INTEGRATED MODELING AND DECISION SUPPORT FOR WATER- AND ENVIRONMENTAL-RESOURCES MANAGEMENT

George Leavesley

USGS
National Research Program
Denver, CO

OVERVIEW

- Review integrated modeling and DSS issues
- Describe modeling-framework components and applications
- Live demonstration of framework components
- Technical discussion of selected tools used to improve water supply forecasts
- Related modeling-framework applications

Components of Water Availability in the West

Water Supply

- Snow accumulation and melt
- Rainfall distribution
- Storage volume / distribution

Water Demand

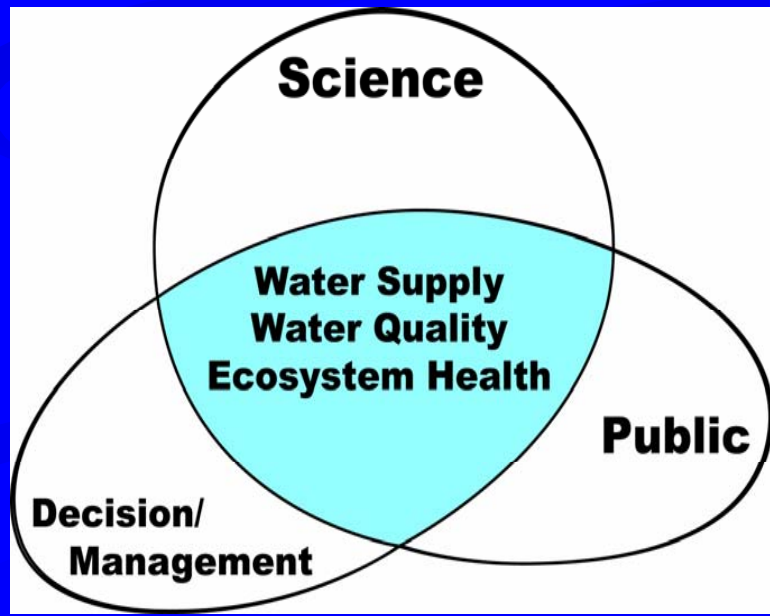
- Environmental
- Agricultural
- Municipal / Industrial / Hydropower
- Recreation
- …

Technical Issues

- A framework in which to integrate models and tools and provide decision support.
- Accurate forecasts of meteorological variables.
- Knowledge of how water moves through a basin.
- Knowledge of the socio-economic processes controlling water supply and demand.
- Dealing with uncertainty.

Integrated Modeling and Decision-Support Systems

- Facilitates multi-disciplinary integration of models and tools to address the issues of water- and environmental-resources management.
- Allows rapid evaluation of the effects of decision and management scenarios.
- Allows incorporation of continuing advances in physical, social, and economic sciences.
- Provides an effective means for sharing scientific understanding with stakeholders and decision makers.



THE USGS MODULAR MODELING SYSTEM (MMS)

A toolbox for the development, application, and analysis of hydrologic and ecosystem models

TOOL BOX MODELING VIEWS

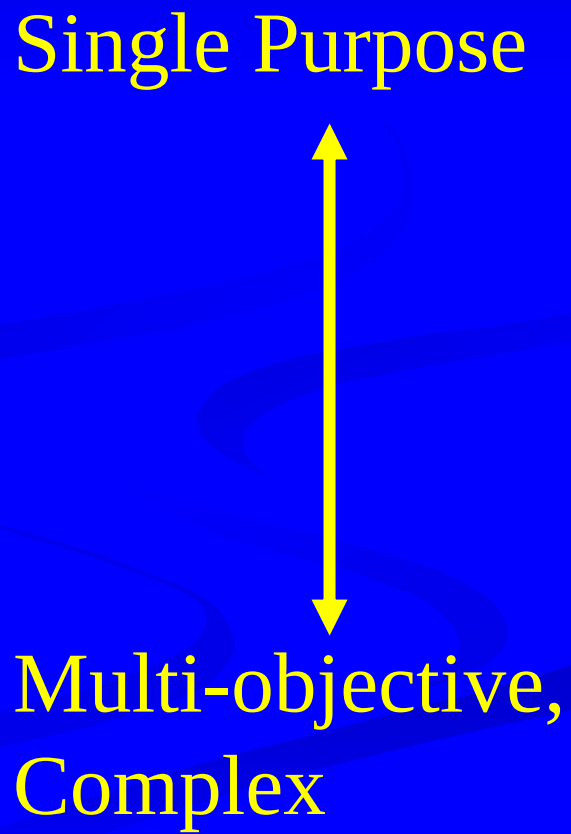
- Research Model Developer
- Application Model Developer
- Model User
- Resource Manager
- Policy Maker

Complex Detail

Condensed Analysis

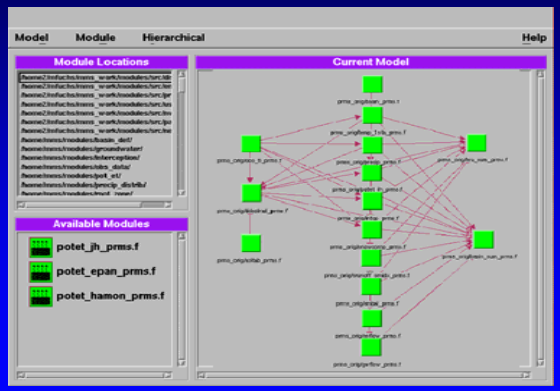
LEVELS OF MMS MODULAR DESIGN

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

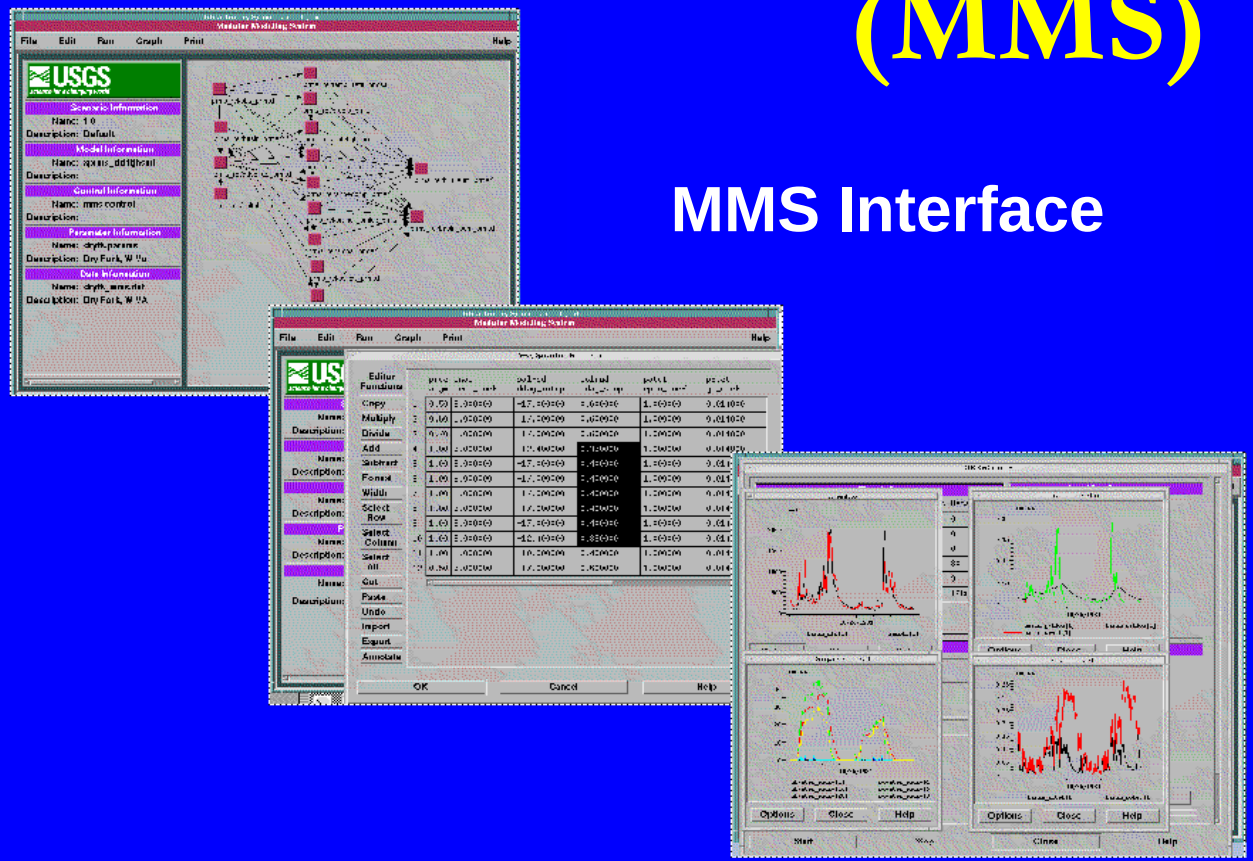


MODULAR MODELING SYSTEM (MMS)

Model Builder

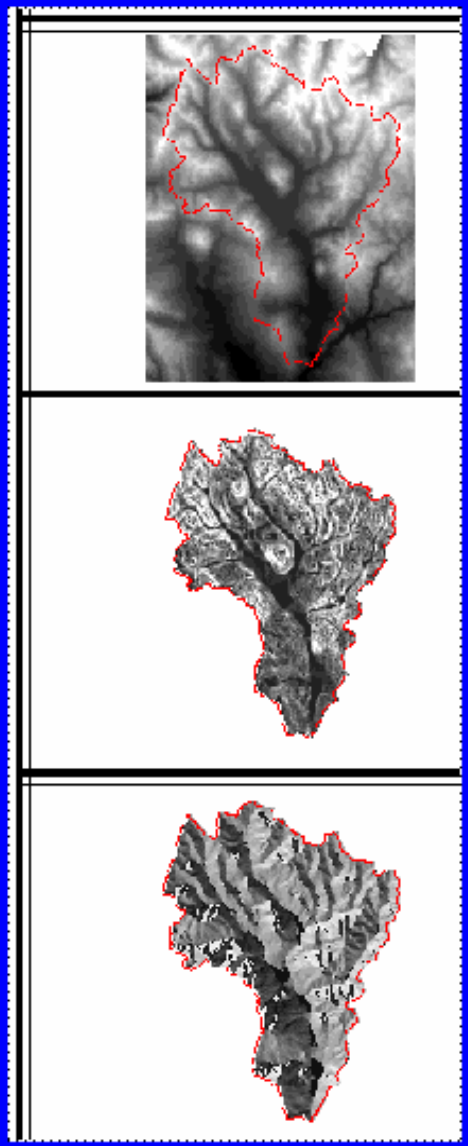


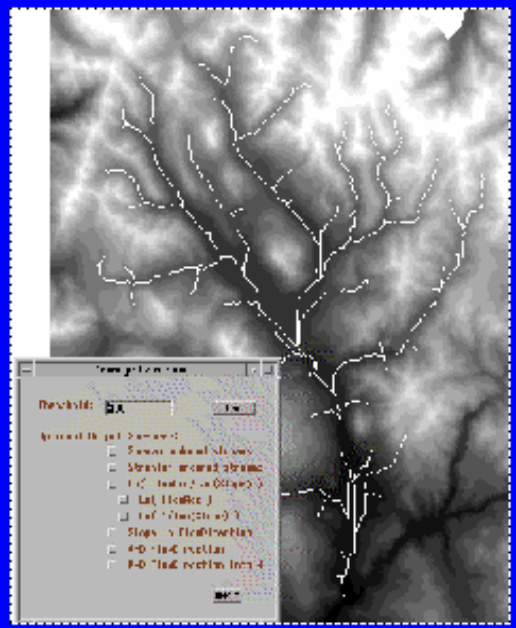
MMS Interface

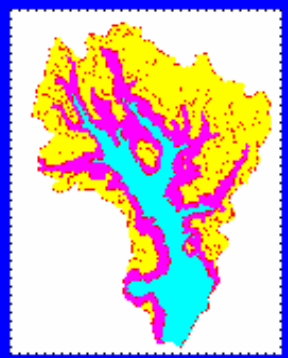


GIS WEASEL

Delineate, Characterize, and Parameterize Spatial Features

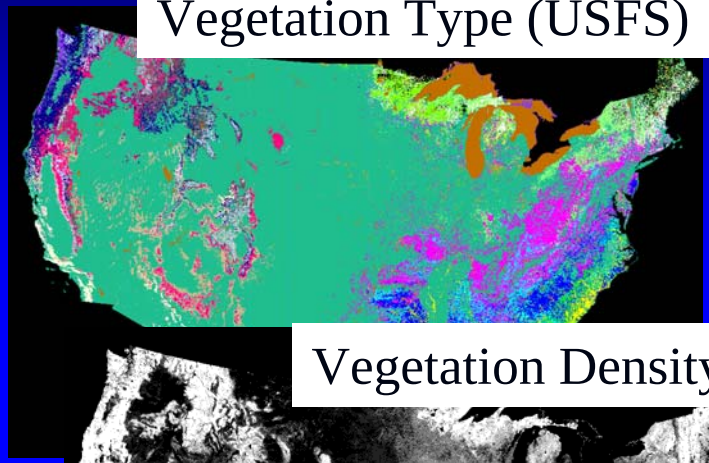




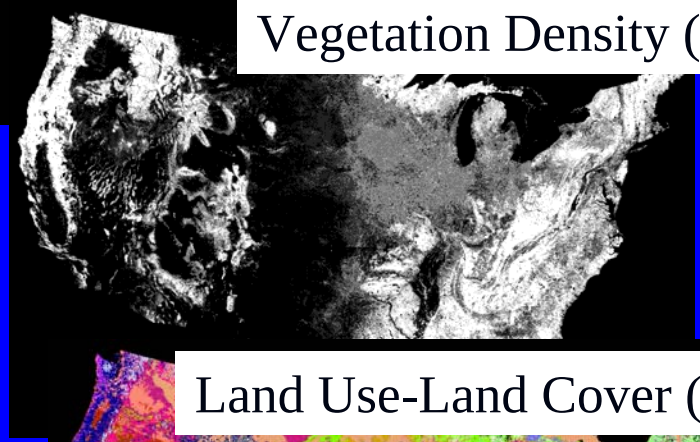


DIGITAL DATABASES

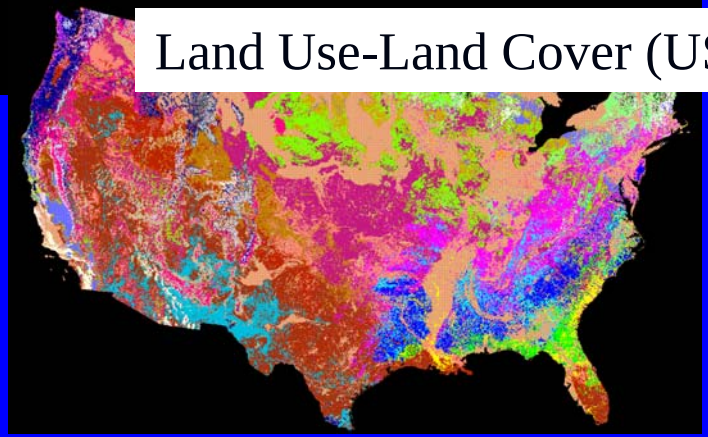
Vegetation Type (USFS)



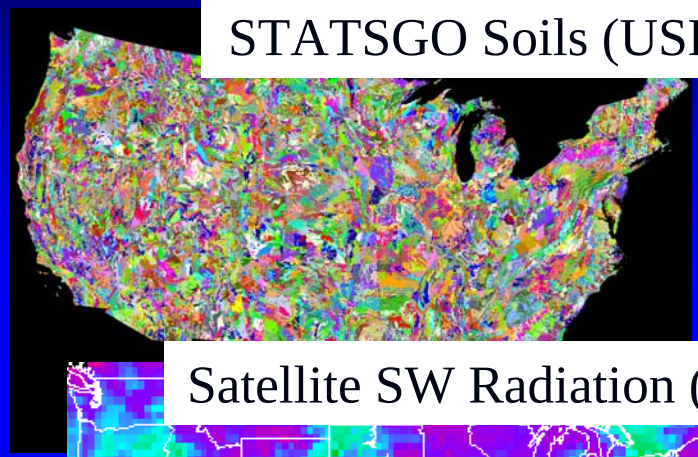
Vegetation Density (USFS)



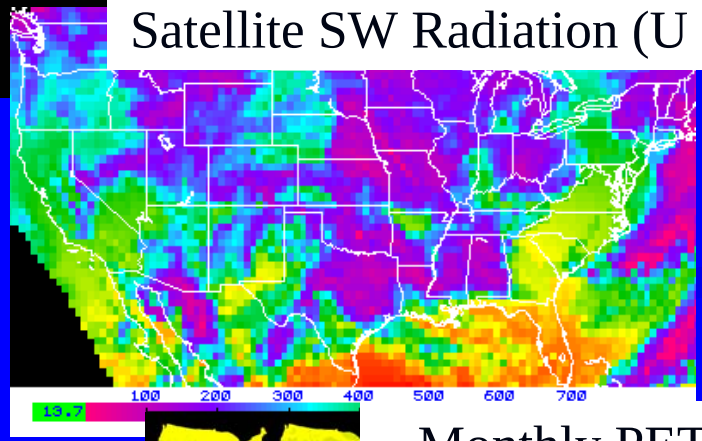
Land Use-Land Cover (USGS)



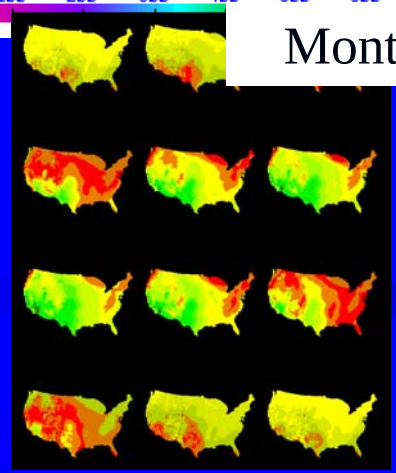
STATSGO Soils (USDA)



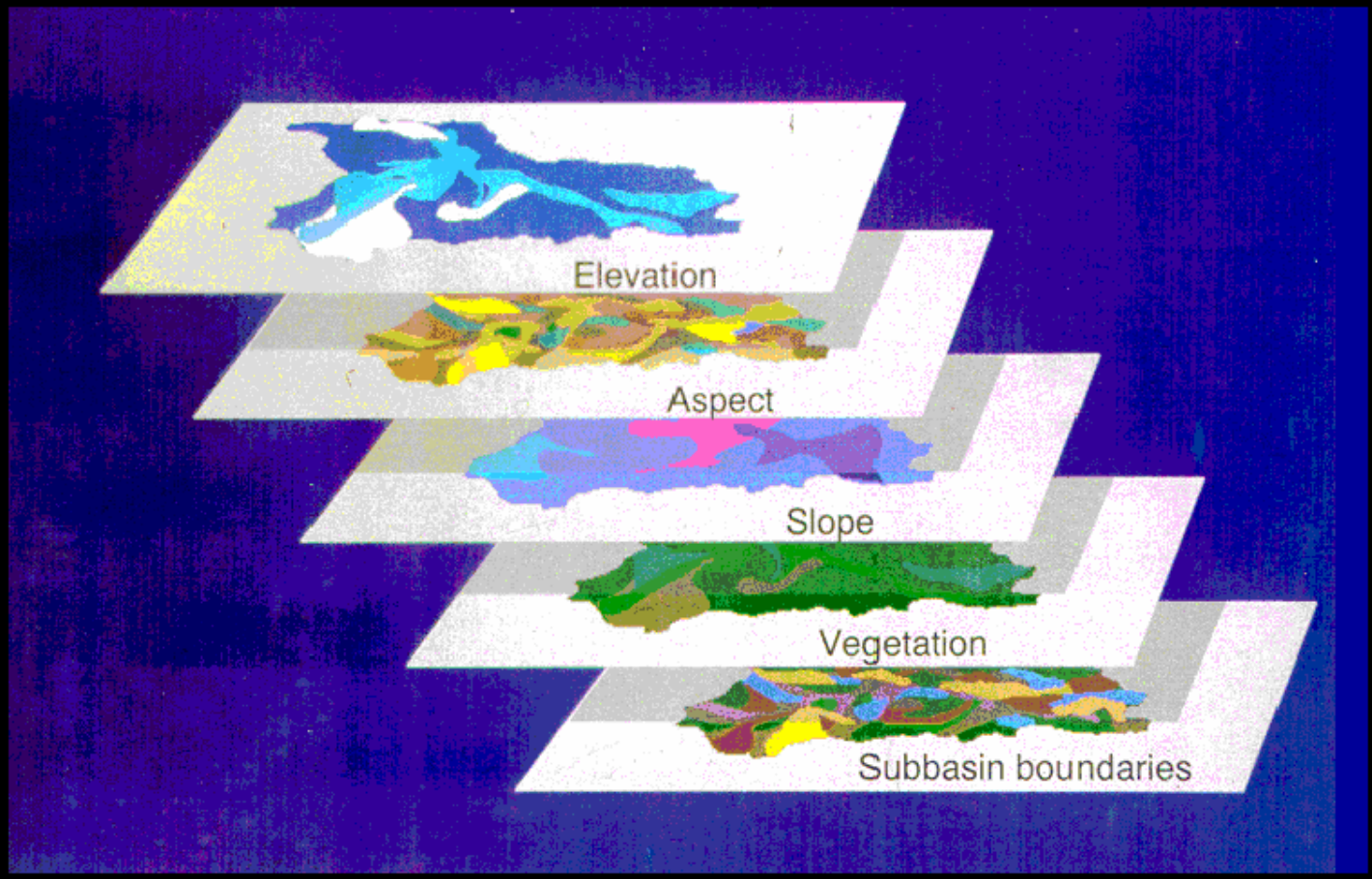
Satellite SW Radiation (U Md)



Monthly PET

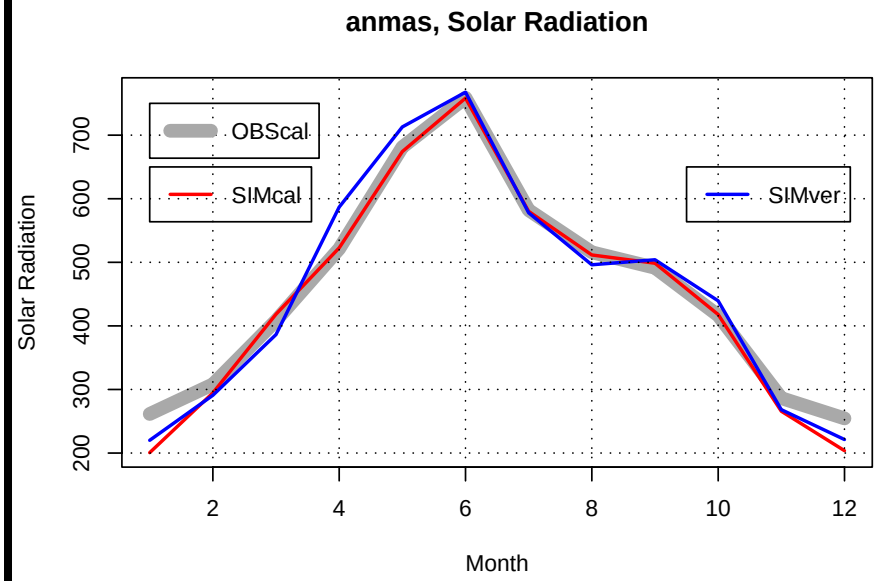


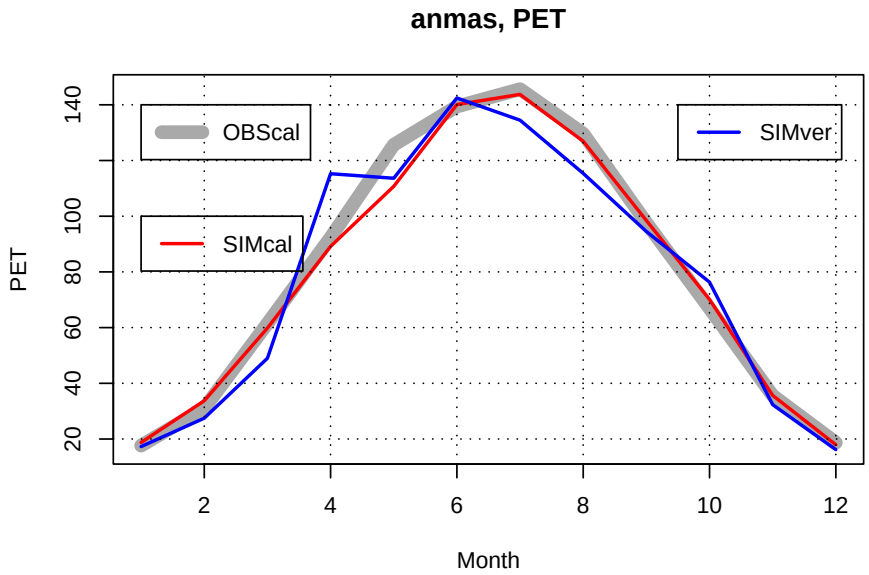
AUTOMATED PARAMETER ESTIMATION USING THE GIS WEASEL



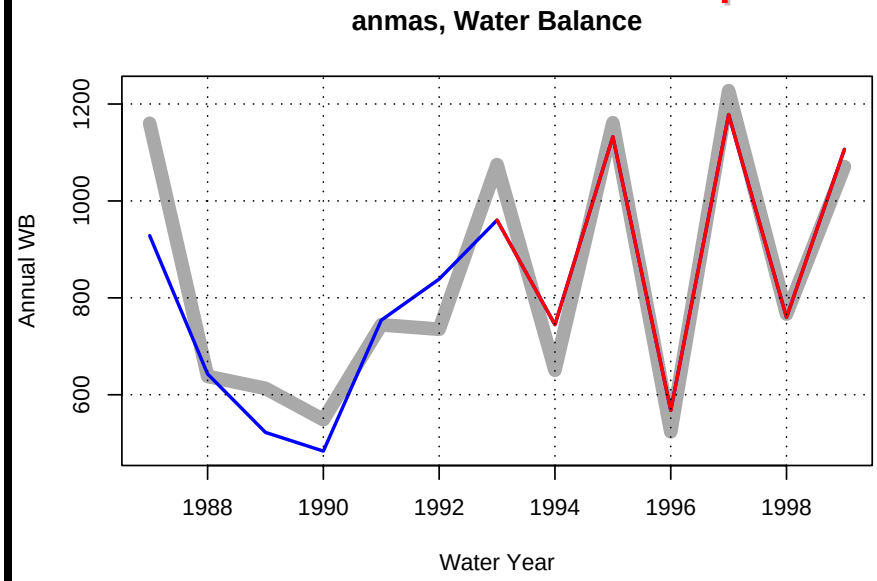
Multi-step Calibration

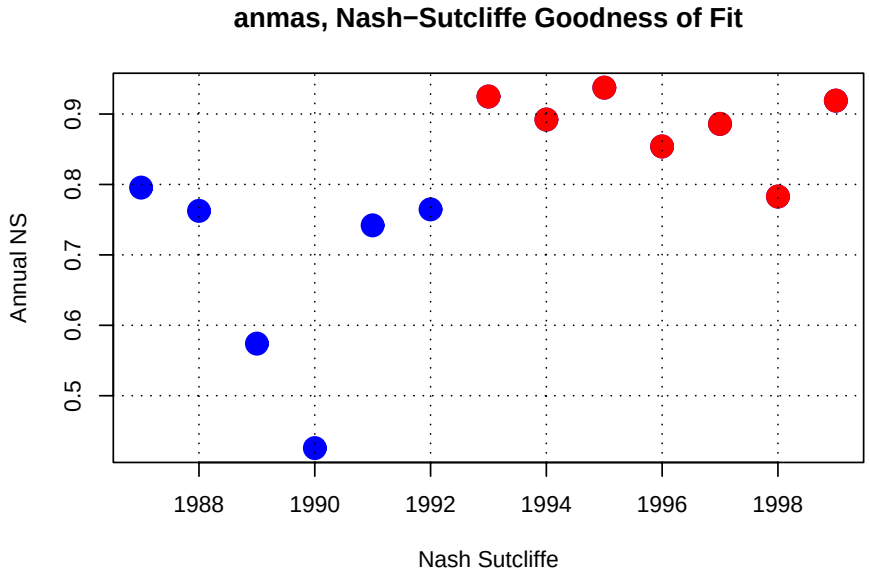
Step	Calibration data set associated with PRMS state	PRMS parameters sensitive to model state	Parameter Description
1	Mean monthly Solar Radiation	dday_intcp	Intercept in temperature degree-day relationship
		dday_slope	Slope in temperature degree-day relationship
		tmax_index	Index temperature used to determine precipitation adjustments to solar radiation
2	Mean monthly PET	jh_coef	Air temperature coefficient used in Jensen-Haise PET computations
3	Annual water balance	adjust_rain	Precipitation adjust factor for rain days
		adjust_snow	Precipitation adjust factor for snow days
		psta_nuse	Binary indicator for using station in precipitation distribution calculations
		psta_freq_nuse	Binary indicator for using station in precipitation frequency calculations
4	Daily flow components: 1. peak flows 2. low flows 3. all daily flows	adjmix_rain	Factor to adjust rain proportion in mixed rain/snow event
		tmax_allrain	If HRU maximum temperature exceed this value, precipitation assumed rain
		tmax_allsnow	If HRU maximum temperature is below this value, precipitation assumed snow
		tsta_nuse	Binary indicator for using station in temperature distribution calculations
		cecn_coef	Convection condensation energy coefficient
		emis_noppt	Emissivity of air on days without precipitation
		freeh2o_cap	Free-water holding capacity of snowpack
		potet_sublim	Proportion of PET that is sublimated from snow surface
		smidx_coef	Coefficient in non-linear contributing area algorithm
		smidx_exp	Exponent in non-linear contribution area algorithm
		gwflow_coef	Groundwater routing coefficient
		ssrcoef_sq	Coefficient to route subsurface storage to streamflow
		soil2gw_max	Maximum amount of soil water excess
		soil_moist_max	Maximum available water holding capacity of soil profile
		soil_rechr_max	Maximum value for soil recharge zone



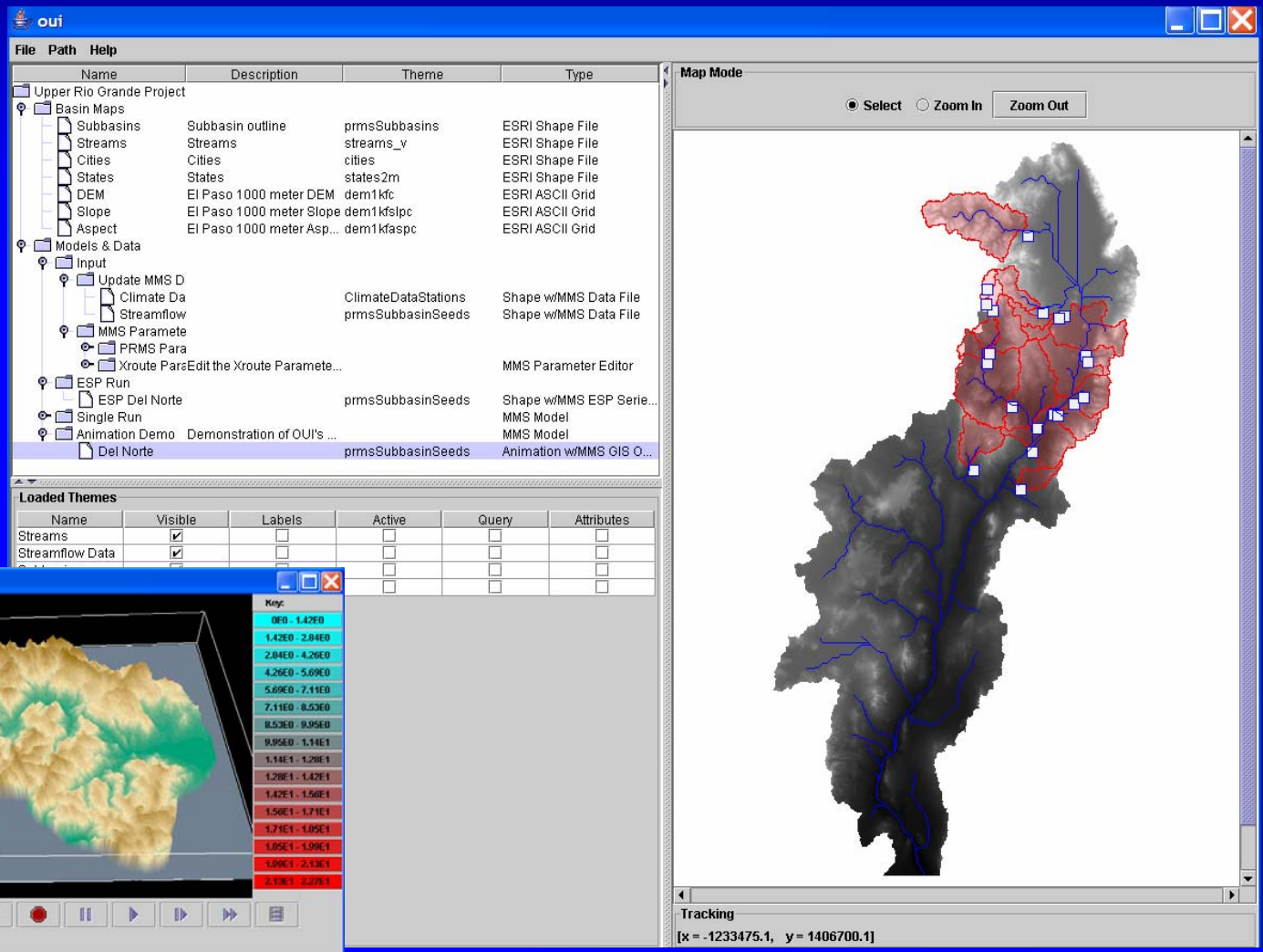


Multi-step calibration visualization





OBJECT USER INTEFACE (OUI)



Watershed and River Systems Management Program

Recreation

Municipal & Industrial

Irrigation

Hydropower

Research and development of decision support systems and their application to achieve an equitable balance among water resource issues.

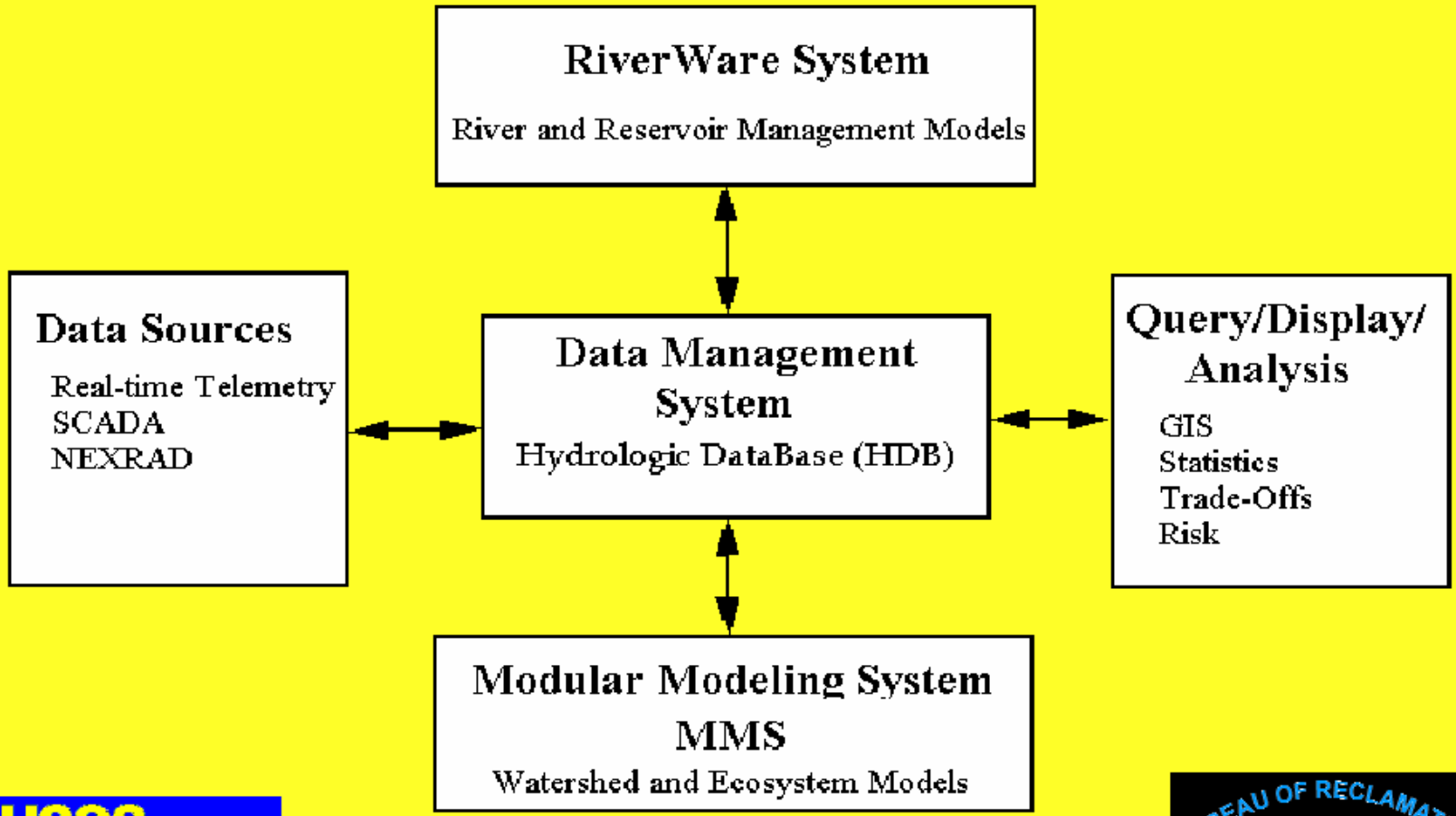
Riparian Habitat

Endangered Species

USGS science for a changing world

U. S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Database-Centered Decision Support System



USGS science for a changing world

BUREAU OF RECLAMATION

Upper Gunnison DSS

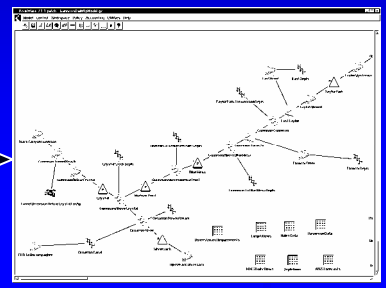
Hydromet

Real-time climate data feed

DMI

Hydrologic Database

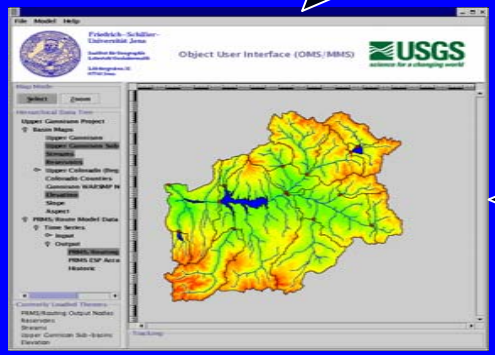
DMI



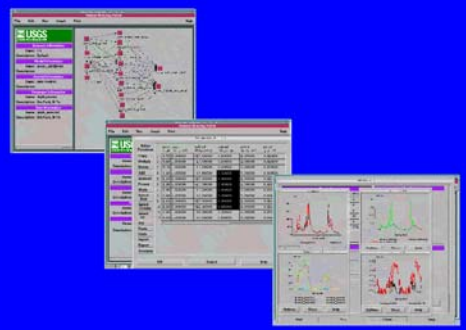
RiverWare

Reservoir and River System Operations Model

DMI



MMI



Object User Interface

Interface for data visualization and modeling

Modular Modeling System

Physical Process Models

Generic DSS Framework for a Wide Range of Management Issues

Climate Data Source

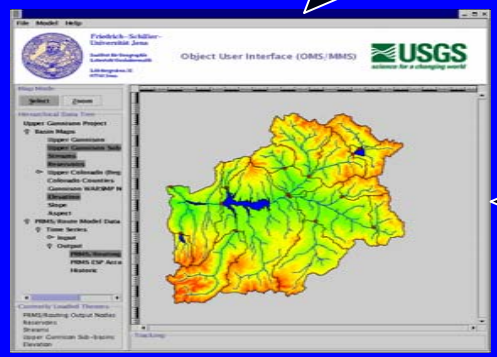
DMI

Any Database

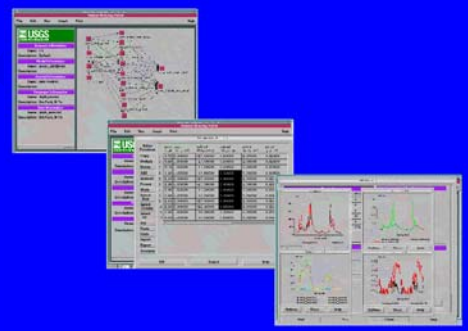
DMI

Any Resource Management Model

DMI



MMI



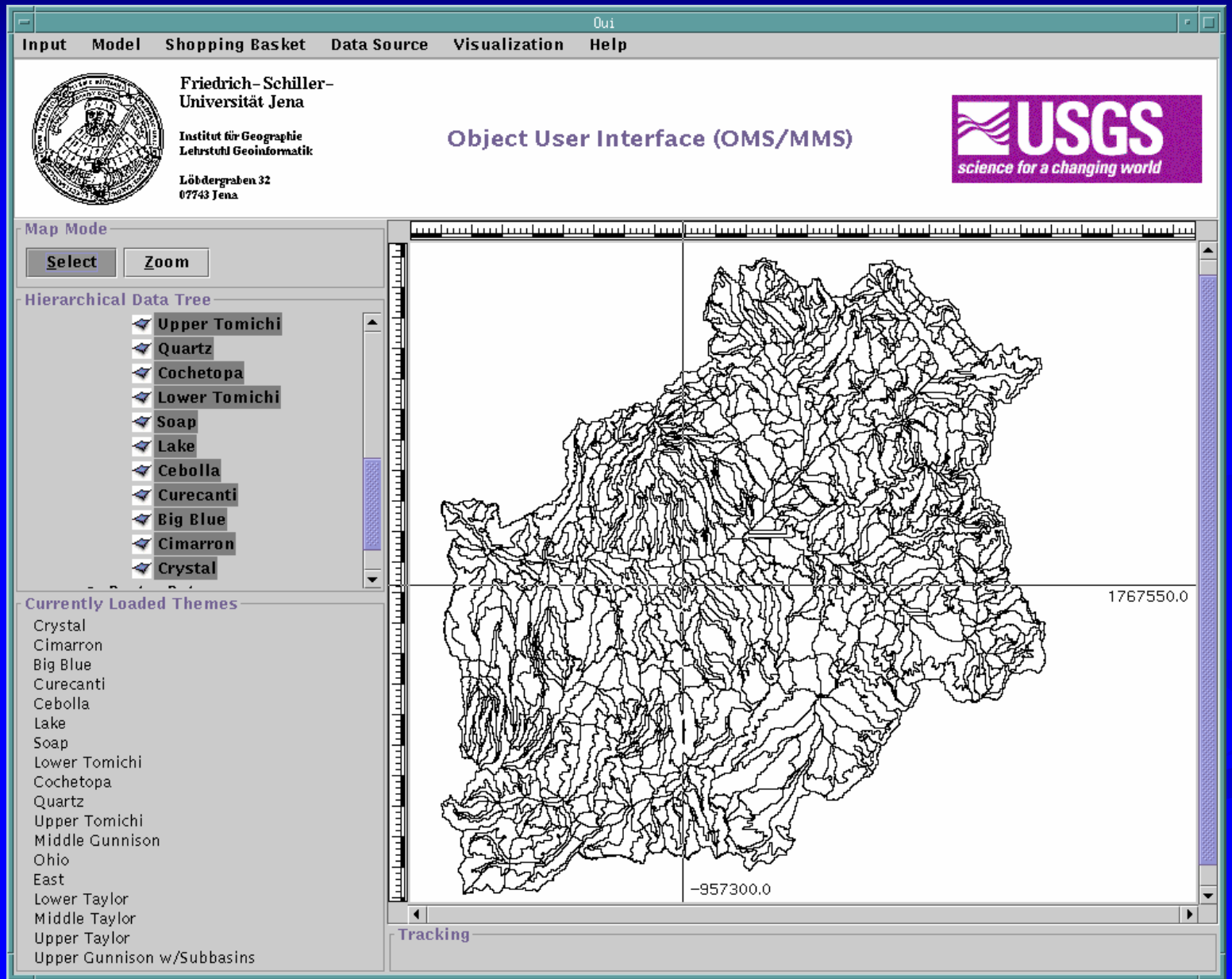
Object User Interface

Interface for data visualization and modeling

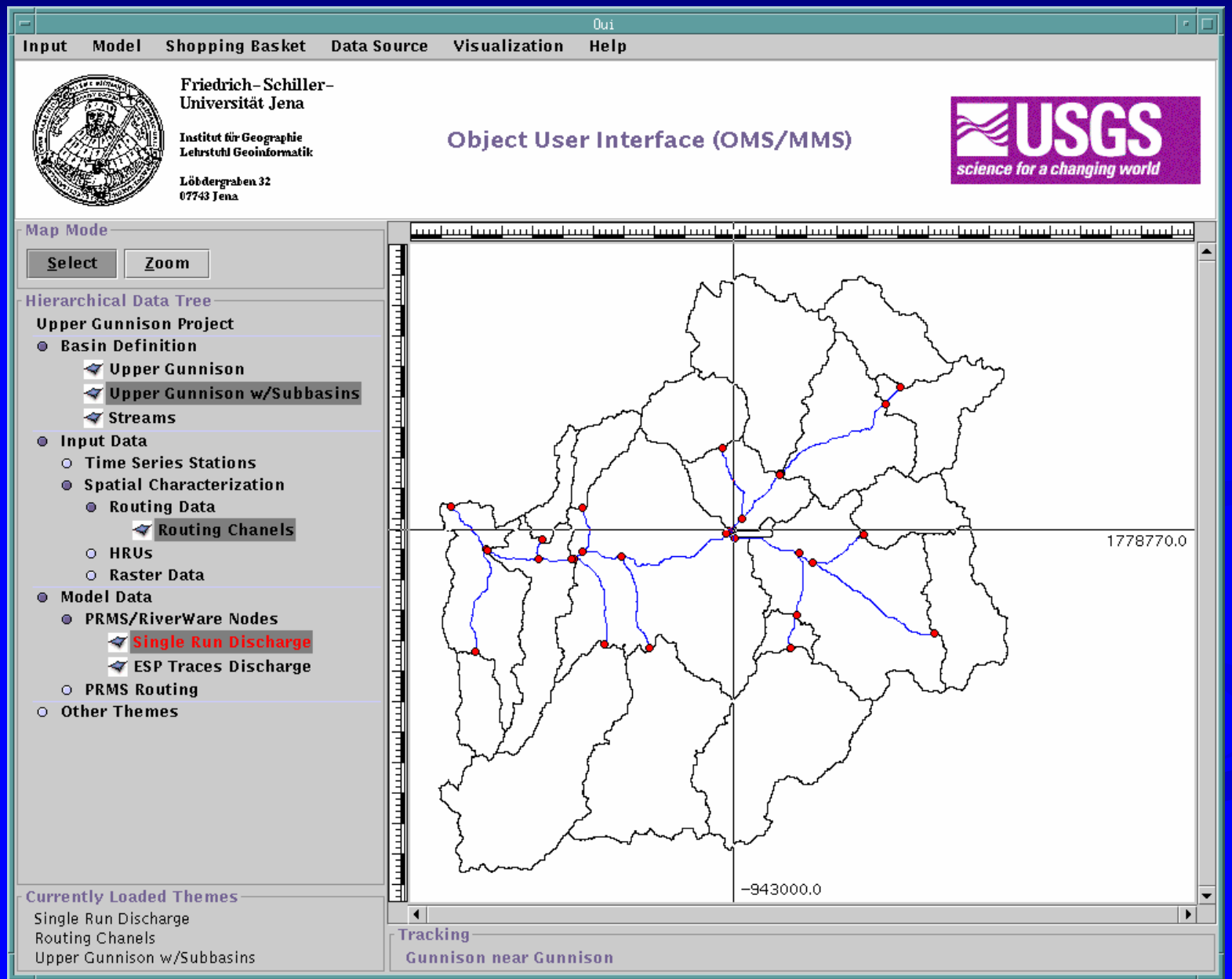
Modular Modeling System

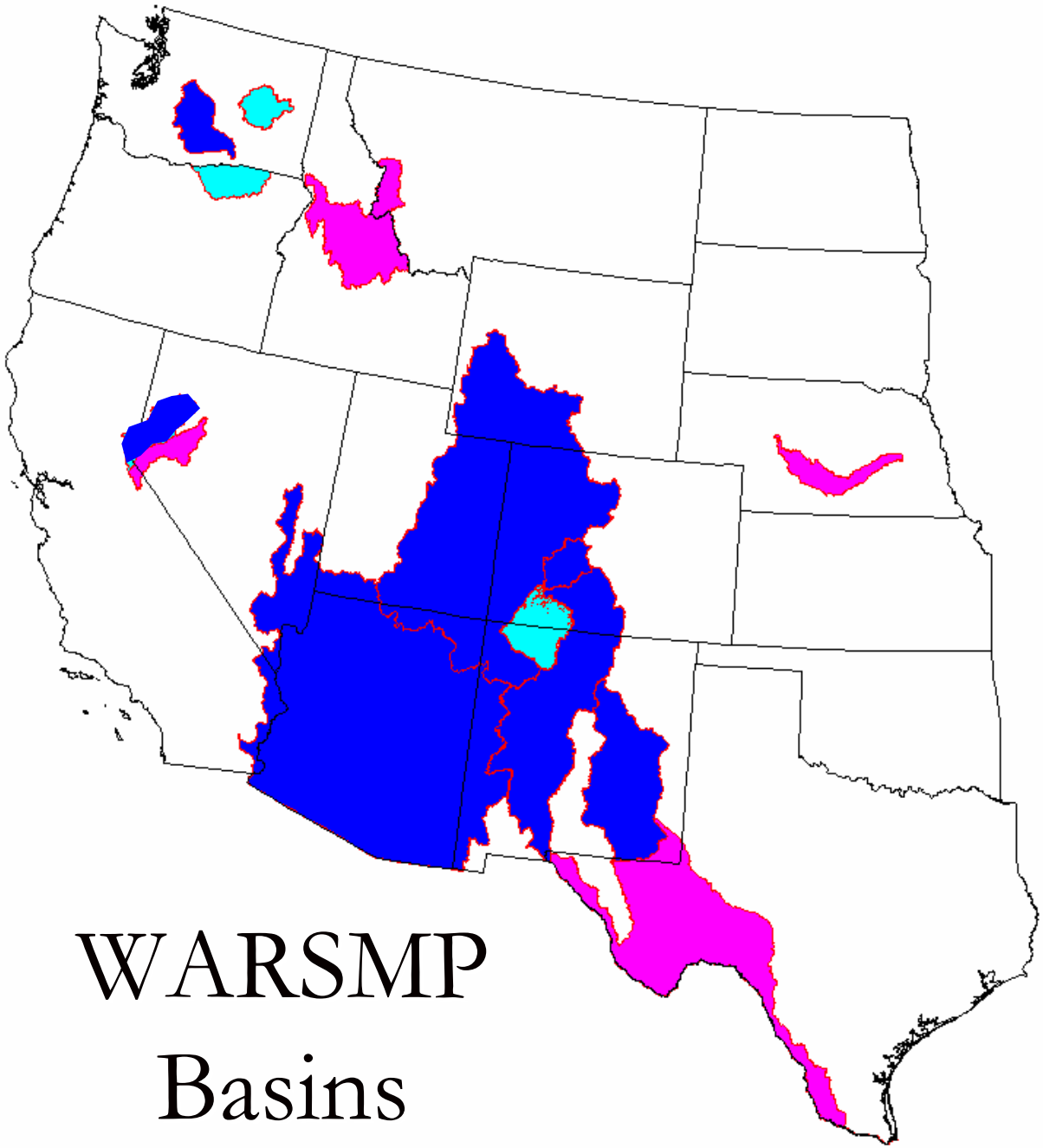
Physical Process Models

HYDROLOGIC RESPONSE UNITS



MODELED SUBBASINS AND FORECAST NODES





WARSMP Basins

Currently Active

Gunnison, Truckee, Upper Rio Grande, Yakima

Under Development

San Juan, Umatilla, Upper Columbia

Future

Bitterroot, Carson, Central Platte, Lower Rio Grande, Salmon

Integrating Water-Resource and Socio-Economic Models

- **Population and Demand Forecasts**
- **Water Markets**
  - (change in ownership in perpetuity)
- **Water Banking**
  - (lease options over some period of time)

Issue: The better the prediction of the spatial and temporal distribution of water, the better the markets can perform.

Being done collaboratively with U. of Arizona, U. of New Mexico, Desert Research Institute

Adding Water Banking to a Water Resources Decision-Support System

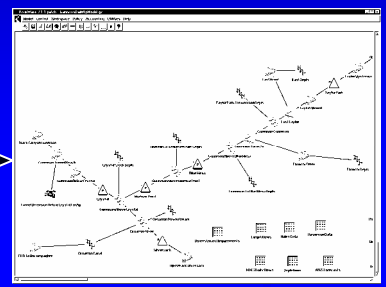
Hydromet

Real-time climate data feed

DMI

Hydrologic Database

DMI



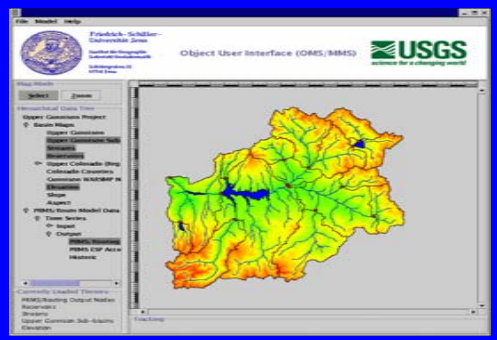
RiverWare

Reservoir and River System Operations Model

DMI

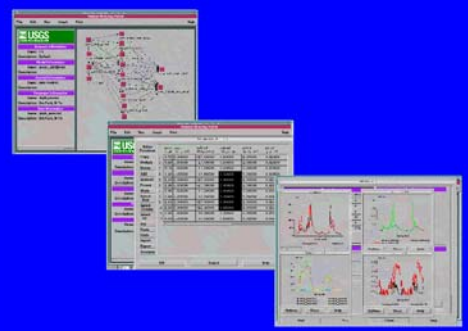
DMIs

DMI



Object User Interface

Interface for data visualization and modeling

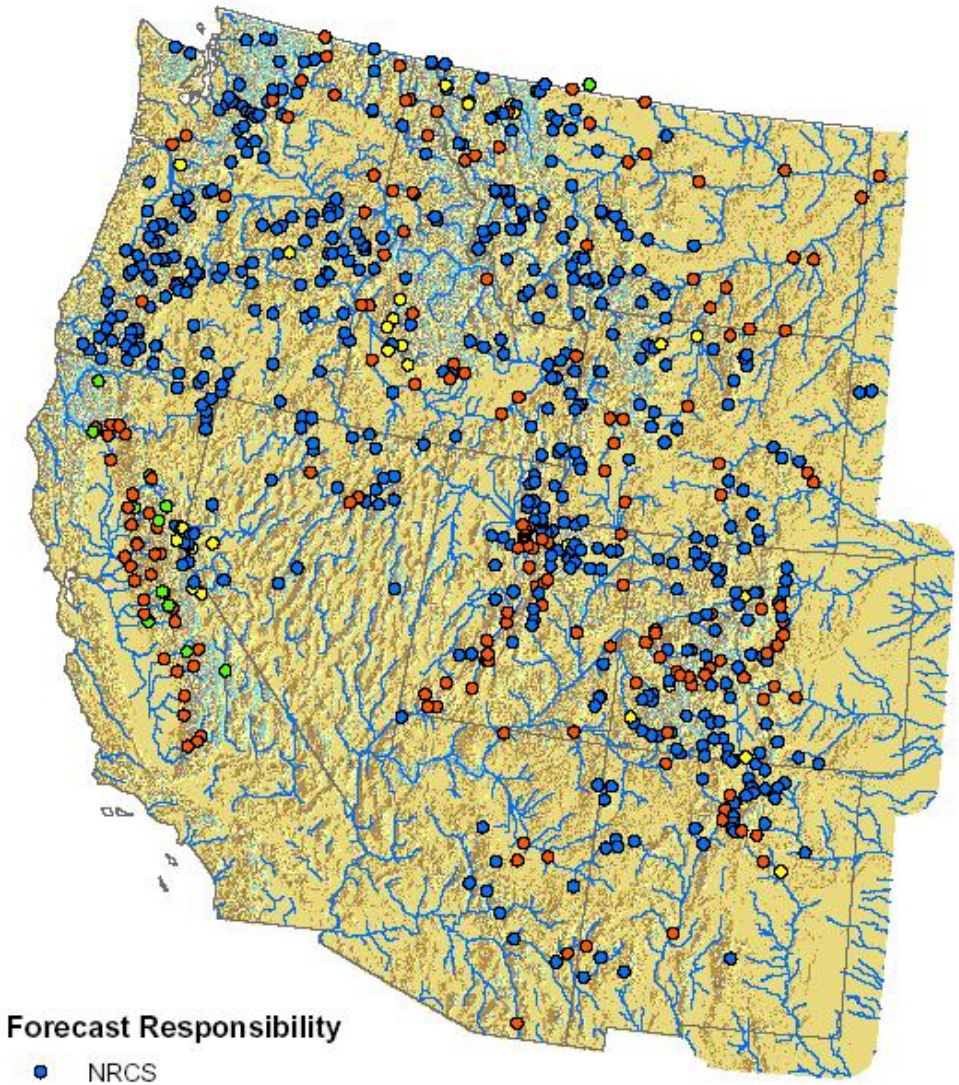


Modular Modeling System

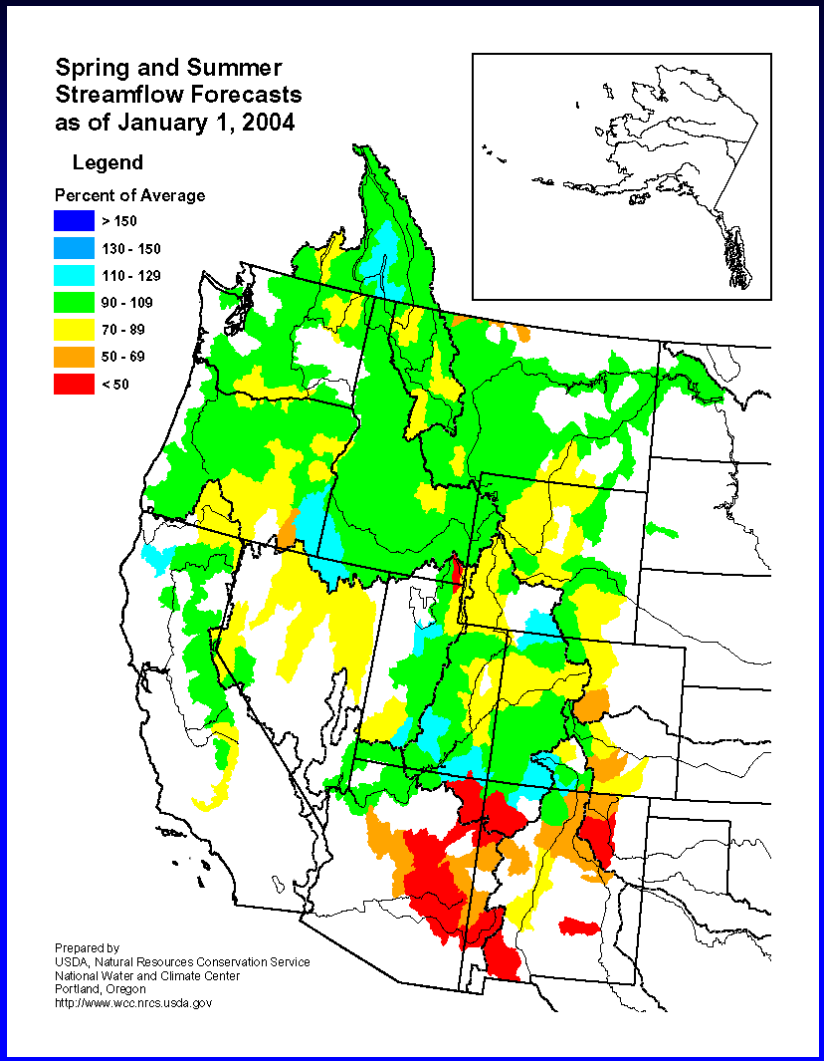
Precipitation/Runoff Model (PRMS)

Water Banking

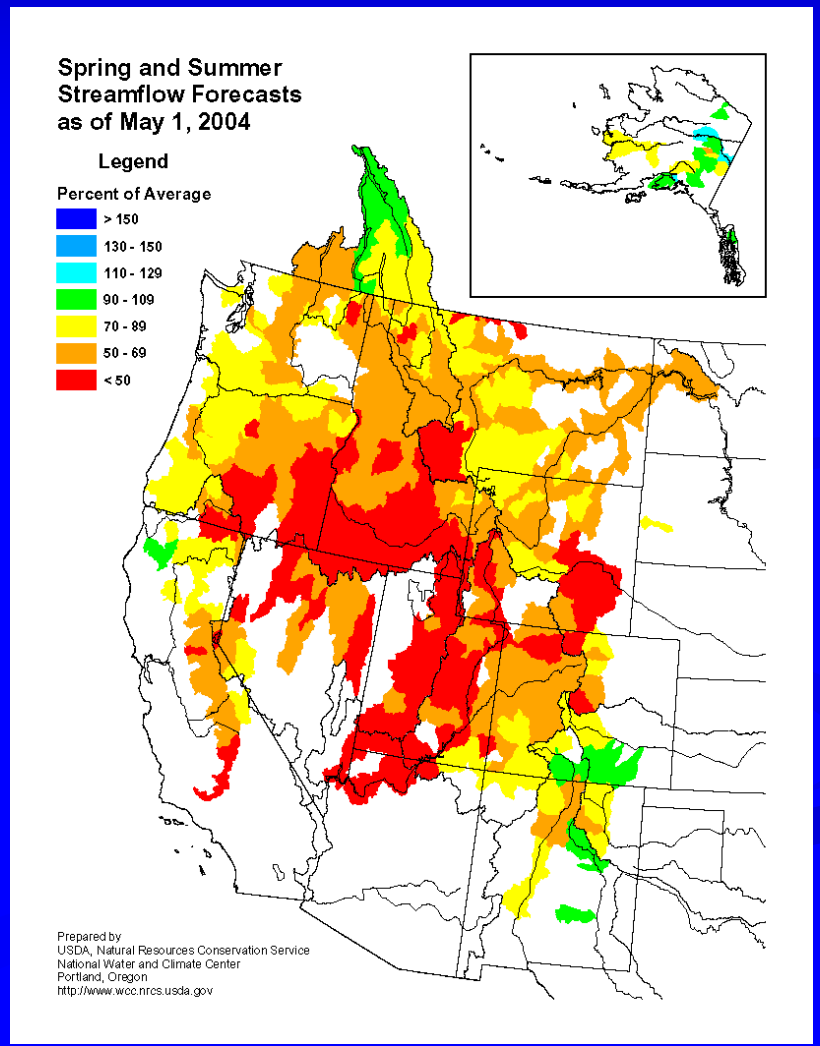
Seasonal Water Supply Forecast Points and Agency Responsibility

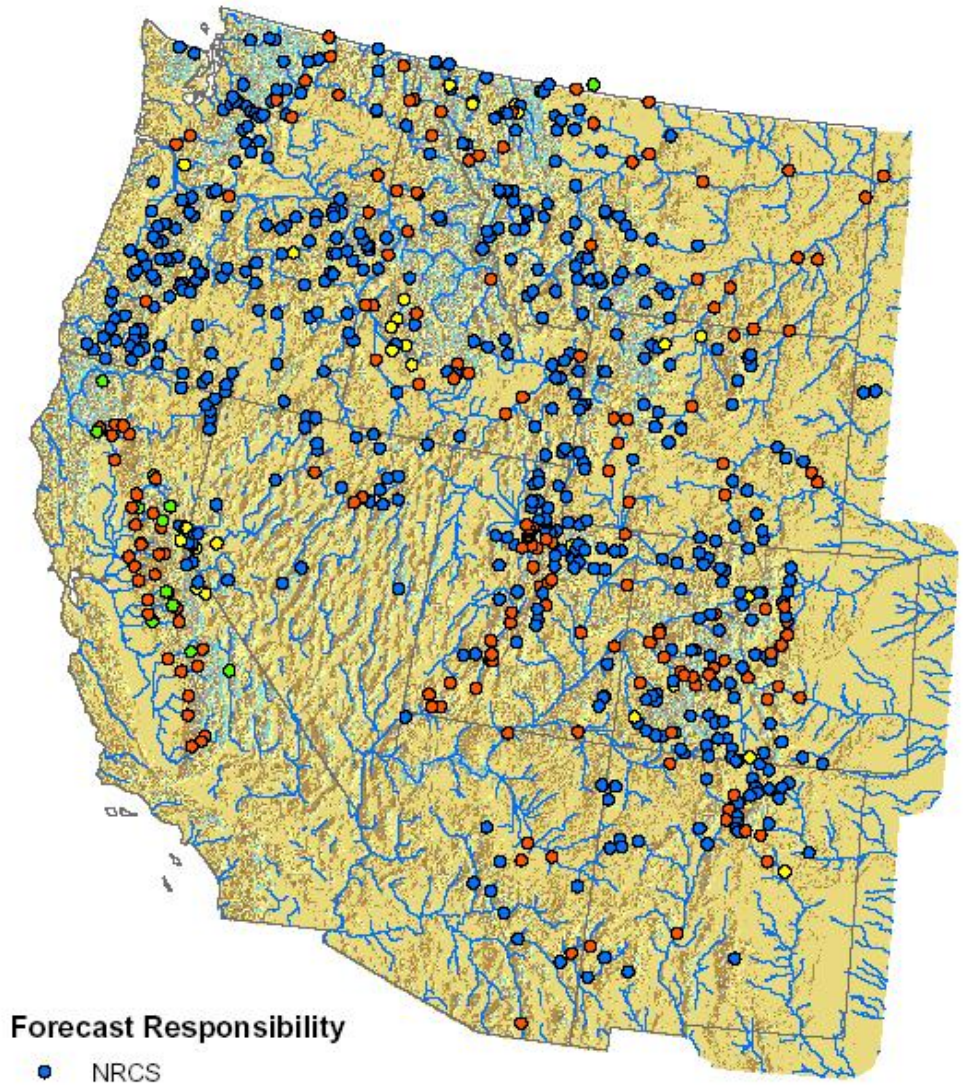


Monthly Product Beginning in January

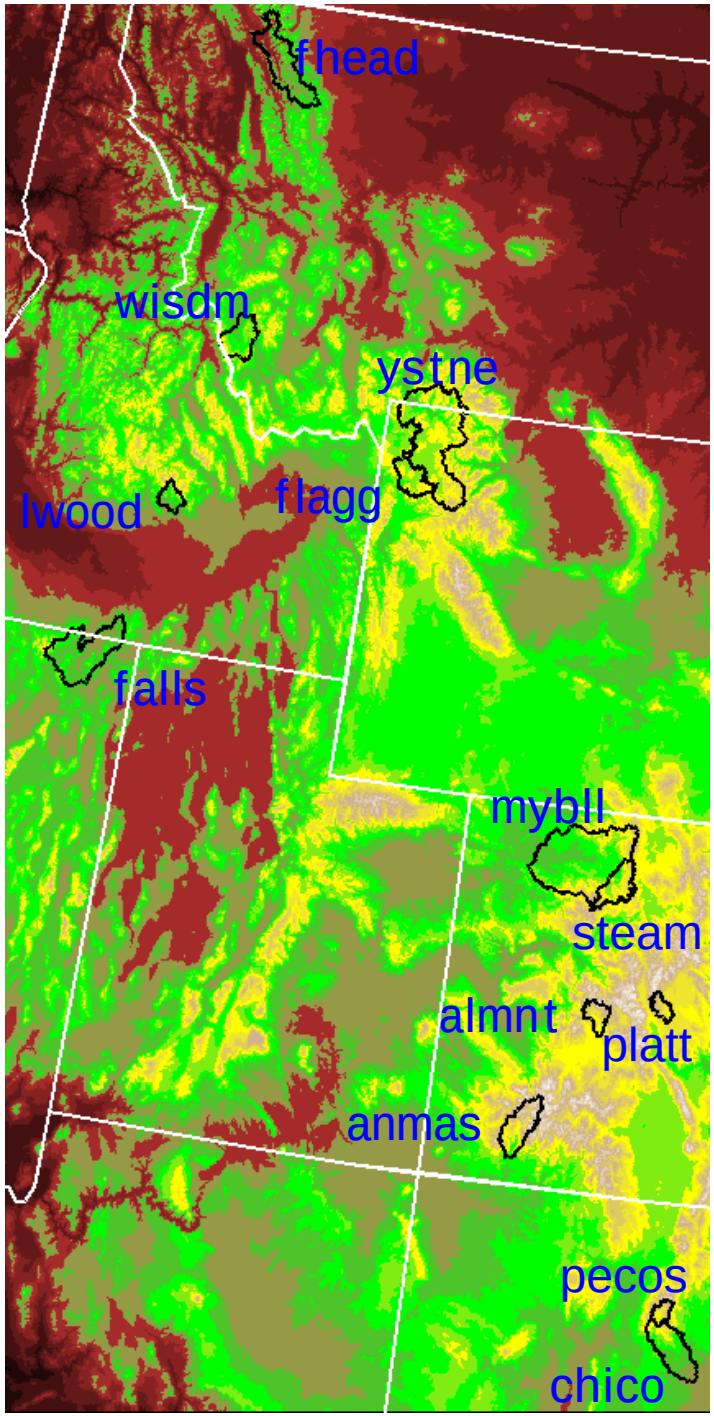


Combined product of NRCS and National Weather Service Forecasts





Working with the NRCS to develop a Modular Modeling System forecasting toolbox using MMS



NRCS Basins

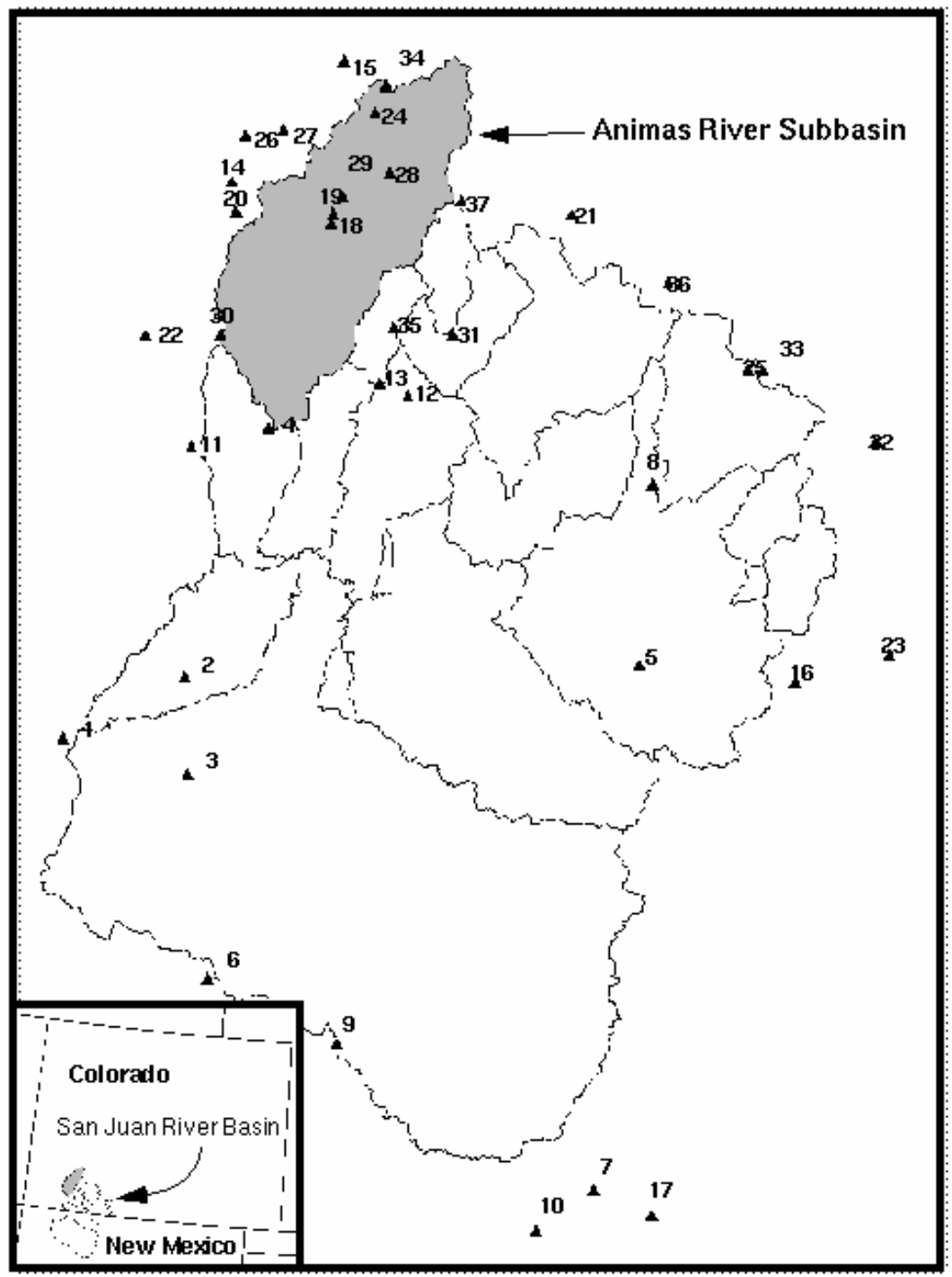
Basin Name	5-letter abbrev
★ Animas Durango	anmas
★ East Almont	almnt
Pecos Anton Chico	chico
Pecos Pecos	pecos
★ Yampa Maybell	mybll
★ Yampa Steamboat	steam
Big Hole Wisdom	wisdm
Flagg Ranch	flagg
Little Wood	lwood
Mf Flathead	fhead
Salmon Falls	falls
★ South Platte Antero	platt
Yellowstone Corwin	ystne

OUI DEMO

Integrated Tools to Improve Water Supply Forecasts

- Distributing point precipitation measurements spatially and with elevation
- Improved forecasting methods
- Using remotely sensed measures of snow cover and snowpack water equivalent to update models
- Using ensembles of different hydrologic models to predict streamflow

Conducted in collaboration with NWS, NASA, NRCS, U. of Colorado, Colorado State U., U. of Arizona, Scripps Institution of Oceanography

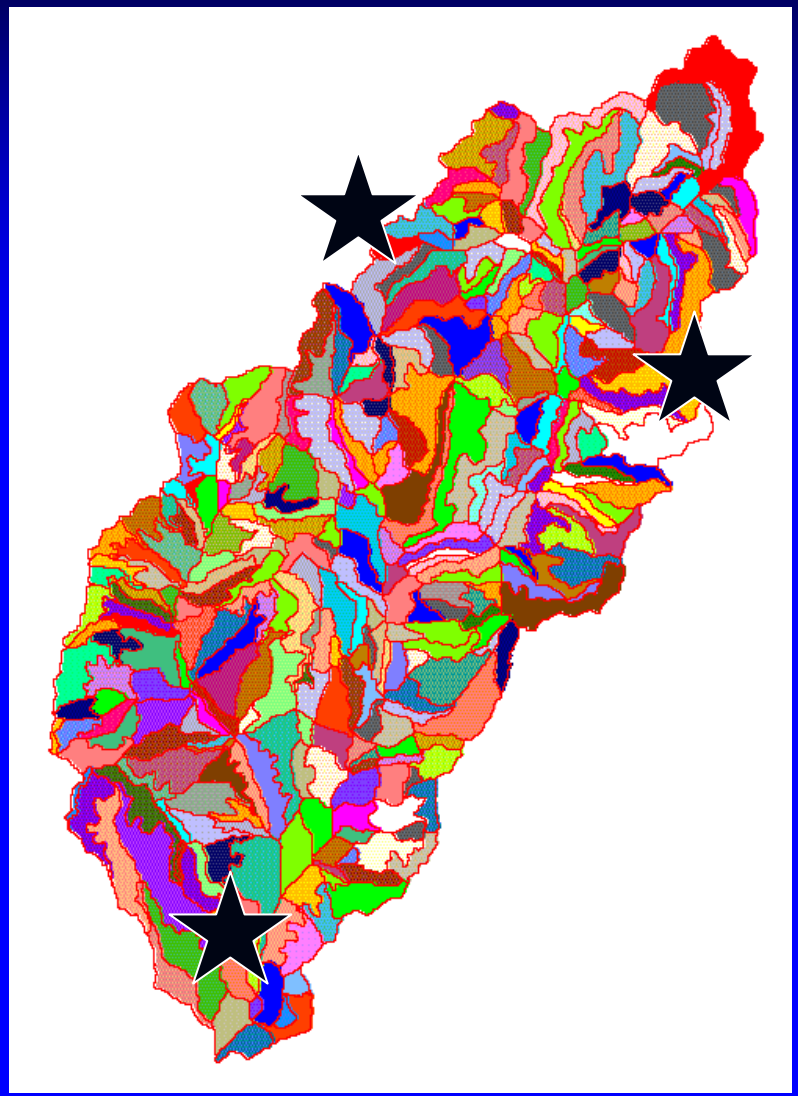


XYZ Spatial Redistribution of Precip and Temperature

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



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

Forecast Methodologies

- Historic data as analog for the future

  Multiple Linear Regression Seasonal Forecast

  Ensemble Streamflow Prediction (ESP)

-Synthetic time-series

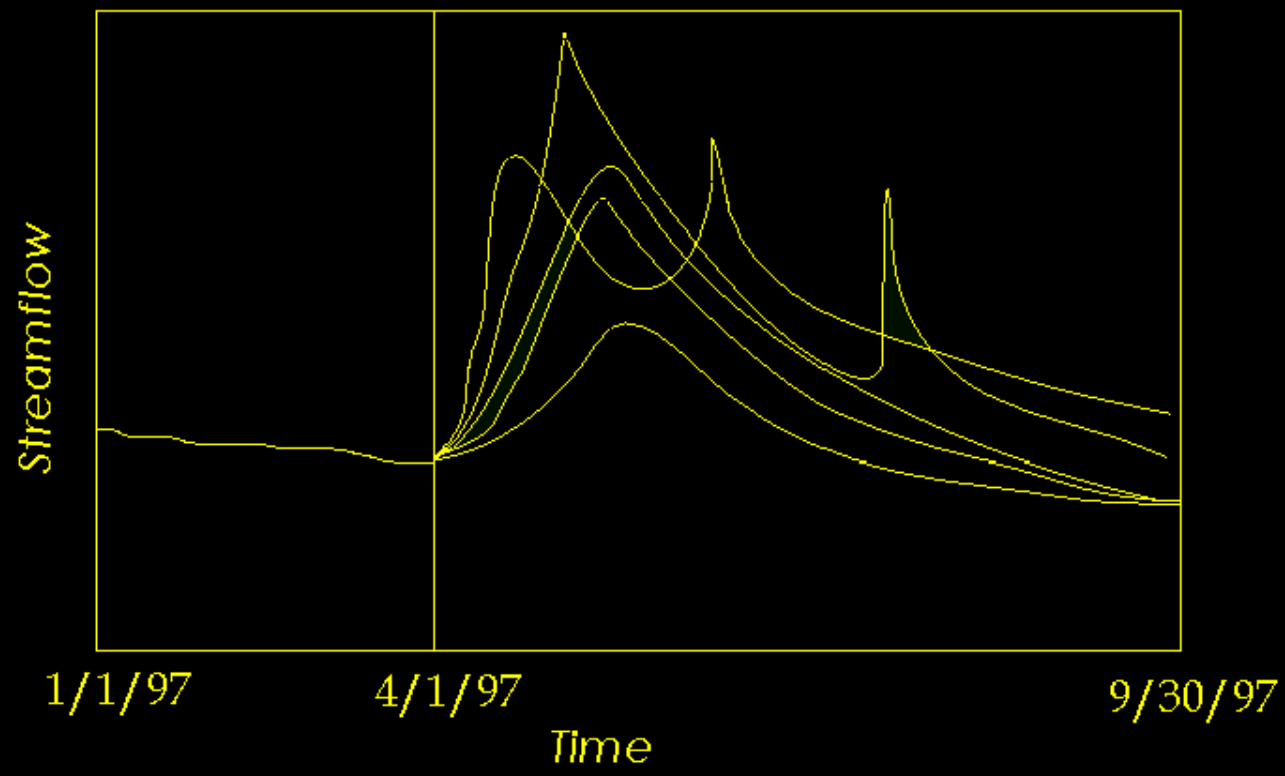
  Weather Generator

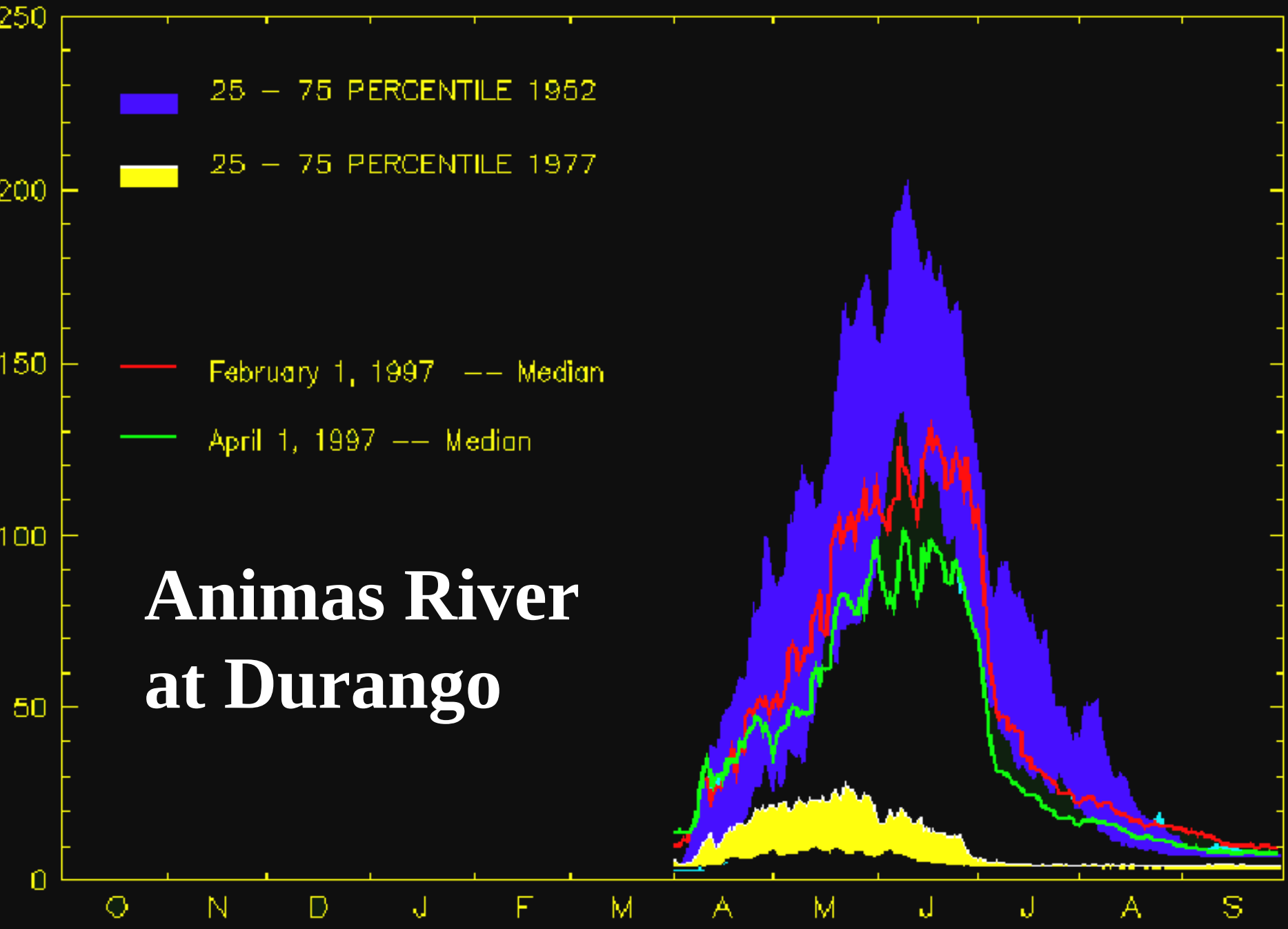
- Atmospheric model output

  Statistical Downscaling

  Dynamical Downscaling

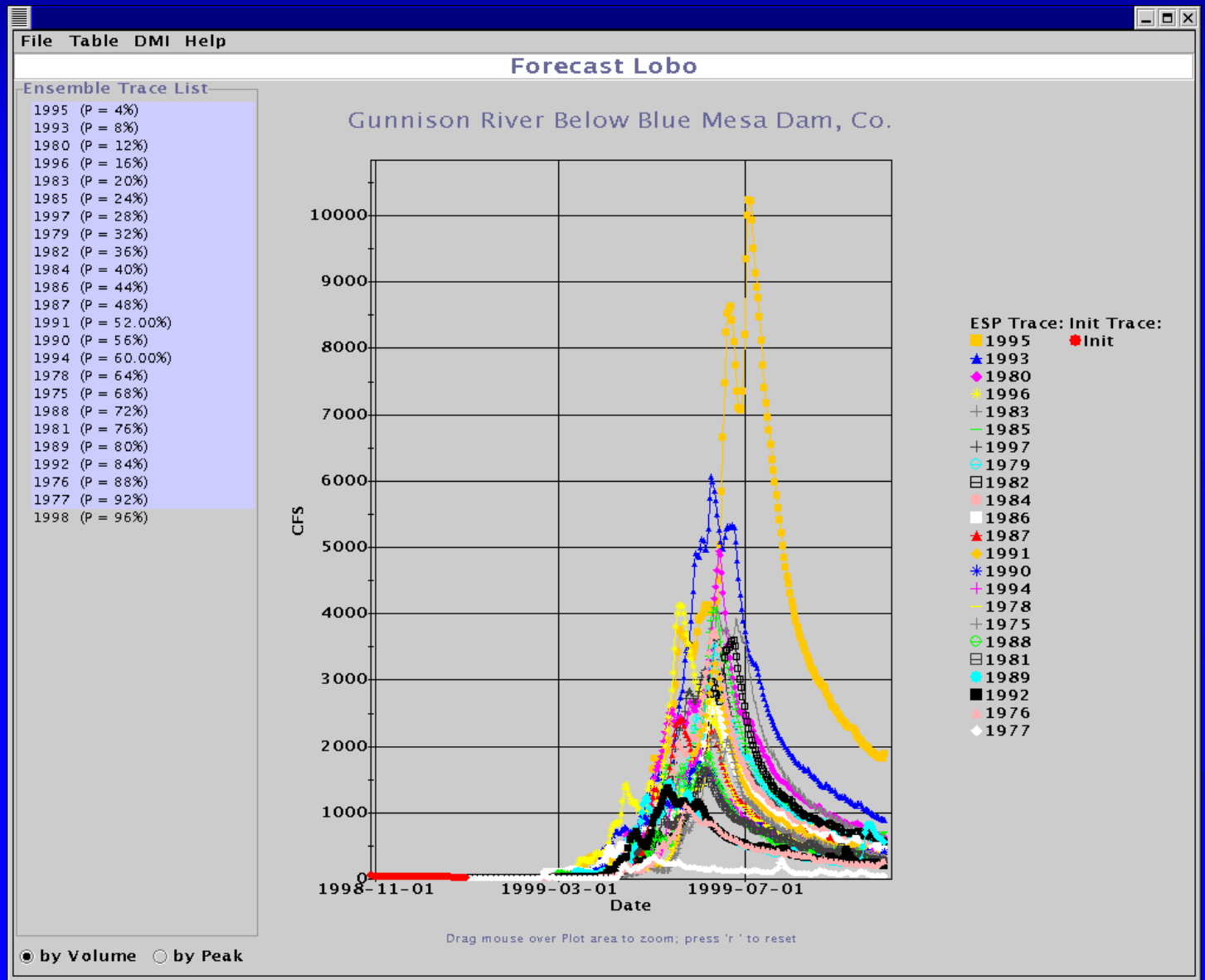
Ensemble Streamflow Prediction




250
200
150
100
50
0
25 – 75 PERCENTILE 1952
25 – 75 PERCENTILE 1977
February 1, 1997 -- Median
April 1, 1997 -- Median
Animas River
at Durango
O
N
D
J
F
M
A
M
J
J
A
S

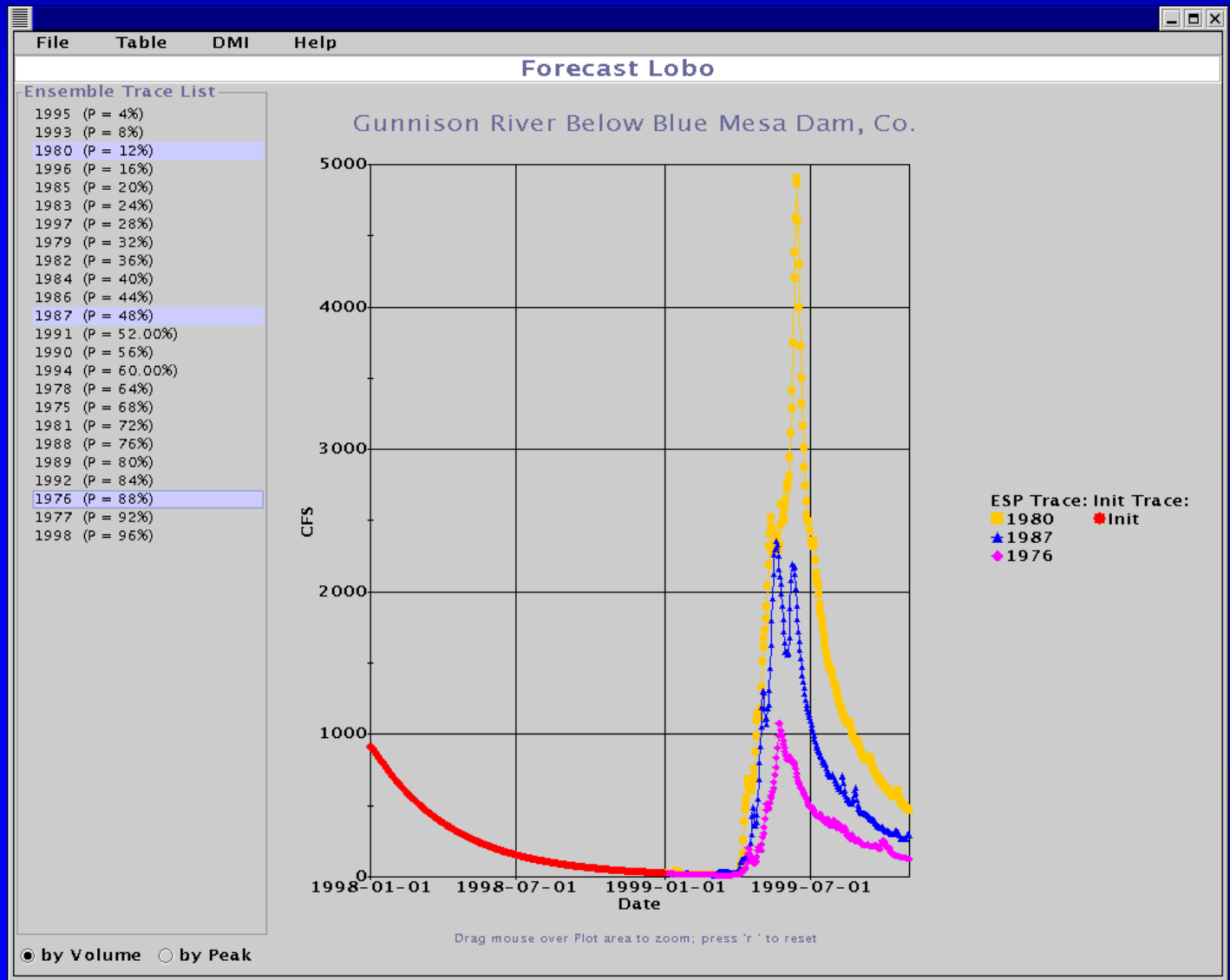
MMS ESP Tool

All Computed Traces using 1975 - 1998



MMS ESP Tool

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



Modeled Watersheds

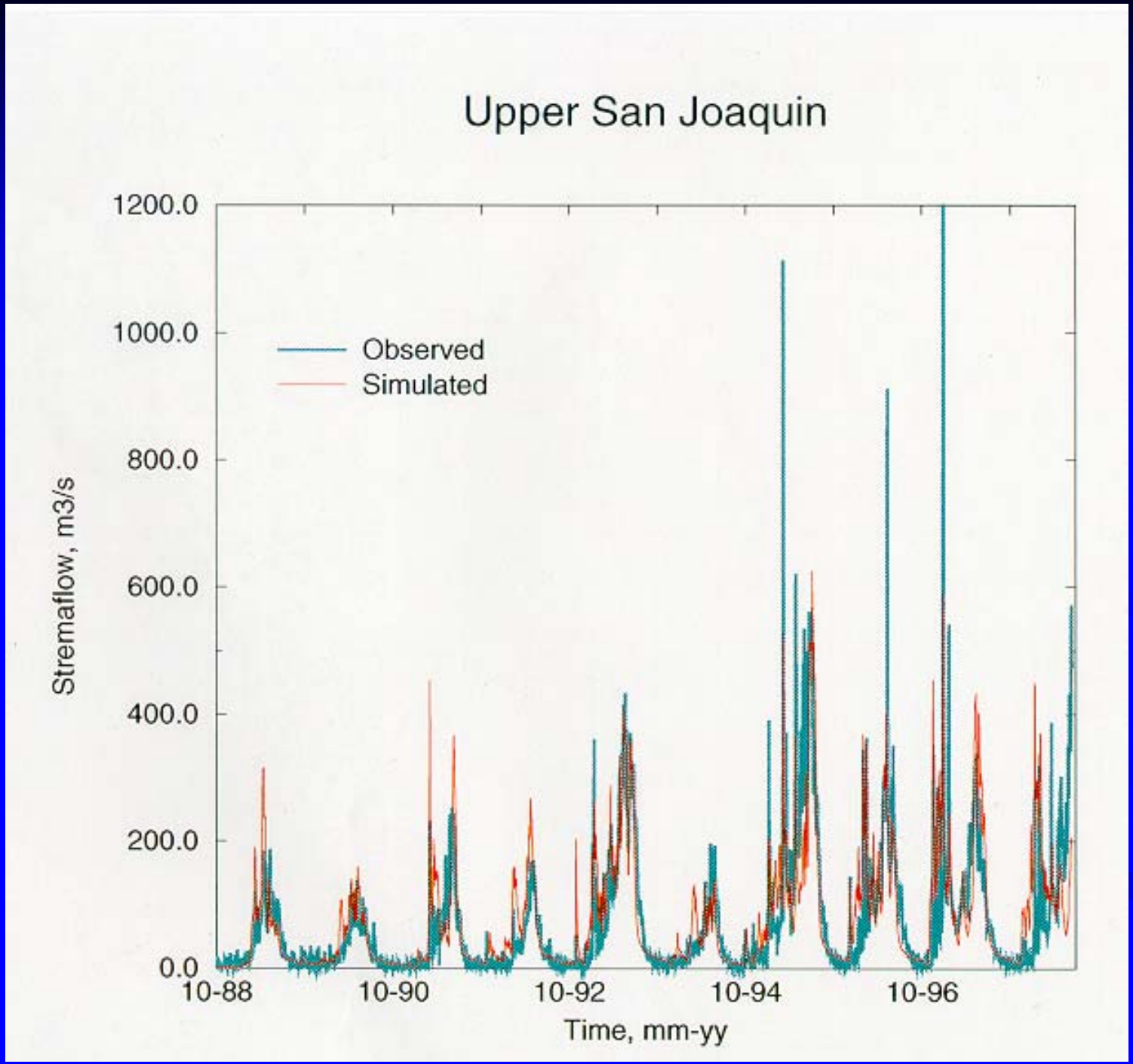
Basin Areas:

Cle Elum 526 km2

East Fork Carson 904 km2

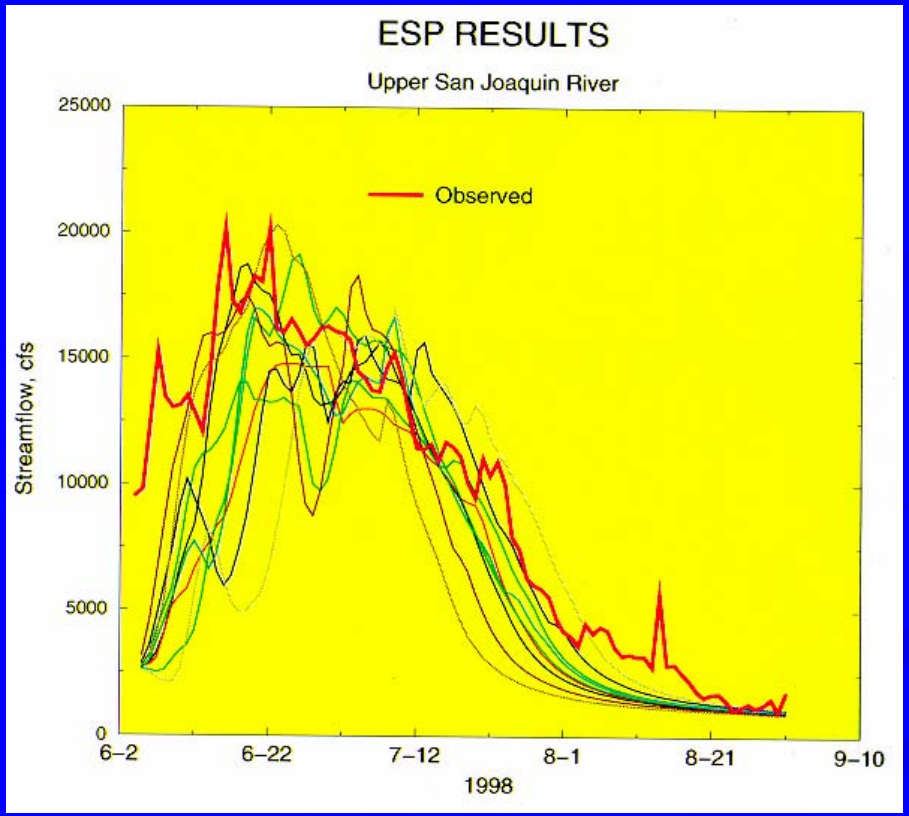
Upper San Joaquin 4,086 km2

Animas 1,805 km2


Upper San Joaquin
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
Stremaflow, m3/s
Observed
Simulated
10-88
10-90
10-92
10-94
10-96
Time, mm-yy

Ensemble Streamflow Prediction -- ESP

uses current basin conditions with historical meteorological data



Weather Generator

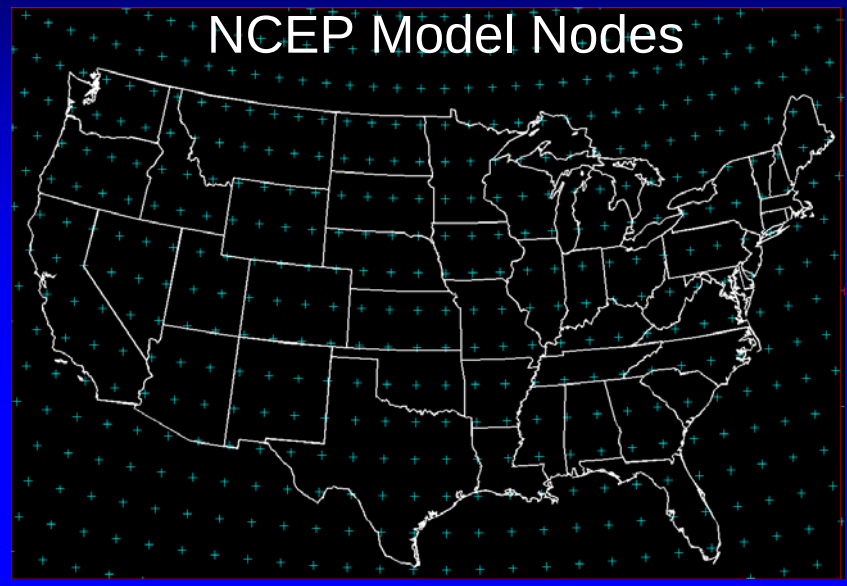
- Develop synthetic time-series of precipitation and temperature
  - Long-term planning or policy analysis
  - Climate change scenarios

Collaboratively with U. of Colorado

Statistical Downscaling Atmospheric Models

- Multiple linear regression equations developed for selected climate stations
- Predictors chosen from over 300 NCEP variables (< 8 chosen for given equation)
- Predictands are maximum and minimum temperature, precipitation occurrence, and precipitation amounts
- Stochastic modeling of the residuals in the regression equations to provide ensemble time series

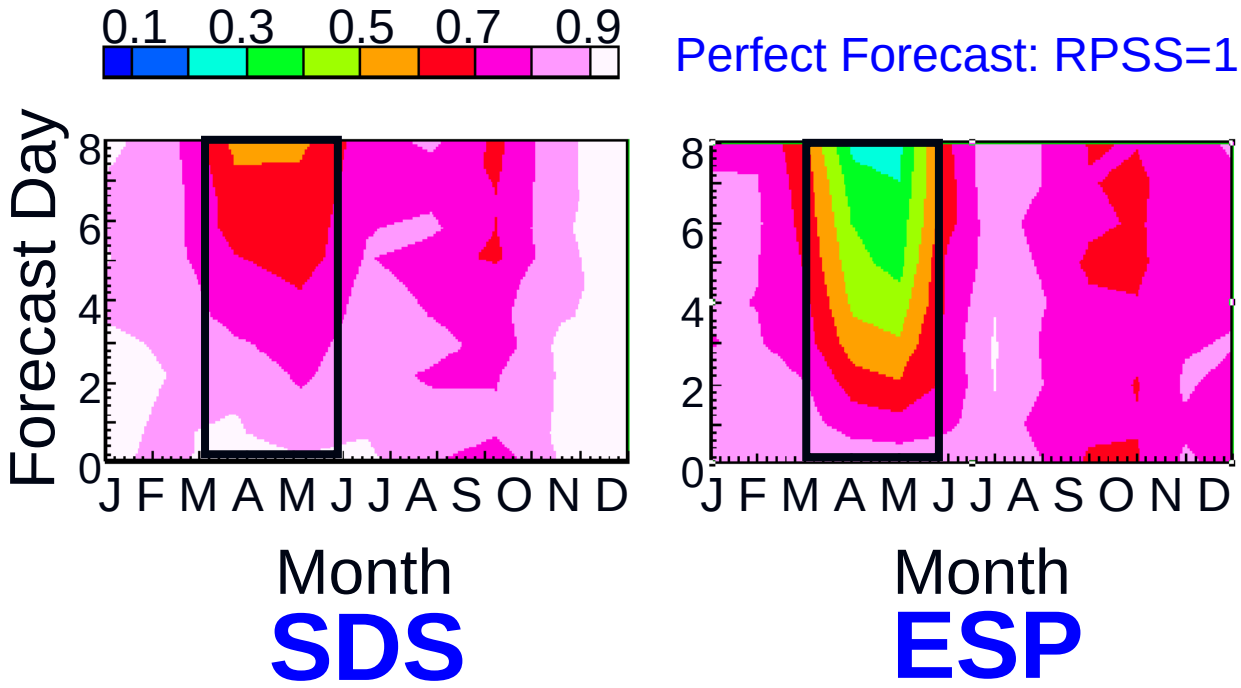
Collaboratively with U. of Colorado



11,000 Climate Station Locations

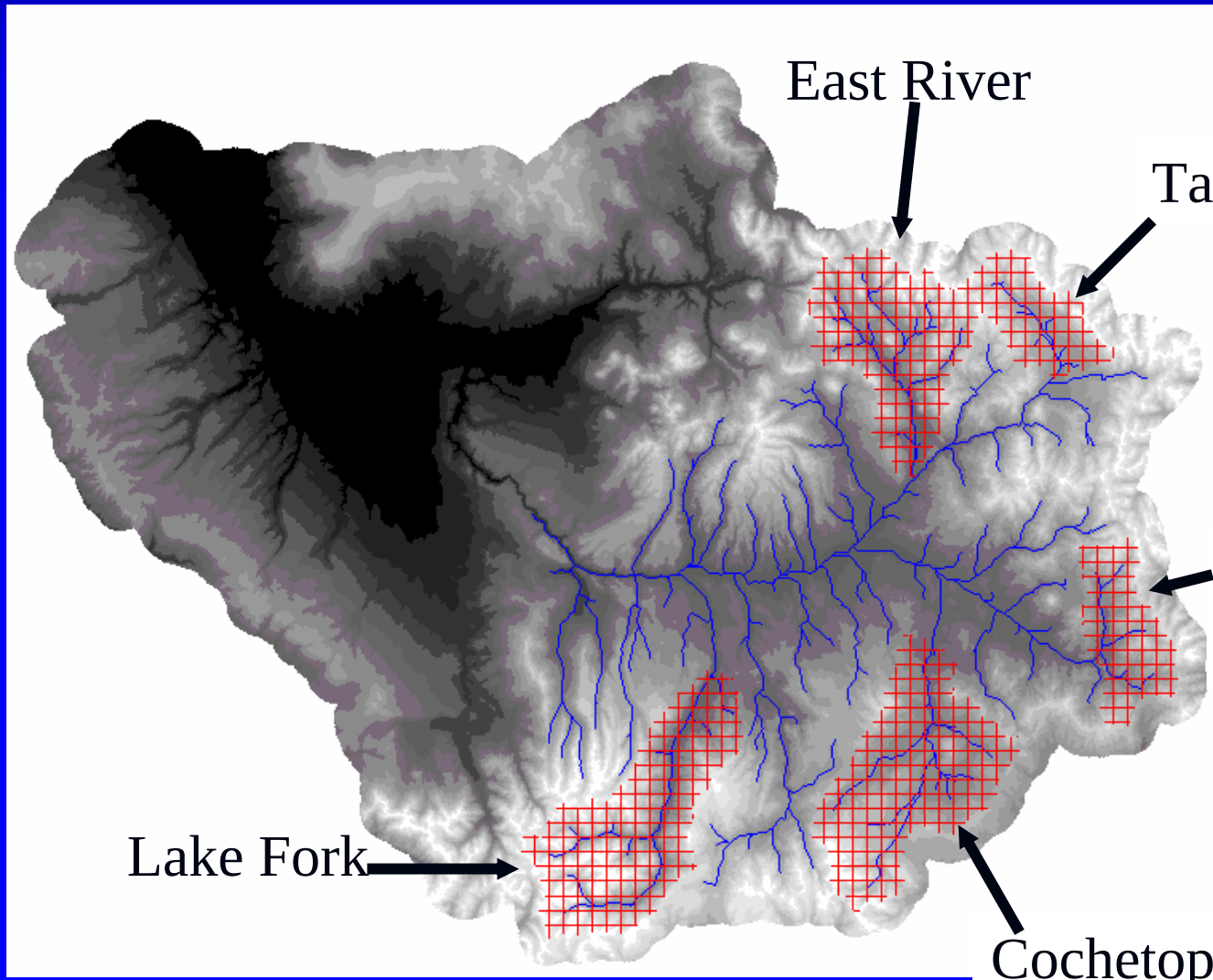
Ranked Probability Skill Score (RPSS) for each forecast day and month using measured runoff and simulated runoff (Animas River, CO) produced using: (1) SDS output and (2) ESP technique

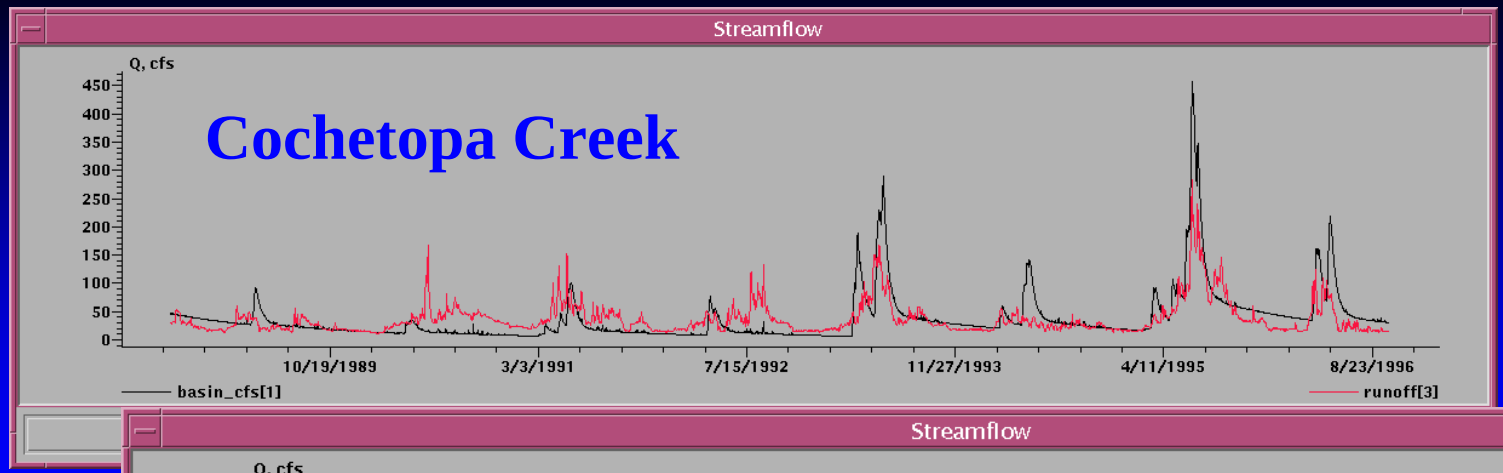
RPSS

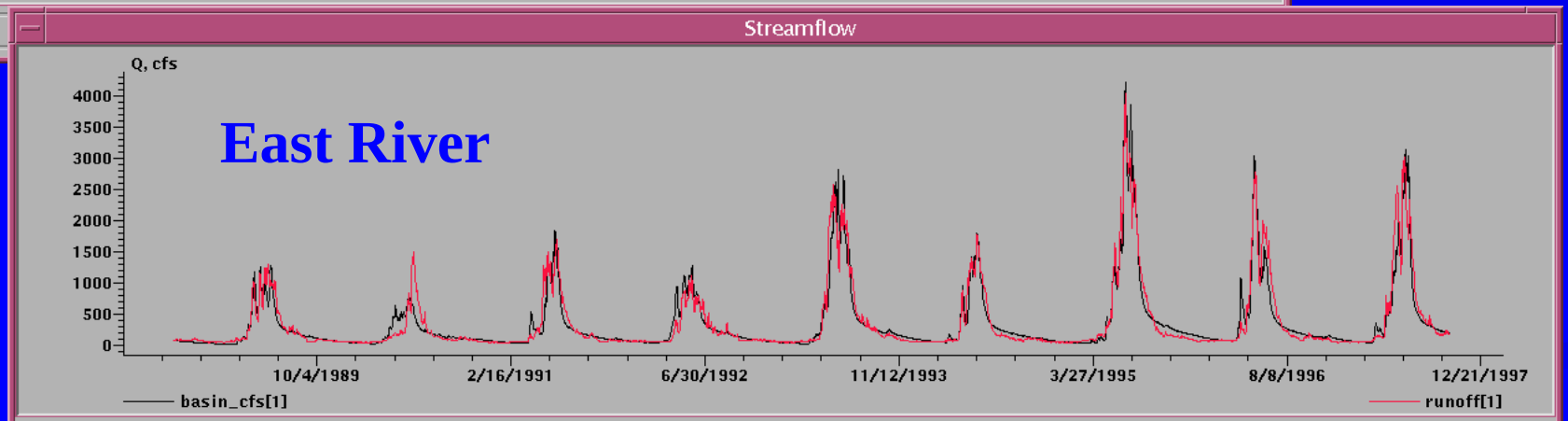


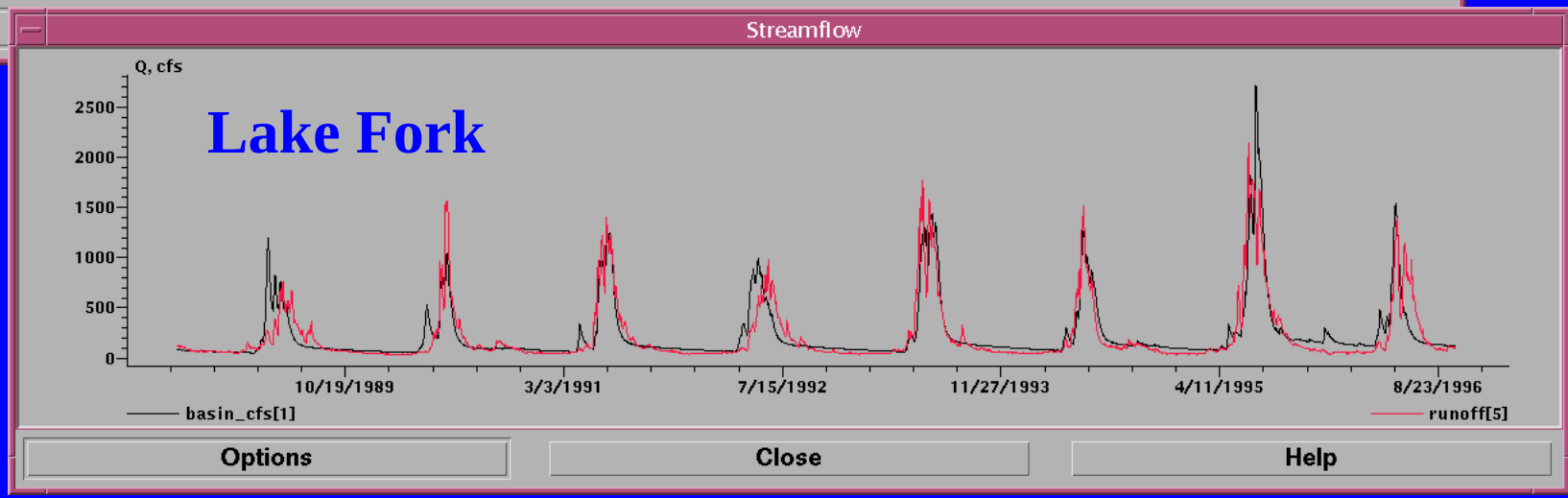
Given current uncertainty in long-term atmospheric-model forecasts, seasonal to annual forecasts may be better with ESP

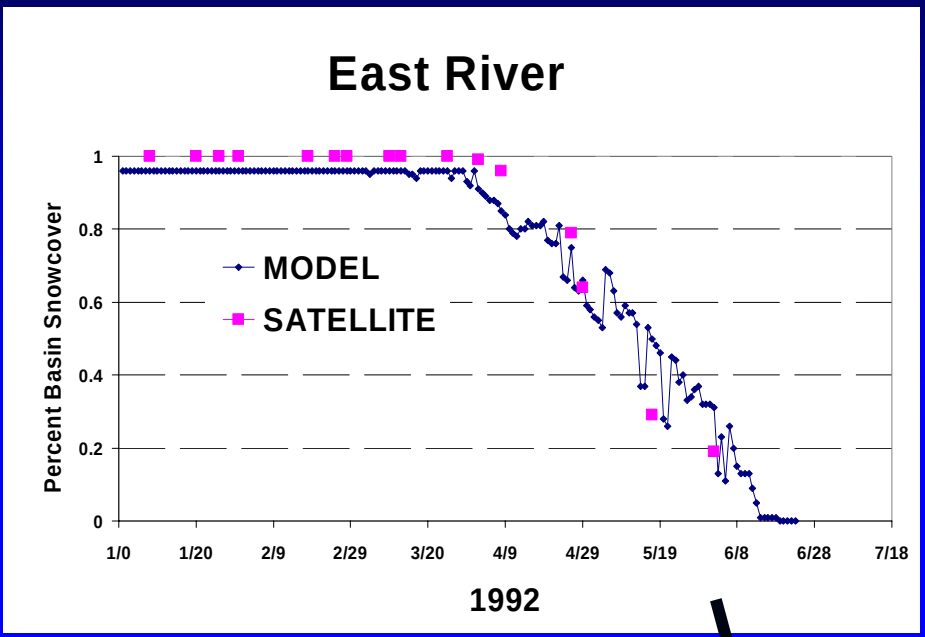
SUBBASINS WITH CONCURRENT STREAMFLOW AND SATELLITE DATA

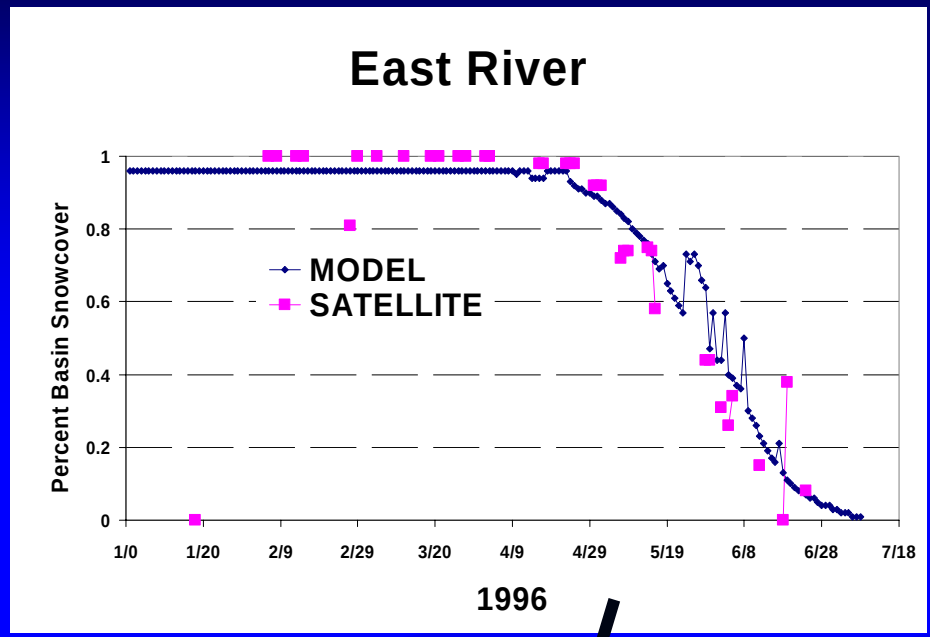


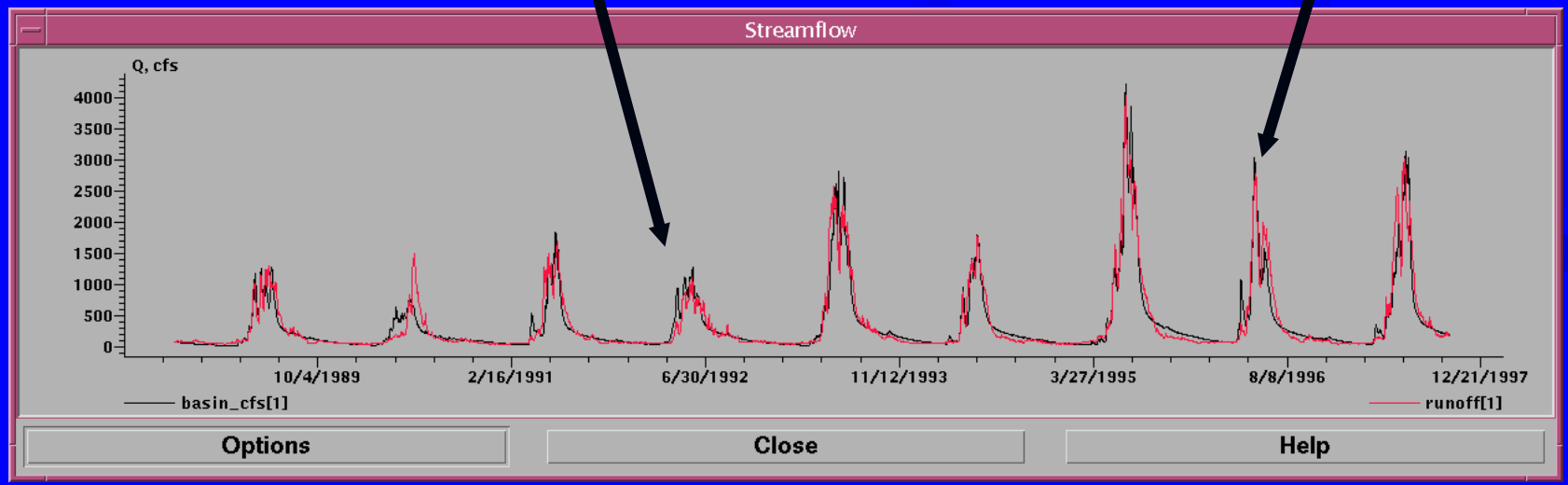

Streamflow
Q, cfs
Cochetopa Creek
10/19/1989
3/3/1991
7/15/1992
11/27/1993
4/11/1995
8/23/1996
basin_cfs[1]
runoff[3]

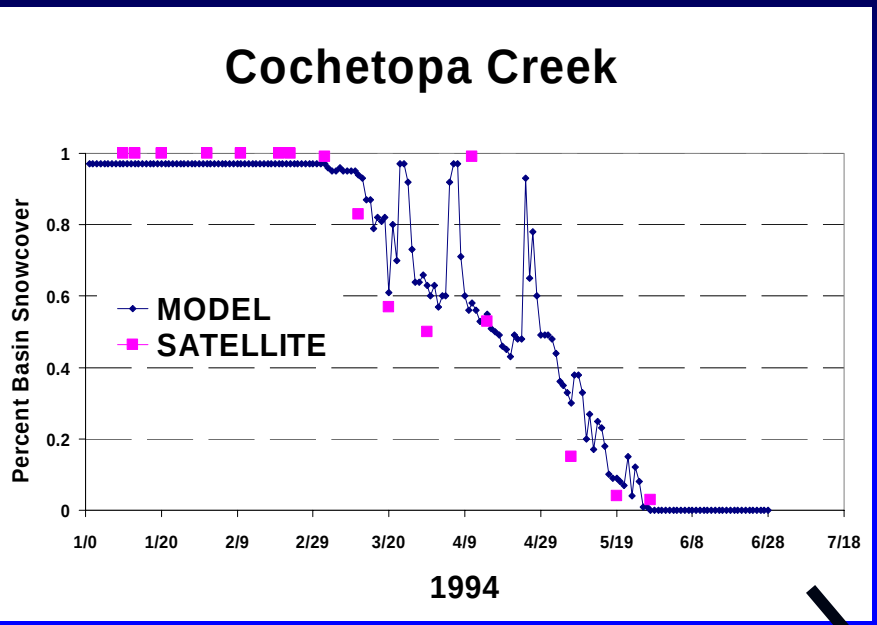

Streamflow
Q, cfs
East River
10/4/1989
2/16/1991
6/30/1992
11/12/1993
3/27/1995
8/8/1996
12/21/1997
basin_cfs[1]
runoff[1]

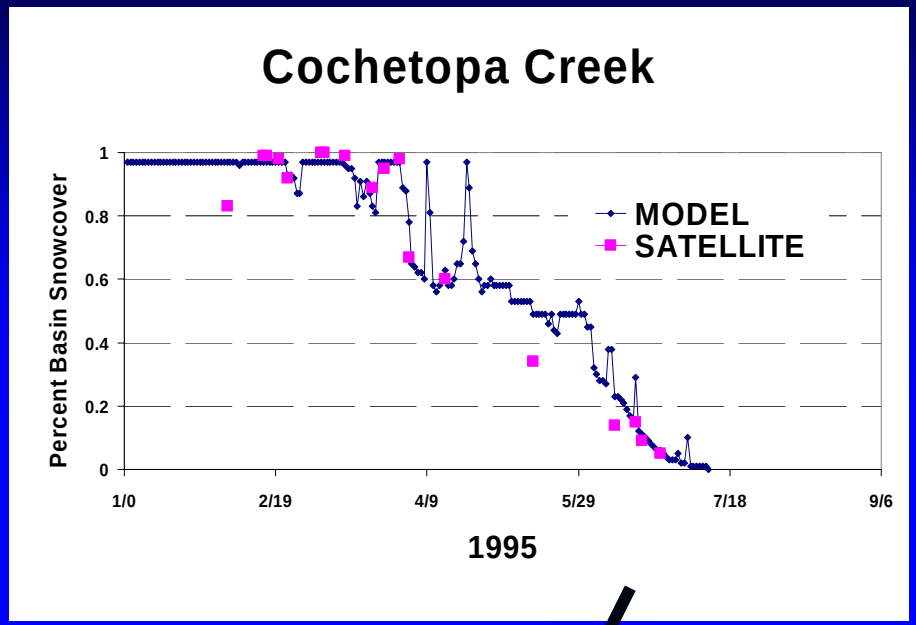

Streamflow
Q, cfs
Lake Fork
10/19/1989
3/3/1991
7/15/1992
11/27/1993
4/11/1995
8/23/1996
basin_cfs[1]
runoff[5]
Options
Close
Help

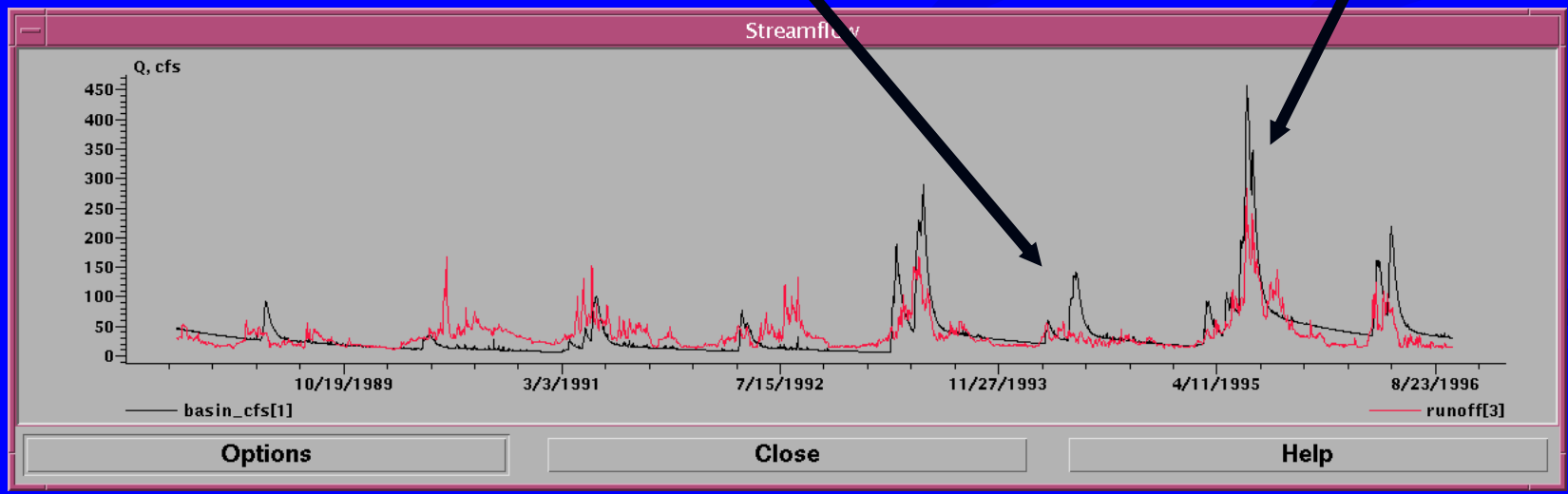

East River
Percent Basin Snowcover
1
0.8
0.6
0.4
0.2
0
MODEL
SATELLITE
1/0
1/20
2/9
2/29
3/20
4/9
4/29
5/19
6/8
6/28
7/18
1992


East River
Percent Basin Snowcover
1
0.8
0.6
0.4
0.2
0
MODEL
SATELLITE
1/0
1/20
2/9
2/29
3/20
4/9
4/29
5/19
6/8
6/28
7/18
1996


Streamflow
Q, cfs
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]
Options
Close
Help


Cochetopa Creek
Percent Basin Snowcover
1
0.8
0.6
0.4
0.2
0
MODEL
SATELLITE
1/0
1/20
2/9
2/29
3/20
4/9
4/29
5/19
6/8
6/28
7/18
1994


Cochetopa Creek
Percent Basin Snowcover
1
0.8
0.6
0.4
0.2
0
MODEL
SATELLITE
1/0
2/19
4/9
5/29
7/18
9/6
1995

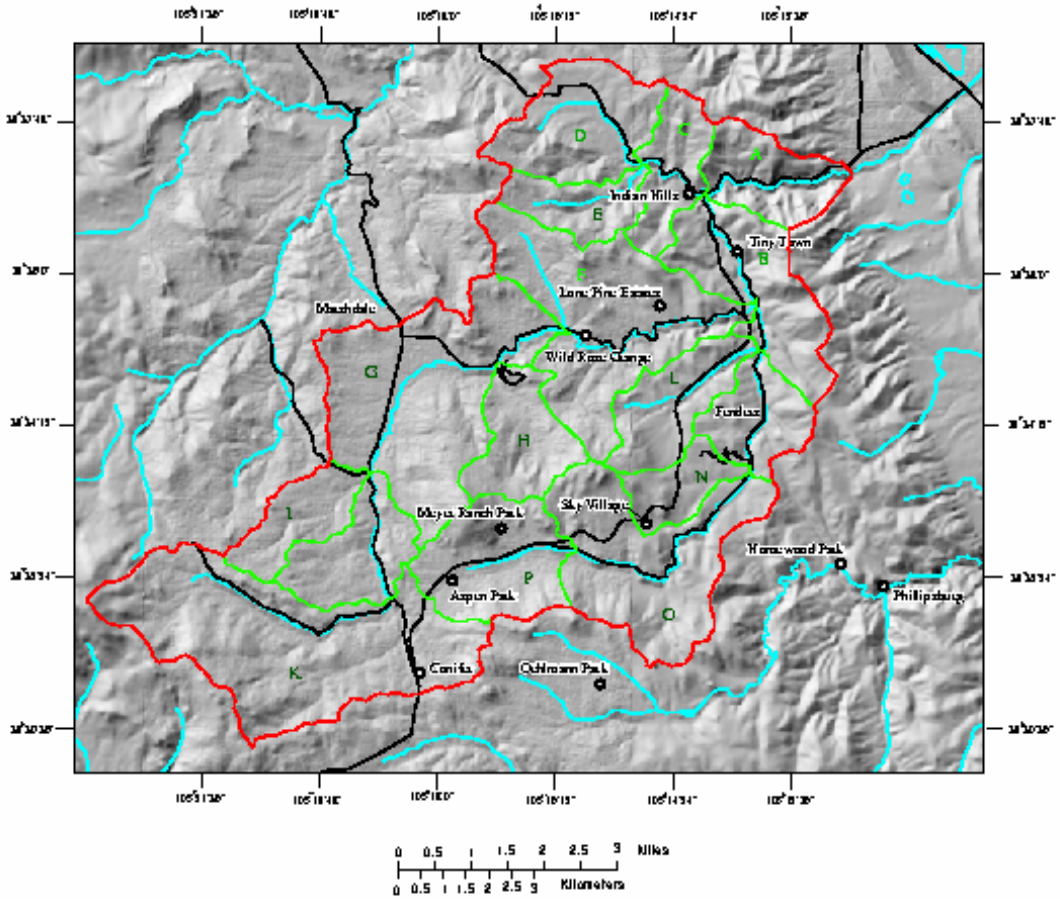

Streamflow
Q, cfs
450
400
350
300
250
200
150
100
50
0
10/19/1989
3/3/1991
7/15/1992
11/27/1993
4/11/1995
8/23/1996
basin_cfs[1]
runoff[3]
Options
Close
Help

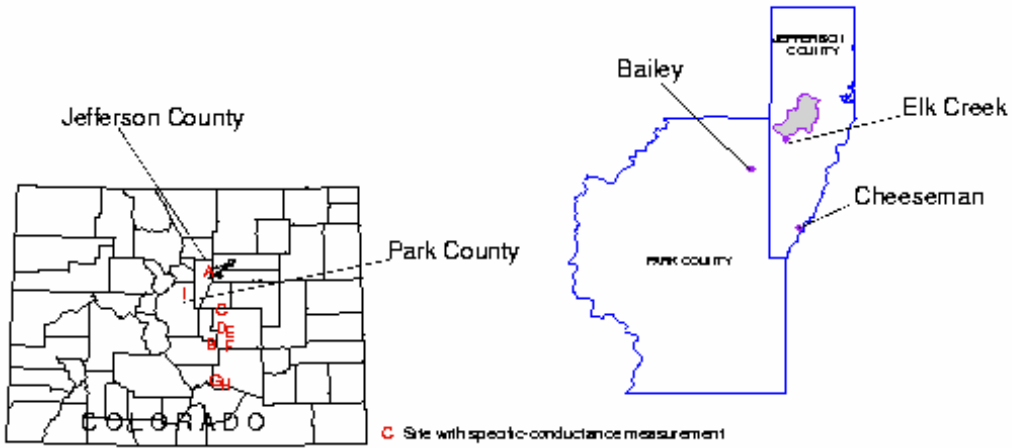
Ensembles of Hydrologic Models

Selected Models and Modules in MMS

- **USGS**
  - PRMS
  - DAFLOW
  - MODFLOW
  - WEBMOD
- **OTHER**
  - TOPMODEL
  - Hydro-17 (NWS snowmelt)
  - Sacramento Model (NWS)
  - Snowmelt Runoff Model (SRM) (ARS)
  - ENNS Model (modified HBV, Austria)

Other Related MMS DSS Applications





Turkey Creek Watershed, CO

Cooperator's Objective:
Limit housing density based on GW recharge

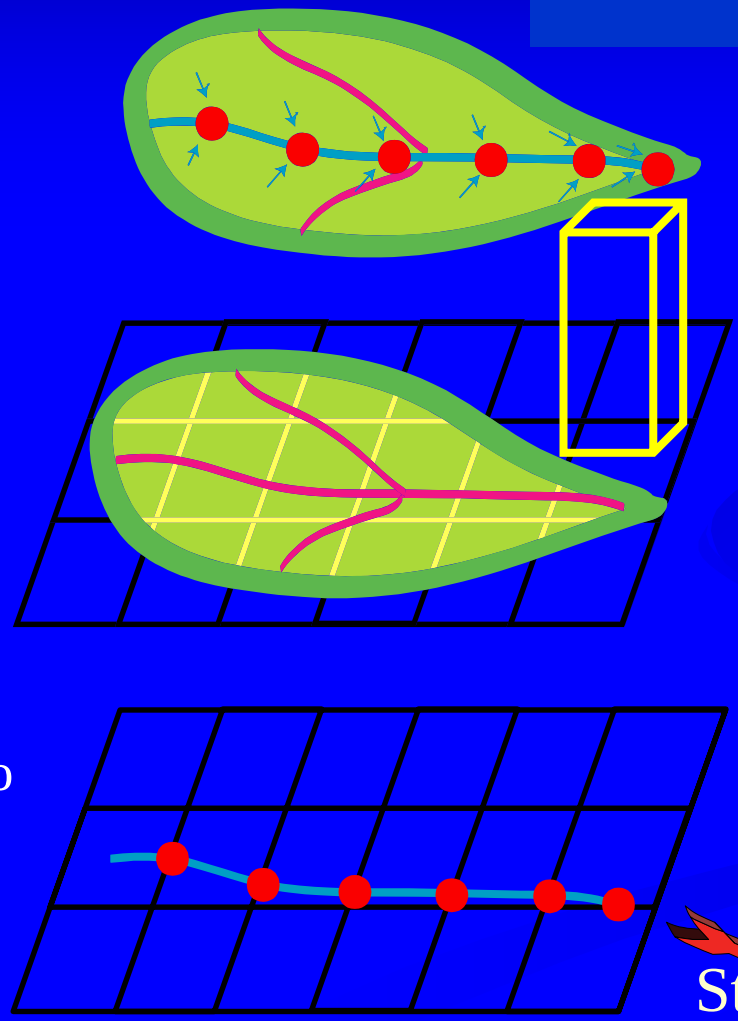
Kip Bossong, CO District

Coupled PRMS, MODFLOW, DAFLOW, Unsaturated Zone Models

PRMS to DAFLOW

PRMS to MODFLOW

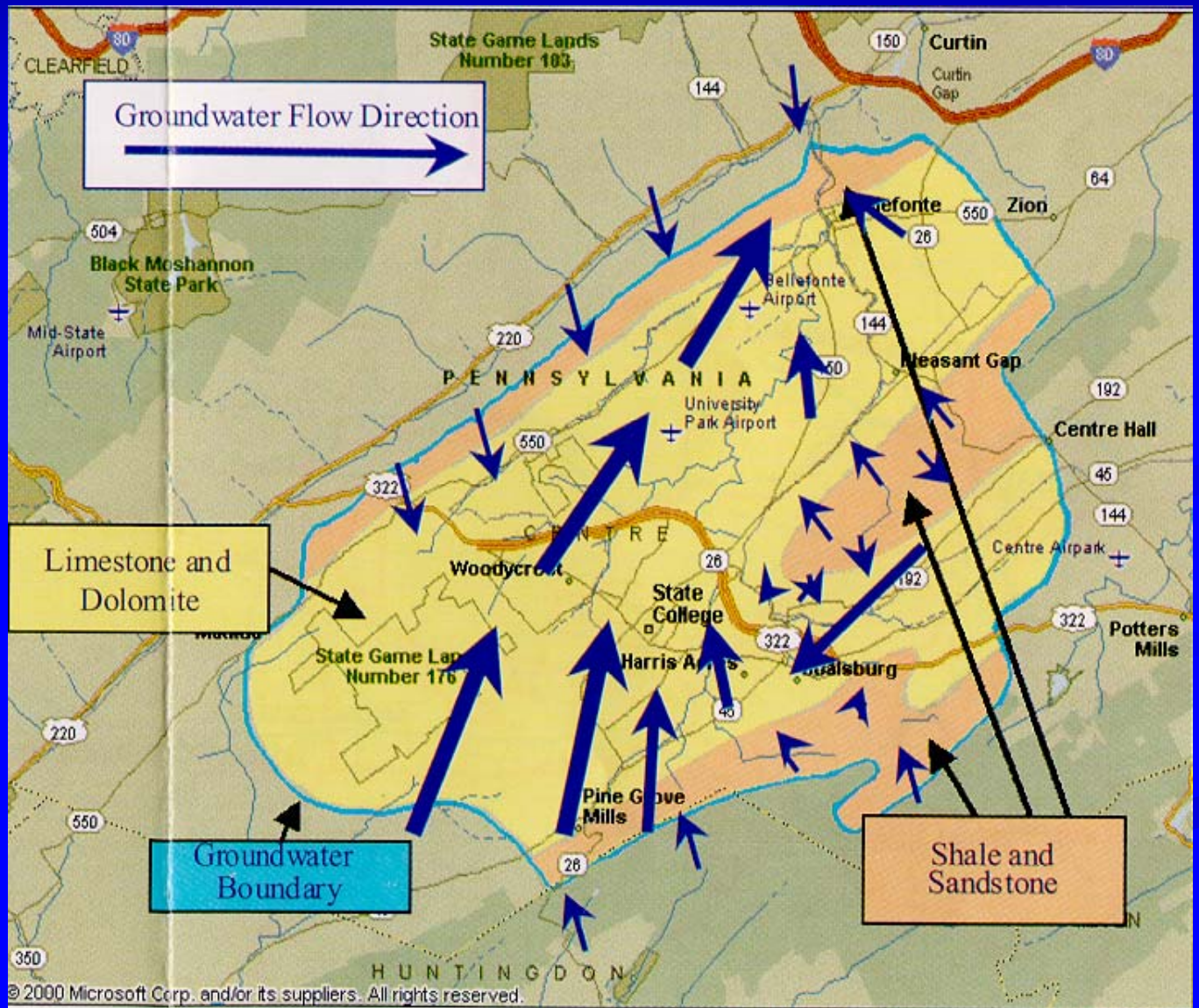
MODFLOW to DAFLOW



Unsaturated Zone Model:

PRMS to UNSAT
UNSAT to MODFLOW

Spring Creek Basin, PA
DSS SW/GW Model



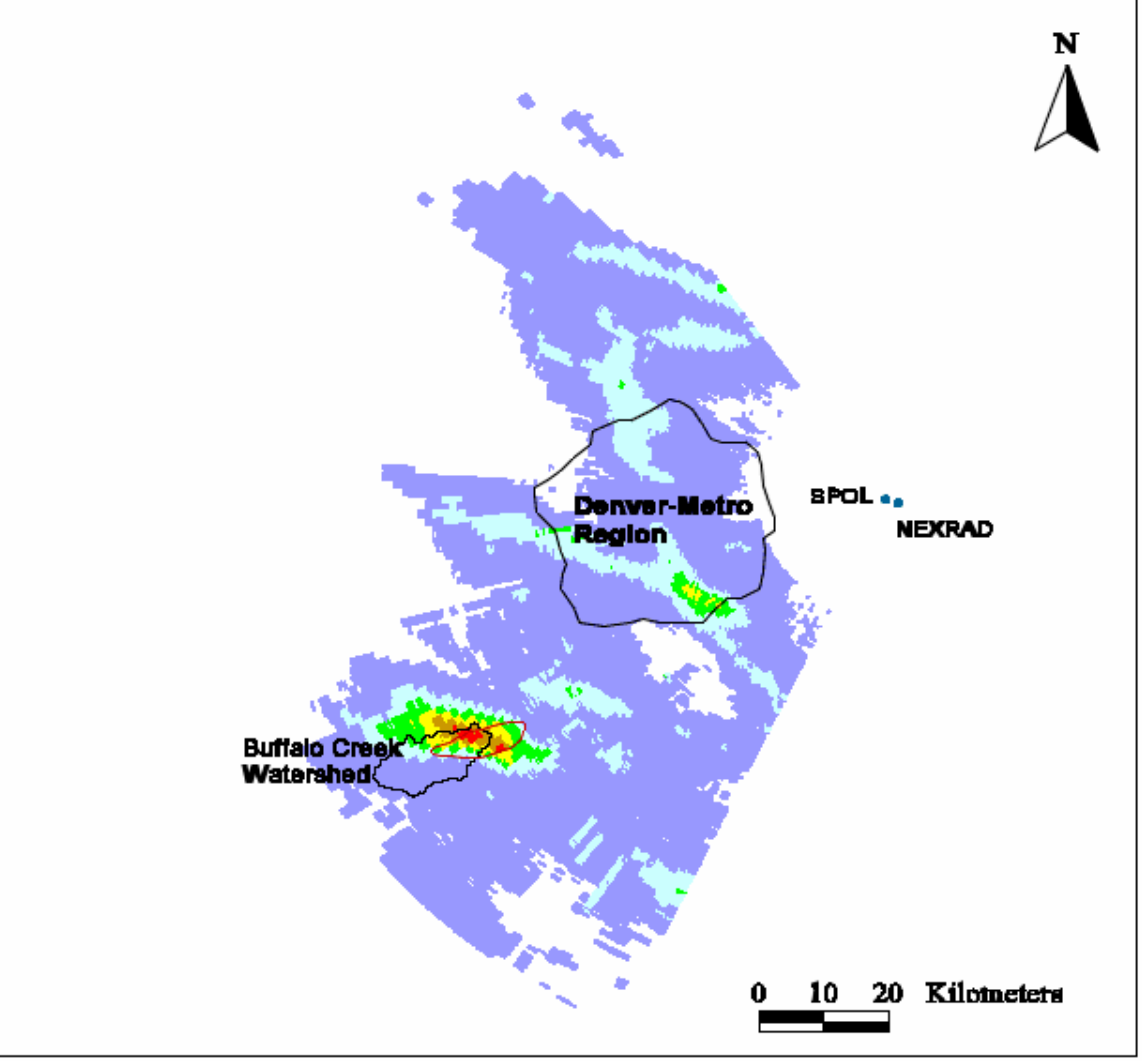
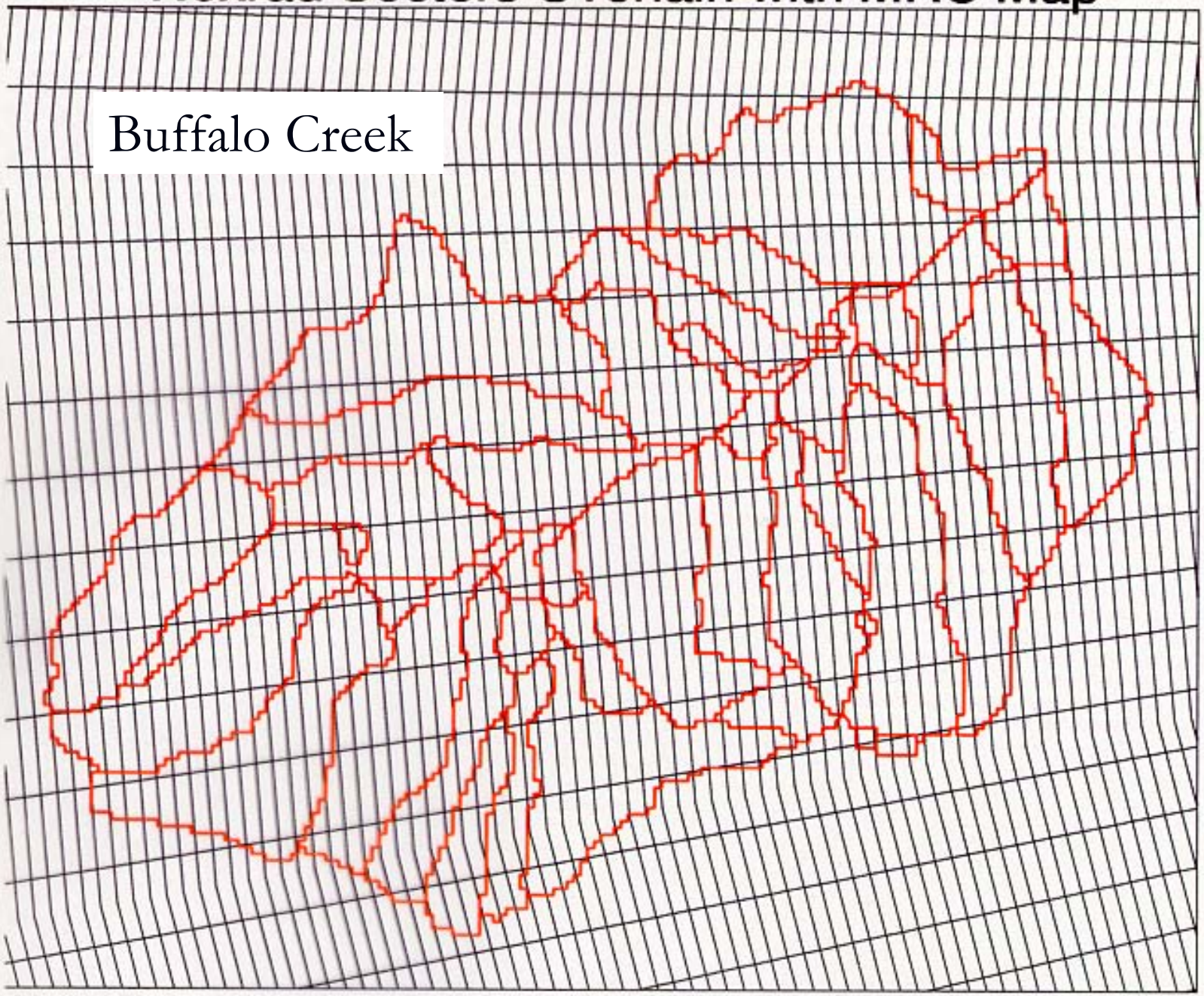


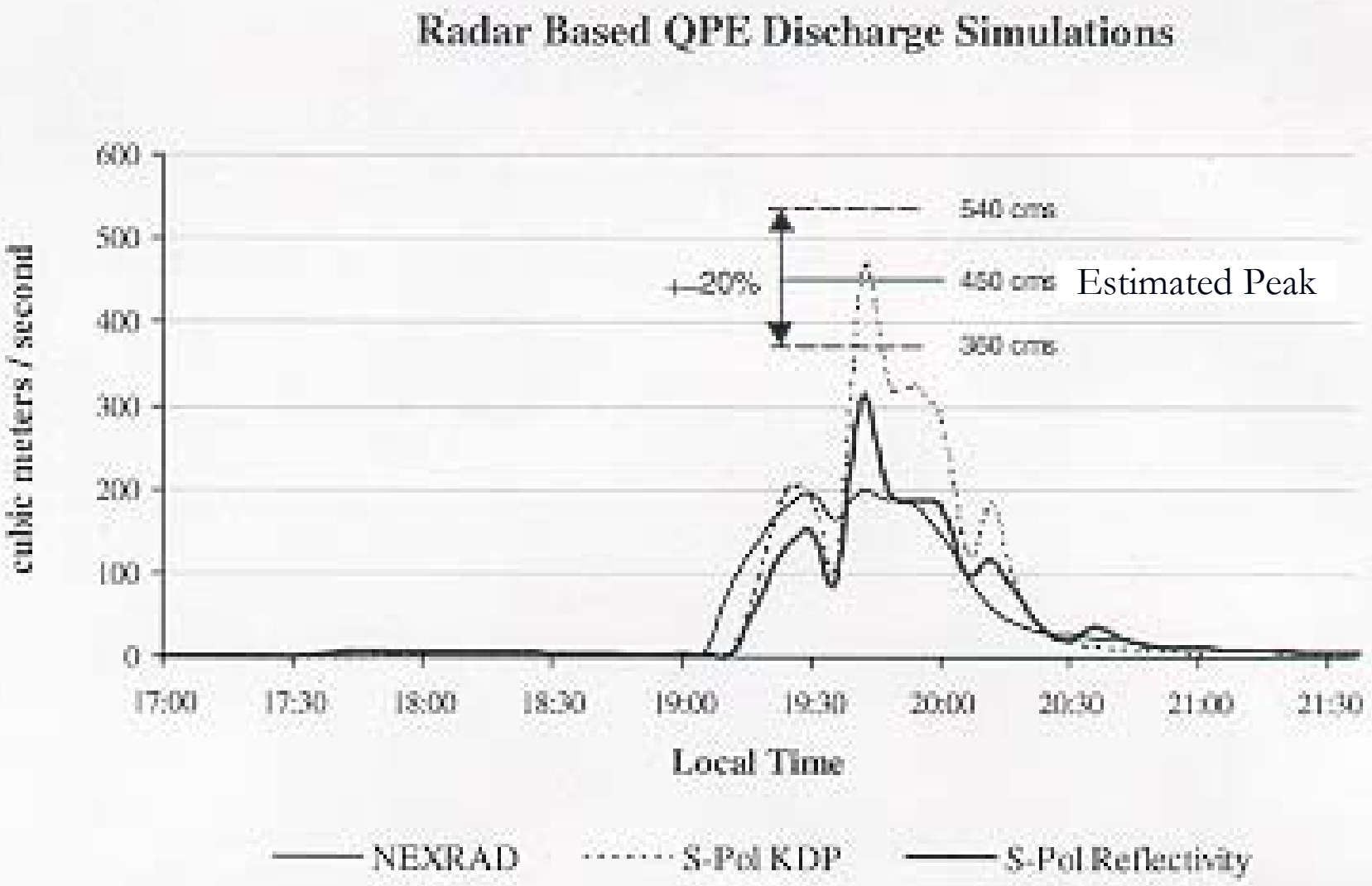
Figure 1. Total precipitation accumulation in the Front Range to the west of Denver for the period of the convection between 0000 UTC and 0423 UTC 13 July 1996 (1700 and 2123 Local Time (LT)), as estimated from the S-Pol KDP data.

RADAR DATA

NEXRAD vs S-POL,
Buffalo Creek, CO

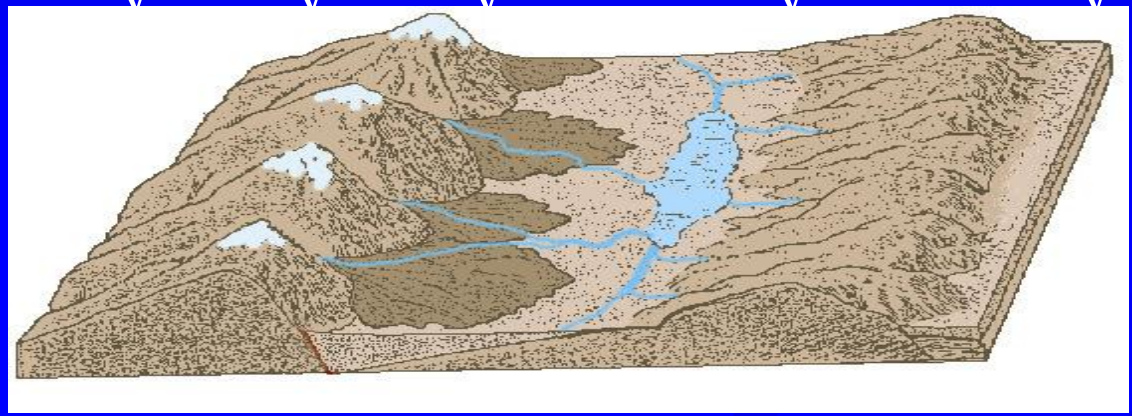
Nexrad Sectors Overlain with MRU Map




Radar Based QPE Discharge Simulations
cubic meters / second
600
500
400
300
200
100
0
540 cms
+20%
450 cms
360 cms
Estimated Peak
17:00
17:30
18:00
18:30
19:00
19:30
20:00
20:30
21:00
21:30
Local Time
NEXRAD
S-Pol KDP
S-Pol Reflectivity

Integrating Science with Resource Management through Collaborative Approaches and Adaptive Modeling Systems

Land Use Climate CO_2 Human population Invasive species



Science Synthesis

- Flood & drought impacts
- Vegetation change
- Wildland fire
- Grazing impacts
- Landslides
- Water quality

Modeling Framework Development

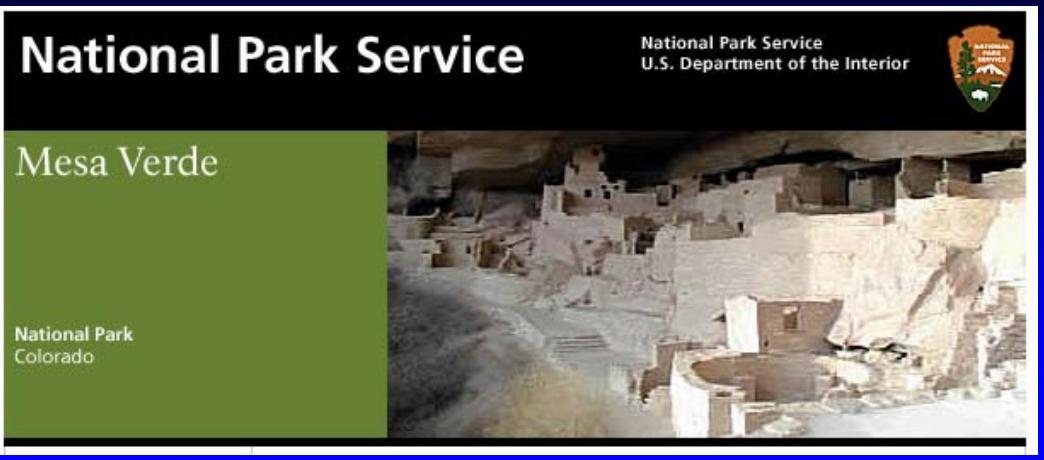
BLM USFS
Management models
NPS CESU

+

NMD BRD
Physical models
GD WRD

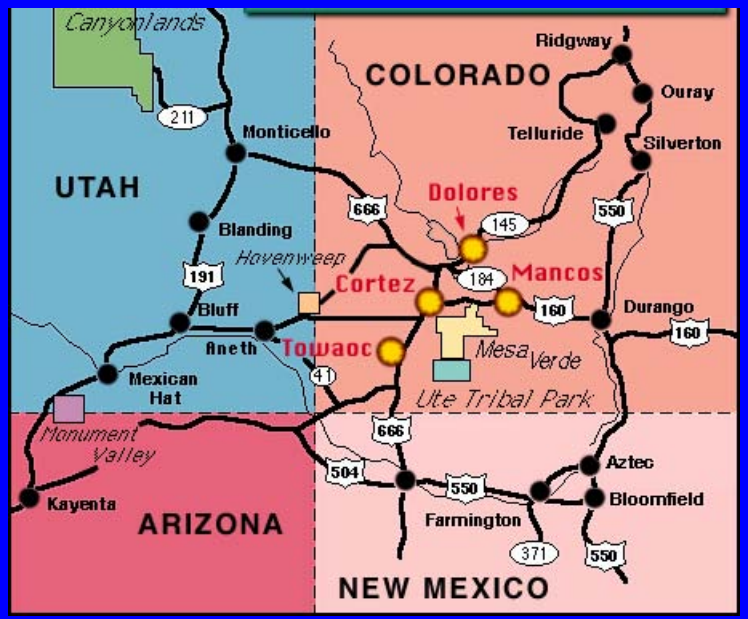
Resource Management

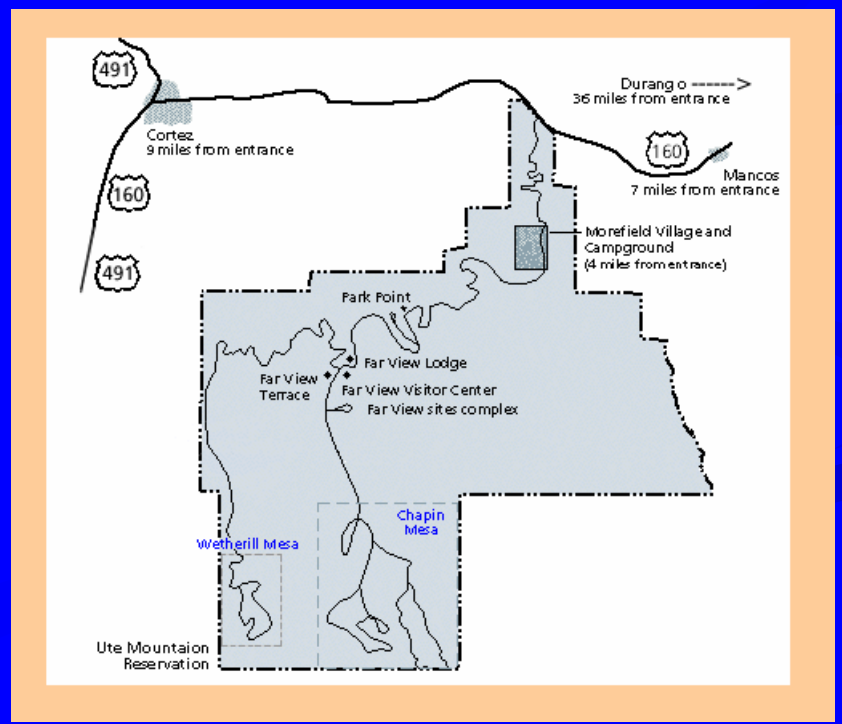
- Resource availability
- Public land management
- Restoration plans
- ...



Initial DSS Development Area

USGS, NPS, USFS, BLM, CO State University, N AZ University





SUMMARY

- Integrated toolbox approach to model development and application for water- and environmental-resources management
- Easily configured and/or enhanced for user-specific needs
- Supports multi-disciplinary model integration for decision support systems
- Flexible framework approach enables the incorporation of continuing advances in science, databases, and computer technology as well as changes in management objectives
- Open source software design allows many to share resources, expertise, knowledge, and costs

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