Strategy for Developing GIS-based Tools for Management of the Effects on Groundwater of Nitrate Leaching from Agricultural Land Use

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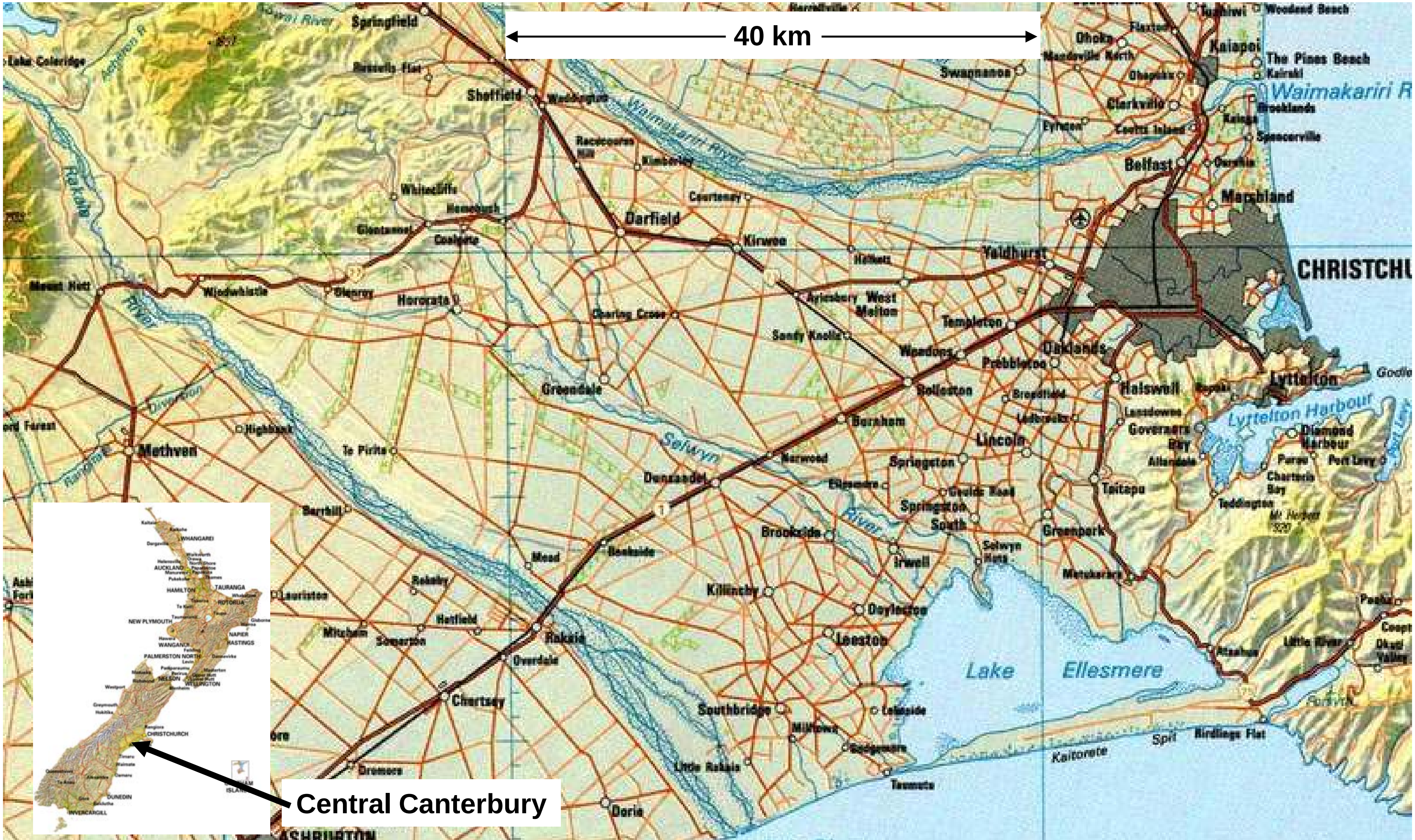
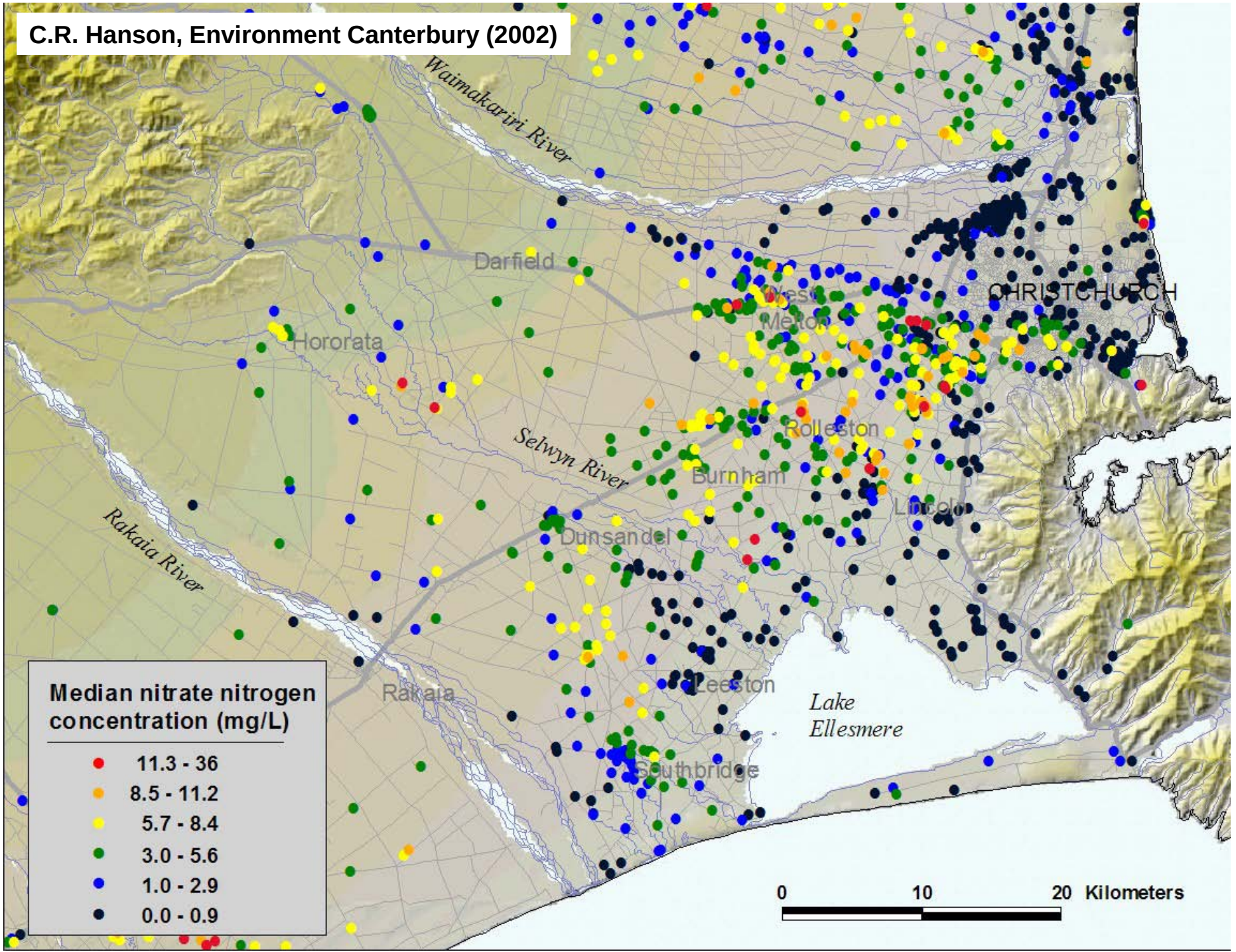
Integrated Research for Aquifer Protection

Outline

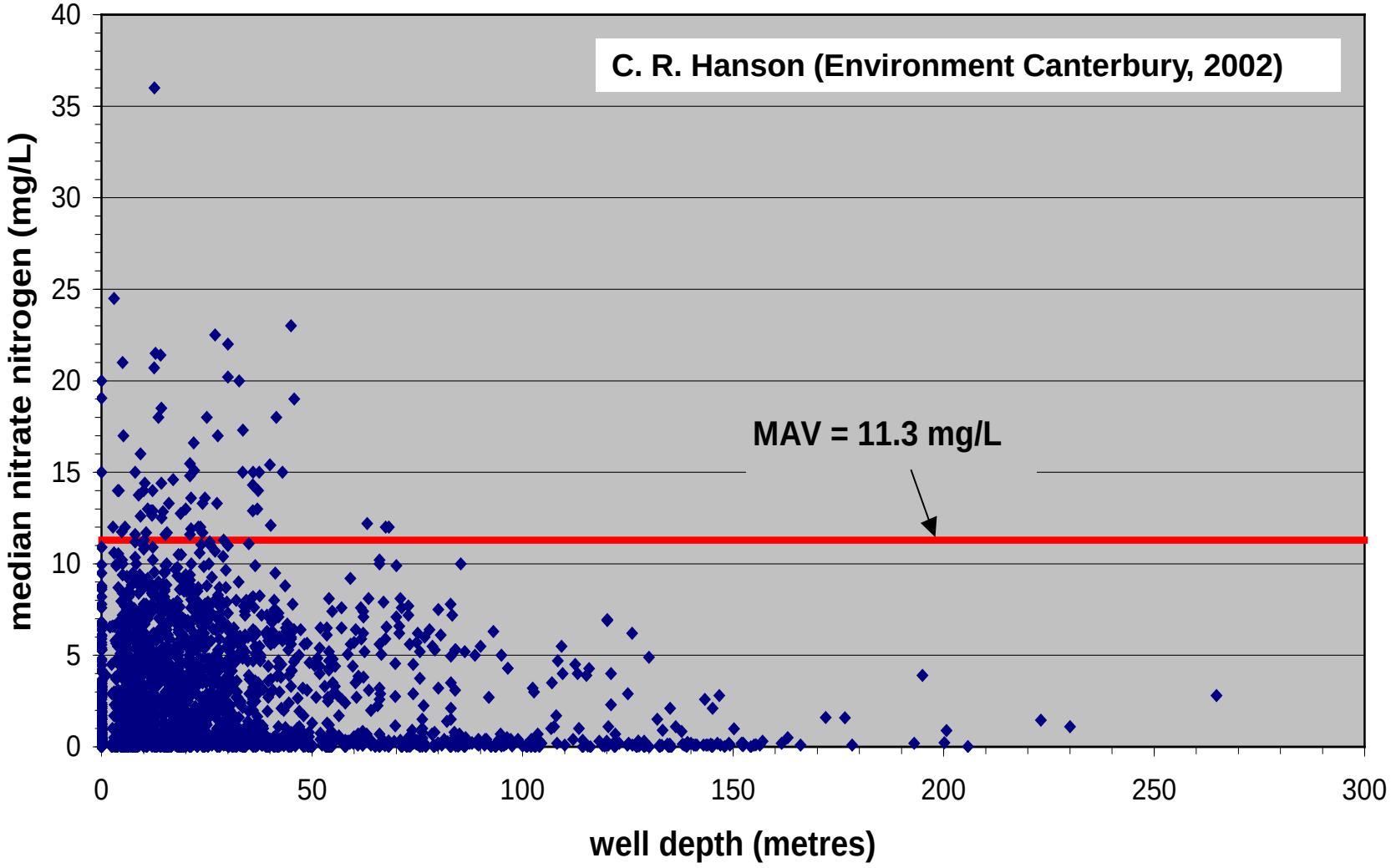
- Problem description
- End users
- Prototype model demonstration
- GIS issues
- Models, software, intellectual property
- Uncertainty

Central Canterbury: an example region




C.R. Hanson, Environment Canterbury (2002)
Waimakariri River
Darfield
Hororata
Selwyn River
Rakaia River
Rakaia
Leeston
Lake
Ellesmere
Southbridge
Dunsandel
Burnham
Rolleston
Lincoln
Templeton
Halswell
CHRISTCHURCH
Median nitrate nitrogen concentration (mg/L)
11.3 - 36
8.5 - 11.2
5.7 - 8.4
3.0 - 5.6
1.0 - 2.9
0.0 - 0.9
0
10
20 Kilometers

Nitrate vs well depth



Nitrate effects in groundwater

- Knowledge of the vertical distribution within an aquifer is important for access to groundwater of drinking quality

- This distribution is determined by the spatial distribution of contaminating land uses above an aquifer and the contributions of all aquifer recharges in terms of flow and quality

- The combine mass flow of nitrate and water from all recharges determines groundwater discharge to surface waters

Users and stakeholders

- Staff of Regional Councils responsible for environmental management under the Resource Management Act (1991) in New Zealand
- District Councils (local government)
- Owners of agricultural enterprises that discharge nitrate to groundwater
- Maori (under Treaty of Waitangi)
- Ministries of Agriculture and Environment
- Agricultural industries

An example of the desired process

- This is work in progress
- The following example is obtained by means of the AquiferSim model in its Excel-based prototype form
- Use of GIS noted

Example of a planning question:
What are the nitrate effects on groundwater of this area of land (GIS) being changed from sheep grazing to dairy farming?

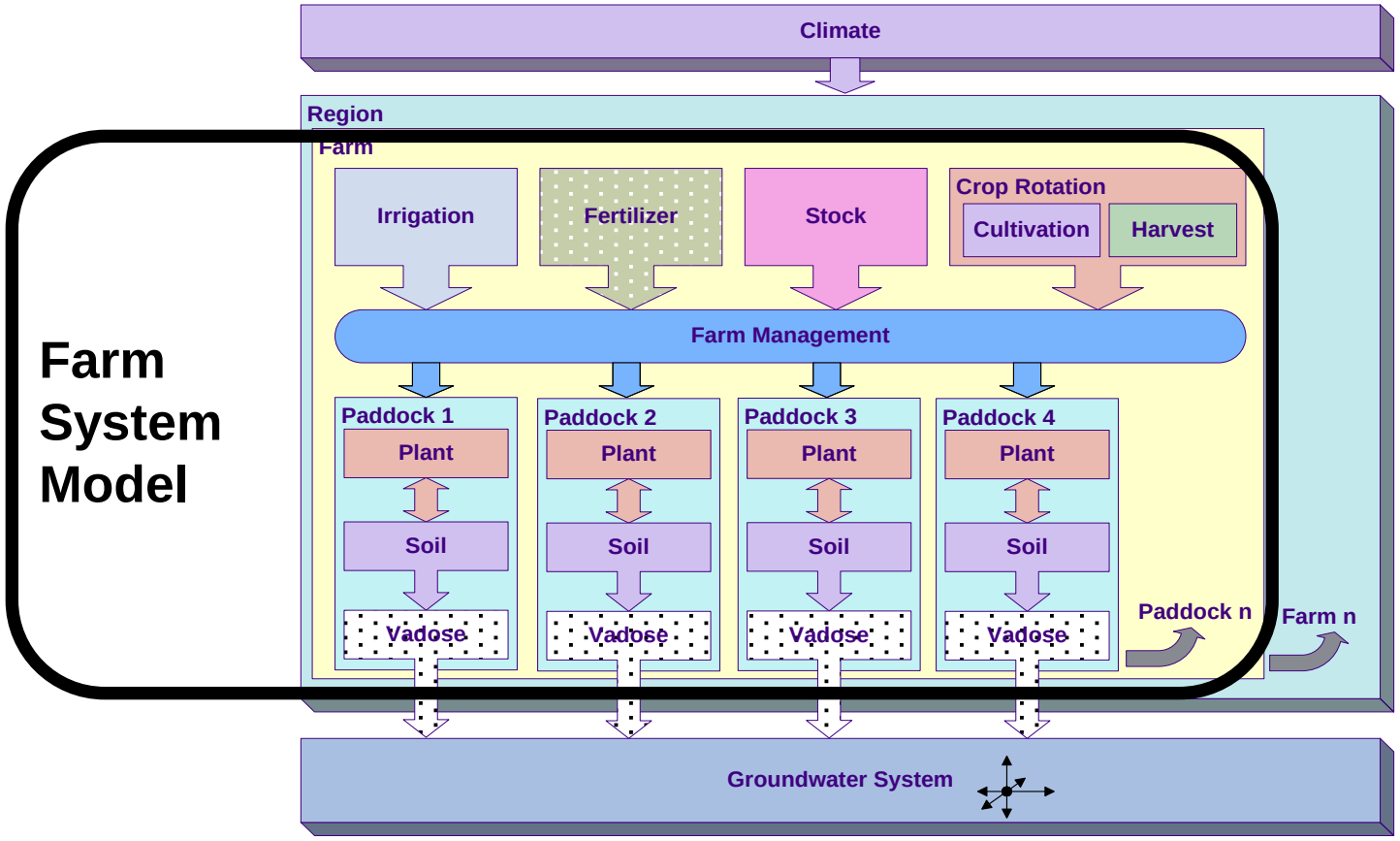
The region of effects is determined by the directions of groundwater flow downstream of the land area.
These directions are obtained from model of steady-state regional groundwater flow, represented as a piezometric surface (GIS)

Nitrate discharge for each land use (GIS) is provided by values from literature, or from land management models, in terms of

- Annual recharge (river, rainfall and irrigation)
- Annual nitrate loading (concentration)

Land use	Recharge (mm/y)	Nitrate-N (g/m^3)
Rakaia River	0.6 $m^3/s/km$	0
Dairy	250	12
Forest	100	1
Sheep	150	3
Crops	200	15

FarmSim: a land management model (Good and Bright, MODSIM05)



FarmSim operation

- Daily time step
- Use off-line with revised inputs for new farm management scenarios
- Calculate new values of annual recharge and nitrate concentration
- Map these values onto GIS land use database

Groundwater models - AquiferSim

- Groundwater flow and contaminant transport models are steady state because of the likely computational time required for metre-scale dispersion calculations over regional scales (~ 1000 km^2)

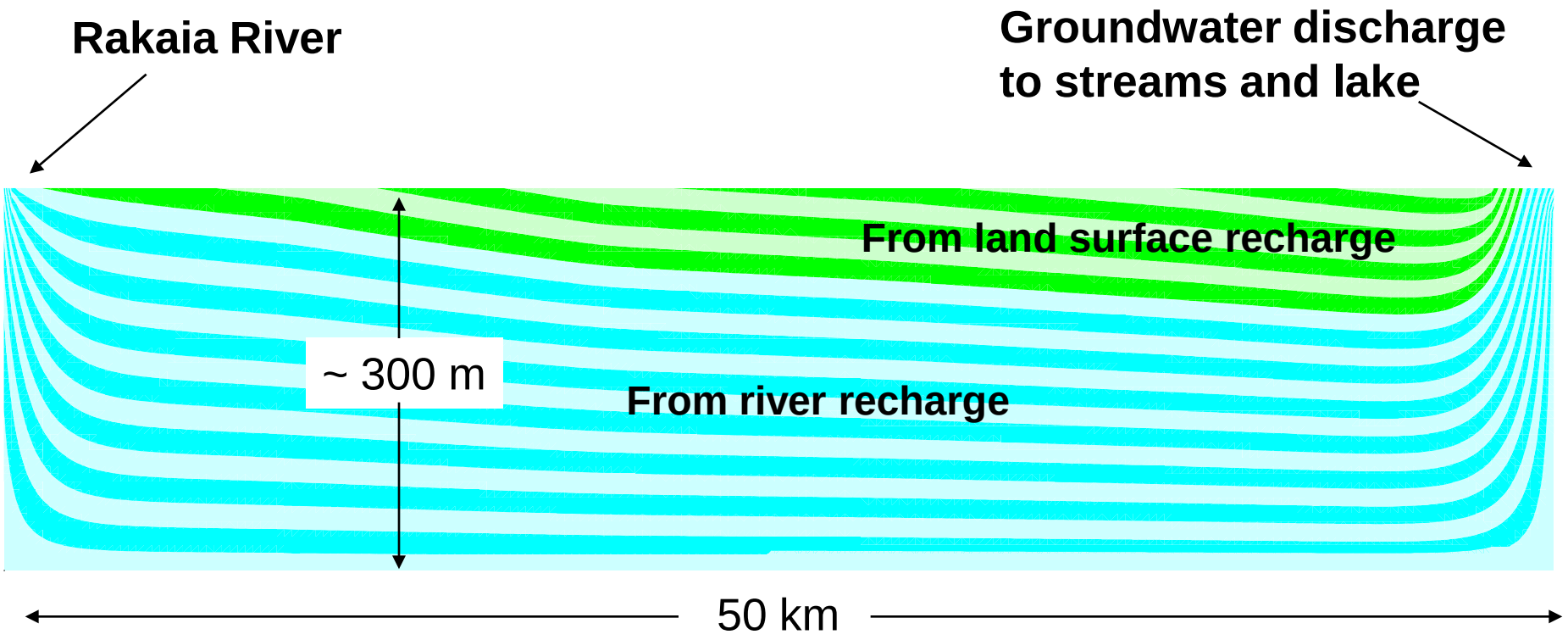
- 2-D vertical distribution of groundwater flow along flow paths is determined by stream function analysis

- Advective-dispersive contaminant transport in groundwater is simulated by a 2-D mixing-cell model at scales of ~ 1 m vertical and ~ 100 m horizontal

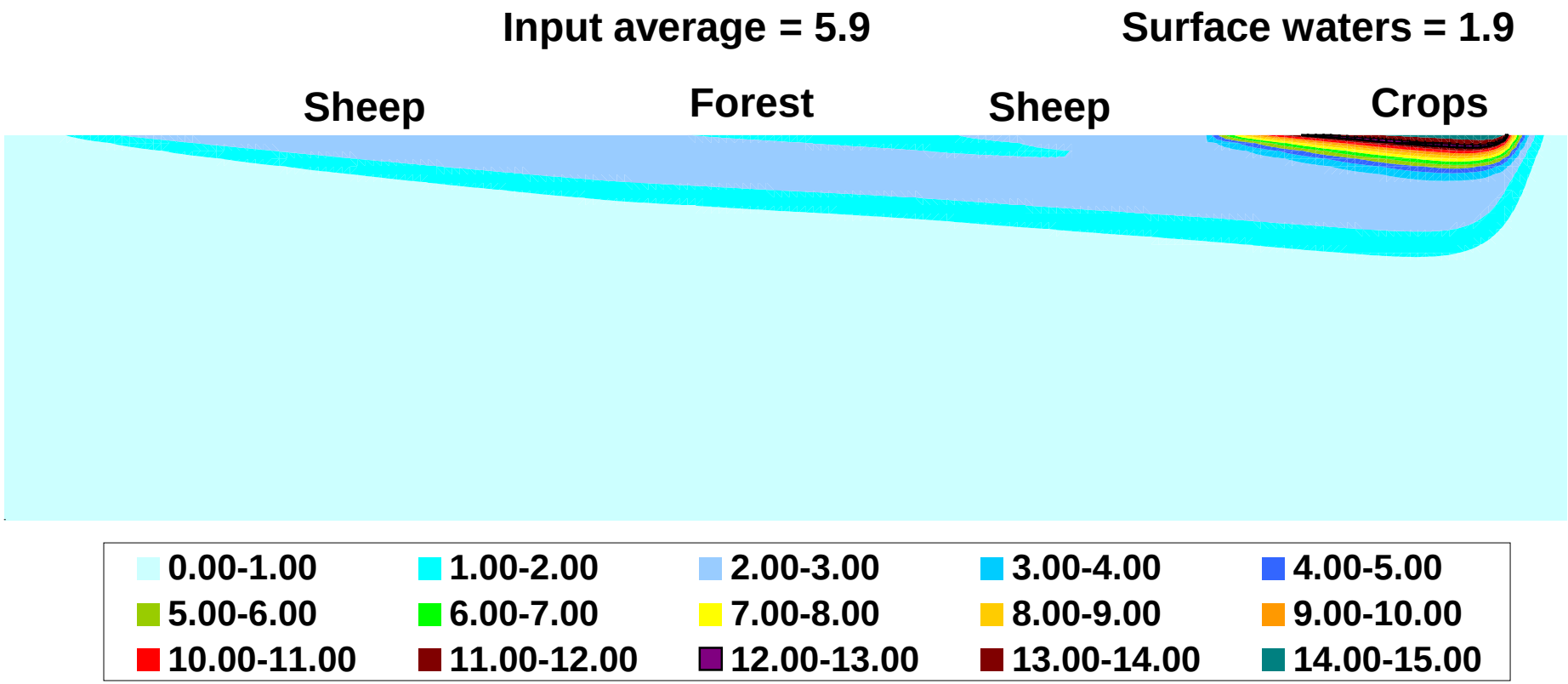
Groundwater flow paths are determined by gradient searches of the piezometric surface (GIS function).
Nitrate effects can be seen by viewing vertical slices of the aquifer along groundwater flow paths.

- **Vertical distribution of groundwater flow in the slice along the groundwater flow path – from streamfunction analysis**

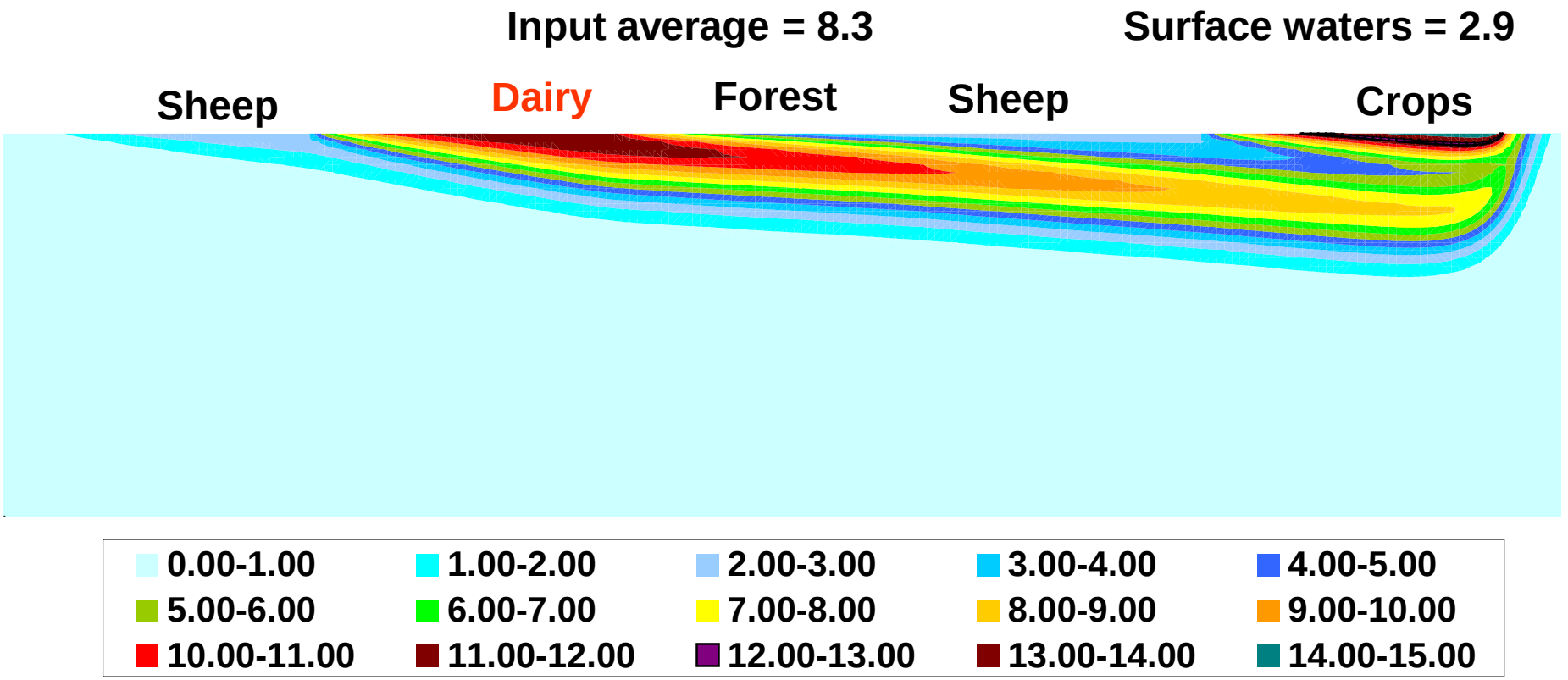
- **River recharge from the provides most of the groundwater flow in this example.**



- **Predicted distribution of nitrate in the vertical slice of aquifer along the selected flow line, before the proposed dairy farming.**
- **Much of the aquifer is uncontaminated by nitrate from the land surface because of recharge from the Rakaia River**



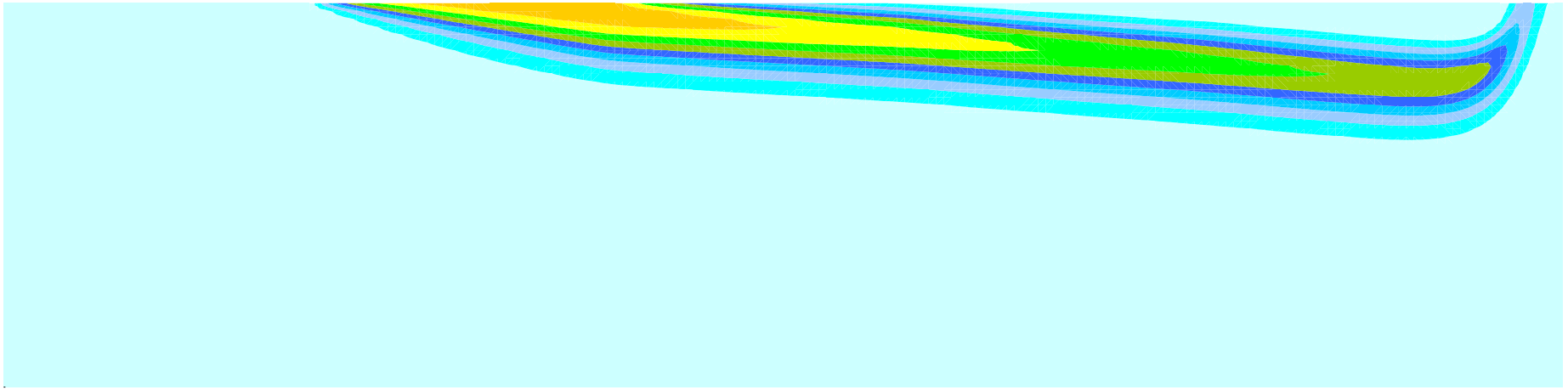
- **Introduction of the proposed area of dairy farming would change the amount and distribution of nitrate in the aquifer.**



Change in nitrate concentration from the proposed change in land use.

Input average = 2.4

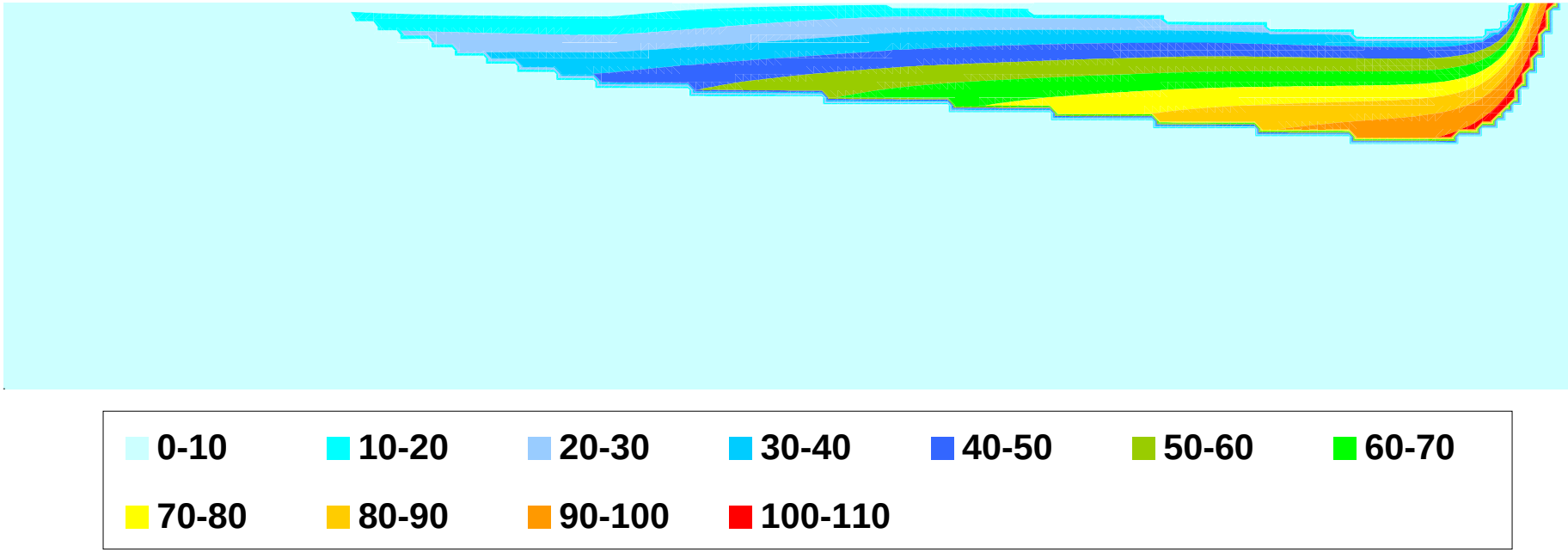
Surface waters = 1.0



0.00-1.00	1.00-2.00	2.00-3.00	3.00-4.00	4.00-5.00
5.00-6.00	6.00-7.00	7.00-8.00	8.00-9.00	9.00-10.00

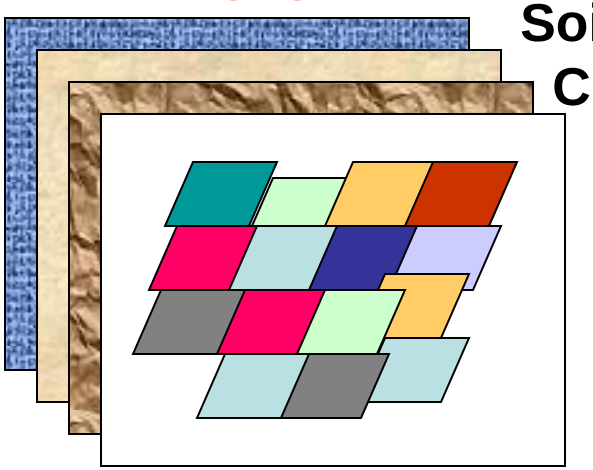
Nitrate concentration g/m^3

Association of groundwater age and long term increase in nitrate-N concentrations of more than 1 g/m^3



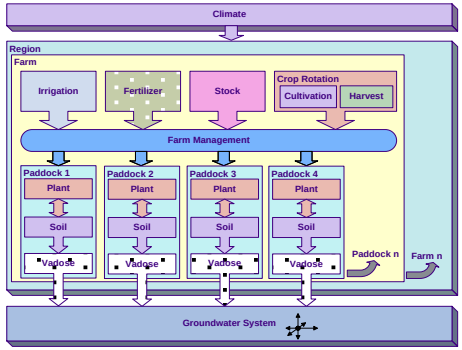
The complete process

GIS



Soil
Climate
Farm type

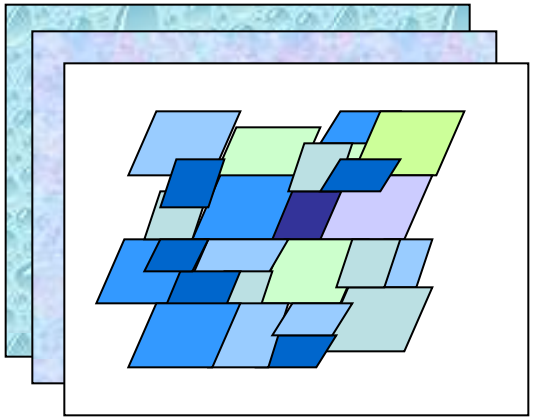
FarmSim



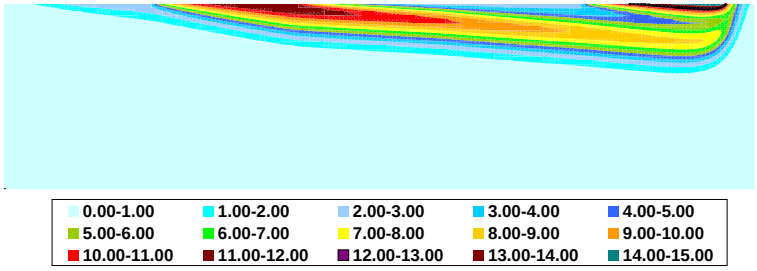
Nitrate concentration & recharge

Aquifer data

GIS



AquiferSim



GIS issues

- User interface is partially geographical (GIS)
- Not all users have GIS, or even the same type
- Databases originate from various stakeholders, and have varying degrees of confidentiality
- Some model developers do not have GIS licence
- Web-based GIS system or open source GIS components are being considered

Software, models, and IP

- Models are contributed by several agencies, in both public and restricted-access form
- Public models are being recoded in .NET
- Restricted models are wrapped in interfaces that connect to .NET architecture
- IP issues not yet all resolved
- GIS databases will interface with .NET architecture

Predictive uncertainty: the approach

- End users want quantification of uncertainty
- Identify contribution of each model parameter to desired predictions
- Recognise the irreducible predictive uncertainty from unobservable processes
- Simple, robust estimation of uncertainty (quick alternative to Monte Carlo)