Introduction by John Dunnicliff, Editor

This is the 81st episode of GIN.

The importance of Step 2 in the Systematic Approach to Planning Monitoring Programs

Those of you who are familiar with my frequent sermons on planning (e.g. red book Chapter 4) will be aware of my Step 2: "Predict Mechanisms that Control Behavior".

The article by Francesca Bozzano elaborates on and extends the importance of this by showing, with two case history examples, that:

> "A general inverse relationship exists between the level of understanding about the ongoing geological/geotechnical process and the complexity (and cost) of an efficient monitoring system. Said another way – the more we understand the process, the less is the complexity and cost of the monitoring system."

A very important message – we should do intensive homework at the beginning of the planning process!

More on fully-grouted piezometers

The article by D'Hollander et al adds to our confidence level for using the fully-grouted method. Site specific solutions were developed to address the challenges of installing the piezometers in a flowing stream with continuous readings obtained in all weather and stream conditions.

Having published several articles in GIN on this subject during the past 13 years (see the next section), I'll now go on hold, and encourage you to transfer your attention to interacting with Gord McKenna, as in the next section.

Fully-grouted piezometers. We need your stories and insights.

Fully-grouted piezometers appeared briefly on the stage in 1969 with Peter Vaughan's paper in Geotechnique, but didn't gain traction until much later. Since then, the method of installing diaphragm-type piezometer tips by simply grouting them in (with no sand pack) seems to have gained fairly widespread popularity. The technique has been supported by the following key publications:

- McKenna, G.T., 1995, "Grouted-in installation of piezometers in boreholes". Canadian Geotechnical Journal, Volume 32, pp.355-363.
- Mikkelsen, P.E., 2002, "Cement-bentonite grout backfill for borehole installations". Geotechnical News, December.
- Contreras, I.A., Grosser, A.T., Ver Strate, R.H., 2008, "The use of the fully-grouted method for piezometer installation". Geotechnical News, June.
- Durham Geo Slope Indicator (DGSI), 2009. "Grout Mixes for Piezometers". http://www.slopeindicator.com/support/piezometers/technote-groutmix-piezometers.php
- Contreras, I.A., Grosser, A.T., Ver-Strate, R.H., 2012, "Update of the fully-grouted method for piezometer installation". Geotechnical News, June.

and again in this episode of GIN (D'Hollander et al), but with a few warnings. Some practitioners enjoy the ease and speed of installation of fully-grouted piezometers while others choose conventional techniques every time.

You now have a chance to share war stories on how the method has been working for YOU: your successes and failures. There's major evidence of success in some parts of the world (for example, in the West Coast of USA, where it has become accepted practice) but concerns remain. There is field evidence of poor sealing, e.g.

- For those who have poor cement-bentonite grout mixes, who add bentonite to the water first instead of cement, or who use a pre-determined quantity of bentonite rather than adding enough to achieve a consistency of thick cream or pancake batter (details of how to do this are in Mikkelsen (2002).
- The few who forget to add the bentonite.

<u>So, please send us your fully-grouted piezometer stories:</u>

- Your anecdotes, improvements, failures, fears and insights.
- Vaughan made calculations to show that the grout could be 2 orders of magnitude **more** permeable than the formation for a good seal. Contreras et al (2008) did numerical analysis to prove that the grout could indeed be 3 orders of magnitude **more** permeable to seal effectively. Do you accept this latter recommendation and use it in your practice? Or do you favor different permeability criteria?
- Are you using this method? If yes, why? If not, why not?
- Do you place the filter up or down? Proponents of "up" claim that this prevents de-saturation during installation.
- Do you surround the tip with a tiny sand sock? Proponents claim that this prevents grout from plugging the filter.
- Are we ready to declare the fully-grouted method as mainstream?
- And if so, subject to what provisions?

Gord McKenna of BGC Engineering Inc., Vancouver has volunteered to assemble your contributions for a future GIN. Please drop him a line as soon as possible by e-mail (GMcKenna@bgcengineering.ca), cc to me (john@dunnicliff.eclipse.co.uk), and let him know if you have anything to contribute. If yes, please follow that up with **brief and crisp** information by **June 30, 2015**. If there is enough information, perhaps a journal article afterwards.

Second International Course on Geotechnical and Structural Monitoring in Italy, June 4-6, 2015

Tenth century Poppi Castle.

We've now confirmed that the course will be held at the same location as last time – in Poppi castle. Poppi is considered one of the most beautiful towns in Tuscany with the spectacular tenth-century castle of the Guidi Counts situated on the hilltop that dominates the surrounding countryside. There will be a much larger exhibition area than last time.

Details are on *www.geotechnicalmonitoring.com*, together with the course schedule and registration information. The list of 14 speakers includes **John Burland** of Imperial College London, **Michele Jamiolkowski** of Technical University of Turin (both of whom were leaders on the International Committee for the Safeguard of the Leaning Tower of Pisa), and **Elmo DiBiagio** of Norwegian Geotechnical Institute.

Several pre- and post-course leisure activities are being planned, and during the course various activities will also be available for accompanying persons. See www.geotechnicalmonitoring.com/en/leisure for details.

Corporate updates

Several manufacturers of geotechnical instruments are now owned by Nova Metrix LLC, Woburn, MA (www.nova-metrix.com). These include Durham Geo Slope Indicator (USA, www.slopeindicator.com), Roctest (Canada, www.roctest.com), Telemac (France, www.telemac.fr), Interfels (Germany, www.interfels.com), Smartec (Switzerland, www.smartec.ch) and Soil Instruments (England, www.soil.co.uk).

Sherborne (England, www.sherbornesensors.com) manufactures sensors that are used in geotechnical and structural applications, is also owned by Nova Metrix.

Both Interfels and Soil Instruments had been part of itmsoil (England), which remains in business as ITM Monitoring Ltd (www.itmmonitoring.com) to provide monitoring services but not manufacturing. ITM Monitoring Ltd is owned by Rcapital, a private investment business in London (www.rcapital.co.uk).

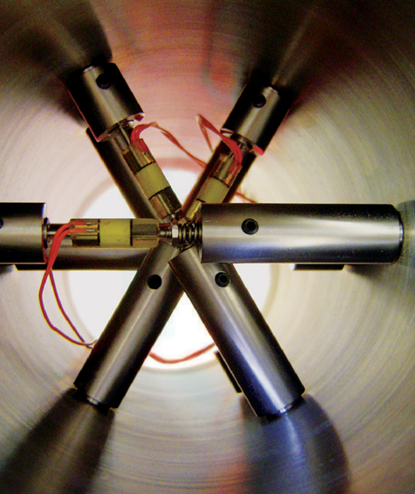
The USA arm of itmsoil is now Specto Technology (www.spectotechnology.com), an independent company providing hardware and software from a variety of manufacturers, with a focus on delivering wireless monitoring solutions.

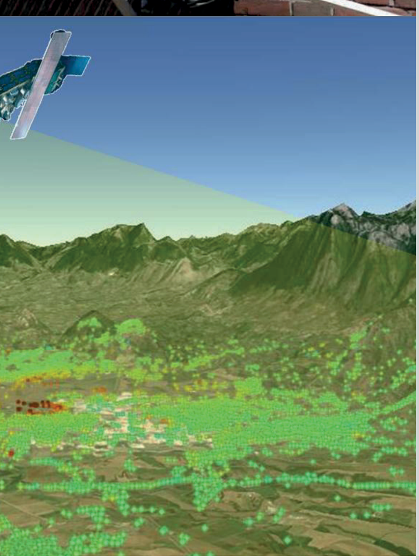
U.S. mid-market private equity firm Hammond Kennedy Whitney & Co, Indianapolis (www.hkwinc.com) has recently bought a majority interest in RST Instruments Ltd. (www.rstinstruments.com). RST management remain substantial shareholders.

Closure

Please send an abstract of an article for GIN to *john@dunnicliff.eclipse.co.uk* —see the guidelines on *www.geotechnicalnews.com/instrumentation_news.php*

Apki Lambi Umar Ke Liye! (Hindi)





SECOND INTERNATIONAL COURSE ON GEOTECHNICAL AND STRUCTURAL MONITORING

June 4-6, 2015 | Poppi, Tuscany (Italy)

Course Director: John Dunnicliff, Consulting Engineer
Organizer: Paolo Mazzanti, NHAZCA S.r.l.

THE COURSE: attendance at the course is a great opportunity **to establish a valuable network** with colleagues from all over the world, **to meet manufacturers** and **see the most recent and innovative instrumentation**, thanks to a large exhibition area.

COURSE EMPHASIS: is on **why and how to monitor field** performance. The course will include planning monitoring programs, hardware and and software, web-based and wireless monitoring, remote methods for monitoring deformation, vibration monitoring and offshore monitoring. Case histories presented by prominent international experts and discussion during the open forum will be an additional source of knowledge.

WHO: engineers, geologists and technicians who are involved with performance monitoring of geotechnical features of civil engineering, mining and oil and gas projects. Project managers and other decision-makers who are concerned with **management of RISK during construction**.

OBJECTIVE: to learn the who, why and how of successful geotechnical and structural monitoring while networking and sharing best practices with others in the geotechnical and structural monitoring community.

INSTRUCTION: provided by leaders of the geotechnical and structural monitoring community, representing users, manufacturers, designers and people from academia from all over the world.

LOCATION: the 3-day course will be held in Tuscany (Italy). In addition to providing an opportunity to increase your own expertise about geotechnical and structural monitoring, attendance at the course will give you a beautiful cultural, historical and taste experience in one of the most attractive places in the world.

As **John Gadsby** (publisher of this magazine) wrote in the September 2014 issue, "*The 2014 edition of this course was a great success. Anyone in the monitoring community should add this course to his/her list of 'to dos'*"

Course Partners: Marmota Engineering, Geokon, Measurand, RST Instruments, Geosense, Canary Systems, Soldata, Mine Design Technologies, Sylex, CSG, Shanghai Zhichuan Electronic Tech, Ace Instrument, 3d Laser Mapping, Smartec, Vista Data Vision, Gkm Consultants, Worldsensing, IDS Ingegneria dei Sistemi, Trimble navigation, Sisgeo.

WWW.GEOTECHNICALMONITORING.COM

Lesson learned from two case histories about the planning of integrated monitoring systems

Francesca Bozzano

The primary lesson

During the past eight years as an engineering geologist on a research team studying geological risks, I have made use of integrated systems to monitor and manage ongoing instability processes. These have included landslides and ground subsidence. In our monitoring systems, contact instruments and remote techniques have been used for monitoring.

This article presents the primary lesson learned from two case histories: that a general inverse relationship exists between the level of understanding about the ongoing geological/geotechnical process and the complexity (and cost) of an efficient monitoring system. Said another way – the more we understand the process, the less is the complexity and cost of the monitoring system. In Figure 1, our understanding of ongoing process is shown at the left, in which the scale indicates low-level (L), medium-level (M) and high-level (H) of understanding. The complexity (and cost) of the corresponding planned monitoring system is shown at the right.

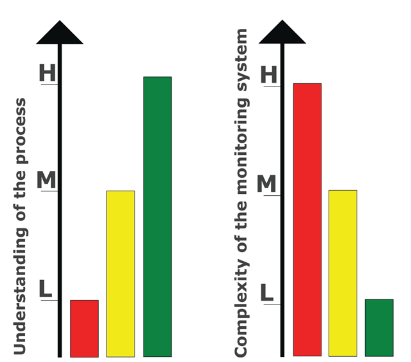


Figure 1. Sketch of the relationships between the level of understanding for an ongoing process and the complexity (and cost) of the monitoring system.

The red bars represent case histories characterised by an *a priori* low-level understanding, for which a highly complex and integrated monitoring system must be planned and executed to close the information gap. The green bars represent case histories characterised by an *a priori* high-level understanding, for which a simple and integrated monitoring system can perform well.

Based on the lesson summarised in Figure 1, efforts should be placed on acquiring and organising qualitative and quantitative information about a specific process in firm reconstructions using an approach that is largely used in engineering geology. This approach, which is known as the geological model, is a very good planning tool for efficient monitoring systems.

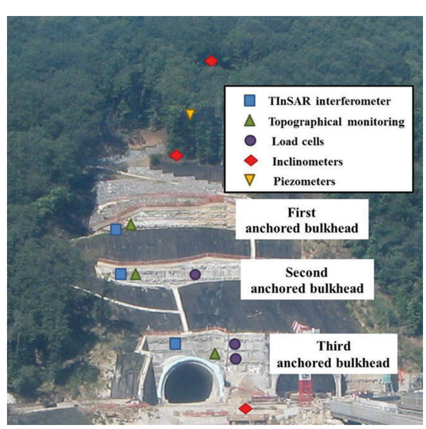


Figure 2. Photograph of the slope, which shows the three anchored bulkheads and the location of the monitoring instrumentation. The symbols for TInSAR monitoring and topographical monitoring indicate that they specifically observe the bulkheads.

In the next section, two opposite case histories are described: the first case history is representative of a low-level *a priori* understanding of an ongoing process; the second case history is representative of a high-level *a priori* understanding of an ongoing process.

Case history 1

The first case concerns an unstable slope that delayed the construction of tunnels along a highway in southern Italy. In February 2007, the tunnel entrances were destroyed by an unexpected translational landslide when the length of the excavated tunnel was approximately 12m. The volume of the landslide was approximately 10,000m^3, which included metamorphic rock debris from the adjacent steep slope. At that time, the tunnel alignment could not be changed and stabilisation of the landslide was imperative.

Geological and geomorphological surveys enabled us to discover that the landslide was embedded in an older and larger and deeper quiescent/inactive rotational landslide with a volume of approximately 1,000,000m^3. The 2007 shallow landslide was located at the toe of the older and larger landslide, and was triggered by the tunnel excavation.

In the following months, three bulkheads (Figure 2) anchored using 30m long tiebacks were placed along the slope to stabilise the shallow part of it. An integrated monitoring system was planned by considering uncertainties in the volume of the ongoing instability process, i.e., small instabilities in the shallow section of a quiescent

Figure 3. Photograph of the valley in which the landslide occurred. The slope involved in the instability (right); the location of the terrestrial interferometer (left). A sketch of the area covered by the TInSAR monitoring is superimposed.

large landslide body or its deep remobilisation? What is the range of the expected displacement velocity? The object to be monitored was not clearly defined, and the monitoring system was multi-purpose and complex.

The monitoring system consisted of:

- Probe inclinometers, for which readings were collected either every week or fifteen days.
- Observation wells and open standpipe piezometers, for which readings were collected every week or fifteen days.
- Electrical resistance load cells installed at the head of some of the tiebacks.
- Topographical monitoring of the three bulkheads by a total station (Figure 2).
- In addition, the slope was monitored by a terrestrial interferometer (TInSAR) located in front of the landslide slope on the opposite side of the valley at a distance of approximately 900m (Figure 3). Interferometric images were acquired every five minutes.
- Hourly rainfall data and daily photographs were also recorded.

TInSAR monitoring was performed by our research team, whereas other companies were responsible for the remaining instrumentation. Our task was to collect all available data and assist with managing the ongoing stabilisation projects and tunnel excavation.

During the six-year monitoring period, many secondary instability events were recorded, such as the occurrence of shallow and small landslides in different sections of the slope, the movement of excavation debris along the slope (triggered by rainfall), the failure of a metallic wall on short piles (installed to protect the downslope trail from excavation debris), and the gravitational settling of gabions located in the upper portion of the slope.

The main recorded event was the reactivation of the larger landslide from late 2009 to early 2010, when the tunnel excavation restarted after completing the remedial projects. All instrumentation recorded the crisis (red rectangle in Figure 4) triggered by the excavation. However, only by the continuous monitoring using terrestrial interferometry the tunnel projects was stopped when a displacement velocity of approximately 1 mm per hour was determined for the first anchored bulkhead.

This complex, redundant and expensive integrated monitoring platform, which was planned due to uncertainties experienced by the *a priori* geological model, performed well, which is indicated by the red bars in Figure 1.

If a well-constrained and calibrated numerical stress-strain model of the slope had been done in order to simulate the effects of the excavation of the tunnel on the stability of the quiescent large landslide, attention would have been concentrated on it. In that case the monitoring would have consisted mainly of continuously recording in-place inclinometers.

Case history 2

This case concerns another category of geological risks: subsidence. The involved area (30 km^2) is located in central Italy, about 30km east of downtown Rome. This area has become intensively urbanised over the decades. In certain small sections, subsidence has caused extensive damage to buildings and infrastuctures. A large quarry basin containing travertine (a sedimentary rock, formed by the precipitation of carbonate minerals from solution in ground and surface waters, and/or geothermally heated hot-springs. It is used as building material) is located within this area;

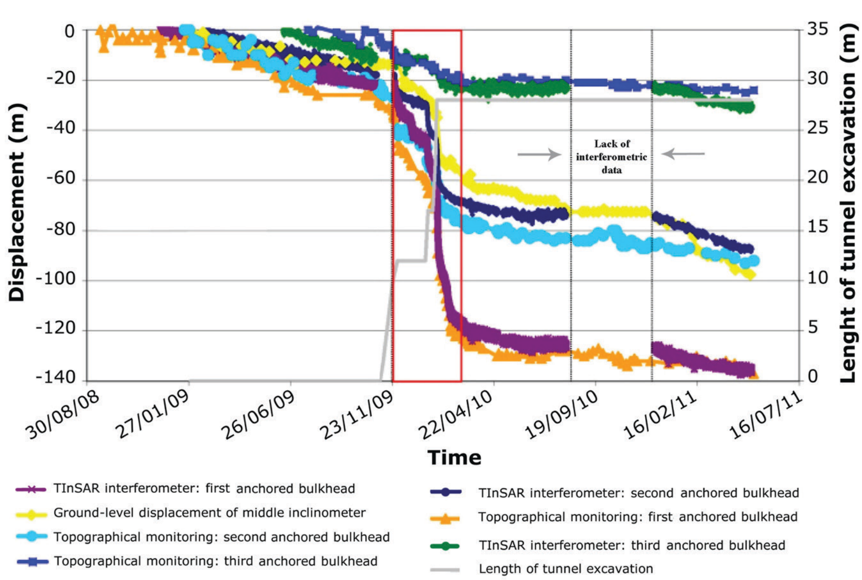


Figure 4. Displacement (left y-axis) and the tunnel excavation length (right y-axis) vs. time monitored using different techniques.

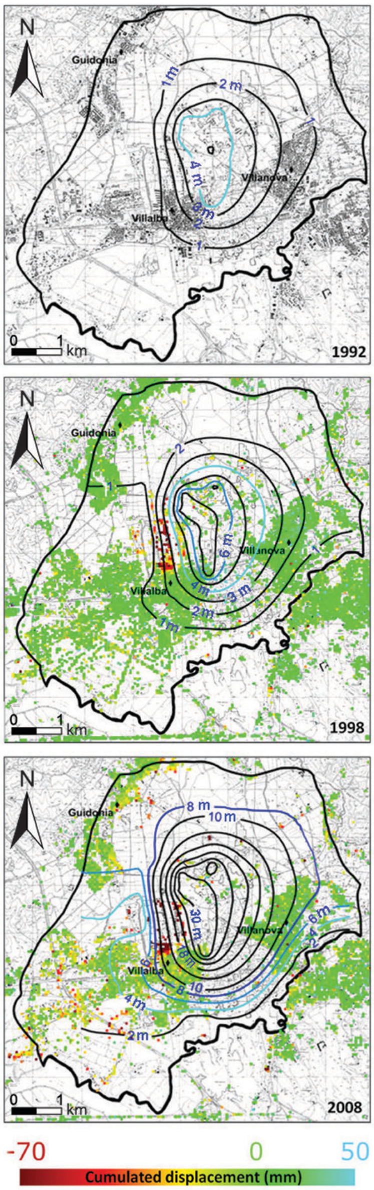


Figure 5. Groundwater depression cone in 1992, 1998 and 2008 reconstructed using a numerical model calibrated on a large piezometric dataset. The black lines represent iso-lowering lines with respect to the groundwater level in 1954. The estimated total displacement (coloured symbols) since 1992 based on the A-DInSAR technique is superimposed on the 1998 and 2008 maps.

the volume of extracted travertine has substantially increased over the last thirty years. The travertine hosts an aquifer; therefore, the consequent mining of travertine includes groundwater drainage. In 2008, the flow rate of this drainage system was approximately $4m^3$/sec.

In certain parts of the area travertine is outcropping, whereas highly compressible soils (fine-grained deposits with organic matter and soil-travertine mixed deposits) overlay travertine in other areas. The thickness of the compressible deposits range between tens of centimetres to tens of metres. These deposits are hydraulically connected to the travertine-hosted aquifer.

In designing a distributed monitoring system to monitor the evolution of subsidence in this region, we first attempted to develop a comprehensive understanding of the ongoing geological/geotechnical process. A large database of existing geological, geotechnical and hydrogeological information was created. The temporal evolution of the ground displacement from 1992 to 2010 was determined using SAR satellite images (ERS and ENVISAT satellites provided by the ESA (European Space Agency)) with the advanced-differential interferometric synthetic aperture radar (A-DInSAR) technique. A hydrogeological model that was calibrated and validated using long-term piezometric data was utilised to reproduce the groundwater drawdown in the studied area.

All collected information was processed and combined (see Figures 5 and 6). Groundwater drawdown was the primary cause of the recorded subsidence, in which the thicknesses of the compressible deposits primarily controlled the extent of subsidence. Throughout the investigated area, the onset of subsidence was strictly related to the groundwater cone depression, whereas the amount of ground displacement was related to the thicknesses of the compressible deposits (Figure 6).

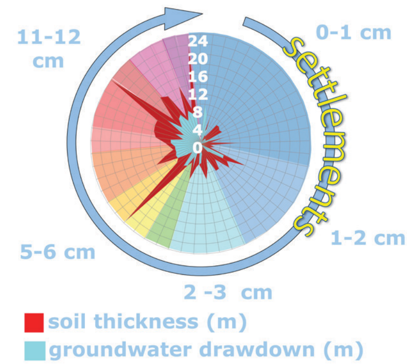


Figure 6. Plot showing the interpretation of the subsidence process. 97 small areas ($50m^2$) are selected as geologically representative. Each one is represented by a circular sector in the graph and ordered clockwise with respect to the settlement measured from 1992 to 2008. The over layered red and blue rose diagrams (the labels in m are along the NS radius) respectively indicate the thickness and ground water lowering for each areal parcel. In this plot it is possible to directly compare the intensity of the predisposing (thickness) and triggering (water lowering) factors with the induced effect (settlement).

Additional useful information was obtained from a monitoring test that spanned one year and was performed in a representative area. For this purpose, an open standpipe piezometer monitored the groundwater in the travertine, a multipoint electrical resistance piezometer recorded pore water pressure in the overlaying compressible deposits and in the travertine and a borehole equipped with a probe magnetic extensometer was used to monitor settlements. A significant relationship was inferred from the collected data, i.e., subsidence occurs when the groundwater level decreases, whereas uplift occurs when the groundwater level increases. A negligible time-delay between the decreased groundwater level and subsidence was observed.

All information provided here constitutes a robust geological model of the area and the ongoing subsidence. To control the evolution of subsidence where vulnerable buildings or lifelines are in the vicinity of susceptible soils, monitoring the subsoil pore water pressure is sufficient (green bars in Figure 1).

Francesca Bozzano
CERI Research Center and Department of Earth Sciences - Sapienza University of Rome, Piazzale Aldo Moro 5, 00185, Rome, Italy.
Tel. +39-6-49914924
email: francesca.bozzano@uniroma1.it

The use of fully-grouted piezometers in a streambed

Raymond D'Hollander, Paul Roth, Shane Blauvelt, James O'Loughlin

The site is a stream located in the northeastern United States with contaminated sediments in the channel bed. Data regarding both vertical hydraulic gradients and absolute piezometric pressures were required during remedial design to evaluate stability of the bed and banks for an excavation scenario and for use in modeling a potential chemical isolation cap.

Selection of fully-grouted method of piezometer installation

Available data during the pre-design planning indicated that the stream water surface and adjacent groundwater elevations are variable with a typical annual range of about 1 m. The groundwater data indicated the potential for significant upward gradients and for some of the groundwater to be saline. The water depth above the proposed piezometer locations was typically about 1 to 3 m. Shearing by ice, debris, and high flows as well as the potential for artesian groundwater made an open standpipe piezometer impracticable for measurements performed over an extended period.

Vibrating wire piezometers with on-shore data acquisition systems were selected for measuring the groundwater pressures in the streambed. It was desirable to position the top piezometer in the creek at about the expected post-remediation sediment surface to evaluate the piezometric pressure and gradient likely at that point. This position ranged from 0.6 m to 1.8 m below the sediment surface. The shallow depth of these piezometer raised concerns with the effectiveness of conventional bentonite seals, particularly given the potential for erosion in the stream bed. Also, access to the locations was difficult and the ability to install the two piezometers quickly in the same borehole was desirable. Based on these considerations, the fully-grouted method was selected for installing the piezometers in the creek, as described in McKenna (1995) and Contreras et al. (2008).

Stream cross-section instrumentation

Instrumentation cross-sections were installed at six locations along the stream. Each instrumentation cross-section included two vibrating wire piezometers in the channel, a stilling well, and two open standpipe piezometers installed at the top of the bank, as shown on Figure 1. The fully-grouted piezometers in the channel were installed in vertical pairs with the bottom piezometer approximately 2.1 m to 3.3 m below the top piezometer. The on-shore standpipe piezometers were installed so that the top piezometer was located near the groundwater surface and the deeper piezometer at about the elevation of the bottom piezometer in the channel pair. Due to the potential for saline groundwater, bentonite seals for the standpipe piezometers were installed using bentonite pre-hydrated with fresh water and then tremied into the borehole.

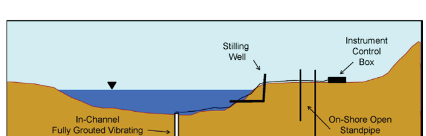


Figure 1. Typical instrumentation cross-section.

Fully-grouted piezometer installation

Drilling

The fully-grouted piezometers were installed in the center of the channel using a CME 45C drill rig on a segmented barge, as shown in Figure 2. The barge was disassembled and reassembled between some of the cross-sections due to the presence of low bridges. The borings were advanced using mud rotary and casing.

Piezometer and tremie pipe assembly

Unvented vibrating wire piezometers with a range of 0.2 MPa were used. They were taped to the Schedule 40, 19-mm diameter PVC threaded pipe used to tremie the grout, as shown in Figure 3. Depending on the water depth, the top pipe length was 1.5 m or 3 m to allow for a convenient stick up out of the water for grouting; this top length was unscrewed after grouting so that the finished top of the pipe was below the sediment surface. The total pipe length was measured to fit the finished depth of the borehole, so that the pipe would rest on the borehole

Figure 2. Drill rig on barge.

bottom to prevent vertical movement of the piezometers before the grout set. The top of the tremie pipe was surveyed after grouting to provide an accurate location and elevation.

Grouting

Portland cement, water, and sodium bentonite powder were blended with a cement to water ratio by weight of 1:2.5, per DGSI (2009). The cement and water were mixed first, with bentonite blended in afterwards as required to achieve a consistency suitable for tremie pumping. A hose was connected to the tremie pipe and the grout pumped in as the drill casing was slowly removed.

Figure 3. Installation of vibrating wire piezometer and tremie pipe.

Cabling and data collection

The cables from the vibrating wire piezometers were threaded through galvanized steel pipes for protection and weight and then laid on the channel bottom to the bank as shown in Figure 4. A data acquisition system was installed in a steel job box as shown in Figure 5. The job box was weighted with concrete blocks and padlocked to discourage theft. The data acquisition system was programmed to take readings at 15-minute intervals to provide adequate data during storm events, which typically cause the creek elevation to peak in 3 to 6 hours. The stilling wells and on-shore standpipe piezometers were monitored using vented water level loggers, also programmed to collect readings every 15 minutes.

Evaluation of in situ hydraulic conductivity

The on-shore open standpipe piezometers in each cross-section were tested using falling and rising head tests. These tests showed that the soils around these piezometers have hydraulic conductivities that range from 3 x 10^{-5} cm/s to 2 x 10^{-2} cm/s, with most between 5x10^{-4} cm/s to 2x10^{-3} cm/s. Grain-size analyses of the materials obtained during the drilling of the in-stream piezometers indicated that the creek sediments in which the fully-grouted piezometers were bedded would also likely be in this range. Since we expected that the grout mix permeability would be about 1x10^{-6} cm/s, we determined that the fully-grouted piezometers should provide accurate readings with good response times. The research of Contreras et al (2102) confirms that this assumption was appropriate.

Figure 4. Stilling well and pipe protection of cables.

Data analysis

Barometric pressure measurements were obtained from a local meteorological station and used in the calculation of the piezometric pressures measured by the unvented vibrating wire piezometers. This permitted direct comparison of the piezometric data between the fully-grouted piezometers and the vented water level loggers in the standpipe piezometers and stilling wells. Contreras et al. (2012) provide a good discussion on the importance of incorporating barometric measurements into vibrating wire piezometer measurements.

Only one fully-grouted piezometer of the 12 installed showed anomalous results. A bottom piezometer had significantly higher piezometric pressures than the on-shore piezometer at about the same elevation, and it showed an upward hydraulic gradient greater than 1. The boring log for the vibrating wire piezometer installation indicated a 0.1 m layer of running sand, and water inflow was observed during drilling at the installed elevation. We were unable to determine if the anomalous readings were a real local phenomenon, or simply an instrumentation error. During design of the stream remedy, neither interpretation created a challenge so the issue could remain unresolved.

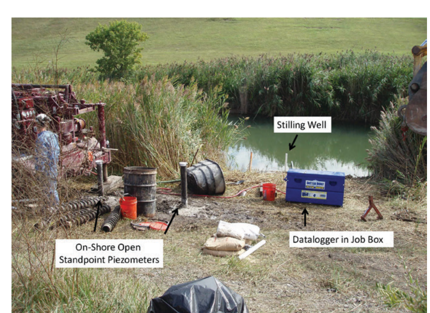


Figure 5. On-shore monitoring location and on-shore open standpipe piezometers.

Summary and conclusion

An accurate picture of the seasonal hydrogeologic interactions between stream sediments, stream water surface, and bank groundwater was developed using fully-grouted piezometers in conjunction with conventional on-shore standpipe piezometers and stilling wells. The fully-grouted piezometers provided valuable, reliable data at relatively low cost and installation time compared to traditional piezometer installation methods. The ability to do on-shore data acquisition of continuous readings allowed for inexpensive monitoring. Upward vertical gradients ranging from 0.05 to 0.6 were measured within the stream bottom, with one exception as discussed above. Site specific solutions were developed to address the specific challenges of installing the piezometers in a flowing stream with continuous readings obtained in all weather and stream conditions.

References

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Raymond D'Hollander, Paul Roth, Shane Blauvelt, James O'Loughlin

Parsons, 301 Plainfield Road, Suite 350, Syracuse, NY. E-mails: ray.dhollander@parsons.com; paul.roth@parsons.com; shane.blauvelt@parsons.com; james.oloughlin@parsons.com