Assuring the Performance of Subsurface Monitoring Systems for Long-Term Stewardship: Challenges

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Abstract: To date, the United States Department of Energy (DOE) has strived to understand the scope of long-term stewardship requirements. This abstract identifies several challenges and needed innovations to provide cost-effective long-term subsurface and surface monitoring as part of Hanford's, and potentially most, large-scale stewardship programs. These challenges range from the long-term storage of records, to demonstrating that the data produced are equally representative of the subsurface conditions and comparable over the long term. These challenges are significant, as DOE has identified greater than 100 candidate sites that may require subsurface monitoring for long-term stewardship. This enormous stewardship mortgage may be reducible through 1) cost-effective application of high-quality emplacement techniques for state-of-the-art monitoring systems and 2) the development of improved or completely new approaches for monitoring the subsurface environment. The consistent attainment of high-quality emplacements requires adequate capability and proper management of contract incentives. High-quality emplacement techniques will produce monitoring networks that will continue to function for 40 years or more. Low quality techniques result in well systems that deteriorate in as little as 5 years. In situ sensors may eventually displace much of the burden of conventional sampling.

Currently, and for the near future, the only reliable subsurface/groundwater plume monitoring and assessment technique is sample collection and analysis via wells and sensors. Currently, no geophysical technique can replace this approach. Long-term performance of well and/or monitoring systems relies on: 1) access to a zone of interest and 2) delivering representative samples for measurements. Well designs must anticipate the future behavior of the aquifer, as well as maintain chemical and physical stability. Well-based network vulnerabilities can be subdivided into various categories, such as changes in the groundwater level and/or flow; subsurface heterogeneities; biological, chemical or physical reactions between the well screen or filter pack and the aquifer; and catastrophic events. For example, over the last 20 years, water levels in different areas of Hanford have declined from 2 to 6 m, and are expected to decline another 2 to 4 m over the next 30 years. The site expects to lose or replace approximately 30 wells over several years. Furthermore, many upgradient/down-gradient relationships are expected to change. Given the expense of accommodating such changes, site-wide (large-scale) hydraulic management of the aquifer may become cost-effective.

Reactions between well or sensor materials and the subsurface include, but are not limited to, corrosion; chemical/electrochemical interactions between contaminants or sensors and well materials; stress on primary structure due to differential settlement; performance of brittle vs. non-brittle annular fill in stressed or seismic environments, or varying states of hydration due to

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changes in groundwater level; or volumetric changes in annular fill relative to host environments. While PVC casing seems to maintain reasonably good chemical stability, over time it gradually becomes brittle, weakens, and gradually breaks in stressed regions of the well bore. Carbon steel generates substantial iron oxy/hydroxides and experiences bacterial growth, both of which may affect contaminant concentrations in the well bore, particularly for low concentrations. Stainless steel offers improved corrosion resistance but raises initial short-term cost. Both carbon and stainless steel are subject to electrolytic reactions with soil and groundwater. Cathodic protection, while commonly utilized for pipelines, is not commonly used for well systems. The effects of cathodic currents on contaminants are not well understood. Fiberglass is claimed to bring chemical stability equal to, or better than and a cost and strength between PVC and stainless steel. The authors are not aware of any studies on the long-term stability of fiberglass-cased wells. At Hanford, 547 carbon steel wells were installed by 1959[6], most without annular seals. Today, all active monitoring wells on the site undergo five-year routine maintenance consisting of bailing, brushing/scraping, and final pumping/bailing or redeveloping. Failure modes include collapsed casing, reduced groundwater flow, high turbidity due to casing corrosion and infiltration, broken joints, and plugged perforations. To some degree, as wells age, they tend to become increasingly corrupted with material from non-target intervals.

Non-specialized annular seals or well grouts, for this writing, are classified as two general types: brittle grouts and plastic self-healing grouts. Portland cement and clay-based suspensions modified to set as a rigid non-healing mass are brittle grouts. Brittle grouts tend to fracture in response to stress. Cement provides strength and enhances corrosion resistance. Cements that expand via ettringite growth, fiber reinforced, in the authors' experience provide the best service, yet are rarely used. Rigid setting clay-based grouts, while more plastic than cement, are not self-healing. Un-modified bentonitic or other clay-based suspensions, result in a plastic semi-solid annular fill that may reseal after deformation. These materials, to a lesser extent, increase resistance to corrosion but add little strength. The long-term performance of both grouts is highly dependent upon emplacement technique, but emplacement usually is executed poorly.

Virtually all subsurface systems are vulnerable to catastrophic events. Collision with surface components of subsurface monitoring systems is common in active sties. Breakaway well heads avoid damage to the deeper portions of wells but are less secure than locked and concealed surface completions. Surface completions minimize damage from collisions. However, in the authors' experience, surface completions commonly leak surface waters into the well bore. Seismicity, while often discussed, is virtually never formally addressed. Note the following[7]:

> …on 28 February, 2001,…At approximately 1055, I was standing on the concrete pad at well site 01-PK-MW-03…when I felt a strong jolt. I realized it was an earthquake…The ground motion was so strong, I had to hold onto the steel well casing to keep my balance…I could…see wells MW-1 and 01-PK-MW-04 moving independently of each other and well 01-PK-MW-03 [like] pistons in an engine [approximately 50 feet between wells] …I also heard water sloshing in the well, and the bladder pump and tubing banging

[6] Brown, R.E. (1959) "Well Drilling Past Performance and Future Plans," Doc. No. HW-60284 (unclassified), Hanford Atomic Products Operation, General Electric Company, Richland WA.
[7] Quote from Joe Marsh (with Glen Terui), Seattle District, ACOE, with permission, author's inserts in brackets.

against the casing sidewalls. No damage to any of the wells was noted after the quake, and well casings and posts appeared plumb and at original elevation.

Surface monitoring must anticipate anthropogenic influences. Sites will require the correct combination of security and concealment from vandalism, while providing signage and ease of access and locating for inspection; maintenance and rehabilitation. The correct (or changing) balance of these requirements may be needed for periods of 100 years or more. New developments should include remotely monitored sensing; ecological sensors; confidential locating systems, break-away or concealed but locatable well heads; or long-term caps with sensors to measure performance. Administrative and legal systems must reliably maintain deed restrictions or other long-term administrative controls.

The cost of long-term stewardship is an incentive to develop new methods and install high-quality systems today to avoid cost or performance deficiencies in the future. Cost-effective monitoring using in situ sensors or automated sampling and analysis systems and remote transmission of data to a central management system hold promise to help minimize long-term labor and analytical costs. But such systems must also accommodate the vagaries of point source data and changes in the subsurface (e.g., large changes in contaminant concentration over the long term or changes in groundwater elevation or flow). Long-term performance will likely require a new generation of in situ sensors as well as data processing and transmission equipment. Detection limits, target constituents, instrument reliability, power requirements, maintenance intervals, and regulatory acceptance are all weaknesses in today's systems. Developers of in situ sensors have recognized the need for cost effective, reliable, low maintenance technology and continue to improve this technology. Their ultimate success is dependent on both a growing understanding gained from use of current instrumentation, as well as funding support for further research and development.

The long-term viability of monitoring systems also needs to be more aggressively addressed in environmental contracting practices, which today tend to minimize near-term costs. Furthermore, some contracting approaches hinder either the comprehensiveness of, or the removal of conflict of interest from, performance assessment. In the authors' experience, in environmental projects emphasis is ***never*** placed on long-term performance and full life-cycle costs. Yet most sites will require at least 10 years to over 50 years of monitoring and/or assessment. A system of conducting environmental work that aligns the regulatory community's needs with the contractor's performance clearly is needed. While easy to describe, formulating such a system is neither simple nor a convenient fit in today's procurement process.

DOE's comprehensive subsurface science and technology agenda ***needs to*** consider activities that will increase knowledge and capabilities in four areas: 1) understanding basic subsurface processes, 2) better monitoring, data collection, and data storage capabilities, 3) better predictive capabilities, and 4) implementing a process that continually upgrades the quality of environmental systems being installed. It is essential that technical and administrative activities correctly take into account the potential long-term needs of current systems. It truly is a pay-me-now or pay-me-more-later situation.