MDH Pathogen Project Recharge Monitoring Study Executive Summary

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Executive Summary

Background

The final phase of the Minnesota Department of Health Pathogen Project (formerly Minnesota Groundwater Virus Monitoring Study) consisted of detailed site investigations at four public water systems that had previously been included in the 2014-2016 occurrence monitoring phase of the study. These site investigations focused on determining the sources of microbial contamination observed in the occurrence monitoring, the pathways traveled by this contamination and the timing of microbial occurrence in relation to recharge events. Statistical analysis of the 2014-2016 data set suggested that microbial occurrence correlated with precipitation events, consistent with observations from other studies. Therefore, a primary focus of this final phase of the project was intensive sample collection surrounding groundwater recharge events, in addition to the detailed site characterization work noted above. Hence, this phase of the project is collectively known as the Recharge Monitoring Study.

Approach and findings

The Recharge Monitoring Study ran from spring 2019 until the end of 2022, with most of the work focused during fall 2020 through fall 2021. Sampling for microbial genetic material and associated chemical and isotopic constituents occurred during that time period using automated sampling equipment that was triggered based on weather forecasts and accompanied by continuous data logging of field parameters. In addition, water level hydrograph responses were tracked via continuous data logging in paired observation wells, which also housed real-time weather stations for tracking precipitation values at the study sites. Additional field investigations included sampling of nearby wastewater infrastructure for comparison with the drinking water results, detailed age dating of the well water, dye trace investigations at three of the four sites and borehole logging investigations at one of the sites characterized by bedrock wells with long open-hole intervals.

Analytical and data logger results were compared with precipitation and water level data to assess temporal correlation between recharge events and water quality degradation. Despite the wide range in hydrogeologic settings included in this study, several common patterns emerged that reflect the importance of precipitation regimes on water quality. Recharge events that followed drier than normal periods, based on comparison with historical averages, showed relatively long lag times between the onset of precipitation and microbial occurrence, as well as relatively low microbial concentrations. With continued wet conditions, subsequent recharge events resulted in decreasing lag times and increasing microbial concentrations, apparently representing a flush of microbial material that had accumulated in the subsurface during drier periods and which required an initial wetting period to activate. Continuing wet conditions through the spring thaw period resulted in the highest percentage of microbial positive samples, though at relatively low concentrations. This pattern then re-set with the onset of drought conditions in the summer of 2021 and into that fall. While the pattern was observed at each site, it was offset in time at the site with the thickest vadose zone, indicating the importance of accounting for this factor when assessing subsurface transit times.

These results, mimicked by some of the other water quality parameters, have parallels with classical tracer responses in groundwater systems and may be meaningful for anticipating and mitigating these pulses of microbial material at public wells. Mitigation measures might include increasing disinfectant residuals during wet periods. Use of water storage to minimize groundwater withdrawals during microbial flushing periods could also be entertained, but uncertainty about the exact duration of these pulses at individual water systems, combined with any negative effects from prolonged water storage, may minimize the feasibility of this option.

These findings may also have bearing on future monitoring strategies and well vulnerability assessments. For example, spring thaw may be the optimal period for assessing vulnerability to microbial occurrence, but the transition from dry to wet conditions may be best for capturing maximum microbial concentrations. Factoring seasonality and precipitation regimes in force at the time of sampling may also be relevant for assessing or reassessing results from previous monitoring studies. Although results obtained in this study were from wells in relatively vulnerable geologic settings, the broad occurrence of microbial genetic material noted in the 2014-2016 monitoring study, along with the similarities in occurrence patterns observed here, may reflect that these findings have some general applicability for assessing risk. It seems likely that whatever types of subsurface heterogeneities were exploited by well pumping at the sites in this study, such as fractures or small-scale coarse-grained deposits, may exist even in relatively protected geologic settings.

Finally, it's possible that some chemical constituents which also share very low levels of analytical sensitivity, such as PFAS compounds, may follow similar trends, although that remains to be seen.

Other findings include:

- Tracer studies resulted in positive identification of possible pathogen sources at two of the three sites, demonstrating their utility as a tool for site investigations. Combining these tracer studies with other investigative tools, such as the paired drinking water-wastewater sampling conducted here, is recommended to provide redundancy as well as account for subsurface conditions that may attenuate tracer transport in some settings.
- Borehole investigations using combined video, geophysical and geochemical monitoring equipment can be an important compliment for understanding local hydrogeologic conditions as they pertain to microbial risk. This is especially true in northeastern Minnesota, where the abundance of low-yield crystalline bedrock aquifers results in wells with shallow well casings and long open-hole intervals that mix shallow and deep groundwater horizons that may have distinct water quality characteristics.
- Groundwater age-dating is a relatively blunt tool for assessing microbial risk, given that it only provides a bulk age for a reservoir that may include a wide mix of ages. For example, the youngest bulk age estimate from the four study wells was 15-years, even though each well showed evidence for microbial pulses or other small-scale water quality changes on the timescale of days. In each case, the estimated volumetric contribution of these short-lived pulses of rapid recharge to the well water column was less than 10-20% of the total, in some cases less than 1%.

- The findings of this study reinforce those of Hunt et al. (2010), which suggests that the occurrence of microbial genetic material in the subsurface is largely due to the rapid transport of small volumes of fast-moving recharge. This mechanism is facilitated by the exploitation of small-scale features such as macropores in the soil horizon and high conductivity zones in unconsolidated sediments or bedrock and energized by the steep localized hydraulic gradients in the immediate vicinity of pumping wells. Further, the continuous leakage of wastewater below the frost zone from infrastructure designed to do so, such as septic drainfields, or unintended losses from features such as sanitary or storm sewer piping, seems likely to prime the subsurface so that the addition of fresh recharge readily drives microbial material into aquifers. These mechanics may be additionally reinforced by the focusing of recharge via runoff from impervious surfaces.
- The health risk associated with consuming water from these wells was highly variable in time, with most daily risk estimates being very low. The less frequent but higher concentration pathogen detections indicate increased daily risk, but may be hard to predict. If they are generally associated with subsurface wetting fronts that follow abnormally dry periods, as suggested by this study, then those characteristics could be used to guide "worst case" sampling studies, as noted above.

Recommendations

Actions that might be taken to maximize pathogen protection at public wells based on these study results might include those shown in the following categories:

Water quality monitoring and well vulnerability characterization

- Focusing future sampling studies or routine monitoring on either the spring thaw period, to maximize the likelihood of detections, or after the return to wet conditions following abnormally dry ones, to maximize the likelihood of capturing peak concentrations. For spring thaw sampling, it is important to note that recharge may be occurring despite the presence of standard indicators of frozen ground conditions, such as ice on area lakes or subsoil temperature measurements for area roadways. However, pathogen occurrence at a well is likely more robustly identified as compared to pathogen concentration characterization when only a few samples can be collected.
- Factoring in vadose zone thickness when designing future monitoring studies designed to address short-term responses to precipitation events. Sites with thicker vadose zones will likely have appreciable lag times for contaminant breakthrough, based on the findings of this study.
- Factoring changing climatic conditions into future monitoring strategies and vulnerability assessments. Although rainfall intensity was not evaluated as a controlling factor in this study, the observations about prevailing moisture conditions may be important when considering microbial risk to public water supply wells as changing climatic conditions, including increasingly wide swings in precipitation patterns, are predicted. In addition, other studies have noted correlations between rainfall intensity or seasonality and chemical contamination in the subsurface, providing further rationale for incorporating these considerations.

- Incorporating repeated measurement of parameters such as nitrate, chloride, bromide, and water isotopes in sampling studies to look at trends that may reflect a flashy response to recharge events and related microbial transport and susceptibility.
- Monitoring for chemical indicators, such as specific conductance and chloride/bromide ratios, when assessing contributions from sources of different but known values or ranges. This monitoring may be especially relevant in settings like northeastern Minnesota where the existence of naturally occurring brines at depth may mix with shallow groundwater flow horizons of differing residence time and chemistry, or where specific sources, such as stormwater runoff or septic waste, are present in the contributing area of a well and are not confounded by multiple sources with identical chemical signatures.
- Incorporating data loggers in public supply wells or paired observation wells for continuous measurement of parameters such as water level or specific conductance to assess variability over time that might be related to recharge pulses and serve as surrogates for microbial risk.
- In low-hydraulic conductivity bedrock aquifer settings where long open-hole intervals are used to maximize yield and provide in-well storage, borehole logging studies may be able to identify different flow regimes at depth. This information may be useful for assessing mixing dynamics during recharge events and reflect on microbial susceptibility.
- The volumetrically small contributions of fast-moving recharge attributed to pathogen occurrence in this study argues for either the continued use of high-sensitivity microbial genetic analysis as the most robust indicator of well vulnerability, or for the use of surrogate parameters with similar levels of analytical sensitivity. Examples might include PFAS compounds, especially PFBA. Reliance on less sensitive parameters, such as tritium, may miss detection of the small components of young water noted here, thereby providing a nonconservative estimate of risk.
- If tritium is to be continued as the dominant indicator of groundwater residence time, it would be more predictive if the lowest analytical reporting limits are sought, even if they result in higher cost or turnaround times. The ultra-low level tritium analysis offered by the Environmental Isotope Lab at the University of Waterloo, the current state vendor, offers reporting levels of 0.1 TU. With a reporting limit nearly an order of magnitude lower than the enriched tritium analysis currently used as the standard (reporting limit of 0.8 TU), and assuming annual average atmospheric tritium levels of approximately 7 TU, ultra-low level tritium analysis should be able to detect as little as 2-3% young water in a sample, like the low mixing levels observed in this study that appear to equate to microbial risk. This compares with the approximate 11% of young water that might be masked by the higher reporting limit. Budgets and sampling schedules would need to be adjusted proportionately for the increase in cost (approximately triple) and turnaround times (at least 6 months) for the more sensitive method. The method is probably best reserved for wells in protected geologic settings and/or which previously showed no detectable tritium at the higher reporting limit.
- The results of this study also argue that indicators of human-impact, such as the ratio of chloride to bromide, should be routinely incorporated when assessing well vulnerability, in addition to standard groundwater residence time indicators such as tritium. Taking a

weight-of-evidence approach to assessing the vulnerability of public wells, rather than over-reliance on a single indicator, will provide a stronger basis for assessing risk, as will acknowledging that well vulnerability represents a spectrum rather than a binary outcome.

Water system operation and risk management

- More fully considering hydrogeologic conditions when siting wells and potential contaminant sources such as septic systems or sewers. Keeping contaminant sources from the upgradient direction of groundwater flow, and outside the one-year time of travel well capture zone, where known, can provide additional protection beyond that provided by isolation distances alone.
- Where feasible, consider using water storage to respond to forecast weather events that might promote microbial transport, especially during spring thaw when microbial lag times are relatively short.
- Increasing chlorine residuals or other disinfection treatments during spring thaw and other recharge events identified by monitoring for microbial contaminants or surrogate indicator parameters, as noted above.