MODELING HYDROLOGIC AND GEOCHEMICAL EFFECTS OF RAPID INFILTRATION BASIN SYSTEMS

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ABSTRACT

Rapid Infiltration Basin Systems (RIBS) use the controlled application of treated wastewater to soil to remove constituents in the wastewater before recharging groundwater. Effluent from most new wastewater treatment plants is enriched in NO_3^-, so denitrification (DNF) is the main reaction for N removal. The absence of molecular oxygen and an adequate supply of carbon to serve as a substrate for heterotrophic bacteria are the required conditions for DNF.

During RIBS operation, wastewater is applied to open basins cyclically, usually with a flooding period followed by days or weeks of drying. Key operational parameters impacting DNF include the ratio of wetting to drying time and the hydraulic loading rate, which affect water saturation and air content in the vadose zone and residence time of contaminants. To investigate effects of complex surface and subsurface flow patterns caused by non-uniform flooding on system performance, a coupled overland flow-vadose zone model is implemented in iTOUGH2 to study the hydraulic performance of RIBS and estimate groundwater mounding under RIBS when wastewater is applied non-uniformly due to overland flow. A simplified approach using a domain-average denitrification reduction factor, F_s, is used in iTOUGH2 to assess the impact of pore water saturation on DNF as well. The coupled overland flow-vadose zone model is also applied in TOUGHREACT to investigate effects of operating conditions on the fate and transport of N where two biological

reactions are assumed: oxidation of *DOC* and DNF, which are modeled using multiple Monod expressions. The effect of using a DNF layer, a layer composed of high water holding capacity material and amended with organic carbon solids, on DNF is also investigated. Simulations are conducted in two representative soils varying the application cycle, hydraulic loading rate, wastewater quality, water table depth, and subsurface heterogeneity.

The results with the modified iTOUGH2 computer code, describing the coupled surface-subsurface flow in RIBS, indicate that the conventional specified flux boundary condition underpredicts groundwater mounding by as much as a factor of 25 in loamy sand and a factor of 6 in sand. The impact of basin boundary condition on F_s is less significant, with F_s reduced by up to 50% if the specified flux boundary condition is used. Thus, ignoring overland flow underpredicts DNF and groundwater mounding. Moreover, for a fixed amount of wastewater discharged over a weekly flooding-drying cycle, simulations indicate that longer flooding periods result in less groundwater mounding but a reduction in denitrification.

Simulations with the coupled overland flow-vadose zone model in TOUGHREACT indicate smaller ratios of wetting to drying time, i.e., shorter but more intense flooding periods, result in greater water saturations, shorter residence times and lower oxygen concentrations in the vadose zone, ultimately resulting in greater DNF which is consistent with the iTOUGH2 simulations. Higher loading rates also result in greater DNF because of favored growth of microbial communities at deeper depths. Using a coupled surface-subsurface model is critical for predicting DNF when the hydraulic loading rate is not sufficiently large to quickly spread the wastewater over the whole basin. Simulations using the conventional specified flux boundary condition under-predict DNF by as much as 450% in sand and 230% in loamy sand compared to predictions from the coupled overland flow-vadose zone model. Across all simulations, cumulative percent DNF varies between 2 and 49%, indicating that NO_3^- removal in RIBS may vary widely depending on operational procedures and subsurface conditions. These modeling results improve understanding of DNF in RIBS and suggest operational procedures that may improve NO_3^- removal.

Reactive transport modeling of RIBS using TOUGHREACT when a layer composed of high water holding capacity material and amended with organic carbon solids (DNF layer) is present indicates that in general, a DNF layer improves denitrification by increasing water retention and creating a completely saturated region beneath the RIBs, and by providing additional carbon for DNF. These factors could be important depending on the soil type and biomass inhibition term ($\hat{K}_b$ =1 versus $\hat{K}_b$ =10 mgL^{-1}). Model predictions with the modified TOUGHREACT computer code, describing the coupled surface-subsurface flow in RIBS, indicate that the conventional specified flux boundary condition underpredicts DNF by up to 20%. Thus, ignoring overland flow underpredicts DNF. Alternative loading rates and application cycles that increase the residence time of the plume in the DNF layer are more effective in DNF.

For example, cycle 2, longer loading period but less intense loading rate, results in higher DNF than cycle 1.