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

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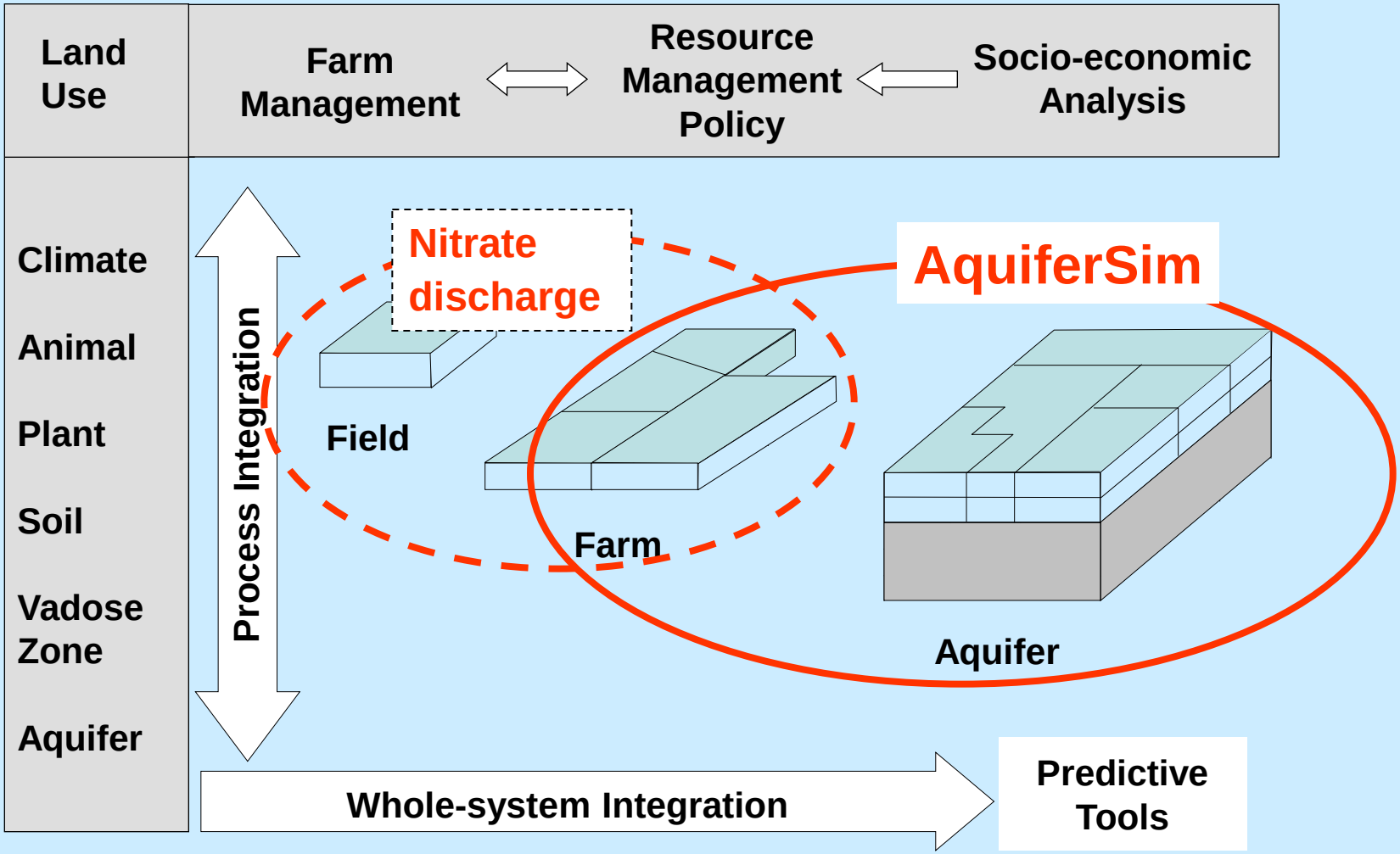
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for aquifer protection
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Farm Management
Resource Management Policy
Socio-economic Analysis
Climate
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Aquifer
Process Integration
Nitrate discharge
AquiferSim
Field
Farm
Aquifer
Whole-system Integration
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 ~ 10^5 – 10^6 cells
- Vertical dispersivity ~ 1 m – 10 m, and vertical resolution of groundwater flow, requires ~ 10 – 100 layers
- Hence, total 3D description ~ 10^6 – 10^8 cells
- Computational time for steady flow, transient transport, model judged to be excessive

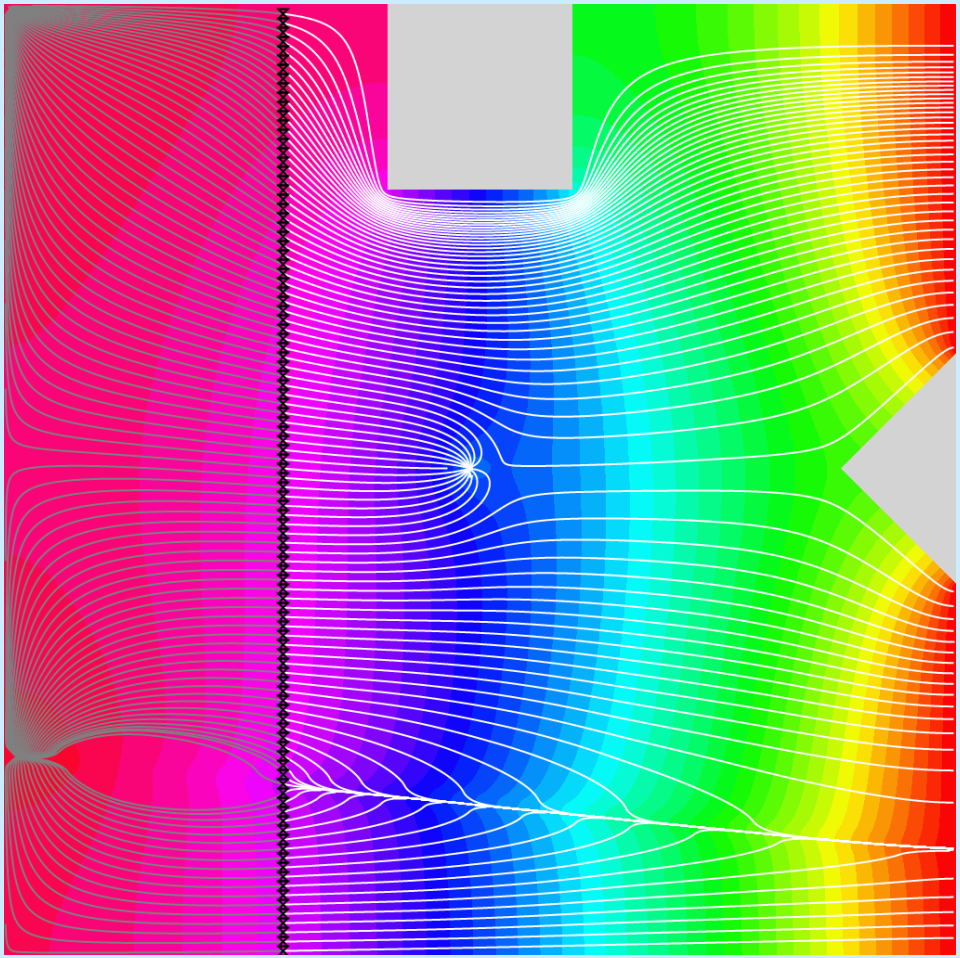
Selected design approach

- 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

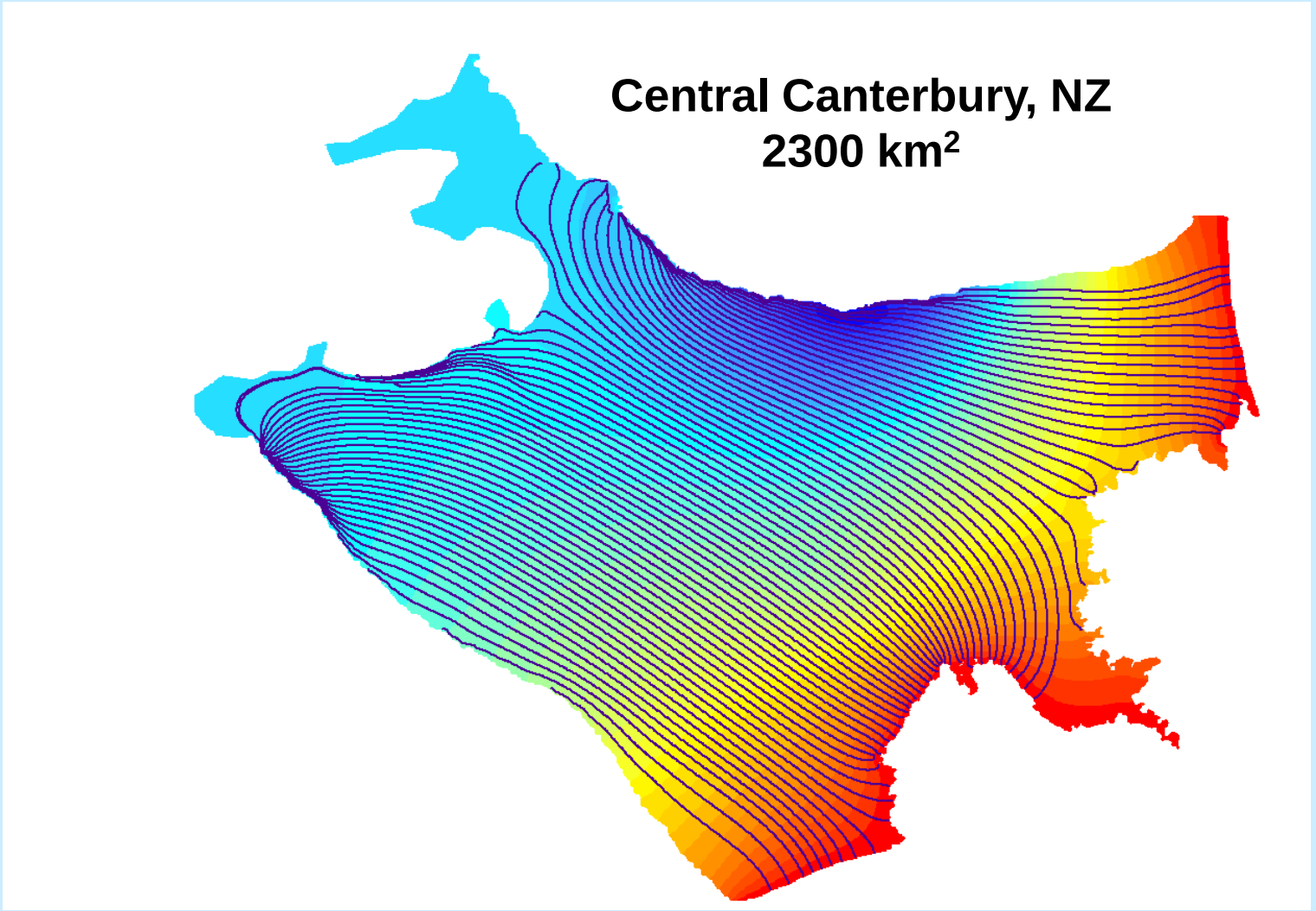
2D/3D groundwater flow

- 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



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

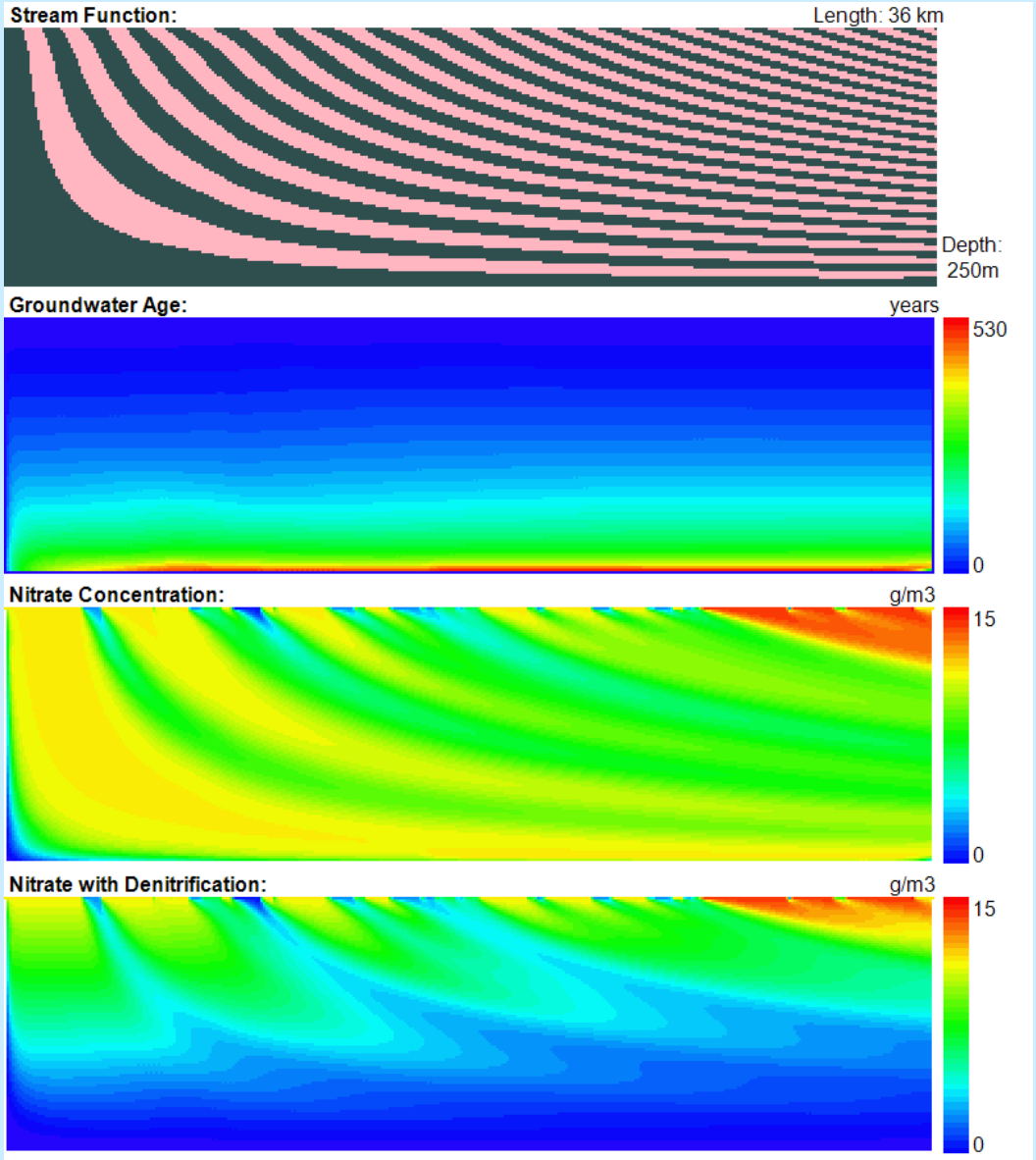
Vertical slice along one groundwater flowpath

Groundwater flow

Groundwater age

Nitrate concentration

Denitrification



Computational solver – 2D horizontal flow

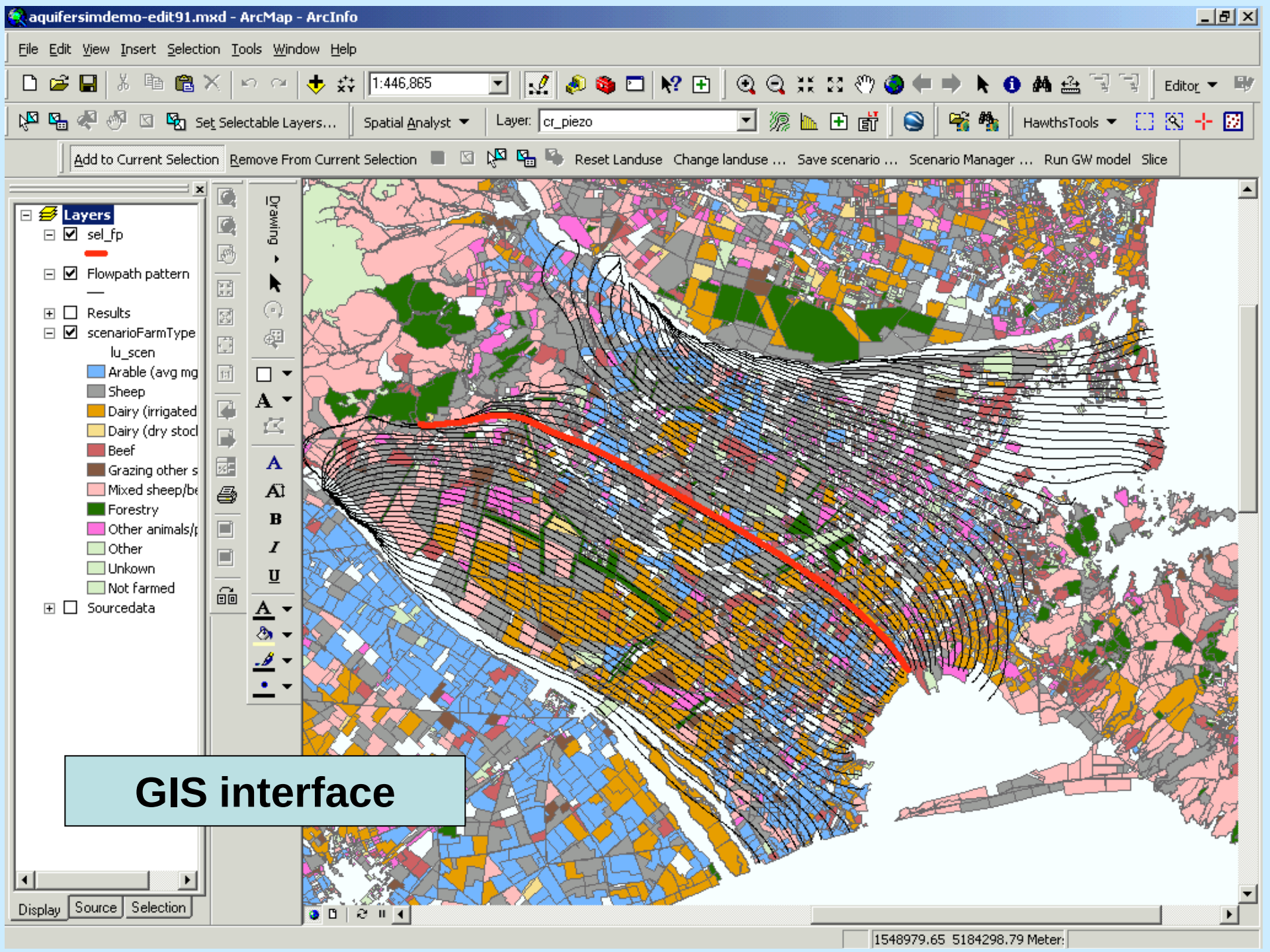
- Steady-state description is an elliptic PDE
- Linear Full Multigrid algorithm (FMG)
- Square computational grids of dimension $(2^n+1) \times (2^n+1)$: six-grid hierarchy, from 33 x 33 up to 1025 x 1025
- Successive over-relaxation (SOR) used for coarsest grid (33 x 33), and solution is propagated 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 ~ 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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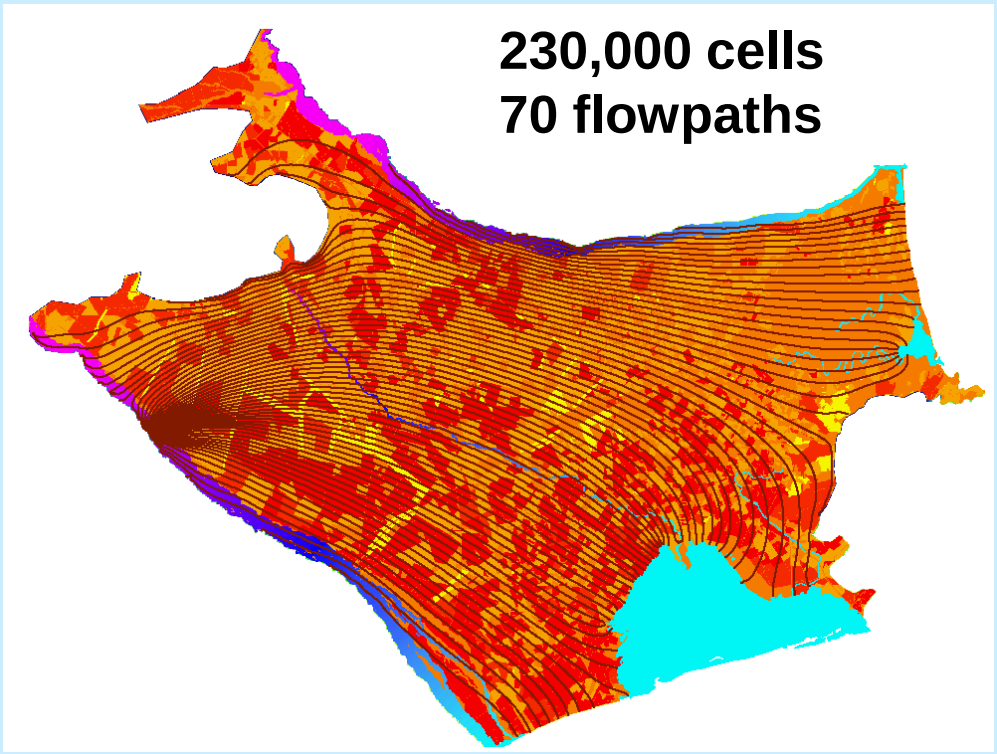
GIS interface

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.



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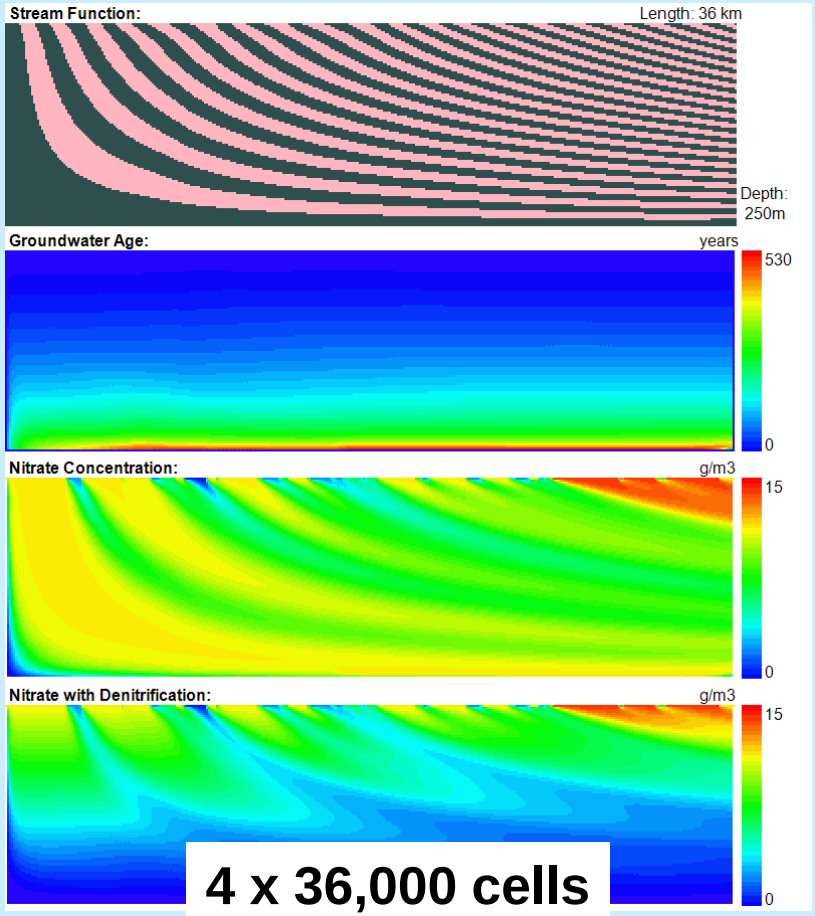

Implementation issues

- 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

Summary

- 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