ground water

Technical Note/

Noise in Pressure Transducer Readings Produced by Variations in Solar Radiation

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Abstract

Variations in solar radiation can produce noise in readings from gauge pressure transducers when the transducer cable is exposed to direct sunlight. This noise is a result of insolation-induced heating and cooling of the air column in the vent tube of the transducer cable. A controlled experiment was performed to assess the impact of variations in solar radiation on transducer readings. This experiment demonstrated that insolation-induced fluctuations in apparent pressure head can be as large as 0.03 m. The magnitude of these fluctuations is dependent on cable color, the diameter of the vent tube, and the length of the transducer cable. The most effective means of minimizing insolation-induced noise is to use integrated transducer-data logger units that fit within a well. Failure to address this source of noise can introduce considerable uncertainty into analyses of hydraulic tests when the head change is relatively small, as is often the case for tests in highly permeable aquifers or for tests using distant observation wells.

Introduction

The pressure transducer is commonly used in ground water investigations for monitoring water levels in wells. This device essentially consists of a pressure-sensitive diaphragm on the back of which are etched a series of semiconductor strain gauges. The front side of the diaphragm faces the water in the well, while the backside faces a chamber that is either at near-vacuum conditions (absolute pressure sensor) or at atmospheric pressure (gauge pressure sensor). A change in the height of the water column above the transducer produces a minute flexing of the diaphragm, which introduces strain to the gauges on the backside. This strain produces an electrical resistance change that is proportional to the change in water pressure. That proportionality is determined through laboratory and field calibrations.

The majority of transducers used for ground water applications are gauge pressure sensors. Gauge pressure sensors have traditionally been preferred over absolute pressure sensors because they provide a measurement that is relative to atmospheric pressure; thus, changes in atmospheric pressure are not misinterpreted as changes in the height of the water column above the sensor. The chamber behind the diaphragm is kept at atmospheric pressure via a small-diameter tube that runs inside the transducer cable for its full length, and is open to the atmosphere at its upper end. Manufacturers caution users to refrain from obstructing this vent tube either by bending the cable at too sharp of an angle and kinking the tube, or allowing debris to accumulate at its upper end.

In a large number of hydraulic tests, we have observed fluctuations in transducer readings that do not appear to represent head changes in the aquifer. Figure 1a displays an example of such fluctuations observed during a recent small-scale pumping test performed in a highly permeable

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aquifer (Davis et al. 2002). The fluctuations, which are most evident between 100 and 1000 s, were not produced by changes in pumping rate or atmospheric pressure. Although the fluctuations shown in Figure 1a do not exceed 0.015 m in magnitude, this level of noise can introduce considerable uncertainty into analyses of hydraulic tests when the total head change is relatively small. Butler et al. (1999) report similar fluctuations in pressure readings from an airline being used to measure water level variations during a pumping test. Anomalous fluctuations of this magnitude have also been observed during slug tests and can lead to shifts in the static head value during a test (Kansas Geological Survey unpublished data).

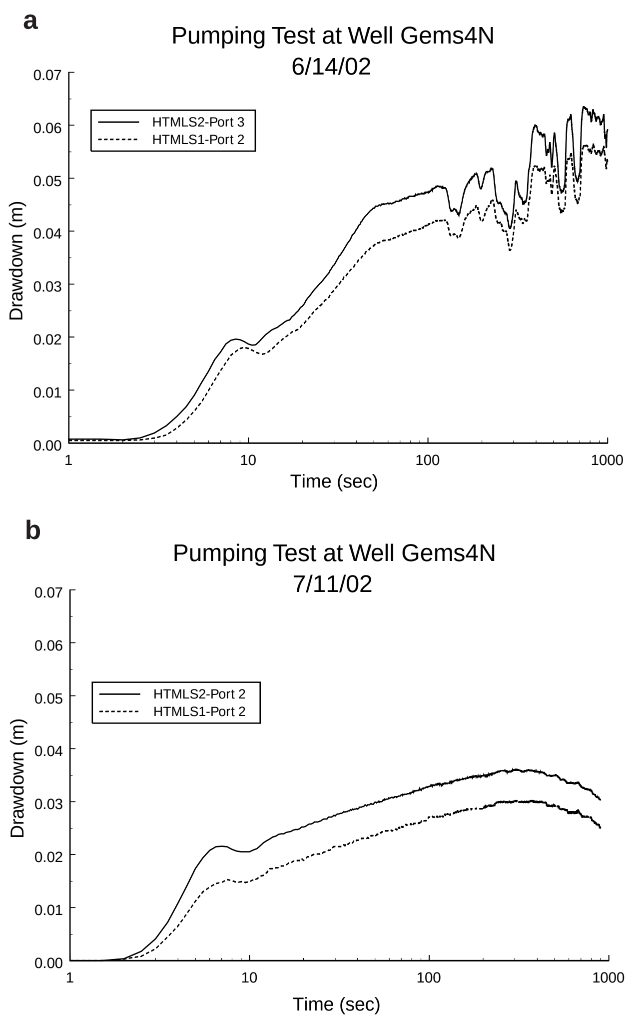

Figure 1. Plots of drawdown vs. logarithm of time since pumping began. (a) June 14, 2002 pumping test. (b) July 11, 2002 pumping test (pumping rate = 1.3 L/s for both tests; pumping well Gems4N fully screened over the 10.7 m sand and gravel aquifer described in Butler et al. (2002); drawdown measured with small-diameter [0.01 m OD] pressure (gauge) transducers [Druck PDCR 35/D]; HTMLS1 and HTMLS2 are multilevel sampling wells constructed with PVC multichannel tubing [Einarson and Cherry 2002] located 6.96 and 3.96 m from pumping well, respectively; ports 2 and 3 are located near the center of the sand and gravel aquifer; transducers thermally equilibrated with the ground water prior to commencement of pumping; differences in the magnitude of drawdown between figures are due to nearby pumping activity.)

In all cases, the fluctuations were observed during hydraulic tests performed in direct sunlight in summer temperatures (> 30°C) in the midcontinent of the United States. Thus, one plausible explanation for the fluctuations would be heating and cooling of the air column in the vent tube caused by variations in the exposure to solar radiation (insolation). Under this hypothesis, the air column would expand with an increase in direct sunlight, producing an increase in pressure in the chamber on the backside of the pressure-sensitive diaphragm. This increased chamber pressure would lead to an apparent decrease in water pressure as measured by the transducer. Similarly, if a cloud passed in front of the sun, the air column in the vent tube would contract, leading to an apparent increase in water pressure as measured by the transducer. In either case, the apparent change in water pressure should be short-lived because of air moving into/out of the small-diameter vent tube to dissipate the thermal-induced change in air pressure.

The pumping test of Figure 1a was performed in a configuration in which the transducer cable ran on the land surface for several meters under direct sunlight. Given the potential for insolation-induced fluctuations in that configuration, the test was repeated under similar temperature and sunlight conditions with a tent covering the observation wells, and all of the cable on the land surface run inside white PVC pipe. The result, as shown in Figure 1b, was a drawdown record with little, if any, of the anomalous noise of Figure 1a. Butler et al. (1999) report similar results using a styrofoam box to cover the observation wells and airline. Decreases in apparent insolation-induced fluctuations were also obtained during slug tests by placing white PVC pipe on top of the transducer cables (Kansas Geological Survey unpublished data).

The decreased noise in the transducer readings indicated that the anomalous fluctuations were likely a product of insolation-induced heating and cooling of the air column in the vent tube. Further work, however, was needed to confirm that hypothesis and to assess the impact of variations in solar radiation on transducer measurements. The purpose of this paper is to describe a controlled experiment performed with that objective. The results of this experiment were also used to develop recommendations for minimizing the magnitude of insolation-induced fluctuations in transducer readings.

Experimental Setup

A bucket with ~0.3 m of water was placed in an air-conditioned building away from direct sunlight. Two pairs of transducers were placed at approximately the same depth in the bucket. One pair—In-Situ (Fort Collins, Colorado) PXD-261 20 psi gauge (psig) pressure sensors (henceforth referred to as the yellow transducers in this paper)—had yellow cable. The second pair—Druck (New Fairfield, Connecticut) PDCR 35/D 15 psig sensors (henceforth called the black transducers)—had black cable. Pertinent specifications for these transducers and their cables are summarized in Table 1. Two of the transducers (one yellow and one black) served as control sensors, so their cables were kept indoors and out of direct sunlight. A portion of

Table 1
Transducer and Cable Specifications

Transducer	Pressure Head Range (m)	Pressure Head Accuracy (m)	Cable Length (m)	Cable Color	Cable O.D. (m)	Vent Tube I.D. (m)
PXD-261	14.06	± 0.007	122	Yellow	0.0064	0.0015
PDCR 35/D	10.55	± 0.01	23	Black	0.0057	0.0006

the cables (~17 to 18 m) for the other two transducers were run outside onto a cement loading dock and coiled on a gray metal cart that was exposed to direct sunlight. The remainder of the cable for these two transducers was coiled indoors, away from direct sunlight. All transducers were connected to the same data logger, a Campbell Scientific (Logan, Utah) 23X with an acquisition rate of 1 Hz.

A temperature probe—an In-Situ MP Troll 9000, accuracy ± 0.1°C, acquisition rate of 0.2 Hz (henceforth called the probe)—was placed on the same metal cart on the loading dock as the coiled transducer cables. The probe was exposed to direct sunlight to account for the temperature changes that the cables would experience as a result of variations in solar radiation. Although the steel-gray color of the probe undoubtedly resulted in a different temperature than that experienced by either the yellow or black cable, the measured fluctuations in temperature were assumed to be a reasonable representation of those occurring on the surface of the transducer cables.

Results

This experimental setup was used to monitor water pressure and temperature between 9:46 A.M. and 2:32 P.M. on August 8, 2002. The height of the water in the bucket did not change over this period; it was expected that the transducer data would plot as a horizontal line after a short period of thermal equilibration. Note that manufacturers recommend that transducers be allowed to thermally equilibrate with the water for at least 30 min.

Figures 2a and 2b display probe temperature and the pressure head records for the black and yellow transducers, respectively. In both cases, the transducer for which the cable was kept out of direct sunlight displayed a small amount of fluctuations (< 0.003 m). However, the transducer that had a portion of its cable in direct sunlight displayed fluctuations that were significantly larger in magnitude. As shown in the expanded view in Figure 3, the records from the black and yellow transducers in direct sunlight were similar in form, but differed in the magnitude of extreme values. The transducer with the black cable had a maximum fluctuation of 0.030 m, while the transducer with the yellow cable had a maximum fluctuation of 0.017 m.

The differences between the pressure records in Figure 3 were undoubtedly produced by differences in cable color and length, and the ID of the vent tube. Although the equipment available for the experiment prevented the influence of each of these factors from being independently assessed, some general statements about their role can be made.

1. A light-colored cable will reflect more solar radiation than a dark-colored cable. Thus, the magnitude of insolation-induced fluctuations should be smaller when a light-colored cable is used.
2. The larger the ID of the vent tube, the less the resistance to airflow in the vent tube. Thus, the magnitude and duration of insolation-induced fluctuations should be smaller when a cable with a large vent tube is used.
3. The longer the cable, the more resistance to airflow in the vent tube there is and, often, the larger the magnitude and duration of insolation-induced fluctuations. However, this is not always the case because the impact of cable length depends on the position of the exposed portion of the cable relative to its two ends.

The differences in Figure 3 are consistent with the first two statements, as the lighter-colored cable with the larger vent tube ID does have diminished insolation-induced fluctuations. However, the role of cable length cannot be ascertained from this experiment. Note that the experimental setup used here represents the case of a relatively high degree of exposure to sunlight. Somewhat smaller insolation-induced fluctuations would be expected under less-exposed conditions (Figure 1a).

The relationship between the surface temperature of the probe and the apparent head pressure recorded by the black transducer is depicted in Figure 4a. As shown in the figure, the extremes in temperature are offset from the extremes in pressure head. One would expect that there would be a lag between temperature and pressure extremes because of the time needed for the movement of heat to the vent tube in the cable interior. The arbitrary addition of 140 s to the temperature record to account for that lag produced a clear inverse relationship between probe temperature and apparent pressure head (Figure 4b). As explained in the introduction, such an inverse relationship would be expected because of the pressures that are exerted on the backside of the diaphragm by the thermal-induced expansion and contraction of the air column.

Conclusions and Recommended Field Procedures

The results of this controlled experiment indicate that the anomalous pressure fluctuations observed during hydraulic tests performed in direct sunlight in summer temperatures are primarily a product of insolation-induced heating and cooling of the vent tube in the transducer cable. The magnitude of these fluctuations may exceed 0.03 m in conditions with a high degree of exposure to sunlight. Fluctuations of this magnitude can introduce considerable uncertainty into hydraulic tests when the head change is relatively small. In those cases, efforts must be made to minimize the impact of insolation-induced fluctuations. The

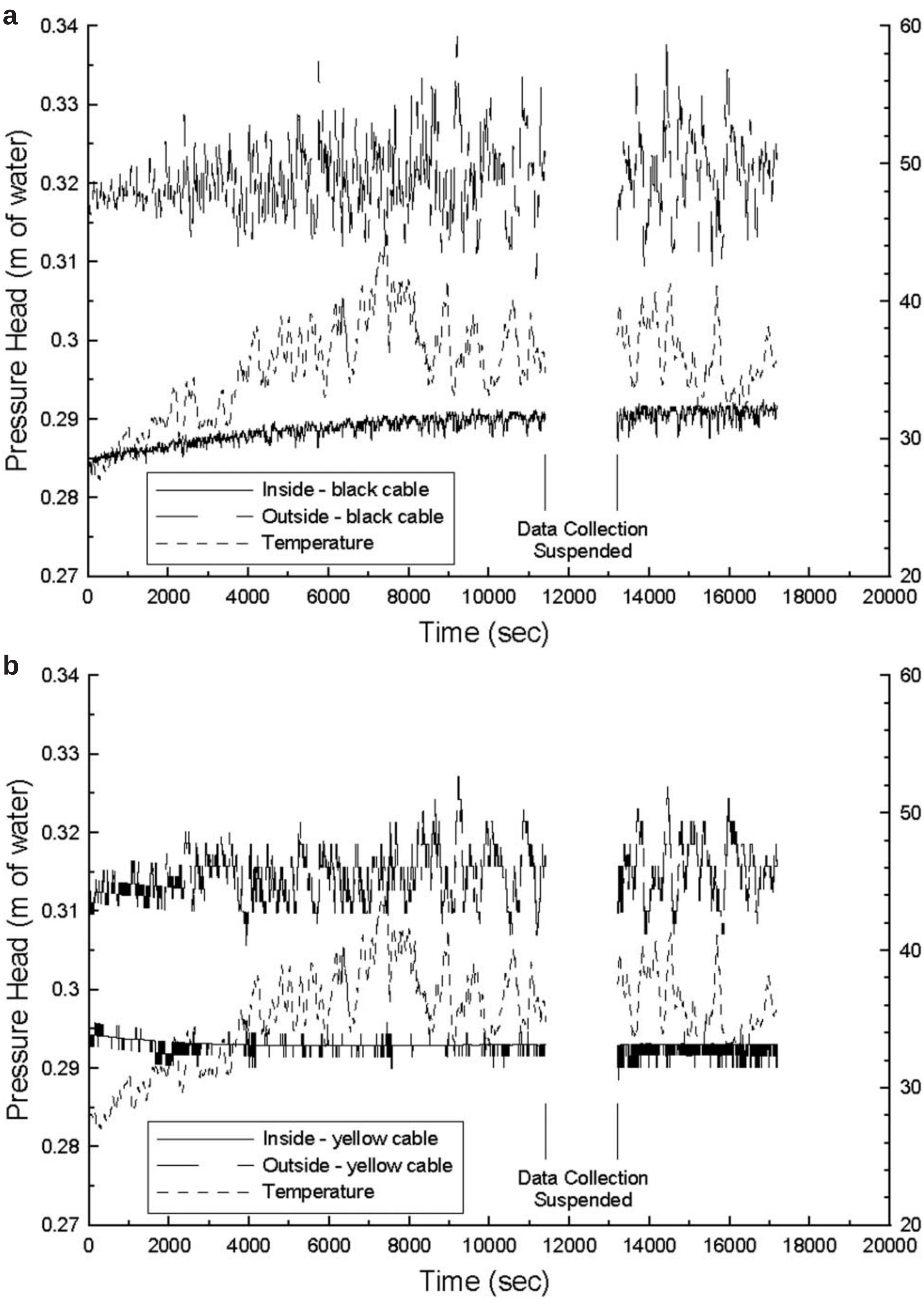

Figure 2. Plots of pressure head and temperature vs. time since the start of data collection (data collection suspended for period shown due to filling of logger memory). (a) Pair of transducers with black cable (vertical position of plot for transducer with the inside cable lowered 0.031 m for clarity; trend in transducer with inside cable is unrelated to changes in water level and may be caused by an extended period of thermal equilibration). (b) Pair of transducers with yellow cable (vertical position of plot for transducer with outside cable raised 0.006 m for clarity; small drop in first 2000 s of record for transducer with inside cable is likely caused by thermal equilibration).

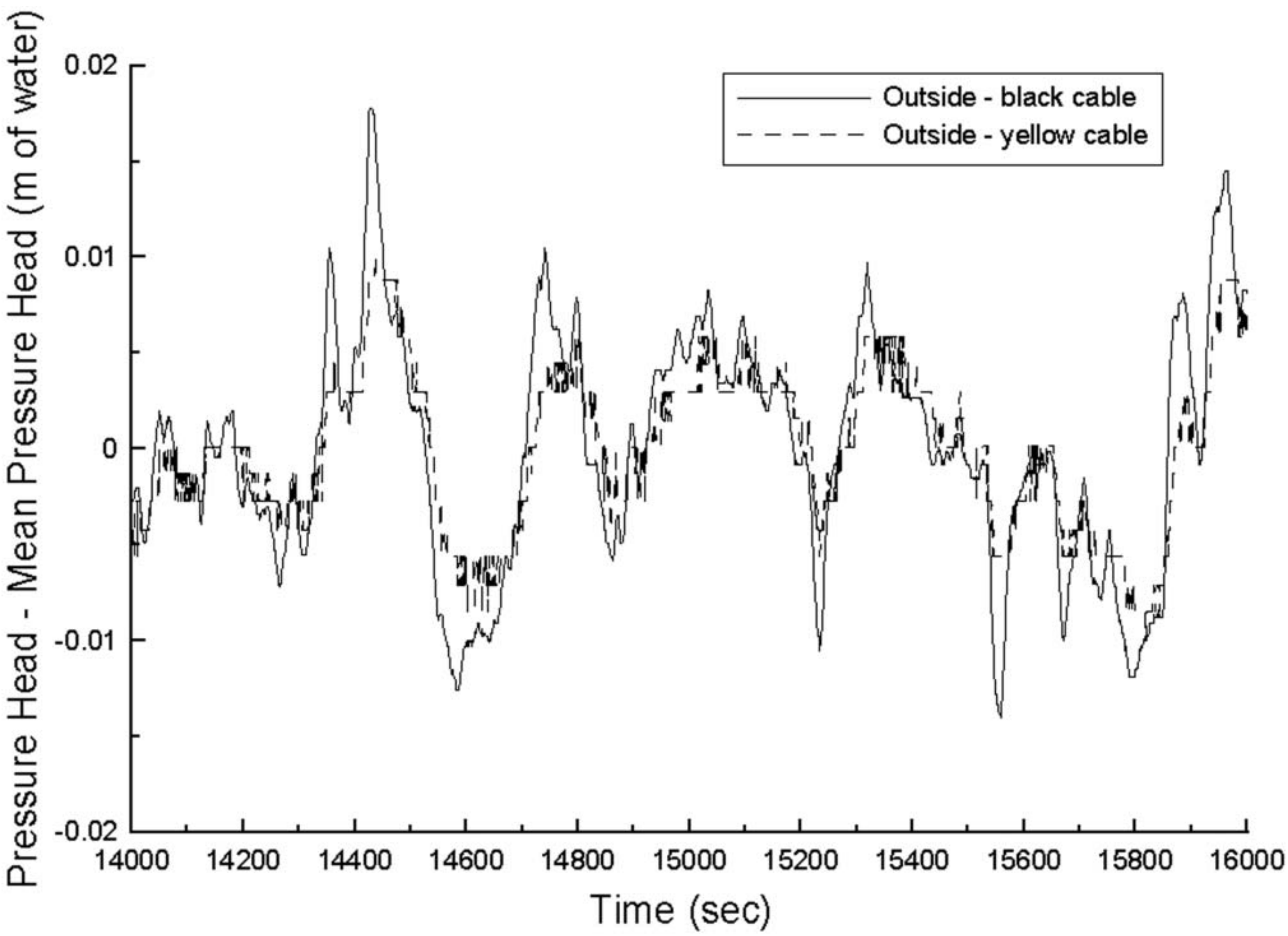

Figure 3. Plot of pressure head minus mean pressure head vs. time for a portion of the latter half of the monitoring record of Figure 2 (mean pressure head for this period was 0.322 and 0.310 m for black and yellow transducers, respectively).

following three field procedures are recommended as a result of this work.

First, the most effective means of minimizing insolation-induced noise is to avoid having any vented cable running on the land surface. This can be accomplished using in-well equipment and/or absolute pressure sensors. Several manufacturers now offer integrated transducer-data logger units that fit inside a well. In our experience, pressure head records from these units are devoid of insolation-induced fluctuations. Similar results can be obtained using a conventional absolute pressure sensor with an unvented cable. An absolute pressure sensor does require a second sensor measuring atmospheric pressure, which increases the cost and the uncertainty of the pressure head measurements. The additional cost per well, however, is relatively small if several observation wells are being monitored.

Second, if vented cable must be run on the land surface, the length of that cable in direct sunlight should be

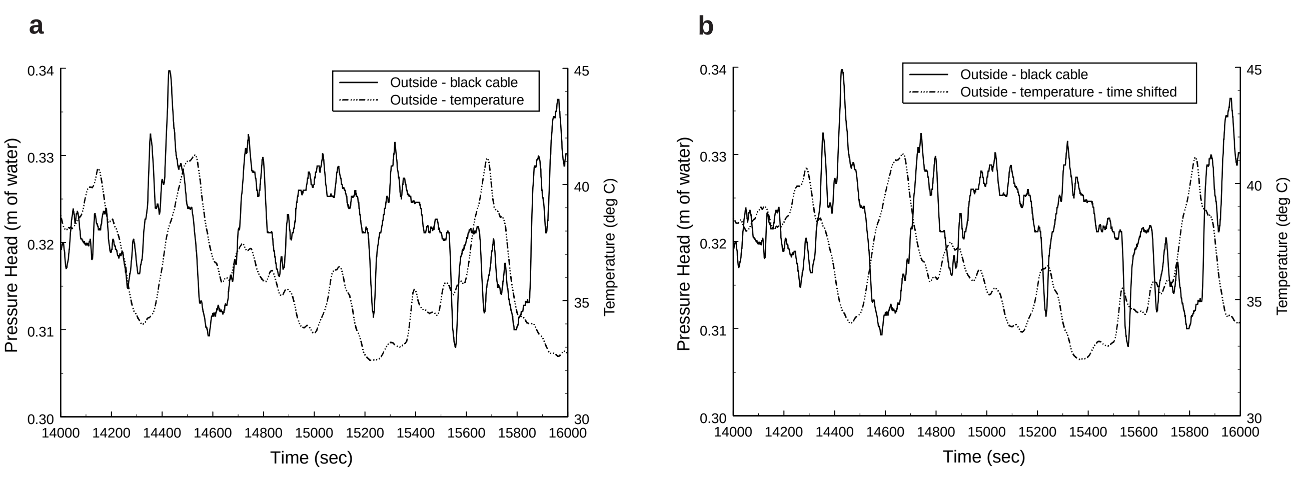

Figure 4. (a) Plot of pressure head and temperature vs. time for a portion of the latter half of the monitoring record of Figure 2. (b) Pressure head and temperature plot in which the times for the temperature readings have been shifted by adding 140 s to the times of Figure 4a.

kept as small as possible. Inexpensive small dome tents can be erected over the observation wells, and cables can be run inside or under white PVC pipe. Alternatively, the cables can be buried a few centimeters below land surface.

Third, if running a certain length of vented cable in direct sunlight cannot be avoided, a light-colored cable with a relatively large vent tube should be used. As shown in the experiment reported here, this approach will reduce, but not eliminate, the impact of variations in solar radiation on readings from gauge pressure transducers.

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