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Modelling of recharge and pollutant fluxes to urban groundwaters

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Abstract

Urban groundwater resources are of considerable importance to the long-term viability of many cities world-wide, yet prediction of the quantity and quality of recharge is only rarely attempted at anything other than a very basic level. This paper describes the development of UGIf, a simple model written within a GIS, designed to provide estimates of spatially distributed recharge and recharge water quality in unconfined but covered aquifers. The following processes (with their calculation method indicated) are included: runoff and interception (curve number method); evapotranspiration (Penman–Grindley); interflow (empirical index approach); volatilization (Henry's law); sorption (distribution coefficient); and degradation (first order decay). The input data required are: meteorological data, landuse/cover map with event mean concentration attributes, geological maps with hydraulic and geochemical attributes, and topographic and water table elevation data in grid form. Standard outputs include distributions of: surface runoff, infiltration, potential recharge, ground level slope, interflow, actual recharge, pollutant fluxes in surface runoff, travel times of each pollutant through the unsaturated zone, and the pollutant fluxes and concentrations at the water table. The process of validation has commenced with a study of the Triassic Sandstone aquifer underlying Birmingham, UK. UGIf predicts a similar average recharge rate for the aquifer as previous groundwater flow modelling studies, but with significantly more spatial detail: in particular the results indicate that recharge through paved areas may be more important than previously thought. The results also highlight the need for more knowledge/data on the following: runoff estimation; interflow (including the effects of lateral flow and channelling on flow times and therefore chemistry); evapotranspiration in paved areas; the nature of unsaturated zone flow below paved areas; and the role of the pipe network. Although considerably more verification is needed, UGIf shows promise for use: in providing input for regional groundwater solute transport models; in identifying gaps in knowledge and data; in determining which processes are the most important influences on urban groundwater quantity and quality; in evaluating existing recharge models; in planning, for example in investigation of the effects of landuse or climate change; and in assessing groundwater vulnerability.

Keywords: GIS; Urban; Aquifer; Recharge; Pollutants; Groundwater; Birmingham; Urgent

1. Introduction

Urban aquifers are of considerable importance to the long-term viability of many cities across the world (e.g., Chilton, 1997; Howard and Israfilov, 2002). A major issue is the sustainability of supplies of sufficient quantities of sufficient quality groundwater, given the potentially major effects that urbanization has on rates and quality of infiltrating water. Despite the importance of recharge in urban development, research is still at a relatively early stage, and there are no generally accepted methods for assessing the rates and quality of urban recharge.

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This paper describes the development of a computer model, UGIf, for use in urban recharge and pollution studies. It is intended that the model be appropriate for the following purposes:

(i) to provide input for regional groundwater solute transport models;
(ii) to identify gaps in knowledge and data;
(iii) to determine which processes are the most important for influencing urban groundwater quantity and quality; and
(iv) to evaluate current recharge models.

Once developed, the code could be used as a planning tool to investigate the effects, for example, of landuse or climate change, and as a tool for assessing groundwater vulnerability.

For most urban areas, a central issue is the heterogeneity of sources, and hence the model has been developed using a GIS. The first part of this paper describes the model design. The process of 'verification' has begun, using data for 1980–2000 from the Birmingham urban Triassic Sandstone aquifer in the UK: this work is reported in the second half of the paper.

2. Overview of model

The model has been developed for the case of an unconfined aquifer overlain by superficial deposits of various permeabilities. It deals with non-point source pollution only, though related models have been developed to deal with point source pollution (petrol stations, including non-aqueous phase liquids, and sewers) (Thomas, 2001). The main calculations evaluate recharge and pollutant flux rates at the water table: the latter include the effects of sorption and first order degradation. The main data sources are: geological maps; ground level and groundwater level maps; land cover maps; and meteorological data. The geological maps have associated attributes of hydraulic and chemical properties, and the land cover maps associated attributes of hydraulic properties and runoff water quality data.

The basic structure of the model is shown in Fig. 1. A landuse/land cover classification allows the production of a land cover map. Each land cover class is assigned attributes relating to permeability/runoff and water quality. With meteorological data and the land cover-related runoff characteristics, an estimate of 'potential recharge' for each of the landuse classes can be made, where potential recharge is defined here

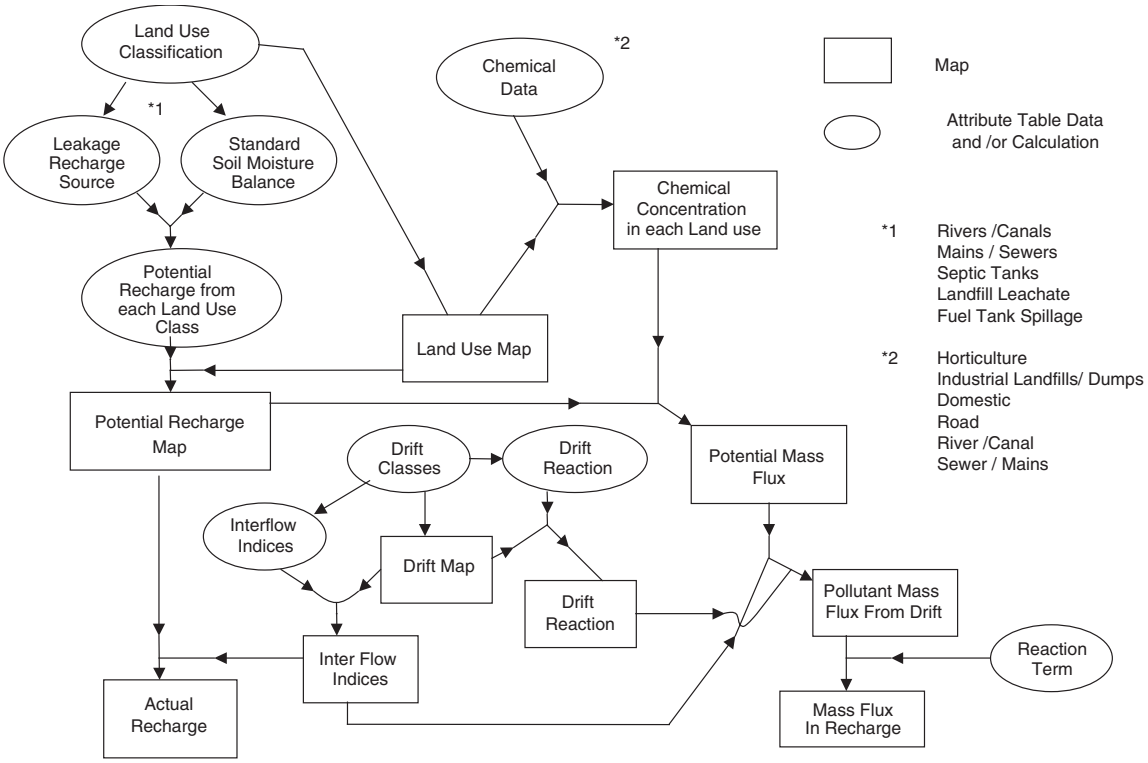

Fig. 1. The structure of UGIf (drift=superficial deposits).