

Potential Cross-Contamination of a Leaky Multi-Unit Bedrock Aquifer System Following Routine Sampling Protocols

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INTRODUCTION

While low-flow purging techniques have gained increased acceptance from regulatory agencies, default well sampling protocols prescribed by the New Jersey Department of Environmental Protection (NJDEP) and some EPA Regions still require the removal of three to five well volumes of purge water prior to sample collection. When this sampling protocol is applied to bedrock wells, a purge volume in the hundreds of gallons generally results. More importantly, in order to expedite the timely completion of well sampling events, purge rates resulting in significant drawdown are common.

When the “three to five well volume” sampling protocol is applied to a leaky multi-unit bedrock aquifer system commonly encountered throughout industrialized regions of New Jersey and elsewhere along the East Coast, the resulting pressure head drop in the pumped water-bearing zone results in leakage of water from the adjacent water bearing zones.

This non-equilibrium condition creates a vertical flow across intervening aquitard units that can promote the spread of contamination, seriously impair the quality of hydrogeologic data obtained, and misguide the development of remedial measures. Using low-flow purge techniques that eliminate or minimize drawdown in the sampled water-bearing zone can minimize these negative consequences.

CONCEPTUAL FLOW MODELS POSTULATED FOR NEWARK BASIN

Newark Basin is the largest of nearly 30 Mesozoic rift basin sequences mapped along the East Coast of the USA (Figure 1). The basin covers more than 2,700 square miles in southeastern Pennsylvania, New Jersey, and Rockland County in New York. It features a half-graben filled with nonmarine sedimentary rocks and basalt flows. Most strata exhibit a homoclinal dip of 5 to 15 degrees. The Passaic Formation is the thickest and areally most extensive of the formations recognized in the Newark Basin. This formation consists of mostly red cyclical lacustrine clastics (mudstone, siltstone, and shale) with minor fluvial sandstone.

In urbanized areas of the Newark Basin, where hundreds of contaminated sites have been identified, usable bedrock aquifers are often impacted by various contaminants. Oversimplified notions regarding the role of bedding-plane fractures on the flow of ground water in the bedrock system are frequently applied during site characterization and remedial activities. Inadequate understanding of the complexities of the bedrock aquifer leads to misdiagnosis of the contamination problem that frustrates ground water remediation efforts.

As summarized by Michalski and Britton (1997), several conceptual flow models have been used to portray the flow of ground water at contaminated sites in the region (Figure 2). The equivalent porous medium (EPM) flow model allows the investigator to treat the bedrock as a single-aquifer

system and to use the continuum approach in order to extend the use of methods of flow and transport analyses developed for granular porous media. Although the EPM model has been widely used in the region, the model ignores bedrock complexities and cannot provide an adequate basis for an effective investigation and remediation of contaminated bedrock aquifer systems.

A variation of the first EPM model is the two-aquifer EPM conceptual model developed in acknowledgement of the significant differences in water level elevations observed between “shallow” and “deep” wells at many sites.

A third conceptual model postulates that near-vertical joints subparallel to the strike of beds provide primary flow pathways through the bedrock and produce its anisotropic behavior. This model can be traced back to Herpers and Barksdale (1951) who observed an anisotropic, elliptical drawdown response during a pumping test conducted in Newark, NJ. The concept that anisotropic behavior of the bedrock is due to the alignment of near-vertical joints along the strike of strata was echoed in later publications (e.g., Vecchioli, 1967).

The fourth and fifth models in Figure 2 feature a leaky, multi-unit aquifer system (LMAS) proposed by Michalski (1990). In these models, the bedding-plane partings (or bedding fractures) with the greatest hydraulic apertures act as major, discrete aquifer units of the bedrock system. The water transmitting capacity of such partings is disproportionately high, which is consistent with the cubic-type relationship between flow and fracture aperture (Snow, 1968). As a result, large-aperture bedding fractures become low-head loci and discrete aquifer units attracting flows from adjacent beds. Near-vertical jointing in these beds provides for leakage between discrete aquifer units. The fifth model in Figure 2 represents a more realistic extension of the fourth model, whereby a weathered (transition) zone and an overburden are superimposed on the LMAS model.

PURGING AND SAMPLING PROTOCOLS SANCTIONED BY REGULATORY AGENCIES

In an attempt to collect a ground water sample representative of the targeted water-bearing zone, it is common practice to remove water from the well prior to collecting the ground water sample, a process termed purging. Purging protocols prescribed by various regulatory agencies are summarized in Table 1.

TABLE 1

Purging Protocols Sanctioned By Various Regulatory Agencies

Regulatory Agency	Default Purging Protocol	Is Low Flow Purging Accepted?
New Jersey Department of Environmental Protection	Three to five well volumes	Pre-approval required. “Low-Flow Purging and Sample Procedures for the Collection of Ground Water Samples,” Draft, January 1996.
Environmental Protection Agency (EPA) Region I	Low-flow	Yes. “Low Stress Purging and Sampling Procedure for the Collection of Ground Water Samples from Monitoring Wells,” July 30, 1996, Rev. 2.
EPA Region II	Low-flow	Yes. “Final Ground Water Sampling Operating Procedure, Low

		Stress (Low-Flow) Purging and Sampling,” March 16, 1998.
EPA Region III	Three to five well volumes	Pre-approval required. “Recommended Procedure For Low-Flow Purging and Sampling of Groundwater Monitoring Wells,” Draft, June 16, 1999. Bulletin No. QAD023.
EPA Region IV	Three to five well volumes	Pre-approval required. “Environmental Investigations Standard Operating Procedures and Quality Assurance Manual (EISOPQAM) Sect. 7, March 1997, Rev. 1.

Examination of Table 1 shows that while low-flow (minimum drawdown) purging techniques have gained increased acceptance from regulatory agencies, default well sampling protocols prescribed by the NJDEP and some EPA Regions still require the removal of three to five well volumes of purge water prior to sample collection.

NEWARK BASIN SITE, CENTRAL NEW JERSEY

A site-specific LMAS model developed for a Newark Basin site located in central New Jersey using several characterization methods detailed by Michalski, et al. (1992) is shown by Figures 3 and 4. Well construction details and associated purge volumes are presented in Table 2.

Using the three to five purge volume sampling protocol specified by the NJDEP (1992), monitoring well MW-C1 was purged at a constant rate of approximately four gallons per minute (gpm) for 19 minutes. Measurements of drawdown data were collected automatically in monitoring wells MW-B, MW-D, MW-C2, and MW-C3 as well as MW-C1. Manual water level measurements were collected from MW-F.

Drawdown measurements after removal of approximately five well volumes from MW-C1 are presented in Table 3. Examination of Table 3 shows the following:

1. The greatest (and almost immediate) drawdown response occurred in monitoring wells MW-C2 and MW-C3 as expected given their postulated direct hydraulic connection with MW-C1.
2. A smaller (and delayed) response was observed in monitoring wells MW-B and MW-D.
3. Negligible response was observed in MW-F, indicating the hydraulic isolation of this well from Aquifer Unit C.
4. The hydraulic gradient (and leakage) between discrete aquifer units increased due to the drawdown created by purging MW-C1 at a rate of 4 gpm.

Implications of the observed drawdown in Aquifer Units B and D in response to routine purging of MW-C1 are as follows:

1. Given the volume of water routinely removed from large diameter bedrock wells using default purging protocols (Table 2), and the desire to complete sampling events in a timely fashion, it is almost certain that purge rates resulting in significant drawdown occur routinely.
2. Drawdown created by excessive purging can change the magnitude, and more importantly, reverse the natural direction of leakage between discrete aquifer units. Head differences that act to drain contamination into large aperture/transmissive aquifer units under non-pumping conditions may be reversed during purging.

3. If the well being purged is positioned in a discrete aquifer unit relatively free of contamination (e.g. MW-E), excessive purging can be expected to reverse the normal leakage direction, inducing flow of contaminated ground water from adjacent aquifer units into the purged aquifer unit.
4. While ground water concentrations marginally above ground water quality standards have been detected in MW-E, no consistent upward trend attributable to purging technique has been observed. The upgradient/upstrike position of MW-E, two hundred feet from the source area, is believed to protect this well from purging-induced cross-contamination effects.
5. Using low-flow purge techniques that eliminate or minimize drawdown can reduce the potential for cross-contamination of discrete bedrock aquifer units caused by excessive purging.

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