BLASTING EFFECTS ON APPALACHIAN WATER WELLS

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ABSTRACT

The Bureau of Mines, in a contract study, examined blasting vibration impacts on low-yield domestic water wells in the Appalachian coal mining region. Researchers surveyed 36 case histories to determine if blasting was likely to have caused the claimed or observed changes, ranging from turbidity to loss of water. Following these investigations, they conducted field studies at four sites where the impacts of surface mine blasting could be directly measured on operating wells of known capacities.

Researchers found no evidence of blasting effects at the 36 well sites; instead, they observed other more likely causes. In the field tests, researchers found no significant direct effects from the blasting. However, in three of the four cases, they did observe changes in the static water levels and specific well capacities as the excavations approached to within 300 ft. Researchers attributed these changes to mass rock movement resulting from downslope lateral stress relief in the low-yield fracture system aquifers. With sufficient recharge, static levels recovered and capacities increased, provided that the nearby mine excavations did not drain the aquifers.

INTRODUCTION

At about the time the Bureau of Mines was studying the problems of dynamic vibration response and safe levels for houses near surface mine blasting, allegations were being made that residential water wells were also being damaged by blasting. Technical experts believed that such effects were unlikely. However, there had never been a carefully designed and controlled study of this problem. Such a study appeared justified by the number of alleged cases, particularly in the Appalachia coal mining region.

The Bureau contracted with Philip R. Berger and Associates, Inc., to examine the problem of possible vibration damage to residential water wells from nearby surface mine blasting. The Berger team, headed by Donelson Robertson, reported their research in a series of three contract final reports available for inspection at Bureau centers and for purchase through the National Technical Information Service (1-2). This paper summarizes the key findings, which were published in November 1980 as volume 1 of the contract final report (1).

The study consisted of three parts: 1) a background review of vibration and other impacts on water wells, such as earthquakes, earth tides, and nuclear blasts, 2) examination of 36 cases of alleged damage from blasting in Appalachia, and 3) a careful study of blasting effects on wells at four surface mine sites in Appalachia.

GENERAL REVIEW OF VIBRATION EFFECTS ON WELLS

The background review found little that was directly applicable. Observed cases of well damage were caused by permanent ground displacement, such as land sliding, rather than vibration. The types of effects observed required vibration levels many orders of magnitude higher than typical blasting vibrations and were listed as "casing collapse, earth displacement, pump base displacement, misalignment of pump column." etc. Cases specifically involving mining were concerned with pit excavations and included interception with the aquifer, pumping from bit bottoms, and ground water pollution.

INVESTIGATION OF REPORTED CASES OF ALLEGED BLASTING DAMAGE TO WELLS IN APPALACHIA

Inquiries to Appalachian surface mines, regulatory agencies, explosives suppliers, coal companies, insurance companies, and trade associations identified 36 reports of blast damage to wells. Of these, 24 sites were visited for either direct well measurements or discussions with owners and/or mine operators.

In the Berger report, Robertson states:

> *In many cases, it was apparent that the damage claimed was caused by something other than blasting. In other cases, it was clear that there had been a general lowering of the water table, possibly as the result of unplugged flowing test holes, drainage at the high wall, or a two-to-threefold increase in the number of residences utilizing a limited supply, combined with seasonal changes.*
>
> *In nearly every case, there was a lack of good benchmark data. Many residents have only a vague idea of the depth of their wells. Fewer know the depth of the casing. None of the residents interviewed knew the source of the water in their wells. About 50 pct had a vague idea of the static water level in the well when it was initially completed. Only one well had been tested in any quantitative way. That test was inadequate and made the owner think he had a much better well than was actually the case.*
>
> *Consequently, it was very difficult to confirm or deny that blast damage had occurred, but among the 36 examples, some of the well histories suggested two scenarios in which blasting might cause damage. The first is that the ground vibrations might be sufficient at times to cause loose material such as drill cuttings to slough off the uncased borehole and cause the water to become temporarily turbid, or if enough material was involved, to bury pump components at the bottom of the well. The second concerns those wells that obtain their water from flooded and abandoned deep mine workings. Ground vibrations might be sufficient at times to cause roof falls*

that could stir up sediment in the water or disturb an existing potable water-mine acid stratification. Of course, sloughing of the well bore and mine roof falls can occur in the absence of blasting, so these scenarios are not exclusive.

APPALACHIAN WATER WELLS

GROUND WATER OCCURRENCE IN APPALACHIA

Most ground water used for domestic supplies in Appalachian coal-bearing strata are in vertical fractures, joints, and along bedding planes Some of these joints are tectonic in origin and have a regional pattern. However, local fracture systems exist from lateral stress relief associated with natural topographic development. The coal seams often serve as the primary water conduit, being low in tensile strength and having extensive vertical fractures. Often, the coal is underlain by relatively fracture-free claylike rock preventing further vertical migration. In their study, Berger engineers found that local systems did not always interact, with static water levels sometimes varying between wells only 10 to 35 ft apart.

TABLE 1. - Appalachian well water characteristics

Iron	Commonly exceeded recommended 0.3 mg/L.
Manganese	Often exceeded standard of 0.05 mg/L.
Sulfates	14 to 240 mg/L, below recommended level of 250.
Total solids:	
Suspended	Within acceptable ranges.
Dissolved	Do.
pH levels	Most were within 6 to 8, with the total range of 5 to 8.7.
Color	Within acceptable ranges.
Odor	Do.
Turbidity	Commonly exceeded standard limit of 5 units.

WATER CHARACTER AND QUALITY

Information on water quality was obtained from the literature and tests made on wells for this project. The general results are summarized in table 1. The only observed problem was an occasional instance of rusty or reddish-colored water seemingly unrelated to the specific iron content. In other studies, this coloration (red slime) was found to correspond to the presence of iron bacteria and was a problem when wells went unpumped for a long time. The sulfate levels suggest no serious acid mine drainage nor influence from acid rain, which is typically of pH 4.5 to 5 in the region.

TYPICAL DOMESTIC WELLS IN APPALACHIA

Residential wells in Appalachia are typically 6-in-diameter rotary or cable-tool drilled and

100 to 150 ft deep (maximum about 400 ft). Normally, only the top 20 ft or so is cased. The remainder is unprotected from sloughing off the well sidewalls, which is a common and normal occurrence. (Recently, it has become popular to line all wells deeper than 100 ft to control sloughing problems.) Important considerations that together determine the continuous capacity of the well are the pump depth below the static water table, storage capacity of the well, natural recharge rate, and pump size.

The response to pumping these low-yield fracture water-table systems is a rapid drawdown until a near-equilibrium situation is reached. The pump must be sufficiently below the static water table (submergence) to allow this drawdown and still retain water above it. Larger pumps produce greater drawdown and require correspondingly deeper submergence, unless the flow is restricted by a valve arrangement. Additionally, rapid drawdowns from high pumping rates can cause abrupt pressure changes, turbid water, and possible "sanding up" of the pump.

As an example, Robertson calculates that an increase of pump submergence from 50 to 100 ft allows a constant pumping rate from a well with only one-fourth the specific capacity. He states that a pumping rate of 5 gal/min could be maintained by the typical Appalachia fracture-system well (specific capacity of 0.093 (gal/min)/ft of drawdown) provided it has 100 ft of pump submergence.

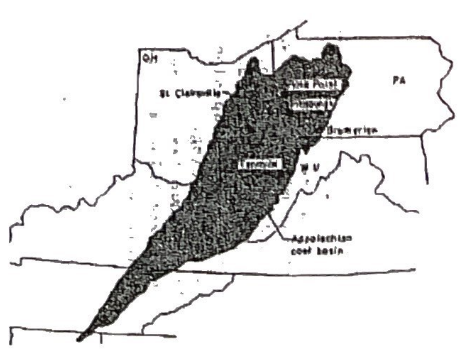
EXPERIMENTAL STUDY OF VIBRATION IMPACTS ON WATER WELLS

EXPERIMENTAL DESIGN

Researchers conducted an evaluation of four producing wells to specifically determine the influence of blasting on well productive capacity. At four sites, shallow wells were drilled to obtain water from the coal measures. Additionally, deep wells drew water from the layers below the coal and were isolated from the upper measures. For each of these test wells, two or three observation wells were used to monitor drawdown at varying distances.

Dynamic effects were measured by 10-h drawdown tests before, during, and following blasting. The static water level was monitored with float gauges. Water quality was also sampled periodically. To monitor blasting vibrations, researchers placed seismic instrumentation on the surface and at the bottom of an observation well for the 1-yr test duration.

TEST SITES



Four sites were found to be suitable for the tests, allowing sufficient monitoring time and standoff distance, and within convenient travel distance from Pittsburgh, PA, where Philip R. Berger and Associates is headquartered (fig. 1). A summary of the four test sites and experimental parameters is given in table 2.

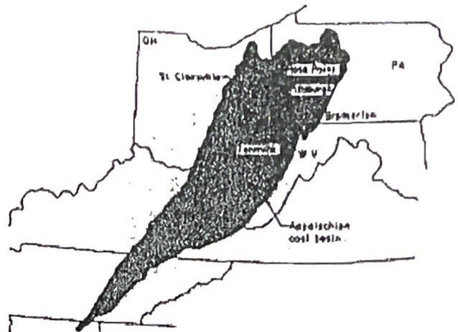


FIGURE 1.—Location of test sites.

RESULTS

Essentially, the same study was done at the four sites in Appalachia. A capsule summary is given in table 3.

BROTHERTON SITE

Researchers observed a correlation between the mining and well changes. The closest blast removed supporting material (e.g., toe), allowing lateral stress relief and the widening of vertical fractures. In other words, the pit excavation and not the vibrations influenced the fracture system. Changes were observed in the shallow well but not in the deep well, likely because of the more extensive vertical fractures near the surface. Significantly, the drops in static water level corresponded to increased specific capacity. The wider cracks allowed a temporary drop in static level, which would recover with sufficient rainfall. However, the cracks also provided increased flow (specific capacity).

Turbidity results were harder to interpret. Irregular fluctuations occurred during the 11-month stud,, and some temporary increases could have been from blasting. The nature of the tests contributed to the turbidity problem: infrequent and periodic pumping, suspended iron and drill cuttings, and disturbance from the manual sample-collecting procedure. A continuously used well would not have some of these problems.

TENMILE SITE

Results were similar to those at Brotherton, except for smaller changes in static water levels. Specific capacities increased during the 12-month test for both shallow and deep wells. They went from initial values of about 0.065 and 0.020 (gal/min)/ft to 0.66 and 0.05, respectively. As at Brotherton, this was attributed to removal of downslope rock, resulting lateral stress relief, and the consequent widening of vertical fractures. Along with the increased capacity was the availability of increased recharge from the coal seam into the tight sandstone formation, possibly accounting for the little observed change in static water levels. Figures 2 through 5 show the site plan, profile, well arrangement, and a drawdown test record for the date June 9, 1979, when an 0.80-in/s particle velocity was recorded.

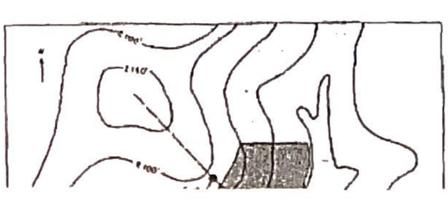
Researchers concluded that ground vibrations produced no deleterious effects on either the deep or shallow well, with one possible exception. A blast that went ȯffscale at 2 in/s (distànce of 85 ft) could have dislodged and caused a loose rock in the sidewall to shift into the hole, producing a partial bridge and preventing the sounding of the bottom.

TABLE 2. - Blasting and pumping tests at four Appalachian mines

Site	Shallow well		Deep well		Blast distances, ft	Scaled distance, ft/lb$^{1/2}$	Resultant vibration velocity, in/s	Notes
	Well depth, ft	Pump rate, gal/min	Well depth, ft	Pump rate, gal/min				
Brotherton, PA.	109	2.5 -7.9	169	4.0 -4.6	165- 500	12.1- 98	0.04-2.20	18 drawdown tests. Well site was 40 ft above initial mining. Pit was pumped at 500,000 gal/d.
Tenmile, WV.	146	.21-4.1	187	.27-1.0	64- 580	2.4- 34	.11-5.44	23 drawdown tests. Well site was on steep slope above blasting.
Rose Point, PA.	None	None	158	1.8 -6.8	175- 775	12.8- 60	.64-2.14	13 drawdown tests. Well site was below mining.
St. Clairsville, OH.	69	.24- .64	163	.24- .64	425-1,000	32 -153	.25- .84	14 drawdown tests. Well site was on slope above mining. Study ended before blasts reached wells.

TABLE 3. - Summary of results at four test sites

Site	Static water level	Specific capacity, (gal/min)/ft	Water chemistry	Turbidity
Brotherton, PA.	Dropped 21 ft in 14 months from pit pumping. Slight drops for closest blasts (shallow well only). Recovery related to rainfall.	Initially 0.34, steady for 11 months and then started to increase (shallow well only).	No changes.......	Possible temporary increases from blasting.
Tenmile, WV.	Minor variation. Some drop for shallow well with recovery by recharge. Little change for deep well.	Improved as test progressed by factor of 10 for shallow well and 3 for deep well. Highest value was 0.66.	...do............	Highly variable. Possible increases from blasting within 300 ft.
Rose Point, PA.	Very minor variation except for one temporary increase.	Initially 0.33. Improved late in test except for one temporary decrease. Then recovered to initial value.	Unexplained variations and discrepancy between field and laboratory tests.	Little variation.
St. Clairsville, OH.	Incomplete data from equipment failure.	Very low at 0.007 to 0.017 except for unexplained initial high values.	Little variation.	Insufficient data.



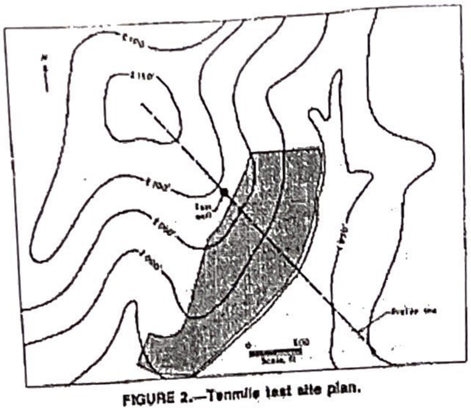


FIGURE 2.—Tenmile test site plan.

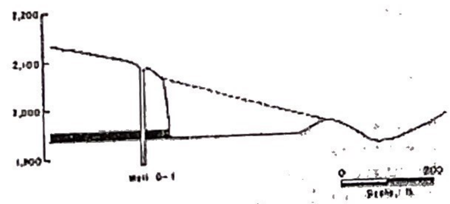


FIGURE 3.—Tenmile test site profile.

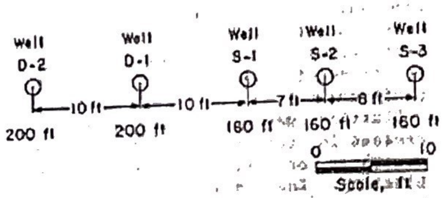


FIGURE 4.—Tenmile well layout. Deep and shallow pumped wells are D-1 and S-1. Others are observation wells.

Turbidity results were also similar to those from the Brotherton tests, with wide variations, difficult measurement conditions, and the suggestion of temporary increases from close-in blasts, less than 300 ft away.

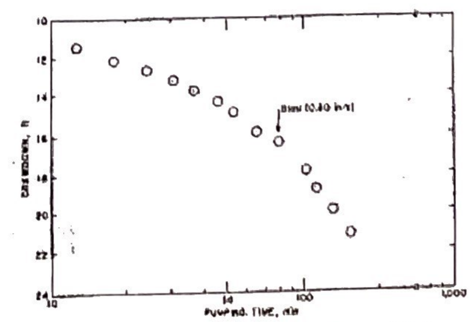


FIGURE 5.—Tenmile drawdown test for deep well (D-1).

ROSE POINT SITE

This site differed from the previous two in that the well was below the blasting. Consequently, researchers expected little stress relief effect. Indeed, little change occurred in either static water level or specific capacity until 5 months into the test, when specific capacity jumped from about 0.33 to nearly 0.60 (gal/min)/ft and later decreased.

Researchers attributed the changes to nearby removal and replacement of overburden, which occurred at that time. As with previous sites, no direct effect of blasting was evident.

ST. CLAIRSVILLE SITE

This site was characterized by very low capacity wells, which were expected to be susceptible to outside disturbances. The initial drawdown test in the shallow well appeared satisfactory, with the well able to sustain pumping rates of 0.86 gal/min, equivalent to a specific capacity of 0.041 (gal/min)/ft.

The deep well was worse, and was only able to maintain 0.21 gal/min for about half the normal test period of 600 min. (For this site, as well as the others, an unperforated liner and packer were used to isolate the deeper well from recharge from the shallower coal measure being mined.)

One month after the initial drawdown test, the shallow well was again pumped, but this time it had a specific capacity of only about one-third as much and at about one-half the pumping rate. Researchers suspected that air had been entrapped from initial tests, preventing full recharge.

In summary, researchers observed no clear blasting effects at this site. Unfortunately, work stopped short of distances found to produce effects observed at the three other sites. Some equipment failures were also experienced.

DOWN-THE-HOLE VIBRATIONS

Vibrations were monitored at the bottom of shallow observation wells as well as on the surface. Downhole vibrations were, as expected, of lower amplitudes, suggesting less risk to subsurface as opposed to surface structures. Table 4 summarizes the average relative resultant velocity amplitudes.

TABLE 4. - Reduced vibrations measured at depth

Depth, ft	Site	Relative amplitude(1)
Brotherton, PA	149	0.34 (2)
		.68 (3)
Tenmile, WV	160	.44
Rose Point, PA	168	.14
St. Clairsville,OH	180	~.25

(1)Depth vibration divided by surface vibration.
(2)Blasting in poorly confined upper layers.
(3)Blasting in well-confined lower layers.

CONCLUSIONS

Research at four sites in Appalachia found no catastrophic effects on water wells from blasting at vibration levels up to about 2.0 in/s. At three of the sites (and possibly the fourth, had testing continued), long-term changes were observed and were attributed to the removal of confining rock.

As blasting and the pit excavation approached within 300 ft of the wells, the mechanism of lateral stress relief allowed vertical fractures to open. Because these fracture systems are typically the abode and conduit of shallow Appalachian ground water, the static water levels then dropped over a period of weeks. With sufficient rainfall, the water levels would return. Where sufficient submergence exists, such minor changes in static level would not be noticed. Of benefit to the well user is the increased storage and flow as shown by higher observed specific capacities. Shallow wells exhibited this effect more than deep wells, consistent with expectations that more extensive fracture systems exist at shallow depths. At one site, backfilling reversed the improvement, either from clogging by fines or reintroduction of crack-closing lateral confinement.

Blasting may cause some temporary increases in turbidity, of the same order as those occurring in the absence of blasting. Results were uncertain on this because of the difficulty of sampling without causing disturbance and natural sloughing. Plastic well liners were recommended to control turbidity.

REFERENCES

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