A MODULAR APPROACH TO ADDRESSING MODEL DESIGN, SCALE, AND PARAMETER ESTIMATION ISSUES IN DISTRIBUTED MODELING

George Leavesley , USGS, Denver, CO

BACKGROUND

1983 - WMO Intercomparison of Snowmelt Models

11 models

1999 - Z-L Yang, University of Arizona Survey of Snowmelt Models

42 models

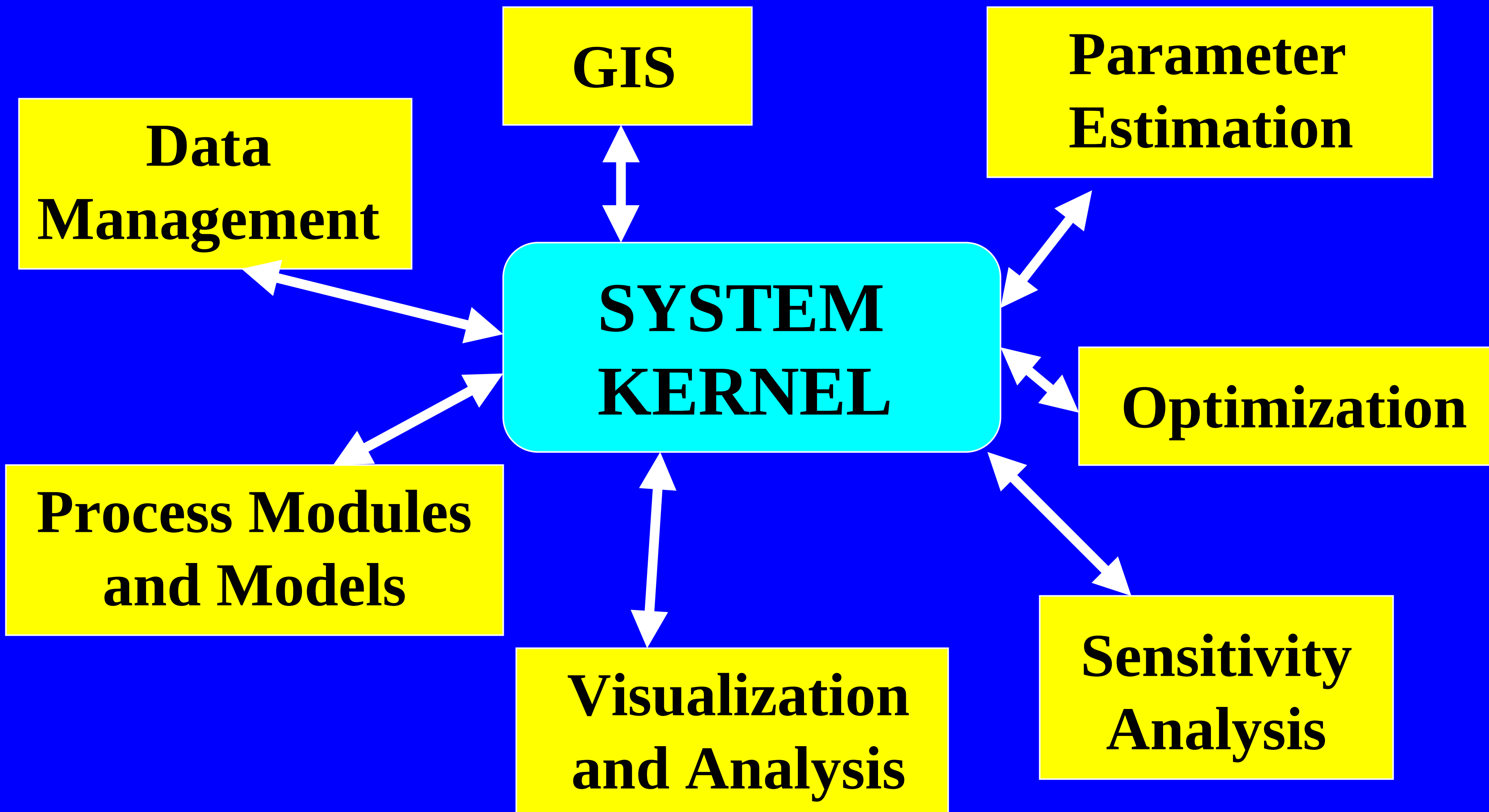
STARTING POINTS

- There are no universal models
- Models for different purposes require different levels of detail and comprehensiveness
- Appropriate model process conceptualizations are a function of problem objectives, data constraints, and spatial and temporal scales of application

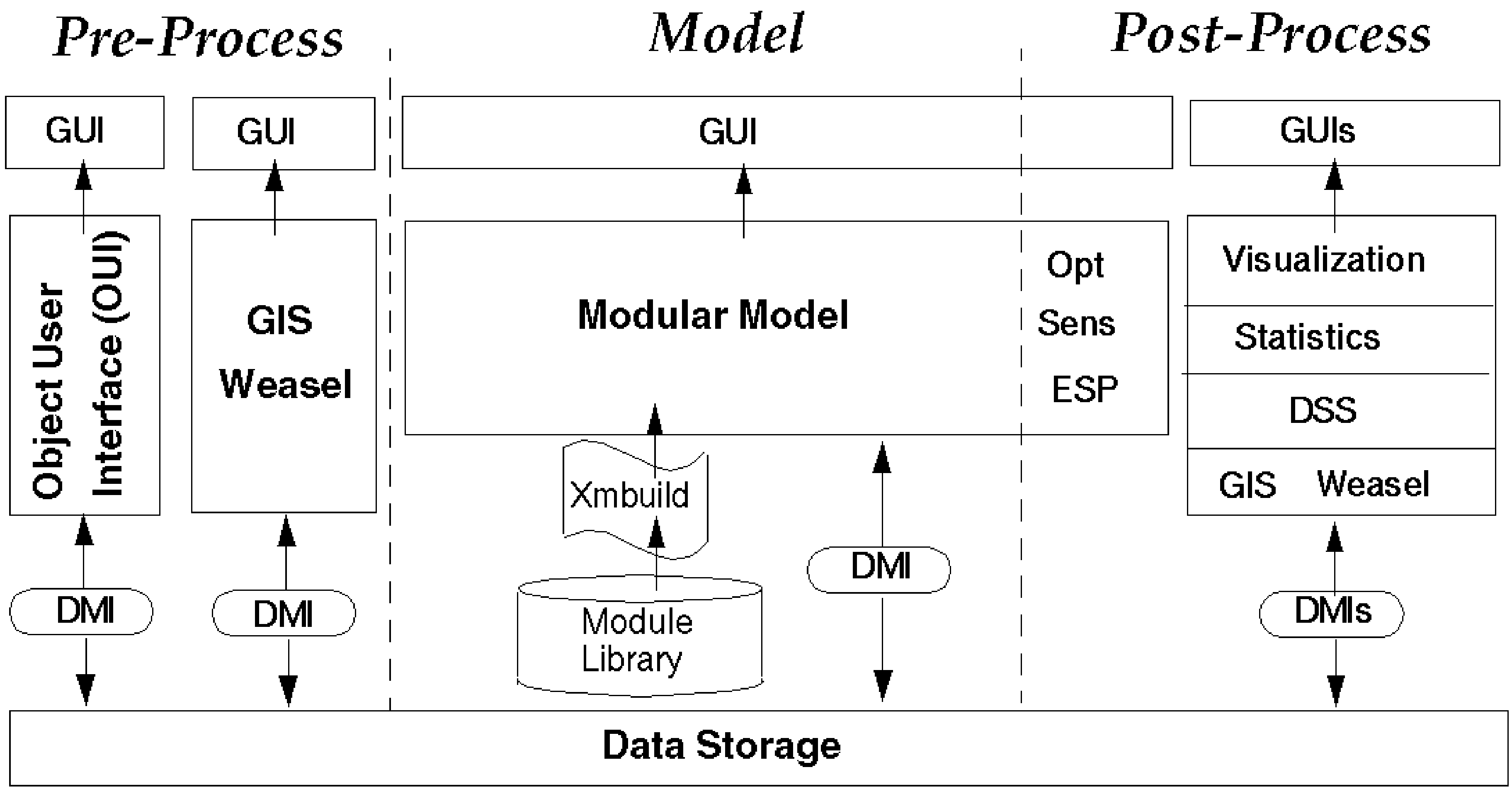
STARTING POINTS

- For a given set of constraints, improved distributed models can be created by coupling the appropriate process conceptualizations

GENERIC MODULAR SYSTEM STRUCTURE (toolbox)



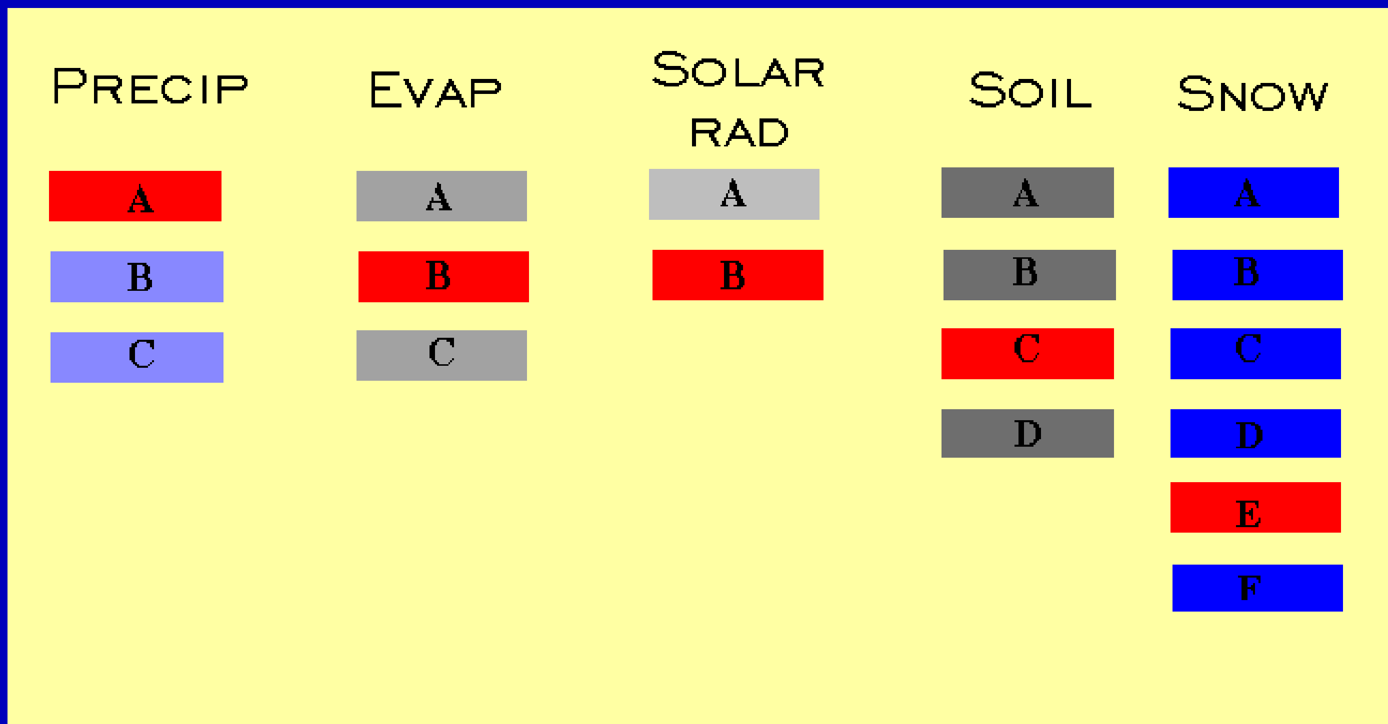
The Modular Modeling System (MMS)



LEVELS OF MODULAR DESIGN

- **PROCESS**
- **MODEL**
- FULLY COUPLED MODELS
- LOOSELY COUPLED MODELS
- RESOURCE MANAGEMENT DECISION SUPPORT SYSTEMS
- ANALYSIS AND SUPPORT TOOLS

MODULE LIBRARY

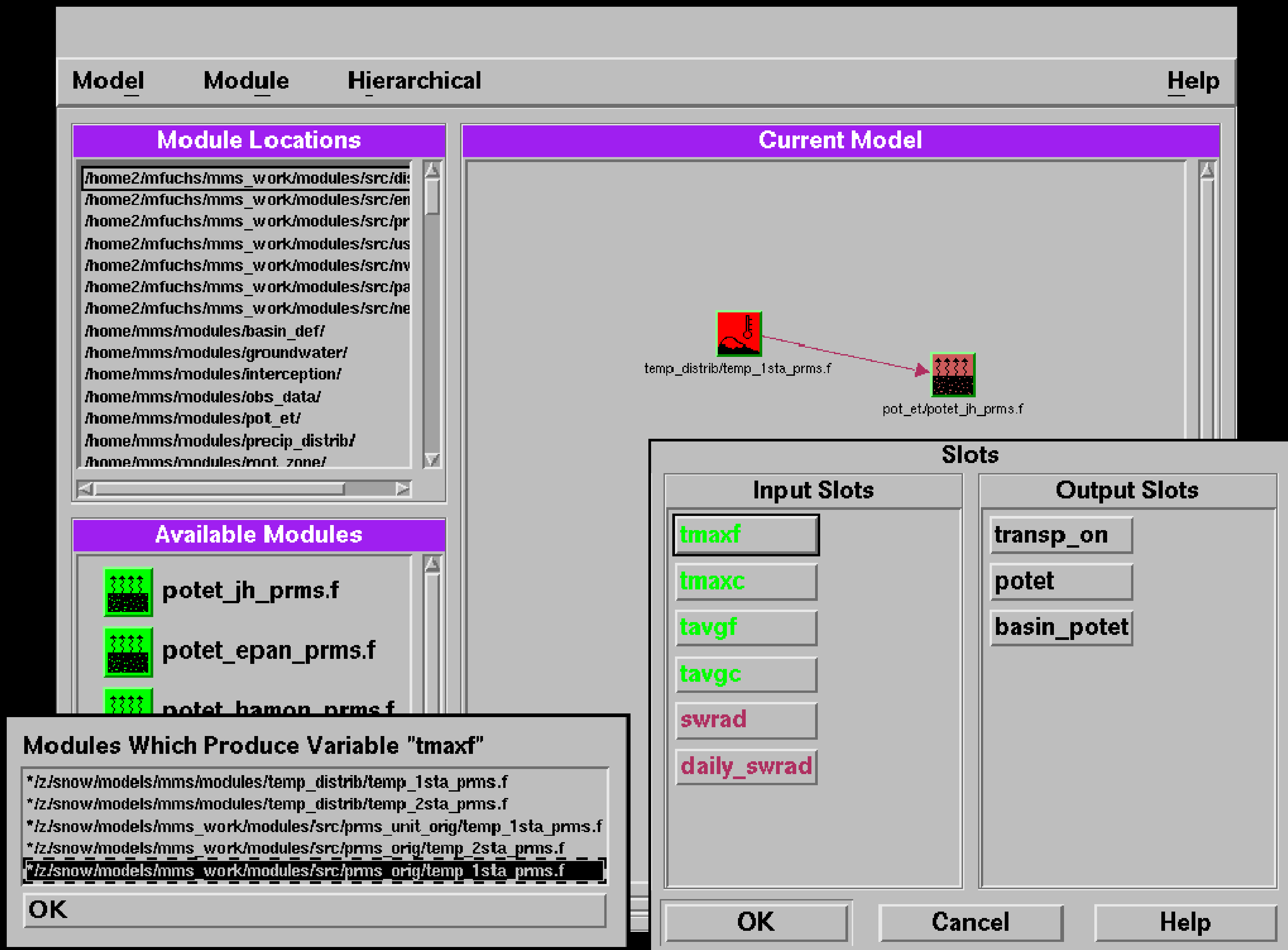


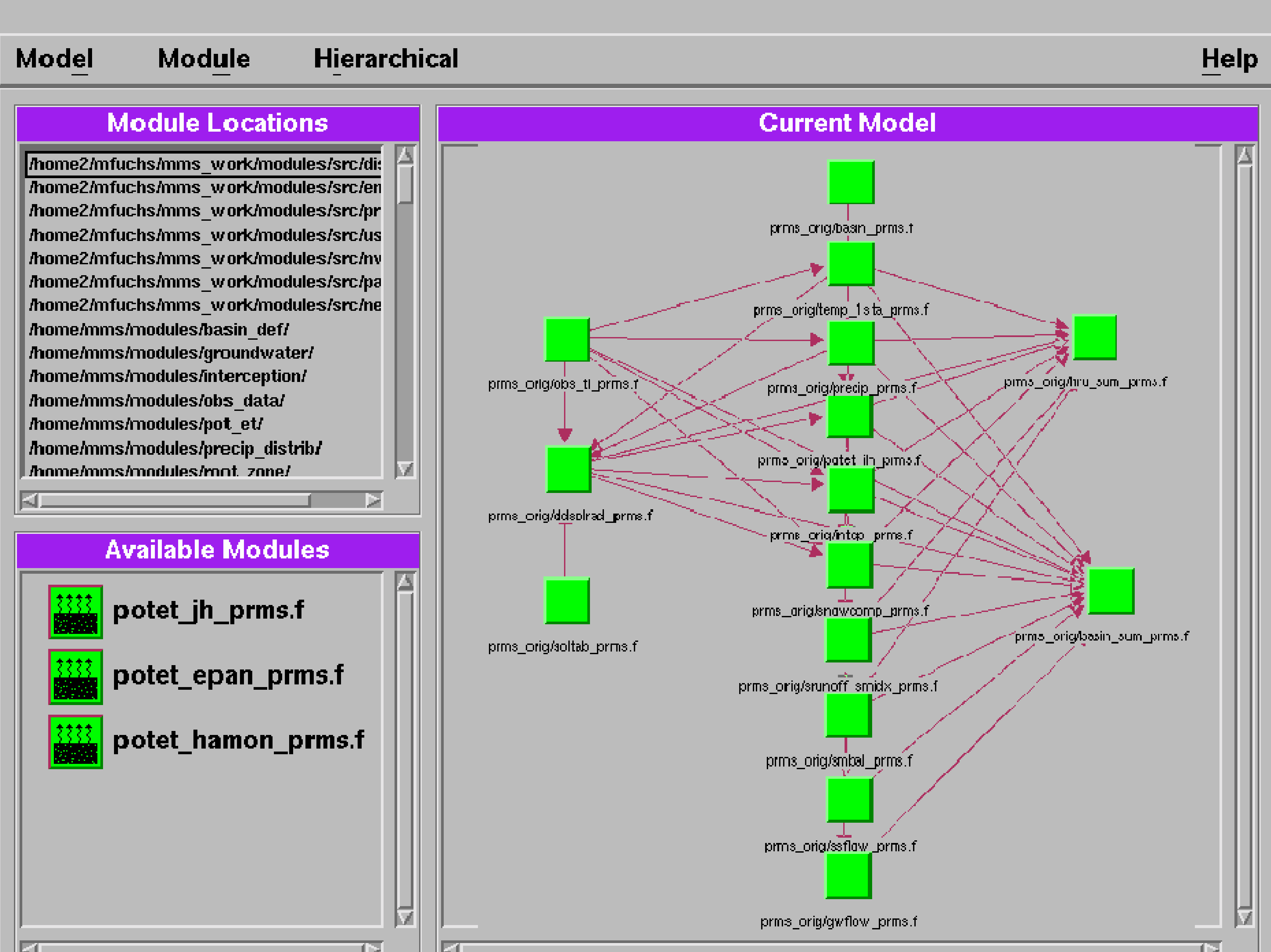
CRITERIA AND RULES FOR GOOD MODULE DESIGN

Modules should

- relate directly to real world components or processes
- have input and output variables that are measurable values
- communicate solely via these input and output variables

Reynolds J.F., and Acock, B., 1997, **Modularity and genericness in plant and ecosystem models**: Ecological Modeling 94, p 7-16


Model
Module
Hierarchical
Help
Module Locations
/home2/mfuchs/mms_work/modules/src/di
/home2/mfuchs/mms_work/modules/src/en
/home2/mfuchs/mms_work/modules/src/pr
/home2/mfuchs/mms_work/modules/src/us
/home2/mfuchs/mms_work/modules/src/nv
/home2/mfuchs/mms_work/modules/src/pa
/home2/mfuchs/mms_work/modules/src/ne
/home/mms/modules/basin_def/
/home/mms/modules/groundwater/
/home/mms/modules/interception/
/home/mms/modules/obs_data/
/home/mms/modules/pot_et/
/home/mms/modules/precip_distrib/
Current Model
temp_distrib/temp_1sta_prms.f
pot_et/potet_jh_prms.f
Available Modules
potet_jh_prms.f
potet_epan_prms.f
Slots
Input Slots
tmaxf
tmaxc
tavgf
tavgc
swrad
daily_swrad
Output Slots
transp_on
potet
basin_potet
OK
Cancel
Help
Modules Which Produce Variable "tmaxf"
*/z/snow/models/mms/modules/temp_distrib/temp_1sta_prms.f
*/z/snow/models/mms/modules/temp_distrib/temp_2sta_prms.f
*/z/snow/models/mms_work/modules/src/prms_unit_orig/temp_1sta_prms.f
*/z/snow/models/mms_work/modules/src/prms_orig/temp_2sta_prms.f
*/z/snow/models/mms_work/modules/src/prms_orig/temp_1sta_prms.f
OK


Model
Module
Hierarchical
Help
Module Locations
/home2/mfuchs/mms_work/modules/src/di
/home2/mfuchs/mms_work/modules/src/en
/home2/mfuchs/mms_work/modules/src/pr
/home2/mfuchs/mms_work/modules/src/us
/home2/mfuchs/mms_work/modules/src/nv
/home2/mfuchs/mms_work/modules/src/pa
/home2/mfuchs/mms_work/modules/src/ne
/home/mms/modules/basin_def/
/home/mms/modules/groundwater/
/home/mms/modules/interception/
/home/mms/modules/obs_data/
/home/mms/modules/pot_et/
/home/mms/modules/precip_distrib/
Available Modules
potet_jh_prms.f
potet_epan_prms.f
potet_hamon_prms.f
Current Model
prms_orig/basin_prms.f
prms_orig/temp_1sta_prms.f
prms_orig/obs_tl_prms.f
prms_orig/precip_prms.f
prms_orig/hru_sum_prms.f
prms_orig/potet_jh_prms.f
prms_orig/ddsolrad_prms.f
prms_orig/intcp_prms.f
prms_orig/snowcomp_prms.f
prms_orig/soltab_prms.f
prms_orig/basin_sum_prms.f
prms_orig/srunoff_smidx_prms.f
prms_orig/smbal_prms.f
prms_orig/ssflow_prms.f
prms_orig/gwflow_prms.f

LEVELS OF MODULAR DESIGN

- PROCESS
- MODEL
- **FULLY COUPLED MODELS**
- LOOSELY COUPLED MODELS
- RESOURCE MANAGEMENT DECISION SUPPORT SYSTEMS
- ANALYSIS AND SUPPORT TOOLS

Coupled MODFLOW and DAFLOW

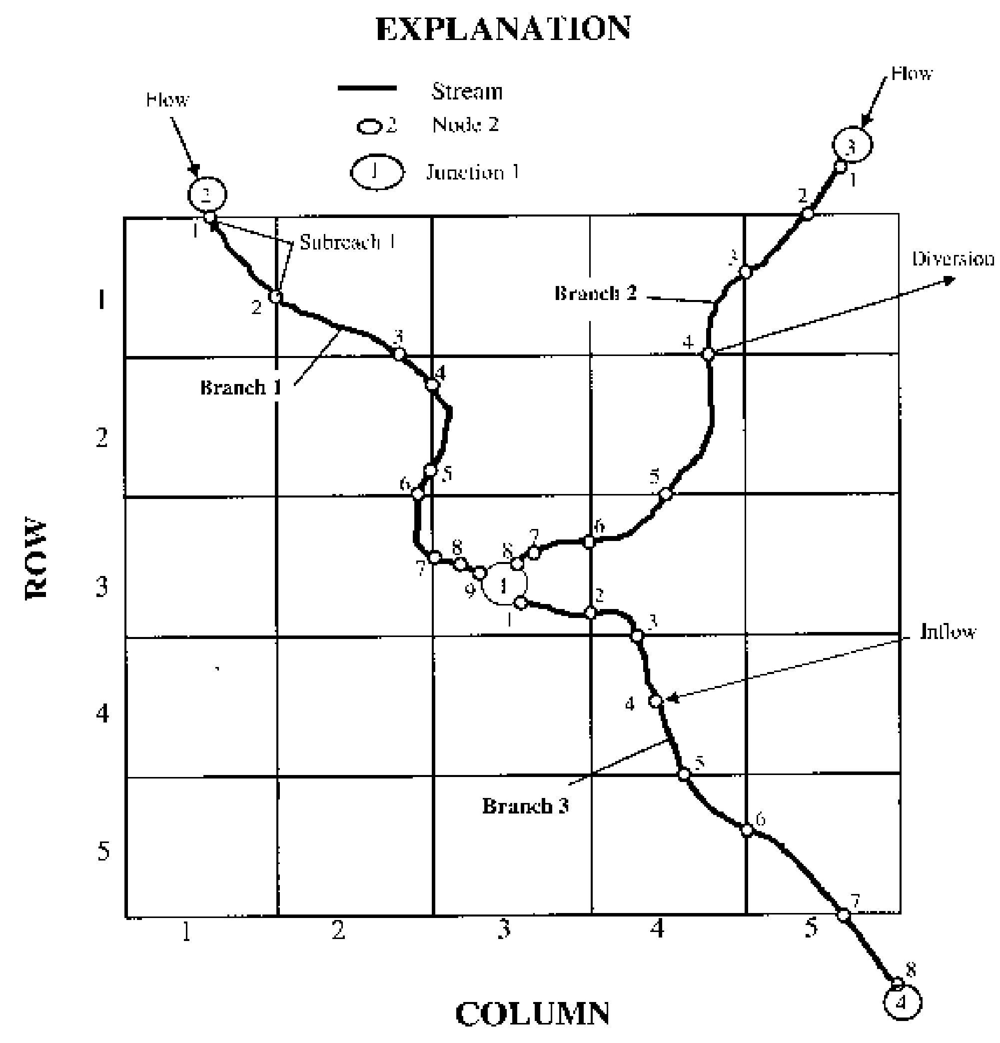


Figure 2. Example schematic showing the numbering system of the linked surface-water and ground-water model.

Ground Water - Surface Water Coupling

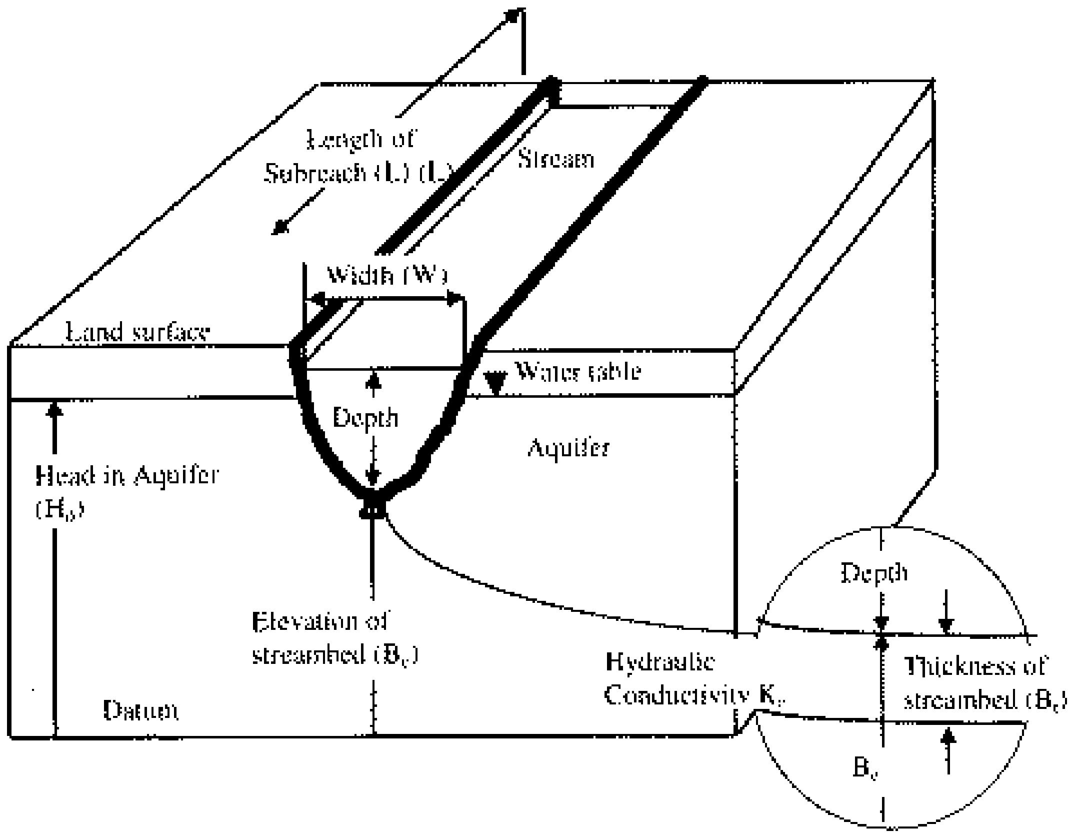


Figure 3. Diagram showing one ground-water cell with stream depicting properties used in calculation of the streambed leakage for a subreach.

For Fully Coupled Models or other Multi-Processor, Parallel Processing Needs

PAWS
Parallel Application Work Space

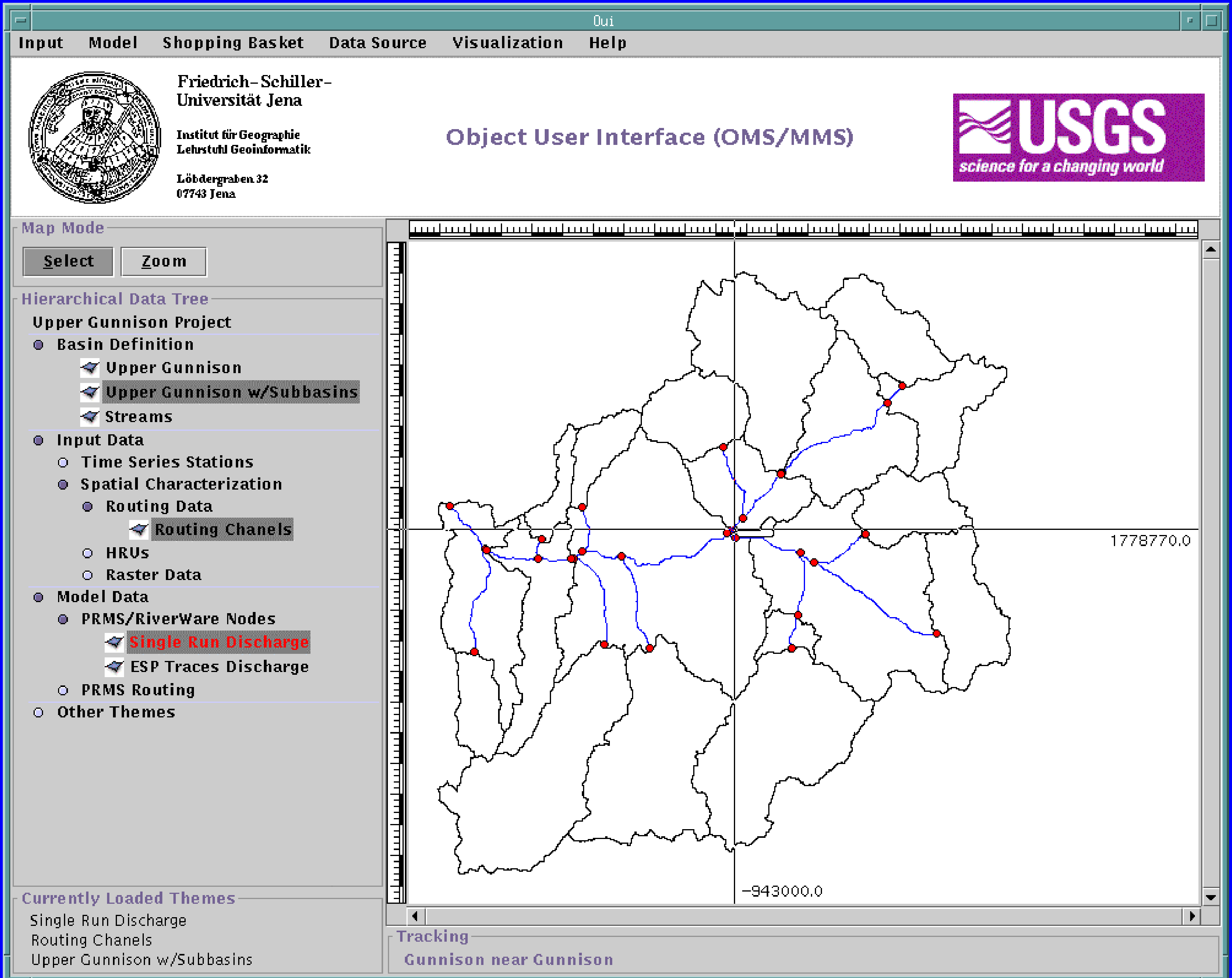
Efficient Coupling of Parallel Scientific Applications Using PAWS

Advanced Computing Laboratory
Los Alamos National Laboratory

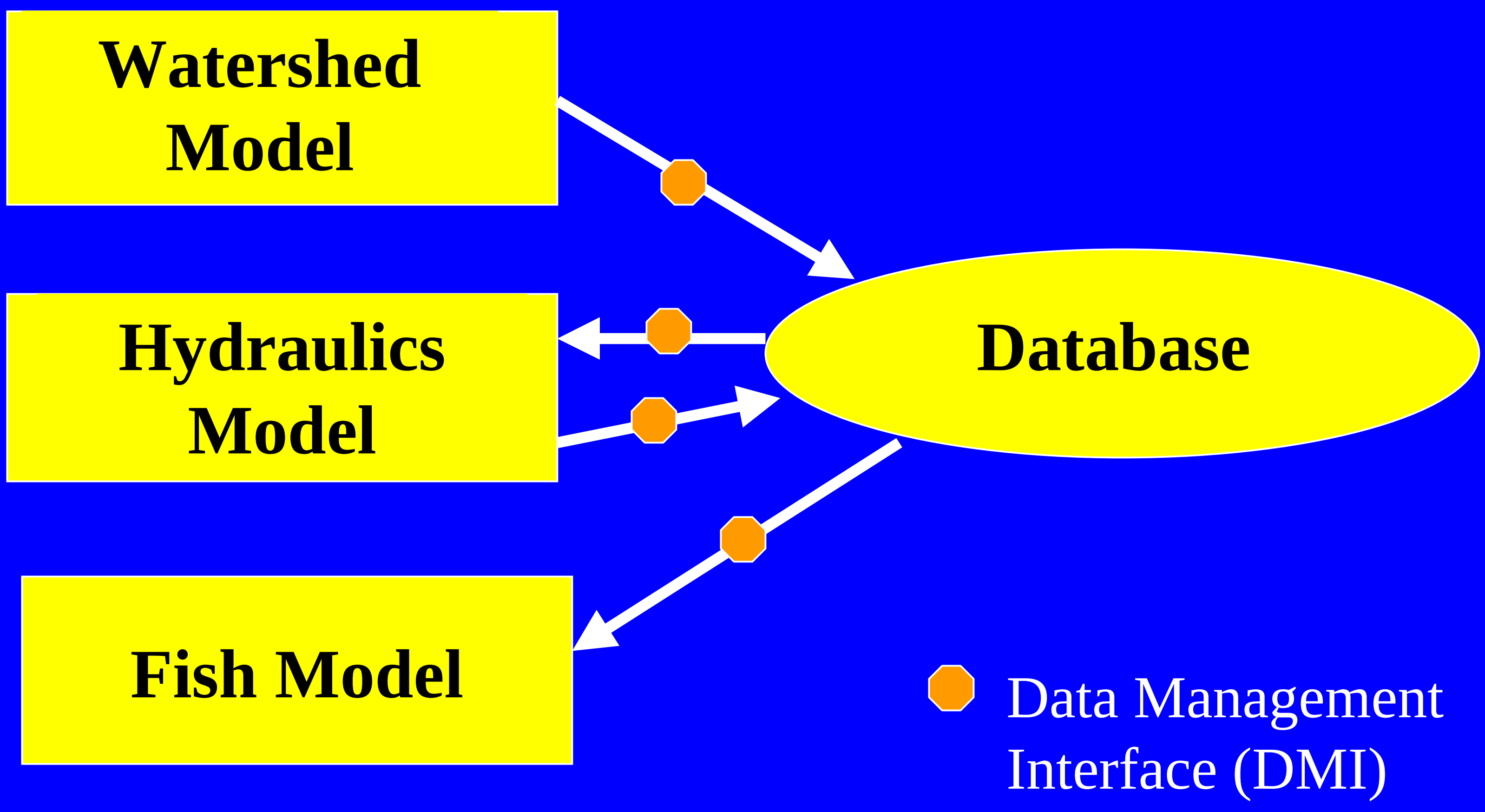
LEVELS OF MODULAR DESIGN

- PROCESS
- MODEL
- FULLY COUPLED MODELS
- **LOOSELY COUPLED MODELS**
- RESOURCE MANAGEMENT DECISION SUPPORT SYSTEMS
- ANALYSIS AND SUPPORT TOOLS

MODELED SUBBASINS AND FORECAST NODES



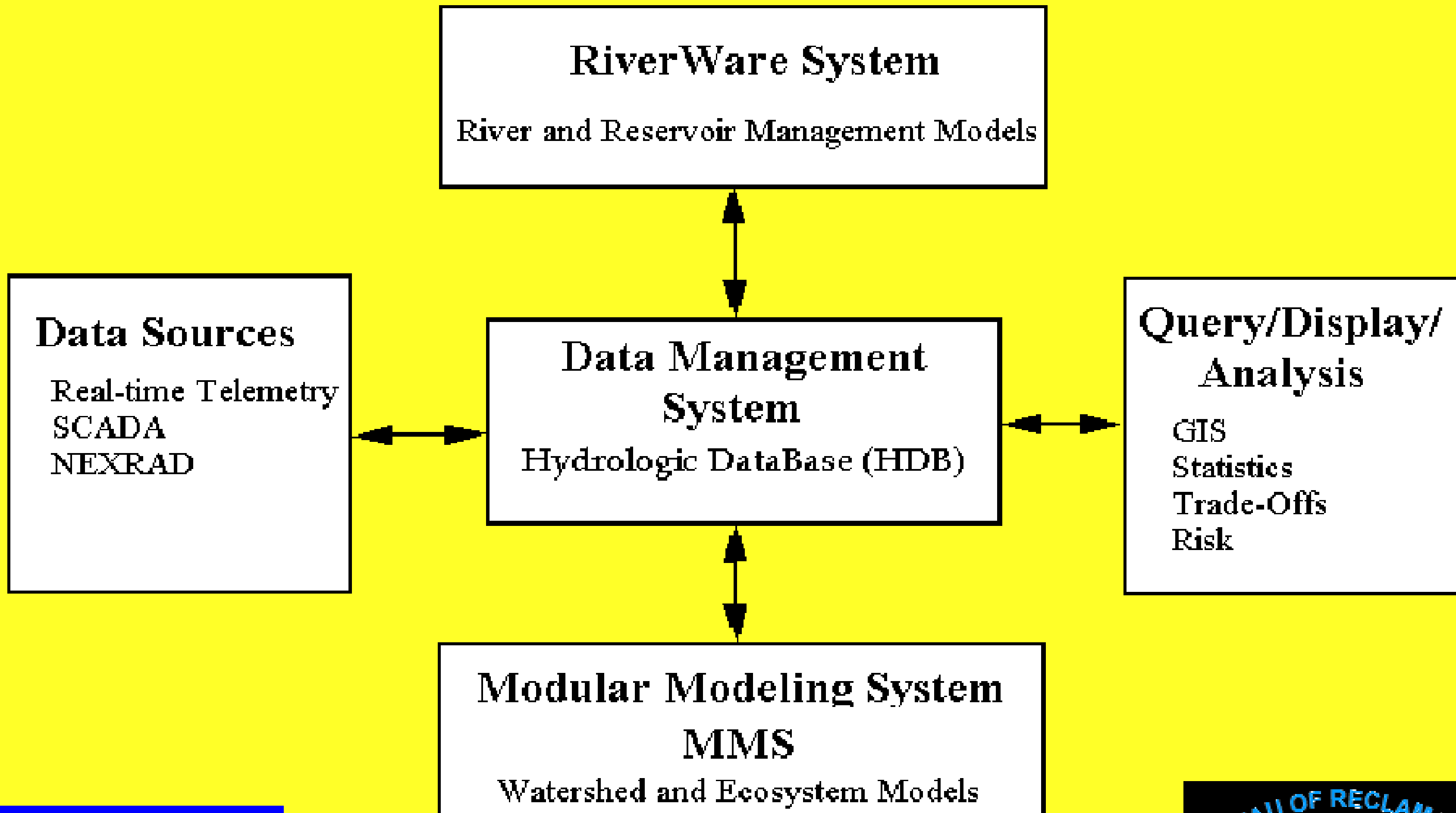
LOOSLEY COUPLED MODELS



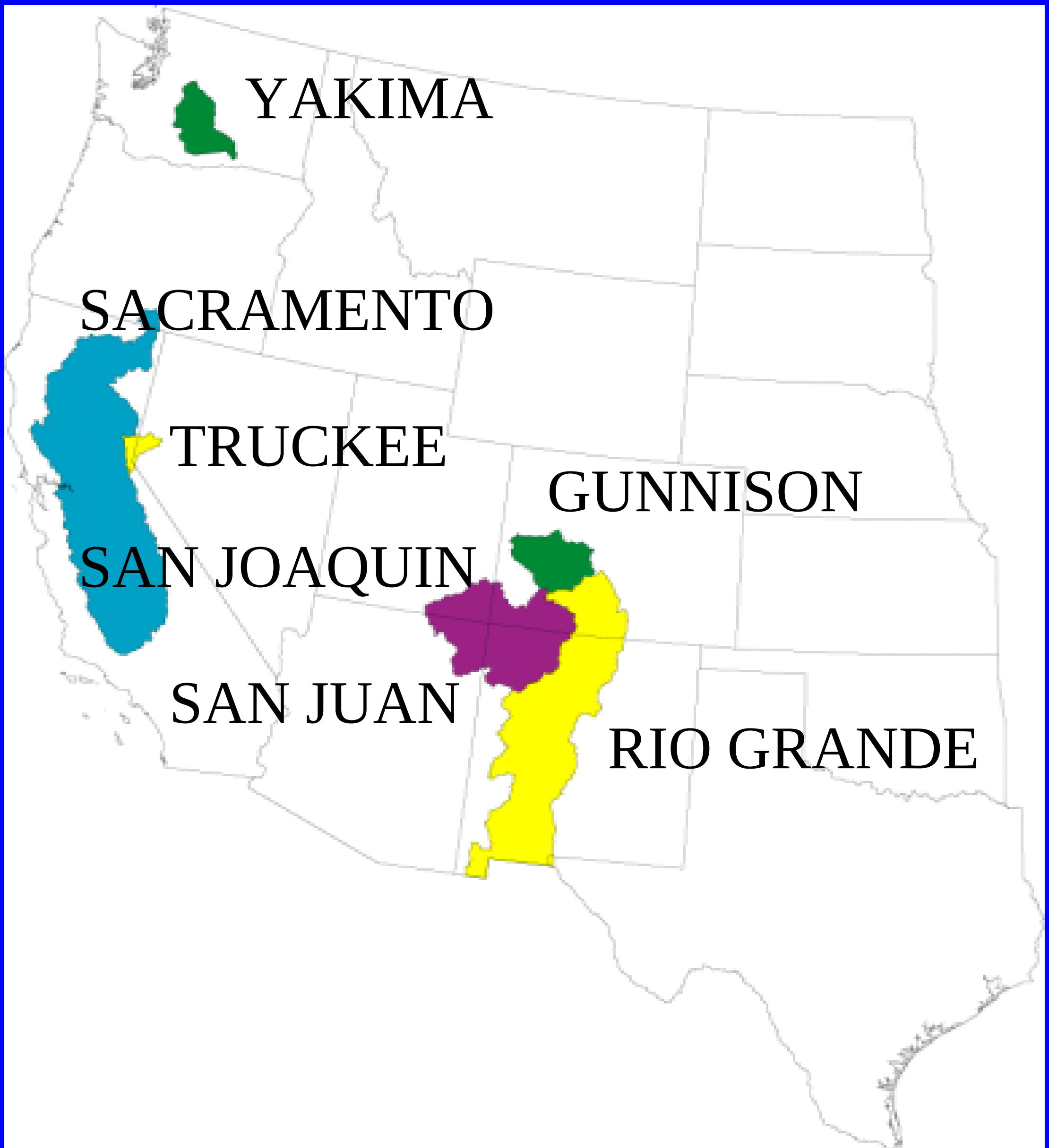
LEVELS OF MODULAR DESIGN

- PROCESS
- MODEL
- FULLY COUPLED MODELS
- LOOSELY COUPLED MODELS
- **RESOURCE MANAGEMENT DECISION SUPPORT SYSTEMS**
- ANALYSIS AND SUPPORT TOOLS

Database-Centered Decision Support System



WARSMP BASINS



CURRENTLY OPERATIONAL

OPERATIONAL 6 - 12 MONTHS

IN DEVELOPMENT

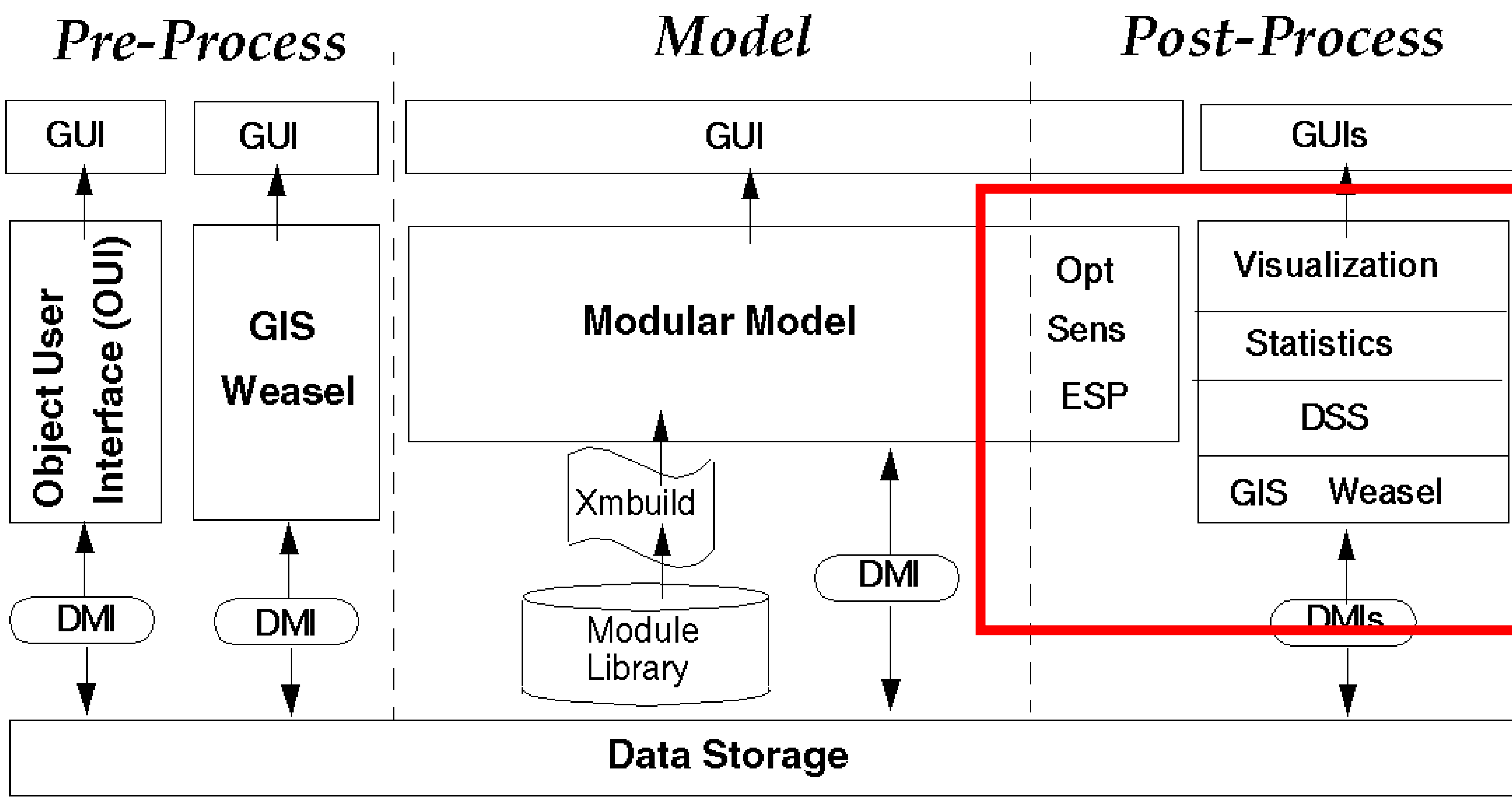
WARSMP RELATED

IN DEVELOPMENT, MMS PLUS

LEVELS OF MODULAR DESIGN

- PROCESS
- MODEL
- FULLY COUPLED MODELS
- LOOSELY COUPLED MODELS
- RESOURCE MANAGEMENT DECISION SUPPORT SYSTEMS
- **ANALYSIS AND SUPPORT TOOLS**

The Modular Modeling System (MMS)



ANALYSIS and SUPPORT TOOLS

Current

Rosenbrock Optimization

Troutman Sensitivity Analysis

Being Added

Shuffle Complex Evolution Optimization

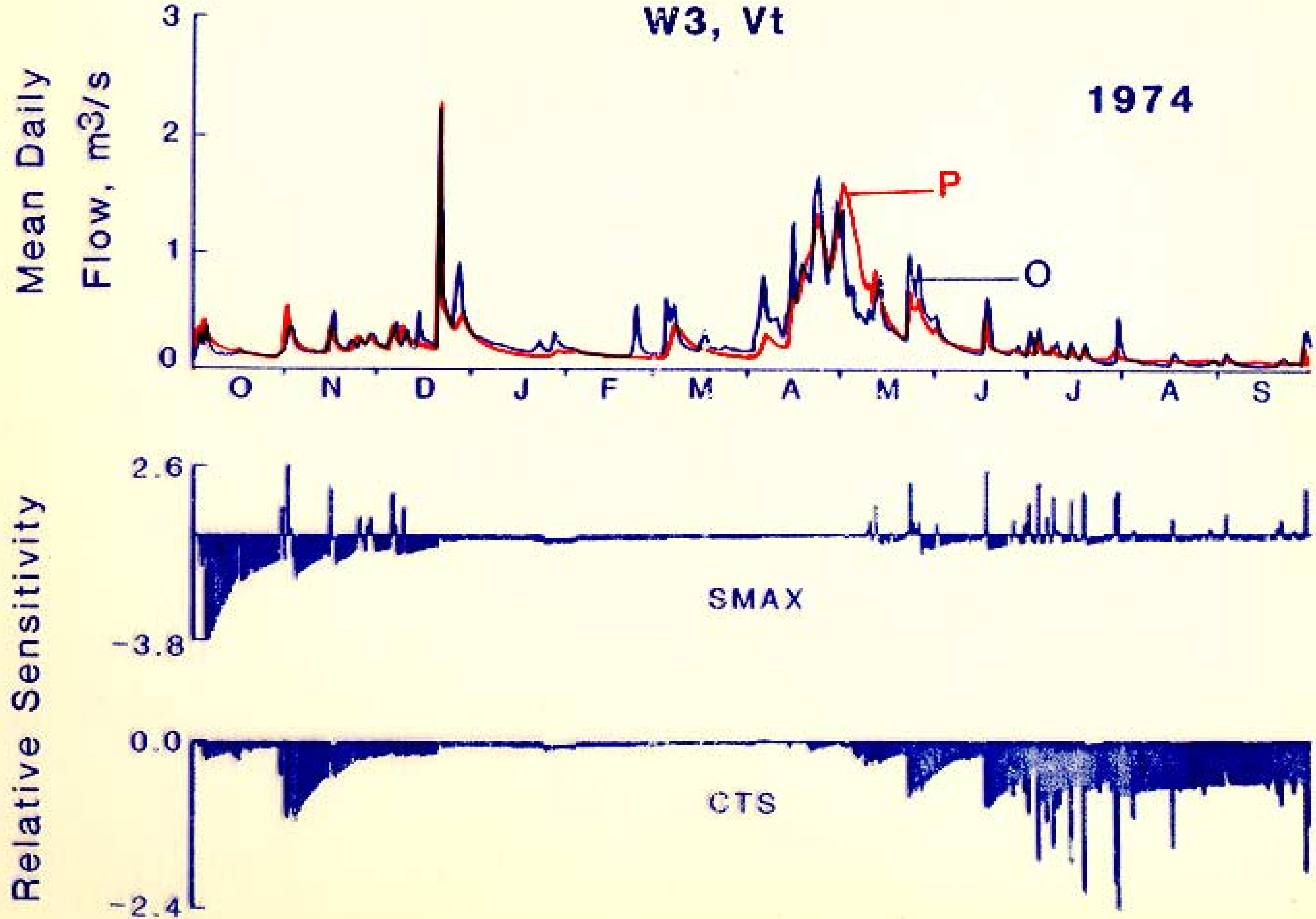
Multi-Objective COMplex Evolution Algorithm

GLUE

Visualization - VISAD

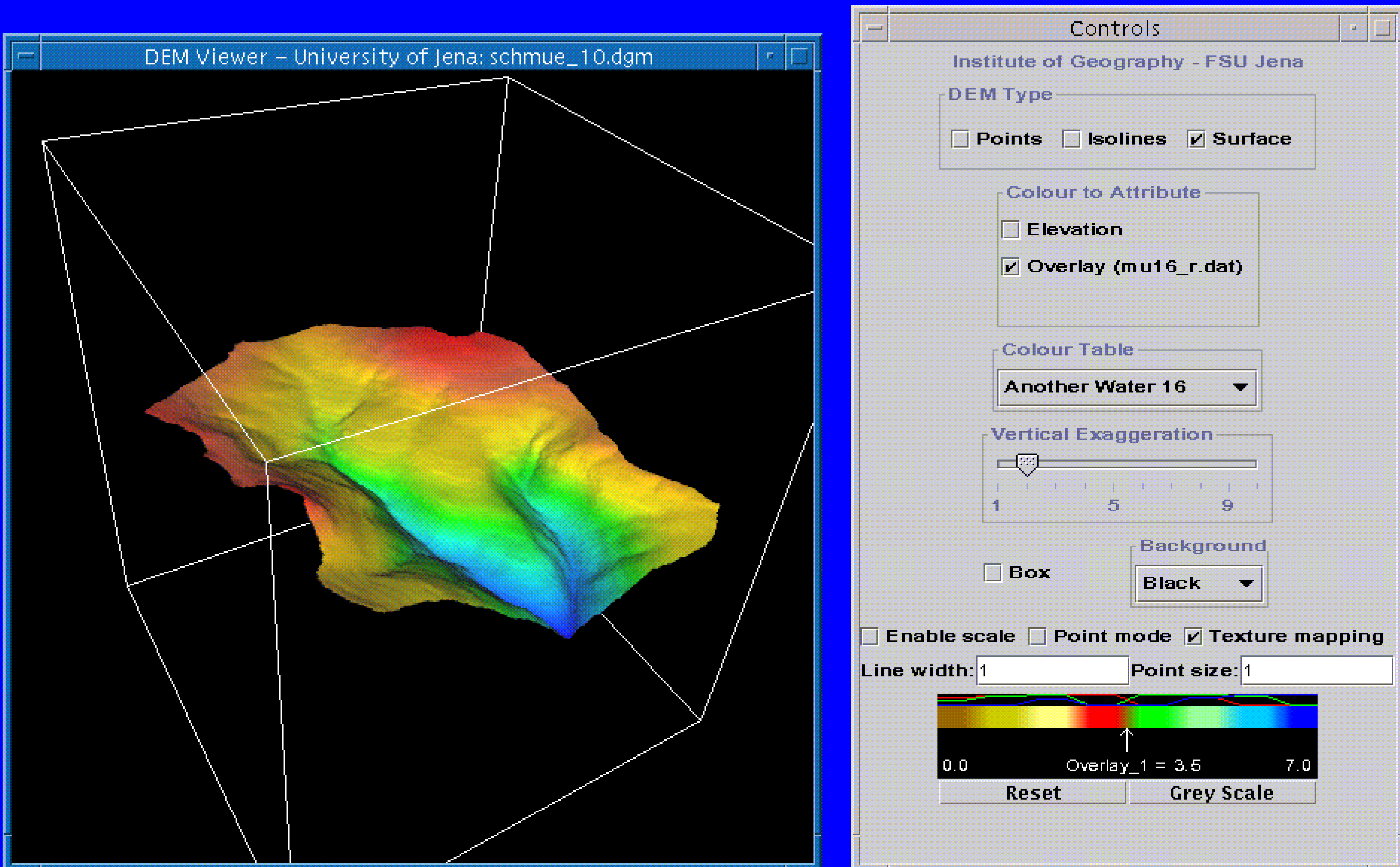
Sensitivity Analysis
(Troutman, 1983)

- Sensitivity Matrix (relative sensitivity)
- Error Propagation Table
  - (5, 10, 20, 50% change in parameter value)
- Joint & Individual Standard Errors in Parameters
  - (measure of confidence)
- Correlation Matrix
- Hat Matrix
  - (diagonal elements are measure of influence a day is having on optimization, range 0-1)

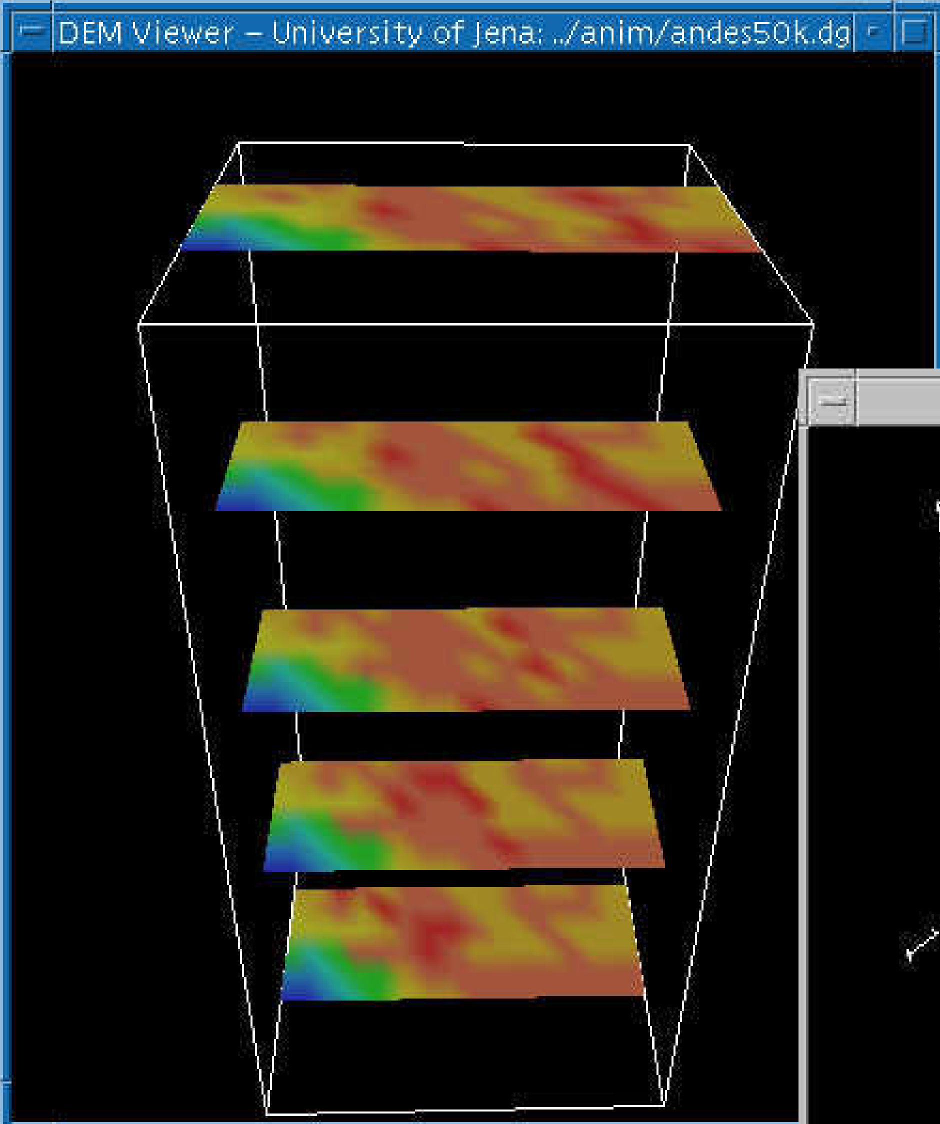


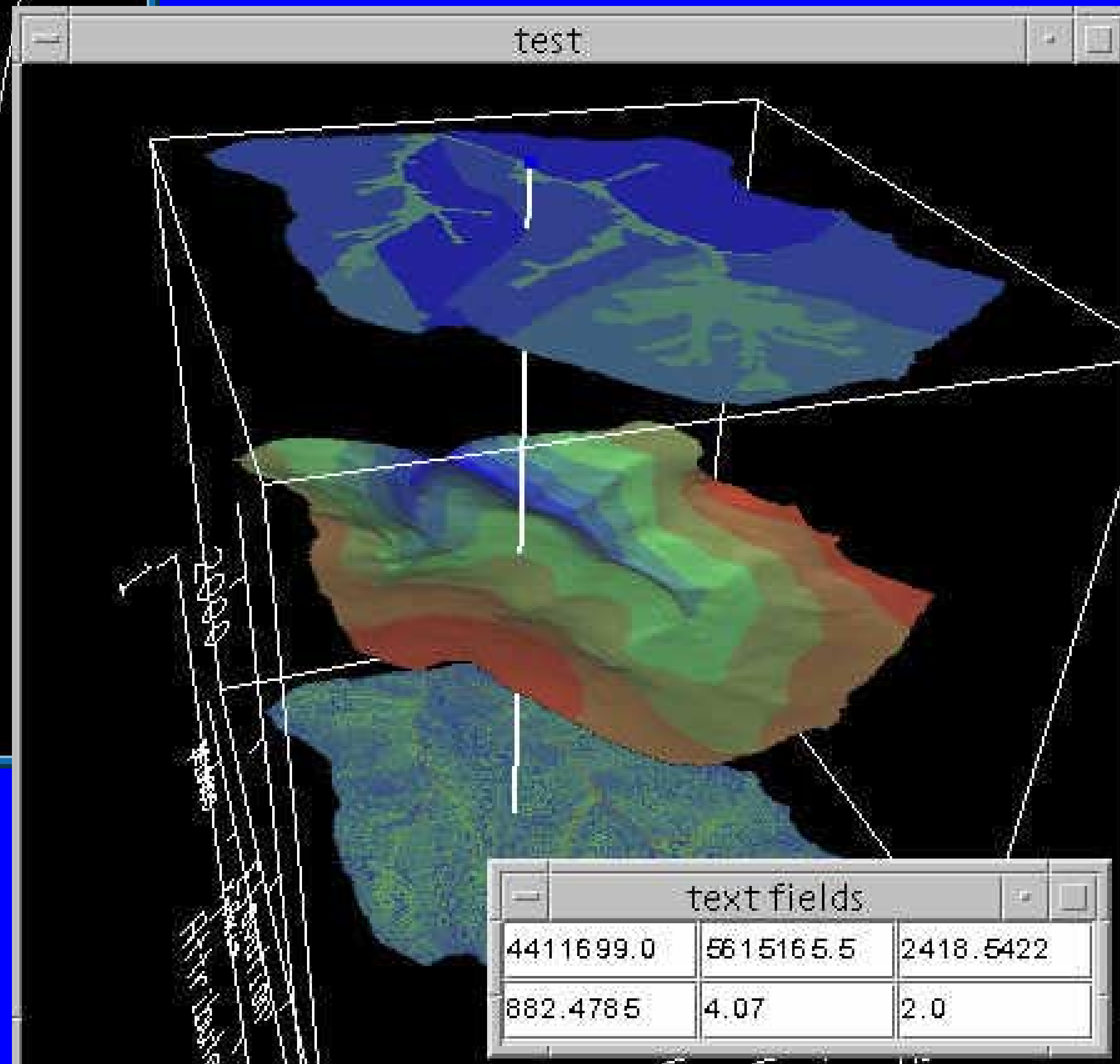
W3, Vt
1974
Mean Daily Flow, m3/s
3
2
1
0
P
O
O
N
D
J
F
M
A
M
J
J
A
S
Relative Sensitivity
2.6
−3.8
SMAX
0.0
−2.4
CTS

VISAD


DEM Viewer – University of Jena: schmue_10.dgm
Controls
Institute of Geography - FSU Jena
DEM Type
Points
Isolines
Surface
Colour to Attribute
Elevation
Overlay (mu16_r.dat)
Colour Table
Another Water 16
Vertical Exaggeration
1
5
9
Box
Background
Black
Enable scale
Point mode
Texture mapping
Line width: 1
Point size: 1
0.0
Overlay_1 = 3.5
7.0
Reset
Grey Scale

VISAD


DEM Viewer – University of Jena: ../anim/andes50k.dg


test
text fields
4411699.0
5615165.5
2418.5422
882.4785
4.07
2.0

CURRENT FOCUS ISSUES IN MMS DEVELOPMENT AND APPLICATION

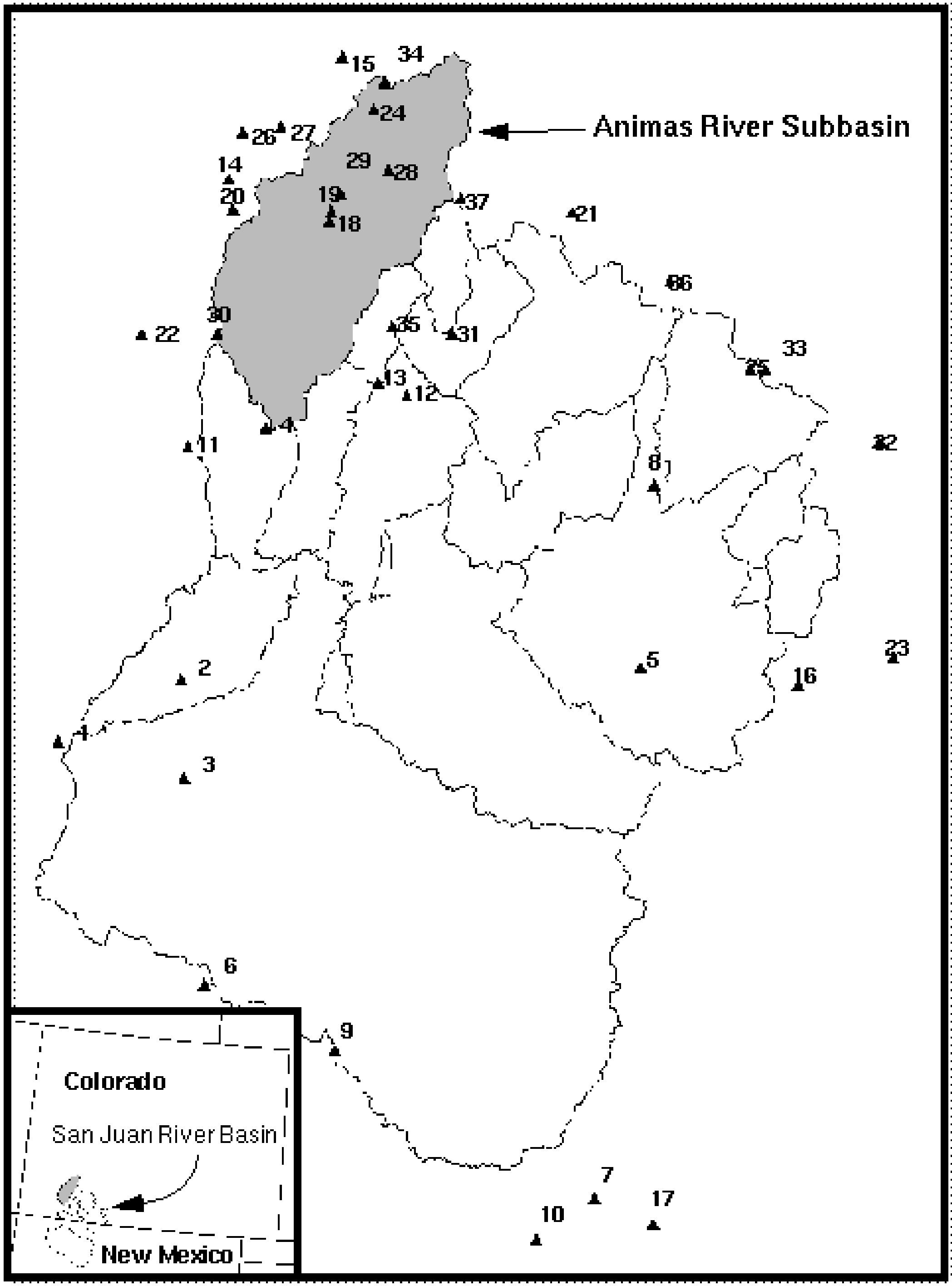
- Objective Parameter Estimation
- Incorporation of Remotely Sensed Data
- Coupling of Atmospheric and Hydrologic Models
- Improved Hydrologic and Ecosystem Process Simulation
- Development of Tools and Techniques to Facilitate the Integration of these Capabilities in Operational Applications

OBJECTIVE PARAMETER ESTIMATION

Need: To identify most robust models and parameters for uncalibrated applications (e.g. land-use and climate change studies)

- Parameters for spatial and temporal distribution of meteorological variables
- Process parameters from measurable basin and climate characteristics

XYZ Spatial Redistribution of Precip and Temperature

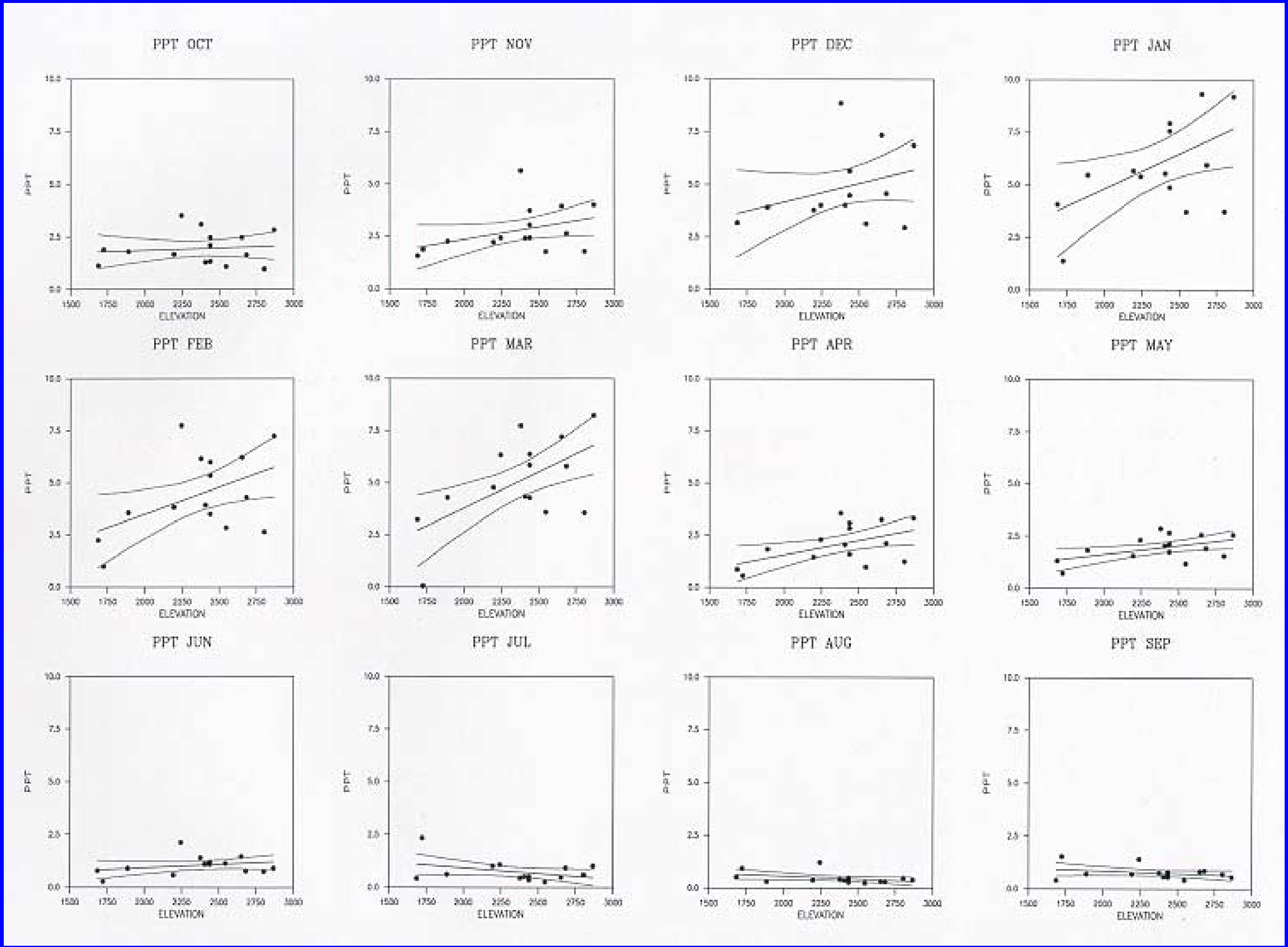


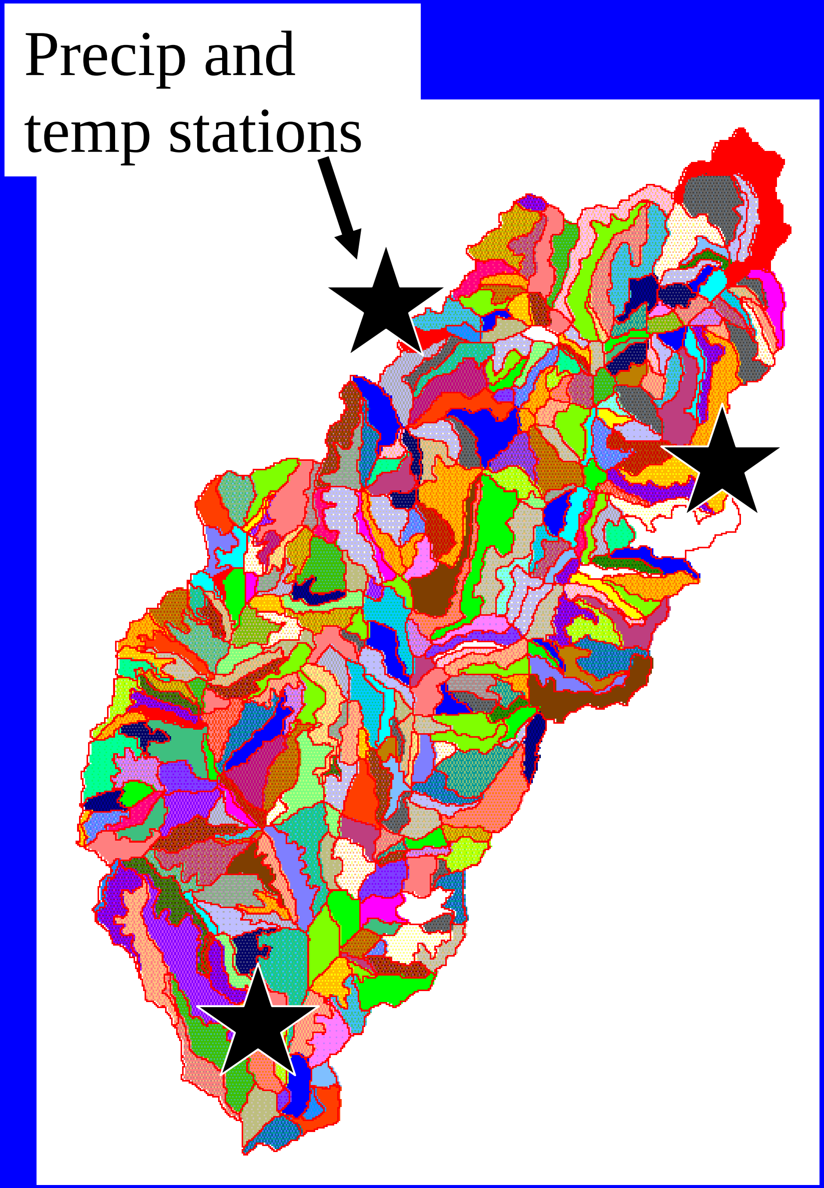
1. Develop Multiple Linear Regression (MLR) equations (in XYZ) for PRCP, TMAX, and TMIN by month using all appropriate regional observation stations.

San Juan Basin

Observation Stations 37

Precipitation-Elevation Relations





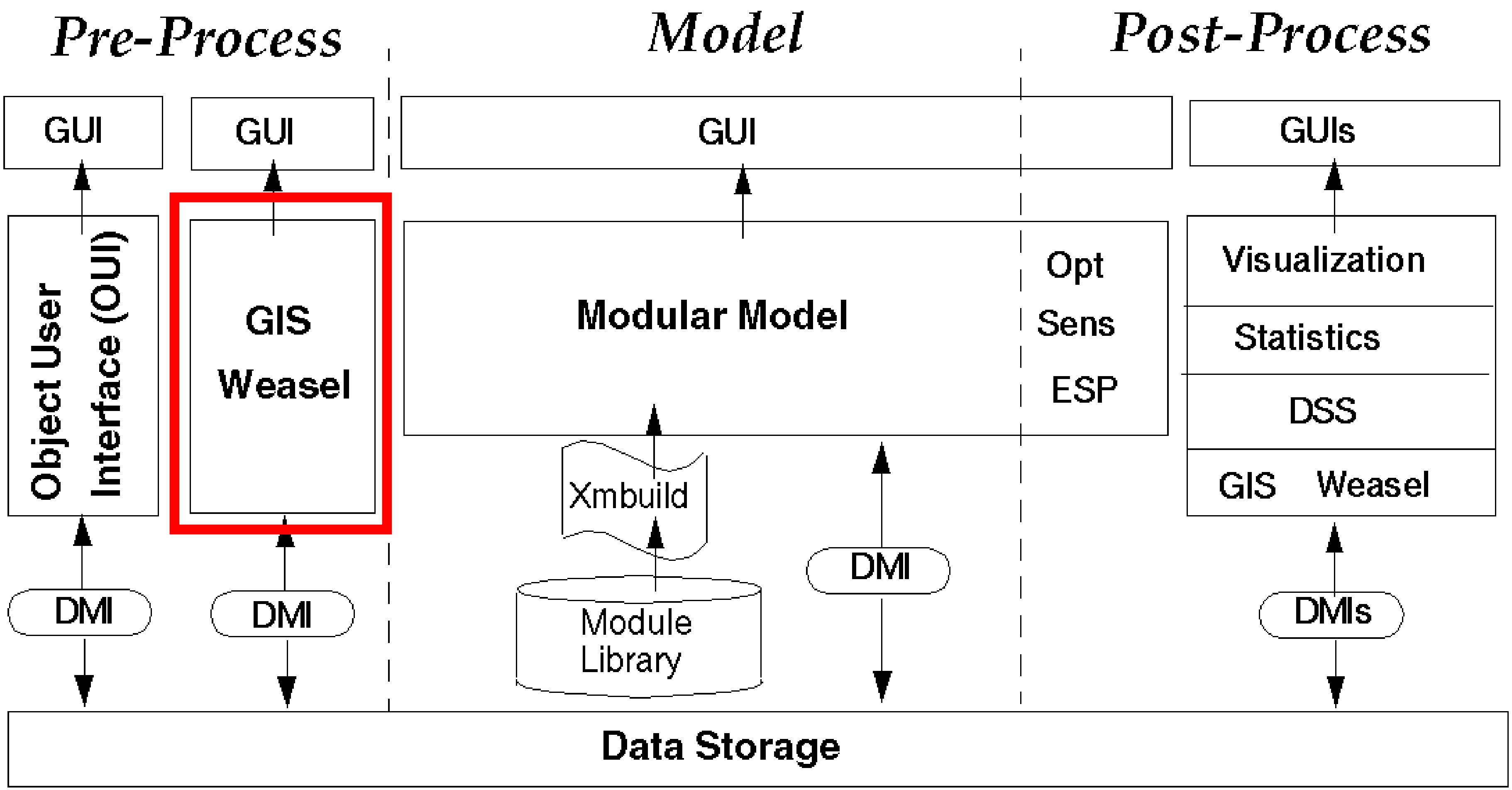
XYZ Spatial Redistribution

2. Daily mean PRCP, TMAX, and TMIN computed for a subset of stations (3) determined by Monte Carlo analysis to be best stations

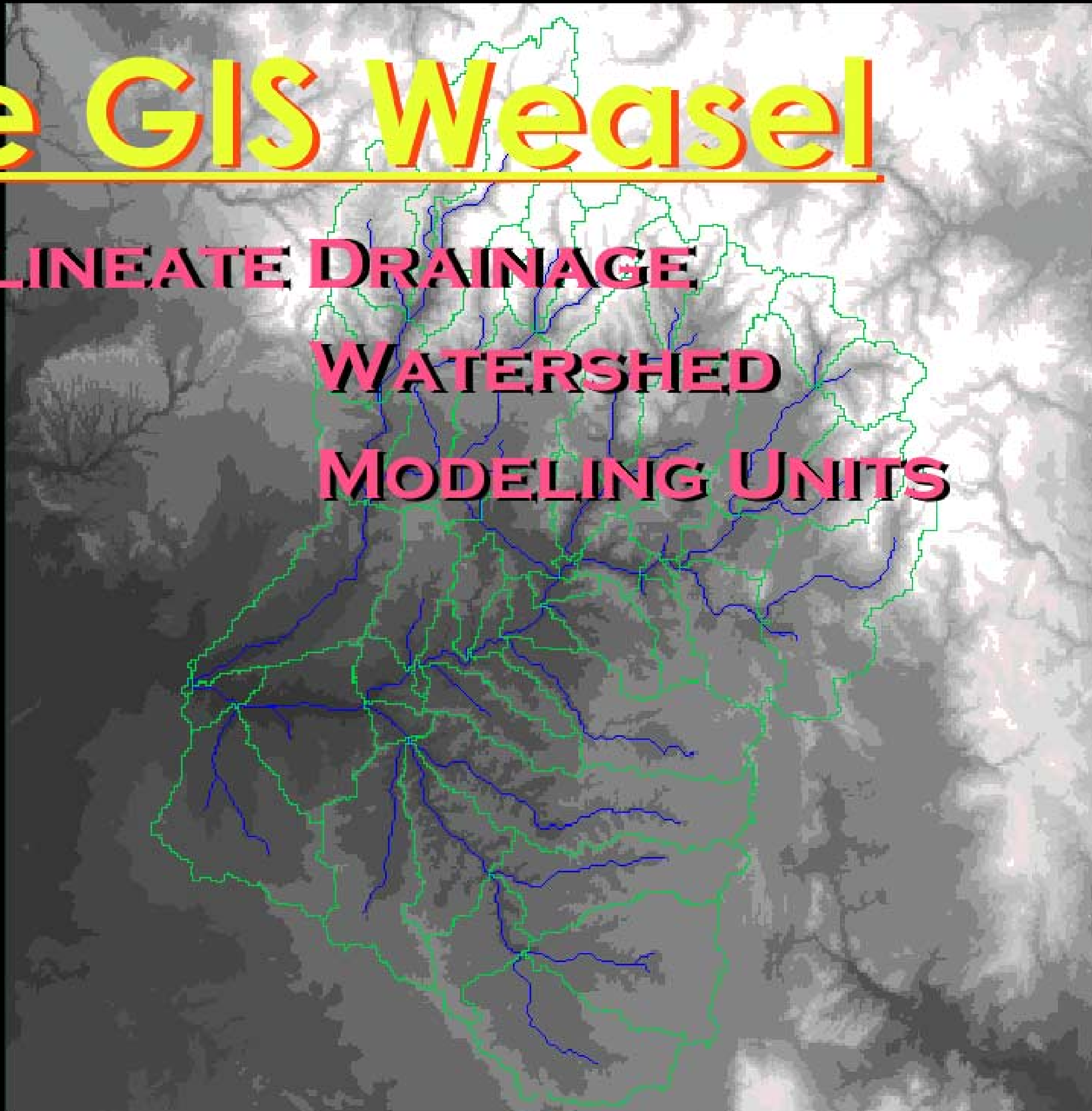
3. Daily station means from (2) used with monthly MLR xyz relations to estimate daily PRCP, TMAX, and TMIN on each HRU according to the XYZ of each HRU

PROCESS PARAMETER ESTIMATION

The Modular Modeling System (MMS)

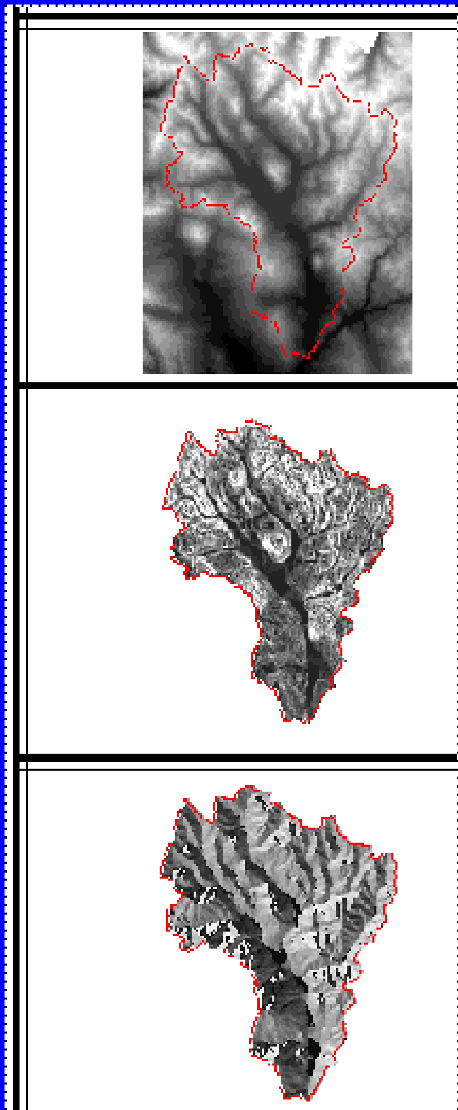


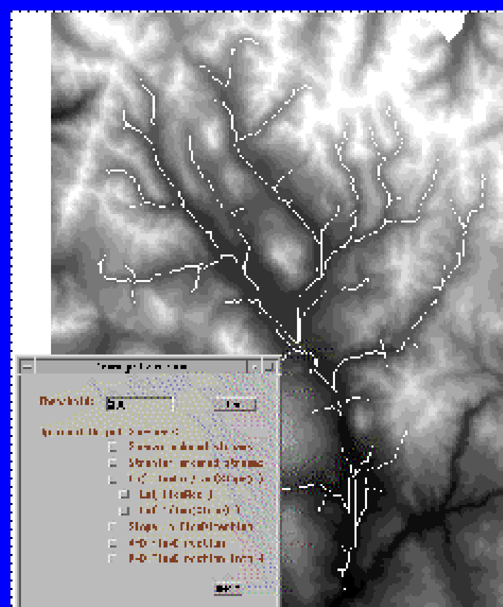
The GIS Weasel

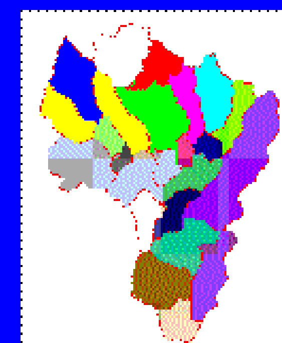


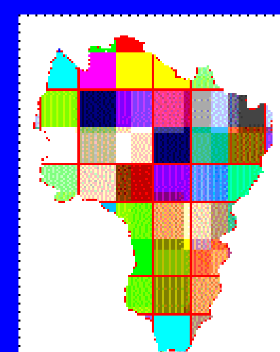
MODULAR MODELING SYSTEM (MMS)

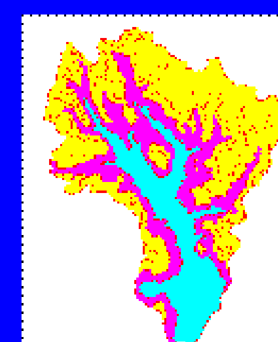
Delineate, Characterize, and Parameterize Spatial Features





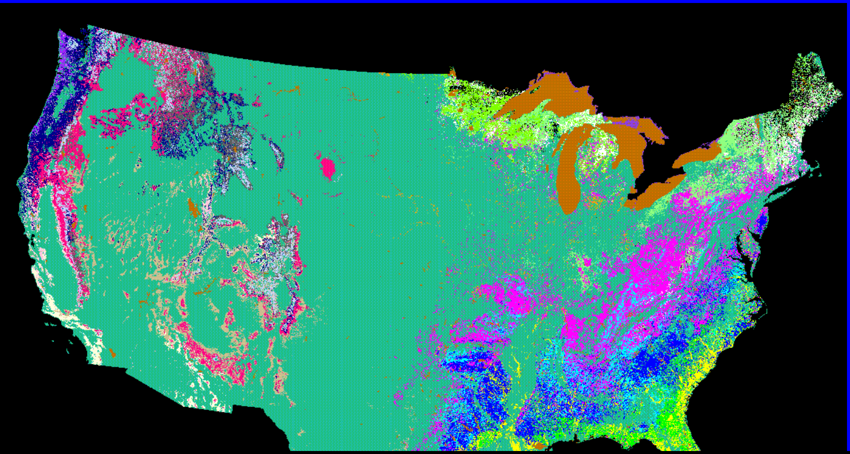




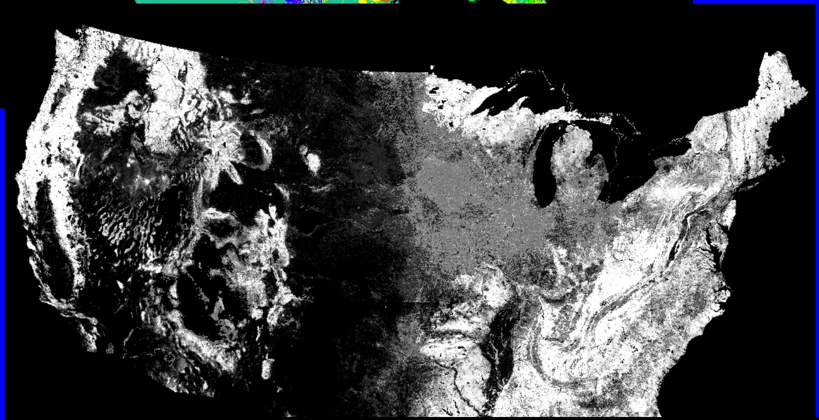


DIGITAL DATABASES

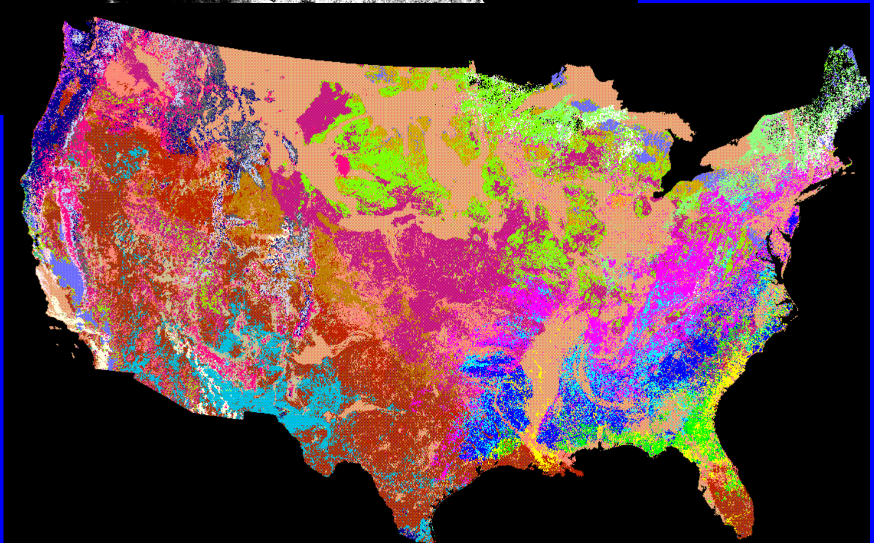
(1 km^2 resolution)



Vegetation Type (USFS)



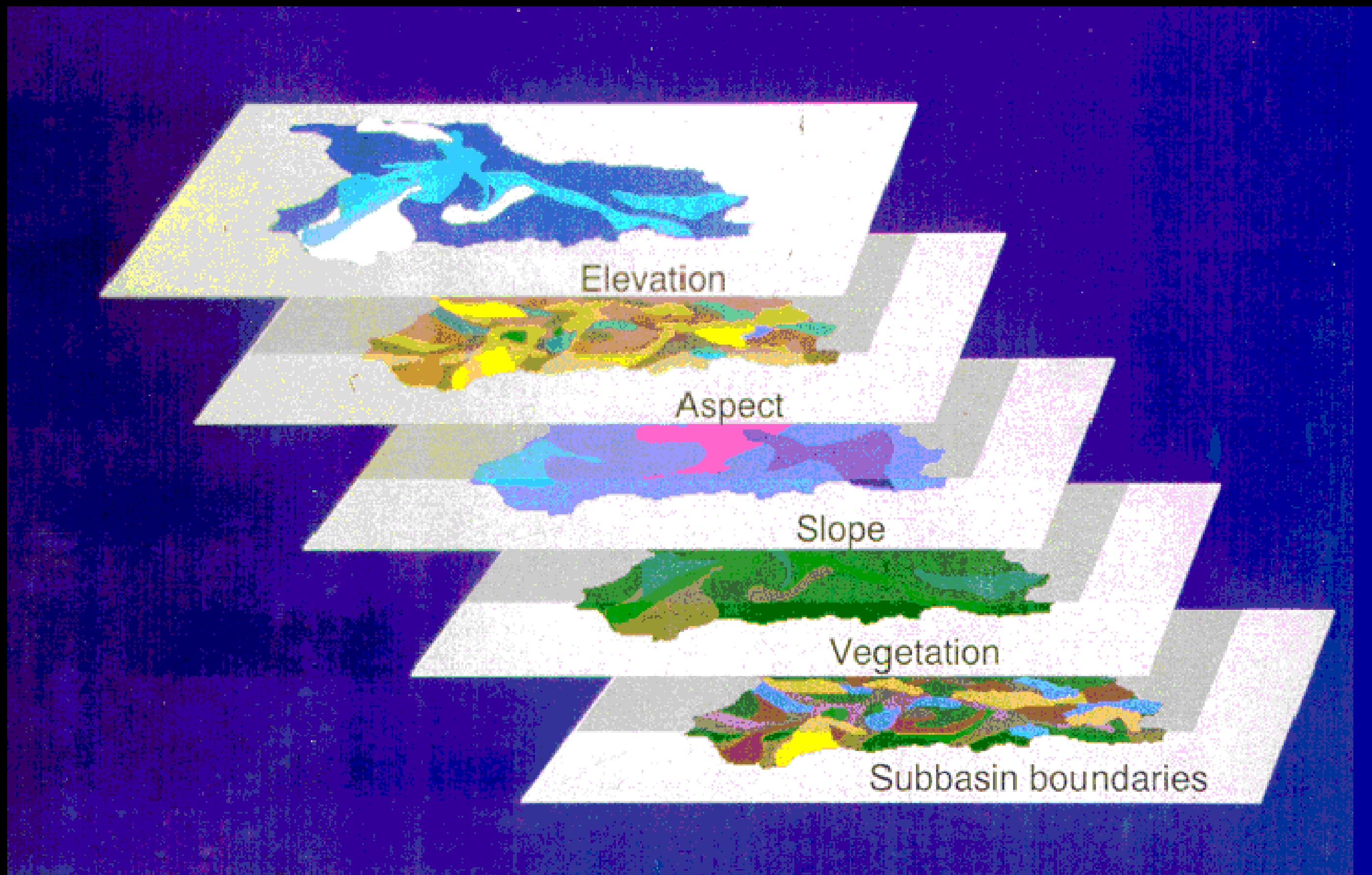
Vegetation Density (USFS)

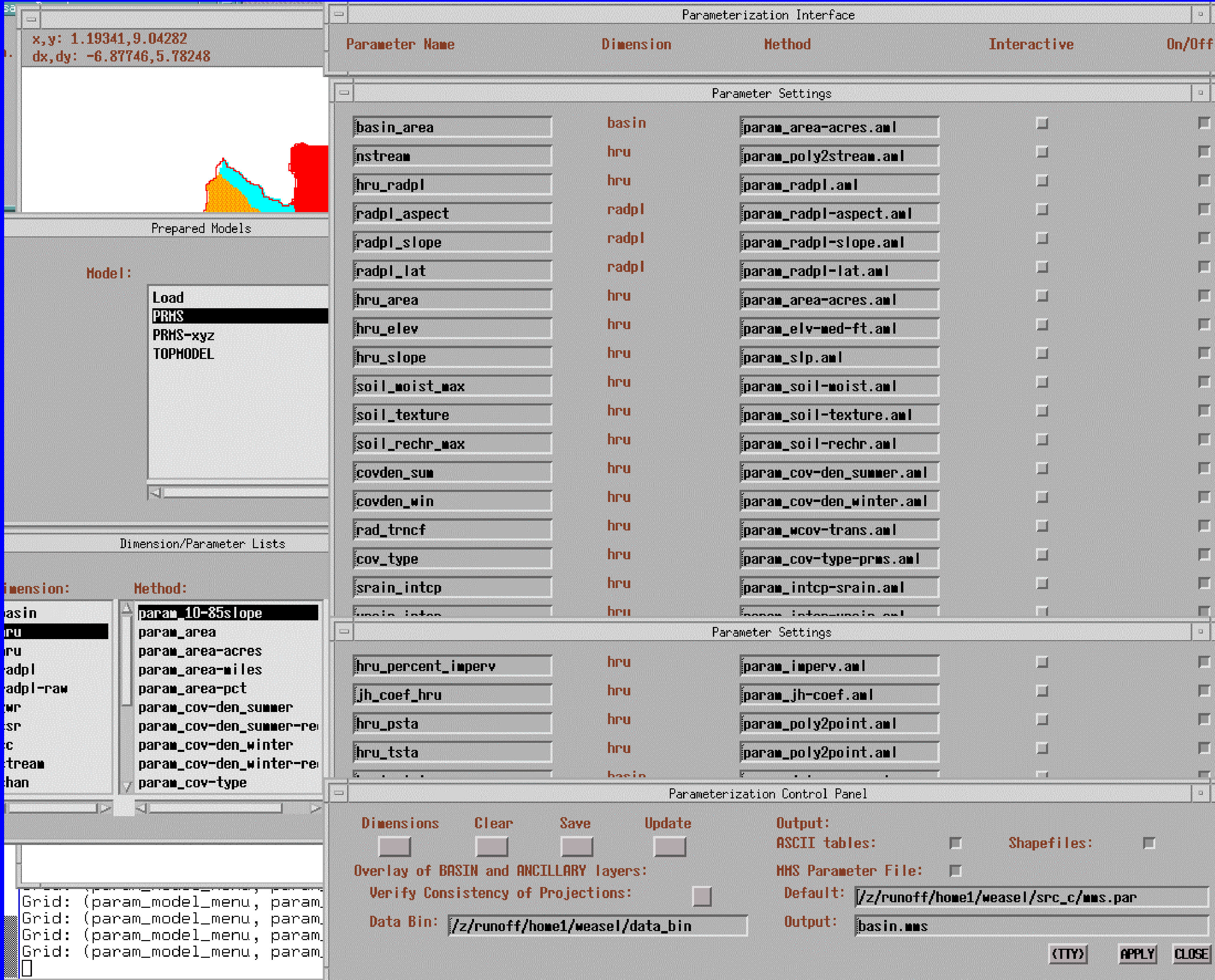


Land Use-Land Cover (USGS)

STATSGO - Soils Data, 1 km2 (USDA)

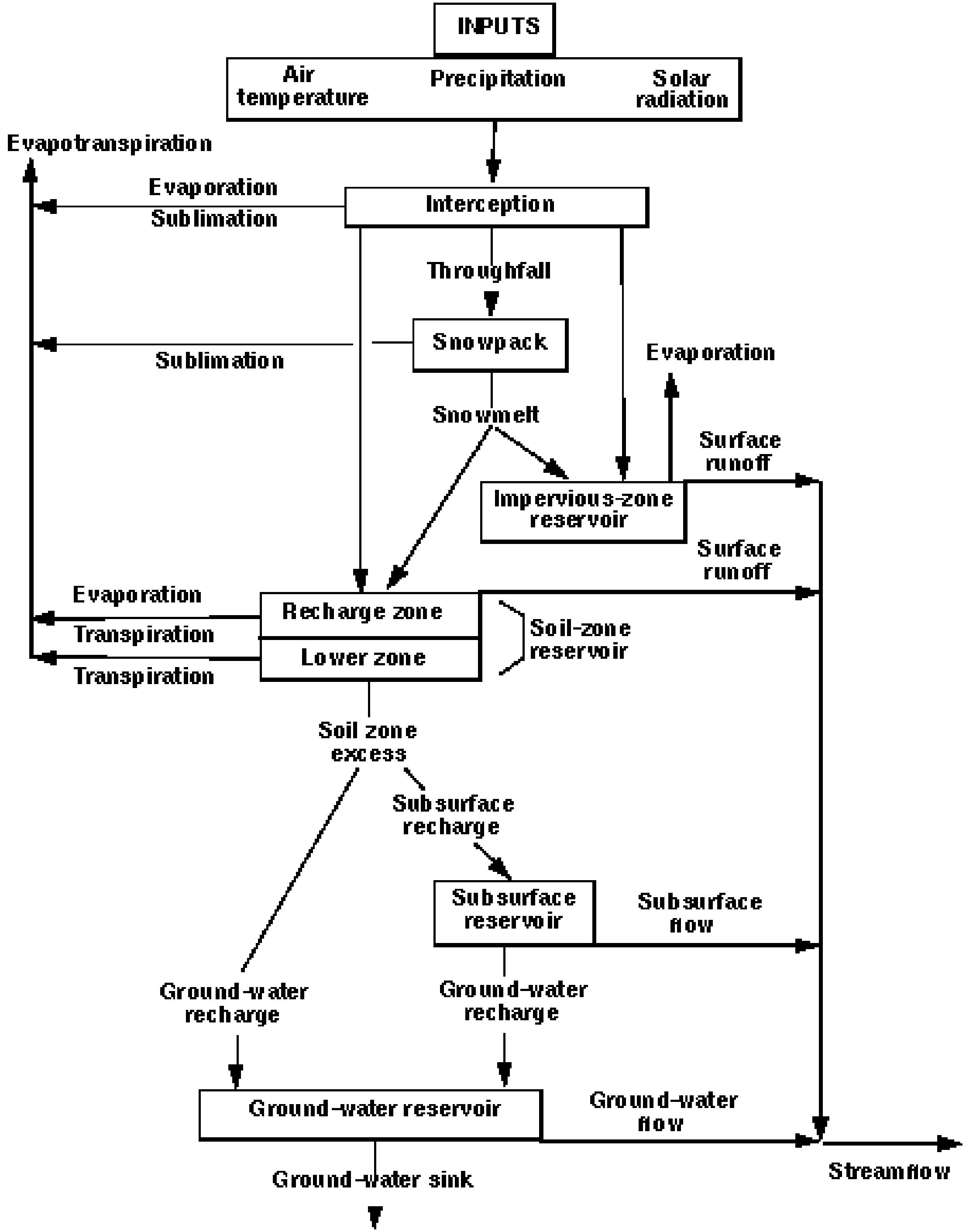
The GIS Weasel

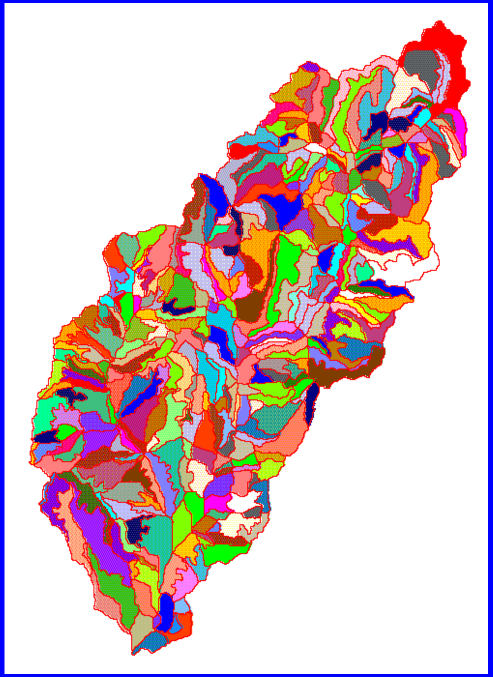




x,y: 1.19341,9.04282
dx,dy: -6.87746,5.78248
Prepared Models
Model:
Load
PRMS
PRMS-xyz
TOPMODEL
Dimension/Parameter Lists
Method:
param_10-85slope
param_area
param_area-acres
param_area-miles
param_area-pct
param_cov-den_summer
param_cov-den_winter
param_cov-type
Parameterization Interface
Parameter Name
Dimension
Method
Interactive
On/Off
Parameter Settings
basin_area basin param_area-acres.aml
nstream hru param_poly2stream.aml
hru_radpl hru param_radpl.aml
radpl_aspect radpl param_radpl-aspect.aml
radpl_slope radpl param_radpl-slope.aml
radpl_lat radpl param_radpl-lat.aml
hru_area hru param_area-acres.aml
hru_elev hru param_elv-med-ft.aml
hru_slope hru param_slp.aml
soil_moist_max hru param_soil-moist.aml
soil_texture hru param_soil-texture.aml
soil_rechr_max hru param_soil-rechr.aml
covden_sum hru param_cov-den_summer.aml
covden_win hru param_cov-den_winter.aml
rad_trncf hru param_wcov-trans.aml
cov_type hru param_cov-type-prms.aml
srain_intcp hru param_intcp-srain.aml
Parameter Settings
hru_percent_imperv hru param_imperv.aml
jh_coef_hru hru param_jh-coef.aml
hru_psta hru param_poly2point.aml
hru_tsta hru param_poly2point.aml
Parameterization Control Panel
Dimensions
Clear
Save
Update
Output:
ASCII tables:
Shapefiles:
Overlay of BASIN and ANCILLARY layers:
MMS Parameter File:
Verify Consistency of Projections:
Default: /z/runoff/home1/weasel/src_c/mms.par
Data Bin: /z/runoff/home1/weasel/data_bin
Output: basin.mms
(TTY)
APPLY
CLOSE
Grid: (param_model_menu, param
Grid: (param_model_menu, param
Grid: (param_model_menu, param
Grid: (param_model_menu, param

USGS Precipitation Runoff Modeling System (PRMS)

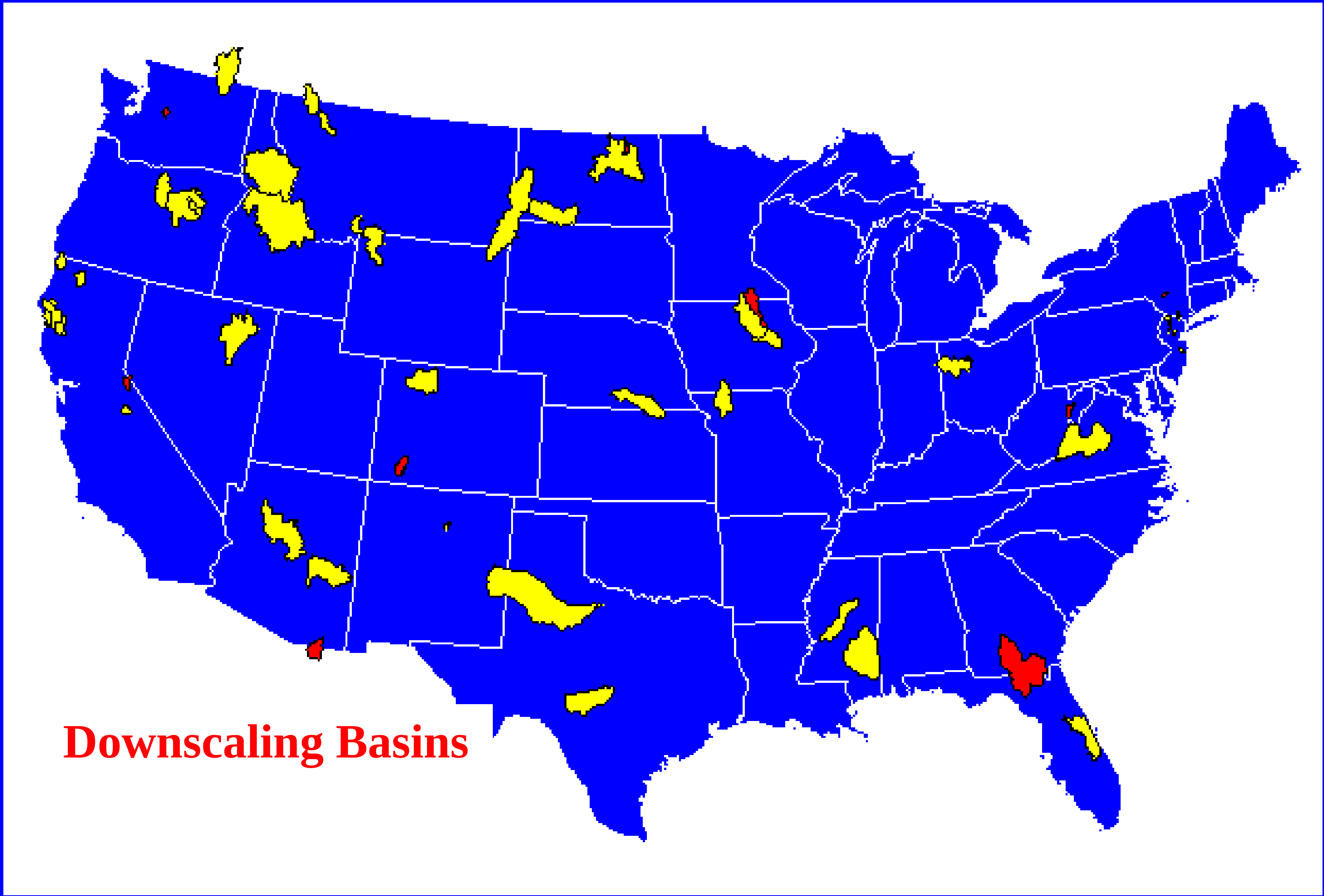




PRMS Parameters Estimated

- 9 topographic (slope, aspect, area, x,y,z, …)
- 3 soils (texture, water holding capacity)
- 8 vegetation (type, density, seasonal interception, radiation transmission)
- 2 evapotranspiration
- 5 indices to spatial relations among HRUs, gw and subsurface reservoirs, channel reaches, and point measurement stations

MODEL PARAMETER ESTIMATION BASINS



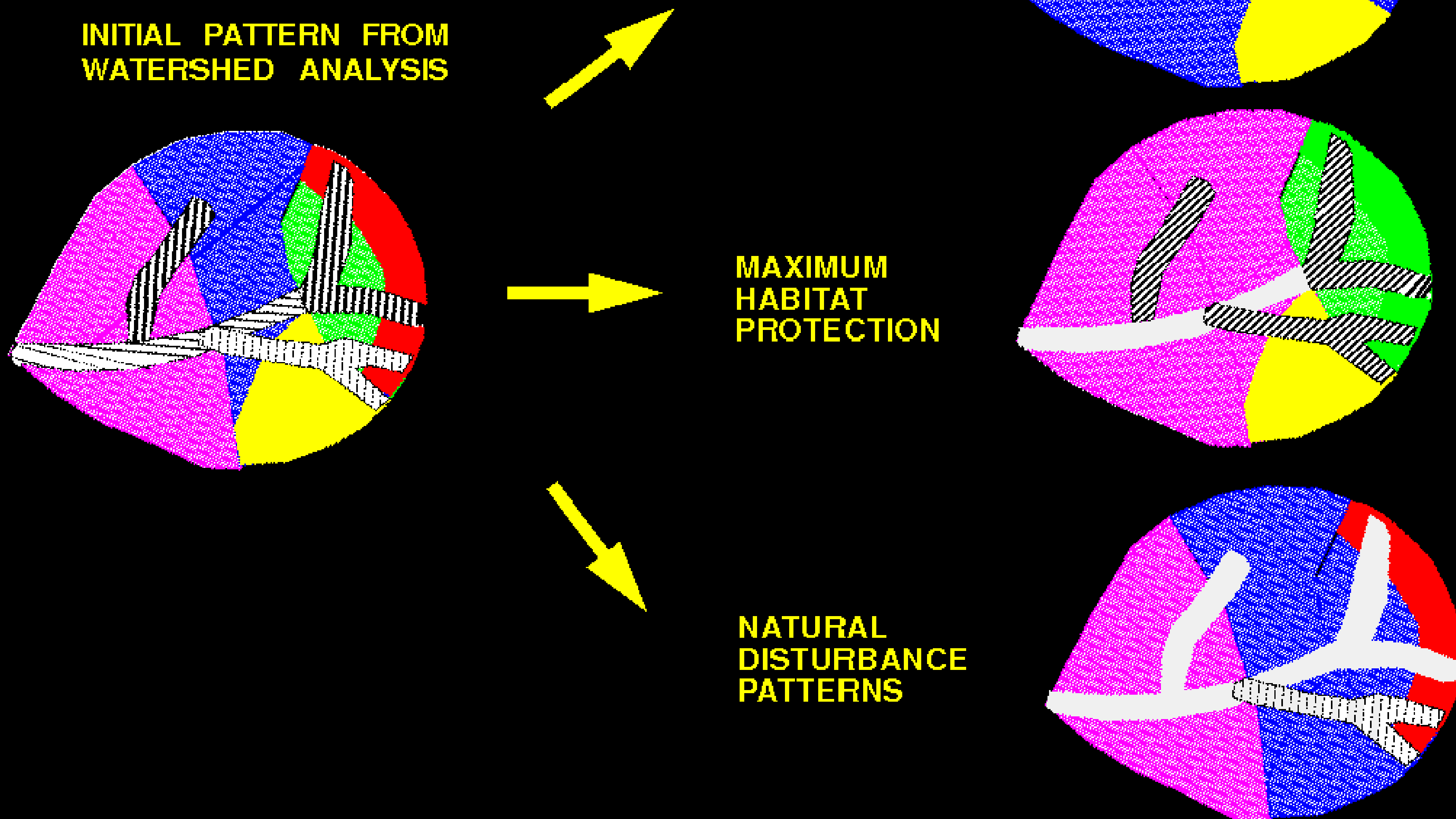
BUREAU of LAND MANAGEMENT

Tools for the Assessment of Environmental Impacts of Alternative Forest-Management Strategies

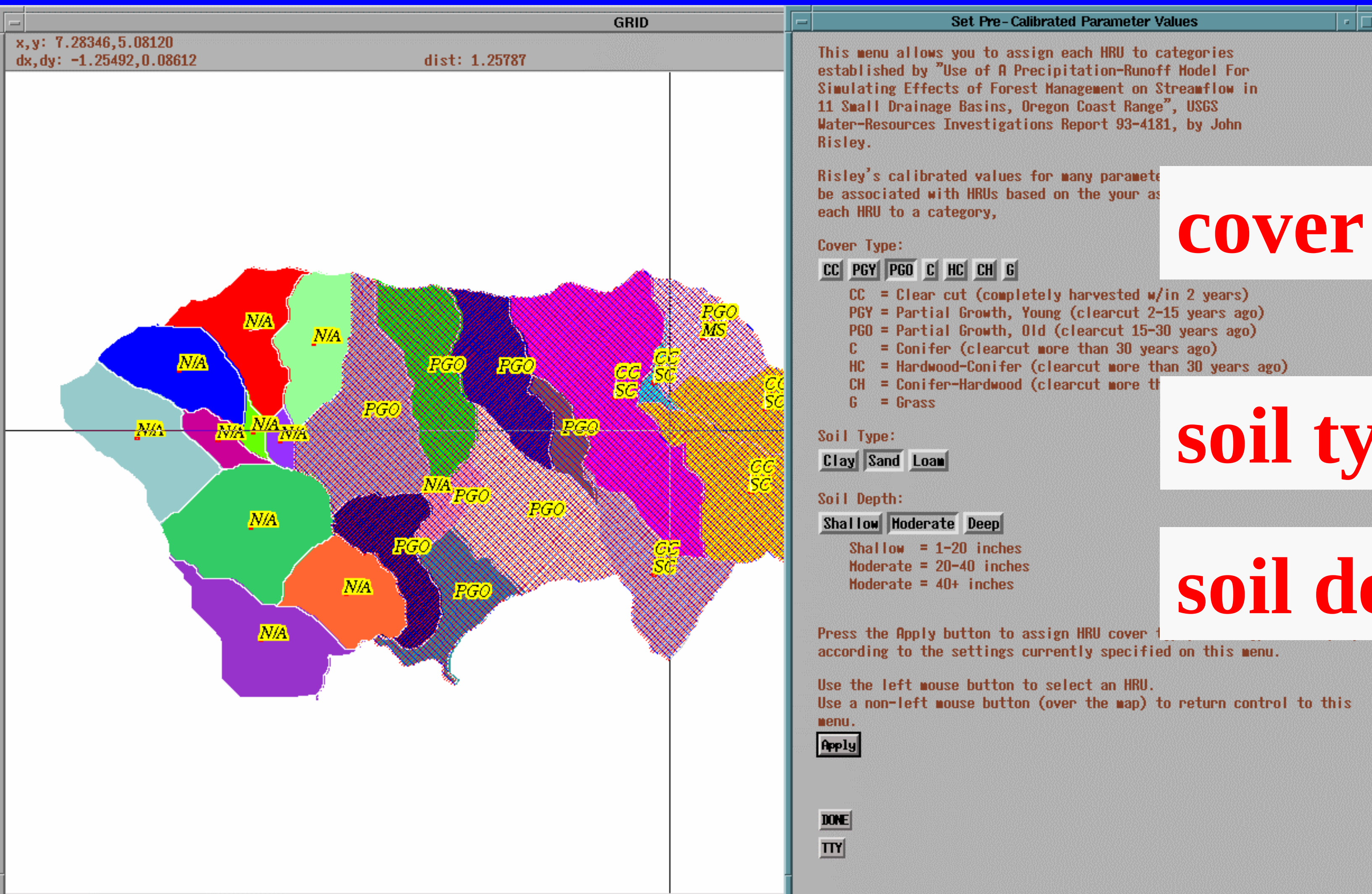
Oregon Coast Range

Initial system based on the findings of John Risley, Oregon District, WRI 93-4181

Ecosystem Management Scenarios



HRU Parameter Assignment using the GIS Weasel

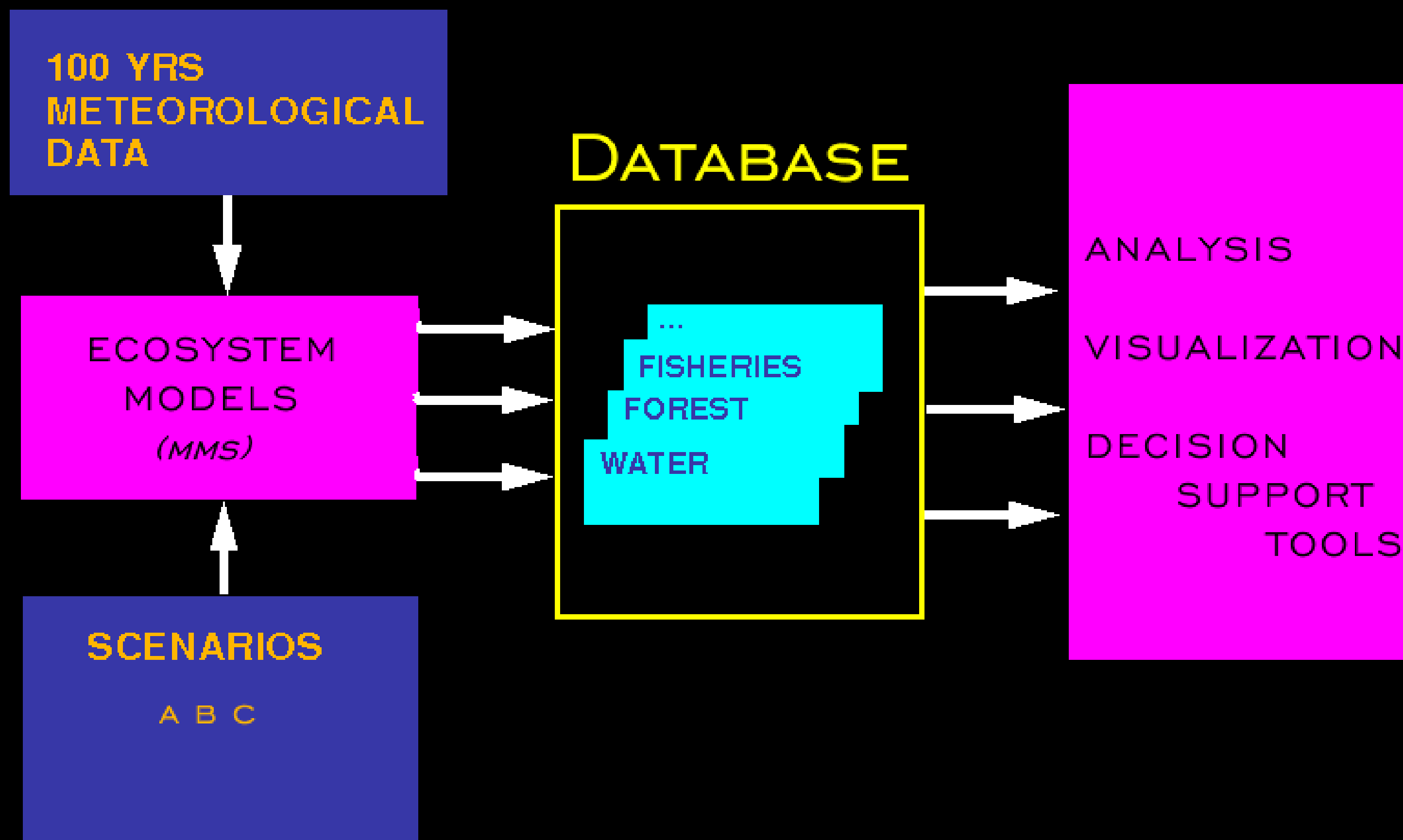


cover type

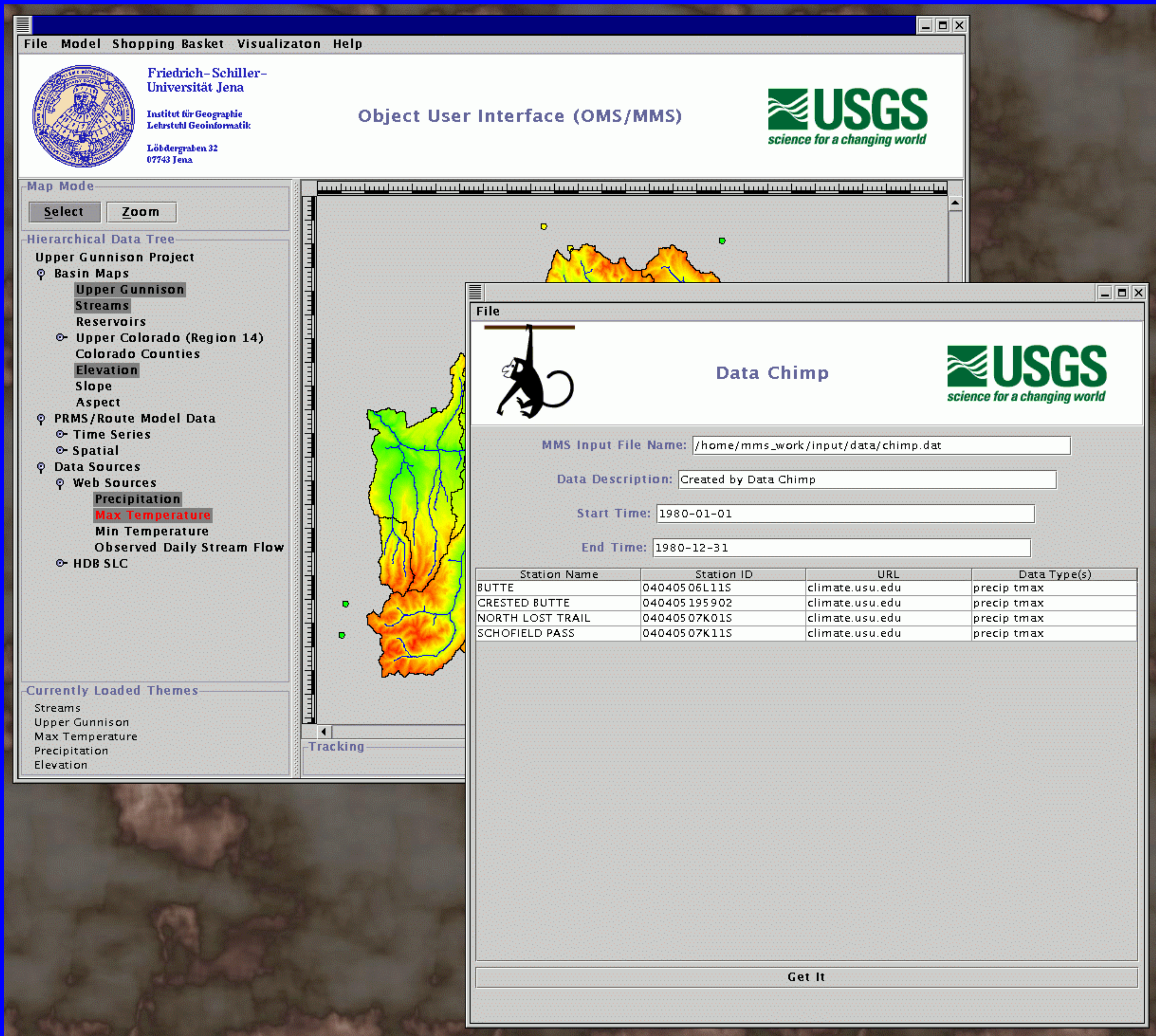
soil type

soil depth

SCENARIO ANALYSIS AND DECISION SUPPORT



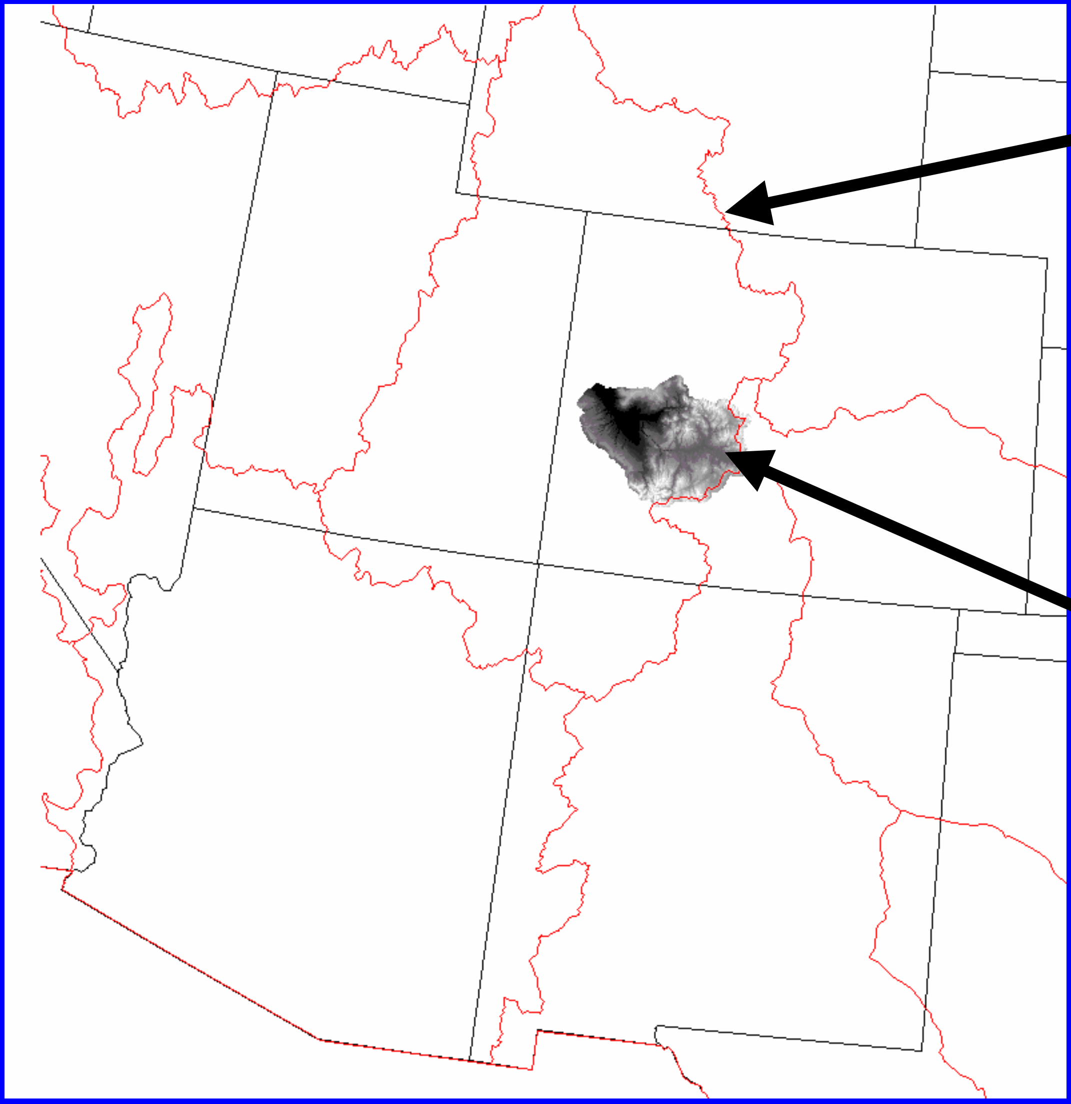
DATA CHIMP



Time-series Data Retrieval

Precipitation, Temperature, Streamflow, ...

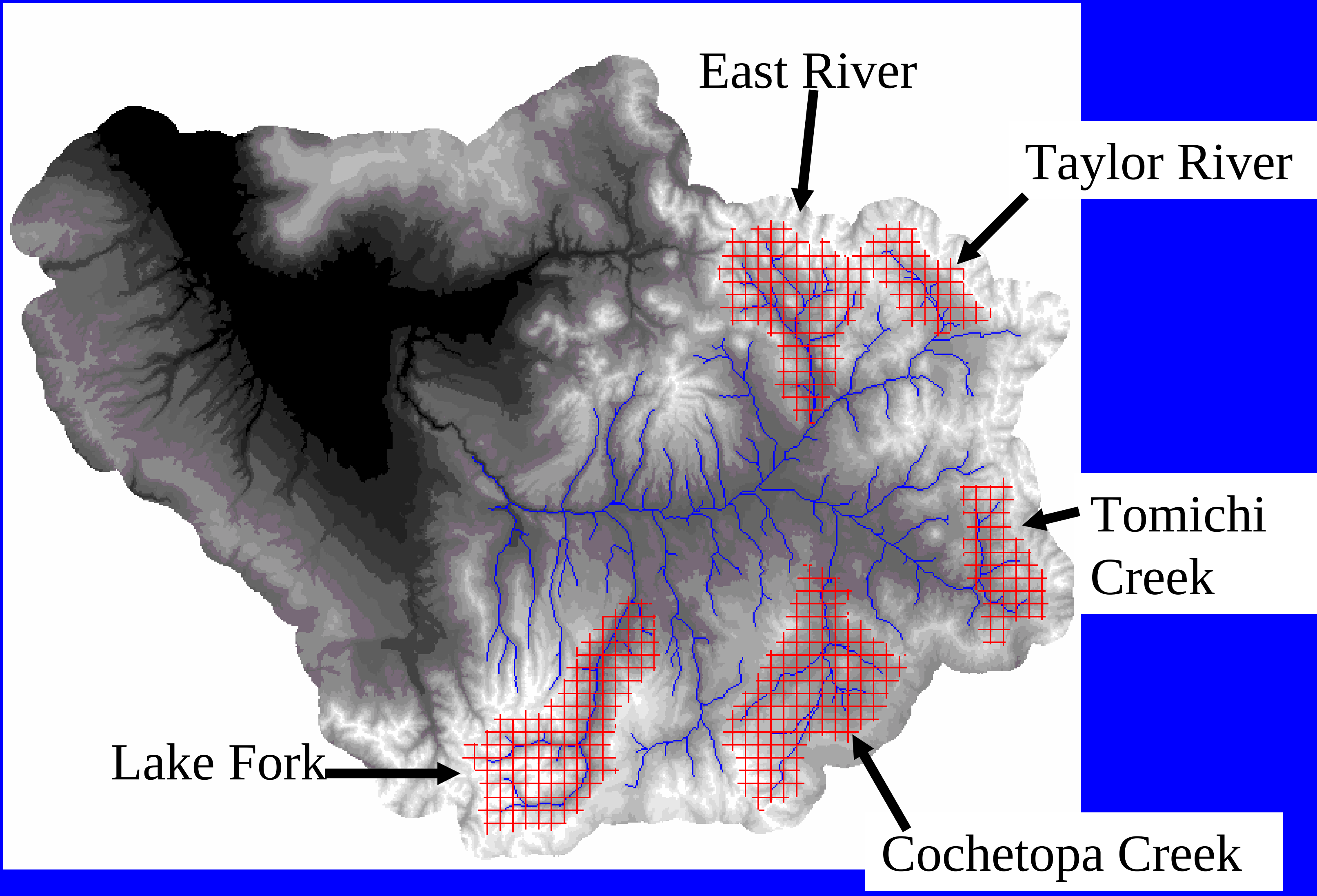
GUNNISON RIVER BASIN LOCATION

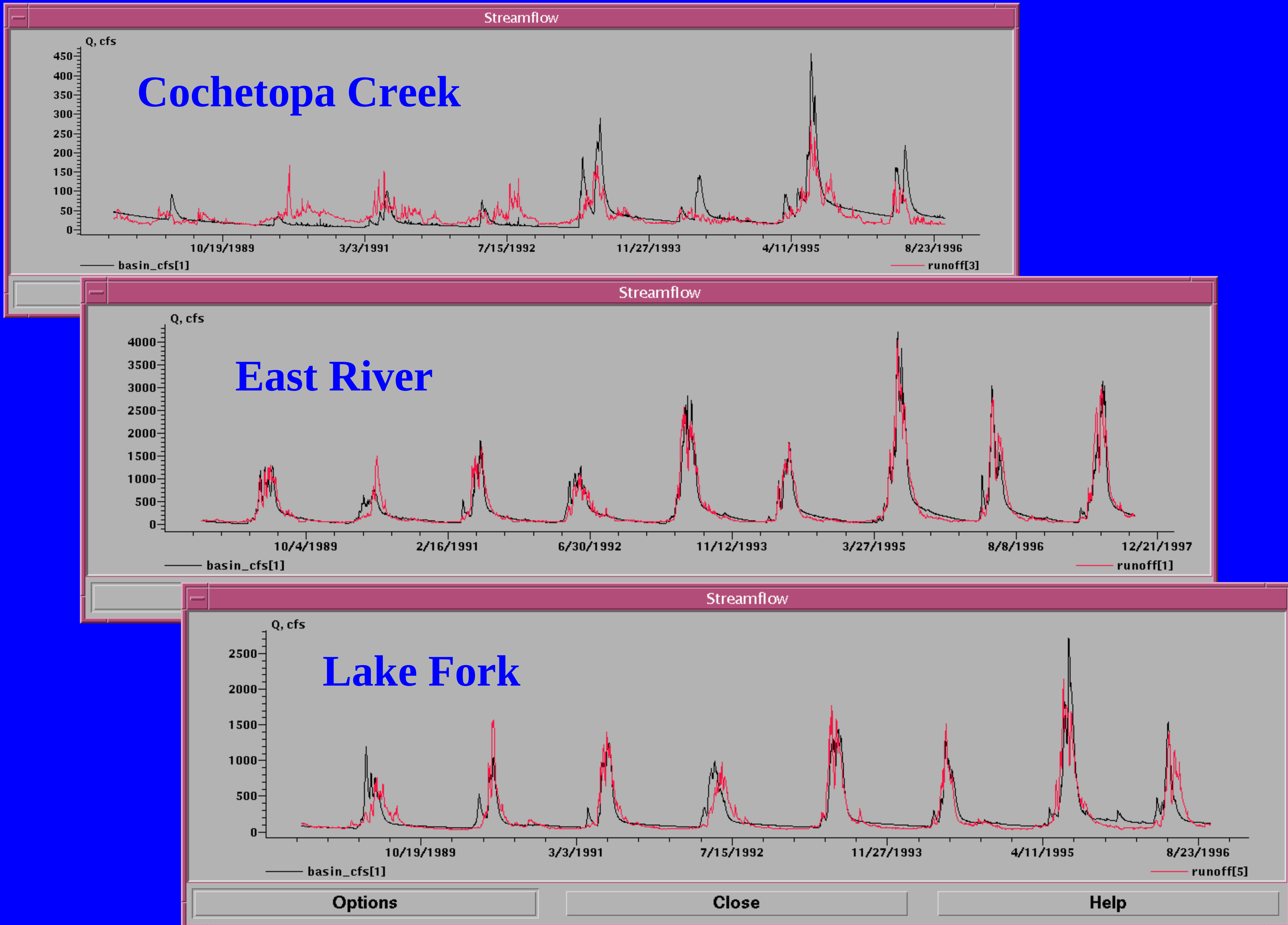


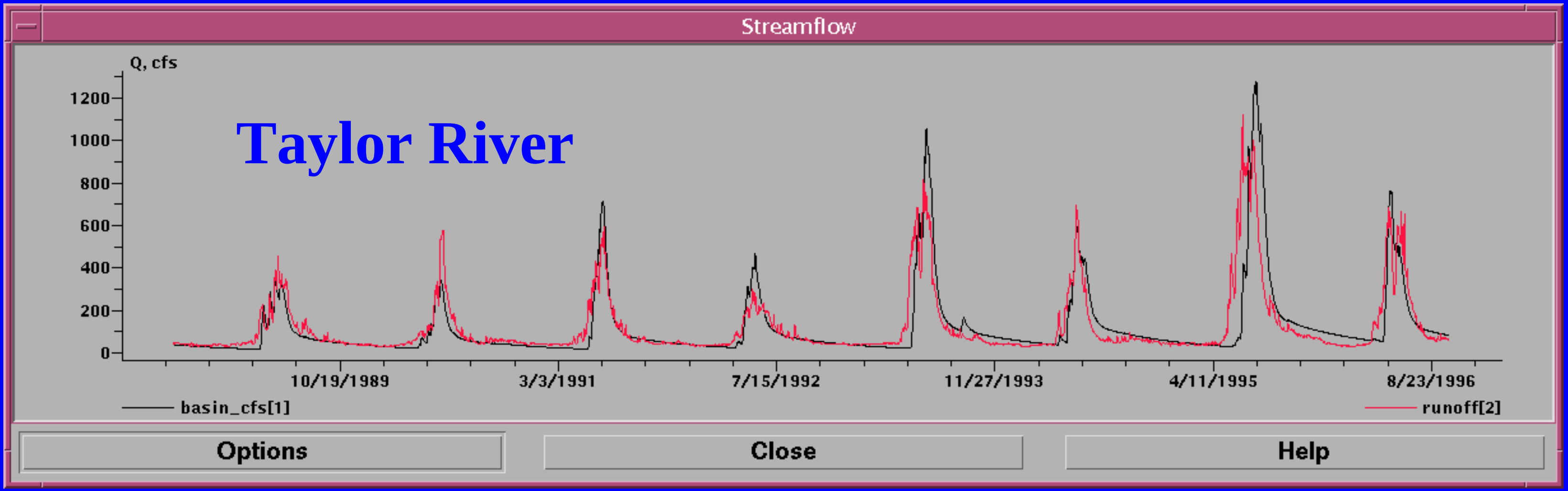
Upper Colorado River Basin

Gunnison River Basin

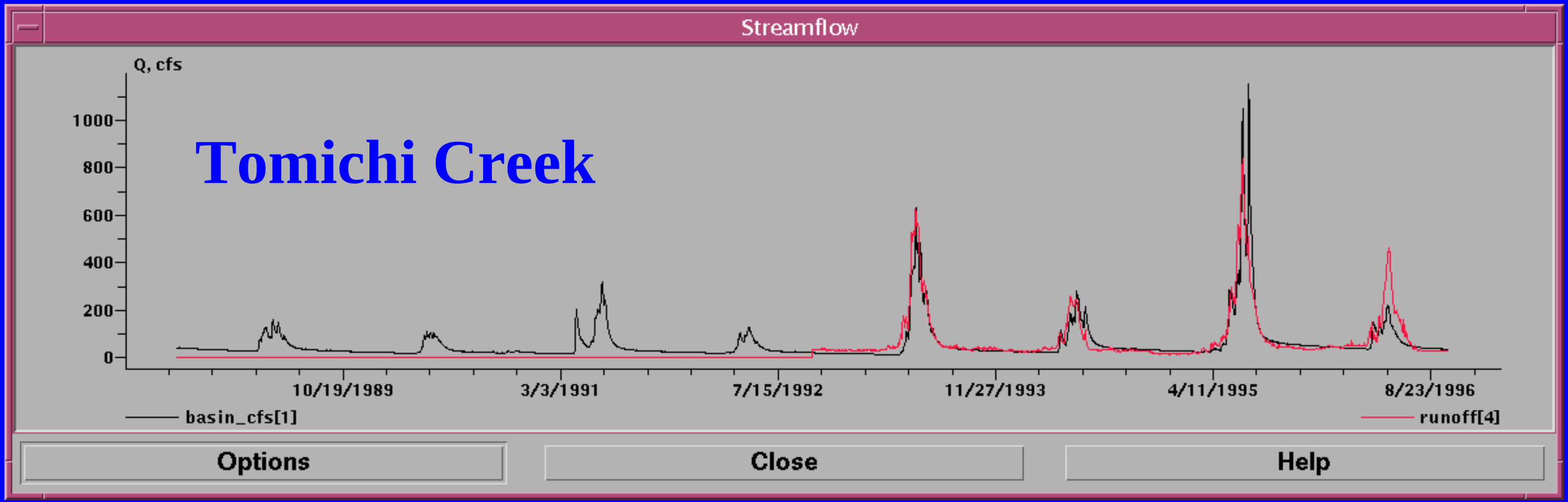
SUBBASINS WITH CONCURRENT STREAMFLOW AND SATELLITE DATA




Streamflow
Q, cfs
Cochetopa Creek
450
400
350
300
250
200
150
100
50
0
10/19/1989
3/3/1991
7/15/1992
11/27/1993
4/11/1995
8/23/1996
basin_cfs[1]
runoff[3]
Streamflow
Q, cfs
East River
4000
3500
3000
2500
2000
1500
1000
500
0
10/4/1989
2/16/1991
6/30/1992
11/12/1993
3/27/1995
8/8/1996
12/21/1997
basin_cfs[1]
runoff[1]
Streamflow
Q, cfs
Lake Fork
2500
2000
1500
1000
500
0
10/19/1989
3/3/1991
7/15/1992
11/27/1993
4/11/1995
8/23/1996
basin_cfs[1]
runoff[5]
Options
Close
Help

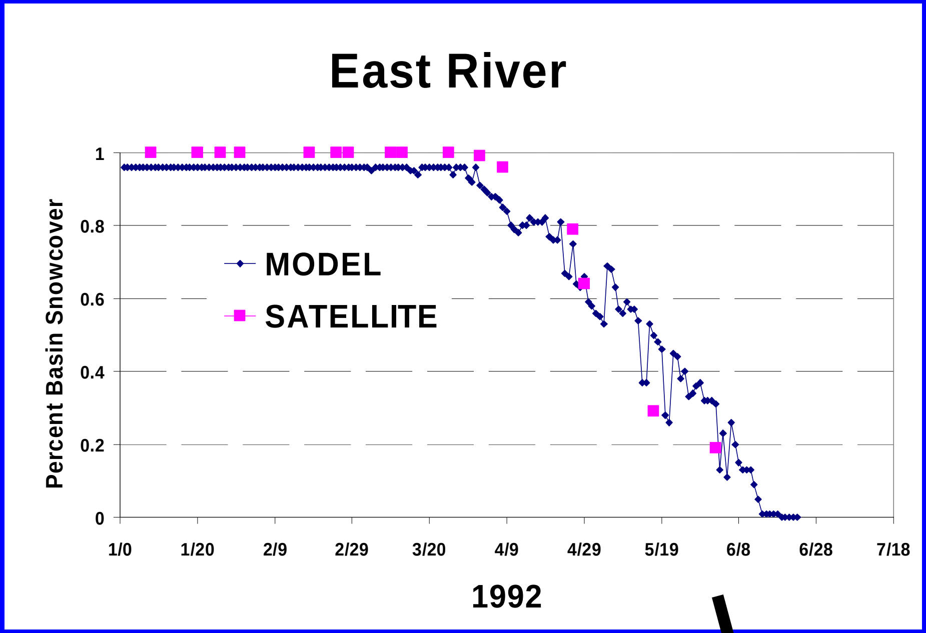


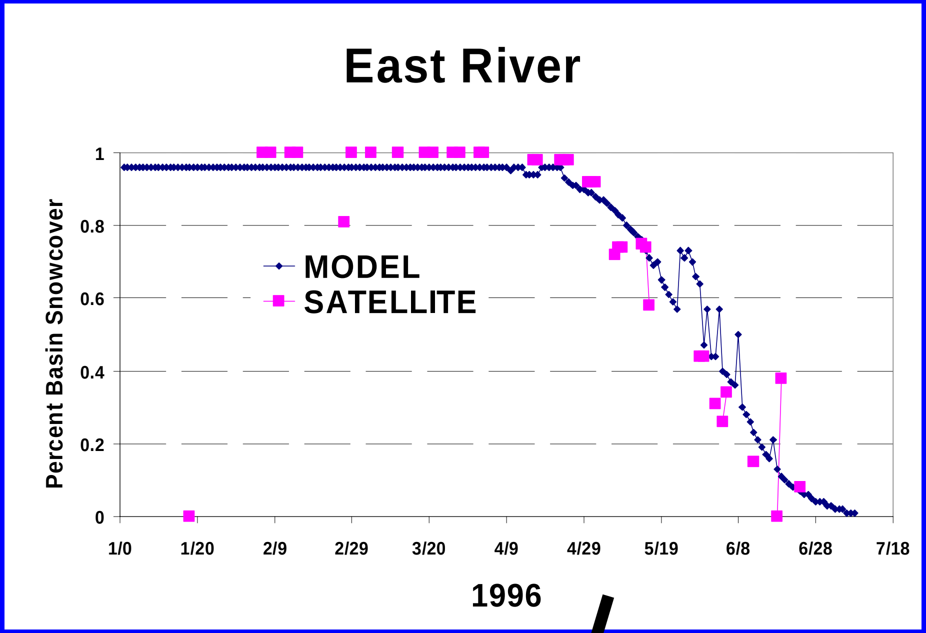
Streamflow
Q, cfs
1200
1000
800
600
400
200
0
Taylor River
10/19/1989
3/3/1991
7/15/1992
11/27/1993
4/11/1995
8/23/1996
basin_cfs[1]
runoff[2]
Options
Close
Help

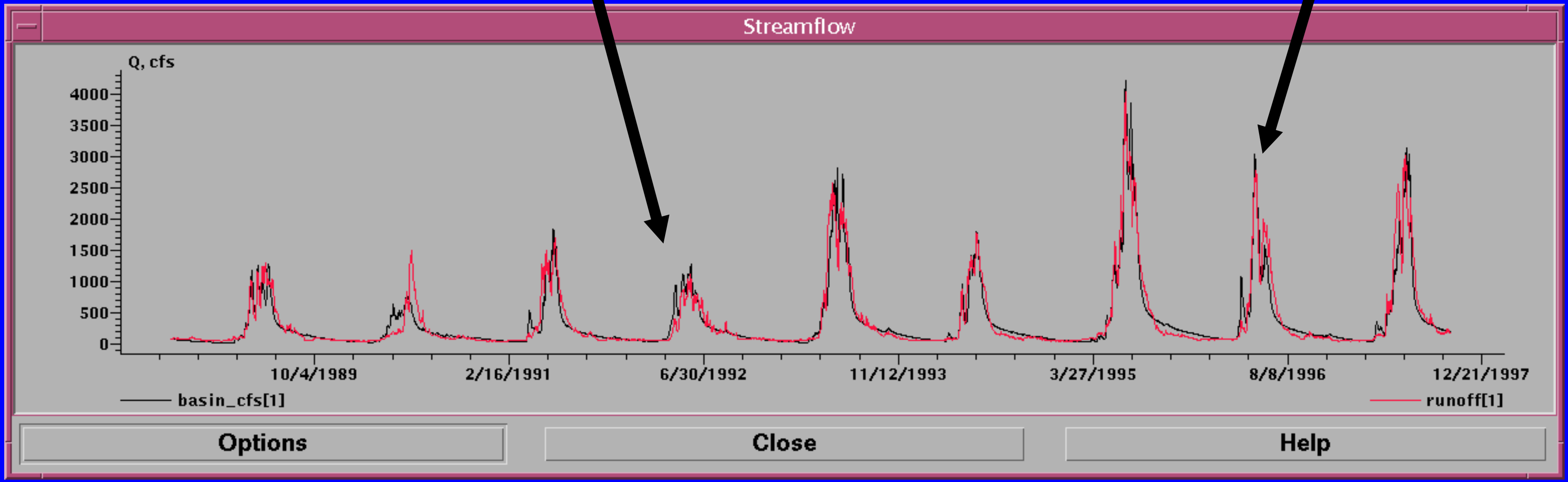


Streamflow
Q, cfs
1000
800
600
400
200
0
Tomichi Creek
10/19/1989
3/3/1991
7/15/1992
11/27/1993
4/11/1995
8/23/1996
basin_cfs[1]
runoff[4]
Options
Close
Help

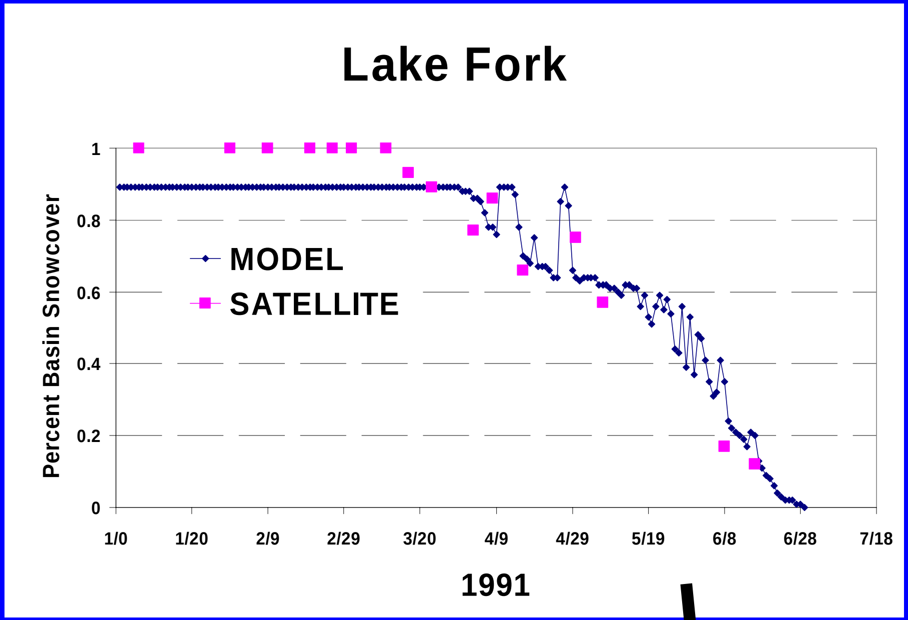
Percent Basin in Snow Cover

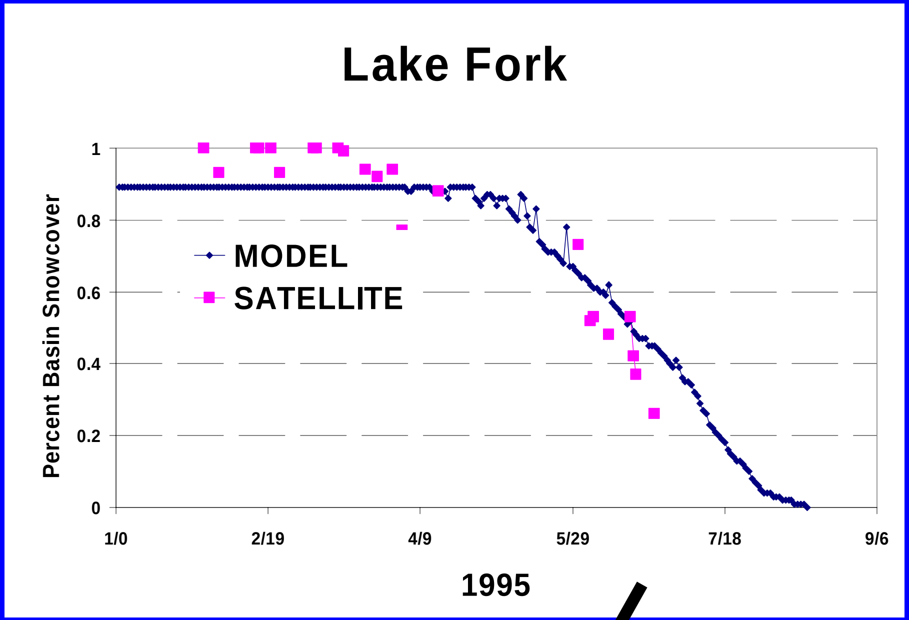


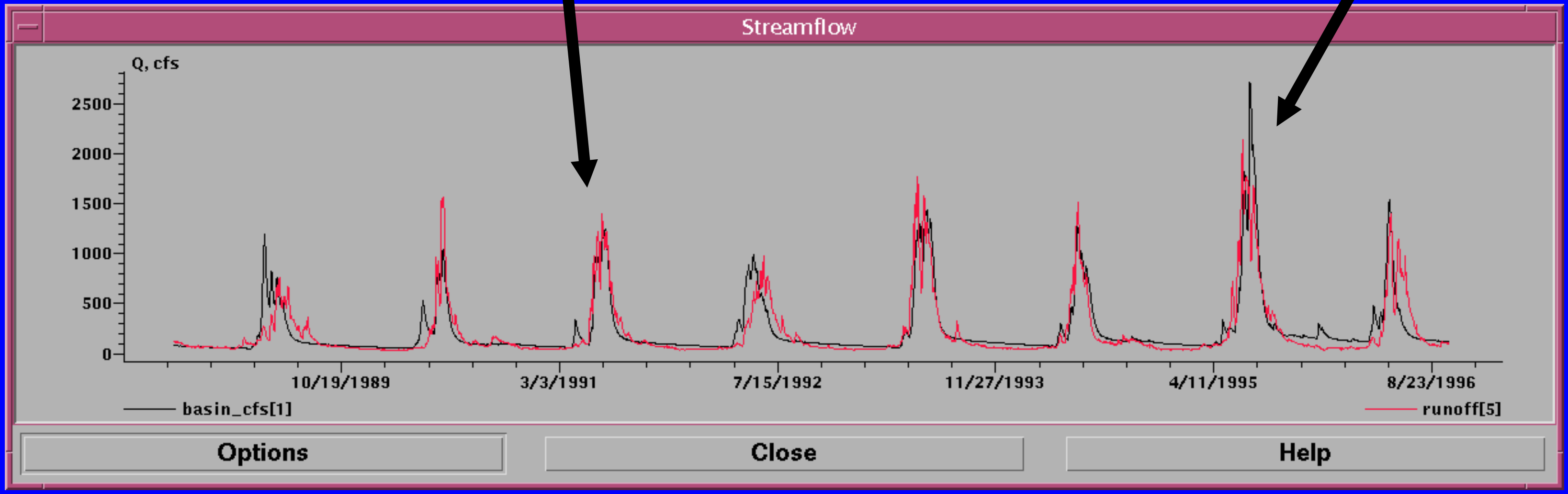




Percent Basin in Snow Cover







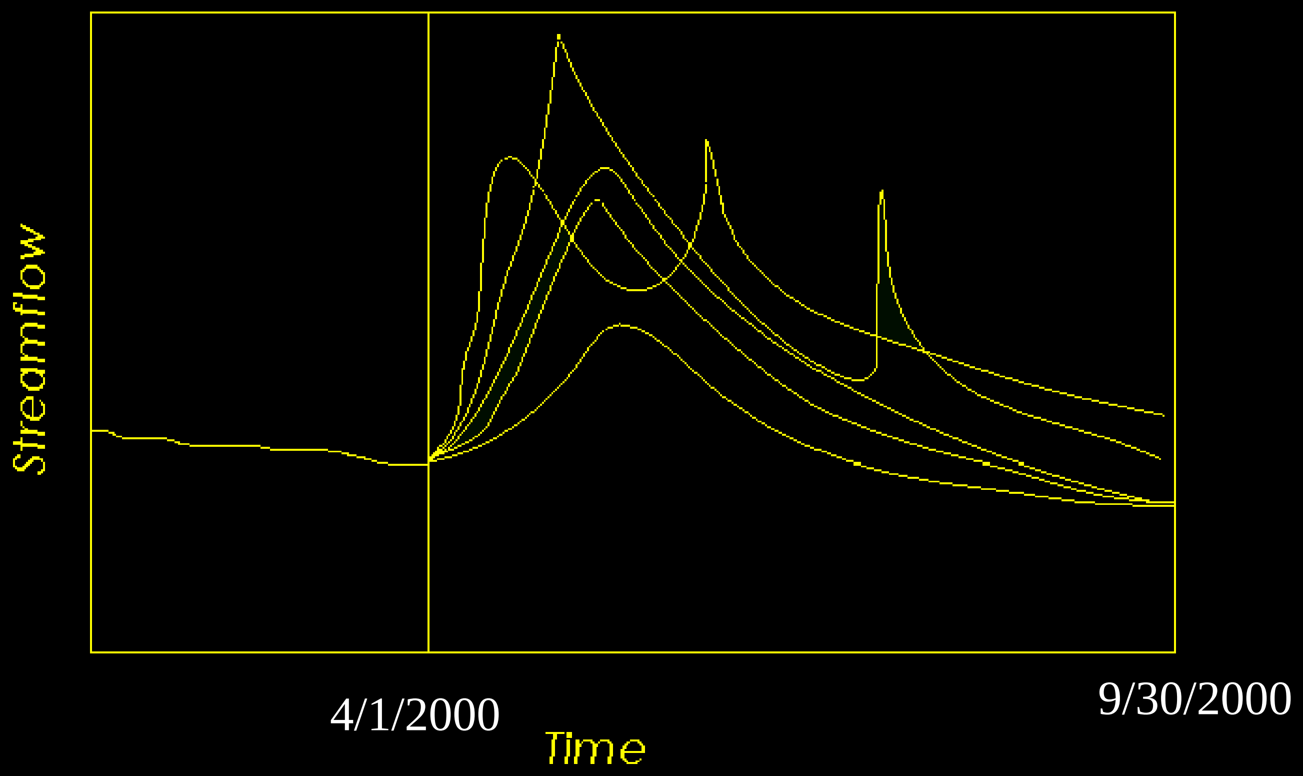
Forecast Methodologies in MMS

Ensemble Streamflow Prediction (ESP)

Atmospheric Model Outputs

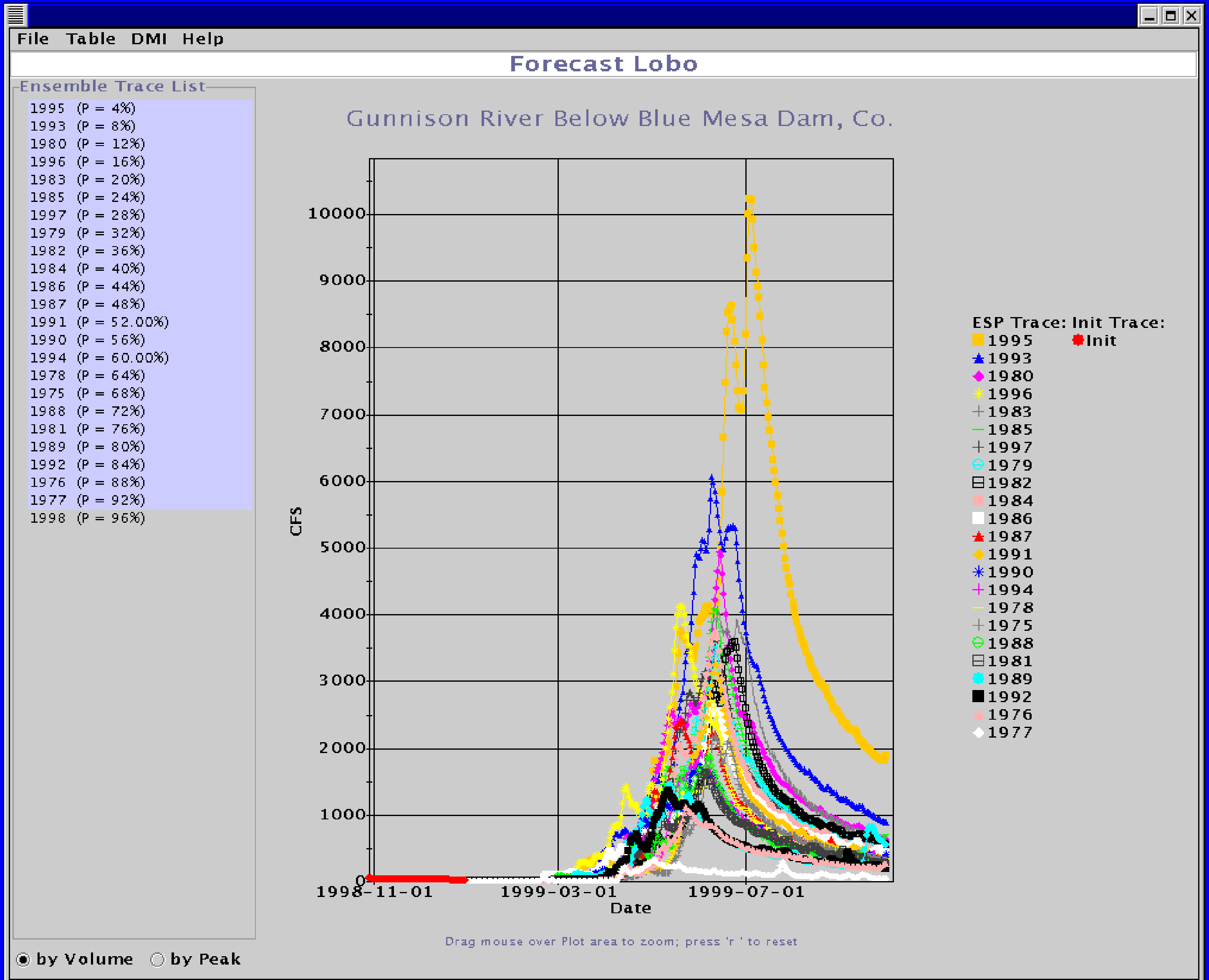
- Statistical Downscaling
- Dynamical Downscaling

Ensemble Streamflow Prediction



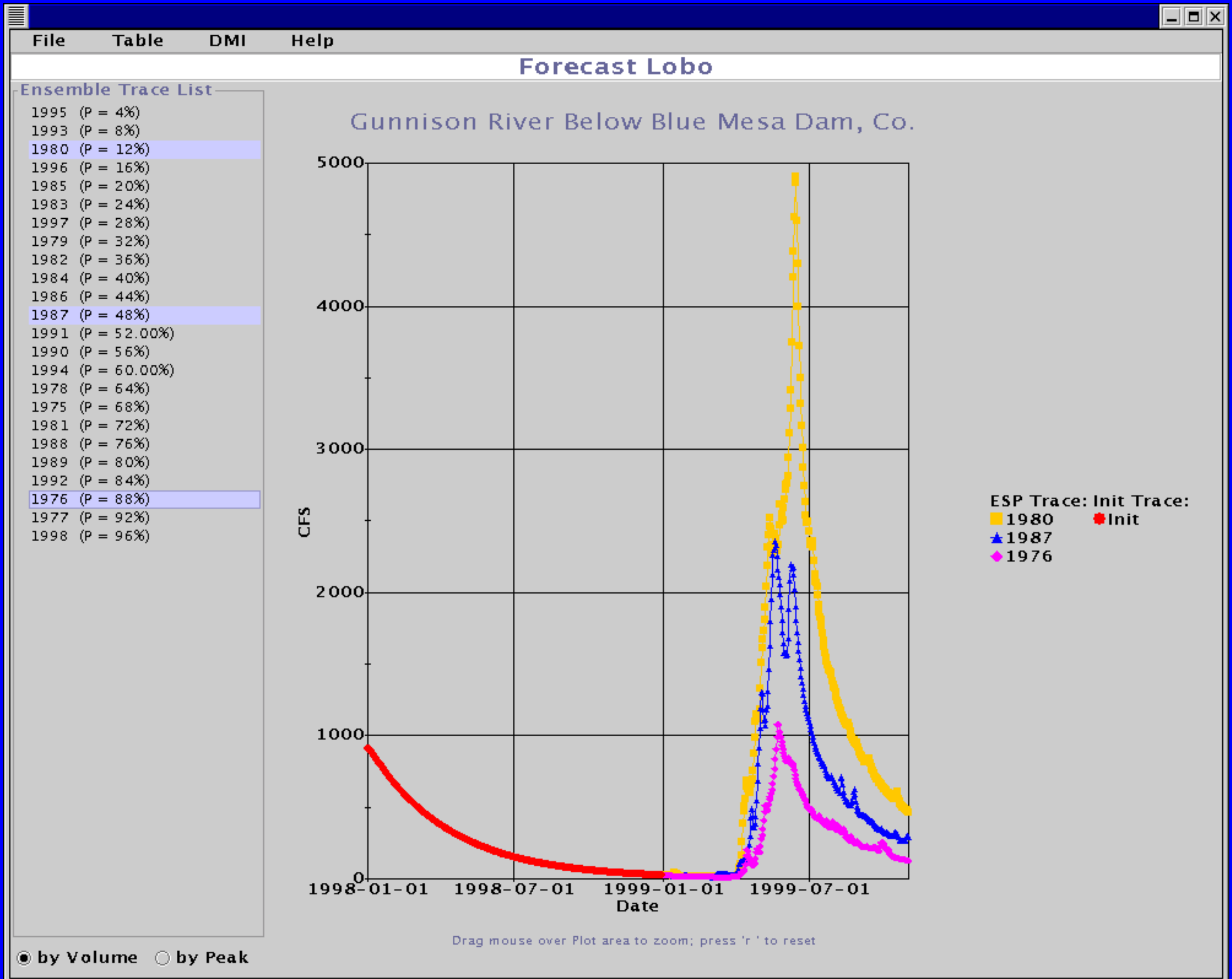
MMS ESP Tool

All Computed Traces using 1975 - 1998

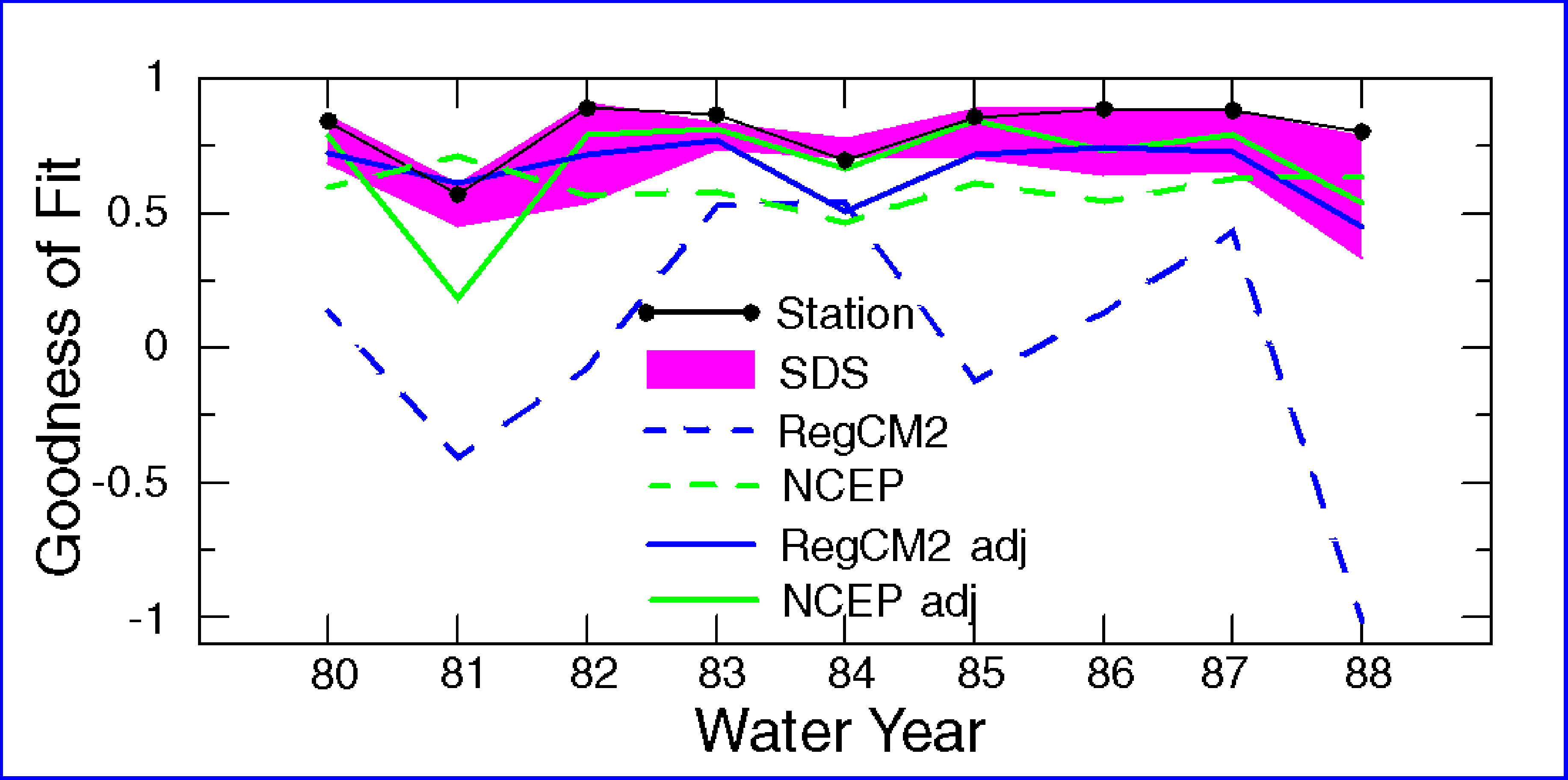


MMS ESP Tool

Manager selected 10, 50, and 90 % probability of occurrence



Nash-Sutcliff Coefficient of Efficiency Scores
Simulated vs Observed Daily Streamflow



Object Modeling System

Olaf David
GPSR

January 17th 2001

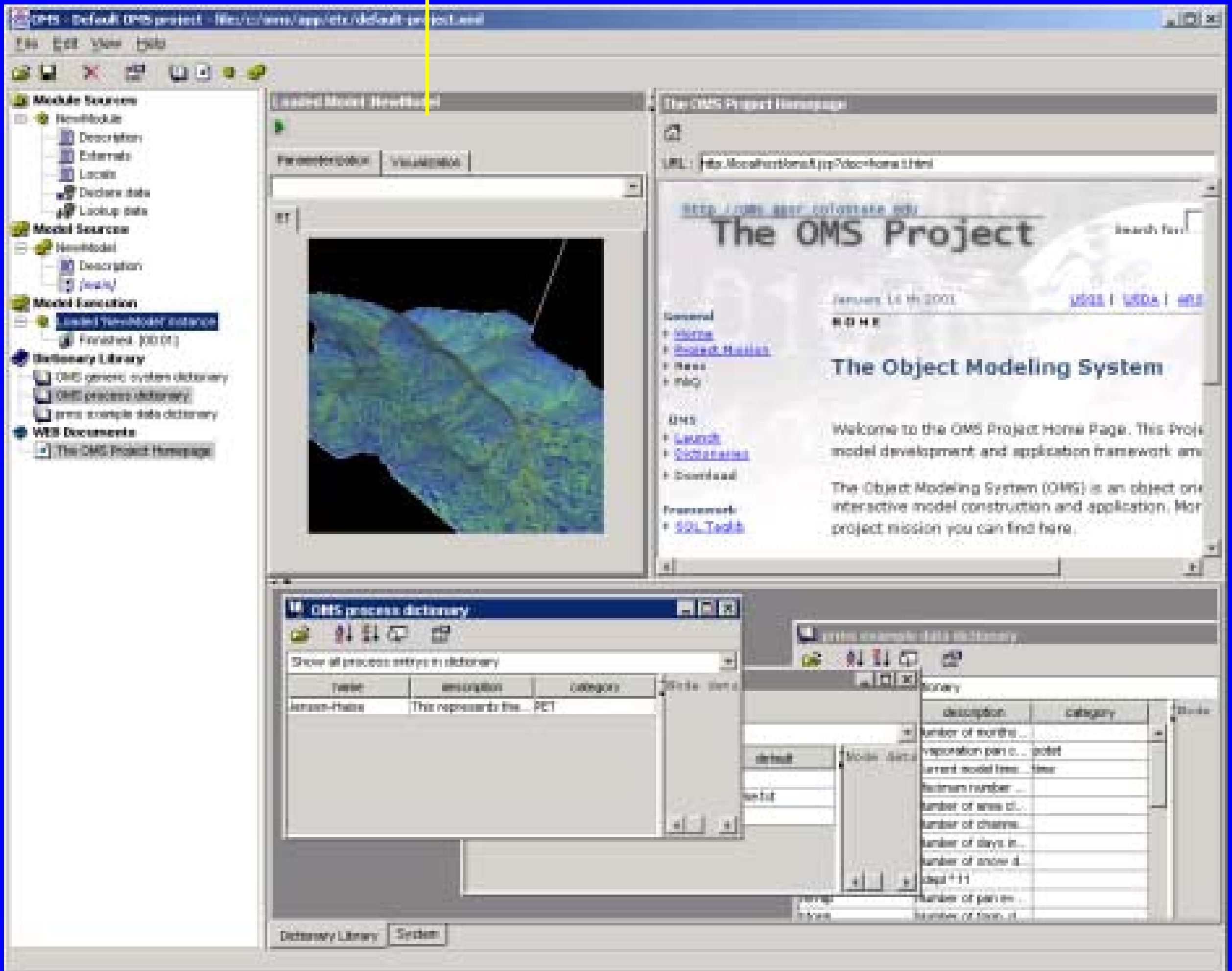
OMS Key Technologies

- Object-Orientation
  - Model Components, Framework
- JAVA
  - System and Models
- XML
  - Resource Representation
- HTTP / Internet
  - Deployment: System, Resources

OMS GUI

Module Panel
Model Src Panel
Moder Loader Panel
Model Execution Panel

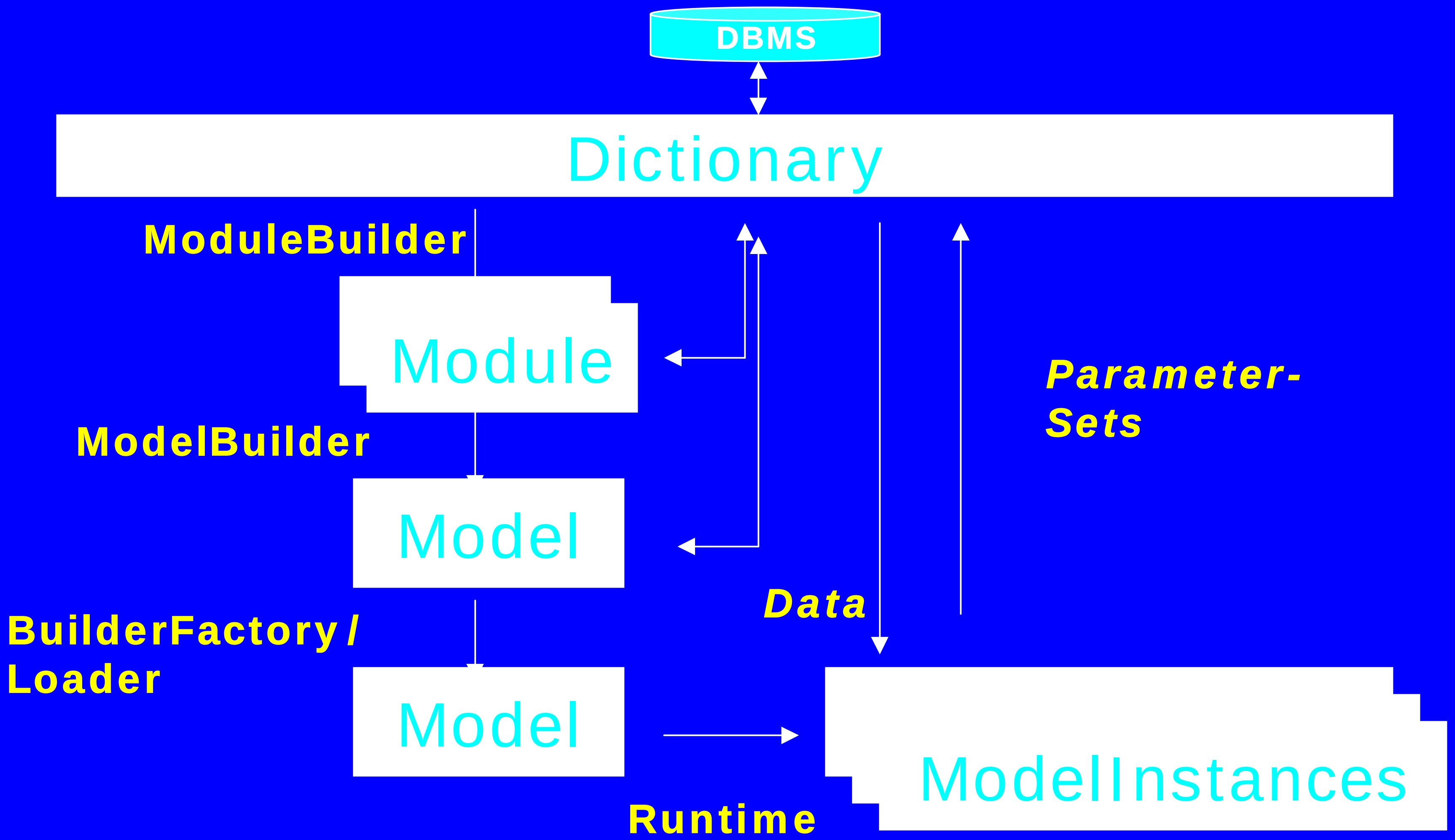
Main Control Tree



Webbrowser

Dictionary Panel

Workflow


DBMS
Dictionary
ModuleBuilder
Module
ModelBuilder
Model
BuilderFactory /
Loader
Model
Data
Parameter-
Sets
ModelInstances
Runtime

What is a Modeling Dictionary ?

- Container for different kinds of modeling resources:
  - Processes, Variables, Parameter,
  - Homogeonous vs. heterogenous
- Presents its content depending on requested views.
- Has associated Rights to manage the container.

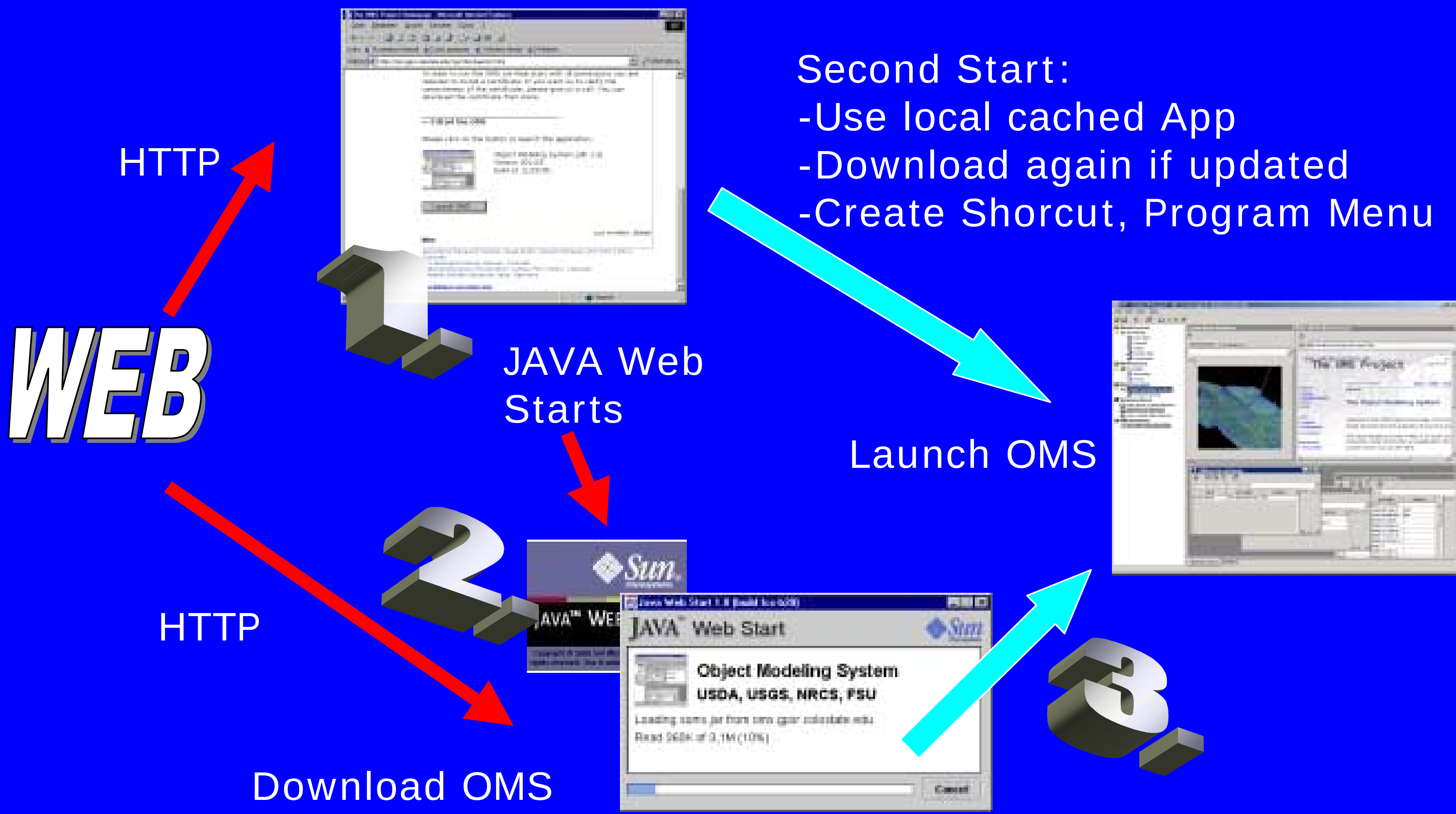
Dictionary Framework (i)

- XML 1.0 Specification
- Container for
  - Data, Parameter, Processes, Modules, Models, ...
  - Type set not fixed, !
- OMS can operate with dictionaries at the GUI level

OMS Deployment

- OMS itself: Java Webstart
- Dictionaries: XML, (SQL/XML)
- Model Code: HTTP accessible jar files
- Documentation: Web/HTTP

Java WebStart ?



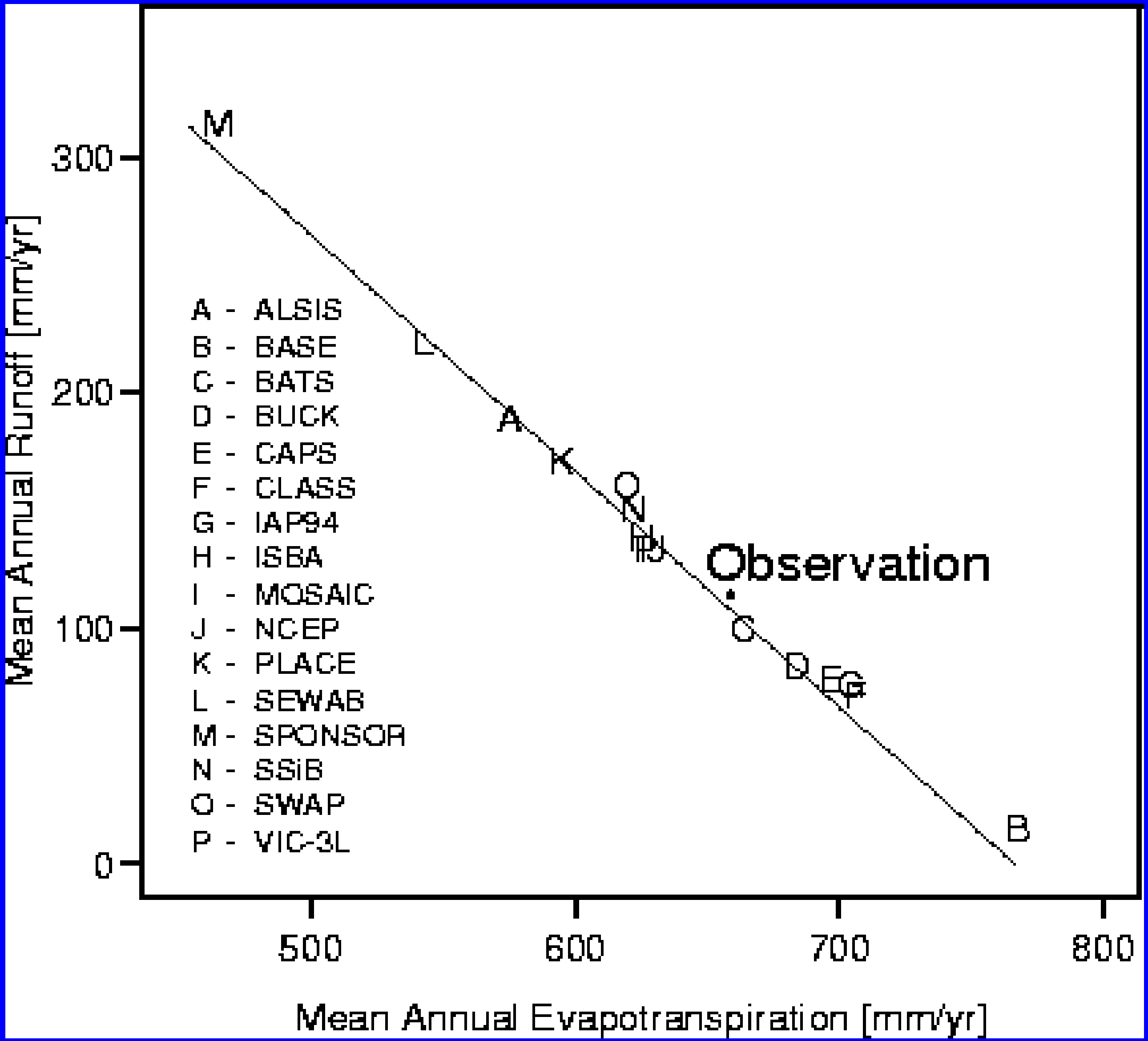
POINTS

- Experimental science builds on hypothesis testing and interpretation based on earlier published hypotheses and results
- Modelers tend to build from the ground up because existing models are not well designed for incremental improvement by others

POINTS

- Current trend of model competitions or comparisons are of limited value without addressing the question of “why”
- A modular framework provides the tools to objectively ask the question “why”

Project for the Intercomparison of Land Surface Parameterization Schemes (PILPS)



What Are The Costs ?

- Acceptance of a modular coding structure
- Willingness to share module code
- Willingness to share analytical tools
- Willingness to develop and share distributed data sets for a wide range of climatic and physiographic regions of the world
- Loss of model name recognition

Benefits ?

- Share a community toolbox for model and system development and for addressing the issues of parameter estimation and scale
- Support a flexible framework that enables the incorporation of continuing advances in science, databases, and computer technology

MMS COLLABORATORS

- **Department of Interior**
  - **USGS**
  - **Bureau of Reclamation**
  - **Bureau of Land Management**
- **Department of Agriculture**
  - **Agricultural Research Service**
  - **Natural Resources Conservation Service**
  - **Forest Service**

MMS COLLABORATORS

- University of Colorado
- University of Arizona
- NASA
- Department of Energy
- Department of Defense
- Friedrich Schiller University, Germany
- Public Works Research Institute, Japan

MODELS AND MODULES IN MMS (USGS)

- PRMS
- TOPMODEL
- DAFLOW (beta)
- 1-D Sediment Transport

OTHER MODELS AND MODULES IN MMS INCLUDE

- Hydro-17 (NWS snowmelt)
- Snowmelt Runoff Model (SRM) (ARS)
- ENNS Model (modified HBV, Austria)
- Root Zone Water Quality Model (ARS)
- Generic Crop (Corn, Soybeans -ARS)
- Shoot Grow (Wheat - ARS)
- Penman-Monteith (NASA, Japan, Thailand)
- GCM Land Surface Parameterizations (Japan-Thailand, UC Davis)

PRECIPITATION - RUNOFF MODELING PROJECT

OPEN SHOP

CONSULTATION

COLLABORATION

POINT

“A fool with a tool is still a fool.”

Chicken Soup for the Modeling Soul

System Development magazine

MORE INFORMATION

http://wwwbrr.cr.usgs.gov/mms

http://wwwbrr.cr.usgs.gov/weasel

http://wwwbrr.cr.usgs.gov/warsmp

http://wwwbrr.cr.usgs.gov/projects/

SW precip runoff/papers