VIRGINIA CENTER FOR COAL
AND ENERGY RESEARCH

AN ANALYSIS OF HOUSEHOLD WATER SUPPLY IMPACTS BY UNDERGROUND COAL MINING IN VIRGINIA

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VCCER Associate Director

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Established in 1977 by the Virginia General Assembly as an "interdisciplinary study, research, information and resource facility for the Commonwealth" (Code of Virginia, Ch. 23-135.7), the Virginia Center for Coal and Energy Research has a three-part mission: to conduct research on interdisciplinary coal and energy issues; to coordinate coal and energy research at Virginia Tech and statewide; and to disseminate coal and energy research information to users in the Commonwealth.

An Analysis of Household Water Supply Impacts by Underground Coal Mining in Virginia

By
Carl Zipper
William Balfour
John Randolph
Richard Roth

Virginia Center for Coal and Energy Research

Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0411
Phone: (703) 231-5038

Report No. 94-2

May, 1994

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Virginia Center for Coal and Energy Research
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0411

Executive Summary

Underground coal mining can affect wells and springs used as water supplies by rural residents. In some U.S. coal-mining areas, research has been conducted to address the effects of underground mining on groundwater resources and household water supplies. In the Virginia coal mining region, however, no published studies of mining impacts on water supplies are available. Such information is relevant to current concerns due to recent federal and state legislation.

In this study, we analyzed the results of 73 investigations of alleged household water supply impacts by underground mining in Virginia. These investigations were conducted by the Virginia Division of Mined Land Reclamation (VDMLR) between 1981 and 1987 for the purpose of resolving disputes between surface residents and underground mining firms. The results were analyzed with reference to guidelines for identifying the zone of subsidence influence on groundwater prepared by West Virginia University geologist Henry Rauch for use in the northern Appalachians. Rauch's guidelines use mathematical relationships to define a primary zone of underground mining influence where dewatering of aquifers is to be expected. Rauch's guidelines also include reference to mitigating factors such as rock type, subsurface features, and surface topography.

The VDMLR data set included 27 investigations of alleged water supply impacts by partial-extraction room-and-pillar mines, 41 investigations of high-extraction room-and-pillar mines, and 4 investigations of longwall mines.

The VDMLR investigations found 14 of 16 water supplies within the primary zone of influence defined by Rauch as likely to have been affected by pillar-retreat mining. No water supplies within Rauch's primary zone of influence for longwall and room-and-pillar mines were represented by the data base. In addition, VDMLR investigators found 42 of 56 water supplies outside of Rauch's primary zones were likely to have been affected by mining; these cases represented room-and-pillar, pillar-retreat, and longwall mining. Geologic circumstances not directly related to subsidence were found to be responsible for 31 of these 42 impacts. These geologic circumstances included subsurface fractures and other geologic features acting as aquifers which were drained by underground mining operations.

VDMLR investigators also found some of the investigated water losses to have been caused by factors other than mining; all such water supplies were located outside of Rauch's primary zones.

The VDMLR data contain no information on the time required for recovery of affected water supplies.

The VDMLR investigations provided limited support for the accuracy of Rauch's guidelines as a means of identifying situations where underground mining operations would be expected to impact groundwater aquifers and water supplies in Virginia. Data set limitations are the primary factor which prevents the drawing of more definite conclusions. The data do demonstrate that it would be inappropriate to rigidly define a "zone of underground mining impact" on water supplies in Virginia based solely on mine subsidence effects.

Introduction

Underground coal mining can affect wells and springs used as water supplies. Subsidence caused by underground mining is generally acknowledged to be a primary cause of groundwater resource effects. In coal producing regions of Virginia and neighboring states, many rural residents depend on groundwater as their primary water source.

Although it is well known that underground mines *can* impact groundwater supplies, guidelines for determining *if* a specific mining operation will be likely to affect a particular water supply have not been developed for the Virginia coalfield area. Complicating factors include variations in mining methods, depth of mining, and geology among locations within the Virginia coalfield area, and between the Virginia coalfield and mining areas in other states. Throughout central Appalachia, contested allegations of water supply impacts have been the subject of disputes between mining firms and residents.

The costs associated with disruptions of groundwater supplies in rural areas can be substantial. When a household's water supply is disrupted, an alternative supply must be developed or the property must be abandoned. One way or the other, somebody must pay. When the cause of a water supply disruption is disputed, both sides must bear costs to resolve that dispute, through litigation or other means. Rational resource management requires that clear guidelines be available for determining cause-and-effect relationships. Such guidelines are not currently available for application to potential water supply impacts of underground mining operations in Virginia.

The purpose of this paper is to report the results of an analysis of water supply impacts of underground mining in Virginia. We analyzed reports of 73 water supply investigations conducted by the Virginia Division of Mined Land Reclamation (VDMLR). These investigations were conducted between 1981 and 1987 for the purpose of resolving disputes between surface residents and underground mining firms.

The results of the VDMLR investigations were analyzed with reference to guidelines for identifying the zone of subsidence influence on groundwater supplies which were prepared by geologist Henry Rauch (1989), based on research which he and his students conducted in the northern West Virginia - western Pennsylvania area. Rauch's "rules of thumb" are the most complete and explicit published guidelines for determining subsidence impacts on water supplies in Appalachia.

This research addresses a subject that is relevant to recently enacted legislation. Section 2504 of the federal Energy Policy Act of 1992 requires mining firms to replace water supplies damaged by underground mining. Virginia House Bill 1687 (1993) also requires water replacement. In developing regulations to implement these laws, federal and state agencies must develop guidelines for determining whether or not alleged water supply impacts are, in fact, mining related.

Background Information

Geology and Hydrology of the Virginia Coal Region

The coalfields of southwest Virginia lie in the Appalachian Plateau physiographic province. The area is characterized by rugged mountains, a deeply dissected, mature topography consisting of V-shaped valleys with steep slopes and narrow ridges. The landforms were shaped by the erosion of a high plateau of sedimentary origin. These sedimentary rocks, which range from Cambrian through Pennsylvanian ages, were uplifted as a block, with minimal deformation compared to the Valley and Ridge physiographic province. Accordingly, geologic strata remain nearly level to gently sloping, except near the edge of the eastern thrust block that marks the beginning of the Valley and Ridge province.

In northern Dickenson County near the Buchanan County border, the Russell Fork fault bisects the Virginia coalfields (Figure 1). North of this shear fault the strata are relatively undisturbed. The remaining area of the Virginia coalfields are contained in what is known as the Pine Mountain overthrust block. This geologic unit is bound on the southeast by the Valley and Ridge province, and on the northeast by Pine Mountain. Further south, this thrust sheet extends into Tennessee and terminates near Caryville. The Pine Mountain thrust sheet moved as a unit to the northeast, resulting in displacements of several miles laterally but only tens of feet vertically. A number of shear faults, occasional deep fracture zones, and numerous shallow fracture zones are contained within this thrust sheet, primarily as a result of geologic movement.

All of the coal-bearing formations mined in Virginia's southwestern coalfield are of Pennsylvanian age. These formations consist of alternating layers of quartzarenite, sandstone, sandy shale and shale, thin layers of clay and underclay, and coal seams. At least 27 major seams are present.

Soils in the coalfields are the product of weathering and disintegration of parent materials. The richest soils are found on floodplains in valley bottoms and consist of unconsolidated material washed down from the hillsides. On the hillsides, soils are generally thin and prone to erosion, especially if vegetative cover is removed. On level-topped ridges that have escaped erosion, soil covers are thick.

The only systematic, regional study of groundwater hydrology in the Virginia coalfield area was conducted by Harlow and LeCain (1993). They assessed hydraulic characteristics of geologic materials at 52 locations, distributed throughout the region. They found that most rock types are sufficiently permeable to form aquifers only in the upper 100 feet where weathering has occurred; below this, coal seams are generally more permeable than overlying and underlying rock units (Figure 2). Thus, coal seams are the primary geologic units capable of serving as major aquifers in the coalfield region.

Potentiometric-head measurements indicated that the ridges function as the major recharge areas, and that the regional fracture system is essential to recharge of the deeper groundwater zones. Water infiltrates through the soil cover and flows downward and laterally through fractures in the shallow bedrock. Where the strata are inclined, water may flow down components of the dip. Increasing depth causes a loss of hydraulic conductivity within the rock units, allowing groundwater to travel

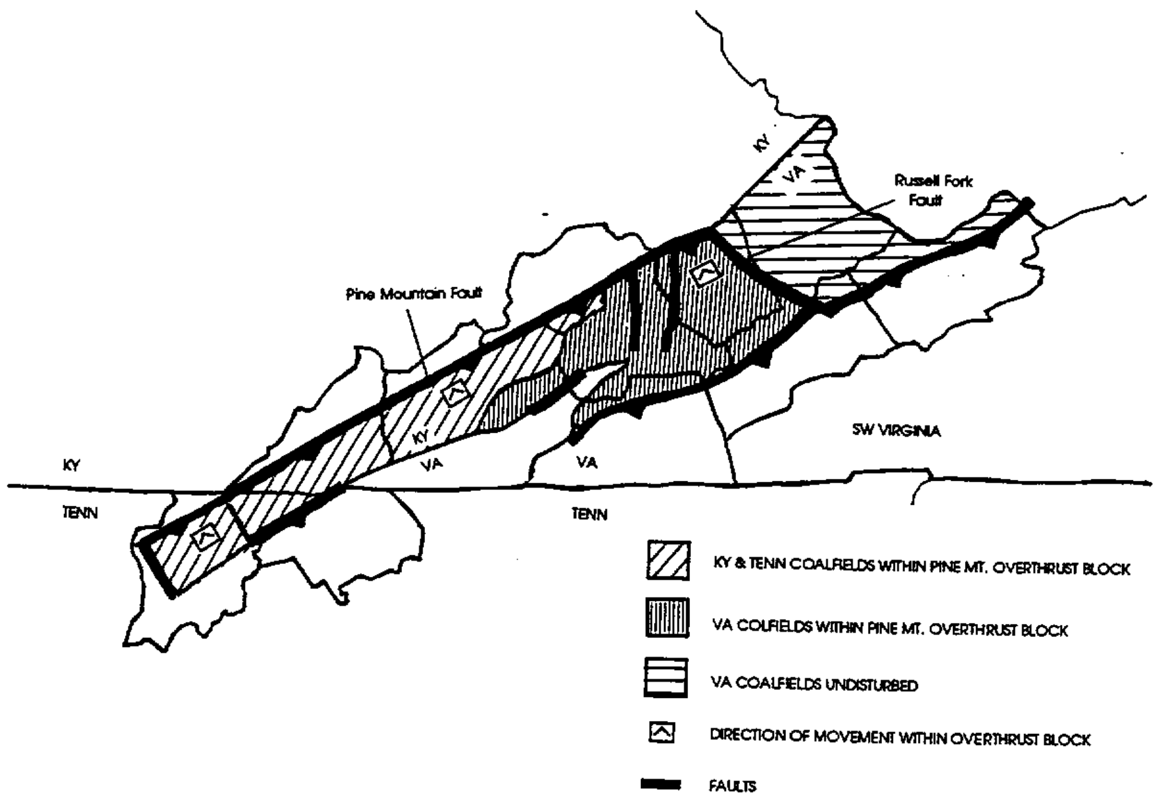

Figure 1. Generalized geology of the southwest Virginia coalfield region.

laterally along fractures, bedding planes, or coal seams, to discharge at springs or seeps on hillsides.

Transmissivity associated with coal seams was found to be be one or two orders of magnitude greater than transmissivity of other rock types. Transmissivity of coal seams was found to decrease with depth. Transmissivity differences of three or four orders of magnitude were found to occur in seams of approximately equal thickness and depth; these were attributed to fractures, bedding-plane separations, and the number and pervasiveness of cleats.

Both the Virginia coalfield region and the northern West Virginia area, where Rauch did his work, are located within the Appalachian Plateau physiographic province. The geology in both regions is sedimentary and dominantly flat lying, with coal seams present. There are distinctive differences between the two areas, however.

One major difference is that the majority of the southwestern Virginia coalfield is a part of the Pine Mountain thrust sheet, while the northern West Virginia's geologic history is far more stable. Thus, fracture zones (faults and lineaments) are more prevalent in southwestern Virginia.

A second difference between the two areas has to do with rock types. Southwestern Virginia's geology is dominated by massive sandstone rock units, while

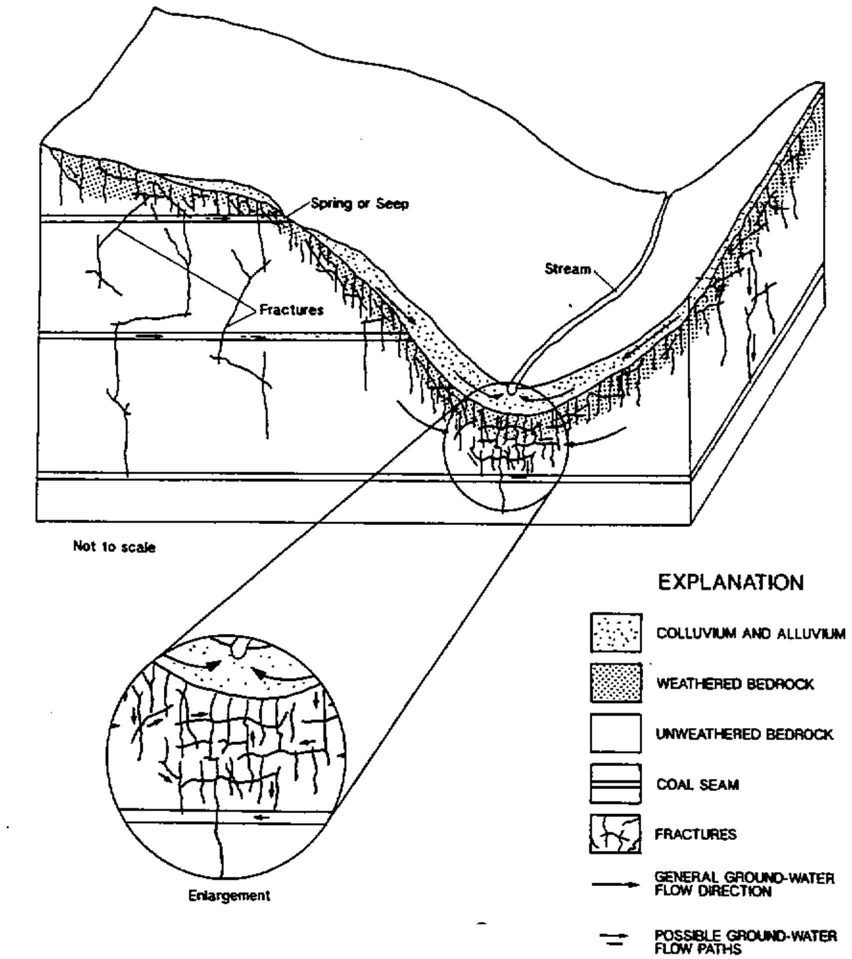

Figure 2. Conceptualized groundwater flow system in the coalfields of southwestern Virginia (from Harlow and LeCain, 1993).

clay-shales are far more prevalent in northern West Virginia. Shales tend to form perched aquifers, and are more likely to swell and seal rock fractures than are the sandstone units of southwestern Virginia. Limestones, virtually absent in southwestern Virginia's coal mining area, are more common in northern West Virginia, sometimes in association with coal seams.

Underground Mining and Water Resource Effects

Underground coal mining is conducted in seven Virginia counties: Buchanan, Dickenson, Lee, Russell, Scott, Tazewell, and Wise. Two underground mining methods are partial extraction room-and-pillar, and high-extraction.

Room-and-pillar (or partial-extraction) mining generally recovers up to 50 to 65% of the coal in the mined area of the seam. Pillars of coal are left to support the roof. Subsidence occurs slowly (over decades to centuries).

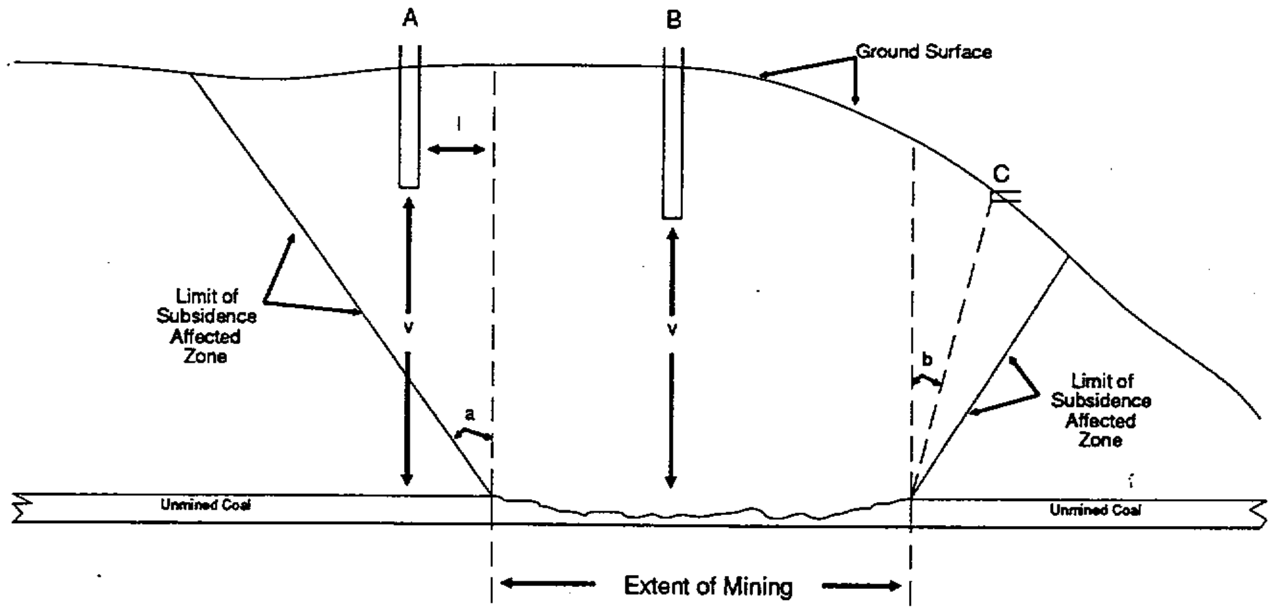

Figure 3. A representation of concepts used to define the location of water supplies, relative to underground mining operations. Wells A and B and spring C are all located within the influence zone.

l = lateral proximity — v = vertical proximity
a = angle of influence — b = angle of proximity

Two different types of high-extraction mining are conducted in Virginia. Retreat mining is a variation on the room-and-pillar method, where the mine is developed in similar fashion to a conventional room-and-pillar mine. However, once the mine works have been fully developed, the operation "robs" the pillars as it retreats back towards the mine entrance. The result is that 70% or more of the coal is removed, leaving the roof essentially unsupported and allowing it to cave in, or subside. Longwall mining removes coal from one or more "panels," each of which can be up to 1000 feet in width and several thousand feet in length.

High-extraction methods remove most or all of the coal seam within the mined panels, which leaves the overlying rock unsupported. The resultant collapse of the overlying rock layers (the "overburden") can affect overlying aquifers and water supplies developed from those aquifers.

In general, the higher the percentage of coal removed, the greater the likelihood that subsidence will occur. If subsidence does occur, water supply impacts can extend beyond the area which directly overlies the mine. The "angle of influence" is a concept used to define the zone where groundwater resources are affected by an underground mining operation[1] (Figure 3). Whether or not supplies directly over the mine are affected will be determined by factors such as vertical proximity of the water supply to the mine, seam thickness, and rock type.

[1] The term "angle of draw" has been used by other investigators to define the zone where subsidence affects water resources through deep fracturing and caving. The term "angle of influence" is used here to avoid implication that water losses were caused by subsidence-related fracturing and caving.

Roth *et al.* (1990) previously reviewed 14 studies of the hydrologic effects of high-extraction coal mining. The mining operations were located in West Virginia, Pennsylvania, and Ohio. With few exceptions, the studies focused on the effects of one, or a small number, of underground mining operations and did not attempt to generalize the observed effects.

All of the reviewed studies showed that coal mine subsidence affects groundwater hydrology to some extent. Wells within the subsided surface area frequently showed some dewatering. Closer vertical proximity of the well bottom to the mine works increased the probability of adverse impact; closer lateral proximity to the mined area also increased risk of adverse impact. Surface water bodies such as springs and streams could also be affected, either by dewatering or by alterations in flow regimes.

Besides proximity of a monitored water source or water body to the mine, other factors influencing the occurrence, type, and extent of impact include lithology of the overburden, strata mechanics, and topography. In some cases recovery has occurred. In most cases, adverse effects such as well dewatering have not been observed over a period sufficient to allow effective documentation of duration or degree of subsequent water-level recovery.

Henry Rauch of West Virginia University has conducted extensive research on the hydrologic effects of underground mining. In a 1989 paper (Rauch, 1989) he summarizes the results of 36 studies and develops some basic principles and "rules of thumb" on the effects of underground mining on water supply wells and springs for the northern Appalachian coal basin. The studies reviewed by Rauch were conducted in northern West Virginia, central and western Pennsylvania, and southern Ohio.

Rauch's findings can be summarized, briefly, as follows: The effects of unsubsided room-and-pillar mines are generally confined to a zone lying directly above the mined-out area. This zone can extend vertically from 20 to 100 feet, with the presence of shales and claystones being a primary factor in limiting the vertical extent of the influence zone.

The effects of high-extraction mining tend to be more extensive than those of low-extraction room-and-pillar mines. Rauch's findings (Rauch, 1989) indicate that the vertical extent of the zone where subsidence-related fracturing and caving affects water resources typically extends from 120 feet to 400 feet above the mined area for pillar retreat mining. For longwall mines, the deep fracturing and caving zone, and related severe dewatering, typically extend vertically above the mine for a distance of approximately one-half the panel width.

An "aquiclude zone" of partial and temporary dewatering is typically located above the severe dewatering zones caused by both pillar retreat and longwall mining. According to Rauch, slight and/or temporary water resource effects can be expected to occur in the aquiclude zone, but impacted water supplies generally recover within a few days, as compressional stresses and infilling close bedding fractures. However, wells located on slopes in excess of 25° and springs in the aquiclude zone may be affected to a greater degree.

Rauch also noted that the above factors are often modified by special circumstances and geologic features. Factors tending to extend the dewatered zone over room-and-pillar mines include pillar collapse, vertical airshafts and pumping boreholes, and fracture zones, while the presence of fireclays, claystones, and shales in the geologic sequence tends to limit the vertical extent of subsidence effects. He also found that factors other than subsidence-related overburden fracturing can affect water resources in the vicinity of subsided mines. For example, he found that the presence of lineaments may indicate fracture zones which can be beneficial in helping to minimize the dewatering effects of subsided mines, when groundwaters infiltrating through the rock fractures in the subsided zone are replenished by the streamflow.

Objectives and Methods

The objective of this study was to test the applicability of the principles identified by Rauch (1989) to conditions in the Virginia coalfield region. The research was conducted by reviewing and analyzing a series of water supply investigation reports compiled by the Virginia Division of Mined Land Reclamation (VDMLR) between 1981 and 1987. These reports contained the results of investigations conducted by the Division in response to citizen complaints alleging water supply disruptions by underground mining operations.

Most instances where mining affects water supplies in Virginia are resolved privately by the parties involved. The reports reviewed in this study represent only those instances where private negotiations were unable to resolve the situation satisfactorily. Thus, the water loss complaints forming the basis for this research probably include those which were especially difficult to reconcile. In cases where an individual's well was being used as a monitoring well by the mining company, water supply inventory information in the permit was often the primary source of pre-mining data. To the extent available, additional information on pre-mining conditions was obtained from the user and the coal company. In some cases, the well driller's record was also accessed.

The study was initiated by reviewing available literature on the water resource impacts of underground mining and subsidence; Rauch's work (1989) was the only literature located which attempted to identify basic principles or guidelines, generalizing from multiple observations.

Two forms were prepared for recording data from the VDMLR investigation reports, one for low extraction mining and the other for high-extraction mining. A trial run was made using several examples and the forms were modified somewhat after input from VDMLR geologists.

The forms broke down the report data into eight categories: general information, supply information, proximity, lithology, seam information, mining impact, other mitigating conditions, and a section for comments (Appendix A). Investigations of VDMLR complaint files were conducted from July through September, 1991. A computerized database was constructed to allow data manipulation and graphic display. Geologic maps, interviews with VDMLR geologists, and and other data from the permit files were examined to aid in interpretation of the complaint file reports.

The VDMLR Complaint Files

Environmental impacts of coal mining are regulated in Virginia by VDMLR, under the provisions of the Virginia Coal Surface Mining Control and Reclamation Act of 1979 (VCSMCRA). VCSMCRA was passed and the Virginia program was implemented in order for the state to assume responsibility for coal mining regulation from the federal government under the Surface Mining Control and Reclamation Act of 1977 (SMCRA). From 1981 through early 1987, VDMLR complaint investigation reports addressed the impact of mining operations on individual water supplies. As a response to the dynamic legal and regulatory environment, later VDMLR investigative reports focused on impacts to the hydrologic balance. Therefore, the current study does not include data on post-1987 VDMLR complaint investigations.[2] While most large coal mining companies operating in Virginia maintain policies for replacing damaged water supplies or compensating owners, these policies were voluntary during the period when the VDMLR investigations were conducted. Most instances of damaged water supplies were settled privately without litigation or regulatory involvement. When disagreements arose between the mine operator and the surface owner, however, some surface owners filed complaints with VDMLR. The VDMLR staff would then investigate and make a determination as to whether the mining operation caused or did not cause the alleged effect.

When a complaint was filed with VDMLR, a field inspector was assigned to investigate the problem. If the complaint appeared to be warranted (*i.e.* the field inspector determined that underground mining could be affecting the water supply), technical services were requested from the VDMLR geological staff. Site visits were scheduled to investigate the claim and talk with the claimant. Information was requested from the permit owner, and visits to the mining operation were common. After assimilating data from involved parties, a written report was prepared to document the investigation and its results. These reports include maps, photos, results of interviews with affected parties, geological and hydrological data, copies of the original complaint forms, permit information, and other pertinent information. The reports were written in a narrative style and included summary sections addressing actions to be taken.

VDMLR decisions were based on a variety of criteria. The two most important were timing and proximity to mining. Water loss concurrent with ongoing mining operations in close proximity was considered to be evidence that a water supply loss may have been mining-related. Geological influences were also evaluated and given close attention. Several instances were observed where a cluster of water supplies several thousand feet away from mining operations were affected by geological circumstances that were in association with those operations. Determination of age, yield, and condition of the well or spring prior to mining was also relevant to understanding the loss of a supply. Subsidence features present at the surface were also taken to be an indication that the water supply loss may have been mining-related.

[2] Due to legal changes resulting from the federal Energy Policy Act of 1992, and Virginia House Bill 1687 (1993), VDMLR's investigation reports are again addressing impacts to individual water supplies.

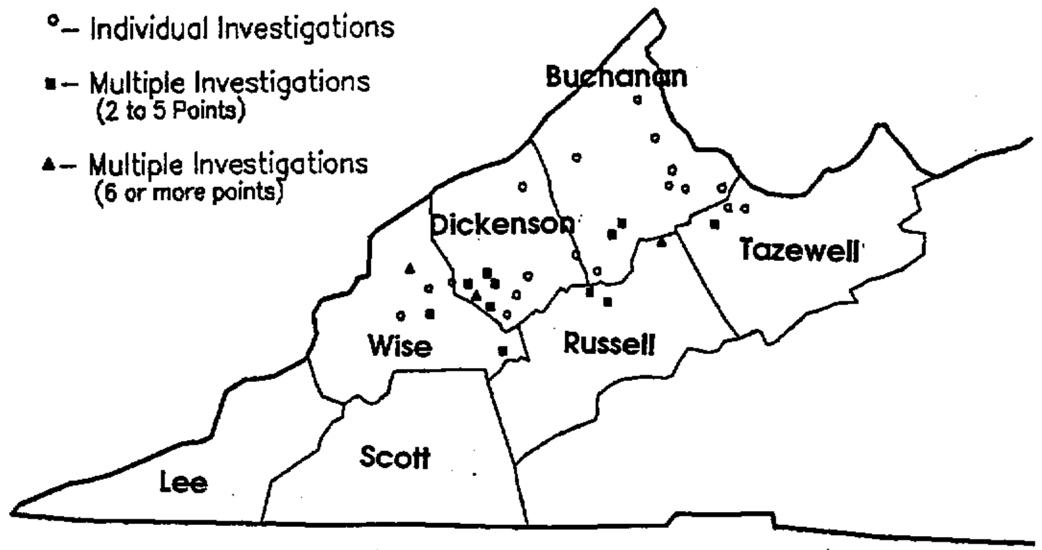

Figure 4. Southwestern Virginia's major coal producing counties, and the locations of VDMLR water loss complaint investigations.

Results

VDMLR investigations resulted in six separate outcomes: Affected, suspected effect, not affected, suspected non-effect, no determination, and unknown. Seventy-three cases were reviewed (Table 1; Figure 4). The cases are reviewed individually in Appendix B. Specific cases are referred to by number in the following text. Table B-1 (Appendix B) references those case numbers to specific VDMLR investigation reports.

Room-and-Pillar Mines

Rauch's review (1989) of studies conducted in northern West Virginia, central and western Pennsylvania, and Ohio led him to conclude that, in general, significant dewatering occurs within 20 to 100 feet vertically above drained room-and-pillar mines, and is usually restricted to within about 40 feet vertically of these mines. The vertical extent of dewatering is strongly controlled by rock lithology in that shale or fire clay (claystone) act as confining layers to maintain aquifers closer to the mine. More extensive dewatering occurs in the vicinity of features such as mine entries, pumping boreholes, and collapsed pillars.

Only limited data are available to evaluate this hypothesis in Virginia. Only one case (case 2) represented a water supply directly overlying a conventional room-and-pillar mine, within the 100-foot vertical proximity zone (Table 2, Figure 5). This case represented a 50 foot drilled well; the mine came within 85 feet of the well base.

Table 1: Summary of characteristics of water supplies investigated by VDMLR.

	Affected	Not Affected	No Determination	Suspected Effect	Suspected Non Effect	Unknown	Total
Mining Method:							
Room and Pillar	13	5	3	3	3	-	27
Pillar Extraction	24	1	5	10	-	1	41
Longwall	4	-	-	-	-	-	4
Unknown	-	1	-	-	-	-	1
Water Supply Type:							
Well	33	7	6	6	2	1	54
Spring	8	0	2	7	1	-	19
County:							
Buchanan	4	3	3	2	-	-	12
Dickenson	3	2	5	7	3	1	21
Russell	15	-	-	2	-	-	17
Tazewell	3	1	-	-	-	-	4
Wise	16	1	-	2	-	-	19
Total	41	7	8	13	3	1	73

Dewatering did not occur until 14 years after the original mining. However, when dewatering occurred, three additional wells were drilled on the property, and all were dry, indicating that the dewatering which had occurred was fairly extensive. Although no subsidence features were present, the lengthy time delay indicates that pillar collapse may have occurred, in which case this situation would not conform to the "unsubsided" category.

In eight partial-extraction room-and-pillar cases of water loss (17 through 24), VDMLR investigators determined that water losses were likely to have occurred as a result of factors other than mining. In these cases, vertical proximities ranged from 90 to 520 feet, and lateral proximities from 0 to 700 feet. In four of the eight cases, the angle of proximity was less than 20° (Figure 5). The existence of these cases does lend limited support to the hypothesis that water supplies lying outside of the 20-to-100 foot vertical proximity zone should not be affected by unsubsided room-and-pillar mining. Case 16 represents the only water supply located within a 20° angle of proximity, at a vertical proximity greater than 100 feet, which was determined (or suspected) to have been affected by partial extraction room-end-pillar mining. It involved a steep-slope spring whose recharge area was suspected of being affected by a retreat-mining operation rather than by the room-and-pillar mine that was the subject of the complaint. This retreat mine was operating underneath the main ridge, approximately 1000 feet away from the disrupted water supply. No subsidence features were present above the room-and-pillar works, but subsidence cracks in the recharge zone were observed in the vicinity of the pillar-retreat operation. Rauch (1989) notes that steep-slope springs tend to be especially vulnerable to mining-related impacts.

In fourteen additional room-and-pillar cases, water losses were judged to have occurred, or suspected to have occurred, as a result of mining. In all cases, special

Table 2. Summary of room-and-pillar mine investigations.

Condition[a]	VDMLR Determination[b] A&SE	NE&SNE	ND	Total
	- - - (Number of Cases) - - -			
Within Rauch Zone:				
v < 40′ and a = 0°	-	-	-	0
40′ < v < 100′ and a = 0°	1[c]	-	-	1
Outside of Rauch Zone:				
v > 100′ or a > 0°	15[d]	8	3	26
Total	16	8	3	27

[a]For explanation of symbols, see Figure 3.
[b]A&SE = Affected and suspected effect. NE&SNE = No effect and suspected non-effect. ND = No determination.
[c]Water supply disruption occurred 14 years after cessation of mining.
[d]Special geologic circumstances noted for all 15 cases (see Table 5).

circumstances were present. In cases 1 and 3, a single mining operation drained coal-seam aquifers that were feeding the wells in question. In cases 5 through 15, a single operation was judged by VDMLR to have drained a fracture zone that was feeding the water supplies of a group of households. Case 4 was judged by VDMLR to involve mining impacts on the recharge area rather than the water supply itself.

All of the investigations where no special circumstances were identified, and where the water supply was not located within the 20-to-100 foot zone directly overlying the mine, determined that the water supply disruptions were not, in all probability, the result of mining.

Cases 20, 21, and 22 represented water supplies that were either directly above, or in close lateral proximity to, room-and-pillar mines, but with vertical proximities ranging from 380 to 520 feet. Water supply impacts in all three cases were judged by VDMLR to have been caused by dry weather, limited recharge areas, or both.

Cases 17, 18, 19, 23, and 24 were all classified as non-effects, or suspected non-effects. All were drilled wells. In two cases (17 and 18), old mine works were closer to the well bottom than the mining operation which was the subject of the complaints, although no cause-and-effect determination was made with respect to the water loss. In two additional cases (19 and 24), the original water supplies were judged to have been poor to begin with.

In summary, the only water supply falling within the zone of influence specified by Rauch (directly overlying, less than 100 feet) was judged by VDMLR to have been affected by mining. However, this water supply was outside of the primary zone of influence defined by Rauch (i.e. the vertical proximity of the water supply to the mining operation was in excess of 40 feet) and there was a 14 year delay between mining and the water supply effect. Fifteen additional water supplies were classified as affected by, or as suspected effects of, mining. However, in all of these cases, special geologic circumstances were present which were judged by VDMLR

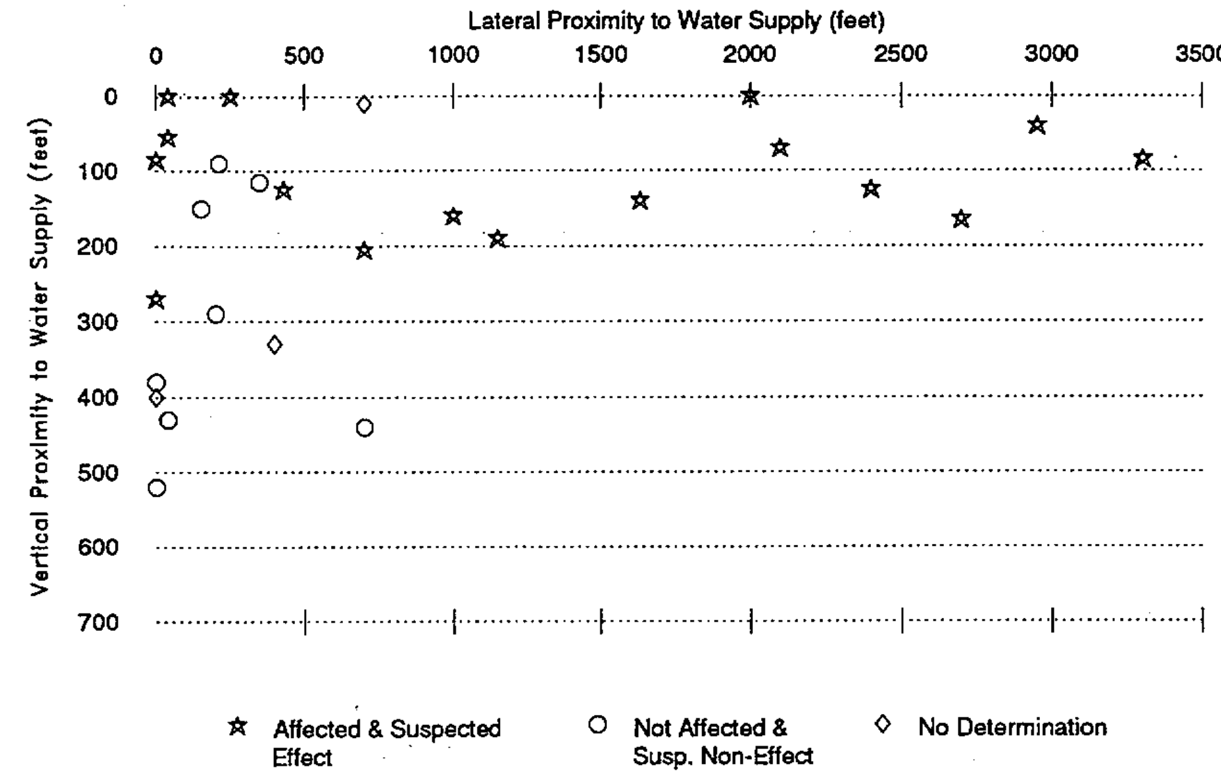

Figure 5. Proximity of water supplies investigated by VDMLR to room-and-pillar mining operations.

geologists to have contributed to the water loss. In all cases where water supplies were located outside the Rauch-defined zone of influence, and where no special circumstances were noted, the water supply disruptions were determined by VDMLR geologists to have been caused by factors other than mining.

Longwall Mines

Rauch (1989) states that the severe dewatering zone of rock fracturing and caving for longwall mines in the northern Appalachian coal basin generally extends for a vertical distance of approximately one-half the width of the longwall panel above the mine, and within an angle of influence between 20° and 40° from the vertical. Partial or temporary dewatering effects can sometimes occur above this severe dewatering zone, in the aquiclude zones. The angle of influence may actually be less than 20° or greater than 40°, depending on the geologic setting. Generally speaking, a sandstone overburden or a steeply-sloped surface would be expected to increase the angle of influence.

The VDMLR data set contains only four complaints regarding longwall mines (Figure 6, Table 3); all were the result of the same mine, and all four water supply impacts were judged to have been effects of the mining operation. The panel width was 400 feet. None of the affected water supplies was located within the "critical" dewatering zone described by Rauch. Only one was located within the 20°-to-40°

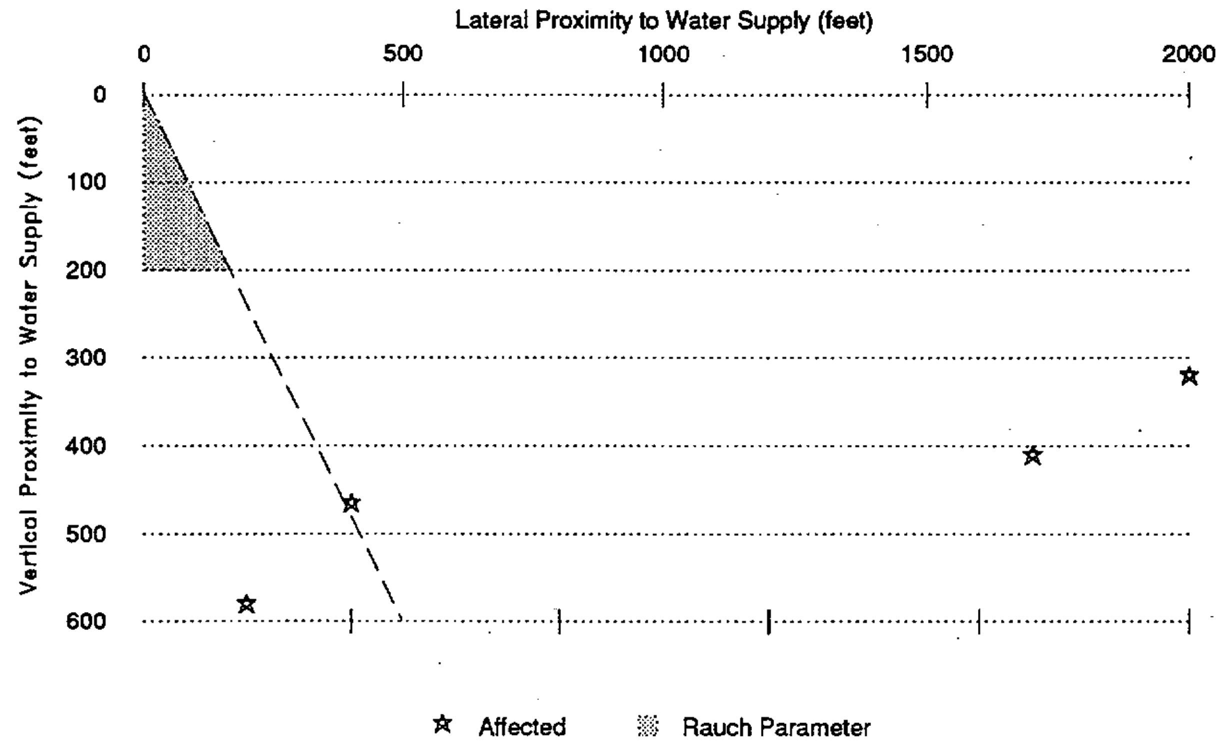

Figure 6. Proximity of water supplies investigated by VDMLR to longwall mining operations.

zone of influence, but above the critical zone (*i.e.*, within the aquiclude zone): Case 31, a hillside spring with vertical proximity of 580 feet, and an 18.5° angle of proximity.

The other three affected water supplies were drilled wells. Case 28, was located at the extreme edge of the aquiclude zone, at a 40.5° angle of proximity. The other two affected water supplies (cases 29 and 30) were located well outside of Rauch's influence zone. All three of the drilled well impacts were reported to have occurred

Table 3. Summary of longwall mine investigations[a]

Condition	A&SE	NE&SNE	ND	Total
	VDMLR Determination			
Within Rauch Zone:				
v < 50% of panel width and a < 40°	-	-	-	0
Outside of Rauch Zone:	4[b]	-	-	4
Total	4	-	-	4

[a]For explanation of symbols, see Table 2 and Figure 3.
[b]One case was a hillside spring, and special circumstances were noted for the other three cases (see Table 5).

Table 4. Summary of pillar-retreat mine investigations[a]

Condition[a]	A&SE	NE&SNE	ND&UNK	Total
	VDMLR Determination			
Within Rauch Zone:				
v < 400', a < 40°				16
Springs	7	-	2	
Wells	7	-	-	
Outside of Rauch Zone:				
400' < v < 430', a < 15°				5
Springs	3	-	-	
Wells	2	-	-	
v > 430'				6
Springs	3	-	1	
Wells	-	1	1	
v < 400', a > 40°				
Wells	14[b]	-	-	14
Total	34	1	6	41

[a]For explanation of symbols, see Table 2 and Figure 3.
[b]Special circumstances noted in 13 of these cases (see Table 5).

within two weeks of mining; two of the wells went totally dry while the third (case 30) was left with only a few feet of water. While the exact duration of impacts is unknown, they lasted for at least three and one-half months. The VDMLR determinations concluded that the three affected wells were impacted because the valley aquifer, which was the source of water for the three wells, was drained by the mining operation.

Pillar-Retreat Mines

Rauch (1989) defines the primary zone of influence for pillar-retreat mining as 120 to 400 feet of vertical proximity, usually within a 20° to 40° angle of draw. Within this zone, according to Rauch, groundwater is affected by rock fracturing and caving caused by subsidence processes. Sixteen of the 41 complaints filed against pillar-retreat mines fell within this influence zone (Table 4, Figure 7). Fourteen of these (including six hillside springs, one spring from an old mine, and seven wells) were determined or suspected to have been affected by mining operations, and no determinations were made with respect to the other two (cases 71 and 72). In case 71, water loss occurred within two months of pillar removal. In case 72, the complaint was filed about one month before pillar removal in apparent anticipation of water loss. No follow-up visit was made to determine whether or not water loss did eventually occur, indicating that the mining company and the complainant settled their differences without further need to involve VDMLR.

Four additional affected (or suspected effect) water supplies were located directly above the mining operations, with vertical proximities in the range of 400 to 430 feet, while a fifth (case 46) was located within this vertical proximity range at a 13° angle

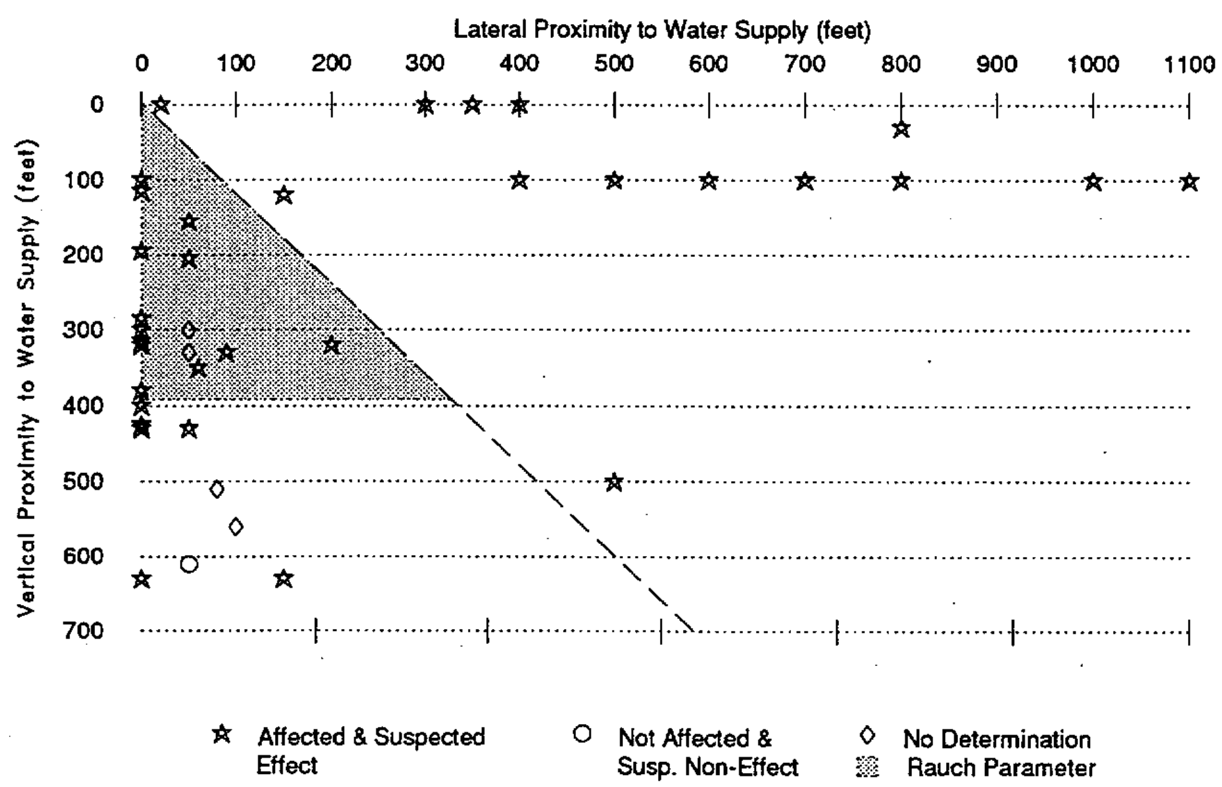

Figure 7. Proximity of water supplies investigated by VDMLR to pillar-retreat mining operations.

of proximity. Three of these cases (32, 35, and 36) represented hillside springs, while the other two (35 and 46) involved ridgetop wells. In four of these five cases, subsidence features were present. No special circumstances, other than subsidence features, were noted by investigators for any of these cases.

Three additional disrupted water supplies located at vertical proximities greater than 430 feet, were classified as affected or suspected effects. Two were located at angles of proximity less than 40°, while the third (case 34) was located at 45°. Cases 34, 47, and 48, were all hillside springs located 500 feet to 630 feet above the mining operation. In cases 47 and 48, subsidence features were present; in cases 34 and 47, water losses occurred shortly after the pillars were pulled. No special circumstances, other than subsidence effects, were noted by investigators for any of these cases.

Case 43 represents an affected well whose base was relatively close to the mining operation (vertical proximity of 150 feet; lateral proximity of 120 feet) and where no special circumstances were noted by investigators. The well went dry within one week after pillar removal, and subsidence features were present. These factors suggest that this water-supply impact may have been the result of rock-fracturing subsidence processes which define the primary zone of subsidence influence, although this well was located at a 52° angle of proximity.

The one non-affected pillar-retreat case (66) was a ridgetop well whose base was 610 feet above the coal seam being mined, with a 50 foot lateral proximity (*i.e.*, an angle of proximity of 4.5°). The causes of water supply disruption were determined to be limited recharge area and extremely dry conditions. In this case, however, two abandoned room-and-pillar mines were located between the mining operation that was the subject of the complaint and the disrupted water supply, at vertical proximities of 355 feet and 410 feet.

Thirteen additional cases were judged by VDMLR investigators to have been affected by (or were suspected to be effects of) mining, where special circumstances were noted. Cases 33, 40, 67, and 68 represented situations where the well tapped a coal-seam aquifer up-dip of a mining operation, and the mining operations drained the aquifer. Eight cases (51 through 56, 61 and 62) were the result of a single mine operating along the axis of a syncline, with the water supplies being located along the flanks of that syncline. Apparently, the mine drained water from the syncline, thus draining these eight wells. All eight wells were at relatively shallow depths (100 feet or less), indicating that they were tapping the weathered surface zone identified by Harlow and LeCain (1993) as an aquifer unit. Case 59 was associated with a mine which required extensive pumping. Although lateral proximity of the well bottom to the mine was 800 feet, vertical proximity was only 30 feet and VDMLR investigators judged the disruption to be an effect of mining; they also stated that they expected water levels to return to normal once pumping ceased.

To summarize the VDMLR investigations of pillar-retreat mining: Of the sixteen cases which fell within the primary influence zone defined by Rauch, water losses occurred in fifteen cases; fourteen of those cases were judged by VDMLR investigators to have been effects, or suspected effects, of mining and no determination was made with respect to the fifteenth. Nine additional cases of mining-affected (or suspected-effect) water supplies, where no special circumstances other than subsidence effects were noted, fell just outside of Rauch's zone of influence. Vertical proximity in six of these cases was 430 feet, or less; the other three were 500 to 630 feet above the mined coal seam. Only two of these nine cases were located at an angle of proximity beyond 40°: Case 43, a drilled well located at a 52° proximity; and case 34, a spring located at 45°. Six of the nine cases (including all three whose vertical proximities exceeded 450 feet) involved hillside springs. Special circumstances were identified as being responsible for all other 13 mining-affected (or suspected-effect) water supplies, including a major fracture zone and drainage of coal-seam aquifers by mining operations.

Analysis

Rauch's Principles

Overall, the results offer limited support for the hypotheses offered by Rauch to define zones of influence over water supplies, with the primary limitations due to the nature of the data set itself. The data did not provide evidence that application of Rauch's observations in Virginia would be incorrect.

The data demonstrate the importance of special geologic circumstances, including fracture zones associated with faults, in situations where the water supply impacts of an underground mine extend beyond the zone of rock fracturing and caving caused by subsidence.

In all cases where the impacted water supplies were located within the primary influence zones defined by Rauch, and where VDMLR investigators identified a cause (or suspected cause) for the impact, the mining operation was identified as that cause. However, all but one of the qualifying observations concerned pillar-retreat mining.

Only one partial-extraction room-and-pillar mining case occurred within the 20-to-100 foot vertical proximity zone of influence defined by Rauch. Although this water supply was determined to have been affected by mining, there was a 14-year delay between mining and the effect. All other affected (and suspected-effect) water supplies were determined to have occurred because the room-and-pillar operation drained fracture zones or coal seam aquifers, or (in one case) impacted a recharge area. The fact that no room-and-pillar mining effects, other than those which could be accounted for by special circumstances, were determined to have occurred outside of the zone of influence identified by Rauch lends support for his observation. A number of room-and-pillar complaints were located outside of the primary zone of influence, where the water supply disruption was determined to have occurred for reasons not directly associated with the mining operation.

Only four cases were associated with longwall mining. All four complaints were filed with respect to the same operation, and the DMLR investigators determined all four water supplies to have been affected by mining. None were located directly above the mine, and none were located within the severe dewatering zone defined by Rauch. Two, however, were located within or directly adjacent to the aquiclude zone defined by Rauch, above the critical dewatering zone. One case (a spring) was well within the angle of influence limits which define this secondary zone but above the vertical proximity limits for the critical zone, while a second was located at the boundary of the limiting angle of influence. Two other wells were well outside of both the critical and the aquiclude dewatering zones. The three wells were determined to have been affected by a special geologic circumstance: the mining operation drained a valley aquifer associated with a major thrust fault.

Sixteen of the cases involved water supplies located within Rauch's primary zone of influence above subsided pillar-retreat mines; fourteen of these were determined to have been affected by (or suspected effects of) mining, while no determination was made on the remaining two. The data also indicate, however, that the zone of influence can extend beyond the 400-foot vertical proximity limit to the primary zone of influence defined by Rauch, especially where steep slopes are present. Six of the eight affected (or suspected-effect) water supplies located within a 40° angle of influence, but at vertical proximities of 400 feet or greater, were springs. Rauch noted that "steep hillside aquifers" such as springs tend to be dewatered above 400-foot vertical proximity level. The two affected wells were at vertical proximities of 430 feet, only slightly above the 400-foot limit of Rauch's primary zone of influence. In addition, one well determined by VDMLR to have been affected by mining was located at a 52° angle of influence. Twelve of the cases determined, or suspected, to have been affected by pillar-retreat mines involved special geologic circumstances.

Table 5. Review of special circumstances determined (or suspected) by VDMLR investigators to be responsible for impacts on water supplies located outside of primary zones of influence defined by Rauch (1989).

Type of Mine Investigated / Circumstance	Number of Cases	Case Number	No. of Mining Operations
Room and Pillar:			
Mining Drained Coal Seam Aquifer	2	1,3	2
Mining Drained Fracture System Feeding Water Supplies	11	5-15	1
Mining Impacted Recharge Area	2	4,16	2
Longwall:			
Mining Drained Valley Aquifer	3	28-30	1
Pillar Retreat:			
Mining Drained Coal Seam Aquifer	4	33,40,67,68	3
Mining Drained Geologic Syncline Associated with Aquifer	8	51-56,61,62	1
Extensive Mine Pumping	1	59	1
Total	31		11

Other Relevant Factors

The data indicate that there are numerous special circumstances which can cause water-supply impacts to occur outside of the zones of influence defined by Rauch (Table 5). Primary among these are the presence of subsurface fracture zones and other geologic features which, if drained by mining operations, can have water supply effects. Similarly, when a mining operation drains a coal seam which is acting as an aquifer, water supplies located up-dip of the operation using that seam as a water source can be affected.

Both of the above circumstances are of significance to Virginia's coal mining region. Harlow and LeCain (1993) determined that coal seams are the only significant deep aquifers, other than fracture zones, which occur in the coalfield region. Fracture zones tend to be more common in the Virginia coalfield region than in northern West Virginia, due to the geologic activity which caused movement of the Pine Mountain thrust sheet (Figure 1).

Hillside springs are well represented in the data set. Of the 73 water supplies represented by the data, 18 were springs. Thirteen of these were determined by VDMLR investigators to have been affected by (or suspected effects of) pillar-retreat mining (Table 4). Hillside springs appear to be susceptible to the effects of subsidence from pillar-retreat mining operations well beyond the 120-to-400 foot primary zone of influence defined by Rauch, possibly due to the effects of subtle changes in strata elevation on groundwater flow patterns.

In terms of timing, only 8 of the 73 cases represented situations where the time delay between mining and water loss exceeded one year. In only two of these cases (2 and 60) was the water supply determined, or suspected, to have been affected by mining. However, either the mining date or the water loss date is missing for an additional 19 cases, 14 of which were judged to have been affected by, or suspected effects of, mining. Therefore, no generalizations are possible with regard to time delays.

An additional 3 cases (17, 18, and 66) represented situations where old mine works were located in the stratigraphic interval between the mining operation and a water supply. VDMLR investigators noted water losses in all three cases, but the mining operation that was the subject of the complaint was not judged to be the cause of the water losses.

Limitations of the Data Set

The results need to be viewed in the context of the limitations of the data set. The data set does have the advantage of multiple observations, as opposed to the vast majority of mine-subsidence water-resource studies which focus on a single mining operation. However, the data set also has significant limitations:

1. Cases which proved difficult to resolve may be overly represented. Situations where issues were resolved without resorting to VDMLR investigation procedures are not represented.
2. The data set does not contain observations of water supplies located close to mining operations which were not affected by those operations, because such cases (if they were to occur) would not require the attention of VDMLR investigators.
3. Although the investigation files give ample evidence that the investigations were carried out with thoroughness, VDMLR investigators are not infallible. They were only able to make use of available information in their investigations: they were not able to conduct subsurface investigations.
4. Pre-mining data are limited.

It is also important to note that Rauch identified a number of principles related to water-level recovery. No evidence to either support or deny these principles is contained in the VDMLR data set. A follow-up survey attempted by VDMLR in 1989 was not successful in updating the data base to include whether or not, or how rapidly, water levels recovered from the effects of underground mining. In cases where the impacted water supply had been replaced rather than repaired (*i.e.*, the majority), no conclusions on water-level recovery are possible.

Summary

We have reviewed the results of 73 water supply investigations conducted by Virginia Virginia Division of Mined Land Reclamation (VDMLR) geologists over a period extending from 1981 to 1987. The investigations were conducted in response to complaints filed by persons dependent upon water supplies alleged to have been affected by mining. We reviewed the investigations for the purpose of drawing insight regarding the relevance of observations made by Henry Rauch to the Virginia coalfields. Rauch is a West Virginia University geology professor who has devoted significant effort to the investigation of the water resource effects of subsidence in the northern Appalachians.

Rauch's guidelines are briefly summarized in the following text. Water supplies tend to be affected by unsubsided partial-extraction room-and-pillar mines in the zone directly above the mining operation, within a vertical proximity of 20 to 100 feet, or when special circumstances related to mining or geologic conditions are present. In high-extraction mines, the severe dewatering effects tend to occur within the zone of rock fracturing and caving caused by the subsidence; this primary zone of influence is located directly over the mine and laterally from the mine within an "angle of influence," generally between 20° and 40°. This severe dewatering zone generally extends from 120 to 400 feet above pillar-retreat mines, and to a height of one-half the panel width above longwall mines. The presence of claystones or shales tends to limit the severe dewatering effects to smaller vertical extents above the mine roof. A secondary dewatering zone, where effects are less severe, may occur above the severe dewatering zone, also within a 20°-to-40° angle of influence. Again, special geologic or mining conditions can have the effect of extending the influence on water resources beyond this primary, or severe, influence zone. Hillside springs tend to be especially sensitive to the effects of subsidence.

The data in the VDMLR files provide evidence which appears to confirm that water supplies are affected within the primary zone of influence defined by Rauch for pillar retreat mines. However, only one observation fell within the zones defined by Rauch for low-extraction room-and-pillar mining, and none for longwall mining.

In Virginia, the primary zone of influence over pillar-retreat mines may extend in some cases beyond the 400 foot maximum vertical proximity defined by Rauch. Two observations indicated that the zone of influence can extend to at least 430 feet for drilled wells. Five springs whose vertical proximities ranged from 425 and 630 feet, and a well located at a 52° angle of influence, were all determined or suspected by VDMLR geologists to have been affected by high-extraction pillar-retreat mining. Although the data base is not sufficient to allow a conclusion that each of these water supplies was affected by subsidence-related rock fracturing and caving, the investigating geologists did not offer any alternative explanation. The data indicate that springs may be especially sensitive to the effects of subsidence, even at vertical proximities exceeding 400 feet.

The VDMLR files also contained numerous examples where water supplies located outside of the primary zone of influence defined by Rauch were judged to have been affected by mining. The vast majority of these cases occurred where geological features functioning as highly permeable aquifer units (including coal seams, lineaments and fault fracture zones, and a geologic syncline) were drained by

underground coal mining operations. Rauch's work notes that such circumstances can cause water losses beyond the zone of subsidence-related impacts.

The limitations of the data source should be considered in interpreting the results of this analysis. The VDMLR complaint files represent only those situations where the VDMLR was called upon to resolve a dispute. Therefore, the data contain no information on situations where mining did not impact water supplies, or where impacted water supplies were replaced without VDMLR involvement. No inferences regarding the relative frequencies of water supply impacts of different types or causes for impacts can be drawn from these data. Similarly, since the data set does not contain examples of water supplies which were *not* affected by mining operations in spite of close proximity, it cannot be used to determine a "typical" vertical or lateral extent of water supply effects associated with underground mining.

Another major limitation to the data set is that is does not contain information on the duration of water supply impacts, so it does not allow conclusions to be drawn regarding the time required for recovery of affected water supplies.

Conclusions

The results of this analysis do not allow us to state, with certainty, that Rauch's principles can be applied in the coalfields of Virginia. Because of data-set limitations, the picture is incomplete. However, while a number of Rauch's observations are supported by the analysis, none were found to be incorrect.

A number of the cases analyzed showed geologic conditions which extend the influence of underground mining practices on groundwater beyond the area directly affected by subsidence. Therefore, it would be inappropriate to develop guidelines for identifying zones of water supply influence of underground mining by defining such zones solely on the basis of parameters related to subsidence. The complex geologic conditions present in southwest Virginia's coal-mining region suggest that any mechanism for identifying water resource impacts of underground mining should be capable of accomodating case-by-case determinations.

Acknowledgements

Our thanks to Virginia Division of Mined Land Reclamation, especially Lynn Haynes, for cooperation and help in conducting this research. Also, thanks to Henry Rauch, for his assistance, and to John Flynn, for his work in preparing graphics. This research has been supported by the Department of Interior's Mineral Institutes program administered by the Bureau of Mines under allotment grant G1114151.

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APPENDIX A: Data Recording Forms

ROOM AND PILLAR
(No Retreat Mining)

DMLR#_______________ County______________ Date____________
LAT______________ LONG______________ Report Date___________
Complaint Date_______ Water Loss Date_______ Mining Date______
Time frame since mining_________ Recovery Date____________

SUPPLY INFORMATION

Dug Well___ Drilled Well___ Well Depth________' Spring_____
Valley___ Ridgetop___ Hillside___ Degree of slope_____
Distance to stream valley_________'
Pre Mining Water Level______' Post Mining Water Level_____'

PROXIMITY

Vertical
within 100'________'(complies)
above 100'_______'

Lateral
within 40'_______'(complies)
greater than 40'______'

ROOF LITHOLOGY

clay & shale__ firm shale__ sandy shale__ sandstones & shale interbedded__ sandstone__ massive sandstone or conglomerate__

Intervening lithology____
____
____

SEAM INFORMATION

Seam thickness____' Depth to seam_____' Seam location________
Feet below drainage_______' (above or below drainage)

MINING IMPACT

affected___ not affected___ no determination___
suspected effect___ suspected non effect___ unknown___

Impacted recharge area____ Subsidence features present____
Damage to well casing_____ Mine size____________________

OTHER MITIGATING CONDITIONS

lineaments____ airshafts____ adjacent dewatering boreholes___
adjacent surface mines______

COMMENTS

HIGH EXTRACTION

DMLR#_______________ County______________ Date____________
LAT______________ LONG______________ Report Date___________
Complaint Date_______ Water Loss Date________ Mining Date_______
Time frame since mining__________ Recovery Date____________

SUPPLY INFORMATION

Dug Well___ Drilled Well___ Well Depth________' Spring_____
Valley___ Ridgetop___ Hillside___ Degree of slope_____
Distance to stream valley_________'
Pre Mining Water Level______' Post Mining Water Level_____'

PROXIMITY

Vertical
within 400'________'(complies)
above 400'_______'

Lateral
within 40 _______'(complies)
greater than 40 ______'

ROOF LITHOLOGY

clay & shale__ firm shale__ sandy shale__ sandstones & shale interbedded__ sandstone__ massive sandstone or conglomerate__

Intervening lithology____
____
____

SEAM INFORMATION

Seam thickness____' Depth to seam______' Seam location________
Feet below drainage_______' (above or below drainage)

MINING IMPACT & INFORMATION

affected___ not affected___ no determination___
suspected effect___ suspected non effect___ unknown___

Impacted recharge area____ Subsidence features present____
Damage to well casing_____ Mine size____________________
Type of mine______________ Panel width____________'
If well overlies, feet from edge of panel__________'

OTHER MITIGATING CONDITIONS

lineaments____ airshafts____ adjacent dewatering boreholes___
adjacent surface mines______

COMMENTS

APPENDIX B: Summary of Complaint File Investigations

Of the 73 water losses documented, a total of 56 were determined (or suspected) to be mining related. Another 10 were determined (or suspected) not to be mining related. VDMLR was unable to make a determination on the remaining seven cases. Room-and-pillar mining accounted for 27 of the VDMLR complaints, pillar retreat mining for 41 complaints, and longwall mining for only 4 complaints. Table 1 summarizes the investigation results, and Table B-1 summarizes individual cases which are discussed below.

Room-and-Pillar Mining

Of the 27 complaints attributed to room-and-pillar mining, 16 were classified as either affected or suspected effect, eight were classified as not affected or suspected non-effect, and no determinations were made on three complaints.

Affected and Suspected Effect

Eleven of the 16 affected and suspected-effect room-and-pillar complaints were the result of one mining operation *(Case 5-15)*. These 11 affected wells were located in a long, linear valley. Developmental mining was taking place parallel to this valley under a ridge. About halfway down the valley a set of entries were developed perpendicular to the mains, with the plan of crossing the valley and developing under the opposite ridge. The entries were approximately 150 feet below the valley. As mining proceeded under the valley a major fracture zone acting as the main conduit for the groundwater in the valley was encountered. Water poured into the mine at this point and pumping was undertaken to keep the entries open. By encountering this fracture zone the mine was quickly able to drain the valley aquifer for over a half a mile in both directions. The impact on the valley wells was almost immediate and even the surface creek went dry. This particular scenario fell outside of Rauch's parameters because the mine encountered a major fracture zone (either a primary lineament or a shear fault). Had this fracture zone been absent, the effects on the groundwater would probably have been negligible, in accordance with Rauch's dictum. This is an example of one of those mitigating circumstances which may be more common in the Southwest Virginia coalfields than in other places.

In *Case 1*, a room-and-pillar mine was developed just 250 feet down dip from a well that was drilled into the coal and was tapping the coal seam aquifer. The groundwater was able to escape via the mine, thus draining the well. This particular scenario was not addressed by Rauch.

Case 2 did somewhat meet Rauch's parameters: a well whose bottom was within 85 feet and directly over room-and-pillar entries was drained. However, the well was affected approximately 14 years after undermining, which is not within the expected timeframe. It is suspected that pillar crushing may have taken place, cracking the strata and lowering the water table. Three replacement wells were drilled on the property and all were dry.

Case 3 involved room-and-pillar entries developed within 40 feet of a well. This well extended 160 feet below the coal seam and prior to mining the water level was

35 feet above the coal. Two months after mining the well went dry. Rauch did not address a situation like this.

Cases 4 and *16* involved suspected impact of recharge areas. In *Case 4*, a drilled well dried up sometime after a mine was developed over 205 feet vertically and 700 feet laterally from it. *Case 16* involved a spring that went dry. The spring was directly undermined by developmental mining at a depth of 270 feet, which falls outside of Rauch's parameters but could still have affected it. In addition, retreat mining took place approximately 1000 feet from the spring and this could also have impacted the recharge area.

Other Room and Pillar Investigations

Water-loss complaints were investigated in an additional 11 cases involving room-and-pillar mining. None of these additional complaints fell within Rauch's parameters and all but three were determined not to be mining related. The causes of these three could not be determined.

In examining these additional cases it was noted that none fell within the Rauch parameters for proximity. All were over 100 feet above the mine or greater than 40 feet laterally from the nearest entry, or both.

Not Affected and Suspected Non Effect

Case 17 involved a 335-foot well that was 290 feet above and 200 feet from a mine. The well was located on top of a ridge with a limited recharge area. *Case 18* involved another ridgetop well 198 feet deep. This well was 440 vertical feet above and 700 feet laterally from the active mine. An old mine had been developed in 1920 at a depth of 175 feet below the base of the well (this mine in all probability predated the well). The well directly overlaid this old mine. However, as in the case of many old mines, pillaring did not occur in this mine. Mining in the underlying seam took place approximately 265 feet below the old mine, but the nearest entries were again around 700 feet laterally from the well. Water loss occurred approximately three years after mining and VDMLR determined that the water loss was due to a limited recharge area and dry weather.

Case 19 involved a valley well that was 51 feet deep and had a premining water level of 30 feet and a postmining water level water level of 44 feet. However, this water drop occurred approximately five years after mining and at the time of acquisition by a new property owner. The well was 90 feet above and 210 feet laterally from the mine, and the nearest pillaring was over 4500 feet from the well. The investigators concluded that evidence gathered was not consistent with the mining-related impact which was the subject of the complaint.

Case 20 involved a hillside spring that was 430 feet above but only 40 feet laterally from previous mining. VDMLR determined that this spring dried up due to a limited recharge area and extreme dry weather. *Case 21* was a ridgetop well 40 feet deep that was drilled in 1915. Although it was directly overlying the mine it was 380 feet above the entries. The age of the well and the location on a ridgetop divide with a limited recharge area were determined to be the cause of the well drying up. It had been approximately 15 years since mining had taken place.

Case 22 was another shallow (50 feet) ridgetop well that directly overlaid mining but was 520 feet above it. Again the well had a limited recharge area and went dry due to weather conditions. Mining had taken place approximately 46 years prior to the water-loss report. *Case 23* involved an 80-foot valley well that went dry one week after mining. However, the mining was 115 feet vertically and 350 feet laterally from the base of the well. It was suspected that mining did not affect this particular well but VDMLR did not completely rule out the possibility of an impacted recharge area. Information on the premining water level was not available and the area was also experiencing drought conditions.

Case 24 was a 270-foot coal test hole that had been converted to a water well. This well's yield was .02 gallons per minute, making it a marginal producer at best. Mining took place three months prior to the complaint and was 150 feet vertically and laterally from the bottom of the well. Only 60 feet of water was left in the hole when investigated. The well had a limited recharge area and that, coupled with the small yield, were enough to cause the well to be unsatisfactory.

No Determination

VDMLR could not make a determination on the effects regarding three water supply complaints. These complaints involved two wells and a spring. The spring complaint (*Case 25*) involved a water supply that was directly overlying mining but 400 vertical feet above it. However, subsidence fractures were noted within the area of recharge and these may have influenced the recharge area by allowing groundwater to seek a lower path. The weather conditions also may have played a part in the drying up of the spring.

The two well loses occurred almost immediately after mining took place. The first well (*Case 26*) was located on a hillside and was 65 feet deep. The bottom of the well was within 10 feet of the seam being mined but was 700 feet from the nearest entry. In addition, several abandoned mines were nearby and thought to be draining the well. The other well (*Case 27*) was a ridgetop well 132 feet deep. It was unknown how much water was in the well prior to mining, but it contained eight feet after mining. The bottom of the well was 330 vertical and 400 lateral feet from the nearest entry. These two water supplies probably should not have been affected but the immediate time frame since mining made them suspect.

Longwall Mining

A total of four water supply complaints were investigated where longwall mining had taken place. Three of these were associated with the same panel and experienced immediate water loss. The other case involved a spring that went dry approximately one month after mining. VDMLR concluded that all of these complaints were mining related.

The three affected wells (*Cases 28-30*) were all located within a valley that was parallel to and within 1000 feet of a major thrust fault. The seam being mined was below regional drainage and dipped parallel to the fault at approximately 10 degrees. The seam was 4.5 feet thick. The bottom of the first well (*Case 28*) was located 465 feet above and 400 feet laterally from the nearest panel. It was 125 feet deep and contained 112 feet of water; after mining the well was dry. The second well (*Case 29*) was 68 feet deep and it also went dry. It was within 320 feet vertically but 2000

feet laterally from the nearest panel. The third well (*Case 30*) was within 410 vertical feet and was 1700 feet laterally from the nearest panel; however, this well was located between two panels. This well had a depth of 37 feet and a standing water level of 31 feet before mining. After mining, only 6 feet of water was in the well. The well was also sucking air at a very noticeable level, indicating that it was probably in communication with the mine and that the well had somehow been fractured. In addition the surface stream in the valley was impacted by the mining and it, too, lost water. VDMLR's conclusions were that the longwall mining had an adverse impact on the valley aquifer and impacted the aquifers' recharge area. The proximity of the major thrust fault and its associated fractures also played a role. However, no subsidence features were noted.

The affected spring (*Case 31*) was located on a hillside with a slope of 25 degrees. It was vertically 580 feet above the panel but within the angle of influence. Subsidence features were present on the surface near the spring. The spring went dry approximately one month after mining during the month of March, a normally wet period of the year.

Retreat Mining

With regard to the other form of high-extraction mining (secondary recovery or retreat mining) the majority of water-loss complaints fell into this category. Of the 41 complaints attributed to retreat mining, 34 were classified as affected (both affected or suspected effect), one as not affected, and no determinations were made on six of the complaints. In looking at the 34 affected and suspected-effect cases, a total of 17 met both of Rauch's parameters on vertical and lateral proximity. Sixteen met one of the parameters and only one failed to meet either of the proximity criteria.

Affected and Suspected Effect

Case 32 involved a hillside spring that directly overlaid a pillared section that was 425 feet below. The spring dried up approximately four months after mining. Subsidence features were present. In addition, a lineament was present within the recharge area. Although this spring was within the angle of influence it was somewhat higher than Rauch's normal interval. *Case 33* involved a well that was drilled into the coal-seam aquifer. Mining took place 350 feet down dip from this well and drained it within one week. This scenario was not addressed by Rauch. *Case 34* involved another hillside spring that went dry one month after mining. This time pillars were pulled under the recharge area for the spring. The pillaring took place 500 feet vertically and laterally from the spring, falling outside of both of these parameters. No subsidence features were present.

Case 35 involved a ridgetop well 105 feet deep that contained 80 feet of water but went dry within a couple of days of pillar extraction. The well was 430 feet directly over the pillared section. Subsidence features were also developed in the vicinity. *Case 36* was a hillside spring that dried up two weeks after pillar extraction took place under it. The spring was 430 feet above the mine. Subsidence features were present within the recharge area, possibly impacting this zone also.

Cases 37, 38, and 39 were springs that were affected by the same mine during a six-month period while pillaring was taking place. All of the springs were between 300 and 400 feet above the mine and all fell within Rauch's angle of influence, thereby meeting both criteria. *Cases 40* through *43* were wells that were affected by the same mining operation as the springs in the preceding complaints. The first well (*Case 40*) was 500 feet deep and was drilled 30 feet below the level of the mine. It was located in an isolated pillar in an area that had been robbed. Well two (*Case 41*) directly overlaid the retreat mining and the bottom was 285 feet above the mine. Well three (*Case 42*) was close to well two and was 315 feet above the mine. Well four (*Case 43*) was only 120 feet above the mine but was 150 laterally from the edge of the panel. Rauch had no parameters for a well drilled into the seam as in well one. Wells two and three were consistent with established parameters but well four only met the vertical parameter. All wells went dry within one week of retreat mining. Subsidence features were present at well four.

Case 44 involved a ridgetop well that was 345 feet deep with 200 feet of standing water and that went dry sometime after retreat mining had taken place. This well was 205 vertical feet above the mine and 50 feet from the edge of the panel and met the established parameters for affected water loss. *Case 45* involved the same mine approximately four years later with water loss occurring in a spring immediately after pillaring had taken place. The spring was directly over the top of the pillared section and vertically 320 feet above it. The recharge area for this spring was also within the area of pillaring. This complaint also met the established parameters for affected water loss.

Case 46 involved a ridgetop well that was 190 feet deep. Developmental and retreat mining was taking place 430 feet below the bottom of the well. Approximately 200 feet above the active works was an abandoned room-and-pillar mine that was flooded. A dewatering borehole was sunk into this flooded mine 110 feet from the water well in question. It initially took eight days to pump out the old works. Pumping to get rid of water buildup was relegated to once a month after that. VDMLR felt that the dewatering borehole was acting as a drain for the well's aquifer, allowing the water to drain into the old mine. It could not be determined what impact the pillaring was having at this time. Water loss occurred one month after mining took place. *Cases 47* and *48* involved two springs that were both 630 feet above the level of the pillaring. One spring that was directly over the top of a panel dried up approximately two years after mining. The other spring was within 150 feet of a panel (within the angle of influence) and dried up within two weeks of pillaring. An abandoned room-and-pillar mine was located approximately 200 feet above the active works. VDMLR felt that, as pillaring proceeded in the lower seam, collapse occurred in the old works above. As the pillars in the old works were crushed they allowed settlement upward into the zone where the springs and their recharge areas would have been affected. The time difference between the two spring failures could be accounted for by differential rates of pillar failure in the old works. No parameters were established by Rauch to cover this type of circumstance.

Case 49 involved a 127-foot ridgetop well that contained only 5 feet of water after mining. The time frame from mining to water loss was nine months. The bottom of the well was 350 feet above the mine and within 60 feet laterally of the panel. Developmental mining had taken place directly underneath the well. The well was also sited directly on a lineament and very close to the junction of three lineaments. *Case 50* involved the same mine. A well 360 feet deep contained 255 feet of standing water but went dry three months after mining. The bottom of this well was 100 feet directly above a panel and was located in between the junction of the three lineaments mentioned in the preceding complaint. Subsidence features were present at both wells.

Both wells fell within the established parameters and were probably also effected by the proximity of the lineaments.

Cases 51 through *56* involved one mining operation that affected a group of hillside residences. Several of the affected water supplies were serving more than one family. All of the wells were within 100 feet vertically of the seam being mined but were anywhere from 400 to 1100 feet laterally from the nearest panels thus falling outside of the angle of influence. The reason the wells were affected had to do with the geologic structure of the area. The wells were developed up dip along the flanks of a syncline. The mine had been developed at and parallel to the axis of the syncline. Groundwater was able to drain down the dip of the rock until it reached the fractured zone associated with the pillaring where it then drained into the mine. This lowered the water table below the level of the wells. Originally, it had been thought that blasting in nearby surface mines might have caused the water losses, but this was ruled out by VDMLR. These well complaints met the established vertical parameter but fell outside of the lateral parameter and were affected by geological influences.

Case 57 involved a 240-foot well that contained 40 feet of water prior to mining. Within a few days of pillar extraction the well went dry. The well was located between two retreating panels and was within 155 vertical feet and 50 feet laterally of the nearest panel. However, the angle of influence from both panels intersected the well. In this complaint both established parameters for water loss were met. Subsidence features were also present close to the well.

Case 58 was a hillside spring that had a building (springhouse/storage building) around it. The spring dried up on the same day as the pillars were pulled 195 feet below it. Subsidence fractures occurred shortly after in the foundation and walls of the building. Displacements were on the order of several inches. Pillaring also impacted the recharge area of the spring. An adjacent surface mine had no effect on the water loss from this spring.

Case 59 involved a 200-feet well that had 160 feet of standing water in it prior to pillar mining. After mining the well went dry. The bottom of the well was only 30 feet above the seam but was 800 feet from the nearest panel. The mine was being pumped to keep it dry; this pumping had lowered the water table to 20 feet below the base of the well. VDMLR thought that once the pumping of that section of the mine stopped the well would recover. *Case 60* involved a well that went dry two years after pillaring. The well was a ridgetop well that was 150 feet deep. The vertical proximity of the well was 330 feet and the lateral proximity was 90 feet from the nearest panel. These parameters were consistent with those established by Rauch. Panels were developed on either side of the well while the immediate area under the well had not been pillared. A lineament was also present but no subsidence features were in evidence.

Cases 61 through *64* were related to the mining operation in *Cases 51* through *56* but were filed at a later date. Two wells (*Case 61* and *62*), both within 100 feet vertically, but 700 and 1000 feet laterally from the pillaring operation, went dry due to drainage along the flanks of the syncline as with the other cases. However, in these two instances water replacement measures where undertaken. One well (*Case 61*) was deepened from 100 feet to 150 feet; water was encountered at 135 feet. The other well (*Case 62*) was abandoned and a new well drilled to a depth of 275 feet, encountering water at 225 and 250 feet. The other two cases *(63 and 64)* involved springs in adjacent hollows that were under the synclinal axis and thus were undermined by the retreating pillar extraction. Both of these springs were approximately 300 feet above the mine and had their recharge areas impacted, allowing the groundwater to escape via vertical fractures associated with the subsidence above the panels. The two springs fell within the established parameters for water loss.

Case 65 was a spring that was issuing from a old flooded mine above drainage. At 115 feet below this abandoned mine another mine was developed. When pillaring commenced in the active mine the intervening strata cracked, draining the water from the old mine into the active works. This dried up the spring that served as a water supply for ten households and its recharge area. This complaint complied with the established parameters for water loss.

Cases 67 and *68* involved wells that were drilled into a coal seam to tap the seam aquifer. One well (*Case 67*) was 40 feet deep and just reached the seam, and the other well was 88 feet deep and encountered the coal at 48 feet. They were 400 and 300 feet up-dip from the active mining. Both wells lost water within days after pillaring started in the panel nearest the wells.

Not Affected

The only complaint investigated regarding retreat mining that was determined to be not mining related (*Case 66*) involved a hand-dug well (all other wells investigated were machine drilled) that was approximately 70 feet deep. This well was 610 feet above a panel and 50 feet laterally from the edge of it. The well was located on a ridge-top with a limited recharge area. It was approximately two months after pillaring began before the well went dry. The premining water level was unknown. Between the bottom of the well and the active mine two other old room-and-pillar mines had been developed. The condition of these abandoned mines was unknown. VDMLR determined that this particular well dried up due to drought conditions and not to any mining-related cause.

No Determination

Three water-supply complaints were investigated where no determination was reached on the cause of the water loss.

One complaint involving a no-determination finding (*Case 69*) involved a spring that was 560 feet above and 100 feet laterally from the edge of a mine where pillaring was occurring. No subsidence features were present to indicate any fracturing, and it had been several months since mining had taken place. Drought conditions were also prevalent in the area.

Case 70 involved a 60-foot well that lost water approximately 2 months after mining took place. The bottom of the well was 510 feet above the mine and 80 feet laterally from it. No subsidence features were present near this site.

Case 71 concerned a well that experienced water loss approximately two months after pillaring took place. The well was 300 vertical feet and 50 lateral feet from the panel being mined. This well would have fallen within the established parameters for water loss but was not reported until more than a year after the initial

water loss. During that time period the well experienced at least partial recovery which again would be in line with what Rauch stated.

Unknown

Case 72 involved a well drilled in August of 1984. One year later pillaring occurred 330 feet below and 50 feet laterally from the well. The premining standing water level in the well was 200 feet. The complaint date was in October of 1985 but as of that date no water loss had occurred. Apparently the owner of the well was expecting it to be impacted at any moment and was taking precautionary measures. This well would fall within the range of the established parameters for affected water supply loss except that no water loss had occurred at the time of the complaint, so VDMLR did not attempt to make a determination.

Unknown Mining Method

The unknown case (*Case 73*) was a well that was undermined about two months prior to the complaint but no water loss had taken place when VDMLR investigated. Apparently the landowner was preparing for the worst-case scenario but since there was no subsequent follow-up complaint it appears that his fears were unfounded.

One additional water supply loss was deleted from analysis because it could not be determined what type of mining had taken place or even if mining had taken place. This loss involved a spring on a hillside that might have had its recharge impacted by mining, but no information was available to substantiate the claim. VDMLR's determination was that the loss was not mining related and the spring had dried up due to drought conditions.

Table B-1. Summary of Individual Water Supply Investigations.

Case #	DMLR#	County	Mining Date	H2O loss date	Mine Type	Result	Lateral Prox.	Vert. Prox.	Angle of Draw
1	850-000-01	Buchanan			r&p	A	250	0	seam aquif.
2	1158-145-87	Buchanan	6-12-72	12-86	r&p	SE	0	85	-
3	1008-000-01	Dickenson	2-15-84	4-15-84	r&p	A	40	0	below seam
4	1072-442-85	Dickenson	unk	12-20-85	r&p	SE	700	205	73
5	945-000-12	Russell	3-24-83	4-1-83	r&p	A	2100	70	80+
6	945-000-01	Russell	3-24-83	4-8-83	r&p	A	2700	165	80+
7	945-000-02	Russell	3-24-83	4-6-83	r&p	A	2400	125	80+
8	945-000-05	Russell	3-24-83	4-24-83	r&p	A	430	125	75
9	945-000-13	Russell	3-24-83	5-12-83	r&p	A	2950	40	80+
10	945-000-10	Russell	3-24-83	4-10-83	r&p	A	1630	140	80+
11	945-000-11	Russell	3-24-83	4-8-83	r&p	A	2000	0	-
12	945-000-03	Russell	3-24-83	4-8-83	r&p	A	1150	190	80+
13	945-000-06	Russell	3-24-83	5-13-83	r&p	A	40	55	33.5
14	945-000-14	Russell	3-24-83	5-1-83	r&p	A	3300	85	80+
15	945-000-04	Russell	3-24-83	4-10-83	r&p	A	1000	160	80+
16	1073-335-85	Wise	6-26-85	8-85	r&p	SE	0	270	-
17	1026-258-84	Buchanan	unk	unk	r&p	NA	200	290	35.5
18	1095-000-01	Buchanan	1920/82	9-85	r&p	NA	700	440	seam aquif.
19	1205-473-87	Buchanan	7-14-82	11-27-87	r&p	NA	210	90	67
20	1040-000-02	Dickenson	5-84	5-26-84	r&p	SNE	40	430	6
21	1131-407-86	Dickenson	1971	7-86	r&p	SNE	0	380	-
22	1072-359-86	Dickenson	1940	7-18-86	r&p	NA	0	520	-
23	1126-372-86	Dickenson	9-86		r&p	SNE	350	115	70
24	1172-272-87	Tazewell	late 86	2-87	r&p	NA	150	150	45
25	928-000-01	Dickenson		1981	r&p	ND	0	400	-
26	1151-083-87	Buchanan	1-87	1-20-87	r&p	ND	700	10	seam ?
27	1072-367-01	Dickenson	8-85	8-7-85	r&p	ND	400	330	50
28	1139-001-87	Russell	12-31-86	1-6-87	lw	A	400	465	40.5
29	1139-002-87	Russell	12-31-86	1-11-87	lw	A	2000	320	80+
30	1139-040-87	Russell	12-31-86	1-5-87	lw	A	1700	410	80+
31	1180-321-87	Russell	3-8-83	4-1-83	lw	A	200	580	18.5
32	1000-210-83	Buchanan	unk	7-83	ret	A	0	425	-
33	1140-011-87	Buchanan	1-87	1-12-87	ret	A	350	0	seam aquif.
34	1183-343-87	Buchanan	7-87	8-10-87	ret	SE	500	500	45
35	1035-338-84	Buchanan	8-84	8-7-84	ret	A	0	430	-
36	1040-000-01	Dickenson	5-84	5-26-84	ret	SE	0	430	-
37	1072-356-85	Dickenson	6-85	6-85	ret	SE	0	400	-
38	1072-396-85	Dickenson	85	9-4-85	ret	SE	0	380	-
39	1072-124-02	Dickenson	12-85	12-85	ret	SE	200	320	33
40	1072-124-03	Dickenson	3-86	3-1-86	ret	A	20	0	below seam
41	1072-443-85	Dickenson	12-85	12-15-85	ret	SE	0	285	-
42	1072-355-85	Dickenson	9-85	9-17-85	ret	SE	0	315	-
43	1072-124-01	Dickenson	12-85	12-85	ret	A	150	120	52
44	1106-000-01	Russell	unk	10-9-82	ret	SE	50	205	11
45	1106-000-02	Russell	4-86	4-86	ret	SE	0	320	-
46	1031-000-01	Tazewell	9-84	10-30-84	ret	A	50	430	13
47	1054-133-85	Tazewell	10-84	10-25-84	ret	A	150	630	14
48	1062-186-85	Tazewell	2-79	1-1-81	ret	A	0	630	-
49	870-000-01	Wise	late 81	9-4-82	ret	SE	60	350	10.5
50	910-000-01	Wise	late 81	82	ret	A	0	100	-
51	1059-199-85	Wise	unk	6-24-85	ret	A	400	100	75
52	1059-198-85	Wise	unk	6-27-85	ret	A	500	100	78
53	1059-215-01	Wise	unk	6-85	ret	A	1100	100	80+
54	1059-215-02	Wise	unk	6-15-85	ret	A	500	100	78
55	1059-175-85	Wise	unk	5-22-85	ret	A	600	100	80+
56	1059-174-85	Wise	unk	5-22-85	ret	A	800	100	80+
57	1050-000-01	Wise	3-85	3-7-85	ret	A	50	155	16.5
58	1064-202-85	Wise	6-15-85	6-15-85	ret	A	0	195	-
59	1067-183-85	Wise			ret	A	800	30	80+
60	1101-210-86	Wise	late 81	6-83	ret	A	90	330	16.5
61	1074-372-85	Wise	unk	10-85	ret	A	1000	100	80+
62	1074-374-85	Wise	unk	unk	ret	A	700	100	80+
63	1074-357-85	Wise	unk	7-85	ret	A	0	300	-
64	1074-341-85	Wise	unk	7-85	ret	A	0	300	-
65	1064-203-85	Wise	2-85	6-15-85	ret	A	0	115	-
66	1052-112-85	Dickenson	10-2-84	late 84	ret	NA	50	610	4.5
67	1160-167-87	Buchanan	4-87	4-17-87	ret	A	400	0	seam aquif.
68	1176-293-87	Buchanan	4-87	4-3-87	ret	A	300	0	seam aquif.
69	1072-277-85	Dickenson	85	7-9-85	ret	ND	100	560	11
70	1119-148-02	Dickenson	4-86	6-86	ret	ND	80	510	9.5
71	1119-148-01	Dickenson	4-86	6-86	ret	ND	50	300	18
72	1072-367-02	Dickenson	8-85		ret	U	50	330	14
73	982-000-01	Wise		7-16-83	UNK	NA			-