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Using 3-dimensional soil sensor networks to trace biomat growth in soil treatment units

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An embedded 3-dimensional network of soil sensors continuously monitoring soil water content, soil temperature, and electrical conductivity was used to determine effluent infiltration and soil water retention patterns in soil treatment units (STUs) for a period of > 2.5 years. STUs are a prevalent final discharge point for primary or secondary treated domestic effluent in on-site wastewater treatment systems, and rely on the gradual development of a microbial biomat in the soil to effectively distribute the water over the entire design area. Understanding the long-term environmental impacts and performance of STUs helps to improve design guidelines and operational procedures as well as minimize the risk for groundwater pollution and adverse effects on human health.

In this study, we traced effluent infiltrating into the vadose zone below shallow gravel trenches in STUs, using a network of soil sensors in three full-scale systems set up to treat the effluent of individual households (2 to 5 PE) in rural Ireland. Before discharge to soil, the flow was split equally into two streams for (i) direct discharge of primary effluent into one half of the STU, and (ii) further treatment in a secondary treatment unit, removing up to 91% of total organic C and 90% of total N, before discharge into the other half of the STU. Data from the sensors and additional effluent quality analysis served as proxies for determining zones of effective infiltration following biomat growth within the STU and were correlated to biogeochemical transformations in the effluent plume. Emissions of greenhouse gases (CO_2, CH4, NO_2) resulting from microbial activity in the soil were traced over the STU using automated soil gas flux chambers.

Over time, increasing soil water retention in the biomat layer (> 2.5% increase over unaffected control soil) was observed and partially inverted the natural water content profile. Sensors expressed distinct responses to hydraulic and organic loading patterns, and environmental factors such as temporarily saturated conditions following heavy rainfall. In times of extreme drought, the biomat in soil receiving primary effluent reduced the soil's effective hydraulic conductivity and acted as hydraulic barrier, thus preventing the soil from drying. In trenches receiving secondary treated effluent, however, considerable drying was observed at distances > 5 m from the inlet, indicating muted biomat growth and pore clogging under substrate-limited conditions.

Results from the field studies were used to inform numerical models for describing the growth and interactions of soil biomass with environmental factors and soil physical parameters. A step-wise numeric model was implemented in HYDRUS 2D, adjusting hydraulic conductivities with linear interpolations of field-measured values obtained from constant-head permeameters. The model was able to replicate the response to effective precipitation and effluent loading patterns under gradual, 2-dimensional pore clogging in the soil, but expressed significantly higher water content volatility as compared to observed field data.