Ground Water Monitoring & Remediation

Geophysical Study of Annular Well Seals

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Abstract

Geophysical logging was conducted in 35 in-service water and monitoring wells installed in unconsolidated sediments using a downhole ultrasonic probe to assess how sealant type, construction method, and site geology affect annular seals. Collapsed sand and gravel was frequently detected in the annulus of wells constructed with mud-rotary methods, precluding the placement of sealant and, in some wells, potentially providing a preferential pathway for contamination. High-solids bentonite grout appeared to create high-quality seals when formation materials did not collapse into the annulus. Seals composed of bentonite chips and pellets remained intact when hydrated upon placement; those not hydrated during placement remained dry and porous, posing a risk of surface water infiltration. Seals made with cement-bentonite grout were generally unsaturated and possibly cracked. Analysis of the data suggests that well designers should specify a construction method that minimizes collapse of the formation to ensure that the sealant is placed where intended. When collapse is avoided, high-solids bentonite grout and hydrated bentonite chips and pellets appear to yield intact seals. However, bentonite chips and pellets may not hydrate adequately in the annulus unless hydration water is added during installation. When cement-bentonite grouts are used, the well designer should ensure that the grout will remain intact and plastic after installation.

Introduction

Studies of well seals have focused on the properties of sealants (Kurt and Johnson 1982; Edil and Muhanna 1992; Edil et al. 1992; Lutenegger and DeGroot 1994; Riewe 1996), methods used to assess well seals (Yearsley et al. 1991; Klima 1996; Yesiller et al. 1997a; Dunnivant et al. 1997; Wheaton and Bohman 1999), and the potential impact of defective or missing well seals on leakage and water quality (Avci 1994; Lacombe et al. 1995; Pekarun et al. 1998). Despite this wealth of information, the integrity of in-service annular well seals and factors affecting their integrity are largely undocumented. Detailed studies of in-service well seals constructed using standards typical of the industry are relatively sparse because the assessment techniques can be complex and expensive, and most regulations do not require in situ assessments.

The goal of this study was to characterize a variety of in-service well seals in unconsolidated sediments and to identify factors affecting their integrity. To meet this goal, well seal logs were collected in 17 monitoring wells and 18 water supply wells in Wisconsin, northern Illinois, and northern Iowa using an ultrasonic geophysical method. These logs, along with geological reports, were used to assess the condition of the seal at the time of testing in the context of the geology of the site, the well construction methods that were employed, and the type of sealant.

Ultrasonic Method

The ideal tool for evaluating well seals would directly measure the ability of fluid to flow in the annulus along the length of the well. However, a tool of this type does not yet exist; thus, an ultrasonic geophysical method was used that is sensitive to properties of materials in the well annulus. Yesiller et al. (1997a) developed the ultrasonic geophysical tool and the logging method. Field experiments conducted by Yesiller et al. (1997b) on test wells purposely installed with seal defects showed that the method yields repeatable results and is able to detect the type of sealant, voids in the sealant, cracks, caved formation material, and the presence of both large and small defects.

The ultrasonic method uses a probe that is deployed into water-filled well casings with a diameter of at least 50 mm (Figure 1). Water is used in the casing as a couplant between the probe and the casing. An ultrasonic piezoelectric transducer housed in the probe emits ultrasonic energy. Air pressure is used to activate a piston that seats the probe firmly against the casing, ensuring that a constant distance exists between the transducer and casing wall. The energy passes through water in the casing and then into the casing, seal, and formation. As the energy passes into the different materials (water, casing, sealant, and formation), differences in acoustic impedance cause a portion of the energy to be reflected back to the transducer.

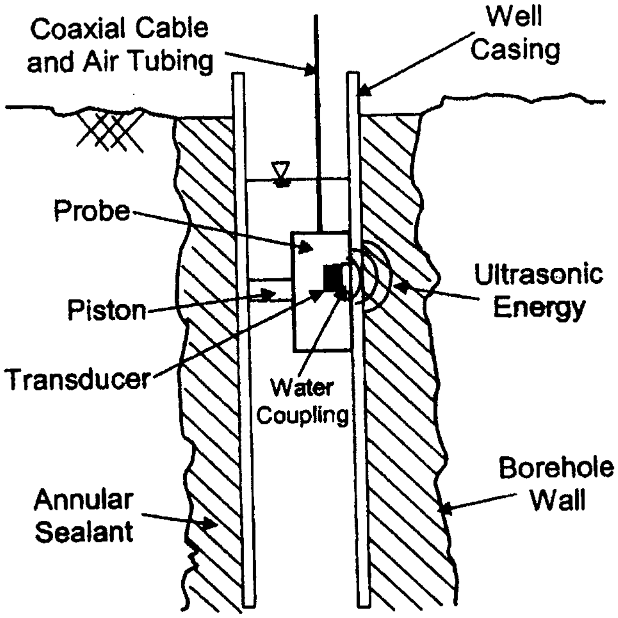

Figure 1. Schematic of well showing ultrasonic probe seated against casing.

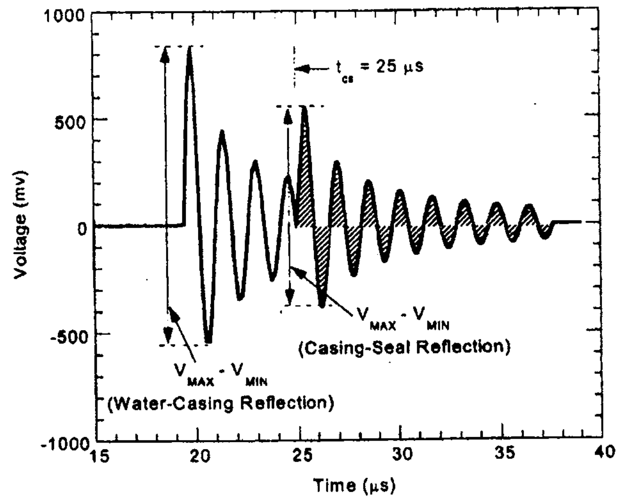

Figure 2. Typical signal showing ultrasonic energy reflected back to transducer from interfaces.

A well is logged with the ultrasonic method by interrogating the casing and seal at a series of locations along the length of the well string. In most cases, logging along a single azimuth is adequate, unless very small cracks or voids need to be detected. At each interrogation point, energy reflected off the water-casing interface and the casing-seal interface is received by the transducer and is analyzed by a waveform analyzer. A typical signal will have two distinct components to the waveform (Figure 2): the first component is from the water-casing interface, and the second component (shaded portion in Figure 2) is from the casing-seal interface. The first component of the waveform is a function primarily of the casing material and thickness and, thus, remains relatively constant from well to well. The second component is affected by the material outside of the casing and, thus, is characteristic of the material in the annulus.

Two indices, peak-to-peak ratio (R_{PKPK}) and a measure of wave energy (ENG), are used to describe the waveform. The equation for R_{PKPK} is

$$R_{PKPK} = \frac{(V_{MAX} - V_{MIN})_{CS}}{(V_{MAX} - V_{MIN})_{WC}} \tag{1}$$

where V_{MAX} and V_{MIN} are the maximum and minimum voltages in the specified part of the waveform for the waveforms emanating from the casing-seal (cs) and water-casing interfaces (wc), as shown in Figure 2. R_{PKPK} is dimensionless. The equation for ENG is

$$ENG = \frac{\int_{t_{cs}}^{\infty} V^2 dt}{(V_{MAX} - V_{MIN})^2_{WC}} \tag{2}$$

where V is voltage at time t, and t_{cs} is the time corresponding to the reflection from the interface between the casing and seal, as shown in Figure 2. ENG has units of time (typically nanoseconds [ns] or 10^{-9} seconds). Both R_{PKPK} and ENG are proportional to the amount of energy reflected from the casing-seal interface. ENG was conceived during development of the ultrasonic method (Yesiller et al. 1997a) and was used to characterize well seals tested at earlier dates. The index R_{PKPK} was established during subsequent development and was used instead of ENG to characterize well seals tested at later dates (Christman et al. 1999). The index R_{PKPK} has more discriminating power and is now preferred for interpreting the ultrasonic logs.

Laboratory measurements of ENG and R_{PKPK} were made using sealants and potential defect materials for use in interpreting logs obtained from the field. A description of the laboratory tests is in Christman (1999). ENG and R_{PKPK} are shown in Figure 3 for various materials. Dry materials typically produce ENG and R_{PKPK} readings greater than that of water (or the water reference), while wet materials produce ENG and R_{PKPK} readings less than the water reference. For unsaturated (moist) sand, R_{PKPK} decreases with increasing water content (w). For uniform sand saturated with water, ENG and R_{PKPK} increase with increasing median particle diameter, D_{50}. For bentonite slurries, R_{PKPK} decreases with increasing solids content. By measuring ENG or R_{PKPK} of known annular materials in the laboratory, ENG or R_{PKPK} may be used, along with information from the driller, to infer the type of materials that exist in the annular space of a well.

Wells Evaluated

Eighteen water wells and 17 monitoring wells were evaluated in this study. The water wells were installed in 220 mm diameter boreholes with 130 mm diameter Schedule 40 PVC casing. Mud-rotary drilling methods were used for construction. Annular seals were placed by pump-

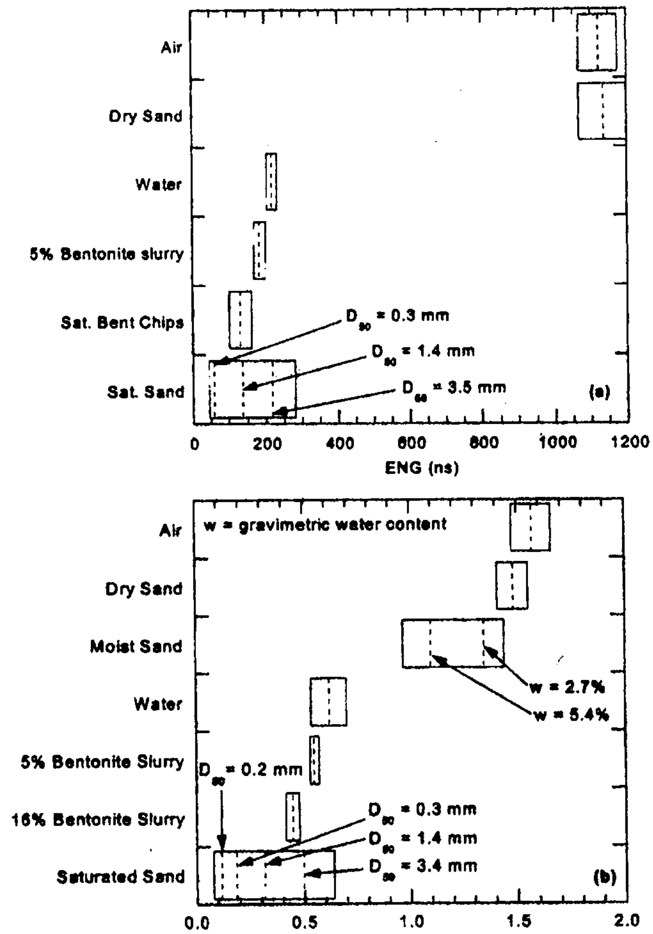

Figure 3. (a) ENG and (b) R_{PKPK} obtained from laboratory tests. Boxes represent range of ENG or RPKPK for a particular type of material. Vertical dashed lines in boxes represent median value for that material. For sands, the dashed lines represent median values for a given D50 (saturated sands) or water content (moist sands).

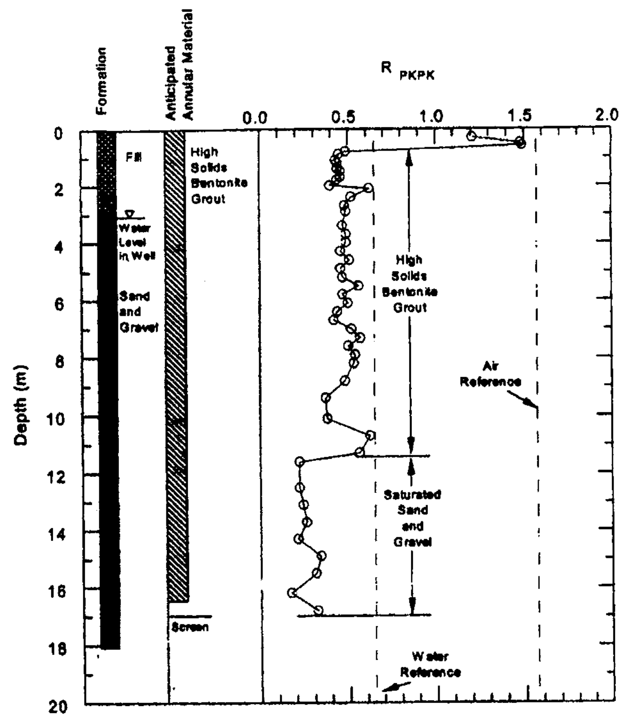

Figure 4. Ultrasonic log for Water Well 4.

ing high solids bentonite grout (>20% solids by mass) through a tremie pipe inserted into the annulus, which is the common construction method in Wisconsin and northern Illinois. The water wells were located in a variety of geological formations ranging from clay to gravel.

All monitoring wells were installed using a hollow-stem auger and used 50 mm diameter Schedule 40 PVC casing. Sealants for the monitoring wells included hydrated and nonhydrated bentonite chips, hydrated bentonite pellets, and cement-bentonite grout. The monitoring wells were located in geological formations consisting primarily of silty clay and clayey silt.

Well Logs

Space restrictions preclude presenting and discussing each of the 35 wells tested in this study. Instead, results from six wells representing the range of conditions observed in the field are shown. General inferences based on all of the data are made in a subsequent section. All of the well logs can be found in Christman (1999). A typical log of a 10 m deep well required about a half-day to complete.

The logs that were collected reflect the condition of the seals at the time of logging. No attempt was made to evaluate temporal changes in the seals, although some of the logs indicate that weathering and other factors have caused changes in the seals over time.

Water Well 4

The log for Water Well 4 is shown in Figure 4. The vertical bar at the left-most edge of Figure 4 describes the formation as reported by the driller. The adjacent bar to the right describes the annular material that was anticipated based on the report filed by the driller.

From 0.5 to about 10 m, R_{PKPK} readings are between 0.4 and 0.6, indicating that high-solids bentonite grout fills the annulus. The high-solids bentonite grout was viscous enough to be retained by the adjacent sand and gravel formation located 3 mbgs (meters below ground surface). A less-viscous grout may have flowed into the permeable formation. The test was conducted 65 days after the grout was placed. Thus, detection of a continuous length of grout indicates that the high-solids bentonite grout was retaining moisture and, therefore, its sealing properties. Three high R_{PKPK} readings were detected in the upper 0.5 m of the well, indicative of the dry, sandy, and gravelly fill material visible in the annulus at the surface.

The sharp decrease in R_{PKPK} near 11 m is associated with a material change in the annulus from grout to saturated sand and gravel. During well development (before the sealant is placed), water was pumped down the casing and out the screen to cause the surrounding formation to collapse around the screen. The collapsed formation then served as a filter pack. The driller has little control over how much of the formation falls into the annulus. In this particular well,

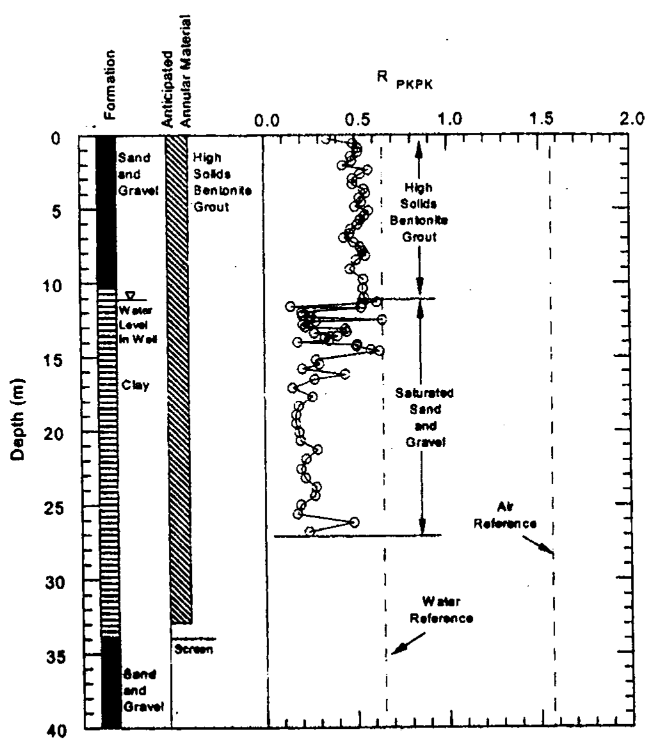

Figure 5. Ultrasonic log for Water Well 8.

the formation appears to fill approximately 5 m of the annulus above the screen. This length of unsealed annulus could pose a problem in some wells. However, in this case the formation adjacent to the portion of the annulus infilled with sand and gravel is not an aquitard and thus preferential flow along the annulus will probably not occur.

Water Well 8

Water Well 8 draws water from a gravel aquifer that is confined by a 24 m thick clay layer. The clay layer restricts both downward and upward flow, and is an important barrier that protects the quality of the underlying ground water. The log for Water Well 8 is shown in Figure 5.

From the surface to 11 m, most R_{PKPK} measurements are typical of high-solids bentonite grout (Figure 5). Below 11 m, the R_{PKPK} profile changes. Most of the measurements drop to approximately 0.2, but some reach as high as 0.65. These readings near 0.2 are typical of saturated sand. The scatter in the measurements between 11 and 16 m suggests that the sand is loose (or mixed with gravel) and that water-filled voids are present.

This interpretation of the annular materials is supported by the events that occurred prior to placement of the grout. A 35 m deep borehole was drilled using a mud-rotary method one day before the ultrasonic tests were conducted. Casing was lowered into the mud-filled hole along with a tremie pipe (25 mm diameter and 25 m long) taped to the outside of the casing. The well was then developed in a manner similar to Water Well 4. During this process, drilling fluid remaining in the annulus was displaced and diluted by water injected into the casing. Following development of the well, construction ceased for the day.

The following day, the first attempt to seal the annulus failed. The bottom end of the tremie pipe was clogged, preventing injection of high-solids bentonite grout. During an attempt to unclog the tremie pipe, the pipe separated at a joint at 12.5 mbgs. After pulling the tremie pipe out of the annulus, it was lowered back into the annulus until it was obstructed by collapsed material at 12.5 m. Grout was then pumped until it flowed out the top of the hole.

The well development technique and the delay in injecting grout caused sand and gravel in the upper formation to slough and fill the lower part of the annulus. Sand from the underlying aquifer may also have been pumped into the annulus during development. The location of the collapsed formation material relative to the confining layer at this site places the well at risk for possible contamination. Before the well was placed, the aquifer was separated from the upper sand-and-gravel formation by the clay-confining layer. However, collapsed formation material now fills 94% of the annulus adjacent to the clay formation. If the hydraulic conductivity of the collapsed material is greater than that of the clay layer, the annulus may act as a preferential pathway for contaminants. Moreover, Pekarun et al. (1998) show that at least 20% of an annulus passing through an aquitard must be sealed for the seal to be effective. In Water Well 8, only 6% of the annulus is filled with sealant.

Water Well 15

The log for Water Well 15 is shown in Figure 6. From the surface to 4 m, measurements of R_{PKPK} indicate the presence of high-solids bentonite grout. However, from 4 to 8 m, readings typical of unsaturated sand and gravel were detected. From 8 to 13.5 m, the measurements are mostly scattered below the water reference, typical of wet sand and gravel. The boundary between the unsaturated sand and saturated sand is slightly above the water table, implying the presence of a capillary fringe. From 13.5 to 20 m, the readings are typical of saturated fine sand.

The depth where the tremie pipe was inserted was not reported, which prevents a definitive understanding of the mechanism responsible for the R_{PKPK} profile. However, caving of the adjacent coarse gravel formation is evident. The borehole wall probably collapsed prior to placement of grout, during or soon after the development of the well.

Even though the majority of the annulus is filled with collapsed material, this water well is probably not at an increased risk for contamination. The high-solids bentonite grout is continuous through the upper clay and gravel layer that protects the underlying aquifer from the ingress of surface water. Collapsed material was detected only at depths where the adjacent formation is coarse gravel. The collapsed material may or may not act as a preferential pathway for contaminants, but the annulus is unlikely to conduct significantly more flow to the well screen at 20.5 m than the adjacent gravel formation.

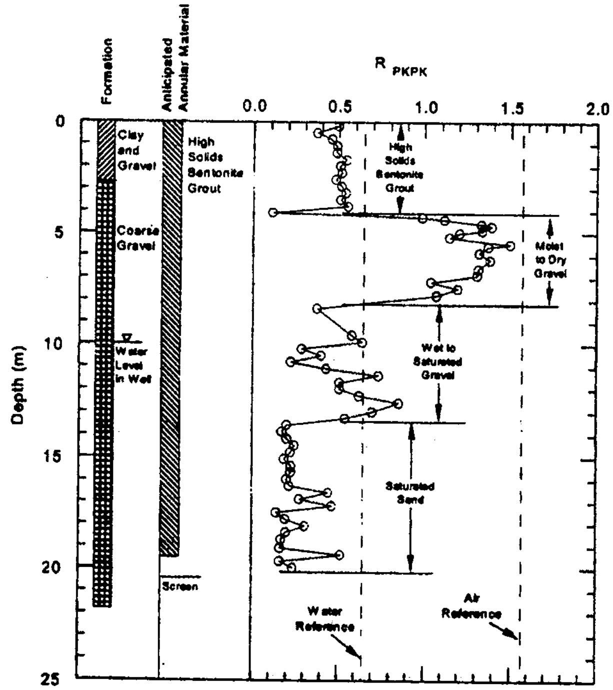

Figure 6. Ultrasonic log for Water Well 15.

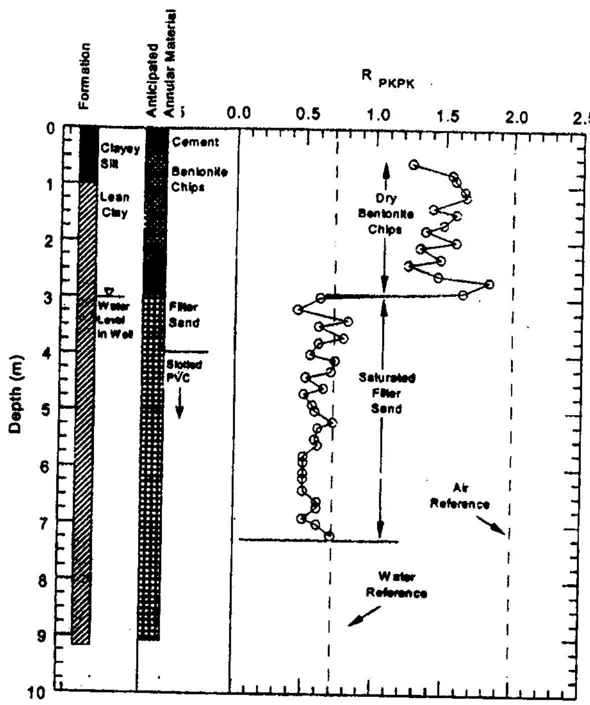

Figure 7. Ultrasonic log for Monitoring Well 6.

Monitoring Well 6

A log from Monitoring Well 6 is shown in Figure 7. This well was one of seven piezometers installed to monitor ground water levels at a site slated for a new bridge over a railroad track. Topsoil at the surface is followed by clay from 0.5 to 9.2 m. The static water level is at 3 m, and the casing is slotted from 4.2 to 9.2 m. Annular materials were placed by pouring from the surface. Filter sand fills the annulus to a depth of 3 mbgs and is overlain by bentonite chips. The upper 0.3 m is sealed with neat cement. The ultrasonic probe was used to test the well seal to a depth of 7.2 m. Tests were conducted seven days after the seal was placed.

The R_{PKPK} readings for this well indicate that the annular material above the water table (at 3 m) is unsaturated, whereas material below the water table is saturated. All tests in the range where bentonite was reported to be placed indicate a material containing significant air voids. Results below 3 m correspond to filter sand, which is typically made up of medium to coarse sand-size particles.

The hydraulic conductivity of the unsaturated bentonite chips forming the seal is especially difficult to assess. If water infiltrated into the annulus (such as during a flood or heavy surface runoff), voids between the bentonite chips could serve as a conduit for flow. However, water would flow along the surface of the chips, so as flow progressed, the bentonite would swell. If the time to swell was less than the time for water to infiltrate, then downward flowing water might be prevented from passing through the total length of bentonite. However, if the time to infiltrate was less than the swelling time for the bentonite, surface water could breach the seal. In this particular well, a poor seal is not critical in terms of water quality because the annulus does not penetrate through the lean clay aquitard. However, heads interpreted from the piezometer could be incorrect.

Monitoring Wells 4 and 7

Results from Monitoring Wells 4 and 7 are shown in Figure 8. These wells were constructed at the same time to monitor ground water quality at a site where an organic chemical was being applied on the ground surface. Ultrasonic tests were conducted in the wells two years after installation. The geology at the site consists of silty clay overlying clayey silt. Sand filter packs were placed at the bottom of the annulus. A combination of hydrated bentonite chips and cement-bentonite grout was used to seal the wells. The parameter ENG was used for analysis because the R_{PKPK} index had not yet been developed.

In each well, ENG measurements distinguish the change from cement-bentonite grout to bentonite chips at a depth of 4.5 m. The ENG profiles are relatively uniform (100 to 150 ns) in the region with bentonite chips (4.5 to 5.5 m), indicating that the bentonite chips remained hydrated even after two years above the water table. The ENG profiles are also similar below the seal within the sand filter pack. Readings in this zone fall between the water and air reference, indicating the sand is moist but unsaturated, which is expected because the sand at this elevation is above the water table.

A large difference exists in the ENG profiles in the region where cement-bentonite grout was placed. In Monitoring Well 7, the ENG profile contains significant scatter, indicating that the sealant is not homogeneous. Most of the ENG readings (84%) fall between the water

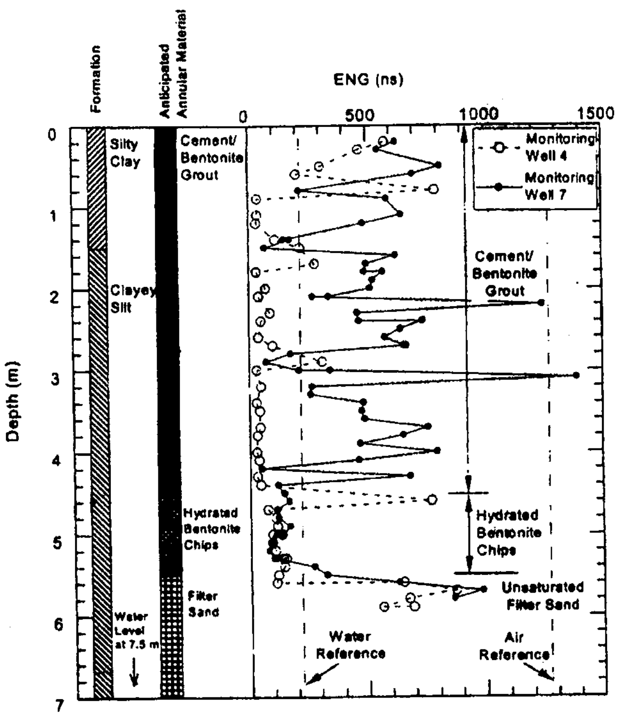

Figure 8. Ultrasonic logs for Monitoring Wells 4 and 7.

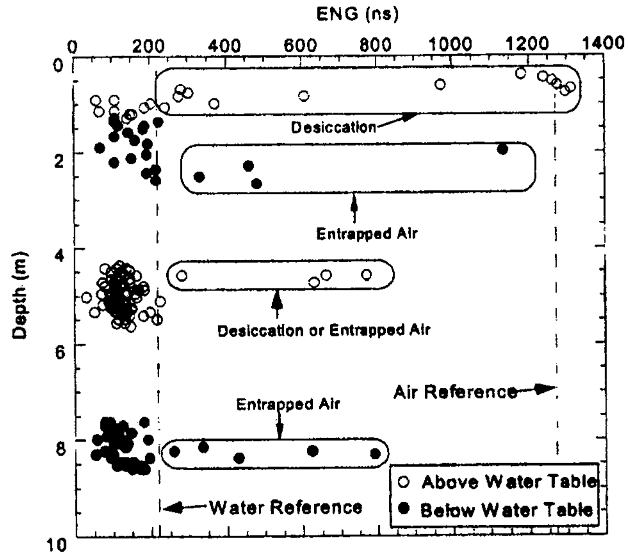

Figure 9. ENG versus depth for hydrated bentonite chips and pellets.

and air references, indicating the presence of air in the pores of the cured grout or the presence of cracks. Apparently, after two years above the water table, the grout did not remain saturated and intact or a microannulus formed. A microannulus is a very small gap between the well casing and sealant that sometimes occurs when cement-based sealants are used (Yesiller et al. 1997a). In contrast, the cement-bentonite grout seal in Monitoring Well 4 appears to be in good condition despite being located above the water table and having aged two years. The ENG readings are predominantly below 50 ns (a few anomalies near 1.5 and 2.9 m have higher ENG readings), indicating the casing is in good contact with a saturated, dense material.

The reason for the difference between the ENG profiles for these two wells cannot be confirmed with the data that were obtained, but variations in the cement-bentonite grout mix may be a reason for the different characteristics of these seals. The geology, water table, and reported construction methods for the wells are essentially identical. One explanation could be that the percentage of bentonite added to the grout in Monitoring Well 4 may have been higher than in Monitoring Well 7, resulting in a sealant that retains more water, or the water-cement ratios may have been different.

Previous water-quality tests on samples from these wells indicated the ground water was contaminated with a very low concentration of the organic chemical applied on the ground surface after the wells were installed. Given the time between application and detection of the chemical, migration through the silty clay probably was not responsible for contamination of the ground water. Migration along the annulus of Monitoring Well 4 is also unlikely, but migration along the annulus of Monitoring Well 7 may have occurred and caused the contamination.

Effect of Sealant

When specifying annular sealants to be used in a well, designers have a wide variety of materials from which to choose. Laboratory test results, claims from the manufacturer, or past experience may influence the well designer's decision regarding which sealant to specify. However, sealant properties in the field may differ from those observed in the laboratory or under controlled conditions.

The results from this study indicate that bentonite chips and pellets can provide a good seal if properly hydrated during construction. Data from 10 monitoring wells where bentonite chips and pellets were hydrated by the driller are shown in Figure 9 at the depths where bentonite chips or pellets were reportedly placed. ENG is used in Figure 9 because the monitoring wells were logged before R_{PKPK} was developed. Most of the data points (82%) fall below the water reference, indicating that the hydrated bentonite generally remains hydrated and probably provides a good seal. Desiccation is apparent at shallow depths (depths less than 1.5 m); 57% of the tests conducted above the water table at depths shallower than 1.5 mbgs resulted in ENG greater than the water reference. Desiccation is not evident at greater depths, despite the unsaturated conditions; 93% of the tests conducted above the water table and at depths of at least 1.5 mbgs had readings below the water reference. Surprisingly, 14.5% of the data collected below the water table fell above the water reference. Air may have become trapped within the bentonite during placement or the water table may have fluctuated, trapping air when the water table rose.

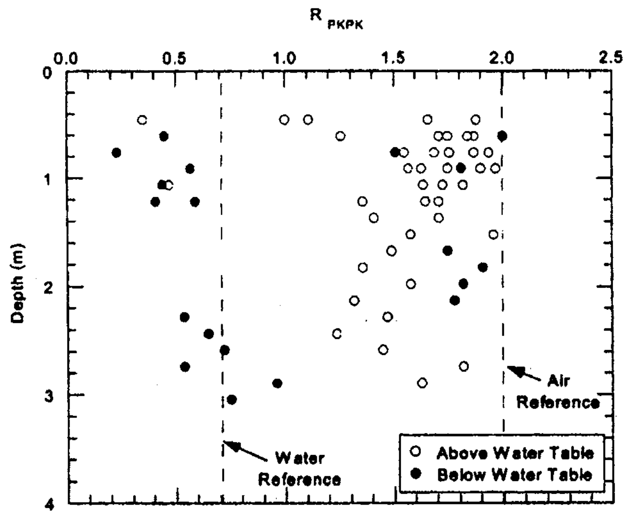

Figure 10. R_{PKPK} **versus depth for unhydrated bentonite chips and pellets.**

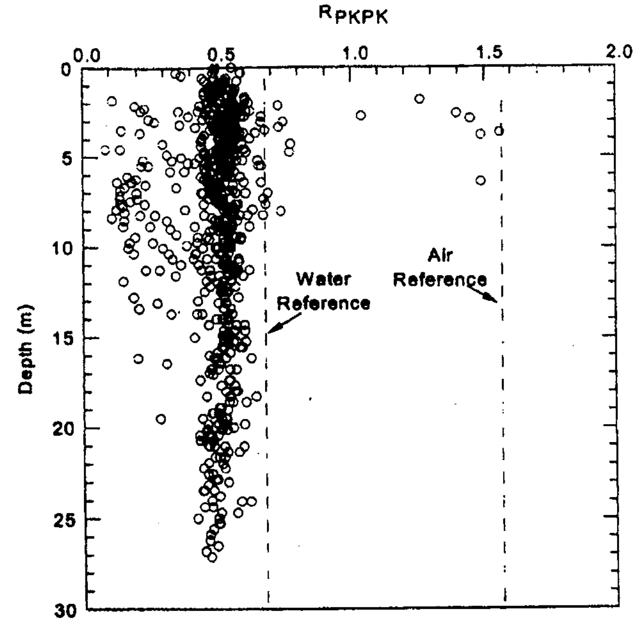

Figure 11. R_{PKPK} **versus depth for high-solids bentonite grout.**

Data are shown in Figure 10 from seven monitoring wells in which chips and pellets were left to hydrate naturally. Eighty-one percent of the R_{PKPK} readings are greater than the water reference. The majority of the readings are closer to the air reference than the water reference, indicating that the bentonite chips were predominantly dry at the time of testing. All of the tests were conducted within one week of seal placement. If more time had elapsed between construction and testing, the bentonite chips may have naturally drawn in more water. However, this presumption may not be warranted considering that entrapped air was interpreted in some "hydrated" bentonite chips below the water table two years after placement. Moreover, most of the unhydrated bentonite chips were placed above the water table. Unless the water table rises, the bentonite can become hydrated only from infiltration of surface water, capillary action, or diffusion of water vapor. If the latter two mechanisms hydrate the bentonite, the seal will likely restrict any water that infiltrates. However, if surface water infiltrates before the chips are hydrated, the seal can be breached if the infiltration rate is greater than the rate at which the bentonite swells. For seals that are designed to restrict flow, not hydrating the bentonite poses an unnecessary risk for infiltration. Thus, hydration of the bentonite during installation of the well is prudent.

Data from the 17 wells sealed with high-solids bentonite grout are shown in Figure 11. The majority of R_{PKPK} readings are centered on 0.5, which is the expected R_{PKPK} for high solids bentonite grout. Anomalous R_{PKPK} readings greater than the water reference were found primarily at shallow depths, suggesting that grout can desiccate near the ground surface. Low R_{PKPK} readings (< 0.3) were also detected, and may be a result of bentonite granules that did not disperse completely upon mixing, inclusions of denser formation material, or water loss from consolidation of the grout. Overall, the high solids bentonite grout seals appeared to be largely intact; 95% of the R_{PKPK} readings are below the water reference line and most fall close to the value anticipated for intact bentonite grout seals ($R_{PKPK} \approx 0.4$ to 0.6).

Data from the wells sealed with cement-bentonite grout are shown in Figure 12. The data are scattered throughout the possible range of ENG. As in Figures 9 and 10, the parameter ENG is shown in Figure 12 because the R_{PKPK} index had not yet been developed when the wells with cement-bentonite grout were tested. More than 50% of the readings are greater than the water reference, indicating the presence of varying amounts of air or gas in the sealant. The readings do not increase nearer to the surface as they would if evaporation was drying out the seal, so evaporation is probably not the cause of the high readings. The high readings are also not indicative of a microannulus, because the ENG distribution is relatively smooth and weighted toward the lower end of the scale. If a microannulus was present, the data would be bimodal, with ENG either near the air reference line in regions where a microannulus existed or below the water reference line where grout-casing contact existed (Yesiller et al. 1997a). Regardless of the cause, these data suggest that cement-bentonite grouts may not retain an intact seal that exists in a semisolid and plastic state.

Effect of Construction Method

The effect of construction method on completeness of the annular seal was analyzed by comparing ratios of interpreted seal length (I) to anticipated seal length (A) for each well (Figure 13). The ratio I/A for wells constructed using a hollow-stem auger ranged from 77% to 100%, with a median I/A of 100%. In contrast, I/A for mud-rotary wells ranged from 20% to 94%, with a median I/A of 53%. Hollow-stem methods were used for the monitoring wells (17), and mud-rotary methods were used for the water wells (18).

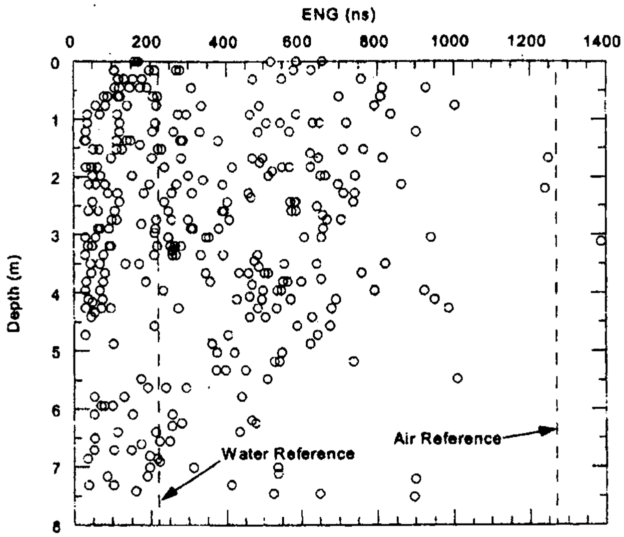

Figure 12. ENG versus depth for cement-bentonite grout.

More complete well seals were obtained in wells drilled with a hollow-stem auger than those drilled with the mud-rotary method for at least two reasons: (1) cuttings are removed more efficiently via auger flights than by circulating mud slurry, and (2) caving of formation material into the drill hole is virtually eliminated using a hollow-stem auger, whereas opportunities for caving commonly exist with mud-rotary methods. In addition to construction differences, the wells installed with a hollow-stem auger in this study had smaller drill hole diameters, were generally shallower, and typically penetrated formations consisting of more cohesive soils. As a result, differences in well constructabilty may have influenced the I/A ratios to the same degree as the construction methods. However, when an annular seal is critical to the success of a well, well designers are prudent to use the hollow-stem method over a mud-rotary method when subsurface conditions permit.

Geological Conditions

In addition to sealant properties and construction methods, geological conditions can affect annular seals (Edil et al. 1992). The percentage of the annulus length actually sealed relative to the percentage of the drill hole where the formation was sand and/or gravel is shown in Figure 14. Data are shown only from wells constructed using mud-rotary methods and sealed with high-solids bentonite grout so that the influence of formation collapse is not confounded by other factors that affect the seal. The sealed lengths typically are shorter (relative to the length of the annulus to be sealed) when formations consisting of sand and/or gravel are more prevalent, whereas seal lengths are longer when sand and/or gravel is less prevalent (i.e., cohesive formation materials are more prevalent). This difference in seal lengths is most likely due to collapse of sand and/or gravel formations into the annulus during construction, precluding the placement of sealant. Loss of grout into gravel zones in the formation

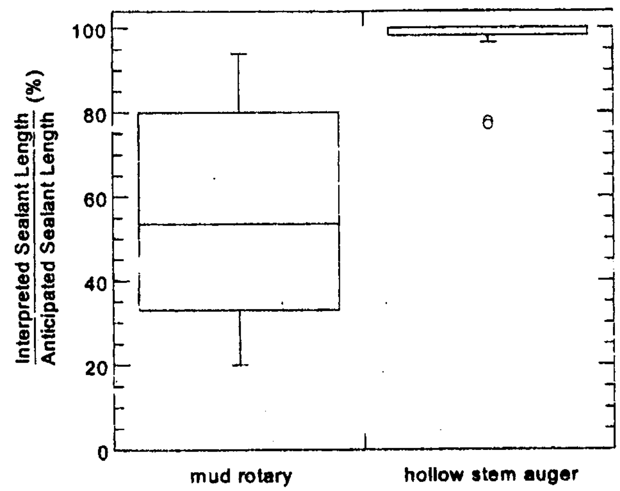

Figure 13. Box plots showing interpreted to anticipated seal length ratio for mud-rotary and hollow-stem drilling methods.

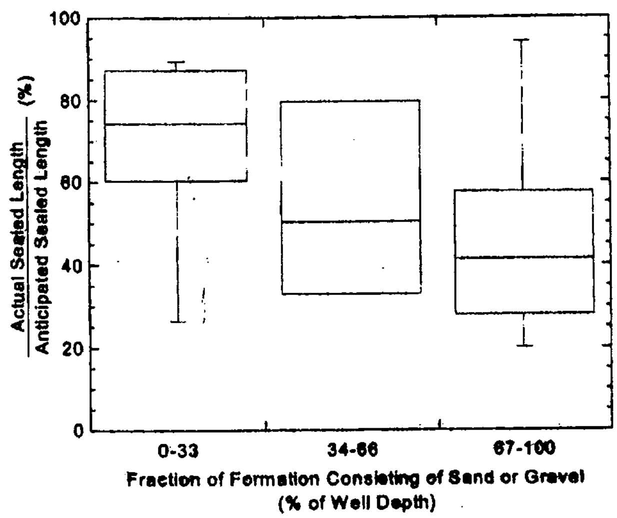

Figure 14. Box plots showing fraction of intended seal length actually sealed for sites with different fractions of sand and gravel layers in the profile.

may also have occurred, but is unlikely given the high viscosity of high-solids grout used for these wells (Edil et al. 1992).

Caving of noncohesive formation materials may be minimized, and seal quality may be maximized, if the well designer and driller take appropriate steps. Subsurface conditions should be characterized to the greatest extent possible prior to drilling. Drillers are typically familiar with subsurface features in their operating area, and geological reports from existing wells and boreholes are often available from government agencies. If potentially caving formation materials are expected to be encountered, the well designer should specify a drilling technique or methodology (e.g., driving casing) that prevents formation collapse if an inadequate seal may compromise the ability to prevent preferential flow along the annulus to the well screen.

Summary and Conclusions

A downhole ultrasonic probe was used to assess annular seals in 35 monitoring wells and water supply wells installed in unconsolidated sediments. Differences in construction methods, site geology, and sealant types were expected to influence the performance of the annular seals, and results from the study confirmed these expectations. These results indicate that well designers and drillers should consider the sealant as well as the construction process, including problems that may arise from geological conditions.

The most inadequate annular seals were found when mud-rotary methods were used to construct wells that penetrated deep or frequent sand and/or gravel formations. Without a driven casing, sand and gravel frequently appeared to have collapsed into the annulus, precluding placement of sealant. Ground water is especially vulnerable to contamination when caved sand and gravel in the annulus compromises an aquitard or confining layer.

Seals composed of cement-bentonite grout or unhydrated bentonite chips had questionable characteristics. Evidence of dryness and variable consistency in most of the cement-bentonite grout seals suggested the sealant did not remain in a saturated and plastic state. Bentonite chips that were not hydrated during placement remained dry, posing an unnecessary risk of flow through the seal. Thus, bentonite seals should be hydrated during well construction and cement-bentonite sealants should be used with care in situations where short-circuiting through the annulus may affect data collected from the well or ground water quality.

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