Title: Groundwater Mounding and Contaminant Transport Beneath Stormwater Infiltration Basins.

Project ID: WDNR Project #189

Investigators:

Principal Investigator: Anita Thompson, Assistant Professor, UW-Madison, Biological Systems Engineering Department.

Research Assistant: Mike Nimmer, Graduate Student, UW-Madison, Biological Systems Engineering Department.

External Collaborator: Debasmita Misra, Assistant Professor, University of Alaska-Fairbanks, Department of Mining and Geological Engineering.

Period of Contract: June 2005 – June 2007.

Background / Need:

Increased impervious areas resulting from urbanization cause an increase in stormwater runoff and a decrease in infiltration to the groundwater table. Infiltration basins are often required to recharge a portion of the pre-development infiltration volume. The localized recharge by these relatively small basins can cause a groundwater mound to form below the basin. Mound formation is important as it may reduce the ability of the soil to filter pollutants, and may reduce the infiltration rate of the basin. Therefore, an accurate understanding of groundwater mound formation is important in the proper design of infiltration basins. Analytical solutions to estimate maximum groundwater mounding have been shown to suffer from many limiting assumptions. Predictions for mound height have generally been much higher with analytical methods than with numerical methods. As over estimation of mound height can have basin siting implications, rendering an accurate estimation of mound formation important.

Objectives:

The goal of this study was to increase our understanding of the causes of groundwater mounding beneath stormwater infiltration basins. By understanding the relative importance of factors affecting groundwater mounding, the potential mound formation at future sites can be evaluated with greater confidence. The main objectives of the project were: 1) To monitor groundwater levels and changes in soil moisture in the unsaturated zone in response to infiltrating stormwater from an infiltration basin, 2) To calibrate and validate a groundwater flow and contaminant transport model using data obtained under objective one, and 3) To use the model to extrapolate field data to other hydrogeologic settings.

Methods:

A 0.10 hectare infiltration basin serving a 9.4 hectare residential subdivision in Oconomowoc, Wisconsin was used in this study. Subsurface conditions included sand and gravel material and a groundwater table at 2.3 meters below grade. Three storm events between August 2006 and April 2007 were modeled using the two-dimensional numerical model HYDRUS. Inverse modeling was performed with HYDRUS to estimate soil and aquifer parameters. The model was calibrated to heads recorded at the basin center. Model validation was accomplished by interchanging fitted parameters between storms. The model was then applied to various basin designs and subsurface conditions to determine their effect on mound height.

Results and Discussion:

Predicted pressure heads at the center of the infiltration basin were in close agreement with measured values (RMSE: 0.016 m – 0.026 m). Hydraulic parameters of aquifer material predicted using the inverse solution were within ranges reported in the literature. The magnitude and timing of maximum mound rise was predicted well for all storms. Differences between modeled and observed mound heights were ≤1.3% for all storms. Maximum mound heights occurred 9.5 – 12 hours after the initial water table rise. The modeled initial water table rise was 20 - 40 minutes later than observed in the field for all three storms. This discrepancy was attributed to preferential flowpaths in the field, either natural or created during well installation. HYDRUS predicted a faster mound recession than observed in the field. The slower recession in the field was attributed to fine-grained material outside the basin reducing drainage away from underneath the basin.

Model performance was validated by using fitted hydraulic parameters from storm #1 to predict mound formation in storm #2. Close agreement between modeled and measured heads was observed (RMSE: 0.026 m – 0.031 m). Fitted parameters from the inverse solution for storm #3 did not produce a good fit when used to model storms #1 and #2. The maximum predicted mound heights for storms #1 and #2 were approximately 20% higher when the hydraulic parameters from storm #3 were used. This discrepancy was attributed to a higher initial water table and soil moisture content for storm #3 compared with the other two storms.

A sensitivity analysis of system parameters showed that mound height was most influenced by hydraulic conductivity. Mound heights increased as hydraulic conductivity decreased with rapid increases below a hydraulic conductivity of approximately 1.5 cm/s. Increasing anisotropy decreased mound height, particularly for anisotropy less than 10. To a lesser extent, mound height was sensitive to saturated thickness; mound height decreased as the initial saturated thickness increased. Increasing the unsaturated zone thickness had less of an impact on mound height; mound height increased slightly and was delayed as the unsaturated thickness increased. Mound heights were not sensitive to the initial soil moisture content (matric potential) of the sand and gravel material. The thickness of the sediment layer on the infiltration basin floor had a significant effect on the volume of water infiltrated and on the groundwater response. Reducing the sediment layer by 50% (10.5 cm to 5.25 cm) caused the water table to rise to the bottom of the basin floor, increasing mound height from 0.38 m to 2.4 m.

Using the calibrated model to evaluate hypothetical basin operation scenarios, the groundwater mound intersected the basin floor in most scenarios with loamy sand and sandy loam soils, when combined with an unsaturated thickness of 1.52 meters, and a ponding depth of 0.61 meters. No groundwater table response was observed with ponding depths ≤ 0.305 meters with an unsaturated zone thickness of 6.09 meters. The mound height was most sensitive to hydraulic conductivity and anisotropy (≤10), followed by unsaturated zone thickness. A 7.62 cm sediment layer delayed the time to reach maximum mound height, but had a minimal effect on the magnitude of the mound. Mound heights increased with an increase in infiltration basin size. Mound heights were more sensitive to matric potential than in the model for the study site; mound heights increased as matric potential decreased.

Conclusions / Implications / Recommendations:

The variably saturated flow model HYDRUS was able to accurately predict the timing and magnitude of groundwater mounding. A sensitivity analysis showed that a number of factors influence mound height and must be considered during infiltration basin siting, including basin size, soil hydraulic properties, and depth and thickness of the aquifer.

Recommendations for future work include applying a three-dimensional model to the study site and collecting water table response data from a site with more fine-grained material beneath the basin for additional model calibration and validation. Field application of appropriate tracers will allow assessment of the effect of mound formation on contaminant transport.

Related Publications: Nimmer, M., A. Thompson, and D. Misra. Groundwater Mounding Beneath Stormwater Infiltration Basins. Paper #072026. Presented at the 2007 ASABE Annual International Meeting, Minneapolis, MN. June 17-21, 2007.

Key Words: Infiltration, infiltration basin, stormwater, recharge, groundwater, mounding.

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Final Report: A final report containing more detailed information on this project is available for loan at the Water Resources Institute Library, University of Wisconsin – Madison, 1975 Willow Drive, Madison, Wisconsin, 53706 (608) 262-3069.