Report on scientific exchange Professor David Radcliffe

"Swatting it out":
The use of the model SWAT for catchment-scale studies in Australia, with particular emphasis on quantifying model uncertainty

1 December 2003 – 20 December 2003
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The University of Sydney

University of Georgia

Queensland Government
Natural Resources and Mines

Australian Cotton
Cooperative Research Centre

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1 Plain English Summary

Catchment scale modelling is an invaluable tool to determine the impact of policies and legislation on the catchment outcomes. However, Australia is relatively poor in catchment level modelling which takes into account the spatial variability of natural resources in the catchment. Current models generally do not take into account all variability. In the United States a GIS (geographical information systems) based model called AVSWAT has been developed. At each point in the landscape AVSWAT uses a similar approach to runoff modelling as PERFECT/HOWLeaky

Professor David E. Radcliffe from the Department of Crop and Soil Sciences at the University of Georgia visited Australia on a scientific exchange grant from the Australian Cotton CRC. The aims of the visit were to:

- Explore the model AVSWAT and discuss the possibilities for using this model as a catchment management tool in Australia.
- Explore uncertainty and how uncertainty could be dealt with using AVSWAT

Dr. Radcliffe has considerable expertise with the programs BASINS and AVSWAT and uses this to model sediment, phosphorus and fecal coliform in catchments in Georgia. The visit was in cooperation with Mr. Dan Rattray from Queensland Natural Resources and Mines. Dan Rattray also has considerable experience with AVSWAT and uses the program to model pesticide runoff in a small catchment near Toowoomba under a GRDC grant.

From the discussions with David Radcliffe it emerged that researchers in the United States have been wrestling with similar problems in terms of water quality and quantity management as Australia and AVSWAT was partly developed in response to these issues. In addition the United States is also wrestling with lack of integration of surface water and groundwater.

As part of the program a small workshop on AVSWAT and uncertainty was organised in Toowoomba. During the workshop presentation were given on the capabilities of AVSWAT and how uncertainty in input data would affect the outcomes of the model. The workshop was attended by 20+ interested researchers and included ample time for discussion.

The issue of uncertainty was further explored in visits with John Doherty (Watermark Numerical Computing, PEST), DIPNR in Parramatta, NSW and during a presentation at the Faculty of Agriculture, Food and Natural Resources at the University of Sydney.

It was concluded that Australia is not totally unique in its management of water and non-point source pollution problems. Many other countries are working on similar problems and have developed considerable knowledge in modeling and management. This is of comfort to the cotton industry and points to new possible international links in the area of water resource management. The specific nature of the Australian environment and production systems would require adaptation, but this can be achieved since for example AVSWAT is freely available and the source code can be easily obtained.

AVSWAT is a model with considerable potential for use in the Australia. It fills a gap between the larger river basin models such as IQQM and EMSS, similar to CATSALT. It has the capacity to simulate the effect on water quality of changes in management within a (sub) catchment.

AVSWAT can simulate a range of pollutants ranging from inorganic to organic to pesticides. AVSWAT is of interest to the cotton industry because the water quality in the upper catchments and the effect of land use on water quality and quantity has major implications for water availability. Even without a sufficiently developed irrigation routine, it is worth supporting modelling efforts in this area.

2 Introduction

Professor David E. Radcliffe from the Department of Crop and Soil Sciences at the University of Georgia visited Australia on a scientific exchange grant from the Australian Cotton CRC. The aims of the visit were to:

- Explore the catchment scale simulation model AVSWAT and discuss the possibilities for using this model as a catchment management tool in Australia.
- Explore uncertainty in data and simulation model outcomes and how such uncertainty could be dealt with using AVSWAT

David Radcliffe has considerable expertise with the catchment scale simulation programs BASINS and AVSWAT and uses these models to simulate the transport of sediment, phosphorus and fecal coliform in catchments in Georgia.

As part of the program a small workshop on AVSWAT and uncertainty was organised in Toowoomba in cooperation with Mr. Dan Rattray from Queensland Natural Resources and Mines. Dan Rattray also has considerable experience with AVSWAT and uses the program to model pesticide runoff in a small catchment near Toowoomba.

3 Background

Would AVSWAT be a model the Australian catchment management community should look at? At Queensland Department of Natural Resources and Mines they surely think so! Or could we use ideas and components of this model in our own systems? What are the weaknesses and strengths of this model and similar models? What are possible data needs and how much do we have available?

Catchment scale modelling is an invaluable tool to determine the impact of policies and legislation on the catchment outcomes. However, Australia is relatively poor in catchment level modelling which takes into account the spatial variability of natural resources in the catchment. Current models are either lumped water balance models (such as APSIM), essentially 1-D models (PERFECT and WAVES) or linear routing models (such as IQQM). Although these models can incorporate some spatial variability through the introduction of parameter distributions (e.g. Monte Carlo simulations), this requires computer time and operator time in terms of data analysis. Similarly, fully distributed models (TOPOG) have been limited to small catchments due to the high data and computer power demands. Modelling frameworks are being developed by several state agencies, but programs are still in the initial stages.

Researchers in the United States have been wrestling with similar problems in terms of water quality and quantity management. The U.S. Environmental Protection Agency has developed a GIS framework of models called BASINS. This model incorporates several modules, some of which are also part of DIPNR models (such as the QUAL2E linkage in IQQM). An important component of BASINS is the actual catchment runoff model, either HSPF or the soil and water tool SWAT, which also exists as a stand-alone GIS based version AVSWAT.

4 Aims of the visit

1. Investigate the similarities in water quantity and quality problems between states in the U.S. and Australia
2. Investigate the model AVSWAT and its use in Australia
3. Investigate how uncertainty in space and time can be incorporated in the model prediction and which factors are to be considered.

5 Similarities in water quantity and quality problems

5.1 *The U.S. and Georgia situation*

5.1.1 Water quality

Water quality issues in the U.S. are driven by the federal Clean Water Act of 1970. Although this act has in the past been mainly interpreted to clean point sources of pollution, the focus is now on the non-point source pollution provisions in the act. The Act stipulates the use of Total Maximum Daily Loads (TMDL's) for pollutants. The system operates as follows:

- A stream section can get listed if a sequence of sample events by any organisation or individual indicates elevated levels of a pollutant.
- The stream section gets listed from the up stream bifurcation to the down stream intersection with the next stream.
- TMDL's are then set for this section and this has to be monitored over time. The water quality in the stream is not allowed to exceed the total daily maximum load at any time
- Simulation modelling is used to determine management options. The law requires TMDL's to be met on every day in an "average" climatic year.

5.1.2 Water quantity

Water quantity is a State issue in Georgia. The growing population and water use of the major city Atlanta has created concern from downstream water users on the Chattahoochee river (Alabama and Florida). Water trading between agriculture and cities is being strongly considered by the Georgia legislature, but would create large inequalities. Problems are the lack of knowledge about exact water use is hampering control.
There is a push to integrate water quality and water quantity to improve management and control.

5.2 *Similarities*

- Both countries are looking towards integrated water management to develop better water quality and quantity legislation
- Water quality is driven by targets (TMDL's and Salinity targets)
- Water quantity management is hampered by lack of data on usage
- Water trading is already possible in NSW, but is still under consideration in Georgia and wider U.S. Surface water trading across years would include uncertainty.

6 Considerations around BASINS, HSPF, SWAT and AVSWAT

6.1 *Choice of models*

The US EPA in search for a universal approach to simulating non-point-source pollution and Total Daily Maximum Loads (TDML's) has paid for the development of BASINS (http://www.epa.gov/waterscience/basins/). BASINS is an ArcView (GIS program) script, which allows the user to import and manipulate spatial data for a catchment and call different other models (modules) to run water and chemical transport processes in the catchment. These models include both HSPF (Hydrological Simulation Program Fortran, http://water.usgs.gov/software/hspf.html) and SWAT (Soil Water Assessment Tool, http://www.brc.tamus.edu/swat) to simulate water transport in a catchment. HSPF originates from the Stanford Watershed model. It has sufficient parameters to reproduce any shape of hydrograph but the relationship between the parameters and physical processes (Deep drainage, lateral flow or infiltration) are not easy to find. SWAT originates from models such as EPIC and GLEAMS. Infiltration and runoff processes in SWAT are semi-physically based and are therefore intuitively easier to understand. In addition, the user can choose between a Green-Ampt infiltration model or use curve numbers.

Although both these models are not fully distributed catchment models (such as TOPOG) they do allow division of a catchment into smaller subcatchments for which homogeneous land and water properties can be specified, the so-called hydrological response units (HRU's). The output of these HRU's is subsequently routed through the channel system to the catchment outlet.

BASINS is freely downloadable from the US EPA internet site, but the model requires a large amount of so-called "core data". This data includes all different GIS data layers which are needed to run all the different modules in BASINS. For the Continental US these layers have all been developed and are stored in a central depository. If the user only wanted to run SWAT, only a few of these layers would be needed, but with BASINS, this selection is not possible.

In response to this, the developers of the model SWAT, which is a Fortran based executable, have developed another ArcView Script called AVSWAT (Di Luzio et al., 2002). This script only runs SWAT and not any of the other models in the BASINS suite. For AVSWAT you only need to provide:

- DEM
- Soils layer and database
- Landuse layer
- Daily rainfall and temperature

AVSWAT then creates the input file for SWAT and runs SWAT. The main problem with AVSWAT was the question how to deal with the output. This is all text file based and difficult to manage. This problem has recently been resolved by Queensland NRM through the development of the program BROWSER. This program allows you to view and display any text file with time series.

Both AVSWAT and BROWSER are freely available from:
http://www.brc.tamus.edu/swat/avswat/ and http://www.ncea.org.au/Browser/

Although good point and paddock-scale models exist in Australia (such as PERFECT and APSIM), there is a limited number of models which capture the (sub)catchment scale spatially.

For larger scales, models such as IQQM and EMSS exist. AVSWAT could fill the gap in this area. In addition, AVSWAT could be used to deliver input into the nodes of EMSS and IQQM.

6.2 *Curve numbers and their derivation*

Curve numbers are still useful because they integrate the effects of land management (land use) and soil type. Curve numbers also incorporate the effect of antecendent moisture. Although the method is empirical (Beven, 2001), several authors have attempted to justify the theoretical basis (i.e. Mishra & Singh, 1999; Steenhuis et al., 1995; Yu, 1998). The analysis from Steenhuis et al (1995) is of interest, since in this paper the curve numbers are linked to variable source runoff (building on earlier work by Hawkins (1979)). Variable source runoff occurs mainly on high rainfall catchments with shallow soils. However the main soil characteristic required to drive the process is the existence of a high contrast in hydraulic conductivity between the top soil and subsoil (such as occurring in many of the duplex soils)

Using the streamflow datasets we can estimate the catchment wide curve number from existing streamflow data (Steenhuis et al., 1995) giving some indication of the variability in curve numbers in Australia or NSW.

Curve numbers basically assume that, for runoff at the catchment level, the landuse effects are overriding any soil effects, since there are only 4 soil classes. This is conceptually interesting from a hydrological perspective. This would suggest that spatial variability in land cover (which can be easily determined from satellite data) is more important than any spatial variability in soils.

Curve numbers are widely used in Australia as part of the PERFECT suite of models. Where possible, curve numbers are calibrated using rainfall and runoff data, mostly from rainfall simulations studies done by QNRM and other state organisations. Curve numbers can also be optimized from other data available. Optimising curve numbers creates error bands, which can be used to derive distribution functions around curve numbers to be used for uncertainty analysis.

As soil crusting appears to be the main factor influencing runoff, curve numbers are a simpler option than a physically based approach such as Green-Ampt or a full Richards equation approach. To simulate the time dependent change in hydraulic conductivity of the crust is a very difficult matter. To be able to use the curve numbers in this situation, Owens et al. (2003) developed an adjustment for the curve numbers based on percent cover on the soil. Soil cover has a major effect on crusting and thus on infiltration rates. More cover is translated into a lower curve number until a cutoff values which is soil specific. In addition, different soil types have different slopes and intercepts for the linear relationship between cover and curve number. From the QNRM group work on curve numbers and the relation between % cover and curve numbers, it seems that the soil hydraulic groups might be more related to soil structure and that the hydraulic conductivity separation thus is not based on soil type (i.e. texture), but on soil structure. However some of this might be dependent on rainfall intensity. However, in general, the strongest relationship is between soil cover and curve numbers.

6.3 *Uncertainty and its effect on output and information*

Uncertainty is introduced in models at different levels (Krystofowitz, 1999). In general, 3 different types of uncertainty are recognized:

- Uncertainty due to input data (such as variability in space in time of rainfall)
- Uncertainty due to the description of the process in the model (parameter or model uncertainty)
- Uncertainty due to observations, i.e. incorrect measurement of validation and calibration data.

The last type of uncertainty is generally ignored, and the main type of uncertainty considered is the first and second type (Krystofowitz, 1999). What this means is that model output is in fact a sample (or the mean) of a distribution of outcomes, and that confidence intervals should be associated with this value (Beven, 2001).

Including confidence intervals with the output of models has certain advantages, since it increases the information of the output. It allows investigation of the accuracy of the model and of the input data. For example, when investigating the model accuracy of predicting salt levels in a catchment:

- If there is less certainty associated with the predictions, it might be useful to invest in research.
- If the predictions are certain, it would be prudent to look at management options within the catchment.

7 Workshop in Toowoomba

7.1 *Program*

Time		Activity	Presenter
1:30	5 min	Welcome	
1:35	15 + 5 min	Overview of AVSWAT and the BASINS modelling suite	David Radcliffe
2:00 – 2:30	20 + 10 min	A U.S. case study	David Radcliffe
2:30 – 3:00	20 + 10 min	An Australian case study: Hodgson Creek	Dan Rattray
3:00 – 3:30	20 + 10 min	Issues with spatial variability of hydraulic parameters and possible solutions	Willem Vervoort David Radcliffe Dan Rattray
3:30 – 4:00		Afternoon tea and further opportunity to explore the issues	

Copies of the presentations are attached to this report as appendix 1.

7.1.1 Attendees

D. Radcliffe – University of Georgia
W. Vervoort – The University of Sydney
D. Rattray – Q. NRM
J. Gaffney – Q. NRM
J. Ritchie – Q. NRM

S. Dutta – Q. NRM
U. Yadav – Q. NRM
D. Freebairn – Q. NRM
M. Silburn – Q. NRM
J. Owens – Q. NRM
P. Webb – Q. NRM
G. Titmarsh – Q. NRM
B. Robinson – Q. NRM
D. Rainer – Q. DPI
N. Gammie – Condamine Alliance
X. Zhang – Q. DPI
G. Fraser – Q. NRM

7.2 *Discussion and conclusions*

The presentations were followed by an animated discussion on the virtues of the AVSWAT model and issues related to uncertainty. It was again clear that the AVSWAT sits in between the larger models such as IQQM and EMSS, and the smaller, paddock scale models such as PERFECT and APSIM. AVSWAT allows introduction of spatial processes, and therefore could be potentially of use to target management.

Interestingly, in the Hodgson creek study, only one soil type was assumed and only four landuses were simulated on the 50,000 ha catchment. This would suggest that detailed and extensive soil and landuse databases might not be necessary for AVSWAT. However it is not clear what degree of uncertainty would be associated with this type of assumption.

If curve numbers are sensitive to cover (as is proven by Owen et al. 2003), then this would create opportunities to use spatial remote sensing data to develop distributions of cover within HRU's to assess the degree of uncertainty due to the homogeneity assumption. This type of analysis was suggested in the presentation by Willem Vervoort. In this very preliminary study it did not appear to have much influence, but this should be further investigated.

There was considerable discussion on the variability of rainfall in the catchment and how this would influence the uncertainty of the prediction. It was thought that variability is very high, but there is little hard data (except for interpolated surfaces such as DataDrill) to quantify the distribution in time and space. There didn't seem to be any work on quantifying the distribution of rainfall in time and space on a catchment the scale of Hodgson creek (50,000 ha). It was suggested that inclusion of information on the degree of uncertainty with the DataDrill output could help in quantification.

It is clear that on longer timescales the effects of spatial variability decreases since the variability in climatic effects dominates over the effects of spatial variability. This is similarly true for variability in, for example, application rates and times of a pesticide.

There is a question about whether spatial variability in landscape properties is more important than temporal variability in operations such as pesticide applications and tillage. In the end, all these can be captured in distribution functions and run through SWAT or initially through 1-D programs such as "HowLeaky". In this context, the paper by Schumann et al. (2000) should be mentioned. The authors of this paper integrated a lumped HSPF type model within each cell of a

GIS and ran simulations. The end model incorporates spatial variability of landscape properties, but the authors did not test their model against a fully lumped model.

8 Other discussions and visits

8.1 *John Doherty (Watermark computing Inc.)*

On 12 December a meeting was held at Indooripilly with in attendance: John Doherty (Watermark computing Ltd.), Mark Gallagher (UQ), David Radcliffe (UGA), David Freebairn and Dan Rattray (QNRM), Willem Vervoort (USYD and ACCRC)

The meeting was aimed at scoping the use of PEST (Model independent parameter estimation) with SWAT to improve calibration and perform parameter uncertainty estimation.

- PEST can be used with SWAT and is currently being used with similar models such as HSPF. PEST will allow automatic calibration of the model parameters by "wrapping around" the model and performing a general inversion of the model using the parameters and observed data.
- Statistically describing parameter uncertainty and predictive uncertainty is difficult to achieve since for statistical correctness the errors should be white noise (uncorrelated with zero mean). This is almost impossible to achieve in hydrological models. A truly optimal calibration would allow this. John Doherty prefers to talk about the "wiggle room" for each of the parameters. Beven (2001) talks about prediction intervals for the predictions, which are defined as the interval in which a certain proportion of the uncertain predictions fall. John Doherty's PhD student Mark Gallagher is currently investigating this area using the model HSPF.
- Interesting and comforting to know is that we can probably be more certain in predicting the change from one model output to another (and thus reflecting the effect of management) than being certain in the actual prediction at each management scenario. This is because the variance of the difference between two scenarios is build up out of the sum of the variances of each prediction minus the covariance of between the two scenarios. Most likely this is large making the variance of the difference a small number.
- John Doherty is keen to expand the possible uses of PEST and is open to suggestion for changes and cooperation.

8.2 *Dugald Black and Geoff Podger (DIPNR Water resources, Parramatta)*

David Radcliffe, Willem Vervoort and I. Odeh visited Dugald Black and Geoff Podger at the NSW Department of Infrastructure, Planning and Natural Resources in Parramatta. The Water Resources Section is responsible for prediction and simulation of salinity targets and the development and calibration of the model IQQM.

The discussion covered the issue of uncertainty and the possibility to use PEST to calibrate and assess uncertainty in IQQM. All agreed that uncertainty, or lack of certainty is an important issue which needs additional research.

For the purposes at DIPNR, there is little interest in SWAT as a modelling tool, considering the capacity of IQQM, the LUOS and CATSALT.

According to Geoff Podger, SWAT has problems with modelling irrigation in Australian systems accurately. This would warrant possible changes in the model, which could easily be discussed with the developers of the model in Texas.

8.3 *John Friend, NSW Agriculture*

John Friend from NSW Agriculture came to visit in Sydney to discuss his work on the catchment near Wellington and scope the possibility of using SWAT for his work.

9 Conclusions and recommendations

Australia is not totally unique in its management of water and non-point source pollution problems. Many other countries are working on similar problems and have developed considerable knowledge in modeling and management. This is of comfort to the cotton industry and points to new possible international links in the area of water resource management. The specific nature of the Australian environment and production systems would require adaptation, but this can be achieved since for example AVSWAT is freely available and the source code can be easily obtained.

AVSWAT is a model with considerable potential for use in the Australia. It fills a gap between the larger river basin models such as IQQM and EMSS, similar to CATSALT. It has the capacity to simulate the effect on water quality of changes in management within a (sub) catchment. AVSWAT can simulate a range of pollutants ranging from inorganic to organic to pesticides.

- (**Recommendation**) AVSWAT is of interest to the cotton industry because the water quality in the upper catchments and the effect of land use on water quality and quantity has major implications for water availability. Even without a sufficiently developed irrigation routine, it is worth supporting modelling efforts in this area. Development of a project to improve the irrigation routine. Possible cooperators: Australian Cotton CRC, CRCIF, QNRM, Texas A&M University, CSIRO L&W, The University of Sydney, University of Sydney (approx. budget: $300,000/3 years)

There are several groups in Australia working with AVSWAT, these include the group at QNRM and work at the University of Western Sydney by Dr Hua Sun which corresponds to the GRDC work by Dan Rattray. There is also wide interest from a range of other groups.

Curve numbers are possibly under valued as a runoff prediction tool. There is still insufficient data in Australia to be confident with the use of curve numbers in every state.

- (**Recommendation**) There are opportunities for in-depth research on relationships between curve numbers and cover, partial source areas and other runoff generation processes. Development of a pedotransfer function for curve numbers would be a worthwhile step. Possible cooperators: QNRM and the University of Sydney (Dr. Budiman Minasny?) (approx. budget: $150,000/3 years)

Calibration and validation of models remains a difficult area. Nature is too complex, to be totally captured in a model, this means that all models make simplifications. Calibration is best done using an automated calibration routine such as PEST. The simplification in models, in addition to errors in input data, creates a band of uncertainty around the outcomes of the model. Quantifying this uncertainty is very well possible using an automatic calibration model such as PEST. Most of the researchers spoken to agreed that some work in this area needs to be developed urgently

- (**Recommendation**) Development of techniques to standardise quantification of the uncertainty of catchment model predictions using automatic calibration. Possible cooperators: The Australian Cotton CRC, DIPNR, QNRM, Watermark computing Inc., University of Georgia (Dr. Bruce Beck), University of Queensland (?)….. (approx. budget: $500,000/3 years)
- (**Recommendation**) Development of a project to assess the sensitivity of existing catchment models to spatial variation and uncertainty in climate data and how this affects other variability effects, such as soil or land use variability. Possible cooperators: The Australian Cotton CRC, QNRM, BOM, The University of Sydney (Dr. Willem Vervoort, Dr. Odeh), University of Western Sydney (approx. budget $300,000/3 years)
- (**Recommendation**) Development of a network of SWAT/AVSWAT users to assist and develop the technology and exchange of information in this area…..(approx. budget $10,000/ 3 years)

10 Acknowledgements

We would like to sincerely thank QNRM for their hospitality and assistance during Dr. Radcliffe's stay in Toowoomba and the Faculty of Agriculture, Food and Natural Resources for their assistance during the stay in Sydney. In particular we would like to thank David Freebairn, Mark Silburn and Jo Owens for their efforts to make this visit a success. We would like to thank the Australian Cotton CRC for funding this scientific exchange.

11 References

Beven, K.J. 2001. *Rainfall-runoff modelling*. The Primer. John Wiley & Sons, Chichester.

Di Luzio, M., R. Srinivasan, J.G. Arnold , and S.L. Neitsch. 2002. Soil and Water Assessment Tool. ArcView GIS Interface Manual: Version 2000. GSWRL Report 02-03, BRC Report 02-07, Published by Texas Water Resources Institute TR-193, College Station, TX. 346p.

Hawkins, R. H. (1979). "Runoff curve numbers from partial area watersheds." Journal of the Irrigation and Drainage Division, ASCE 105(4): 375-389.

Krzysztofowicz, R. (1999). Bayesian theory of probabilistic forecasting via deterministic hydrologic model. Water Resour. Res 35(9): 2739-2750.

Mishra, S. K. and V. P. Singh (1999). "Another look at SCS-CN method." Journal of hydrologic engineering 4: 257-264.

Schumann, A. H., R. Funke, et al. (2000). "Application of a geographic information system for conceptual rainfall-runoff modeling." Journal of Hydrology 240(1-2 SU -): 45-61.

Steenhuis, T. S., M. Winchell, et al. (1995). "SCS runoff eqation revisited for variable source runoff areas." Journal of Irrigation and Drainage Engineering. ASCE 121(3): 234-238.

Yu, B. (1998). "Theoretical justification of SCS method for runoff estimation." Journal of Irrigation and Drainage Engineering. ASCE 124: 306-310.

Appendix 1: “Watershed scale modelling in Georgia” Presentation by Dr D.E. Radcliffe, University of Georgia

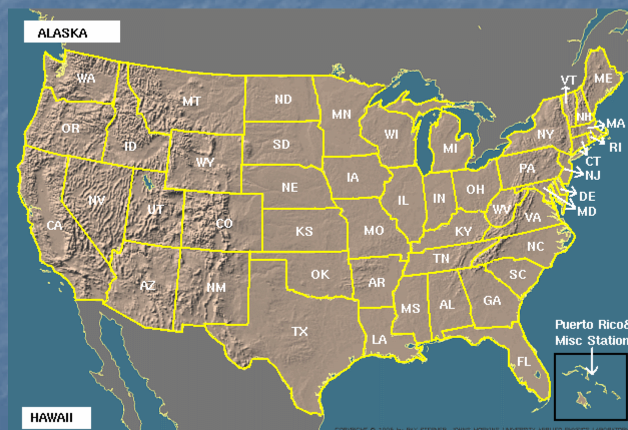
Watershed-Scale Modeling in Georgia

David Radcliffe
University of Georgia

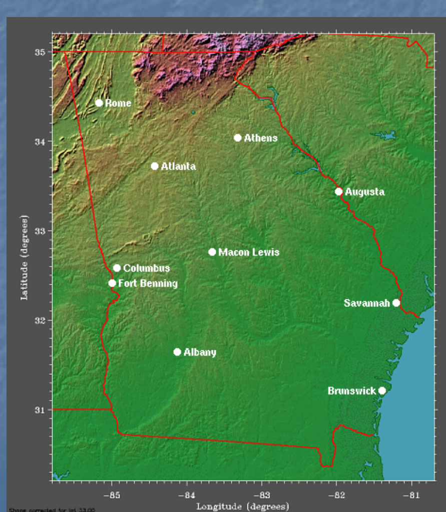
Outline

- Introduction to Georgia
- TMDLs
- SWAT vs. HSPF
- AvSWAT vs. BASINS SWAT
- SWAT Infiltration
- Model Uncertainty
- Georgia Watershed Modeling Projects

Georgia



Georgia Statistics



- State population 8 million
- Metro Atlanta population 4 million
- Annual rainfall 1,270 mm
- Poultry, forest products, cotton, peanuts, vegetables, beef cattle

Federal Water Quality Laws

- Water quality regulations are driving watershed-scale modeling
- Clean Water Act of 1970's
  - Focused on point sources initially
  - Federal funds available to upgrade municipal waste systems
  - Big improvements in water quality in 1980's
- TMDL program began in 1990's
  - Lawsuits brought against EPA by environmental groups

TMDL Program

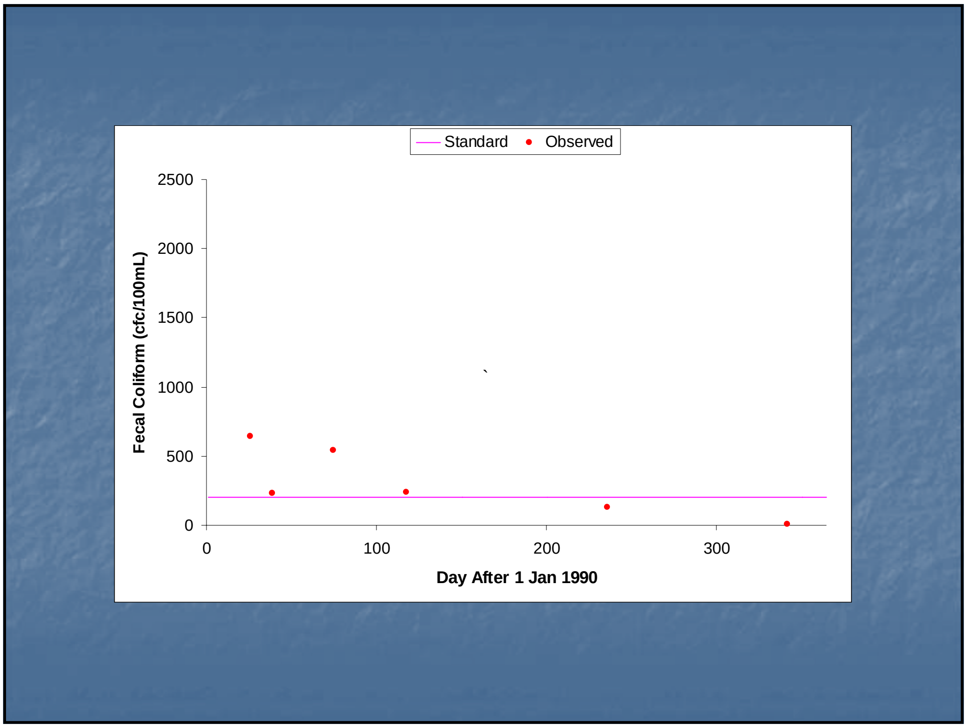
- Total Maximum Daily Load
  - Part of Clean Water Act but overlooked until lawsuits
- Addresses point <u>and</u> nonpoint sources
- Requires states to
  - Set water quality standards
  - Set water quality targets for pollutants on stream/lake segments that do not meet standards
  - Implement management plans to meet targets

TMDLs in Georgia

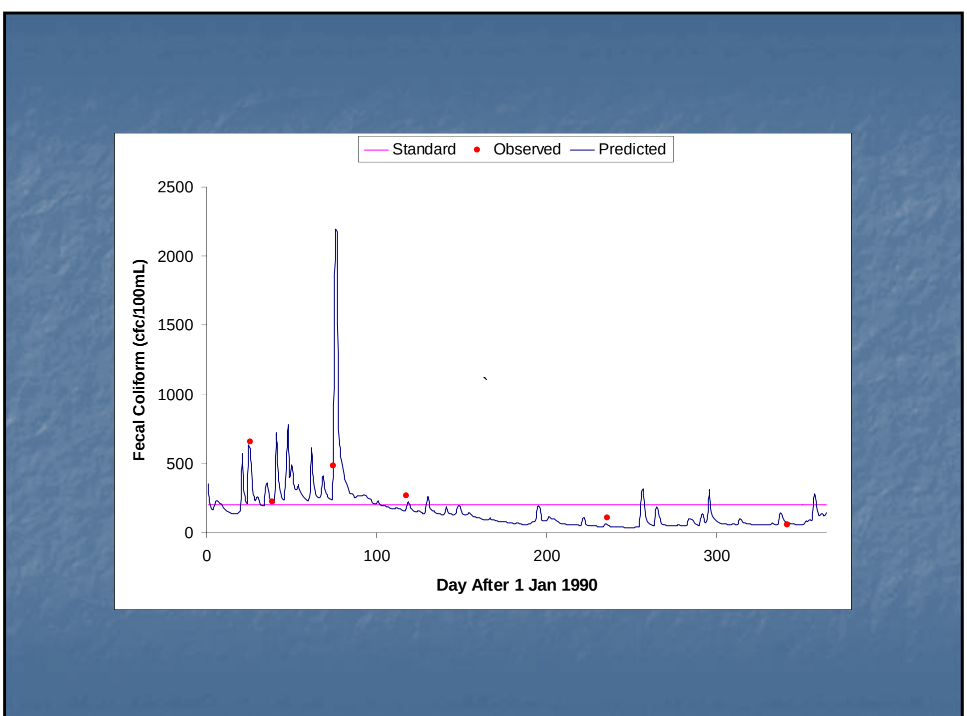
- 806 stream/lake segments listed for Georgia
- 355 listed for bacteria (fecal coliforms)
- Other pollutants are:
  - Sediment
  - Low dissolved oxygen
  - Heavy metals
- A few large lakes have phosphorus TMDLs
  - Affects entire upstream watershed

Models and TMDLs

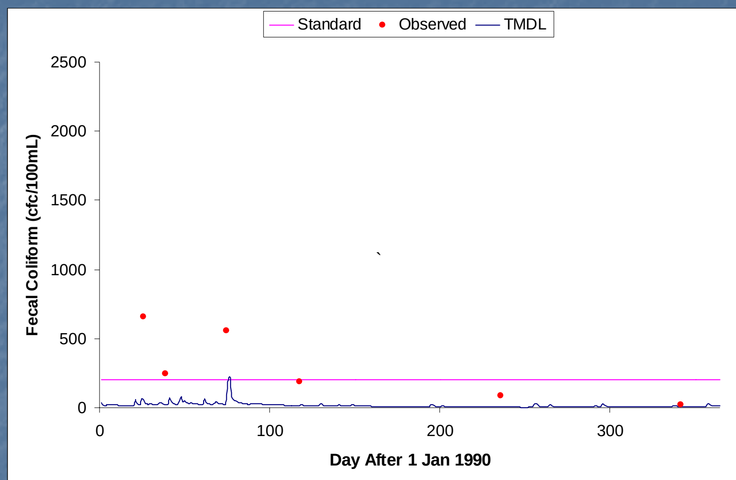
- Potential for models to be used to determine:
  - Setting target daily load limit – “interpolate” between observed values
  - Effect of management practices used to reduce loads



Standard
Observed
2500
2000
1500
1000
500
0
0
100
200
300
Fecal Coliform (cfc/100mL)
Day After 1 Jan 1990



Standard
Observed
Predicted
2500
2000
1500
1000
500
0
0
100
200
300
Fecal Coliform (cfc/100mL)
Day After 1 Jan 1990



Water Quantity Issues in Georgia

- Despite high annual rainfall (1,270 mm) Georgia is running out of water
- Population growth and periodic droughts (El Nino related)
- Water wars:
  - Alabama and Florida have sued Georgia over minimum flow required in Chattahoochee River where it enters their territory
  - Disputes within Georgia between agricultural users and cities

Water Quantity and Quality

- Bill last year to create market for selling water permits among users caused public outcry
- Last month Governor appointed committee to develop Comprehensive Water Management Plan
  - Includes scientists
- Trick will be to merge water quality (federal concern) and water quantity (state concern) issues

IWRM

- Integrated Water Resource Management (IWRM): a framework for making decisions
- Example is article by Warren Viessman
  - Water source and water quality linkages
  - Capturing society's views
  - Articulating risks
  - Educating and communicating
  - Uniting technology and public policy
  - Forming partnerships
  - Role of universities in fostering integrated water management

SWAT vs. HSPF

- Most common dynamic models
  - Hydrological Simulation Program Fortran – HSPF
  - Soil Water Assessment Tool – SWAT
- Many similarities in groundwater and stream modeling
- SWAT has more mechanistic soil dynamics
  - HRUs in HSPF are based on land use only
  - HRUs in SWAT are based on land uses and soils
  - Soil inputs in HSPF are unlike any other model

BASINS

- Better Assessment Science Integrating Point and Nonpoint Sources developed by EPA
- An Arcview script that includes watershed-specific “core data”
  - GIS layers and databases for U.S. watersheds
- Creates input file for various watershed-scale models
  - HSPF, SWAT, PLOAD, QUAL2E

AvSWAT

- ArcView SWAT
- An Arcview script that uses GIS layers and databases input by user
- Only need to provide
  - DEM
  - Soils layer and database
  - Landuse layer
  - Daily rainfall and temperature
- Creates input file for SWAT

AvSWAT vs. BASINS SWAT

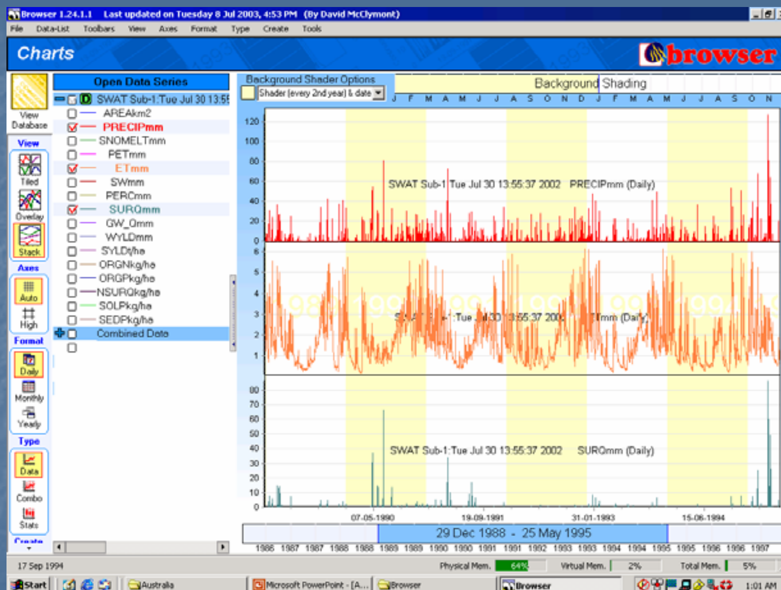
- BASINS SWAT (from EPA)
  - Advantage – Excellent software (Genscen) for viewing and analyzing results
  - Disadvantage – “Core” GIS layers and databases are not available for watersheds outside U.S.
- AvSWAT (from SWAT developers)
  - Advantage – relatively easy to set up GIS layers and databases for watersheds outside U.S.
  - Disadvantage – Genscen doesn’t work with AvSWAT

SWAT Infiltration

- Green Ampt
  - More mechanistic than CN
  - Sensitive to K_s
  - No land use effect unless parameters are modified
  - No crusting effect unless Ks is reduced
  - "Infiltration excess" process
- Curve number
  - Empirical
  - Based on small US agricultural watershed stream flow data
  - Soils in 4 groups
  - Extensive land use effect (crusting)
  - Can be interpreted as "Saturation excess" process
  - CN's suitable for Australia?

Future Developments AvSWAT

- AvSWAT2003 due out this month?
- Will include model sensitivity routine developed by Ann van Griensven?
- Someone needs to figure out how to view AvSWAT output
  - No longer true!! – Use "Browser" developed by Queensland NR&M



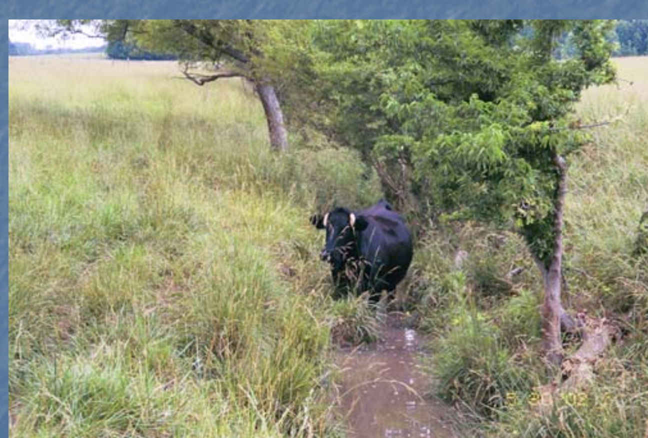
Model Uncertainty

- How accurate are our model predictions?
  - Stakeholders, regulators, and the larger scientific community wants to know
- Software (such as John Doherty's PEST) available for
  - Quantifying sensitivity to parameters
  - Automated calibration (probably will be required for first-rate publications in the near future)
- Next step is to use software to quantify predictive uncertainty
  - Little work has been done on uncertainty of complex watershed models

Watershed Projects

- Little River Watershed (Cattle) Project
- Pollutant Trading Project

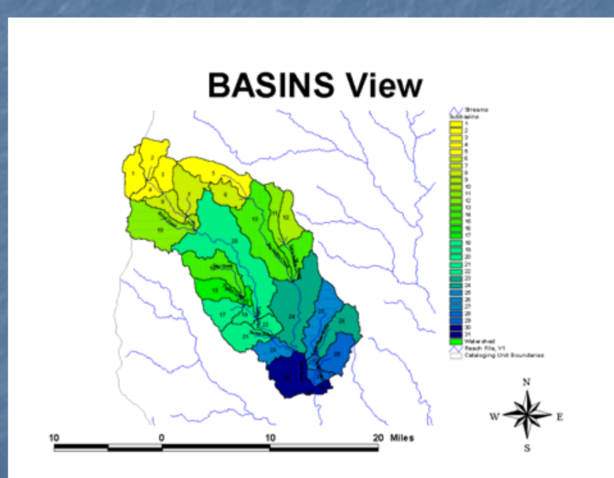
Little River Watershed Project

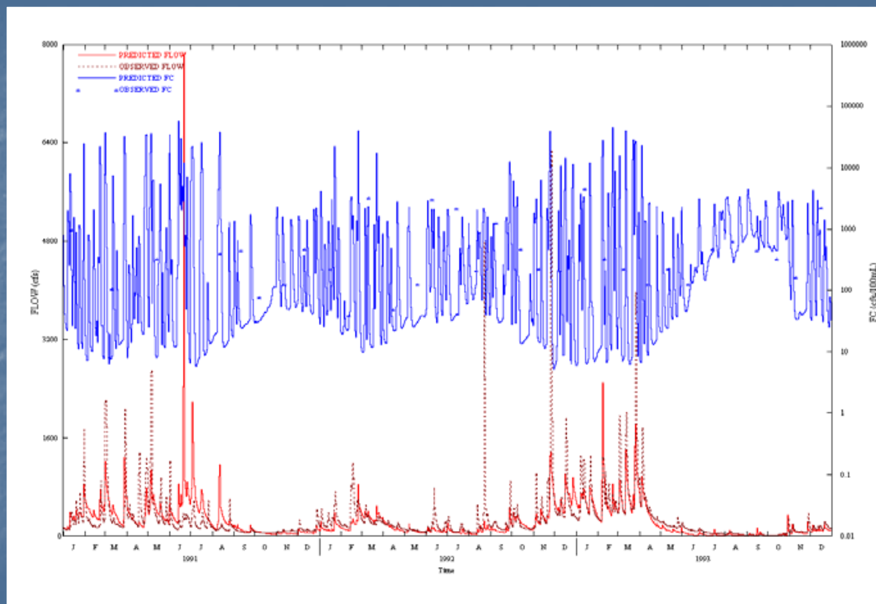


Little River Watershed Project

- Many Georgia streams are listed for TMDLs due to bacteria
- Many of these watersheds have beef cattle that are not fenced out of the stream
- What effect do cattle in streams have on bacteria?
- Used HSPF to model fecal coliforms and test for sensitivity to bacteria parameters

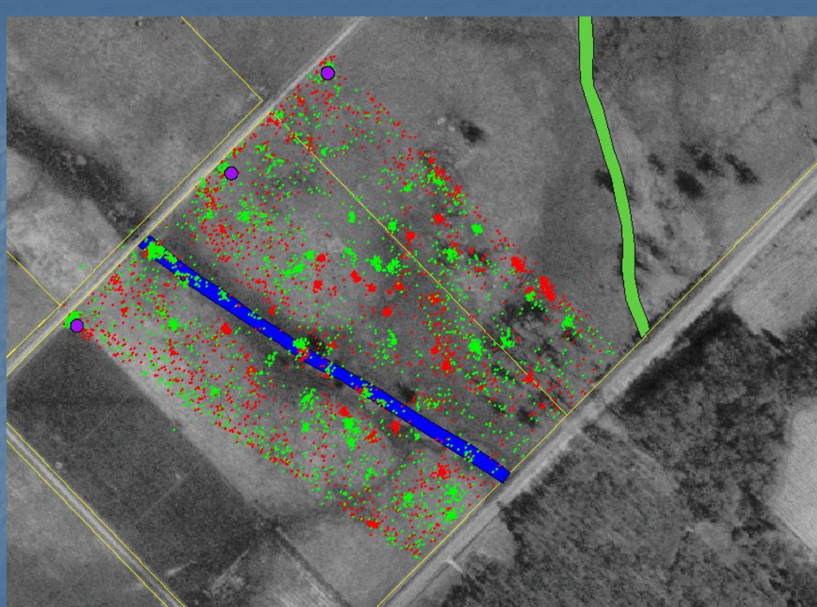
Little River Watershed Project

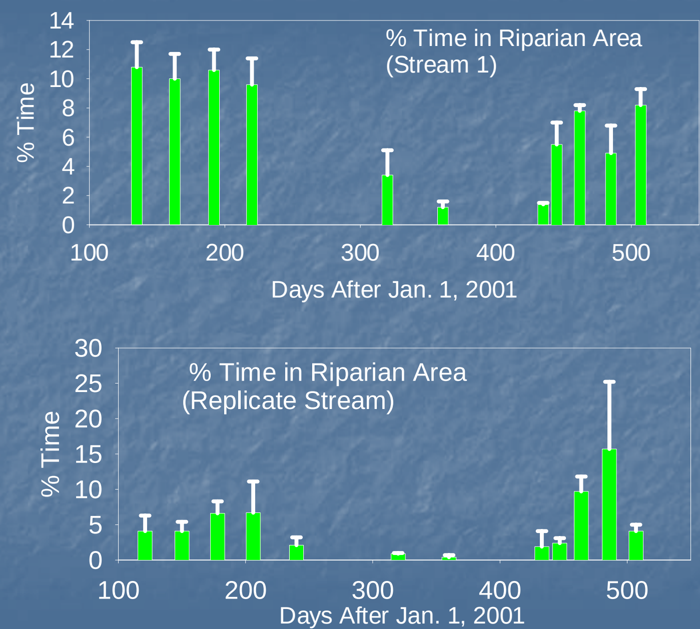




Parameter Sensitivity

Parameter	*Effect of Doubling*	*RMSC* (%)*
Beef cattle number	Increase	43.4
Dairy cattle number	Increase	39.2
Time beef cattle in stream	Increase	31.9
First order in-stream decay rate	Decrease	28.3
Poultry number	Increase	5.4
Septic system number	Increase	5.1
Septic system failure rate	Increase	5.1
Deer density	Increase	3.0

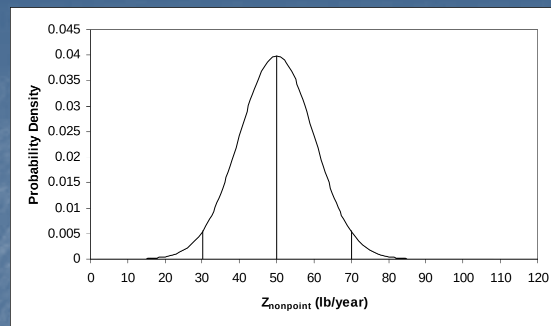


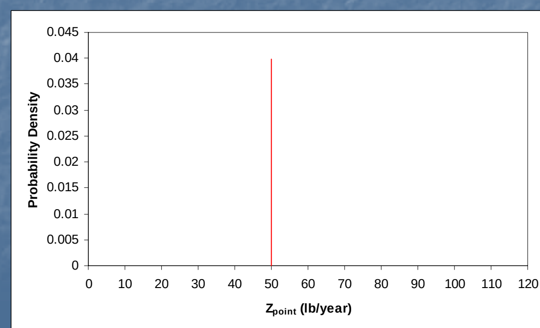


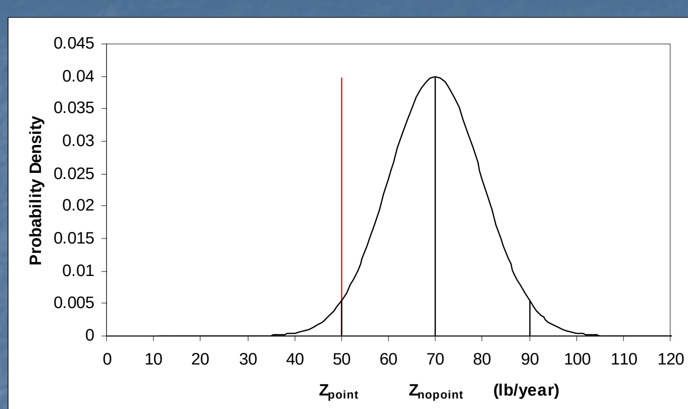
Pollutant Trading Project

- Pollutant trading used successfully in air pollution control programs
  - Trades between point sources
- EPA and USDA encouraging states to consider pollutant trading to control nutrients
  - Likely to be from point source to non-point source
- What should the "trading ratio" be?
  - Not 1:1 due to uncertainty in non-point sources

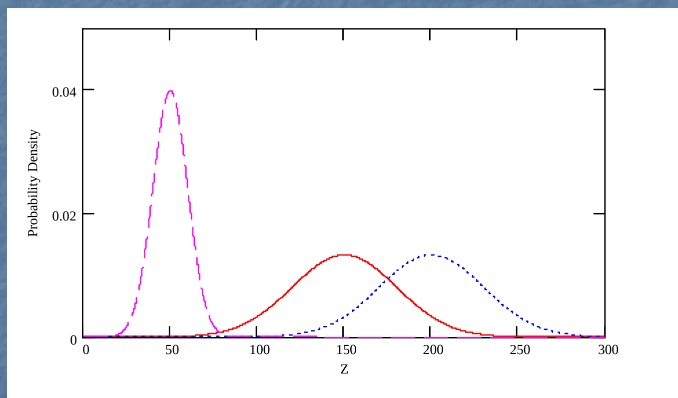
$$t = \frac{Z_{nonpoint}}{Z_{point}}$$





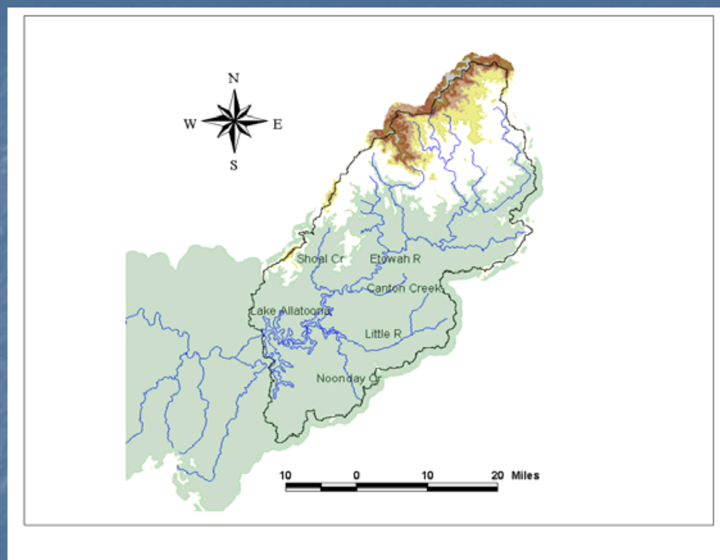


$$t = \frac{Z_{nonpoint}}{Z_{point}} = \frac{Z_{point} + 2\sigma}{Z_{point}} = 1 + \frac{2\sigma}{Z_{point}}$$



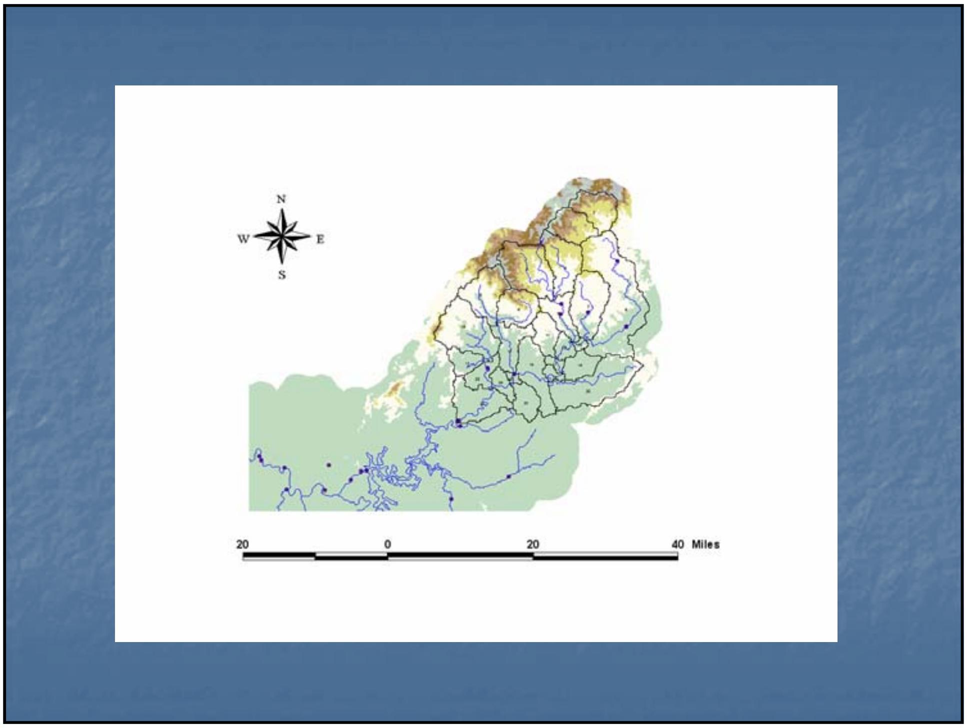
Pollutant Trading Project

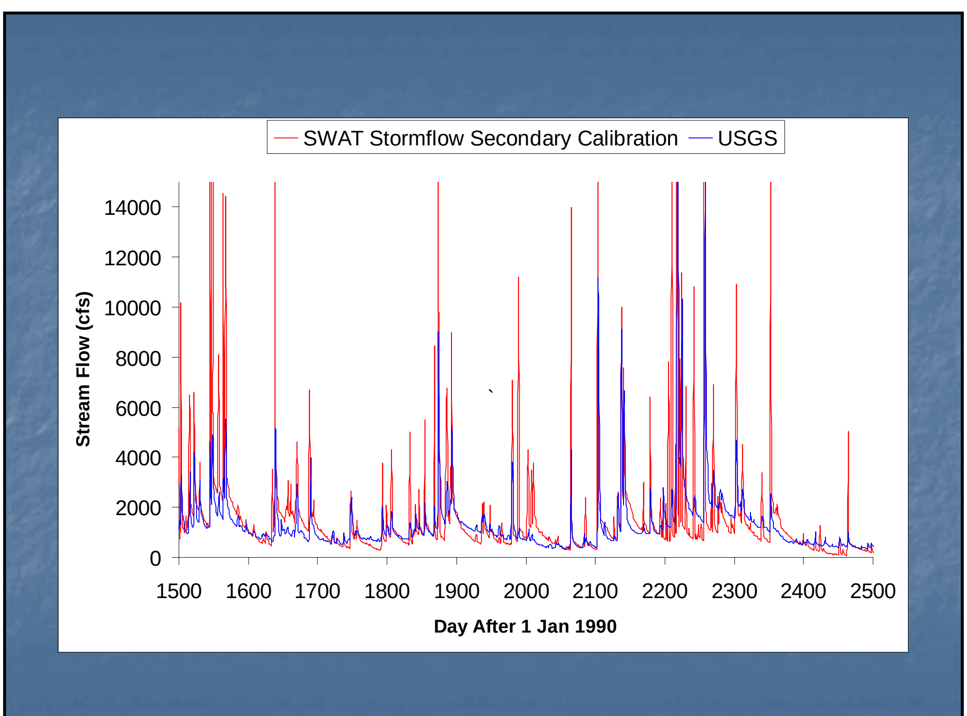
- Variance of a difference:
  - $\sigma^2_{a-b} = \sigma^2_a + \sigma^2_b - 2\sigma_{ab}$
  - σ^2_{a-b} small if σ_{ab} is large



Pollutant Trading Project

- Calibrate SWAT for flow, sediment, and P using PEST
  - Existing data extensive for flow, relatively good for P and sediment on large tributaries
  - Set up 12 first-second order stream sampling sites with single predominant landuse
  - Calibrate SWAT to get landuse-related parameters
- Determine predictive uncertainty and trading ratios using PEST


N
W
E
S
20
0
20
40 Miles


SWAT Stormflow Secondary Calibration
USGS
Stream Flow (cfs)
0
2000
4000
6000
8000
10000
12000
14000
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
Day After 1 Jan 1990

Australia II

- Just my first trip to Australia...
- Hope to return and work on predictive uncertainty of SWAT with:
  - John Doherty, Indooroopilly
  - Dan Rattray and Mark Silburn, Queensland NR&M
  - Willem Vervoort, University of Sydney

Appendix 2: "SWAT on the Darling Downs, Hodgson Creek Catchment" Dan Rattray, David Freebairn, Mark Silburn, Jo Owens, John Doherty. Queensland Natural Resources and Mines

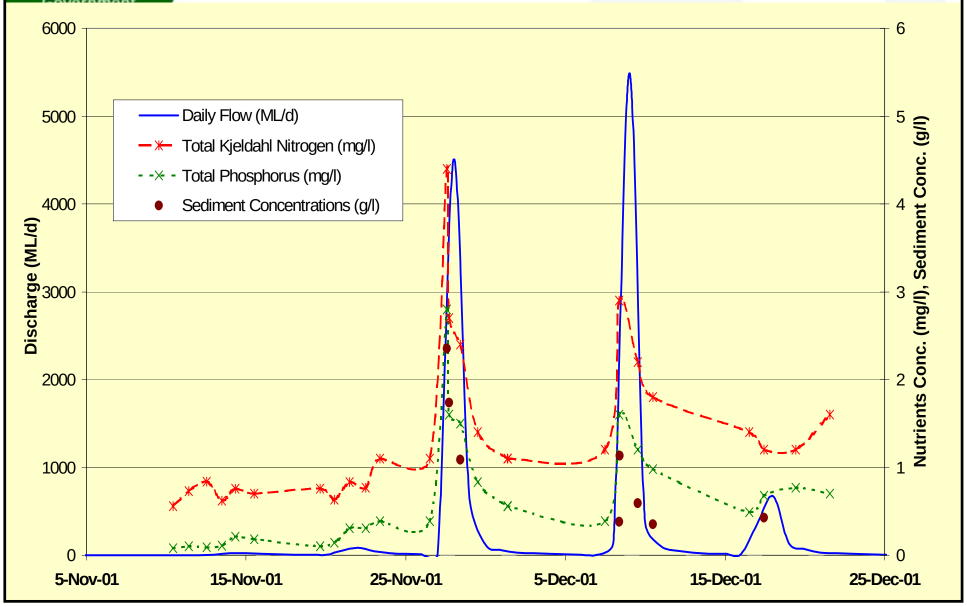
SWAT on the Darling Downs Hodgson Creek Catchment

Dan Rattray, David Freebairn, Mark Silburn,
Jo Owens, John Doherty

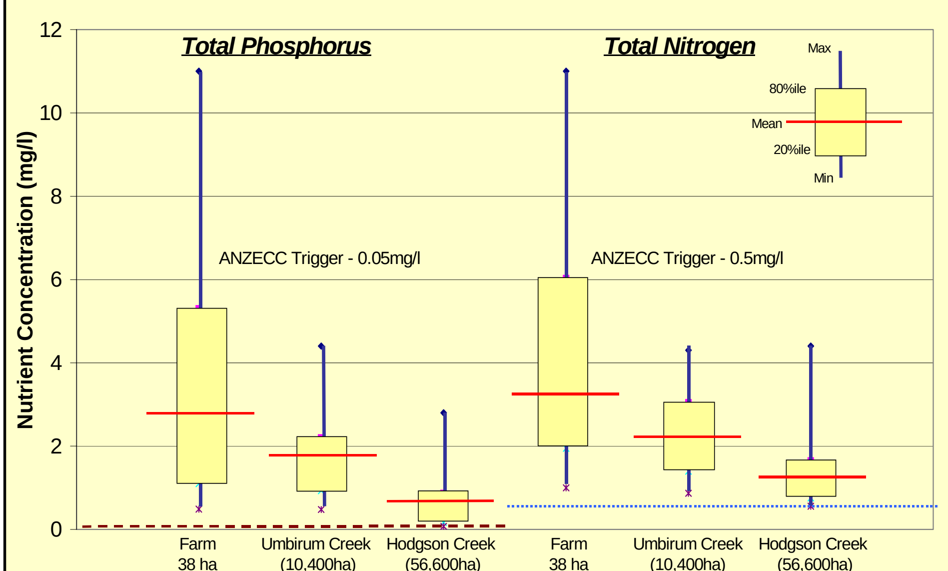
BMP for Pesticides Project Overview

Monitoring
↓
Point scale modelling
↓
BMP development
↓
Catchment scale modelling

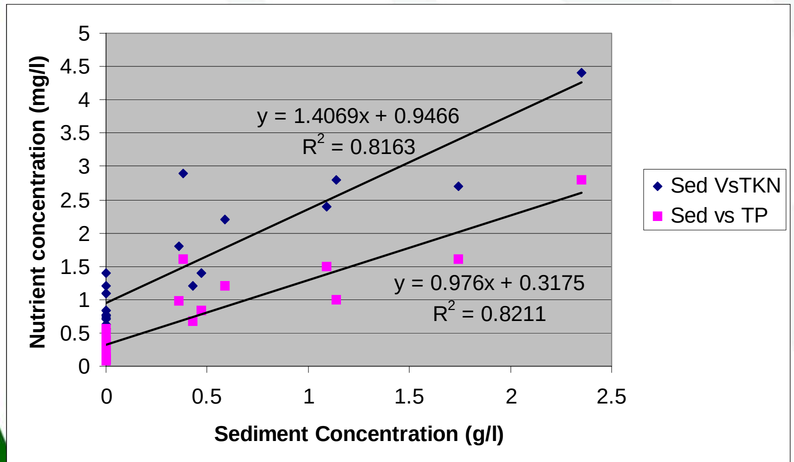
Hodgson Creek Gauging Station



Effect of Scale on WQ



Sediment vs Nutrient relationships – Hodgson at GS

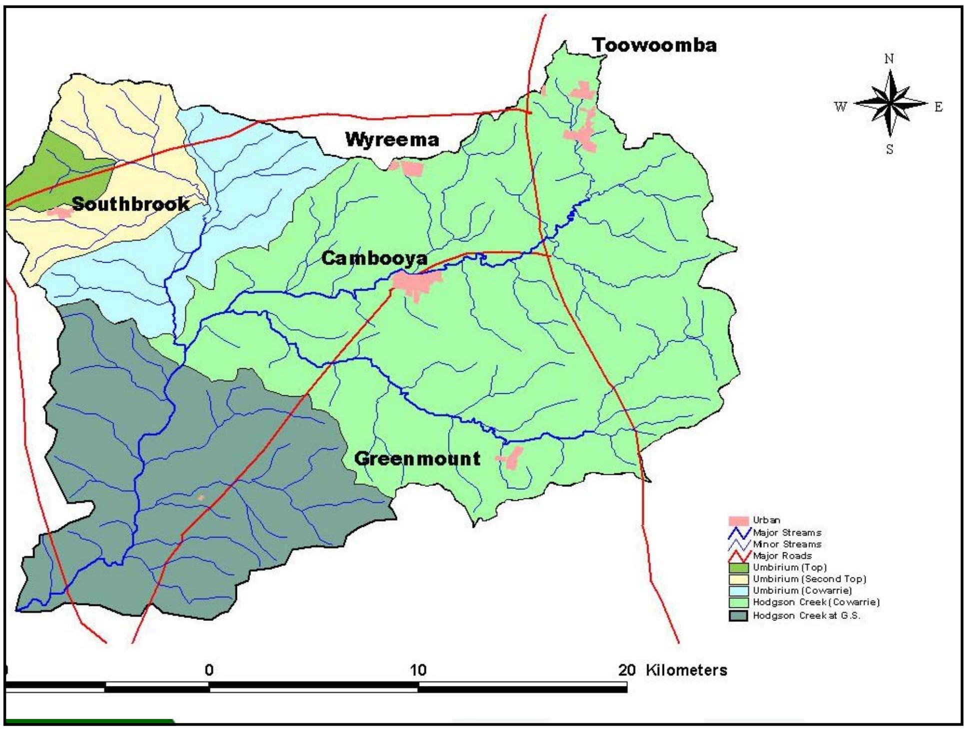


SWAT overview

- Developed by USDA – Texas
- Physically based
- Deals with hydrology, erosion, sediment transport, nutrients and pesticides
- Arcview interface for building model files
- Dos-prompt executable to run

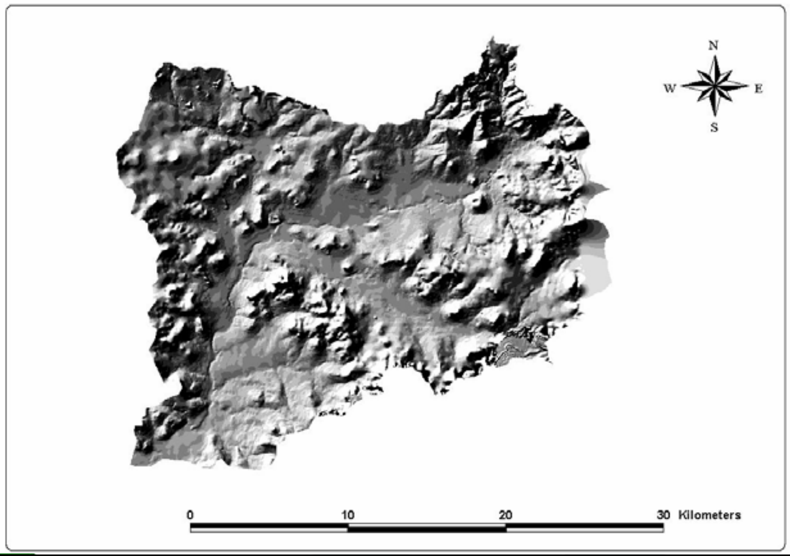
Hodgson Creek SWAT

- Hodgson Creek catchment
- 56,000 ha
- One gauging station
- 4 nested water quality sites
- Soil
  - Undulating rises and rolling low hills of black to dark brown clays with alluvium plains of self mulching cracking clays
- Rainfall gradient 950m/yr at Toowoomba to 700mm/yr at Pittsworth.



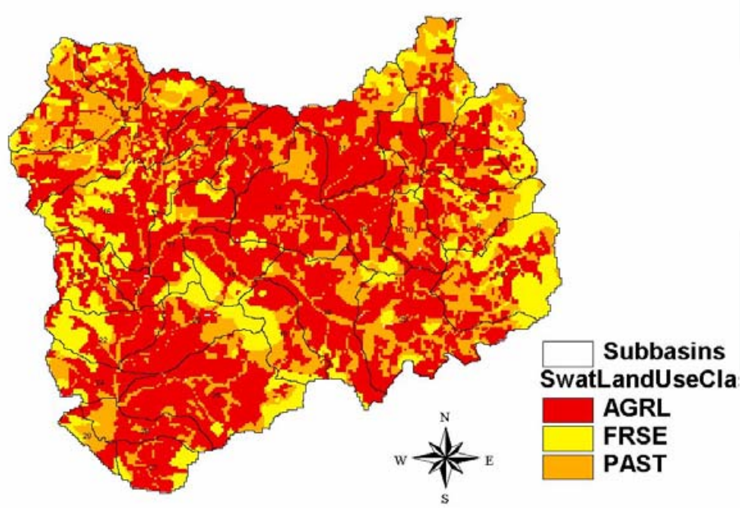
Queensland Government
Natural Resources and Mines

Digital elevation model



Queensland Government
Natural Resources and Mines

Land use map



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PEST (Doherty)

- Parameter estimation
- Multiple objective function (multiple obs v pred and multiple parameters)

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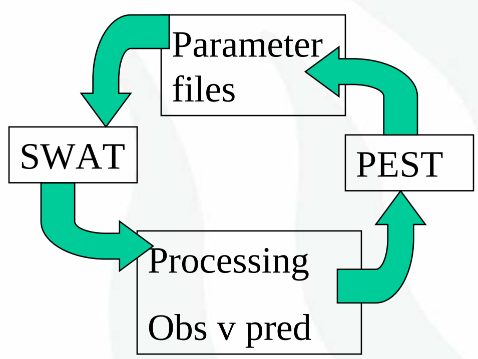
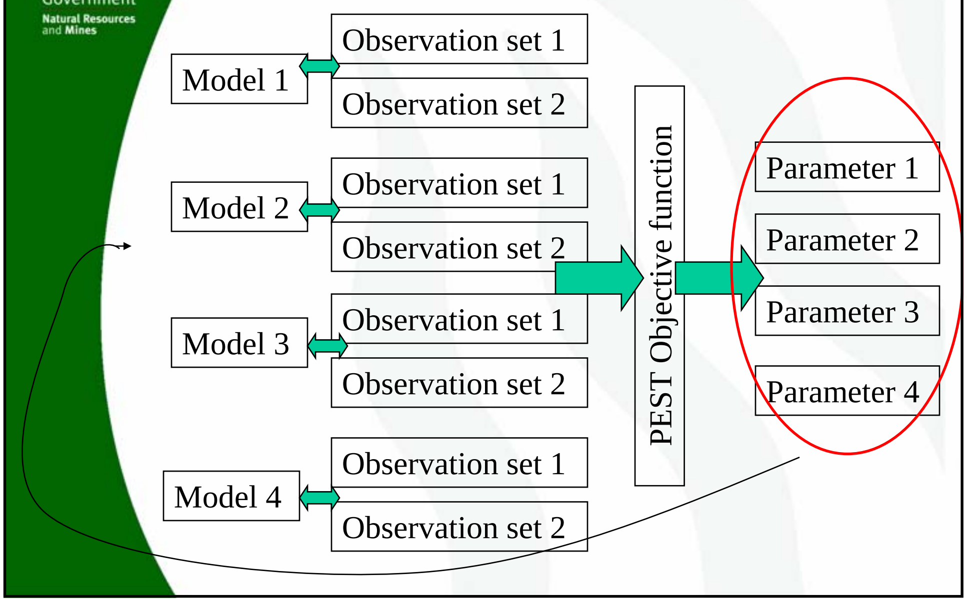
PEST



- Code changes in SWAT

PEST



PEST

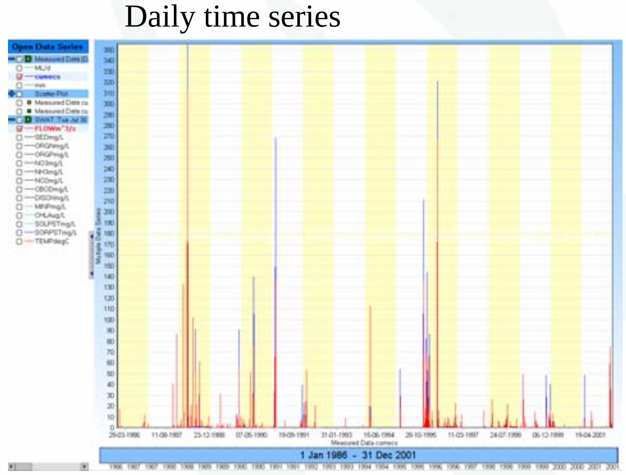
- Have got SWAT and PEST working for calibration
- Predictive uncertainty is coming!!

BROWSER

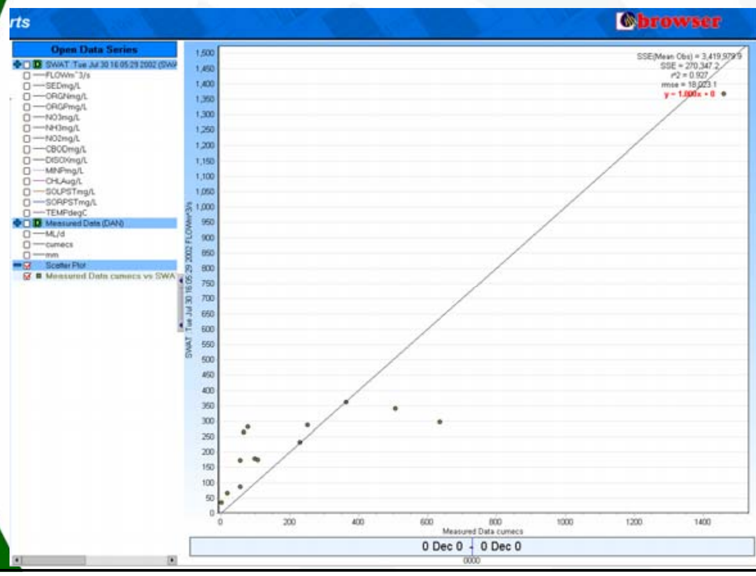
- Daily time step data viewer
- Reads in SWAT outputs with no post-processing
- Allows time series viewing, scatter plots, cumulative plots
- Is now on the SWAT developers web-site

BROWSER

Daily time series



BROWSER

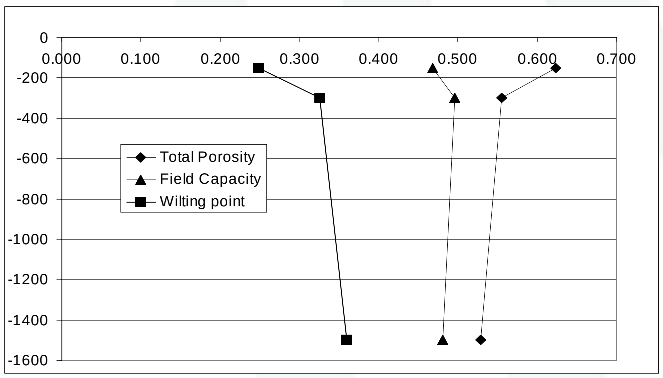


SWAT
Calibration process

- Soil Water Profile
- LAI
- Cover
- Soil Water
- Runoff

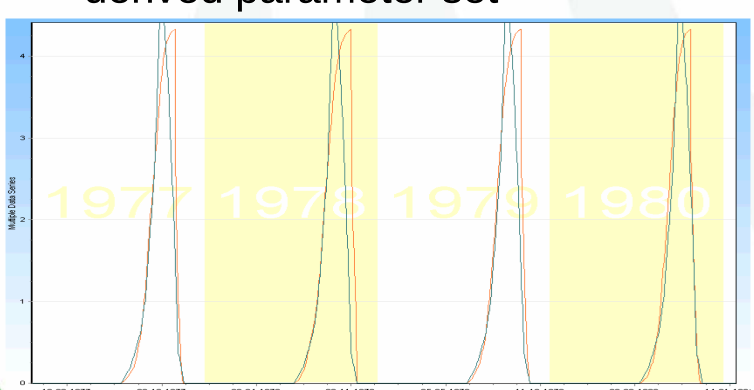
Soil water profile

- Clay%, BD,AWC, WP and FC



Leaf area index

- Fit to characterised shape by forcing dry matter
  Allow to be dynamic using derived parameter set



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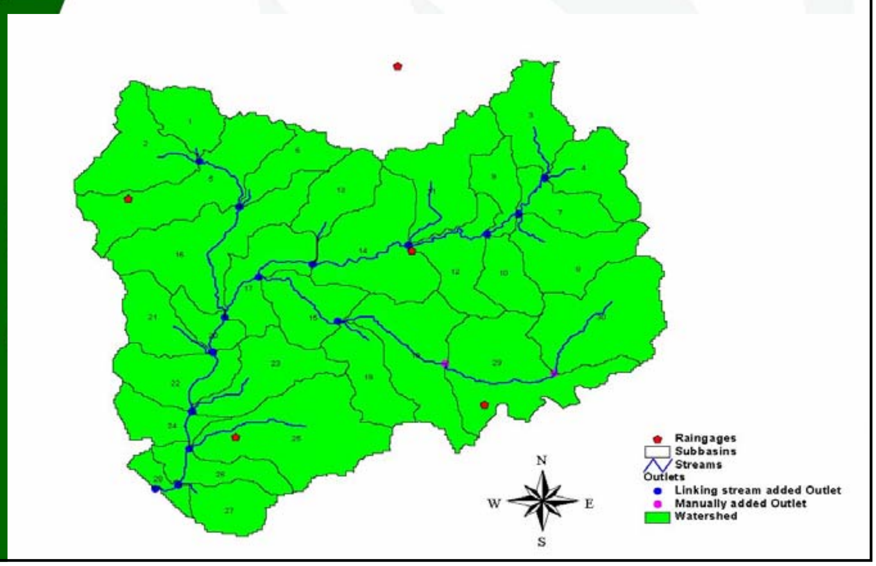
Soil water at point scale

- Calibrate EPCO/ESCO to get best fit obs v pred

Queensland Government
Natural Resources and Mines

SWAT streams and sub-basins



This week

- Looking at spatial variability –my interest is in how much crop was grown in a season
- Looking at distributions – pesticides in a catchment are not all applied on the same day, there will be some distribution – need to capture that in model.

Satellite Classified Data

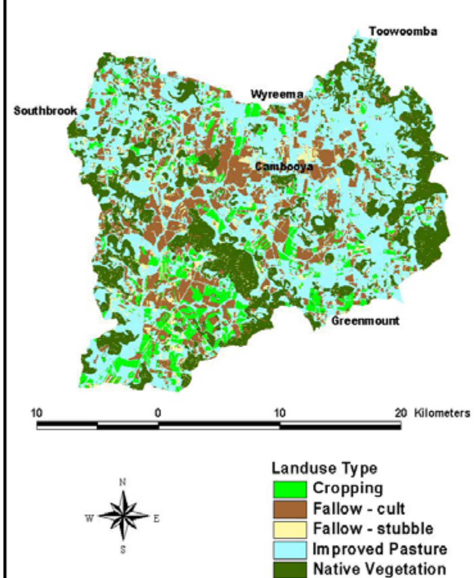
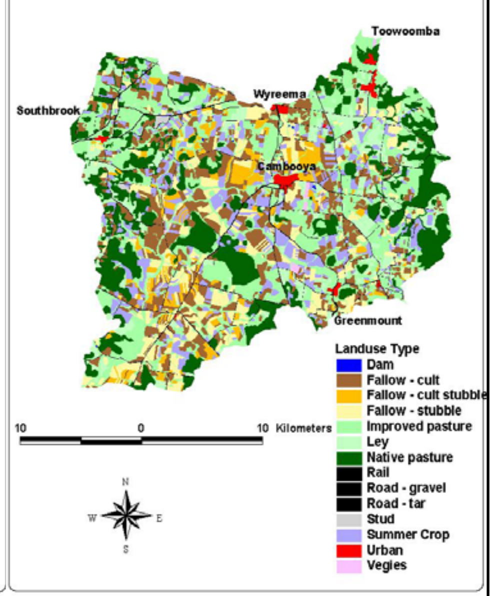


Photo Digitised Data



Summary

- Model similar to what we are used to ie PERECT, GLEAMS
- ArcView interface – essential for spatial modelling
- Uses interface to write model input files
- Code is provides so can make changes to model

Future work

- Sediment calibration
- Predictive uncertainty
- Calibration against relationships, not daily values

  ie. Flow vs sed distribution

Appendix 3: "Uncertianty and variability in time and space. Can we do something about it and does it matter" Willem Vervoort, The University of Sydney, Australian Cotton CRC.

Uncertainty and variability in time and space

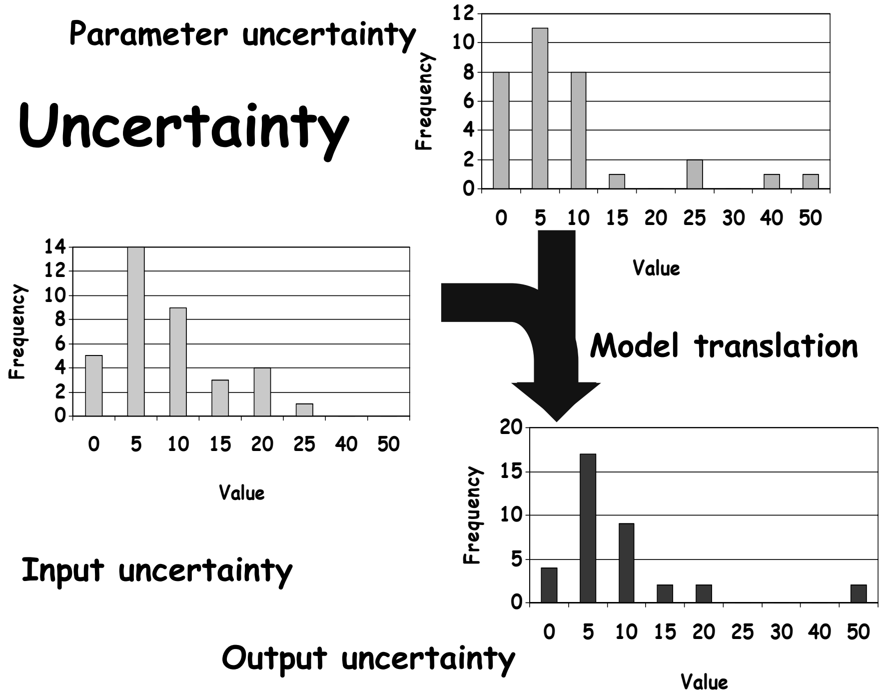
Can we do something about it and does it matter?

R.W. Vervoort, The University of Sydney,
Australian Cotton CRC, NMD - WBG

Uncertainty

- Three types:
  - Observations
  - Input
  - Model inherent
- Best dealt with using a stochastic approach
- Output needs to indicate level of confidence

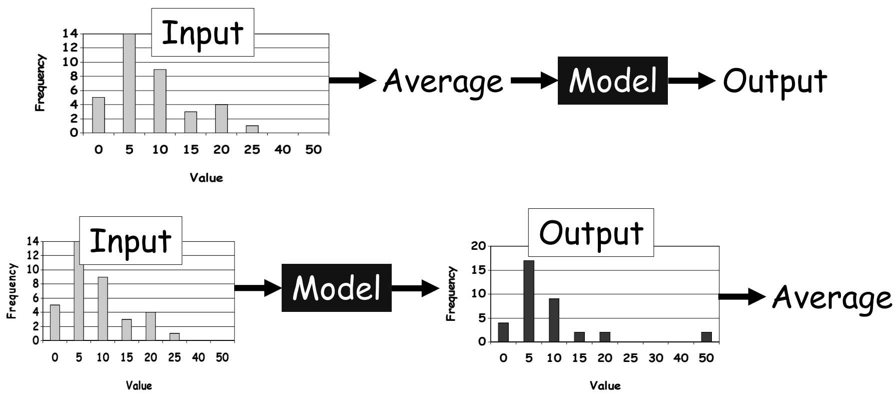
Uncertainty



Quantify output uncertainty

- Mean: 7.2
- Stdev: 10.3
- Confidence interval: 3.4
- CV: 143%
- Probability of exceeding Mean: 0.35
- Politics: Are those few exceedances important?

When do we average?



- For linear process, both outcomes are the same
- For non-linear process, outcomes are different

What could be creating uncertainty in SWAT?

Examples:

- Application dates of atrazine
- Variation in soil cover
- Variation in growth
- Variation in C?
- Others?

Recap HRU (SWAT)

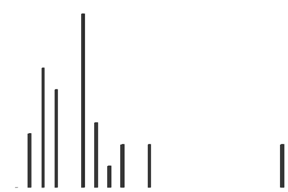
- Homogeneous
- Size depends on accuracy of:
  - Landuse map
  - Soil map
- Balance between minimum size of HRU and number of parameters to calibrate

Example: Atrazine application

- Atrazine application dates and the effect of rainfall after application
- Currently: 1 application date for all atrazine
- What would happen if application dates are spread out (distributed)

Distribution of atrazine application dates

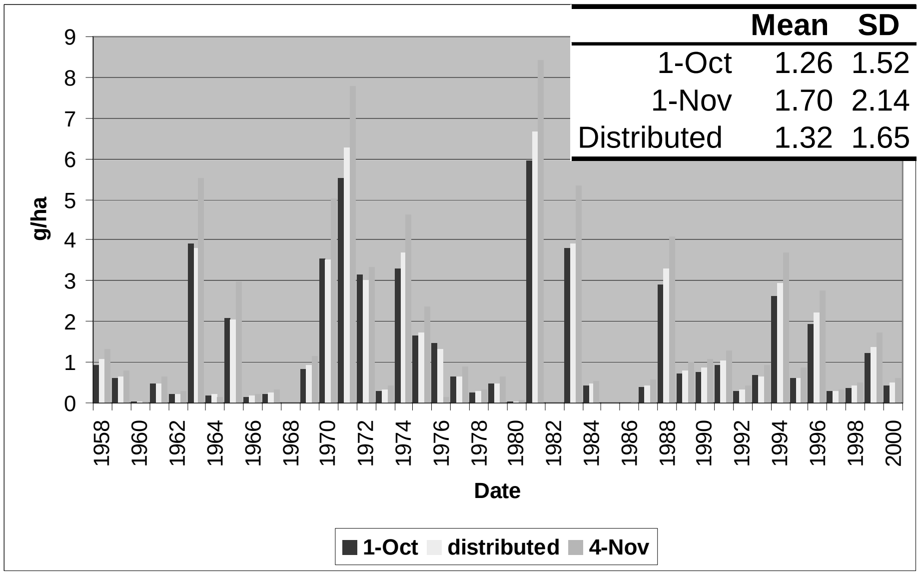
Number	Date
0	15-Sep
5	20-Sep
11	25-Sep
9	30-Sep
16	10-Oct
6	15-Oct
2	20-Oct
4	25-Oct
4	04-Nov
4	24-Dec



Atrazine application

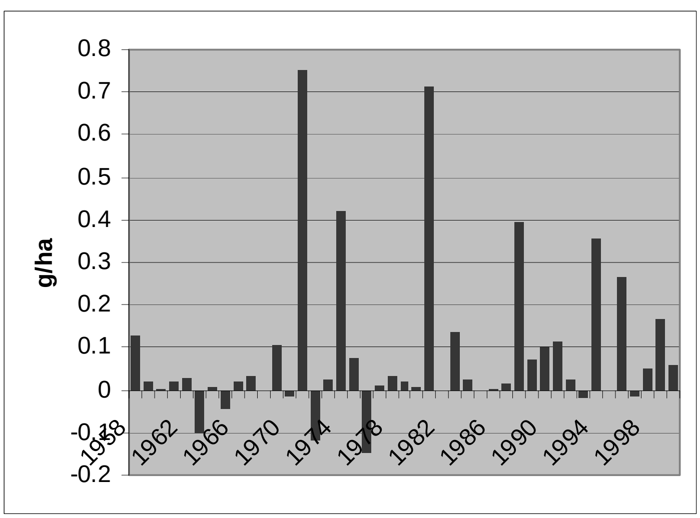
- Run “How Leaky” for all values in distribution
- Scale outcomes by relative abundance
- Calculate mean concentration in distribution
- Similar approach to a Distribution Function hydrological model (i.e. Topmodel)

Annual atrazine runoff



	Mean	SD
1-Oct	1.26	1.52
1-Nov	1.70	2.14
Distributed	1.32	1.65

Difference between distributed and average Atrazine application

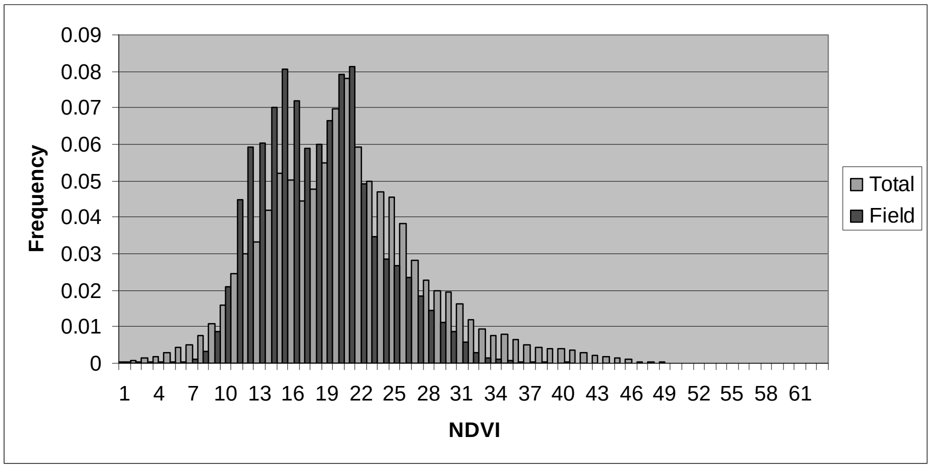


Mean: 0.08 g/ha
SD: 0.19 g/ha

But what about soil cover?

Suggestions

Distribution of NDVI



NDVI = Soil cover = C? = CN?

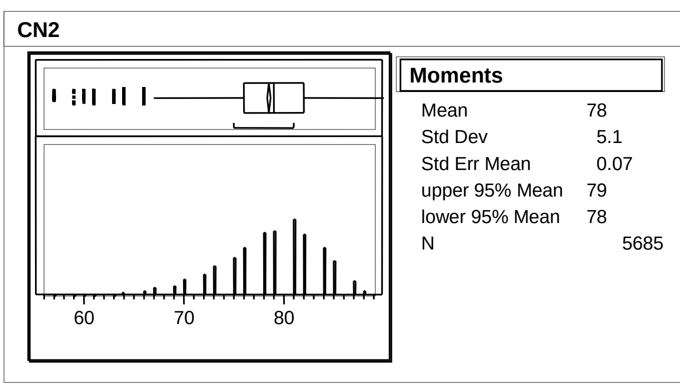
Example: using satellite data

- Calculate distribution of NDVI
- Convert/scale to parameter (i.e. CN or C?)
- Sample distribution ***n*** times
- Run SWAT ***n*** times for the distribution of parameter values (i.e. CN or C?)
- Calculate Mean, SD, CI or probability of the output

Example: using satellite data

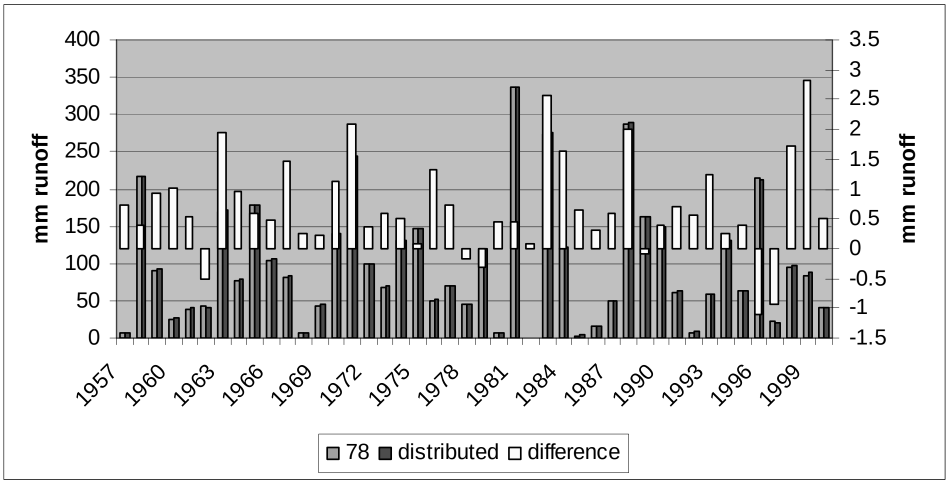
- Use "Browser" to summarise the output
- PEST can be used to run the distribution
- Initially will use "How Leaky" to figure out whether it matters
  - Black earth in Dalby under wheat

Calculation of CN_2 for field



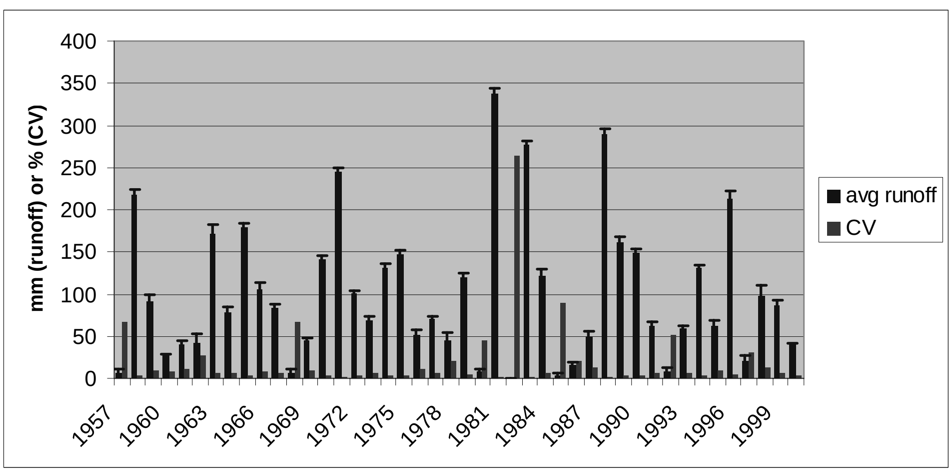
- Translated NDVI into %cover (61 max and 10 min)
- Translated cover into CN_2 using Owens et al. (2003)

Field runoff



	Mean	Stdev
78	99.5	82.8
Distributed	100.2	83.1
Difference	0.69	0.82

Variation in CN on runoff



CV = coefficient of variation = stdev/mean

Greater variation in dry years!
Episodic nature of rainfall becomes important

End remarks

- Including uncertainty allows better interpretation of the data
- Running distributions of input follows hydrological distribution function approach
- Variation in input contributes to variation in output
- Variation in input does not always create major uncertainty
- Incorporation in simulations through PEST?