Assessing Aquifer Susceptibility to and Severity of Atrazine Contamination at a Field Site in South-Central Wisconsin

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ABSTRACT

A 2.5 yr field study was conducted on a 4.1 km2 area encompassing three dairy farms in south-central Wisconsin, to evaluate sources and distribution of atrazine metabolites in groundwater and to relate the contaminant distribution to the groundwater-flow system. A modeling approach was used to assess deep aquifer susceptibility to contamination and the long-term impact of atrazine contamination on drinking water quality. A particle-tracking program, PATH3D, was used in conjunction with a calibrated MODFLOW simulation to estimate groundwater travel paths and times in the monitoring area. Estimated travel time (TT) from the water table to the bedrock surface indicated the susceptibility of the bedrock aquifer to contamination. In addition to depth to bedrock and hydraulic conductivity, shallow surface-waterbodies can have a dramatic influence on TT to bedrock. TTs to private wells were estimated and are related to atrazine residue concentrations found in water. The impact of long-term atrazine use and leaching to groundwater on aquifer water quality was investigated by nonpoint- and point-source simulations of atrazine fate and transport using MT3D and the MODFLOW simulation. The predictions integrate flow-paths and estimated chemical parameter values to show aquifer susceptibility to atrazine contamination. A modeling approach was used in which predicted concentrations at various depths and times are presented. The regulatory implications of the modeling results were considered.

TECHNICAL SUMMARY

INTRODUCTION: The Wisconsin Department of Agriculture, Trade and Consumer Protection currently regulates atrazine use by establishing maximum application rates for atrazine or outright prohibition. To assess the effectiveness of such actions, regulators must know the longevity of atrazine in groundwater. Assessment of susceptibility, long-term threat, and potential dissipation is presented for atrazine at the field site, but the strategy has universal applicability. A two-pronged approach is used. The first component estimates groundwater TT from the watertable to the bedrock surface and to area domestic wells using a particle-tracking program, PATH3D in conjunction with a 3-dimensional simulation of groundwater flow using MODFLOW. Since only advection is considered, the first component is not compound-specific. The second component is a contaminant-transport model for specific compounds using MT3D and MODFLOW. In lieu of actual contaminant-input information, nonpoint- and point-source contamination scenarios are simulated and predicted concentrations are noted at various depths and times. The scenarios include eradication of atrazine use to address atrazine dissipation. The MT3D simulations incorporate sorption, degradation and dispersivity--estimated by a 1-dimensional contaminant-transport model--into the calibrated flow model. Because much uncertainty is associated with estimation of those parameter values, a modeling approach is employed by which predicted concentrations are presented with associated uncertainties.

MODELS USED: The MODFLOW simulation incorporates the spatial variability of depth to bedrock and accounts for the hydrologic effects of local surface waterbodies. The groundwater flow system was modeled assuming steady-state conditions. Distance between watertable and the Precambrian bedrock surface was divided into 6 model layers. The number of layers representing the till and bedrock was spatially variable. For most of the monitoring area, the till-bedrock interface was between either Layers 2 and 3 or 3 and 4. The model was calibrated to watertable elevations, bedrock hydraulic heads, shallow vertical gradients and groundwater flux into Sixmile Creek. PATH3D is a particle tracking model that calculates groundwater paths and TTs in transient and steady-state 3-dimensional flow fields. It is run in conjunction with MODFLOW and used to calculate the advection-controlled component of pesticide movement. MT3D is a modular computer model that solves the 3-dimensional advection-dispersion equation. The modular structure is similar to MODFLOW, with separate packages for simulating advection, dispersion, sources and sinks, and chemical reactions. As with PATH3D, the velocity term in the advection-dispersion equation is calculated from the MODFLOW simulation using hydraulic conductivity inputs and simulated heads to calculate hydraulic gradients. MT3D allows simulation of sorption with a linear, Freundlich isotherm and simulates degradation assuming pseudo-first order kinetics with a separate degradation rate for sorbed and dissolved phases. The atrazine concentration of the recharge was specified; its entry into the system is analogous to the third-type boundary used in the one-dimensional model.

CONCLUSIONS

From models reported here, concentrations of atrazine at specific locations are largely controlled by TT to those locations. Relationships between average TT to area private wells and measured atrazine and metabolite concentrations indicate that groundwater-flow modeling and particle tracking can evaluate relative contamination susceptibility. Particle tracking indicated that TT to the bedrock surface varies widely across the monitoring area from <0.25 to >512 yr (see Figure, right) due to variations in depth to bedrock and hydraulic conductivity. While these factors are often incorporated in susceptibility maps or computer models, the particle tracking demonstrated that TTs to bedrock were partially controlled by proximity to Sixmile Creek and Waunakee Marsh. Thus, there are complex and subtle hydrogeologic factors controlling groundwater movement and velocity that can be overlooked when assessing susceptibility of an aquifer to contamination. Even without the surface waterbodies, the range of expected bedrock contaminant concentrations varies considerably in response to variations in hydraulic conductivity, and gradient and depth to bedrock that are of too small a scale to incorporate into a regulatory framework. Continuing to regulate according to groundwater standards violations is the only reasonable alternative.

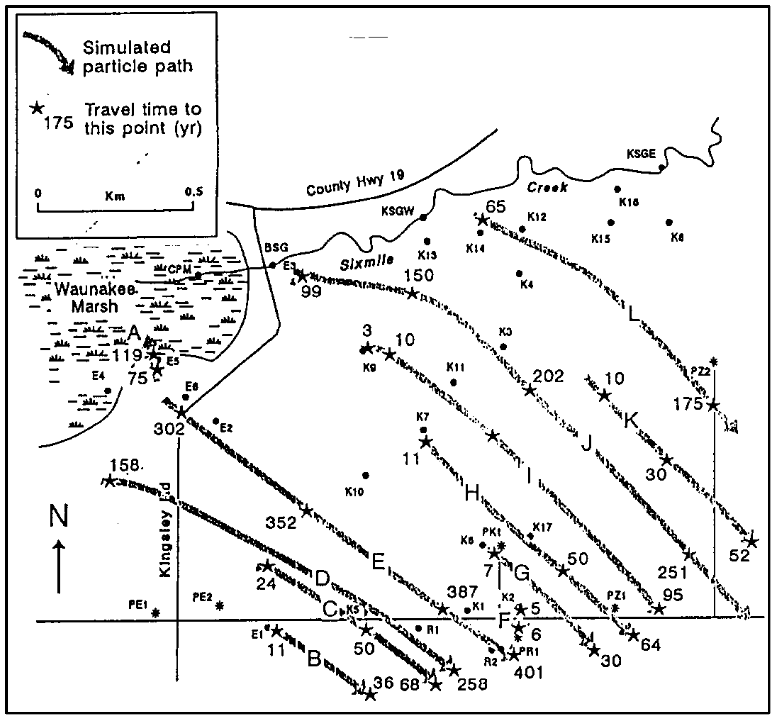

Figure 1.
Plan view of particles path A-L.Stars and numbers indicate TT in years.

The chemical transport modeling predicted the range of expected long-term atrazine concentrations at various depths for constant inputs at the watertable, thus assessing potential severity of present and future contamination of the bedrock aquifer. The simulations combined the calibrated, steady-state 3-dimensional groundwater flow model with estimates of atrazine transport parameters. 95% confidence intervals for concentration predictions in shallow groundwater were large but indicated that, given 3.0 ppb entering the system, maximum Layer 1 (0 to 8.2 m below water table [BWT]) concentrations are not likely to exceed 2.4 and 1.6 ppb in areas of relatively large and small Horicon till groundwater velocities. At >8.2 and 17.8 m BWT concentrations are unlikely to exceed 0.8 and 0.5 ppb given the nonpoint case. For the point-source case (based on highest atrazine concentrations detected), the 95% confidence intervals suggest that concentrations in private wells PK1, PR1, PE2 and PE1 (see Figure) are unlikely to exceed 2, 0.6, 0.2 and 0.1 ppb, respectively. AG 30 took effect before the 1991 growing season and imposed statewide and area-specific rules including areas of atrazine-use prohibition (APAs) and areas of reduced maximum atrazine application rates (AMAs). AG 30 is updated annually. The 1991 atrazine rule called for a review of atrazine provisions in 1996 by evaluating the success of AG 30 in attaining and maintaining compliance with groundwater standards. Obviously, APAs will eventually reduce atrazine contamination of groundwater. Depending on aquifer characteristics, however, immediate beneficial results are not expected. The contaminant-transport simulations performed here suggest that it can take 5 to 10 yr after contaminant movement to the watertable ceases before the groundwater concentration is reduced by half at relatively shallow depths. For example, it takes >10 yr before it is likely for concentrations in Layer 1 to be <0.3 ppb. At greater depths, expected concentrations are likely to be less, but dissipation takes longer. The “best-case” assumption was always made, i.e., when application stopped, leaching stopped. Some leaching of atrazine residues is likely to occur in AMAs and perhaps APAs, even if at reduced rates. Continued input to the water table will lengthen the time of dissipation to a predetermined benchmark such as the PAL or ES.

DISCUSSION

Large-scale surveys will be an essential component for critical review of atrazine rules, but in many pedologic and geologic settings, 2 to 4 yr may be insufficient to make an accurate assessment of the long-term effects of altered application rates. Such complications need to be taken into account by regulators and legislators.

PROJECT INFORMATION

This summary number 038, along with 4 others in this Site's Listing (Numbers 054, 051, 042, and 019) are all based on sequential research conducted between 1988 and 1993. The continuation project was supported in part and at different times by General Purpose Revenue Funds of the State of Wisconsin through the Wisconsin Departments of Agriculture, Trade, and Consumer Protection and the University of Wisconsin System to the UW-Madison Water Resources Center (WRC). The project also received partial support from the U.S. Department of the Interior through the Geological Survey (USGS) to the WRC. The final technical report for this project has been published and is available on loan from the WRC Library as document call number 140719. To request a document call (608) 262-3069, email the library at askwater@macc.wisc.edu, or visit us on campus at 1975 Willow Drive, Madison, WI 53706.