Automated Calibration of Watershed Models

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Watershed-Scale Models

- Used in TMDL analysis
  - Estimate current pollutant loads (especially non-point source loads)
  - Estimate effect of BMP’s in reducing loads
- Dynamic vs. static
  - *Static* models predict annual loads
  - *Dynamic* models predict daily or hourly stream flow and pollutant concentration

Watershed-Scale Models

- Lumped models
  - Group land-uses and soils into large units that flow directly into the watershed outlet
  - Parameters averaged over watershed
- Semi-distributed models
  - Divide watershed into sub-basins
  - Model flow from sub-basin to sub-basin
  - Within each sub-basin land-uses and soils lumped
  - Parameters can vary among sub-basins

Watershed-Scale Models

- Dynamic semi-distributed watershed-scale models
  - Soil Water Assessment Tool (SWAT)
  - Hydrological Simulation Program Fortran (HSPF)
  - Many parameters
- Models require calibration
  - Some parameter values determined by fitting model predictions to observed flow and pollutant concentration (usually at outlet)

Calibration

- Most dynamic watershed-scale models calibrated manually
- Software exists for automated calibration
- Parameter Estimator (PEST) software developed by John Doherty
  - Can be used with any Fortran code model
  - Reads input and output files
  - Finds optimum values and does sensitivity analysis
  - Requires starting values and may not find global “best-fit”
  - Free software
  - Can be run with HSPF (but not SWAT) in BASINS 3.1?

Objectives

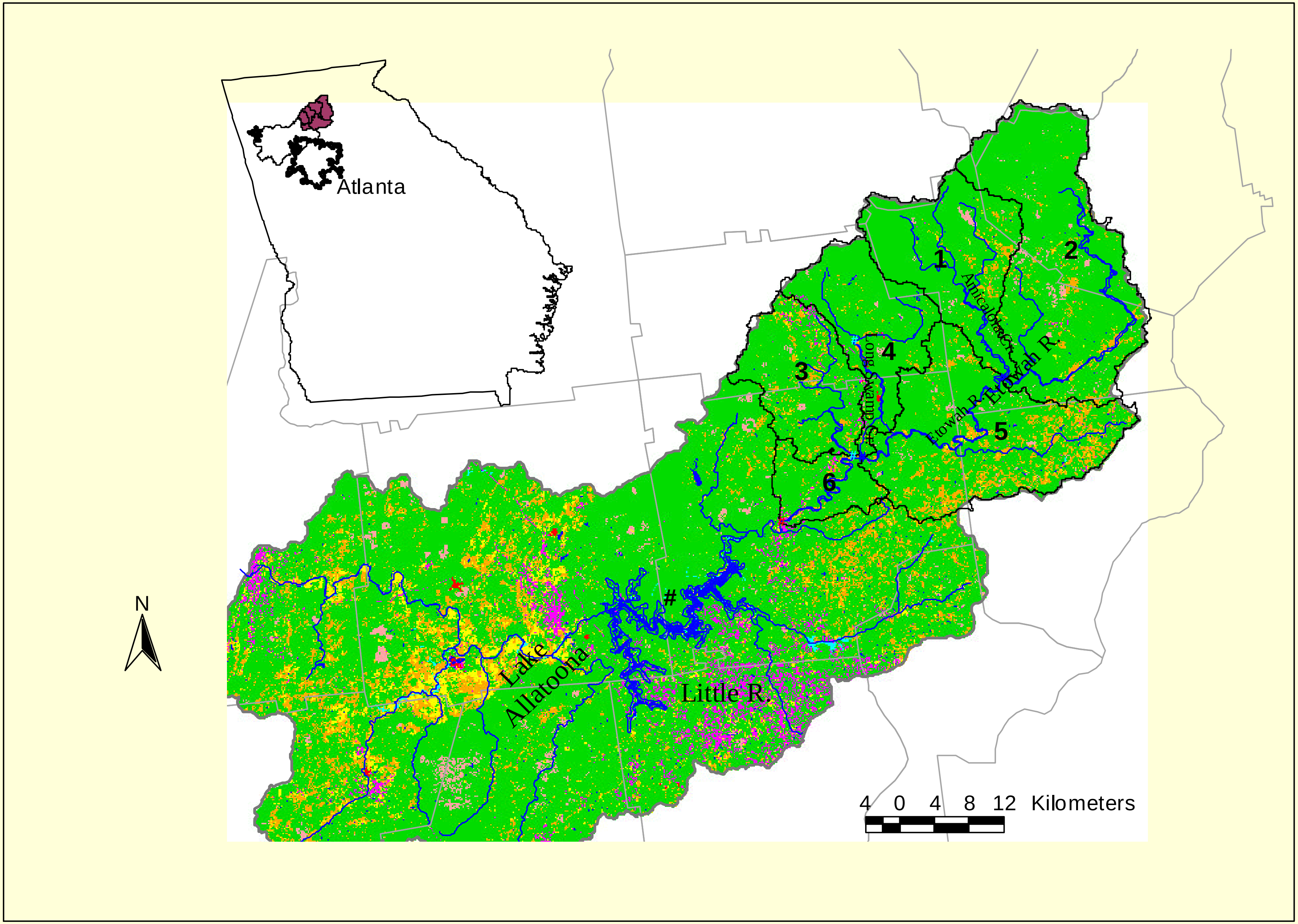
- Short-term: perform automated calibration
  - Using SWAT and PEST
  - Upper Etowah River watershed
  - Daily water flow available 1983-1993
- Short-term: determine uncertainty of model predictions
  - Automated calibration is first step in process
  - Put confidence intervals (CI's) on model predictions of annual and daily flow
- Long-term: use CI's to determine trading ratios between point and non-point sources

Outline

- No calibration
- Manual calibration
- Automated calibration
- Model uncertainty

SWAT Set-up

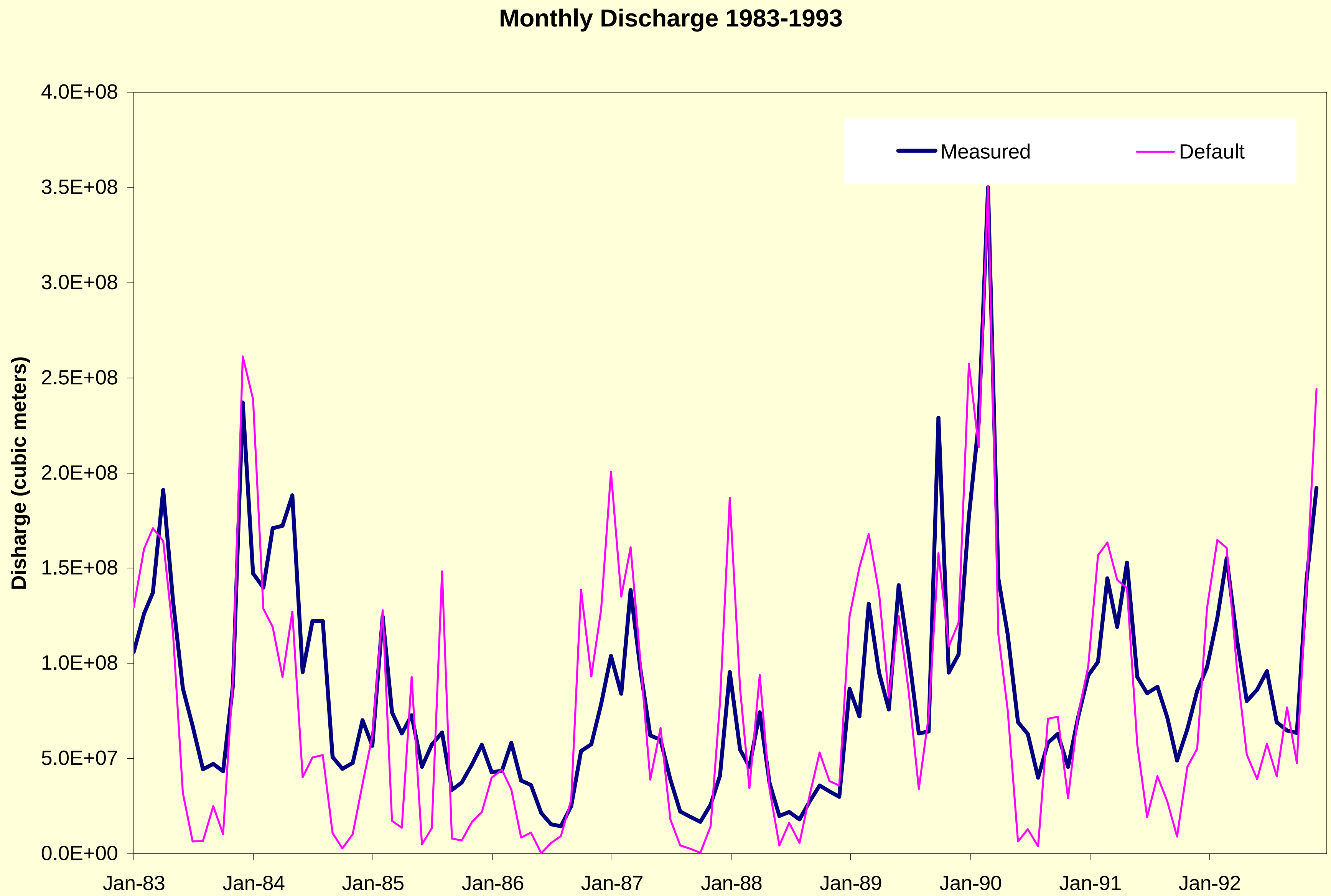
- Automated delineation of watershed from USGS gauging station at Canton
  - Watershed area 1,580 km^2
  - 89.7% forest, 7.9% grass, 1.9% row crop, <0.5% urban
  - STATSGO soil layer
  - Precipitation from 4 gages in watershed
- 6 sub-basins
- Within each sub-basin each combination of land-use and soil is a hydrologic response unit (HRU)
  - 72 potential combinations of sub-basin, soil, and land-use
  - 48 actual HRU’s (not all soils and land-uses appear in each sub-basin)



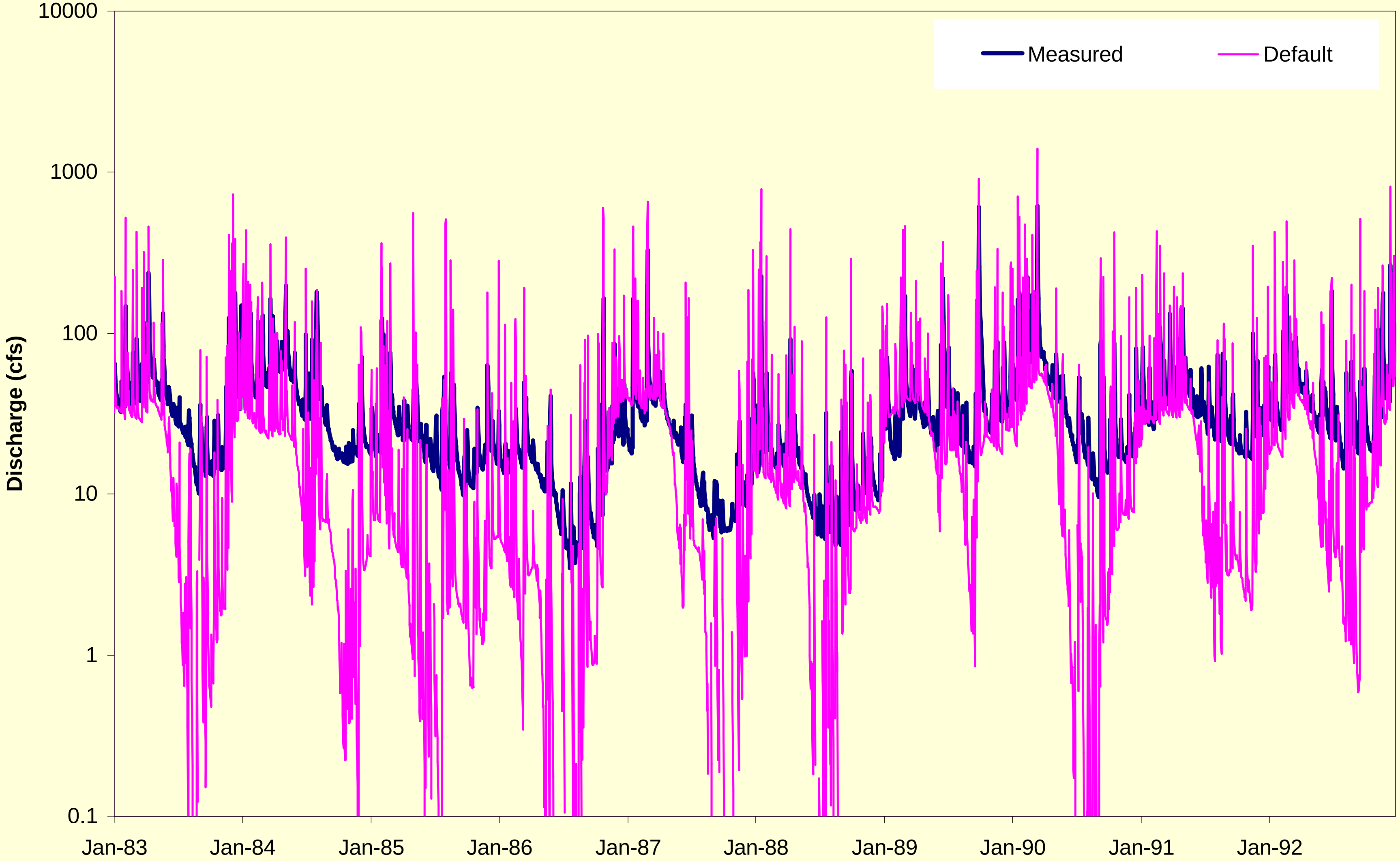
Atlanta
N
1
2
3
4
5
6
Etowah R.
Etowah R.
Lake Allatoona
Little R.
#
4 0 4 8 12 Kilometers

Outline

- No calibration (default parameter values)
- Manual calibration
- Automated calibration
- Model uncertainty


Monthly Discharge 1983-1993
Measured
Default
Disharge (cubic meters)
4.0E+08
3.5E+08
3.0E+08
2.5E+08
2.0E+08
1.5E+08
1.0E+08
5.0E+07
0.0E+00
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92

Daily Discharge 1983-1993



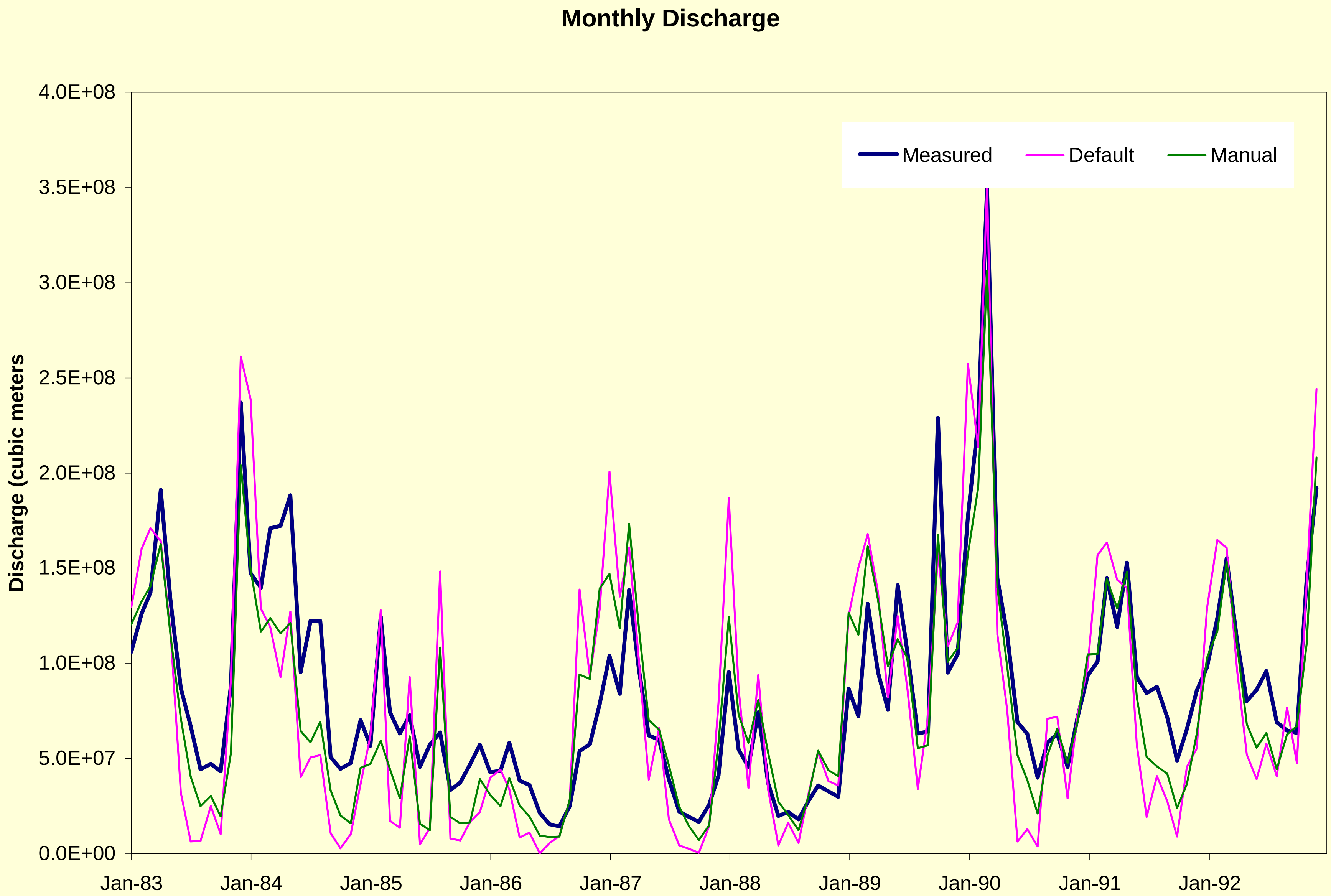
Parameter	Description	Sensitivity	Class
ESCO	Soil evaporation depth coefficient	1.917	I
GW_DELAY	Time for groundwater to reach shallow aquifer	0.670	II
CN2F	Curve number forestry	0.666	II
SOL_AWC	Soil available water content	0.275	II
GW_REVAP	Threshold depth for water transfer from shallow aquifer to root zone	0.254	II
CN2P	Curve number pasture	0.119	II
CH_K(1)	Ephemeral channel bottom conductivity	0.042	III
GWQMN	Threshold depth for groundwater flow to stream	0.033	III
SURLAG	Surface lag coefficient delays runoff	0.027	III
ALPHA_BF	Base flow recession constant	0.014	III
RCHRGDP	Deep aquifer percolation fraction	0.011	III
CN2U	Curve number urban	0.009	IV
CH_N	Manning's "n" for tributary channels	0.009	IV
CN2A	Curve number row crop agriculture	0.008	IV
OV_N	Manning's "n" for overland flow	0.002	IV
REVAPMN	Threshold depth for water transfer from shallow aquifer to the unsaturated zone or deep groundwater	0.001	IV

Outline

- No calibration
- <u>Manual calibration</u>
- Automated calibration
- Model uncertainty

Manual Calibration

- Manually adjusted 11 most sensitive parameters
- Class I–III sensitivity
- All parameters had the same values across sub-basins
  - Lumped fitted parameter values



Monthly Discharge
Discharge (cubic meters
4.0E+08
3.5E+08
3.0E+08
2.5E+08
2.0E+08
1.5E+08
1.0E+08
5.0E+07
0.0E+00
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Measured
Default
Manual

Nash-Sutcliffe

- Nash-Sutcliffe efficiency

$$E = 1 - \frac{s_{error}^{2}}{s_{observed}^{2}}$$

σ_{error} = *error variance* or root mean squared error of observed – predicted

$\sigma_{observed}$ = variance of the observations

- E = 1: perfect fit (zero error)
- E = 0: no better than a model that uses the mean of observed as prediction
- E < 0: worse than mean of observed

Nash-Sutcliffe

Calibration	Monthly Discharge	Daily Discharge
Default	0.50	-1.39
Manual	0.77	0.62

Outline

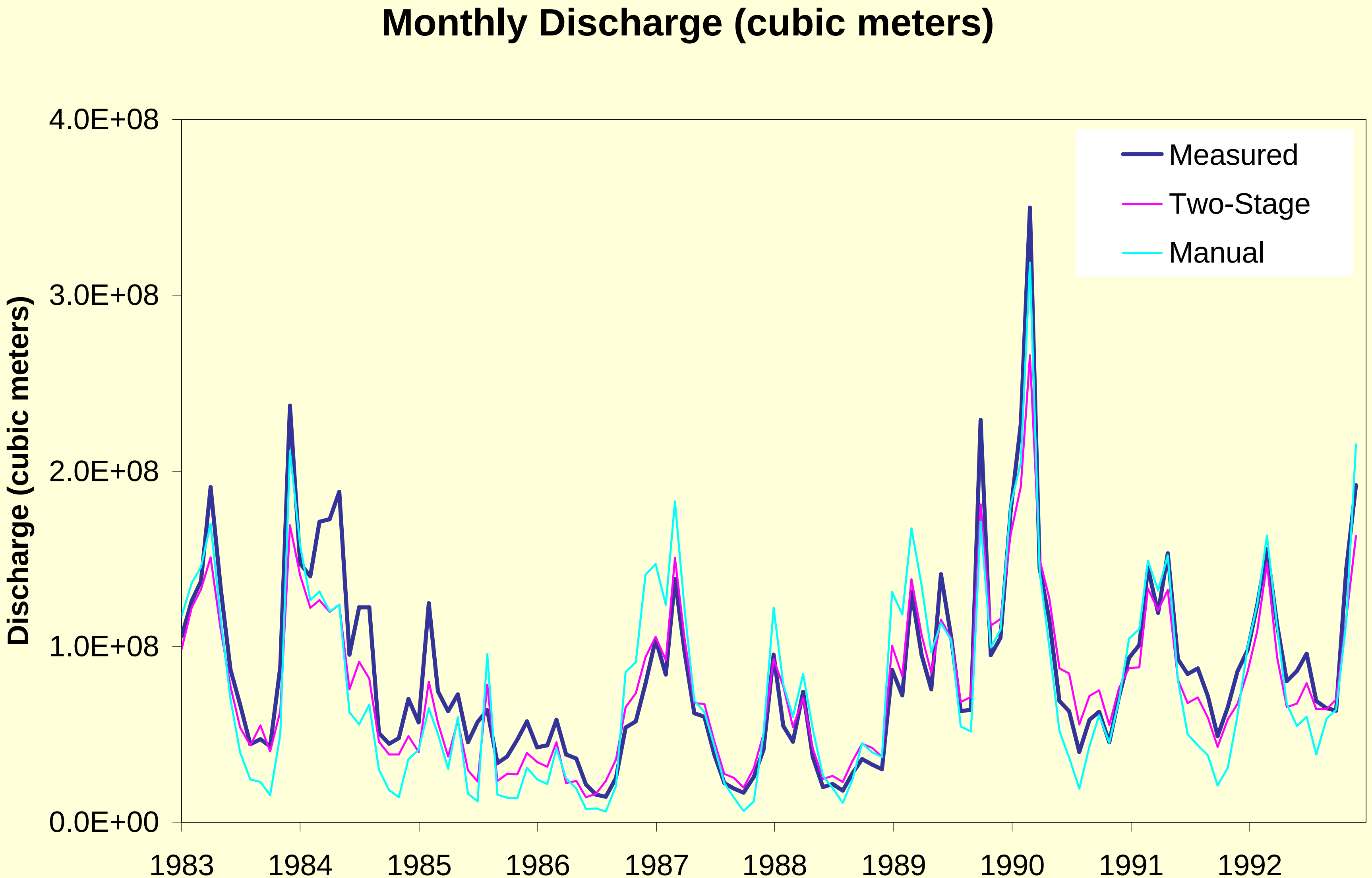
- No calibration
- Manual calibration
- <u>Automated calibration</u>
- Model uncertainty

Automated Calibration

- Two-stage automated calibration using PEST
- First stage
  - Used Shuffled Complex Evolution (SCE) option in PEST to find approximate global minimum
  - Accelerated process by
    - using lumped parameters (11 parameters)
    - relaxing requirements for fit

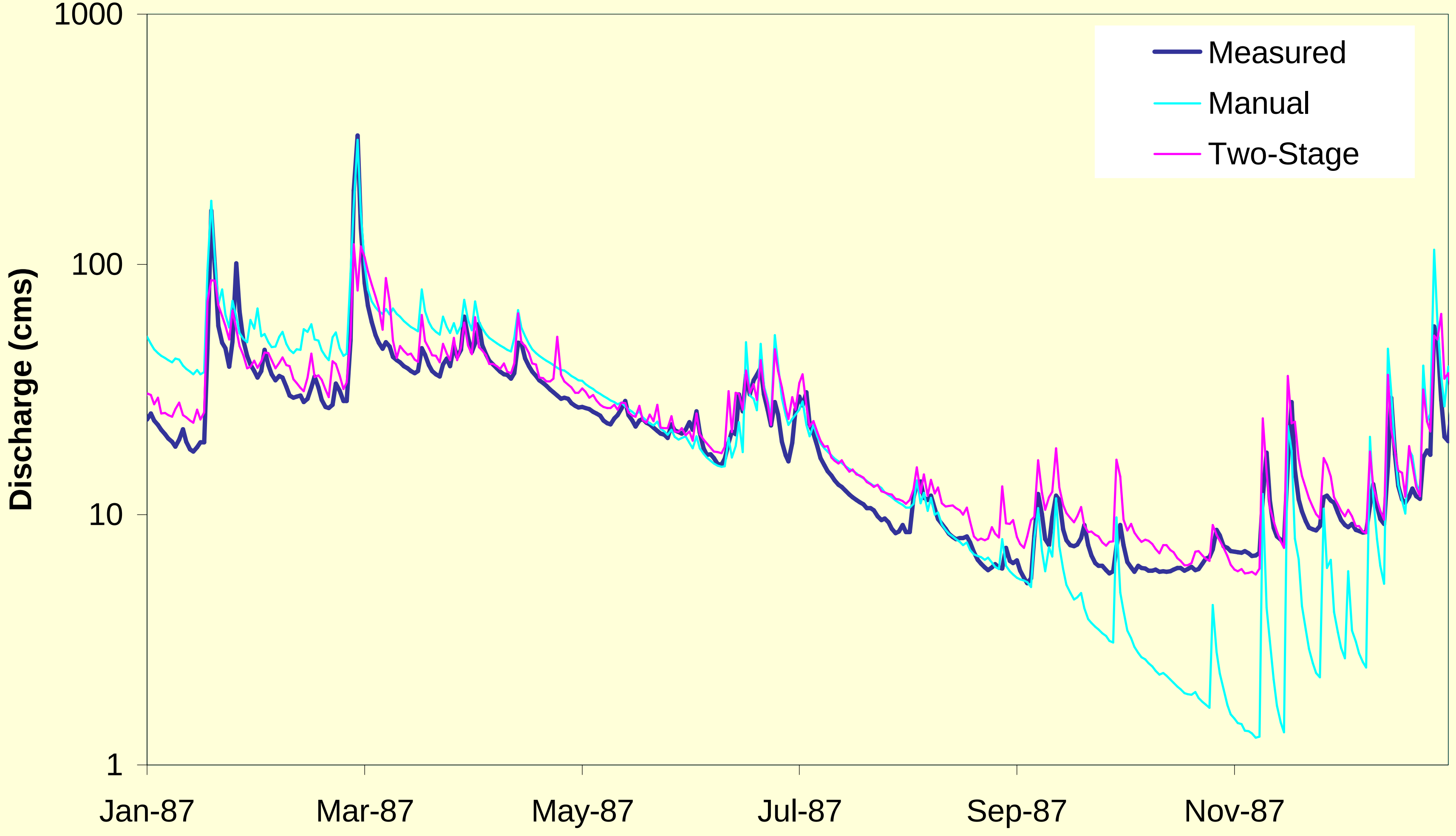
Automated Calibration

- Second stage
  - Used local method to refine global minimum
  - Used parameter values found in first stage as starting values
  - Allowed parameters to vary among HRU
    - Increased parameter number from 11 to 69
  - Used "regularization" to restrain variation among HRU



Monthly Discharge (cubic meters)
Discharge (cubic meters)
4.0E+08
3.0E+08
2.0E+08
1.0E+08
0.0E+00
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
Measured
Two-Stage
Manual

Daily Discharge 1987



Nash-Sutcliffe

Calibration	Monthly Discharge	Daily Discharge
Default	0.50	-1.39
Manual	0.77	0.62
Two-stage PEST	0.86	0.61

Number of Model Runs

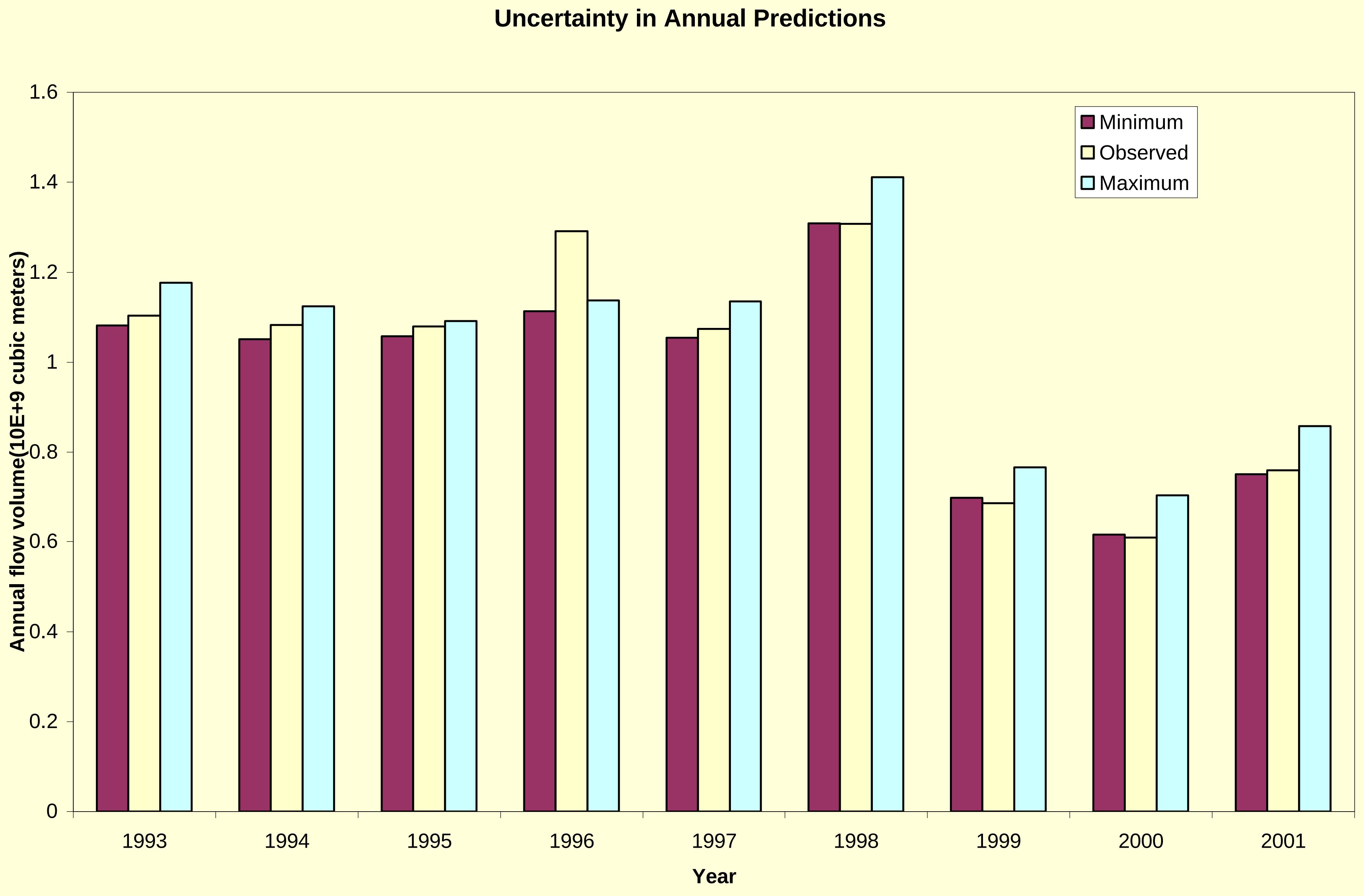
Calibration Method	Approximate Number of Model Runs	Nash-Sutcliffe Coefficient for Monthly Flow
Two-stage PEST	3000	0.86
Conventional Global Method (SCE)	8000	0.83

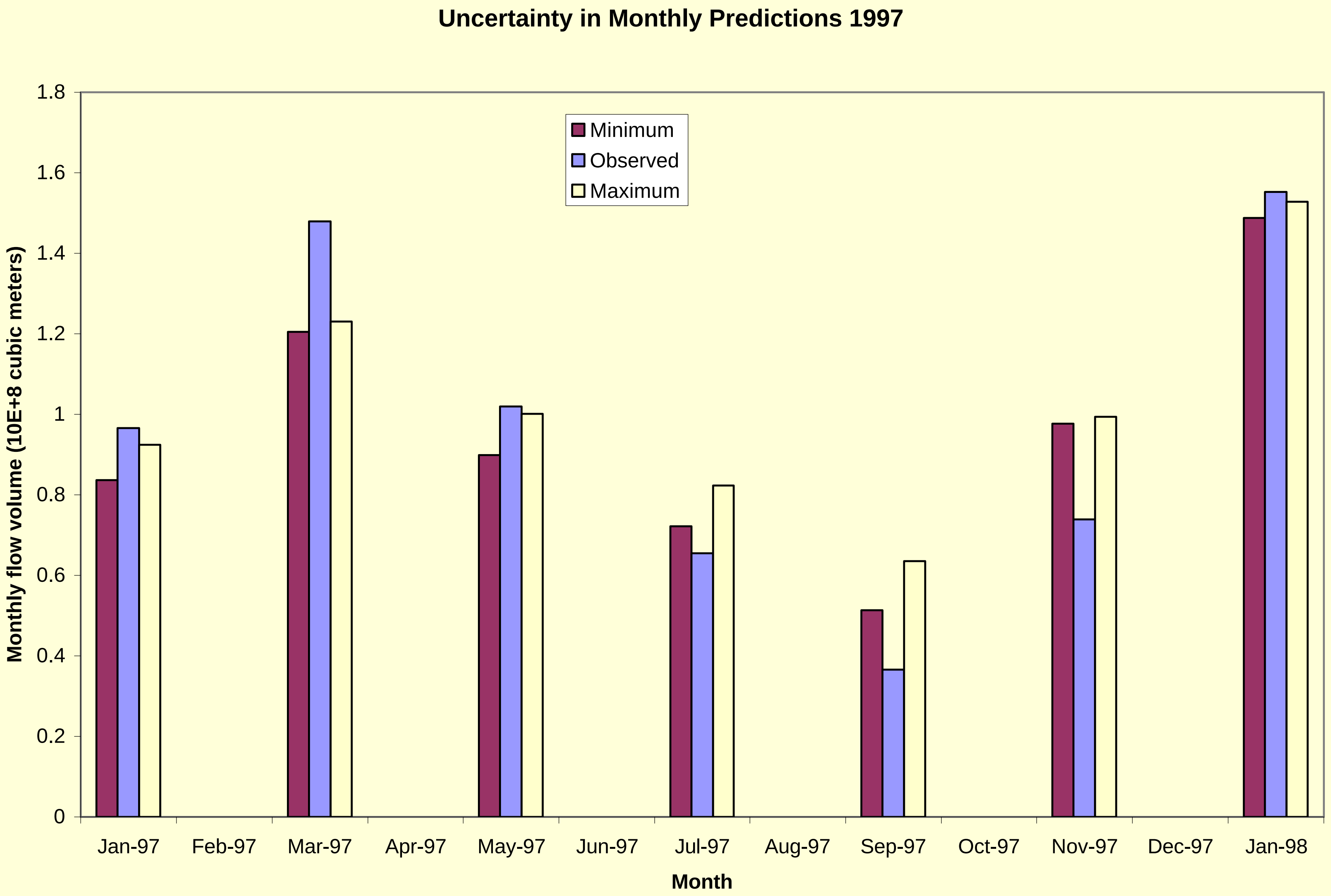
Outline

- No calibration
- Manual calibration
- Automated calibration
- Model uncertainty

Model Uncertainty

- No widely accepted method has been developed for setting confidence limits on predictions of dynamic watershed-scale models
- PEST includes a “non-linear calibration constrained optimization” method for setting 95% confidence intervals (CI) on predictions
- We used this to set CI on annual, monthly, and weekly predictions for calibration period


Uncertainty in Annual Predictions
Annual flow volume(10E+9 cubic meters)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Minimum
Observed
Maximum
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year


Uncertainty in Monthly Predictions 1997
Minimum
Observed
Maximum
Monthly flow volume (10E+8 cubic meters)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Jan-97
Feb-97
Mar-97
Apr-97
May-97
Jun-97
Jul-97
Aug-97
Sep-97
Oct-97
Nov-97
Dec-97
Jan-98
Month

Conclusions

- Automated calibration of SWAT
  - Can be done with PEST (free software)
  - Allows a large number of distributed parameters to be fitted
  - First step in analyzing model uncertainty
- Model uncertainty
  - PEST has a method for setting CI on predictions
  - For annual flow CI were narrow and encompassed observed flow CI for monthly and weekly flow did not encompass observed flow
  - Time scale for trading program is annual