AGRICULTURAL NON-POINT SOURCE POLLUTION:
MODELLING & ECONOMICS

André Görgens (Editor)

Simon Lorentz (Presenter)

Another project sponsored by www.wrc.org.za

Research context

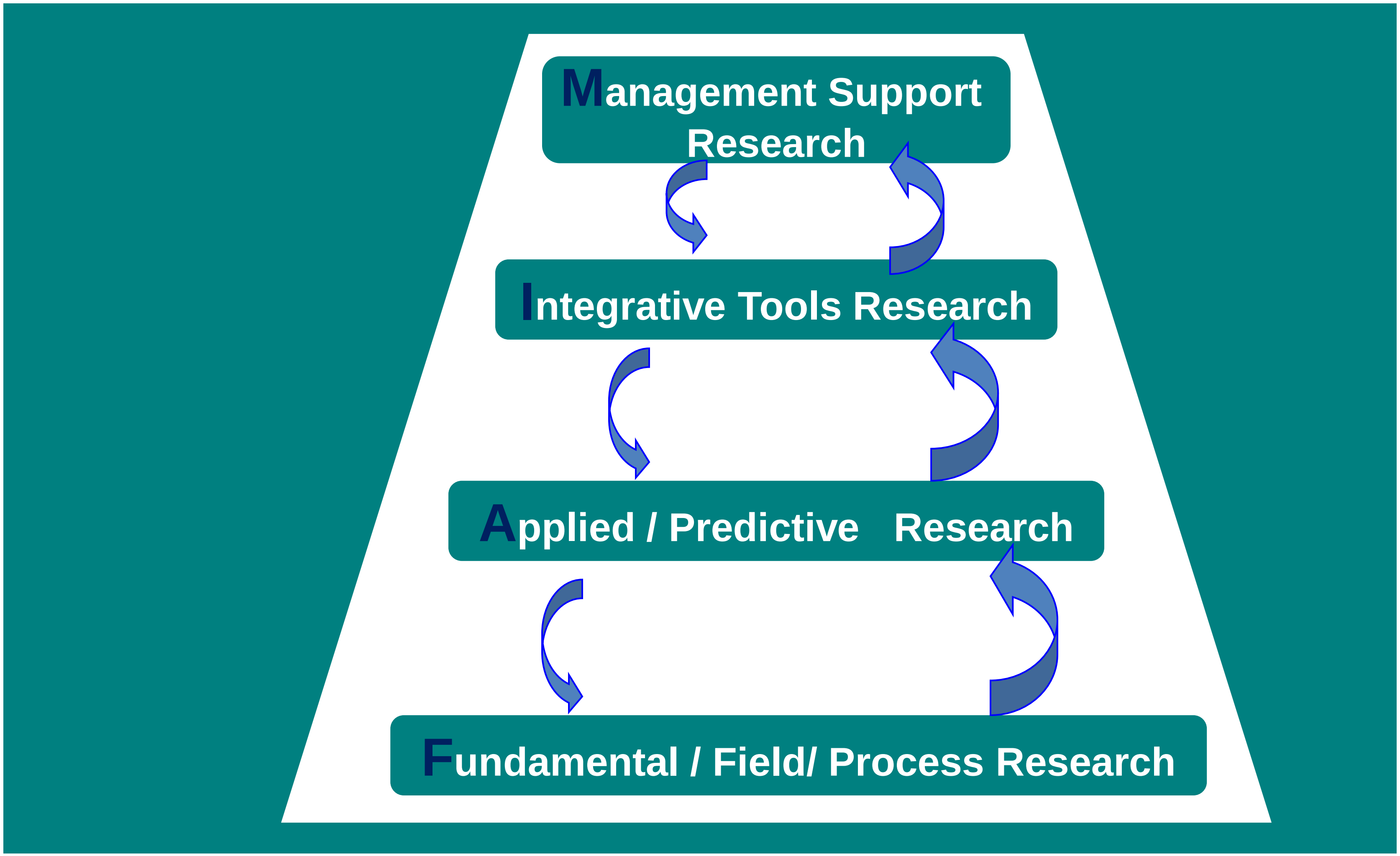
- Agricultural activities well recognised as a contributor to surface & groundwater pollution in particular catchments
- Point sources: feed-lots, fruit processing factories, wine cellars, agricultural waste stockpiles
- Non-Point sources: inter-connected function of fertilizing & crop rotation & tillage & drainage & pesticide & riparian/ wetland practices, etc….

➢ ***Economics of both agricultural pollution impacts and their control measures… ??***

Research context (cont.)

- In 2005, WRC commissioned a widely-consulted “Knowledge-and-Gaps Synthesis”, regarding agriculturally-related water pollution, eventually captured in two extensive WRC Reports
- In 2006, WRC commissioned a solicited research project of duration 6 years, based on a TOR formulated ito priorities formulated during the prior “Synthesis”

Conceptual research structure : FAIM



Research foci and scales

- Focus pollutants: Nutrients (N & P); Sediments; selected Pesticides
- Scale for N & P & S – observed and simulated Field-scale processes as well as Catchment-scale dynamics and connectivities
- Scale for Pesticides – Field-scale DSS

Details of research teams & their foci

- *UP & UFS* – Nutrients & Crop Production: Field-Scale Process Monitoring & Modelling

- *UKZN* – Nutrients, Sediments & Crop Production: Catchment-Scale Monitoring & Modelling

- *ARC* – Nutrients & Sediments: Catchment-Scale Modelling

- *UFS* – Economics of Agricultural Pollution Control Management
- *UWC / CSIR* – Pesticides: Field-Scale Monitoring & Decision Support System

- *Aurecon* - Conceptual Project Leadership & Administrative/ Financial Management

WATER RESEARCH COMMISSION

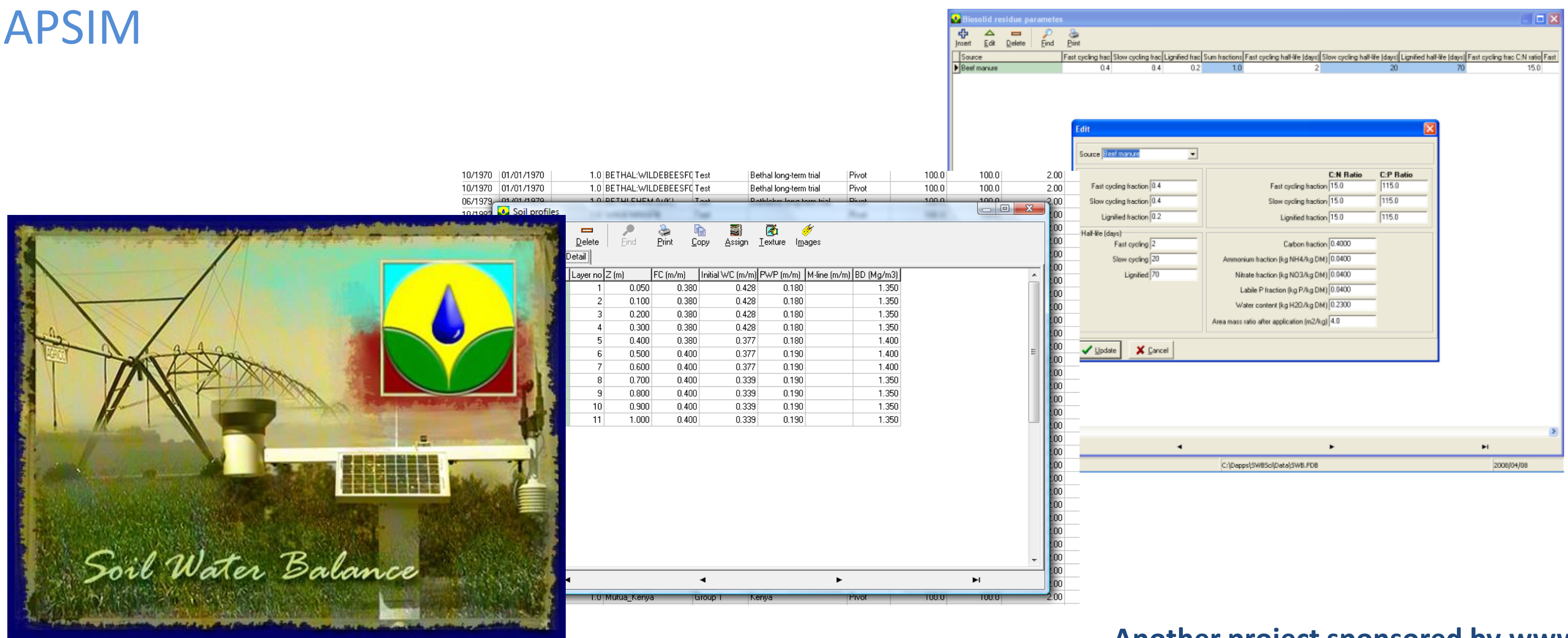
Field-Scale Nutrient Modelling Team

Michael van der Laan, John Annandale and Chris du Preez

Another project sponsored by www.wrc.org.za

Soil Water Balance (SWB-Sci) model

- Mechanistic, generic crop model
    - Originally developed as a real-time irrigation scheduling tool
    - Layered, cascading soil water balance
- Nitrogen and phosphorus subroutines included to enable local scale NPS pollution studies
    - Algorithms mostly adapted from existing models CropSyst, Gleams, SWAT, APSIM



Another project sponsored by www.wrc.org.za

Suggested equations for the estimation of labile P pool size for South African soils

WATER RESEARCH COMMISSION

Soil Group	Number of observations	R^2
Slightly weathered	35	
P_{lab} = 0.56BP1 + 5.1[§]		0.79
= 1.07OP + 4.1[§]		0.77
= 0.13MP1 + 11.4[§]		0.39
= 0.69AP + 7.2[ι]	n/a	
= 0.24BP2 + 5.9[ι]	n/a	
= 0.38IP* + 4.69[ι]	n/a	
Highly weathered	20	
P_{lab} = 0.14BP1 + 4.2[§]		0.83
= 0.55OP + 2.1[§]		0.74
= 0.24MP1 + 2.9[§]		0.51
= 0.17AP + 4.7[ι]	n/a	
= 0.059BP2 + 4.4[ι]	n/a	
= 0.09IP + 4.1[ι]	n/a	
Calcareous	23	
P_{lab} = 0.55BP1 + 6.1[§]		0.76
= 1.09OP + 3.2[§]		0.61
= 0.10MP1 + 10.2[§]		0.84
= 0.68AP + 8.2[ι]	n/a	
= 0.23BP2 + 6.89[ι]	n/a	
= 0.37IP + 5.70[ι]	n/a	

* All P tests on a mass basis (mg kg^{-1}), except the IP test which is on a volume basis (mg l^{-1})

Soil Group	Number of observations	R^2
Highly weathered acid tropical (> 30% Al saturation)	32	
P_{lab} = 0.41BP1 + 5.55[†]		0.86
= 0.20TP + 5.62[†]		0.80
= 0.43CP + 4.21[†]		0.84
= 0.64MP3 + 5.72[†]		0.71
= 0.50AP + 7.12[ι]	n/a	
= 0.17BP2 + 6.14[ι]	n/a	
= 0.28IP + 5.25[ι]	n/a	
Highly basic calcareous (> 50 g kg^{-1} $CaCO_3$)	23	
P_{lab} = 0.69BP1 – 1.76[†]		0.35
= 0.96OP – 0.19[†]		0.90

Van der Laan et al. (2010) South African Journal of Plant and Soil, 26, 213-219

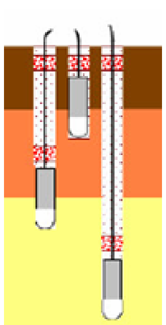
Simulating draining and resident soil water nitrate concentrations

- Incomplete solute mixing accounted for using the approach developed by Corwin et al. 1991

$$[Solute]_{mob} = \frac{SoluteMass_{layer} \times F_{mix}}{\theta_{layer} \times d_{layer} \times \rho_w}$$

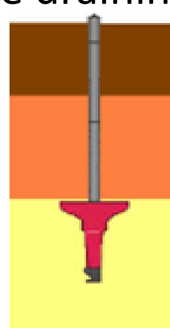
$[Solute]_{mob}$ = mobile soil water phase solute concentration
$SoluteMass_{layer}$ = mass of solute in layer
F_{mix} = solute mixing fraction
θ_{layer} = volumetric water content of layer
d_{layer} = depth of layer
ρ_w = density of water

- Tested using active and passive soil water samplers in a large drainage lysimeter facility

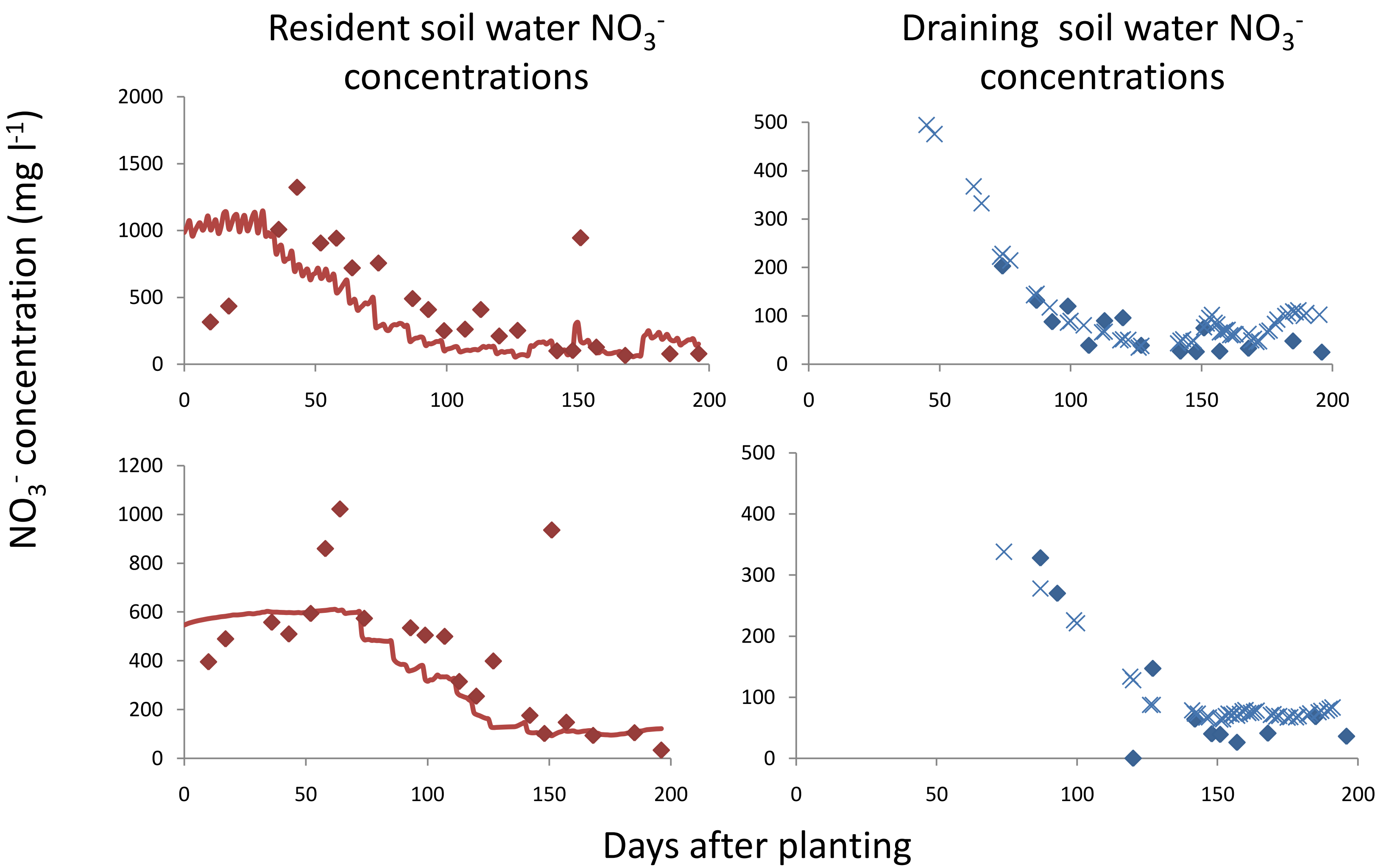


Ceramic suction cups
~ sample resident soil water

Wetting front detectors
~ sample draining soil water



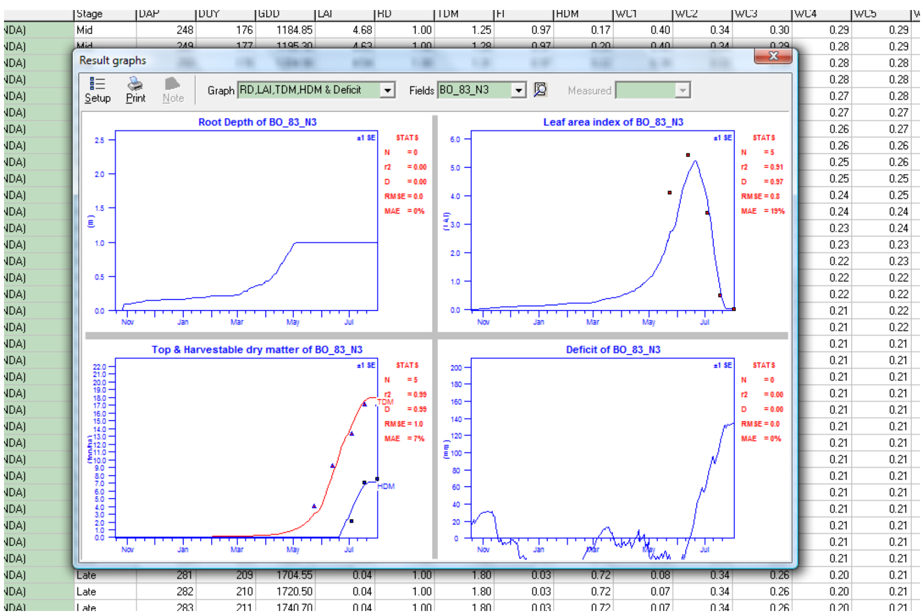
NO_3^- concentrations (0-30 cm)

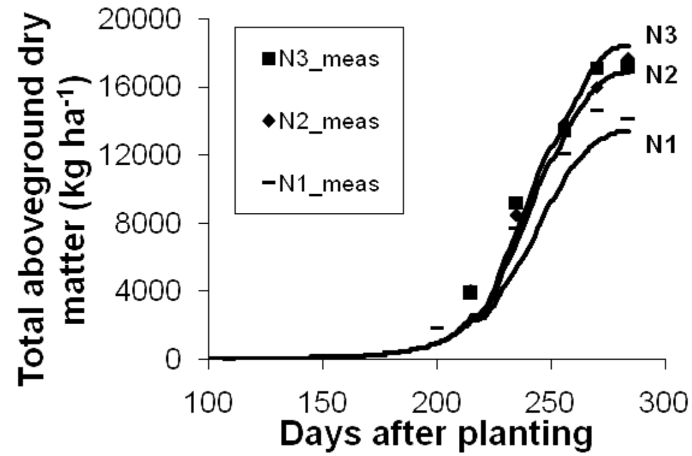


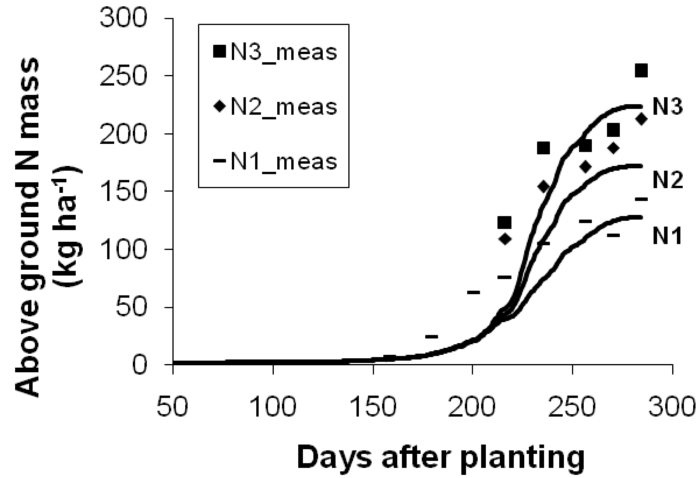
Van der Laan et al. (2010) Agricultural Water Management, 97, 1779-1786

Additional model evaluation

Further testing using historical datasets from South Africa, the Netherlands and Kenya







Another project sponsored by www.wrc.org.za

Catchment-scale model parameterisation

- Guidelines for catchment scale model parameterisation developed
- Makes use of information from land-type maps (1:250 000)
- e.g. Grouping of South African soils as slightly weathered, highly weathered or calcareous

Soil form			
Group 1	**Group 2**	**Group 3**	**Group 4**
Kranskop	Arcadia	Katspruit	Champagen
Magwa	Inhoek	Fernwood	Nomanci
Inanda	Milkwood		Sterkspruit
Avalon	Mispah		Estcourt
Pinedene	Rensburg		Kroonstad
Glencoe	Willowbrook		Constantia
Clovelly	Bonheim		Shepstone
Bainsvlei	Tambankulu		Houwhoek
Hutton	Mayo		Lamotte
Shortlands	Swartland		Cartref
	Valsrivier		Wasbank
	Vilafontes		Longlands
	Oakleaf		Westleigh
	Glenrosa		Dundee

Van der Laan et al. (2010) South African Journal of Plant and Soil, 26, 213-219

WATER
RESEARCH
COMMISSION

Catchment-Scale Modelling Team

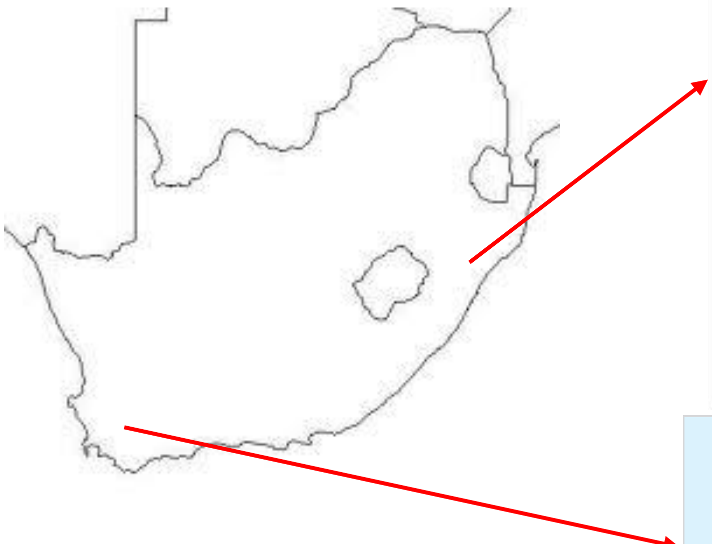
Simon Lorentz, David Clark and Julius Kollongei

Another project sponsored by www.wrc.org.za

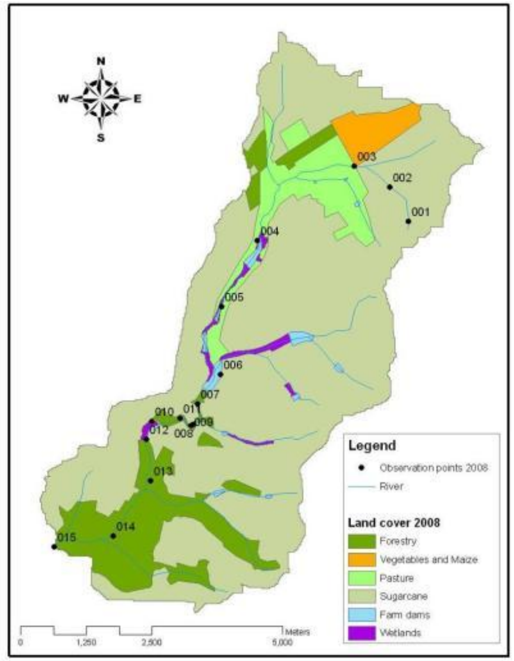
Catchment-Scale Sediments and Nutrients

- *Experimental catchments:*

Wartburg,
KZN Midlands



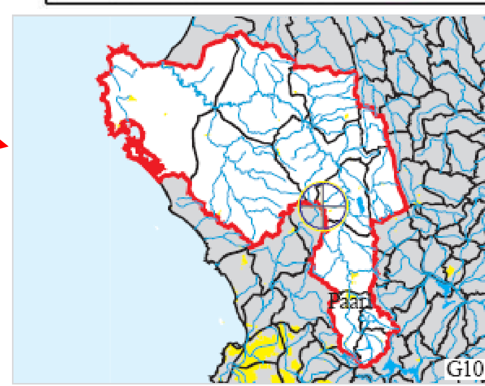
Goedertrou,
Western Cape

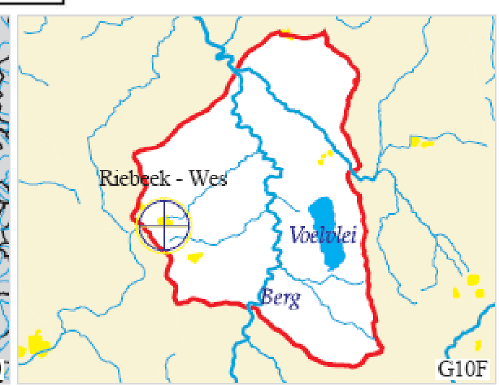


- *Different climate zones*

Wartburg:
Summer rainfall 740mm/a
Sugar, forestry
Well-poorly drained soils

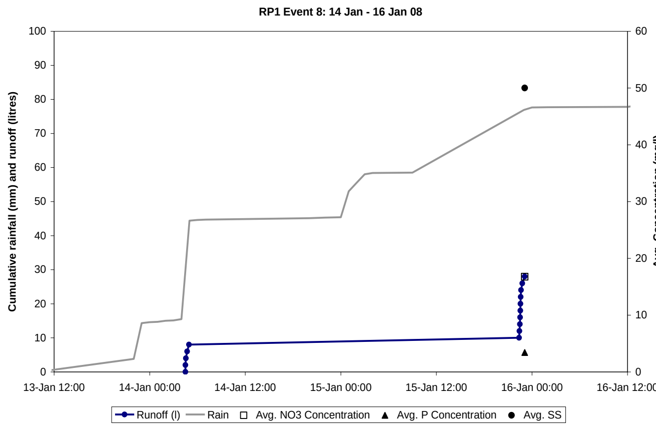
Goedertrou:
Winter rain 330mm/a
Dryland winter wheat
Sandy clay loam- Clay loam



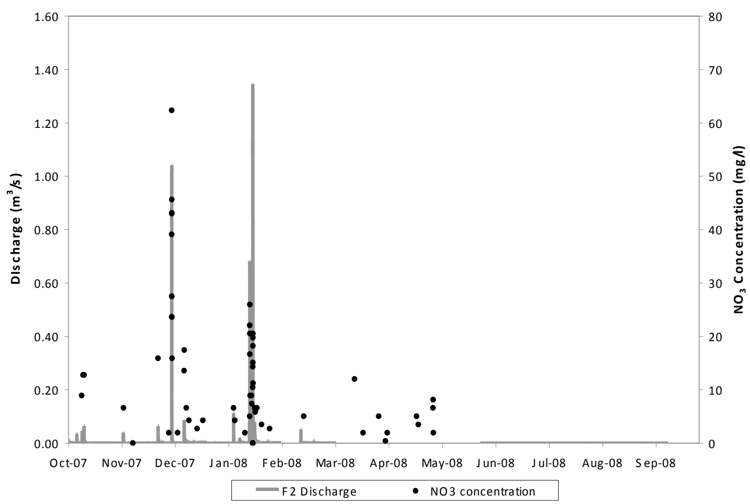


- *Catchment scale model development and simulation*

Multi-scale observation

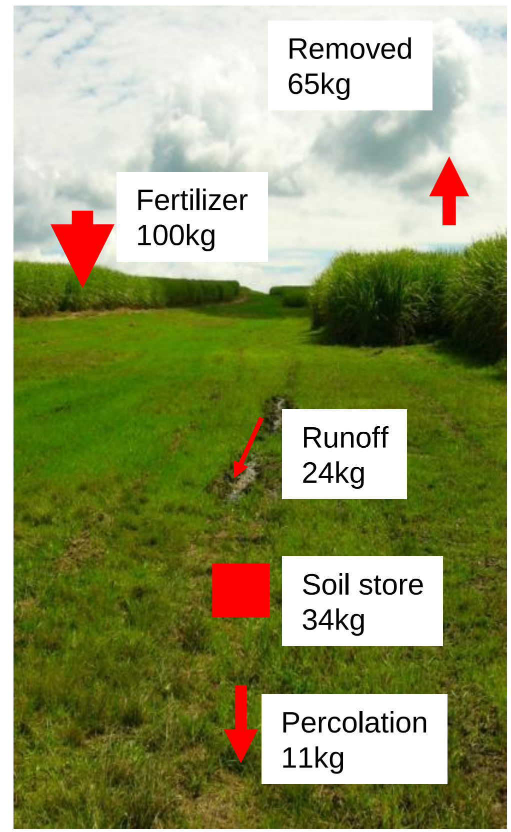


- Local scale, runoff plots
- Field scale, flumes

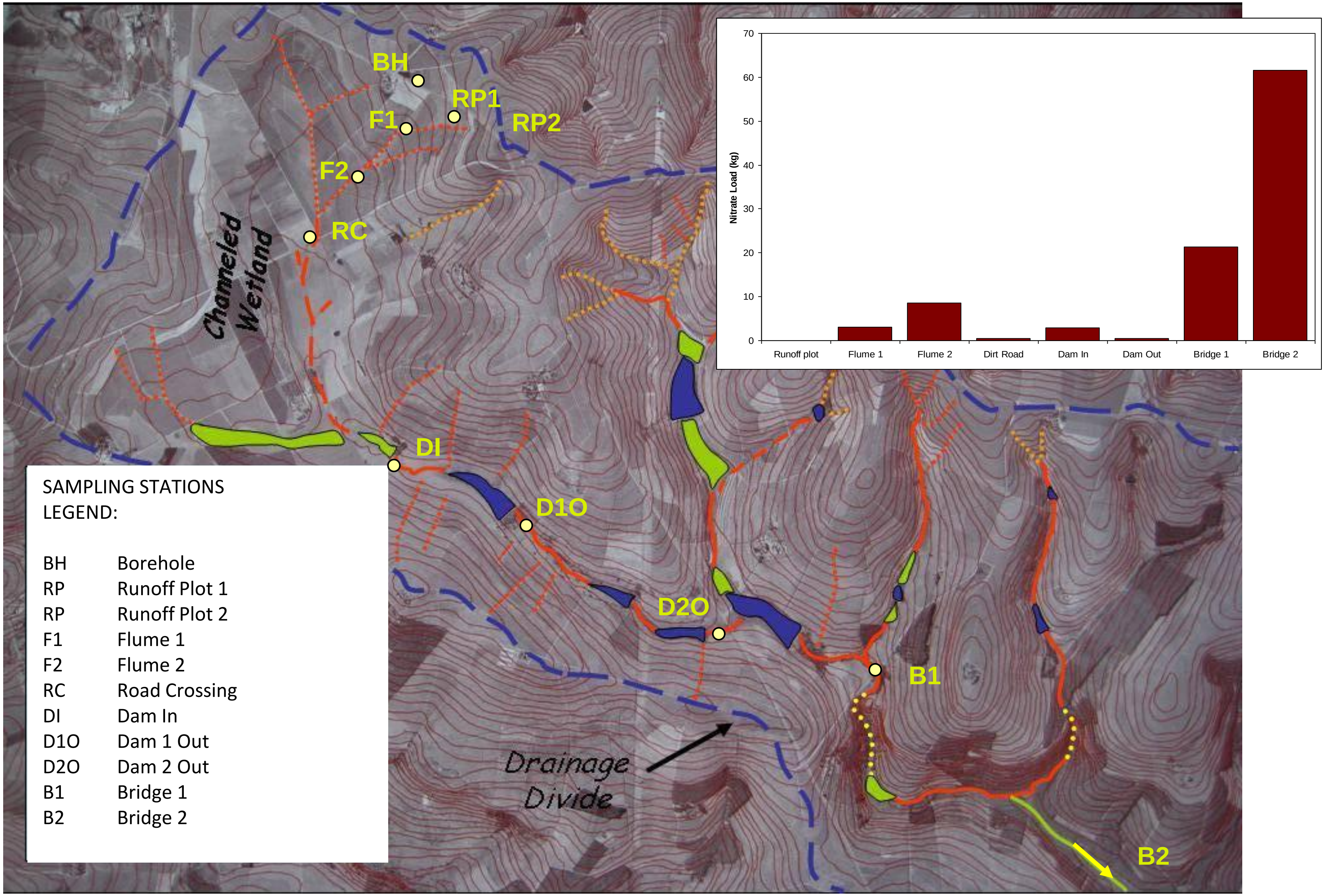


- Catchment scale, rated section - grab sampling

Nitrogen N mass balance per ha per annum

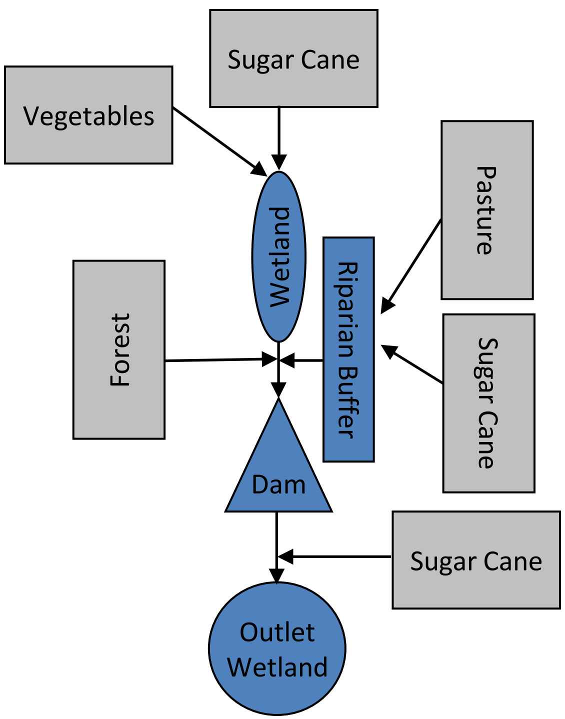


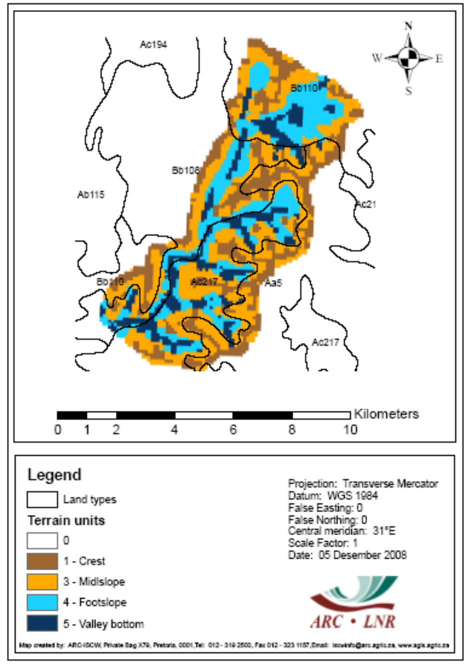
Nutrient and sediment connectivity

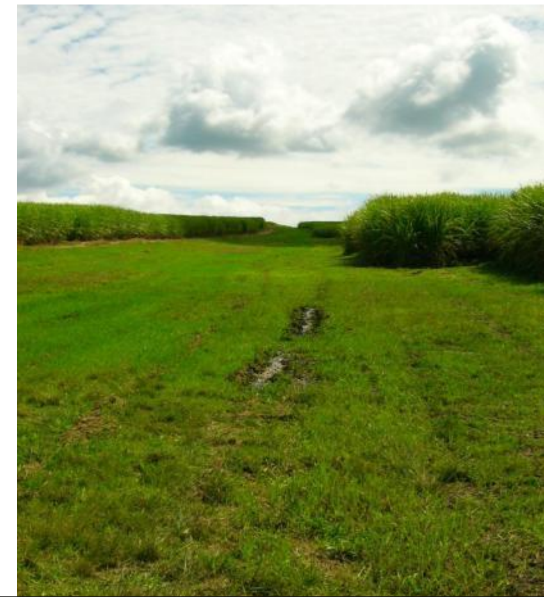


ACRU-NP Model Development

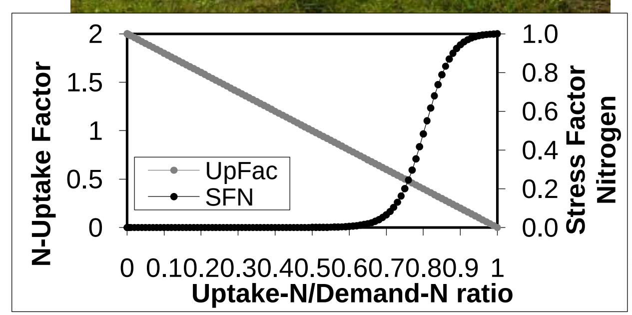
- Water quality connectivity and controls





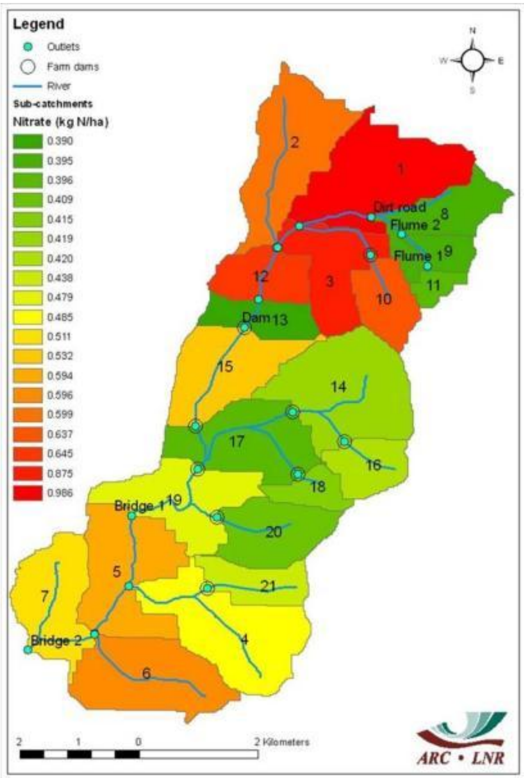


- Input parameter derivation from Land Types

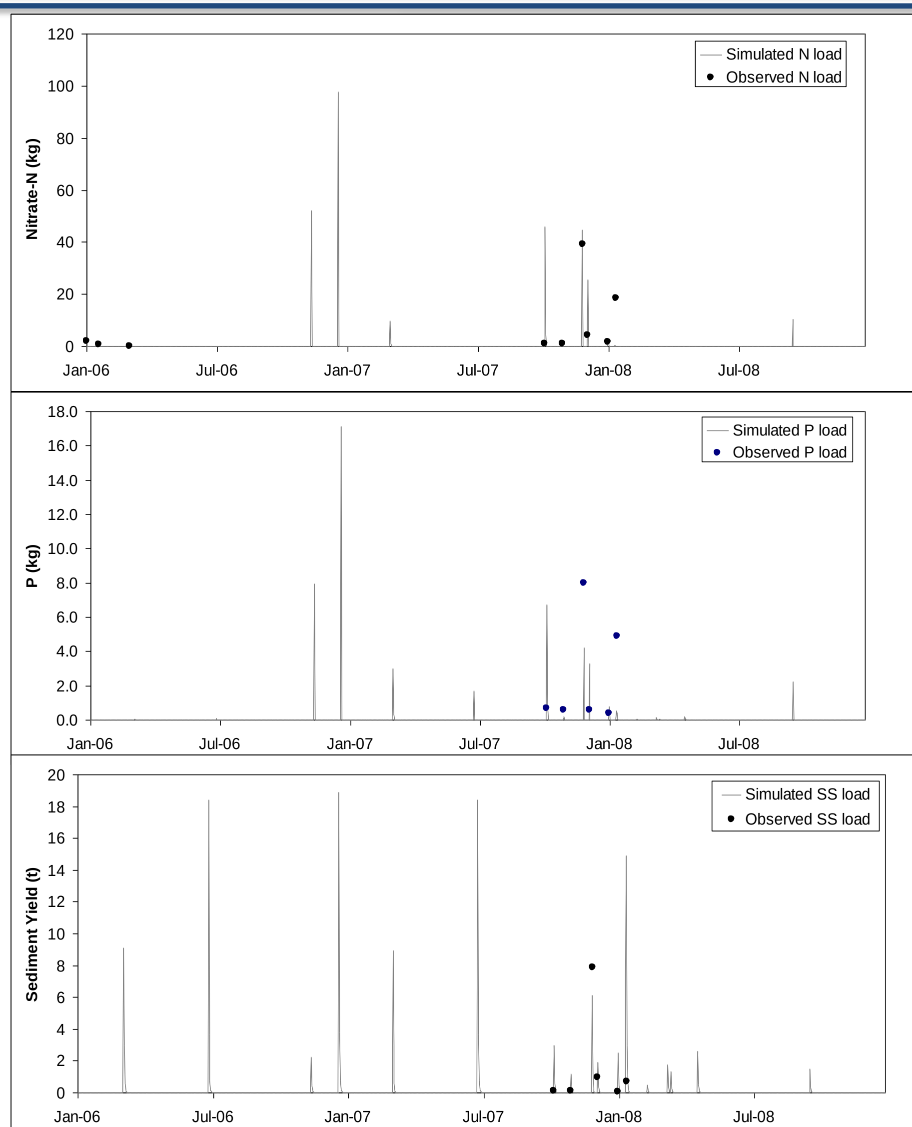


- Crop response to water and nutrient stress

Modelling Results



SWAT : N loads



Flume 2
ACRU-NP : NO_3

Phosphorus

Suspended solids

Catchment-scale nutrients and sediments

Conclusions

- Scaled observations quantify connectivity and controls
- *ACRU-NP* development, including influence of controls, aids nutrient management and identifies hotspots.

Recommendations

- Testing nutrient stress and crop yield,
- Study migration of organic P
- Detailed observation of control features and hillslope connectivity

WATER RESEARCH COMMISSION

Pesticide Task Team

Nebo Jovanovic

Aims and approach

- Identification of primary processes, state-of-the-art in modelling and knowledge gaps
- Data collection to support integrated modelling at different scales
- Development of an expert system for pesticides

Fundamental processes

Primary processes with associated variables, their mechanisms and factors

- Overland flow and pesticide transport
- Vertical water and pesticide fluxes
- Preferential flow
- Throughflow and pesticide transport
- Pesticide plant uptake
- Pesticide properties
  - Volatilization
  - Sorption
  - Persistence

Field research

Data collection of water and pollutant fluxes in the hydrological system

- Weather
- Crop yields
- Soil water content and chemistry
- Overland flow and runoff quantity and quality
- Drainage (leaching) and groundwater levels and quality
- Pesticides, sediments, nutrients in the environmental compartments
- Sediment chemistry: Interactions between pesticides, sediment and nutrients

Main outcomes of data collection

Large variations in contaminant fluxes and loads

- Contaminants fate and behaviour is environment-specific (e.g. semi-arid region of the Western Cape)
- Cropping systems determine practices: type of pesticides, fertilizers, tillage etc.
- Overland flow was between 4 and 19% of annual rainfall, depending on vegetation, soil type, slope and orientation
- Pesticide degradation was enhanced by high temperature and transport retarded by low rainfall and sorption
- Fluxes of pesticides, N and P dependent on rainfall/runoff and timing of application: e.g. 0.24 and 3.65 kg ha^{-1} a^{-1} of NO_3^-
- Fluxes of sediments dependent on rainfall/runoff, slope and vegetation: e.g. 0.02 and 0.85 Mg ha^{-1} a^{-1}
- Nutrients and pesticides are sorbed on sediments
  - Depending on sediment size (e.g. 5 and 15 µm - silt)
  - Origin and history of sediment transport in catchments
  - Size of mobilized sediments depends on soil texture and slope, and not on rainfall and overland flow volumes

Pesticide modelling

Screening of field models

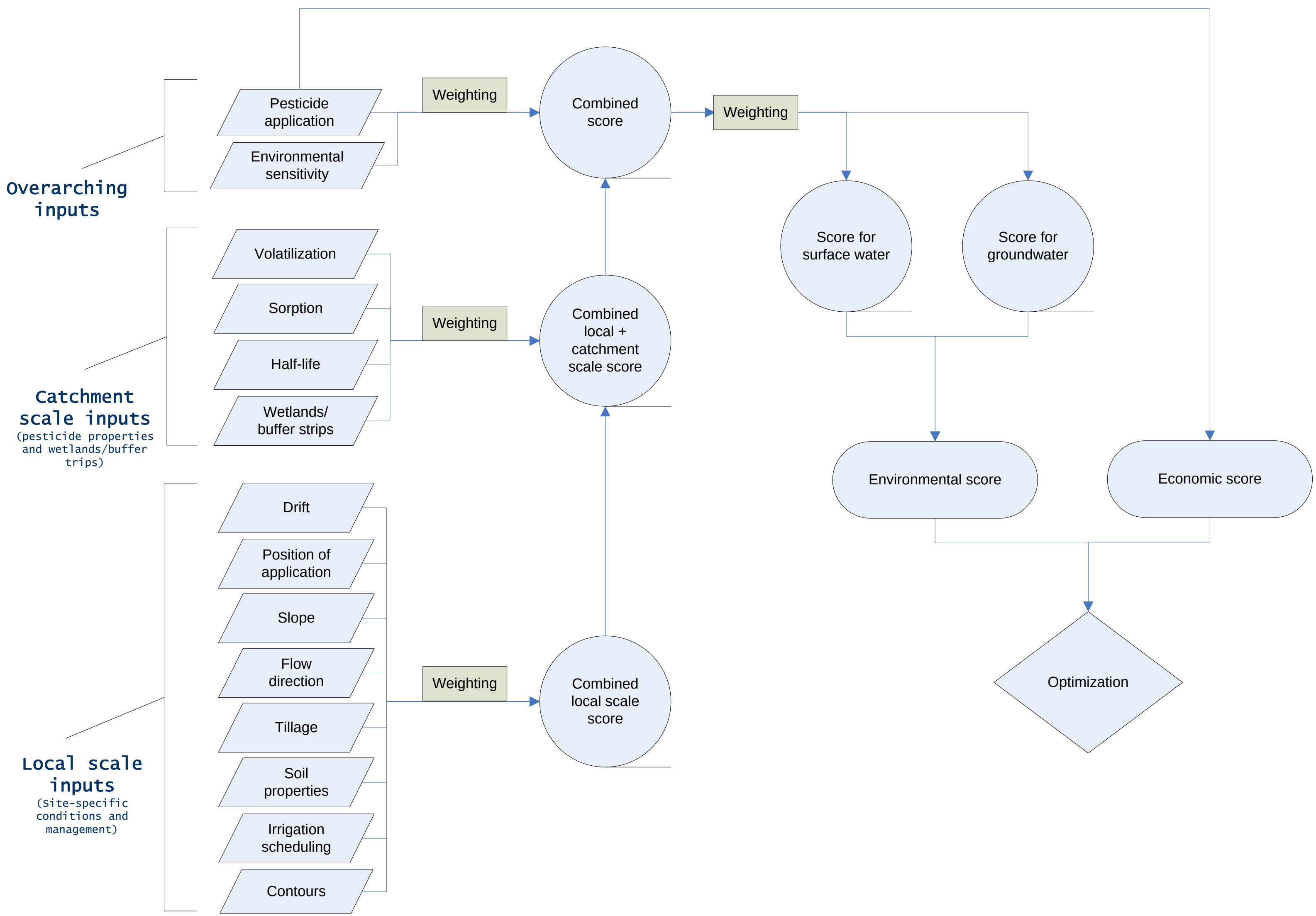
- Screening of field models
  - FIRST, GENEEC, HYDRUS-2D, PELMO, PESTAN, PRZM, SWAP, SWAT and VS2DT
- Difficulties in model application
  - Complexity of the soil-plant-atmosphere system
  - Large amount and intensity of input data required
  - Large number of chemicals available on the market with specific properties
  - Lack of knowledge on pesticide behaviour and toxicity
  - Spatial and temporal uncertainties
- Alternative
  - Expert systems: interactive computer programmes that include quantitative informational databases and qualitative knowledge, experience and judgment to support decision- and policy-making

Development of an expert system for modelling the fate of pesticides

PestEX: Environmental performance index to assess the mobility of pesticides and their potential for landing up in a water resource

- Excel-based calculator
- Main factors:
  - Pesticide drift; Position of application in relation to streams and groundwater; Slope; Dominant flow direction; Tillage practices; Soil hydraulic properties; Irrigation practices/rainfall distribution; Contours
  - Pesticide properties (volatilization, sorption and degradation); Presence of wetlands or buffer strips
  - Pesticide application; Sensitivity of the receiving water resource
- Factor score: Rating x weighting, fuzzy logic normalization
- Novelty inclusions:
  - Mitigation/management practices
  - Combination of different scales
  - Environmental costs (pollution abatement cost)

Flow diagram of PestEX



Main menu of PestEX

		Surface water			Groundwater		
		Rating	Weight (Input)	Score	Rating	Weight (Input)	Score
Local scale inputs	Drift	1.00	1	1.00	None		
	Position of application	1.00	1	1.00	0.00	1	0.00
	Slope	1.00	1	1.00	0.00	1	0.00
	Flow direction	1.00	1	1.00	0.00	1	0.00
	Tillage	0.00	1	0.00	1.00	1	1.00
	Soil properties	1.00	1	1.00	0.00	1	0.00
	Irrigation scheduling	0.00	1	0.00	0.00	1	0.00
	Contours	0.00	1	0.00	1.00	1	1.00
Combined local scale score		5.00	8.00	0.63	2.00	7.00	0.29
Catchment scale inputs	Volatilization	1.00	1	1.00	1.00	1	1.00
	Sorption	0.96	1	0.96	0.96	1	0.96
	Half-life	0.00	1	0.00	0.00	1	0.00
	Wetlands		1		None		
Combined local + catchment scale score		2.58	5.00	0.65	2.24	4.00	0.56
Overarching inputs	Pesticide application	1.00	1.00	1.00	1.00	1.00	1.00
	Environmental sensitivity	0.00	1.00	0.00	0.00	1.00	0.00
Combined score		0.00	3.00	0.55	0.00	3.00	0.52
ENVIRONMENTAL SCORE			1	0.53		1	

Purpose:

- Comparative analyses of different chemicals
- Sensitivity analyses
- Minimization of costs

Potential users:

- Scientific community, farmers, pesticide consultants, regulatory authority

Main lessons learned and recommendations for further research

Lessons learned

- Research Design
  - Monitoring all components of the catchment system
  - Detection of target spectrum of pesticides at key locations to identify priority species to be monitored
- Approaches to scaling
  - Intensive monitoring at local/field scale of water and nutrient fluxes to inform distributed hydrological models
  - Determination of transfer coefficients
- Interfacing Management Needs and Scientific Realities
  - Scenarios modelling with a participatory approach to recommend the most environmentally and economically acceptable practices

Recommendations for further research

- Lack of data: Need for monitoring programmes and ecotoxicological studies
- Need for a soil quality research programme
- Integrated pest management or alternative methods of pest control

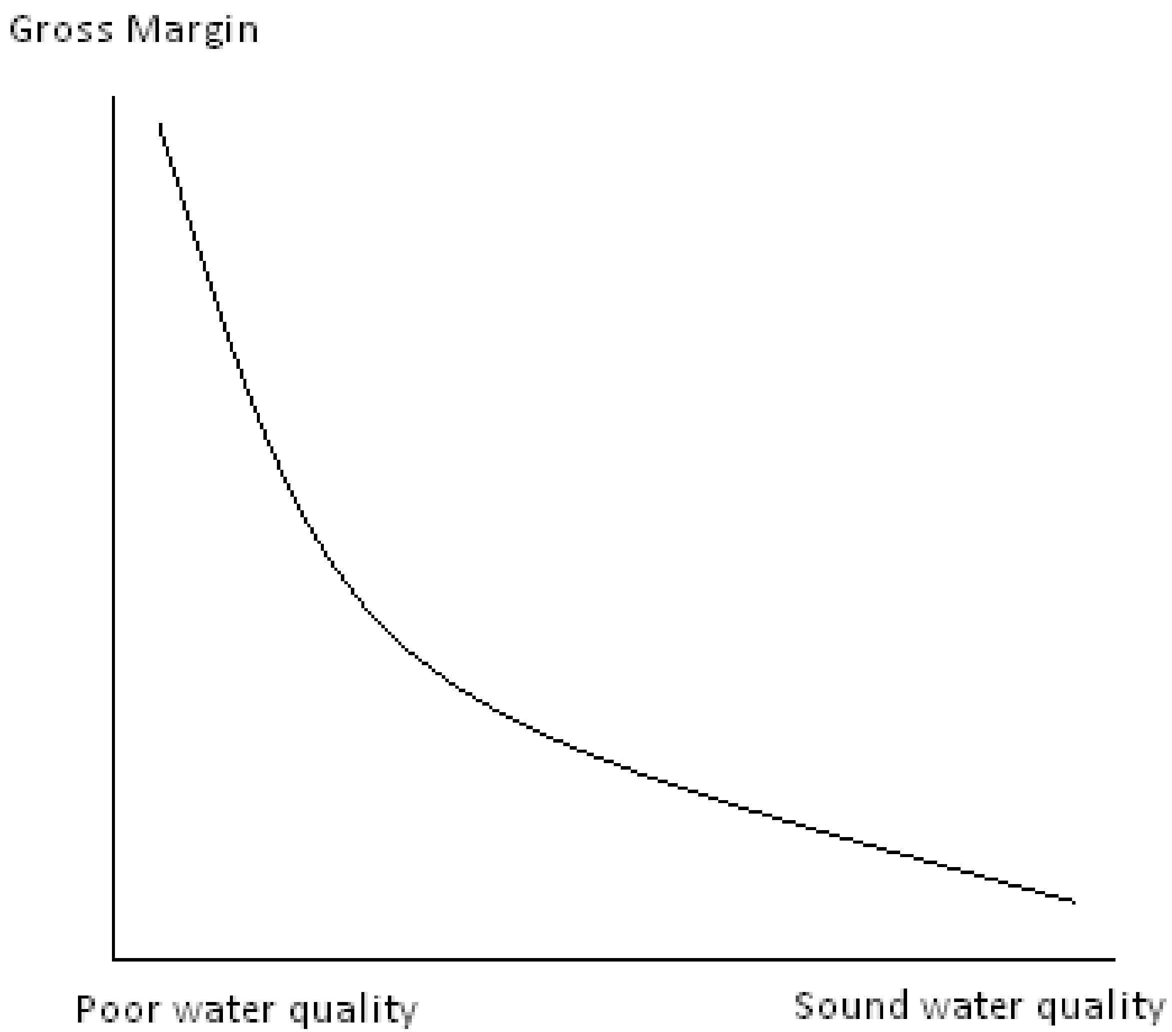
Economics Task Team

Nicky Matthews & Bennie Grové

Economic decision-making criteria

- MB = MC
  - Marginal benefit - additional benefit of producing one more unit of output
  - Marginal cost - additional cost of producing one more unit of output
- No market exists for the environment
  - Difficult to determine benefits of an action
- Agricultural NPS pollution
  - Economic-environmental trade-off

Economic-environmental trade-off



Economic-environmental trade-off

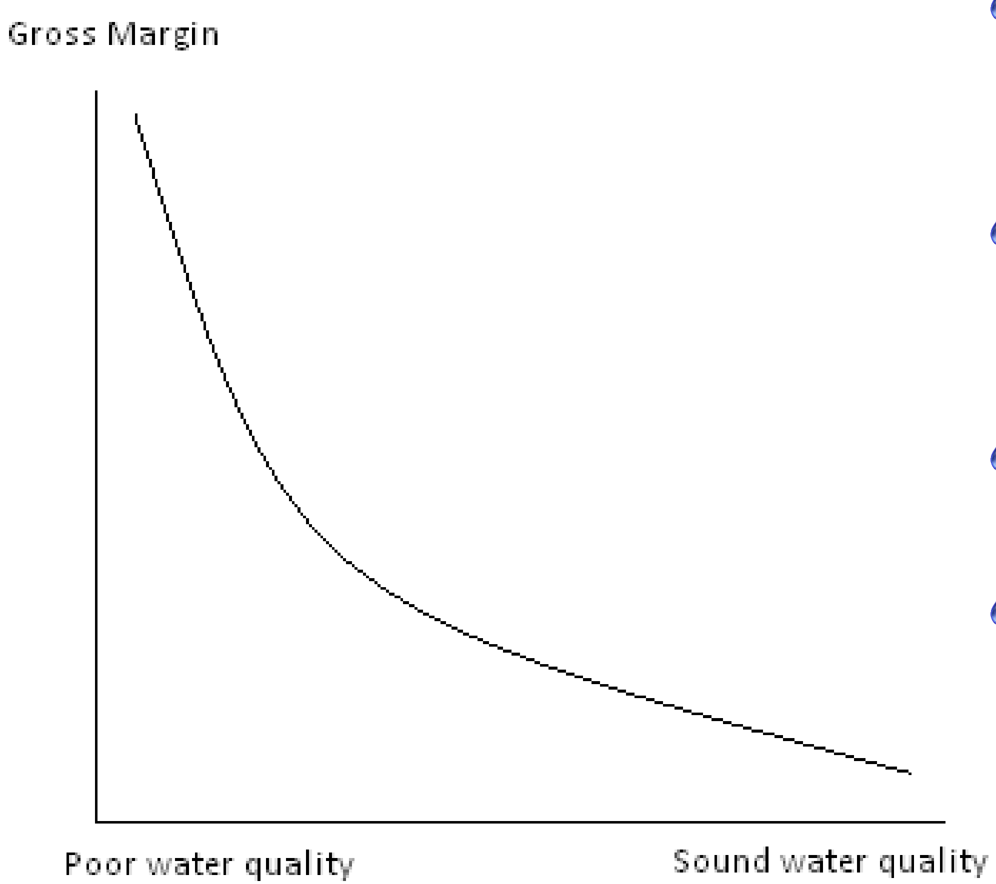
Pollution is an externality

- Need to internalise the costs

How do we internalise the cost of an externality

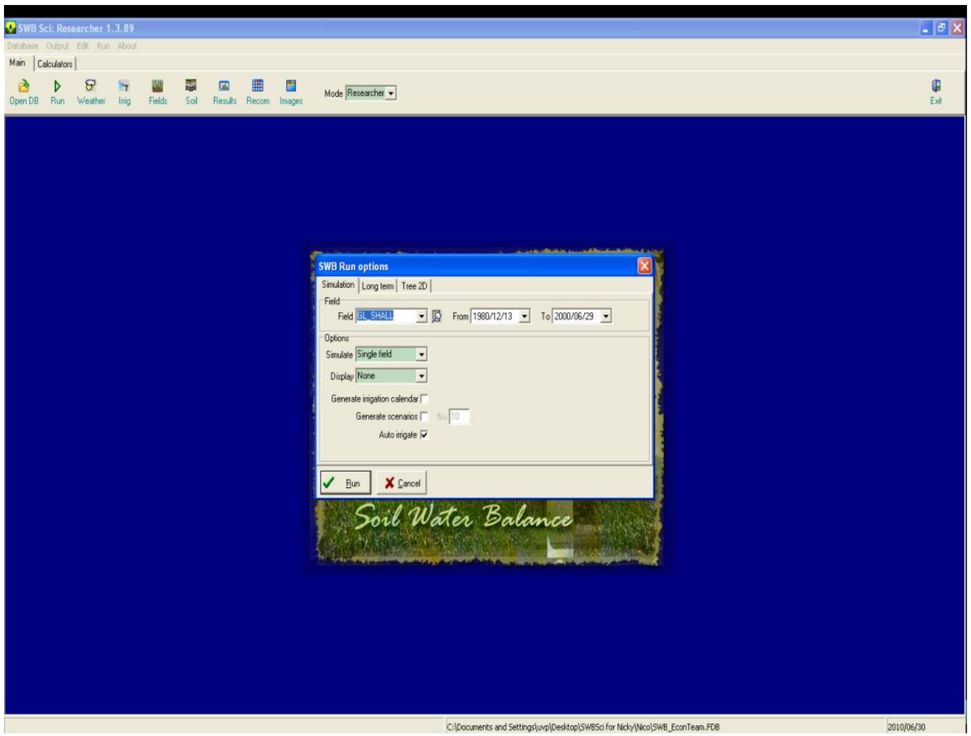
- Command and Control
- Pollution "tax"
- Incentive based regulation (permits)

Modelling tradeoffs



- Use optimisation model to determine trade-off curves
- Optimise farmers gross margin above specified costs
- Production data necessary
- Evaluate best management practices
  - Fertiliser regime
  - Cultivation practices

Use of crop production modelling: SWB_Sci Model and ACRU_NP Model



- SWB_Sci is a crop growth model developed for irrigation purposes
  - Nutrient sub-routines added
  - Used for field-scale modelling
- ACRU_NP is a agrohydrological model with added nutrient routines
  - Used at catchment-scale

Lessons learned

Linkages with crop modellers is important to ensure the success of a NPS project

A modeller's work is never done

- Have to weigh the benefit of improving the simulation and economic models with the cost of improving the models