Development of the AquiferSim model of cumulative effect on groundwater of nitrate discharge from heterogeneous land use over large regions

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Integrated research for aquifer protection

Land Use
- Climate
- Animal
- Plant
- Soil
- Vadose Zone
- Aquifer

Farm Management

Resource Management Policy

Socio-economic Analysis

Process Integration

Whole-system Integration

Nitrate discharge

AquiferSim

Predictive Tools
Model requirements

- Predict nitrate concentration in groundwater and discharge to surface waters, caused by agricultural land use

- Process inputs of nitrate discharge data at hectare-scale resolution over regions of a few thousand square kilometres

- Model run time that enables convenient assessment of land-use scenarios and computation of predictive uncertainty
Implications for computation

- Horizontal description \( \sim 10^5 - 10^6 \) cells

- Vertical dispersivity \( \sim 1\,\text{m} - 10\,\text{m} \), and vertical resolution of groundwater flow, requires \( \sim 10 - 100 \) layers

- Hence, total 3D description \( \sim 10^6 - 10^8 \) cells

- Computational time for steady flow, transient transport, model judged to be excessive
Selected design approach

- Steady-state groundwater flow
- Steady-state contaminant transport
- 2D/3D model: vertical slice construction of 3D picture
- Predict groundwater age for assessment of transport dynamics
2D/3D groundwater flow

- 2D horizontal, steady-state groundwater flow

- Finite-difference piezometric model for heterogeneous, isotropic, aquifer transmissivity

- Groundwater flow path through any location determined from gradient search of the piezometric surface

- 2D vertical, groundwater flow determined for the curved vertical plane along the groundwater flow path
2D horizontal, groundwater flow paths - test pattern
2D horizontal, groundwater flow paths - pilot region example

Central Canterbury, NZ
2300 km²
2D vertical, flow and transport

- 2D vertical flow: finite difference, streamfunction model
- Heterogeneous, anisotropic, hydraulic conductivity
- Cell dimensions control dispersivity
- No simulation of transverse horizontal dispersion – justified by relativity between vertical and horizontal concentration contrast
- Finite volume transport model
- First-order decay of contaminant
- Simulates groundwater age as a solute with initial value zero and zero-order growth with cell residence time
Vertical slice along one groundwater flowpath

Groundwater flow

Groundwater age

Nitrate concentration

Denitrification
Computational solver – 2D horizontal flow

- Steady-state description is an elliptic PDE

- Linear Full Multigrid algorithm (FMG)

- Square computational grids of dimension \((2^n+1) \times (2^n+1)\): six-grid hierarchy, from 33 x 33 up to 1025 x 1025

- Successive over-relaxation (SOR) used for coarsest grid (33 x 33), and solution is propagated up and down the set of grids
Computational solver – 2D vertical, flow and transport

• Steady-state flow and transport are elliptic PDE’s

• Grid size is $\sim 10^4$ (compared to $10^5 – 10^6$ for horizontal)

• Grid is not square

• Use SOR solver
Software design

• AquiferSim groundwater flow and transport model is designed as a stand-alone computational engine separate from user interfaces.

• Can be controlled from GUI’s such as GIS or batch-processing interfaces (e.g., for uncertainty analyses)

• Developed in Microsoft Visual C# on .NET 2.0 framework

• Custom solvers were developed based on standard numerical methods with emphasis on computational speed
Software design contd.

• Engine interfaces directly with data stored as ESRI GRID files – standard raster format in ArcGIS

• Utilises the open source GDAL (Geospatial Data Acquisition Library) through a C# wrapper for this interfacing.

• Slice graphics are created directly by the engine using GDI+

• Typical total computation times of around 30 seconds on a standard Windows Office PC (excluding GIS processing)
Computational performance (excl. GIS interface)
Central Canterbury pilot application

5 secs.
230,000 cells
70 flowpaths

20 secs.
4 x 36,000 cells

Stream Function:
Length: 36 km
Depth: 250 m

Groundwater Age:
years

Nitrate Concentration:
g/m³

Nitrate with Denitrification:
g/m³
Implementation issues

• AquiferSim capacity for input data about groundwater recharge and aquifer properties exceeds typical knowledge base of the end user

• End users (regional councils) may need to commit resources to information sources such as regional groundwater modelling and assessment

• Effects of uncertain knowledge incorporated into AquiferSim by means of predictive uncertainty analysis, which requires many model runs
The way forward

• Current implementation is ongoing at Canterbury Regional Council (ECan)

• Regional groundwater flow model is being calibrated

• Nitrate discharge mapping project is planned

• AquiferSim is to be modified to incorporate desired output information, such as nutrient discharge to specified surface water bodies
AquiferSim is a regional scale, steady-state, nitrate transport model

Predicts long term effects of nitrate discharge on quality of groundwater and groundwater discharge to surface waters

Time scale of effects can be assessed from spatial distribution of groundwater age

Fast run time for scenario and uncertainty evaluations