produced by blasting activities were attenuated by the greater distances and were in many instances not strong enough to trigger the seismographs, indicating little vibratory effect in the ground surrounding the wells. No adverse impacts to domestic water wells from surface coal mine blasting were measured during this study. This lack of impact is valid for peak surface ground motions that fall within 0.125 ips (the maximum ground motion recorded at the surface during the study).

Few changes that could be directly attributed to a blast event were observed in the water quality and well yield data collected. Water quality parameters did change slightly over time during measuring periods, but none of these changes seem to be related to blasting, but appeared instead to be the result of sensor drift and mixing of the water in the well due to pump cycling. Well yield and water level remained in a constant range throughout each individual monitoring season.

References

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