

USES OF THE BOREHOLE CAMERA IN HYDROLOGIC INVESTIGATIONS RELATED TO COAL MINING¹

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Abstract. Use of a borehole camera in a hydrologic investigation, can yield information that may not be otherwise obtainable. The camera permits confirmation of stratigraphy, fracture and bedding plane separation locations, ground water inflow zones, fracture accentuation due to mine subsidence, and other features. A borehole camera also permits viewing of well bore features that otherwise may be unknown to exist, such as the conditions of the well bore, casing, and pumping system, historic water levels indicated by staining or corrosion, presence or absence of bacterial growths, existence of other organisms, the presence of foreign objects, and influx of gases.

Combined with other instruments, the borehole camera can greatly enhance the information derived from either individually. A camera has been used in conjunction with a pump or an electrical specific conductance meter to determine the location of water-bearing and non-water bearing fractures. The flow direction of water within the hole has been determined using the camera with a neutral-buoyancy tape attached. Subsidence features (e.g., fractures, sheared casing, and borehole offsets) have been documented using a borehole camera.

The borehole camera has proved almost indispensable as a tool for several hydrologic investigations conducted by OSM personnel. While not the only piece equipment used during an investigation, it has yielded information that was otherwise unavailable.

Additional Key Words: Water wells, slime bacteria, gases, subsidence fractures, bedding plane separations.

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Introduction

Hydrologists have at their disposal an array of equipment and testing methods that are routinely used during the investigation of hydrogeologic problems. An additional tool that can be added to the hydrologist's toolbox is the borehole camera. While not exactly new technology, the borehole camera has in recent years become more affordable in price and more portable, thus becoming more accessible to a larger number of ground water professionals. Many of the borehole cameras on the market are easily portable and can be used by a single professional without the need for a specialized vehicle. A great deal of hydrogeologic information can be obtained and documented by use of a camera coupled to a video recorder.

The camera can also be directly coupled with other instruments to maximize the collection of information. For example, a specific conductance meter attached to the camera can yield real-time information of changes in the water conductivity at specific points or at visible fractures in the borehole. Attaching an instrument to the camera is achieved with low-tech means of electrical ties or common duct tape. If the circumstances preclude using two instruments at once (e.g., the hole diameter is too small), the video of the borehole can also be put side by side with data from various other down hole instruments, such as a variety of electronic loggers or borehole flow meters to be able to tie the borehole characteristics to measured parameters.

The remainder of this paper will discuss potential uses of the borehole camera along with a few brief example studies where the camera was successfully used in the course of a hydrologic investigation.

Background

In recent years, the use of the borehole camera in hydrologic investigations has become more common. Johnson (1996) determined color, mineralogy, texture and other rock features of folded and faulted metamorphic and igneous rocks in New Hampshire. Borehole fracture orientation was determined by use of magnetic orientation and compared to surficially mapped fractures. Fracture density trends were related to depth, elevation, and topographic setting (Johnson, 1996). Fracture density was found to decrease with depth. Mack et al., (1998), used a

borehole camera to determine rock types, fractures, potential faults, and the general borehole condition in fractured bedrock in New Hampshire.

Hawkins et al., (1996), used a borehole camera to ascertain the fracture density of undisturbed strata overlying the Middle and Lower Kittanning coals in central Pennsylvania. A trend of decreasing fracture density with increasing depth was observed.

Potential Uses

Mining related hydrologic investigations include problems dealing with well dewatering (partial or complete), well contamination, and loss of well or casing integrity. The camera can identify whether the problem may or may not be mining related. The borehole camera provides an opportunity to view the subsurface under insitu conditions. Specifically, the camera can provide direct observation of lithologies to confirm the stratigraphy exposed in the well bore, determine fracture and bedding plane separation locations, identify ground water inflow zones, document fracture accentuation due to mine subsidence, and other features. A borehole camera also permits viewing of drill hole features and conditions that otherwise may be unknown to exist, such as the conditions of the well bore, casing, and pumping system, historic water levels indicated by staining or corrosion, presence or absence of bacterial growths, existence of other organisms, the presence of foreign objects, and influx of gases.

Lithologic or Stratigraphic Logging

This application of a borehole camera is to view and record stratigraphy and lithology of the accessed units. There are situations where little is known of the stratigraphy for the area in question. While the borehole camera is less than ideal for detailed logging of a hole for lithology, it can allow a moderate level of lithology determination. Sandstones, shales, and coals can usually be differentiated. Separation of shales and siltstones are also at times possible. Conglomeritic zones, nodules, and concretions can be easily observed within units with contrasting color. Lithologic determinations work best with a color camera setup. The use of lithologic logs for a well bore allows for more confident identification with the camera. While the borehole camera is not a substitute for good lithologic logs, it can provide lithologic information when the logs are incomplete or missing.

Fracture Logging

The location, orientation, rough width (aperture size), and condition (open or plugged) of fractures can be viewed and recorded. The frequency of fractures within lithologic units, with changes in depth, topographic location, and well location with respect to geologic structure, mines, and other salient features are all of interest in these types of investigations. With the right equipment, fracture strike and dip can be estimated. Fracture orientation is of interest because it can yield insight as to the ground-water sources, origin of the fracture (stress relief verses tectonic), and degree of fracture interconnectedness. Fracture aperture size is important in estimating potential inflow rates or possible impacts from mine subsidence. The degree to which a fracture is filled is important as to whether it can contribute ground water, the type of fill material or precipitate may be indicative of the water quality yielded by that fracture, or if biological plugging (biofouling) has occurred. Fracture strike and dip can be important in determining the types and directions of stresses to the strata.

Well Bore and Casing Integrity

The camera can be employed to observe the general condition of the well bore in terms of hole off-sets, zones of sloughing, precipitate build-ups, sediment accumulation, or blockages. The length of casing used in a well, cracks or holes in the casing, casing deterioration, leaking joints, and casing buckling can all be documented.

Ground Water Information

A multitude of information concerning ground water conditions can be ascertained with the borehole camera. Some useful information might include:

- The location of the standing water level can be determined generally within a foot. Water levels are most frequently determined using an electronic water level meter.
- The general color and clarity of the water can be assessed.
- The camera will show location, color, consistency, and amount of precipitates.
- Vertical (up or down) flow direction and ground water inflow points can often be observed in wells. Changes in water color or clarity are commonly indicative of zones of inflowing water. If this color continues below a certain point, this indicates a downward flow. If the

discolored water stops at a certain level this may indicate water flowing back into the aquifer or another source of water entering the well bore.

- Gas bubbles (e.g., methane, hydrogen sulfide, carbon dioxide) in the well water can be observed.
- Historic water levels can be determined. The location of historic water levels can be determined if there is substantial staining present on the casing or well bore. Historic water levels well above present water levels would indicate a diminution of the water supply. If the water is corrosive, the historic water level can also be determined by determining the upper limits of pitting in the metal well casing.

Impacts of Mining

Some mine subsidence impacts can be determined from viewing boreholes and wells. This is especially true if these holes can be viewed before and after an event. These observations include offsets in the well bore, unnaturally widened fractures, ruptured, sheared, or pinched casing, and rubble or caved zones above subsided sections. The fractures are frequently at angles oblique to horizontal and vertical. The presence and thickness of mine voids can also be identified with the borehole camera especially if auxiliary light sources are used.

Use with Other Instruments and Equipment

The use of other instruments can provide more insight into the ground-water quality and quantity that exists in the well bore. Some examples are included below.

- A conductivity meter can be coupled with the camera to identify which fractures are yielding ground water and to some extent the relative amount by determining the conductance of the water. The meter probe can literally be attached to the camera and run simultaneously or it can be run separately and the results of each can be compared at a later date.
- A neutral buoyancy filament can be attached below the camera to allow determination of flow direction within the borehole when the camera is held stationary.
- The camera can be used in conjunction with pumping of the well. When the water level is drawn down the water bearing fractures become more noticeable. The degree to which the

fractures yield can be determined on a qualitative scale. Additionally, clarity of the borehole is commonly improved by dewatering the targeted sections.

Example Investigations

Example – 1. Hydrologists from the Office of Surface Mining (OSM) conducted an investigation of alleged water loss due to underground mining in Wayne County, West Virginia. Numerous hand dug and relatively shallow drilled domestic water wells were reported to have been partially to completely dewatered from underlying mining. The underground operation involved only first mining with no secondary pillar removal. However, there was some reported pillar punching and associated floor heaving, which indicated some downward movement of the overburden.

The wells were all located in a narrow steep-sided stream valley. Many of the wells had been used continually for several decades with some having been used for nearly a century reportedly without experiencing yield problems. As is commonly the case, most of the wells had little to no documented background pre-mining water level or yield information.

The borehole camera was used to view the condition of a significant number of the wells. In the course of inspecting the condition of the wells, historic water levels (Fig. 1) were ascertained

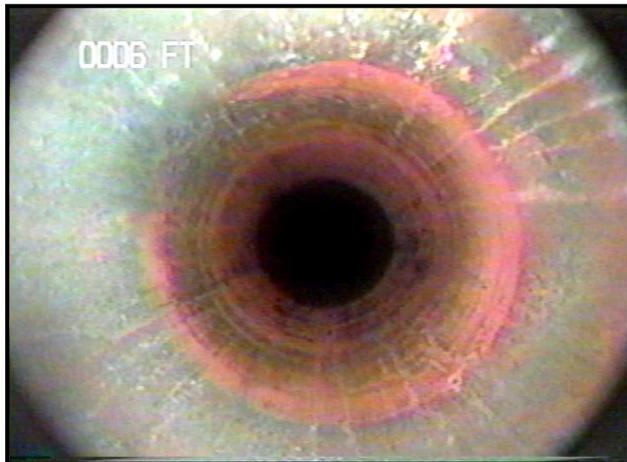


Figure 1. Iron oxide ring indicating the historic water level.

from the upper limit of extensive iron staining and casing corrosion in several wells. Most of the wells had iron concentrations exceeding 1.0 mg/L, which is well above the threshold for iron precipitation and staining. The observed water level for wells where a historic water level was determined was between 14 and 24 feet lower.

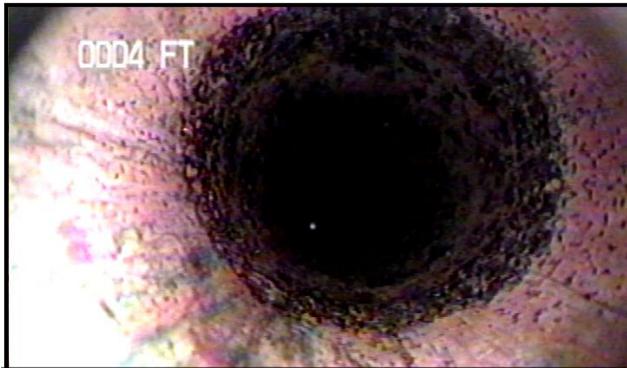


Figure 2. Upper limit of a corrosion zone on steel casing.

The location of the staining or corrosion (Fig. 2) is an indication of the average water level over time. While the notation of staining or corrosion may not be conclusive as to what the exact water level was prior to mining in any single well, observing this phenomenon in several wells in close proximity to one another is strong evidence that there has been a widespread change in

the water table. The determination of whether this water level change is due to the mining, protracted drought, or some other cause will depend on many other lines of evidence collected and analyzed during the course of the rest of the hydrologic investigation.

Example – 2. During the course of investigations in Ohio and West Virginia, the borehole camera was used to determine that the casing of a domestic water well, and a piezometer, respectively, were compromised.

In the first instance, a fairly deep domestic water well was drilled and cased through a flooded abandoned underground mine that contained water of poor quality. The well was

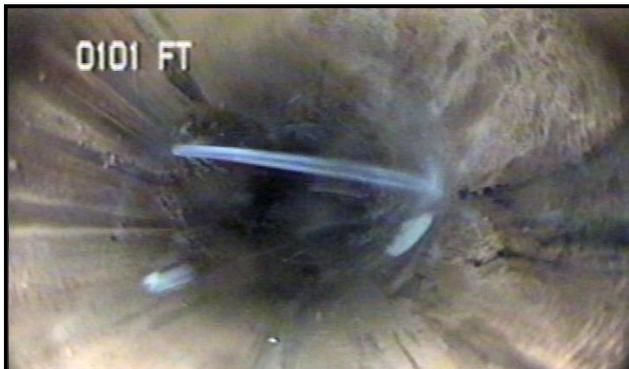


Figure 3. Rupture in PVC casing allowing mine water to enter water well.

relatively new and had good quality water at the time of completion, once the overlying mine was cased off. The casing was schedule 80 PVC. The citizen's complaint was that the water quality had begun to deteriorate in recent months.

The borehole camera was employed to help determine the cause of the change in water quality. At the 102-foot level a rupture (Fig. 3) in the casing was observed. Mine water under high pressure was streaming through a break in the PVC casing and then flowing unimpeded downward. The reason for this casing breach is not known.

In the second case (an on-going investigation and monitoring of flooded/flooding abandoned underground mine complex in northern West Virginia), a series of monitoring wells and piezometers were installed. Pressure transducers and data loggers were installed in these wells to monitor the water level changes with time at a high and consistent frequency.

The deepest well was approximately 450 feet into a completely flooded mine. This mine was relatively deep in the basin approximately 8 miles from the coal outcrop. After about a year of monitoring since well installation the water level exhibited an unexpected rapid rise. At the same time, the pressure transducer became stuck at a level below the original water level.

The borehole camera was sent down the well to determine the nature of the problem

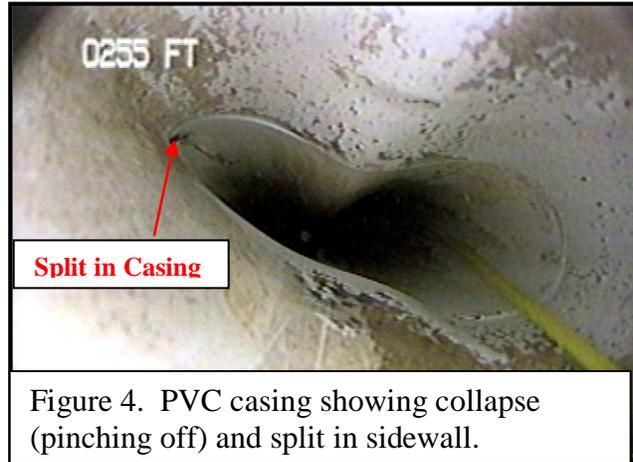


Figure 4. PVC casing showing collapse (pinching off) and split in sidewall.

and to determine the possibility of extracting the transducer. At the 256-foot level the casing (schedule 40 PVC) had collapsed or pinched (Fig. 4). The process of pinching off the casing, a split formed at a joint and a significant ground water inflow from overlying aquifers recharged the monitoring well bore. This was the source of the rapid rise in water level observed. The collapse of the casing is what prevented the removal of the pressure transducer.

It is likely that additional subsidence movement above the mine (several years) after abandonment was the cause of the casing failure. This well has been replaced with a new well using steel casing.

Example-3. In this case, the impacts of a flooded abandoned underground mine in Raleigh County, West Virginia on the ground and surface water systems were investigated. Specifically, a flowing artesian well began to exhibit degraded water quality caused by an adjacent underground mine that flooded several years after the mine was abandoned. The well flowed prior to mining and the water was historically potable. During mining, the well was dewatered and ceased flowing.

Critical to the investigation was the determination of which point(s) the uncased well was receiving ground-water inflow. If the units that were yielding the bulk of the water to the well could be ascertained, the ultimate source of the degraded water and the flow path could be determined.

The borehole camera by itself may not be able to note inflow points below the water level, unless there is some variation in the color or clarity of the inflowing water. Therefore, a neutral-buoyancy tape (Fig. 5) was attached to the camera to identify water movement within the well bore, which indicates inflow points and a relative indication of the rate of flow. As

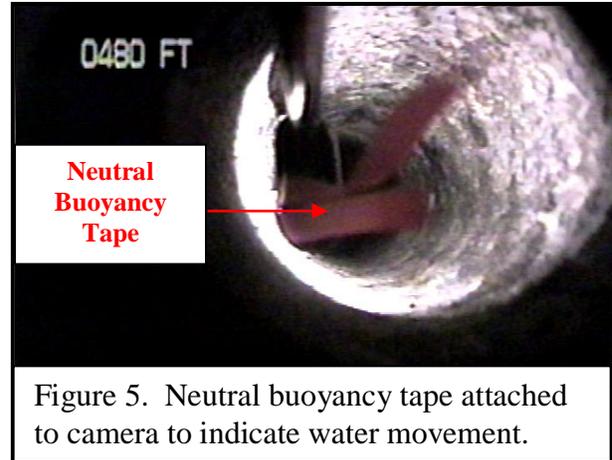


Figure 5. Neutral buoyancy tape attached to camera to indicate water movement.

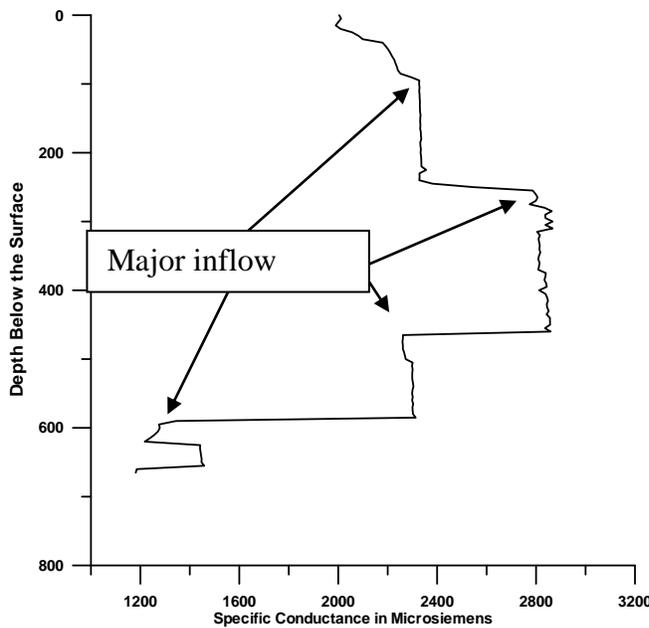


Figure 6. Specific conductance log showing the major inflow points.

mentioned above, a specific conductance meter can also be used in conjunction with the borehole camera to aid in the determination inflow points and their relative contribution.

Using the camera with a neutral-buoyancy piece of tape, we were able to determine that the artesian well had no less than four discrete major inflow points and several more minor inflow points. These inflow points were confirmed with a specific conductance meter, which was used to log the hole at five-foot intervals. Figure 6 is the specific conductivity log of the artesian well with the location of the major water-bearing fractures indicated by changes in specific conductance.

Example – 4. Visual inspection of clear water pumped from domestic water wells and monitoring wells generally leaves the impression that there may be no problems. However,

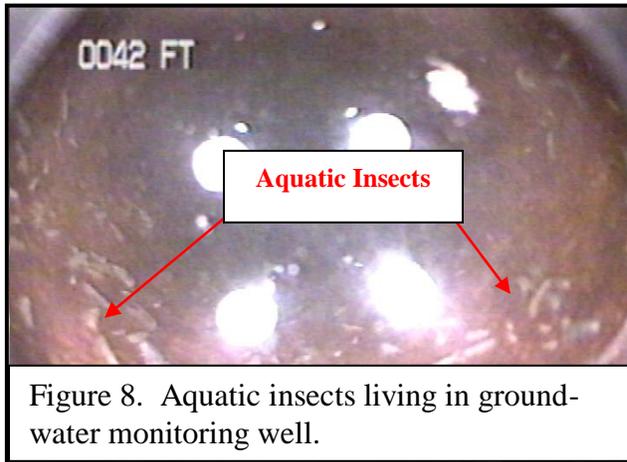
inspection of these same wells with a borehole camera can illustrate a different story. Insects, bacteria, and other living and dead things are not infrequently found in these wells.

During a routine inspection of a domestic water well in the course of an investigation of alleged yield loss, the presence of massive bacterial colonies (slimes) were noted (Fig. 7). The well is located on ridge adjacent to an underground (longwall) mine panel in Washington County, Pennsylvania.



The bacterial slimes exhibited a variety of colors including translucent white, gray, pink, yellowish, and orange. The well was located in the middle of a horse pasture, so the nutrient source for the large bacterial colonies is likely the nitrates from the horse manure.

A long-term water level monitoring well in Greene County, Pennsylvania was reviewed to



determine its potential for monitoring of a flooding underground mine. The well which had been used for many years no longer had records for the construction details and total depth. While not really a problem in terms potability, this well had a colony of aquatic insects living near the surface of the water (Fig. 8). Although the species of these insects is not known, they

appeared to be some type of amphipod. It is doubtful that pumping from this well would yield any of these insects. This is because they were only found at near the surface and pumping at a lower level should not encounter them.

Sometimes animals are introduced into the well that are not suited to the environment and will die shortly after their introduction. In the course of an investigation of alleged water loss in

Wayne County, West Virginia, series of active and abandoned water wells were viewed using the borehole camera.

One of the abandoned wells was being capped with a rock. When the rock was lifted a large lizard came out from beneath the rock and unfortunately scurried into the open hole (Fig. 9).

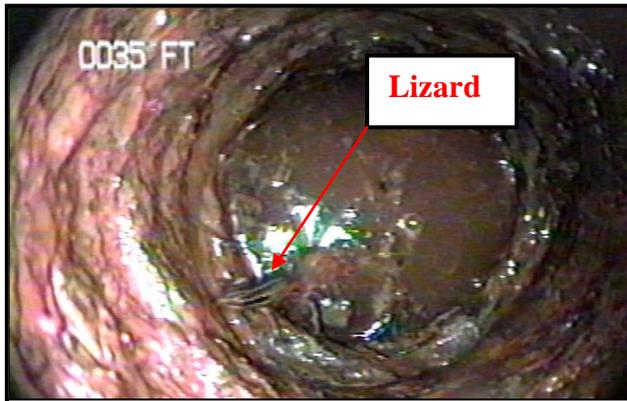


Figure 9. Lizard in domestic water well.

Given the vertical and wet sides of the well, the lizard became permanently trapped.

Example – 5. One of the dangers associated with wells impacted by coal mining is the introduction of hazardous gases. The most common of these gases are methane and hydrogen sulfide. However, carbon dioxide is also occasionally associated with mining

and reclamation activities. These gases are explosive, toxic, and/or can become hazardous by the displacement of oxygen. Gases enter wells dissolved in the water or in the free gaseous state.

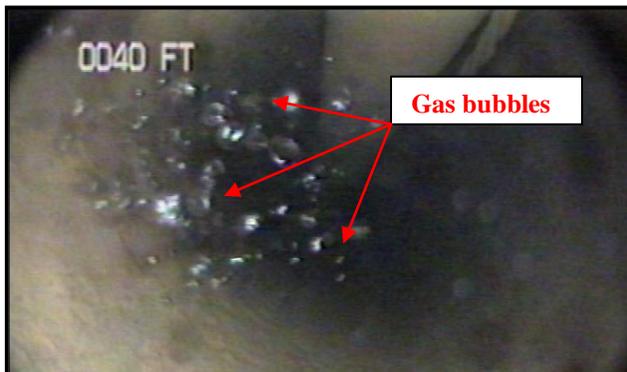


Figure 10. Gas bubbles in municipal water well.

The investigation of potential dewatering of a well field for a small municipal water supplier in Guernsey County, Ohio revealed significant influxes of hydrogen sulfide from fractures intersected by the borehole (Fig. 10). In this well, gas inflow occurred near the 46-foot level and was in the form of periodic

bursts, rather than a steady stream. Determination of the level and rock unit source of the gas often proves helpful in establishing the origin of the gas.

Under certain conditions, the presence of gases entering a well dissolved in the water can be observed. For example, the flowing artesian well discussed in Example - 3 has a significant concentration of hydrogen sulfide. The gas is not seen in the water until the pressure from the overlying water is reduced as it nears the surface. Once the pressure is sufficiently reduced, gas bubbles are observed exsolving from the water. As the water flows to the surface the overlying

pressure is reduced to a point where the water becomes supersaturated under the existing pressure and the gas will come out of solution.

Example – 6. The borehole camera is commonly used view the integrity of a well and the possible physical impacts from mine subsidence. The interpretation of mining-induced physical impacts to wells ranges from subtle to the glaringly obvious.

One of the more subtle changes includes slight offsets (Fig. 11) of the borehole caused by adjacent mining. In one case from Washington County, Pennsylvania, an undeveloped domestic



Figure 11. Offset in rock layers caused by subsidence.

water well was situated adjacent to a completed longwall panel. The tensile stresses created by the subsidence caused a 2 to 3 inch offset in the well bore. The offset is partially concealed by bacterial slime.

Fractured overburden for an abandoned partially subsided underground mine was viewed using the borehole camera. The fractures (Fig. 12, Fig. 13) are characteristically irregular, sharp edged, and indicative of fairly recent movement. They tend to exhibit an openness that signifies a downward movement caused by tensile stresses from gravitational forces. The fractures tend to be an accentuation of pre-existing horizontal fractures (bedding plane separations) or are an oblique angle.

Fractured overburden for an abandoned partially subsided underground mine was viewed using the borehole camera. The fractures (Fig. 12, Fig. 13) are



Figure12. Accentuation of horizontal fractures in borehole.



Figure13. Accentuation of oblique fractures in borehole.

Summary and Conclusions

While not the only tool a hydrologist can or should use during an investigation, the borehole camera is an extremely powerful one. It affords the ability to observe and record aspects of the subsurface via boreholes that otherwise would be unknown.

Used in conjunction with other instruments and devices, the borehole camera significantly enhances the ability to acquire specific information and data that would otherwise be unobtainable. The information obtained using the borehole camera may prove crucial in drawing the correct conclusions. The ability to graphically document the observations made via the camera (videotape and still shots made from the videotape) aid in the illustration of and ultimately proving one's case, regardless of the ultimate source of the problem.

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