Ground Water Monitoring&Remediation

Numerical Modeling of Unsaturated Flow in Wastewater Soil Absorption Systems

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Abstract

It is common practice in the United States to use wastewater soil absorption systems (WSAS) to treat domestic wastewater. WSAS are expected to provide efficient, long-term removal of wastewater contaminants prior to ground water recharge. Soil clogging at the infiltrative surface of WSAS occurs due to the accumulation of suspended solids, organic matter, and chemical precipitates during continued wastewater infiltration. This clogging zone (CZ) creates an impedance to flow, restricting the hydraulic conductivity and rate of infiltration. A certain degree of clogging may improve the treatment of wastewater by enhancing purification processes, in part because unsaturated flow is induced and residence times are significantly increased. However, if clogging becomes excessive, the wastewater pond height at the infiltrative surface can rise to a level where system failure occurs. The numerical model HYDRUS-2D is used to simulate unsaturated flow within WSAS to better understand the effect of CZs on unsaturated flow behavior and hydraulic retention times in sandy and silty soil. The simulations indicate that sand-based WSAS with mature CZs are characterized by a more widely distributed flow regime and longer hydraulic retention times. The impact of clogging on water flow within the silt is not as substantial. For sand, increasing the hydraulic resistance of the CZ by a factor of three to four requires an increase in the pond height by as much as a factor of five to achieve the same wastewater loading. Because the degree of CZ resistance directly influences the pond height within a system, understanding the influence of the CZ on flow regimes in WSAS is critical in optimizing system design to achieve the desired pollutant-treatment efficiency and to prolong system life.

Introduction and Background

In a conventional wastewater soil absorption system (WSAS), wastewater and waste solids are delivered to a septic tank for primary treatment. The solids and oils remain in the tank after settling, flocculation, and density separation, while the remaining wastewater is delivered to a subsurface trench for subsequent infiltration into the vadose zone. The bottom, and eventually the sides, of the trench serve as infiltrative surfaces for wastewater application to the subsurface soils. During the infiltration process, the wastewater constituents are presumably treated before the wastewater reaches the water table. A typical residential-household WSAS generally operates for 15 years or more.

Soil clogging by the accumulation of suspended solids and organic matter at the infiltrative surface of WSAS is a phenomenon known to occur as a result of continued wastewater infiltration (Jones and Taylor 1965; Siegrist 1987; Tyler et al. 1994). This clogging zone (CZ) creates an increased resistance to flow. It is logical that a certain degree of clogging may improve the treatment of wastewater by causing an unsaturated flow regime, as discussed later. However, excessive clogging can lead to eventual system failure if the CZ becomes essentially impermeable and wastewater can no longer infiltrate (Siegrist 1987; Siegrist and Boyle 1987). The service life of a WSAS is often gauged by its hydraulic performance, which is closely related to CZ development and the long-term infiltration or acceptance rate of the system (Siegrist et al 2001).

Unsaturated-flow conditions below the infiltrative surface of a WSAS are achieved when the hydraulic loading rate of septic tank effluent (STE) is significantly less than the soil media's saturated hydraulic conductivity (Siegrist and Van Cuyk 2001). Intermittent dosing of wastewater and spatially uniform application of wastewater to the soil's infiltrative surface can also promote unsaturated flow conditions (McCray et al. 2000). In unsaturated flow environments, a multiphase system develops where water has a high affinity for soil grains. Water preferentially enters smaller pores, enhancing media contact with pollutants, thereby enhancing filtration and removal of chemical and microbial pollutants. In essence, the specific surface area for reaction processes to occur between soil media and pollutants is larger in the vadose-zone system than in the saturated system. In addition, the hydraulic conductivity increases nonlinearly with water content, and thus unsaturated conditions cause a decrease in the velocities of wastewater and associated pollutants compared to water-saturated media, resulting in longer retention times within the WSAS. A longer retention time results in