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Consequences of using different soil texture determination methodologies for soil physical quality and unsaturated zone time lag estimates

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ABSTRACT

Elucidation of when the loss of pollutants, below the rooting zone in agricultural landscapes, affects water quality is important when assessing the efficacy of mitigation measures. Investigation of this inherent time lag (t_T) is divided into unsaturated (t_u) and saturated (t_s) components. The duration of these components relative to each other differs depending on soil characteristics and the landscape position. The present field study focuses on t_u estimation in a scenario where the saturated zone is likely to constitute a higher proportion of t_T. In such instances, or where only initial breakthrough (IBT) or centre of mass (COM) is of interest, utilisation of site and depth specific "simple" textural class or actual sand–silt–clay percentages to generate soil water characteristic curves with associated soil hydraulic parameters is acceptable. With the same data it is also possible to estimate a soil physical quality (S) parameter for each soil layer which can be used to infer many other physical, chemical and biological quality indicators. In this study, hand texturing in the field was used to determine textural classes of a soil profile. Laboratory methods, including hydrometer, pipette and laser diffraction methods were used to determine actual sand–silt–clay percentages of sections of the same soil profile. Results showed that in terms of S, hand texturing resulted in a lower index value (inferring a degraded soil) than that of pipette, hydrometer and laser equivalents. There was no difference between S index values determined using the pipette, hydrometer and laser diffraction methods. The difference between the three laboratory methods on both the IBT and COM stages of t_u were negligible, and in this instance were unlikely to affect either groundwater monitoring decisions, or to be of consequence from a policy perspective. When t_u estimates are made over the full depth of the vadose zone, which may extend to several metres, errors resulting from the use of hydraulic parameters generated from hand texture data will be resultantly greater, and may lead to flawed predictions regarding the achievability of water policy targets. For this reason laboratory analysis, regardless of method, should be preferred to simple field assessments.

1. Introduction

The elucidation of the time lag (t_T) (Fenton et al., 2011; Huebsch et al., 2014) or residence time (Bechmann et al., 2008) of nutrients migrating through the unsaturated (t_u) (Vero et al., 2014) and saturated (Fenton et al., 2011; Sousa et al., 2013) zones to ground and surface water receptors is highly important (Fenton et al., 2011: Wang et al., 2012), particularly with regard to correlating water quality with agricultural mitigation measures. However, in reality it is rarely considered, as the data requirements and investment with respect to monitoring networks and high resolution analysis, is large. Instead, the soil is often treated as a homogeneous overburden

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of a certain depth, with a single textural class; or if some data are available, the soil is treated as a multiple of homogeneous layers with differing textural classes. Herein we assume that flow through the unsaturated zone is predominantly vertical (1D) and vertical flow still occurs to some degree even where low permeability layers cause interflow (Nimmo, 2005).

The present study further develops the research of Vero et al. (2014), where consequences of using varied soil hydraulic and meteorological complexity on time lag estimates in the unsaturated zone (t_u) were examined. The level of data complexity required by users of numerical models depends on site specific characteristics, the stage of travel time in question (initial breakthrough, centre of mass or exit) and resource availability (i.e. human and monetary). Data options to obtain soil hydraulic properties (ranked from low to high complexity) include: pedotransfer functions (PTF) such as Rosetta (USA) (Schapp et al., 2001) or new generation PTFs for Europe such as those introduced by Tóth et al. (2015); computational processes such as integrated particle swarm optimisation (IPSO) (Yang and You, 2013); or construction of soil water characteristic curve (SWCC). The two former methods infer soil hydraulic properties from soil databases where known characteristics are derived using fitting equations (Vereecken et al., 2010). Hydraulic properties can be determined directly from a measured SWCC using fitting equations (e.g. van Genuchten, 1980; Brooks and Corey, 1964; Kosugi, 1996; Durner, 1994), which are incorporated within a dedicated RETC programme (van Genuchten, 1980). Hydrus 1D (Šimůnek et al., 2013) is a numerical model which allows the user to estimate t_u regardless of the complexity of the input data. Vero et al. (2014) concluded that the use of high complexity data (i.e. measured SWCCs) was likely to lead to more realistic simulations of long term t_u, due to more accurate hydraulic parameters reflecting the soil profile in question. However, the IBT and the centre of mass (COM) of a transported solute from the unsaturated groundwater (which are useful for informing efficacy trends of mitigation measures and impacts on contaminant hydrology) could be adequately described using low complexity data such as soil texture class derived from a knowledge of the site or using actual site specific sand–silt and clay data.

In the field, textural class can be rapidly determined using hand texturing techniques (minutes). In the laboratory, the sand–silt–clay percentages of a soil sample can be determined using different methods, requiring different durations e.g. pipette (weeks) (PM, BS 1796; British Standard Institution, 1989), hydrometer (weeks) (BS1377, Part 2, 1990) or laser diffraction (days) (LDM, BS ISO, 13320:2009).

The relative importance of t_u within the context of t_T changes depending on the scenario in question e.g. hydrogeologic characteristics of the soil/subsoil/rock material and the landscape position (Sousa et al., 2013). Vero et al. (2014) showed that as one gets closer to a receptor, the level of data complexity to estimate t_u increases. Conversely, as one migrates farther away from the receptor (e.g. upslope areas of catchments) the data needed can be simpler as the saturated zone is likely to dominate. It may also be important to consider the soil physical quality of the soil layers in question, as the same hydraulic data used to estimate t_u can also be used to estimate this soil physical quality (S) (Dexter, 2004a,b,c). Soil horizons with low soil physical quality may prolong t_u, have less organic matter and carbon, and in-turn may inform the practitioner regarding aspects of possible attenuation. Soil physical properties and behaviour are predominantly controlled by soil structure, which is reflected in pore size distribution and in turn is affected by particle size distribution. After calculation of soil hydraulic parameters using RETC, it is now easy to estimate soil physical quality using the SAWCal model of Asgarzadeh et al. (2014). The S term can be determined mathematically from the SWCC using the slope of the inflexion point (at the junction between structure and texture) (Dexter et al., 2004a,b,c; Dexter and Czyż, 2007). Dexter (2004a,b,c) introduced an index of S values where values < 0.02 indicates very poor soil physical quality, 0.020 to 0.035 indicates poor quality, 0.035 to 0.050 indicates good quality and values > 0.050 indicates very good quality. Since the S-index was initially introduced as a concept (Dexter et al., 2004a), it is being increasingly used in equations for predicting various soil physical properties (Dexter and Czyż, 2007) e.g. hydraulic conductivity, friability, tillage, compaction, penetrometer resistance, plant-available water, root growth and readily dispersible clay.

The soil/subsoil layer is multi-functional (Schulte et al., 2014; O'Sullivan et al., 2015) providing food, controlling pollutant migration (Richards et al., 2005; Meals et al., 2010), purifying water (e.g. nitrate denitrification (Fenton et al., 2009; Jahangir et al., 2013)), sequestering carbon and providing a biodiversity habitat. It is therefore a complex layer which should be characterised to a greater extent and not simplified or homogenised. There is a need to quantify the influence such simplifications have on various applications of interest to the contaminant hydrology community (Young et al., 2001; Lin, 2011).

The primary objective of this soil profile study is therefore to assess how the textural class or sand-silt-clay determination method of a soil sample could dictate modelled soil hydraulic outcomes. A secondary objective is to illustrate the implications of selecting one soil texture methodology over another with respect to unsaturated soil physical quality index designation and vertical travel times.

2. Materials and methods

2.1. Site description

The permanent grassland study site was located on a beef farm at the Teagasc, Johnstown Castle Environmental Research Centre, Co. Wexford, south-east Ireland (latitude 52° 12 N, longitude 6° 30 W). This site has a 30-year-average annual rainfall of 1000 mm and a mean daily temperature of 9.6 °C (Baily et al., 2011). Typically approximately 50% of this becomes effective rainfall (leached).

The soil profile examined was excavated along an open drain that was approximately 2.5 m deep. The soil profile was described by a soil scientist following Irish Soil Information System guidelines (Jones et al., 2011; Teagasc, 2015). Following this, a 1.4 × 1.4 m grid was created on the face of the soil test pit (Fig. 1) and divided into 49 equal sampling areas, each of 0.04 m^2 area. Soil samples were taken from each of these sampling areas.