A Practical Framework for Flux-Based Monitoring Programs

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Background/Objectives. It is increasingly recognized that the complete restoration of some source and/or high concentration zones to drinking water quality standards may be impractical and very costly due to a variety of rate-limiting mechanisms including dissolution, desorption, and diffusion from storage zones. In response, some regulatory programs are beginning to support remedial performance objectives targeted primarily at reducing contaminant mass in the highest permeable/flux zones to achieve risk-based goals. These risk-based goals conceptually acknowledge the importance of reducing mass discharge, that groundwater quality standards may not be achieved at some sites, and acknowledge that mass may remain in low-permeability zone(s). While the concept of using contaminant mass flux as a performance goal is increasingly accepted, there remains ambiguity and regulatory inconsistencies related to its practical implementation. This presentation provides perspective on the future of flux-based remedial goals and a pragmatic approach to developing monitoring programs. The approach that integrate mass flux and mass discharge concepts and their correlation with potential risk exposure that otherwise historically primarily has been defined by concentrations.

Approach/Activities. Risk-based remedial goal setting and flux-based remedial performance monitoring programs at a half-dozen sites are evaluated. The sites are at least three years and up to a decade into their respective remedial programs. The reviewed sites include a range of geologic settings including complex overburden sites with significant mass storage in silts and clays, as well as fractured sedimentary rock sites with significant mass storage in the unfractured rock matrix. Common for all evaluated sites is an appreciable scale of hydraulic conductivities: ranging over six orders of magnitude to provide meaningful contrast between zones of high (advective transport) and low (storage) mass flux.

Results/Lessons Learned. The successful implementation of remedial goals based on mass discharge/mass flux concepts requires monitoring well networks that focus on the mass that moves. Unfortunately, conventional monitoring programs are not designed to measure changes in mass flux, but are primarily intended to monitor changes in the plume's spatial footprint. Further, data originates at wells with high concentrations without specific consideration to whether these wells best represent changes in mass flux. Fortunately, at many recently-investigated sites, most monitoring wells already target higher flux zones. However, for legacy sites, where monitoring wells were installed at predetermined depths and with little consideration for the risk-relevance of high and low hydraulic conductivity zones, it is possible for stakeholders to develop a framework that integrates both the contaminant concentrations and hydraulic conductivities of existing well networks in order to shift the focus of performance monitoring to wells screened within zones that contribute most to the overall mass discharge and potential risk. This assessment could include a statistical approach, but as a rule of thumb, higher weight would be placed on zones with hydraulic conductivity of $>10^{-2}$ cm/s for unconsolidated aquifers and $>10^{-4}$ cm/s for fractured rock. Hydraulic tests or single-well tracer tests can provide compelling quantitative data to support this type of assessment. In many

cases this will result in deemphasizing or even abandoning impacted monitoring wells in low-permeability materials.