

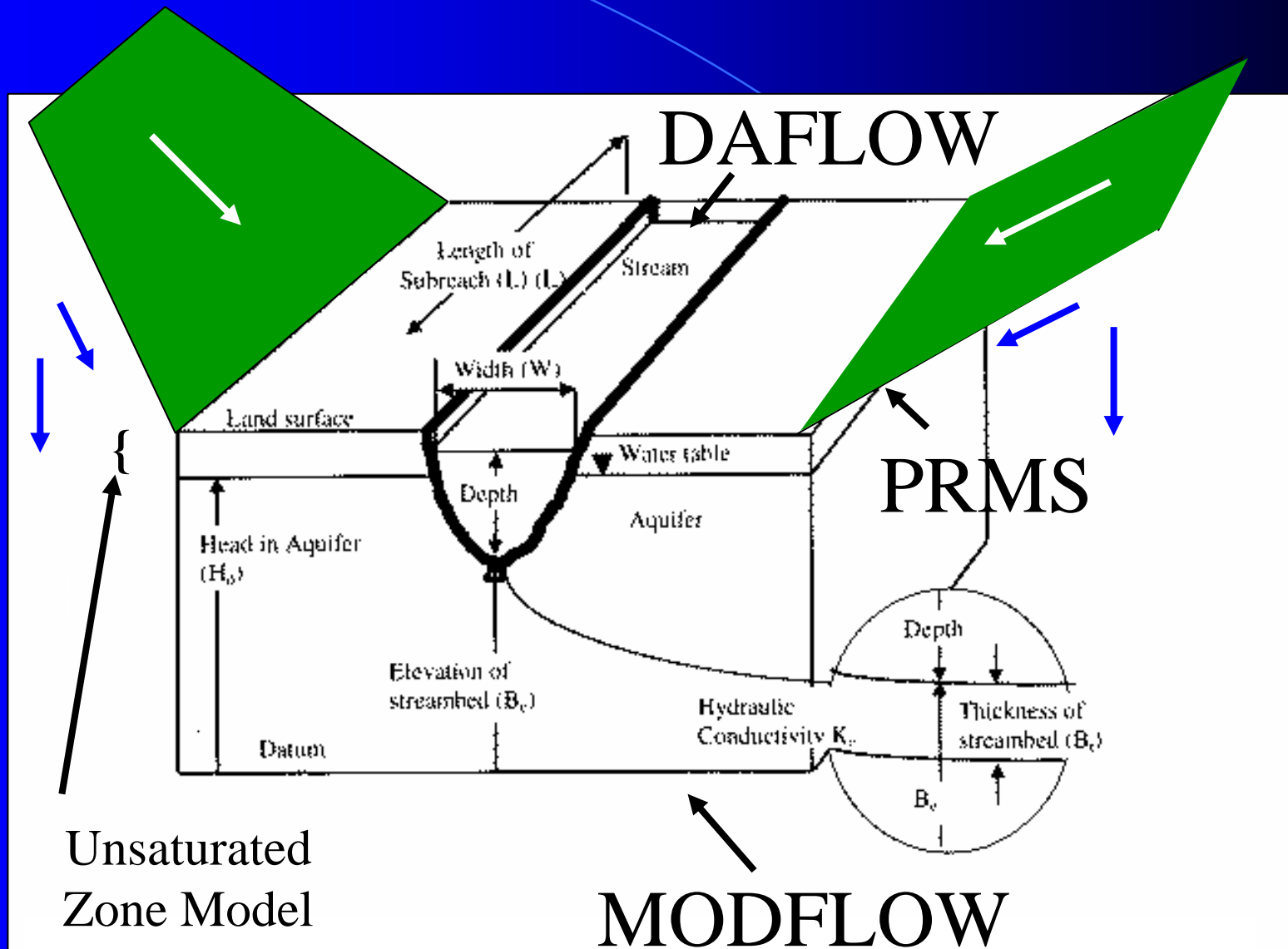
COUPLED GROUND WATER - SURFACE WATER MODELING

**George Leavesley¹, Steve Markstrom¹,
Rich Niswonger², Dave Prudic²,
Steve Regan¹, and Roland Viger¹**

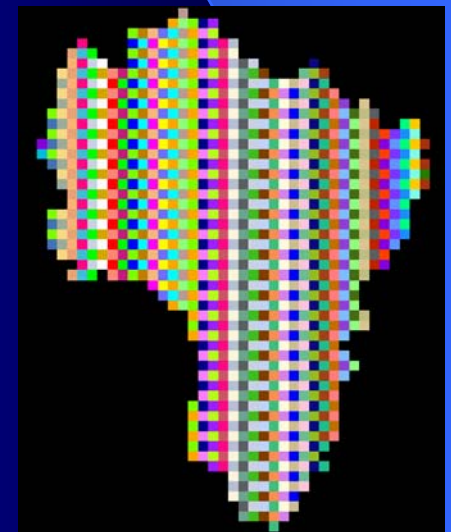
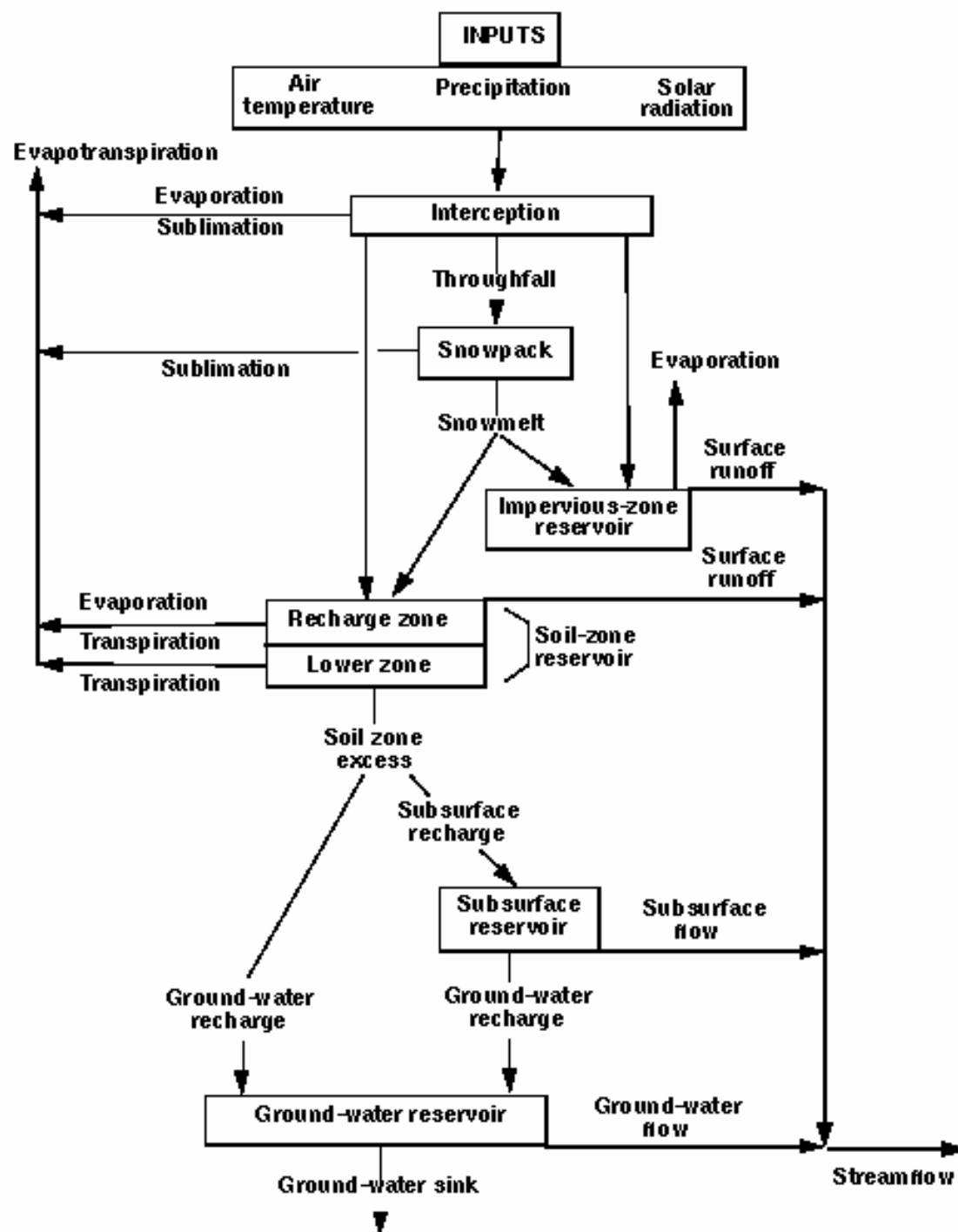
¹USGS, Denver, CO

²USGS, Carson City, NV

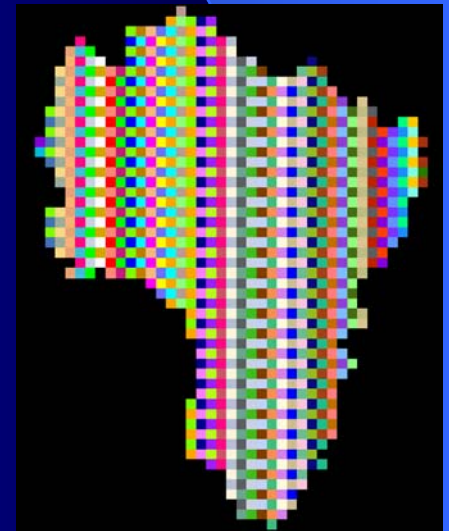
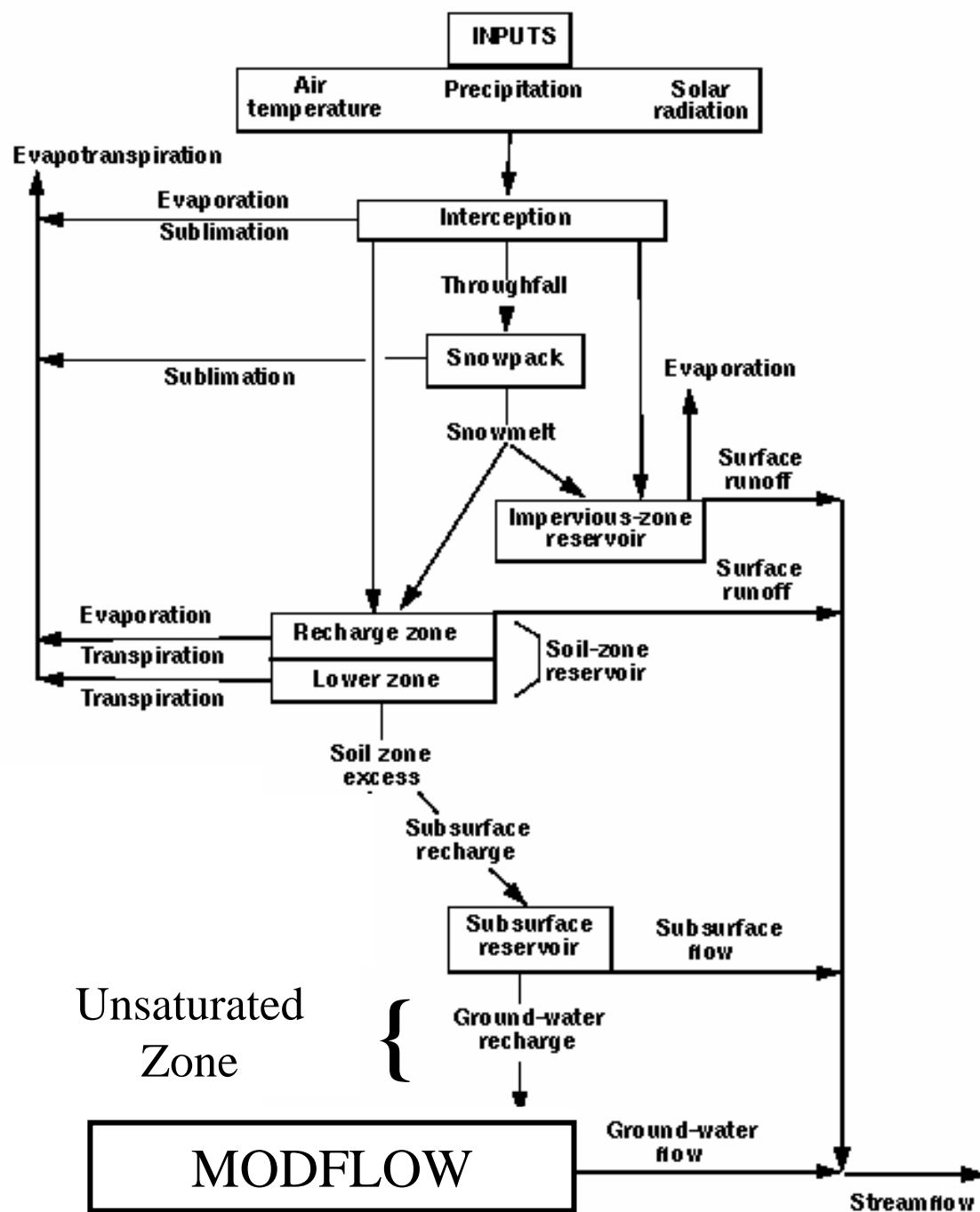
Ground Water - Surface Water Coupling



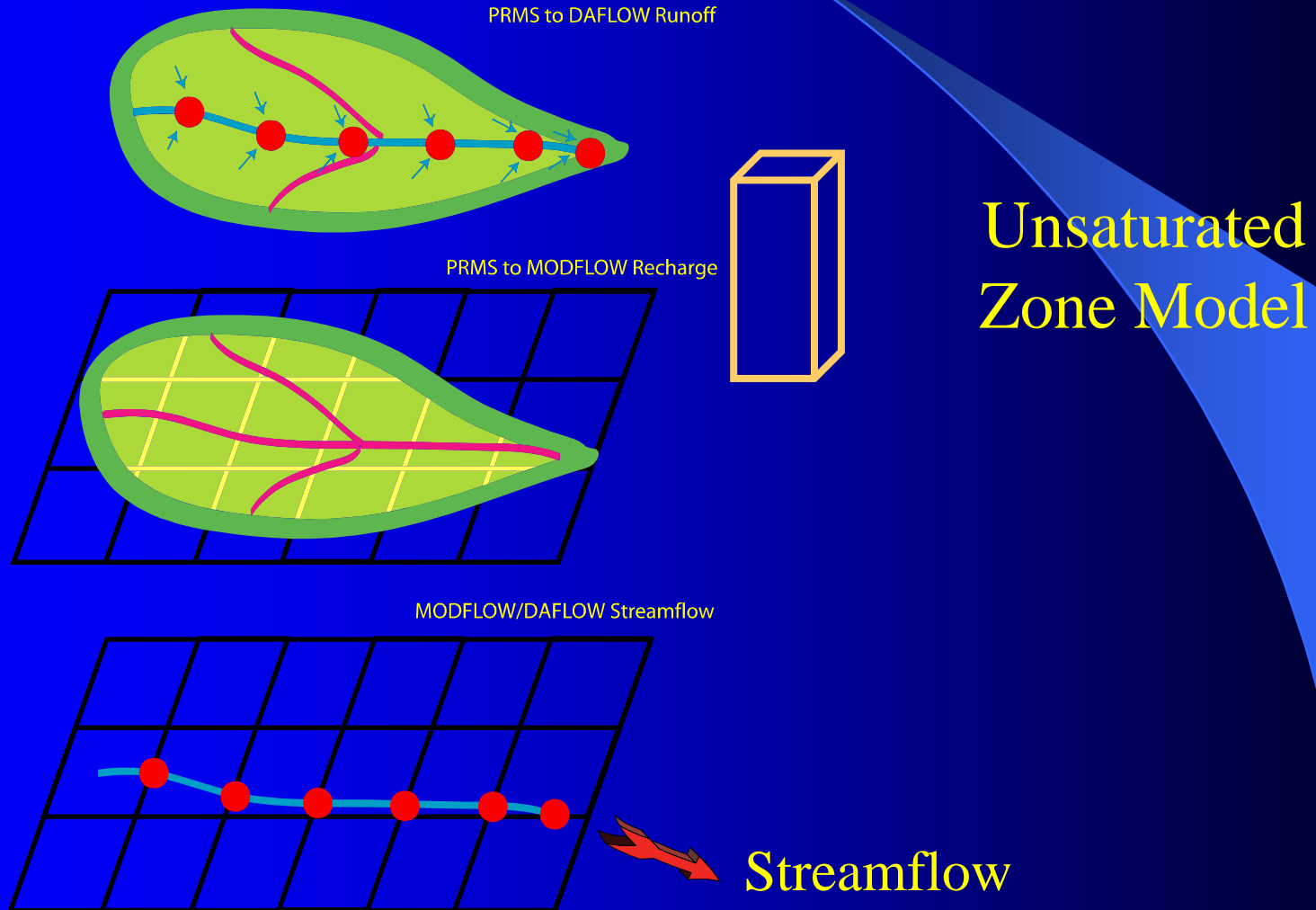
PRMS



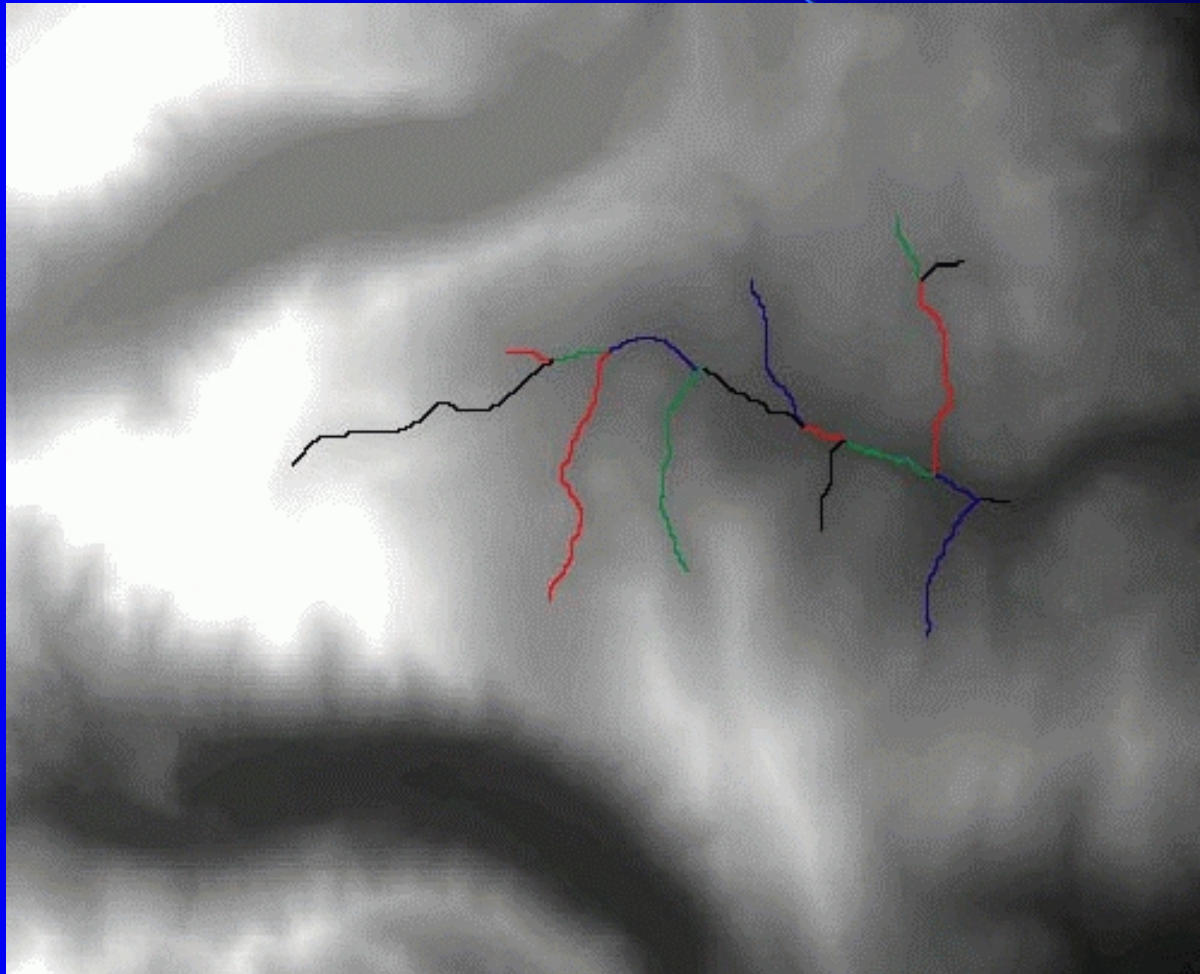
GSFLOW



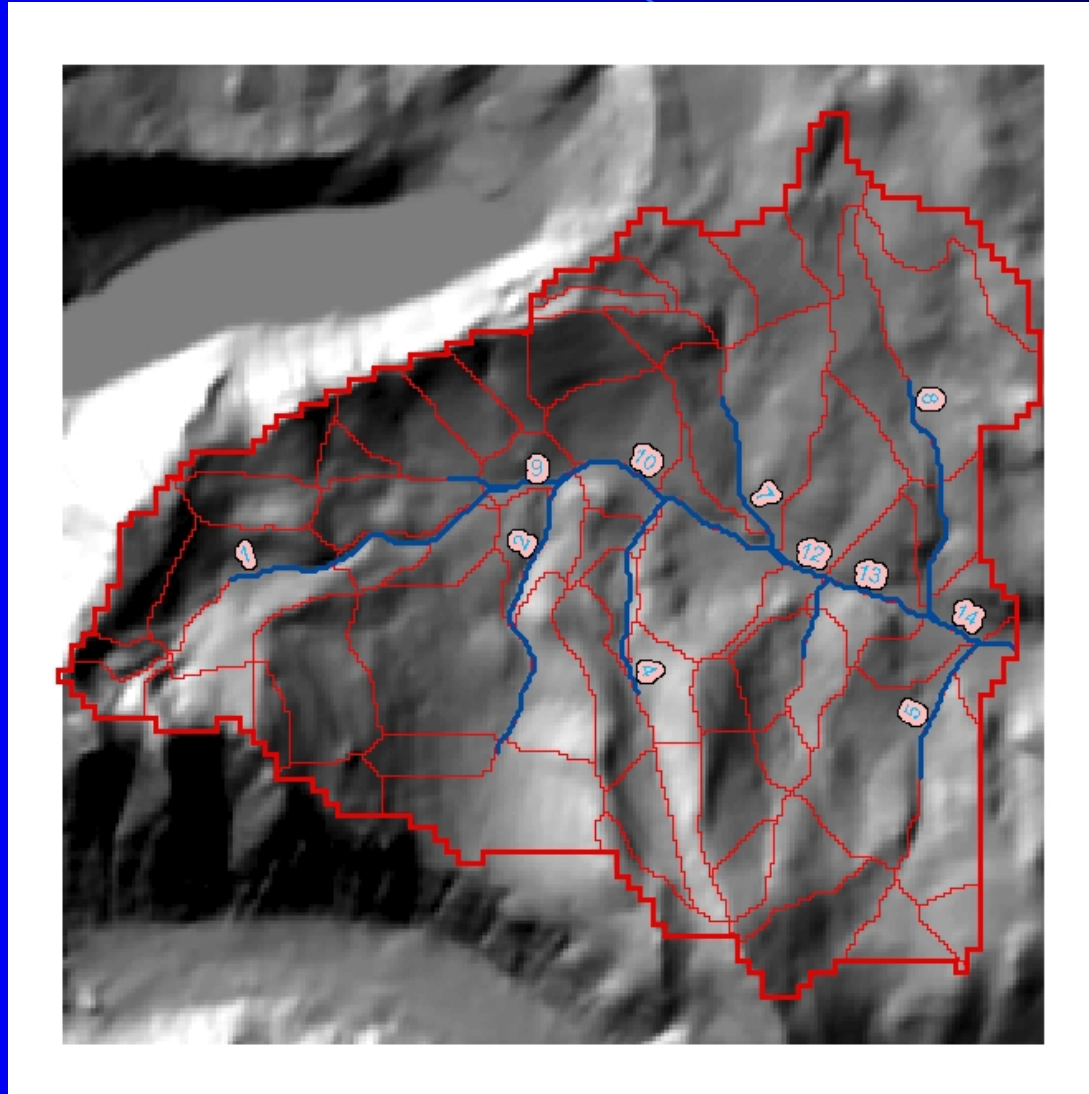
Ground-Water / Surface-Water Flow (GSFLOW) Model



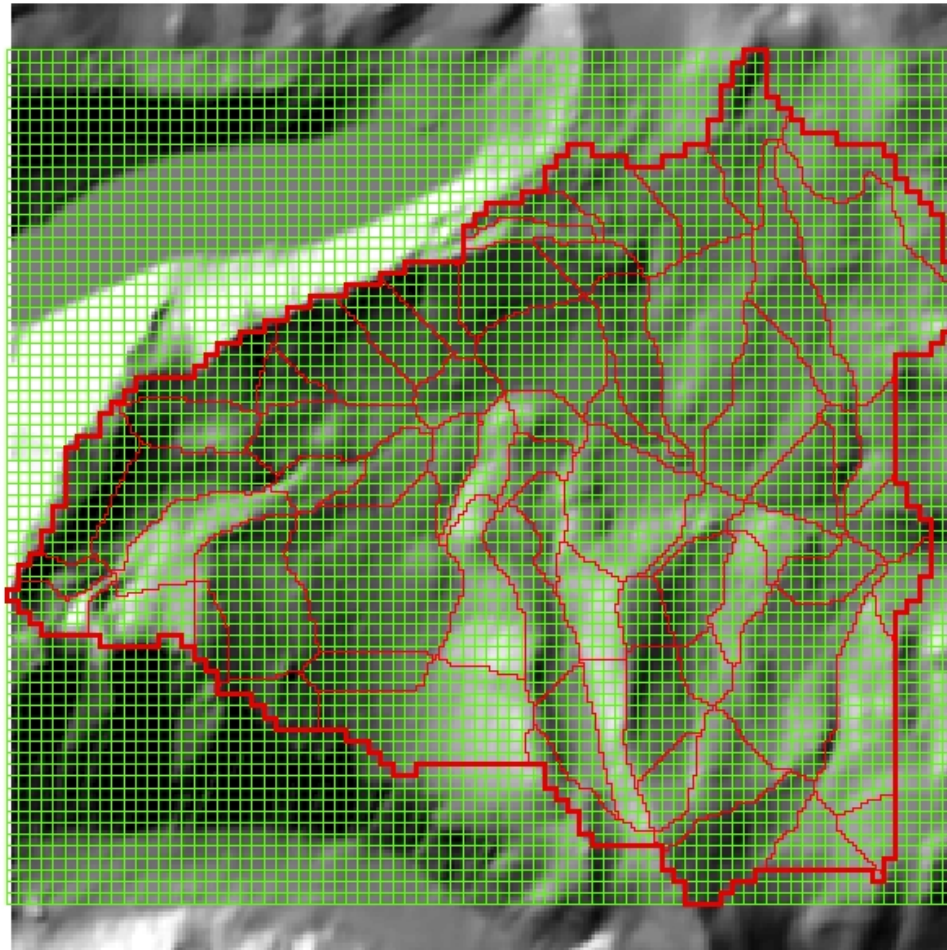
DEM/Branch



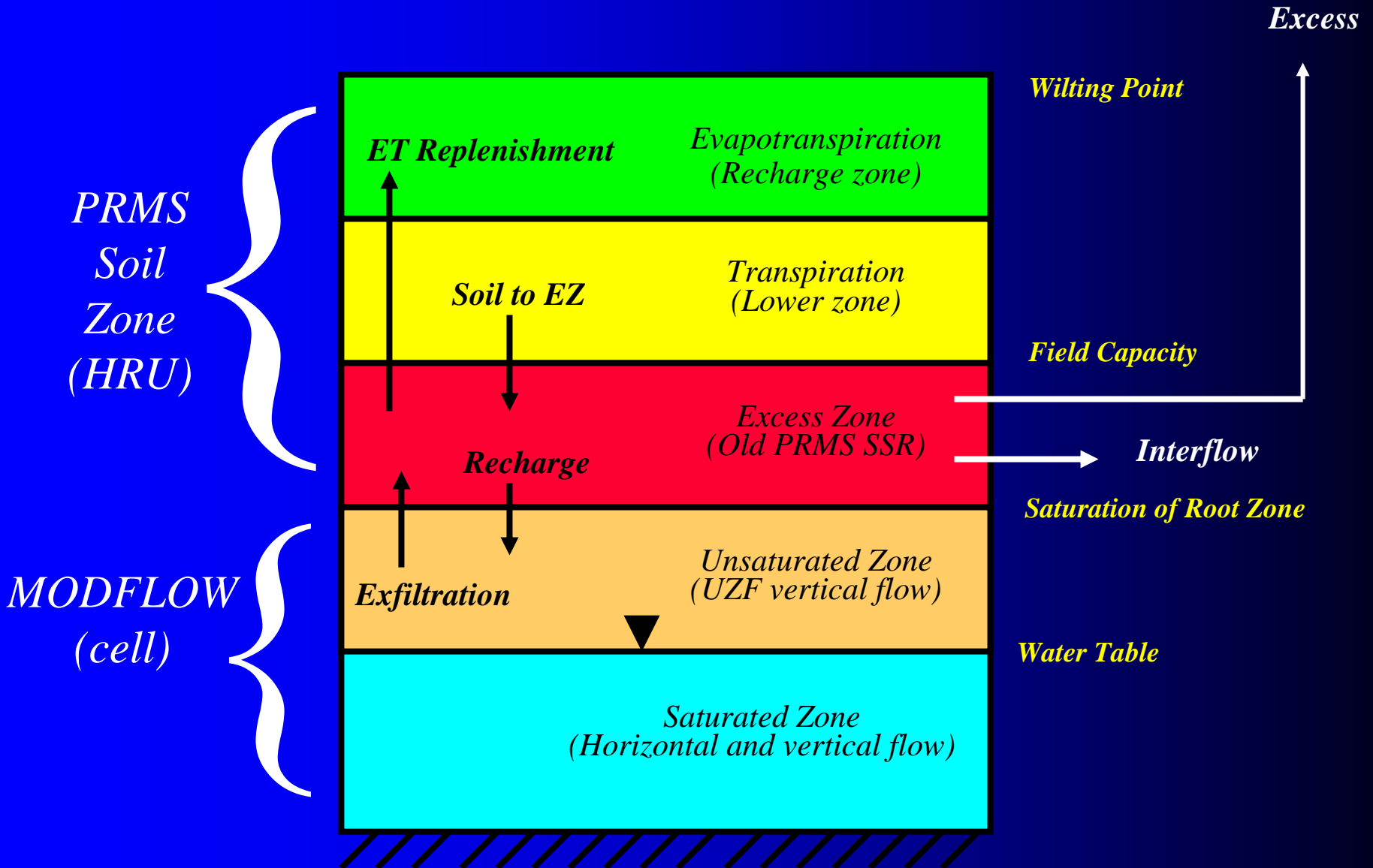
HRU/Stream Segments



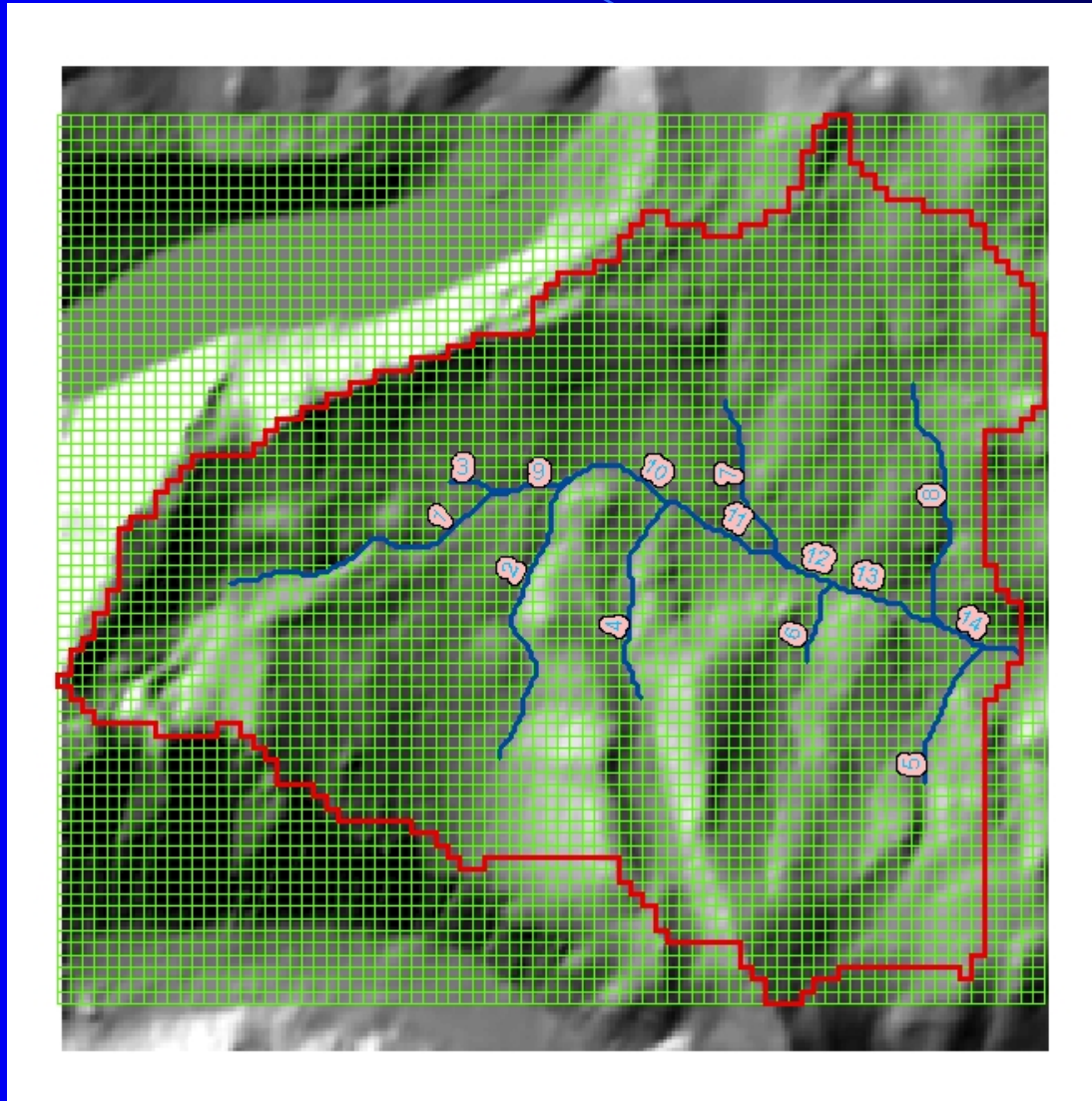
HRU/GW Cells



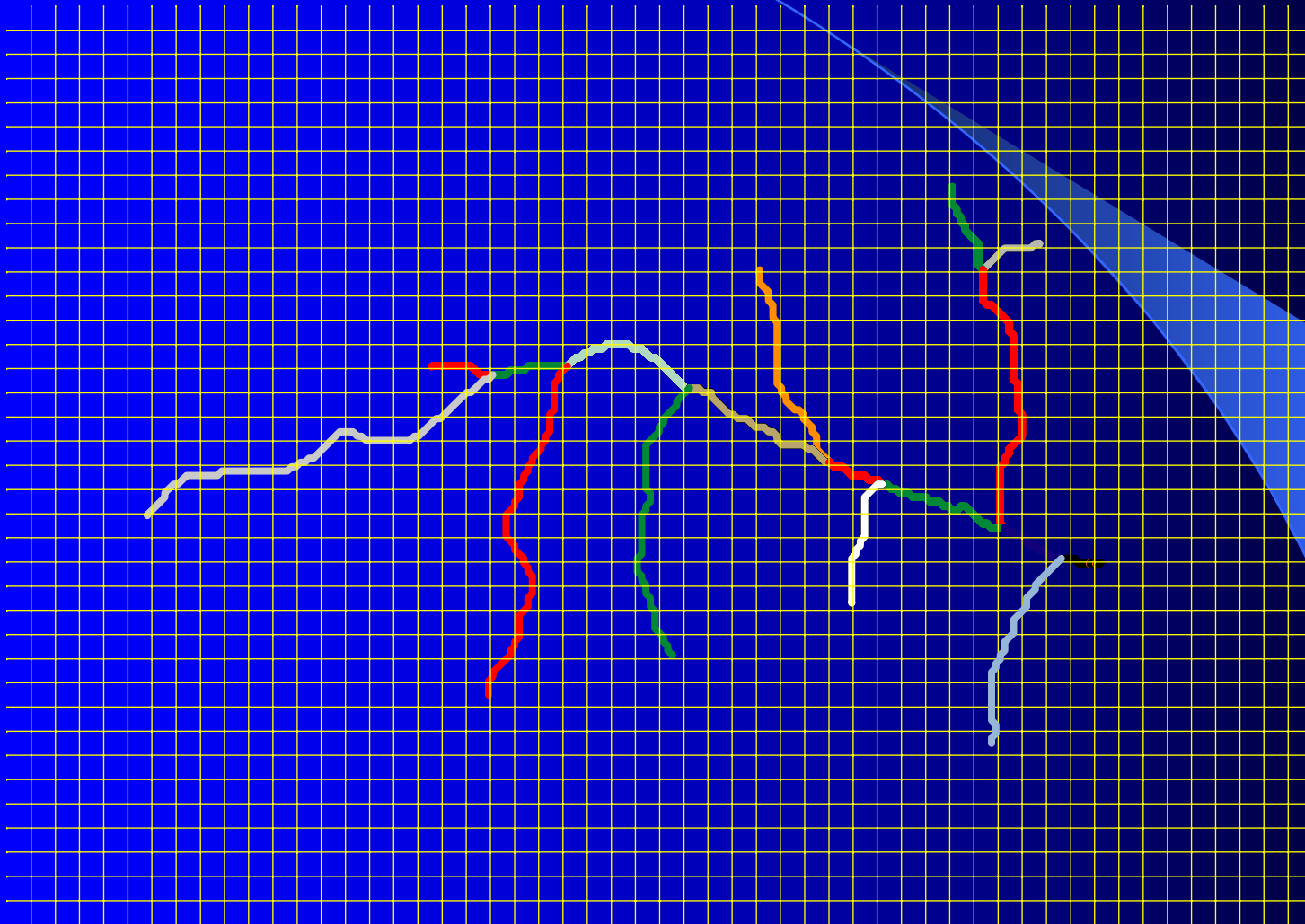
HRU/GW Cells



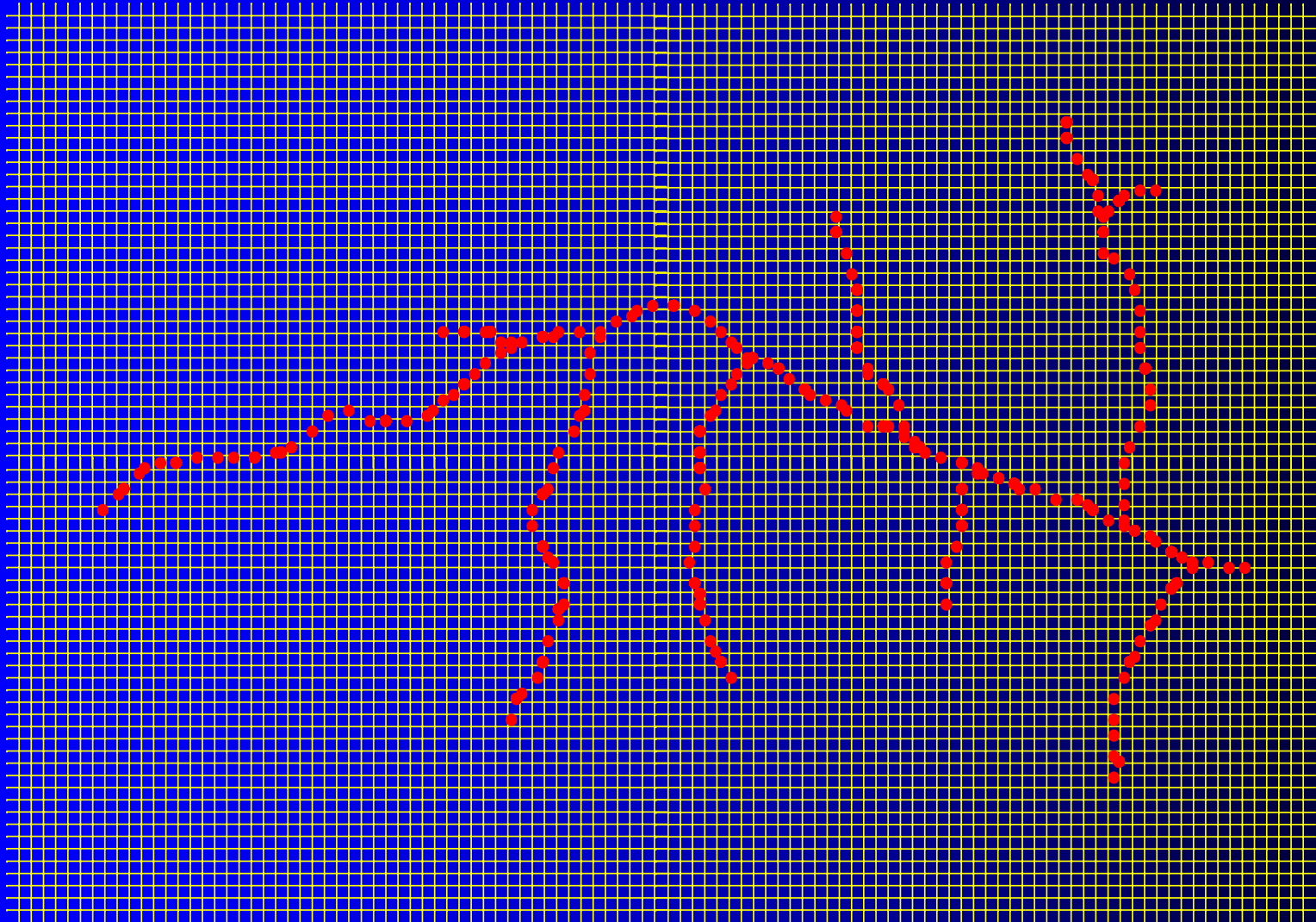
Stream Segments/GW Cells



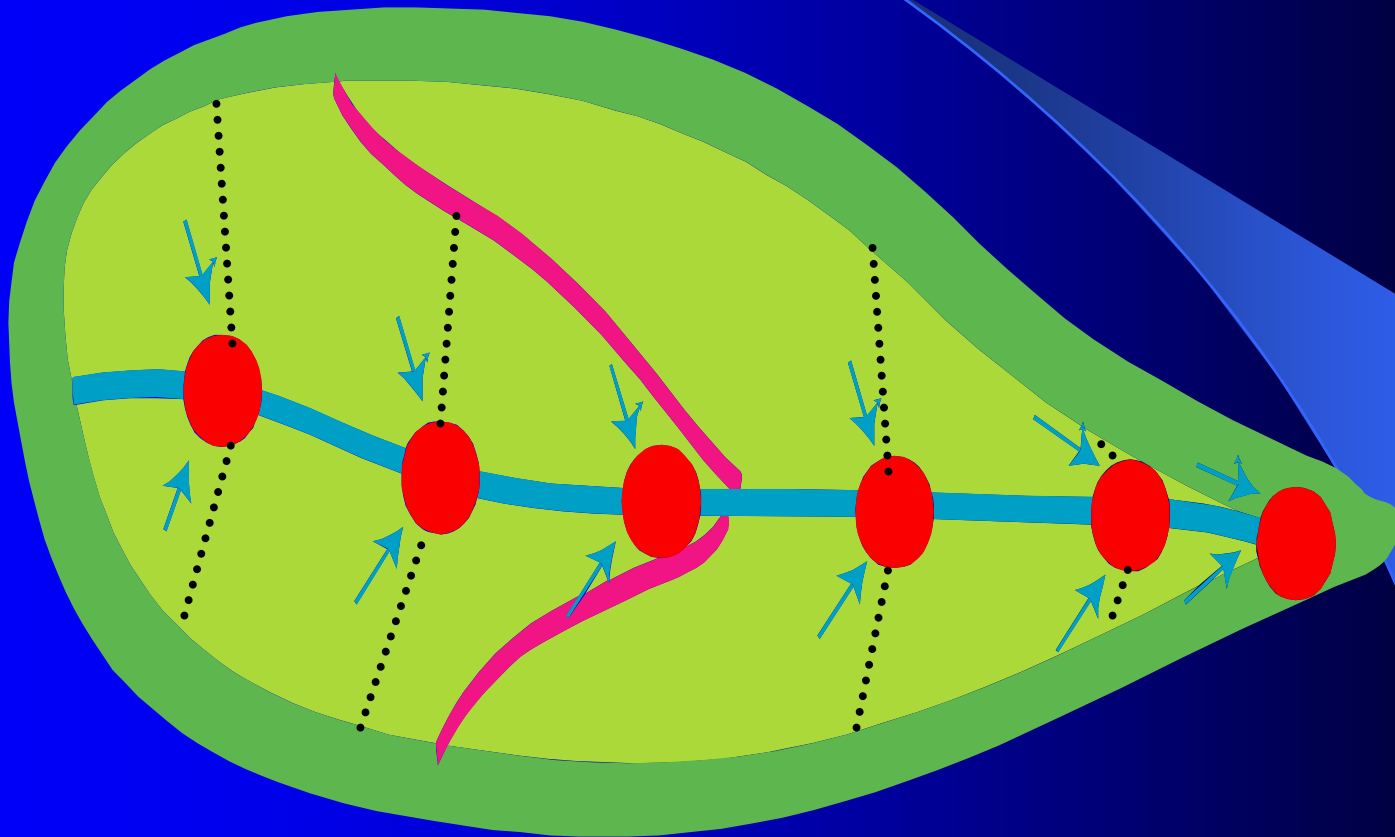
Branch/GW Cells



Nodes to GW Cells



HRU/Stream Segments

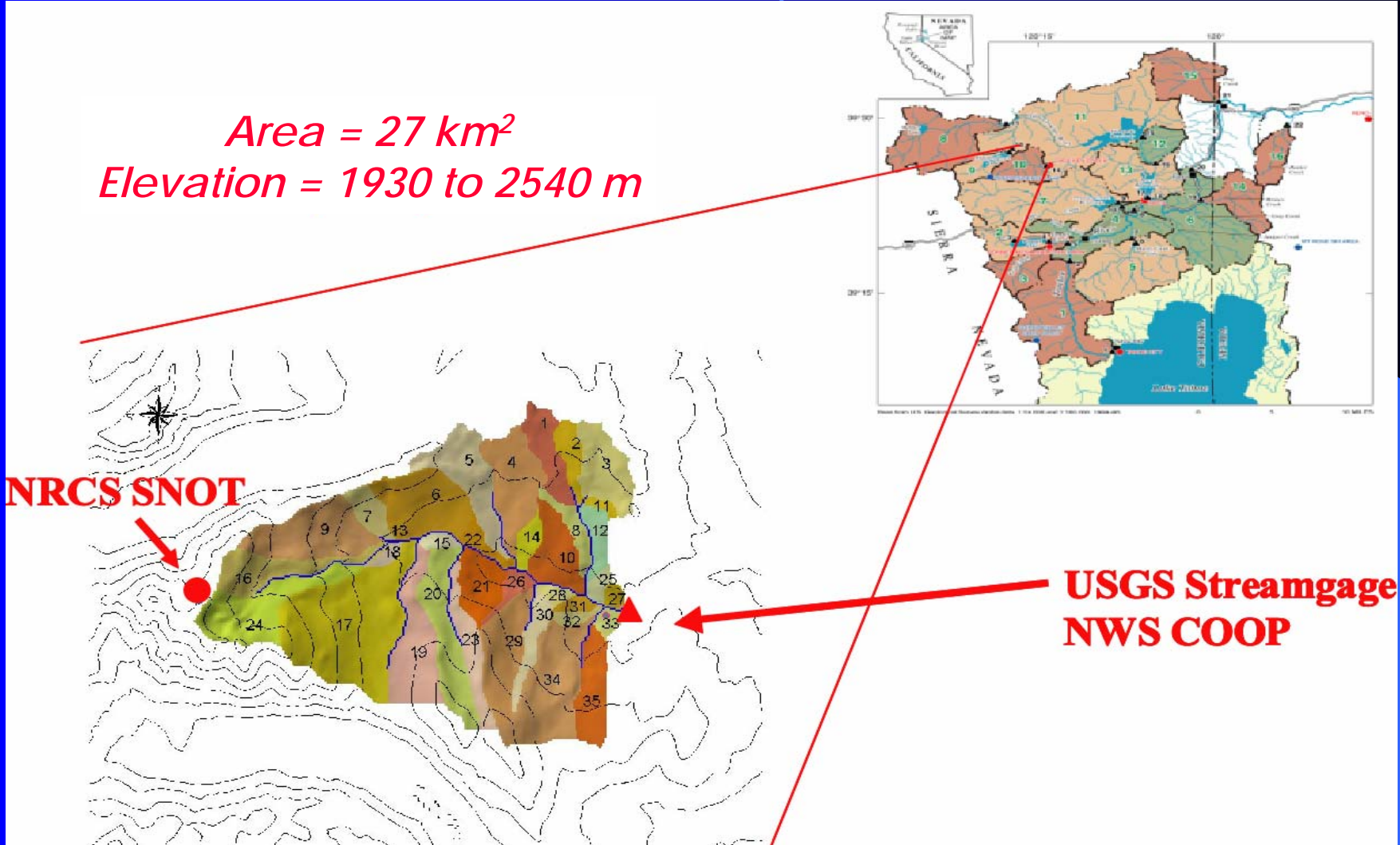


Sagehen Creek

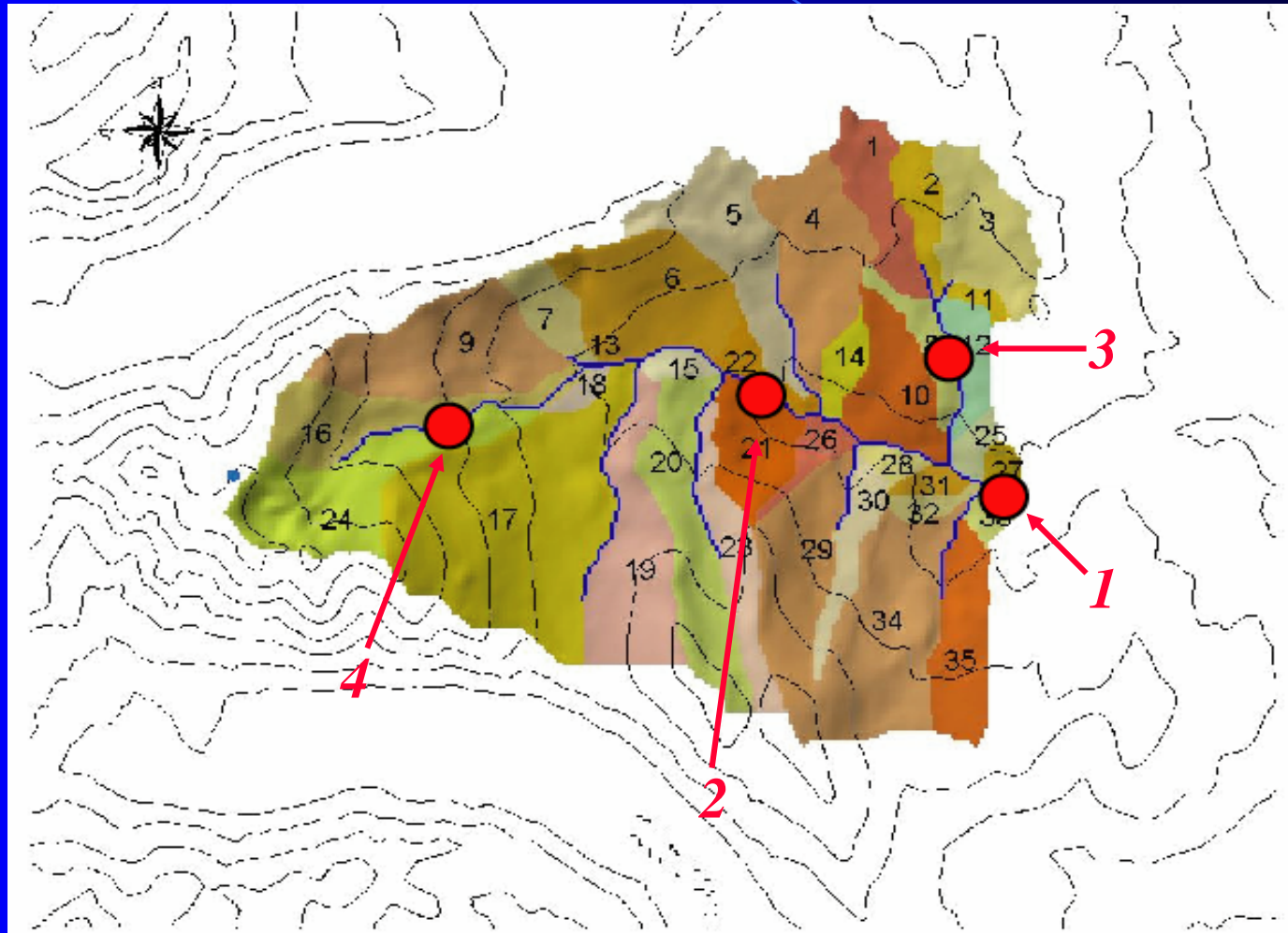
Area = 27 km²
Elevation = 1930 to 2540 m

NRCS SNOT

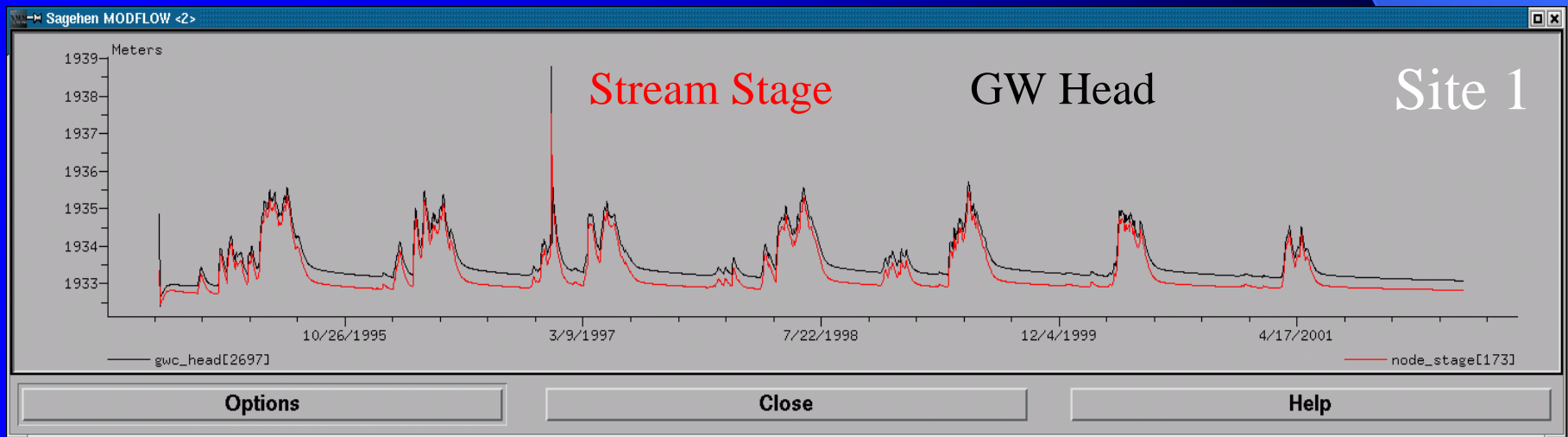
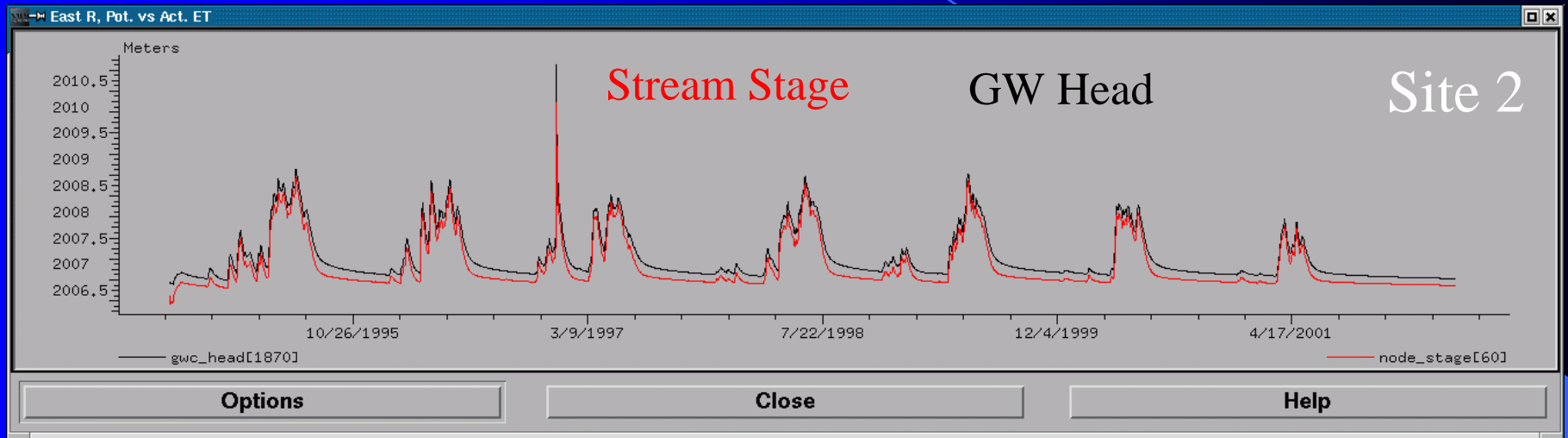
**USGS Streamgauge
NWS COOP**



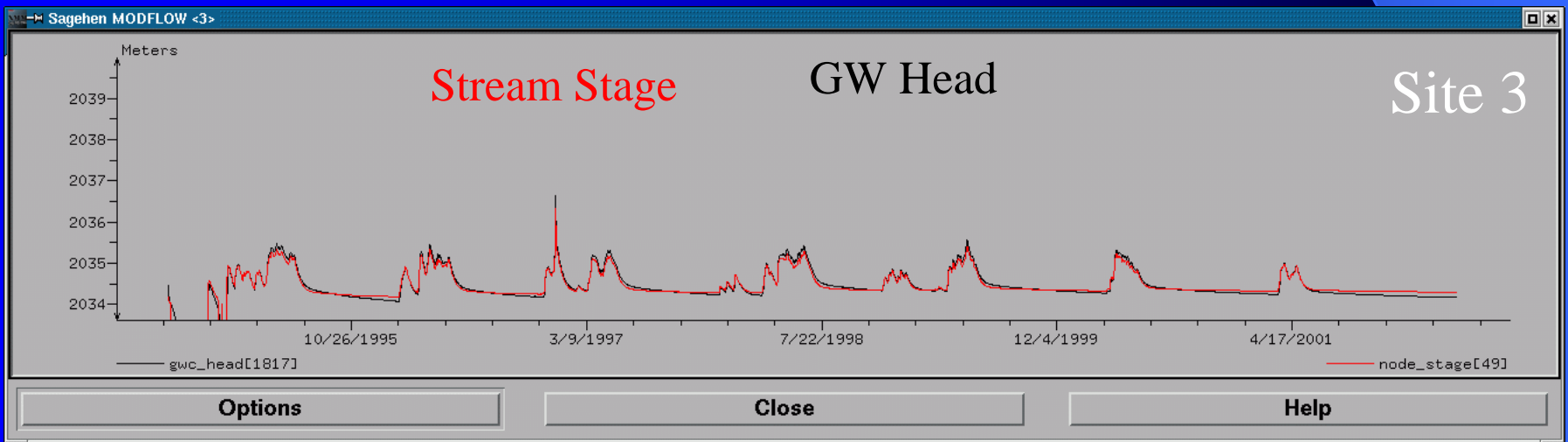
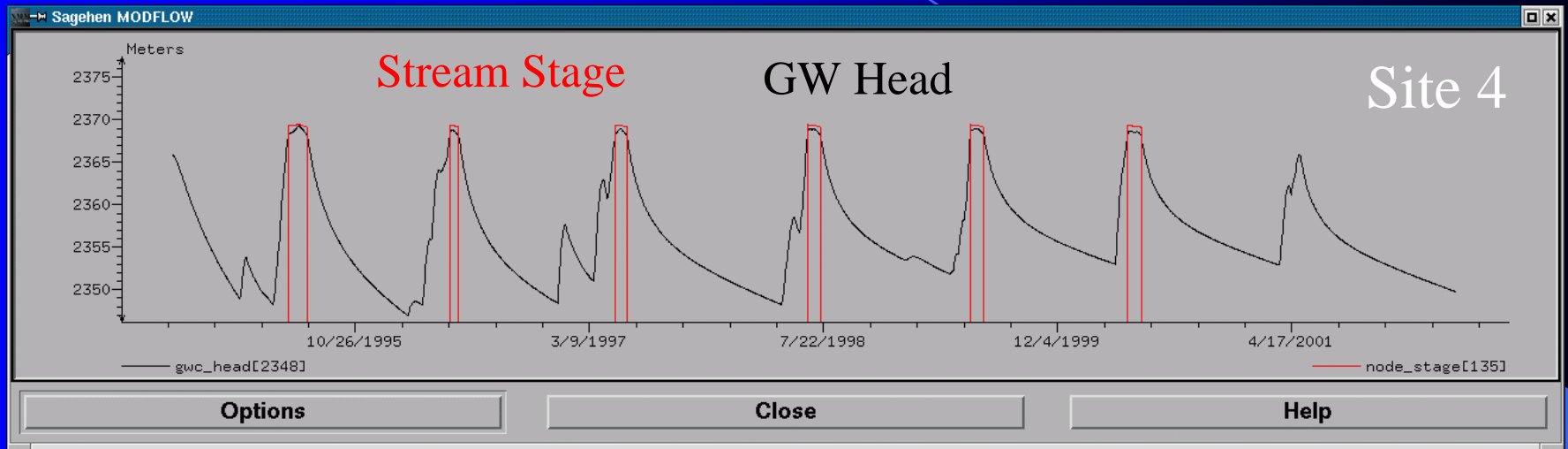
GSFLOW Results



GSFLOW Results

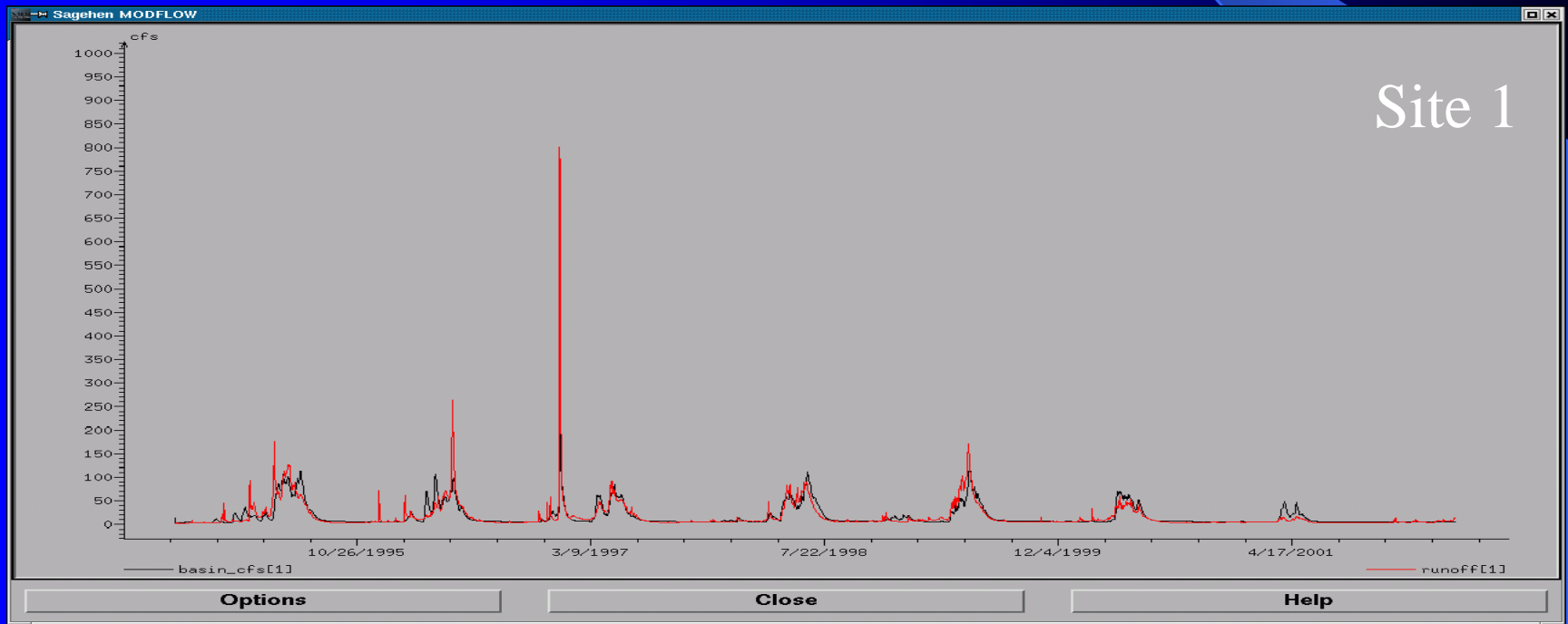


GSFLOW Results



GSFLOW Results

Observed & Predicted Streamflow

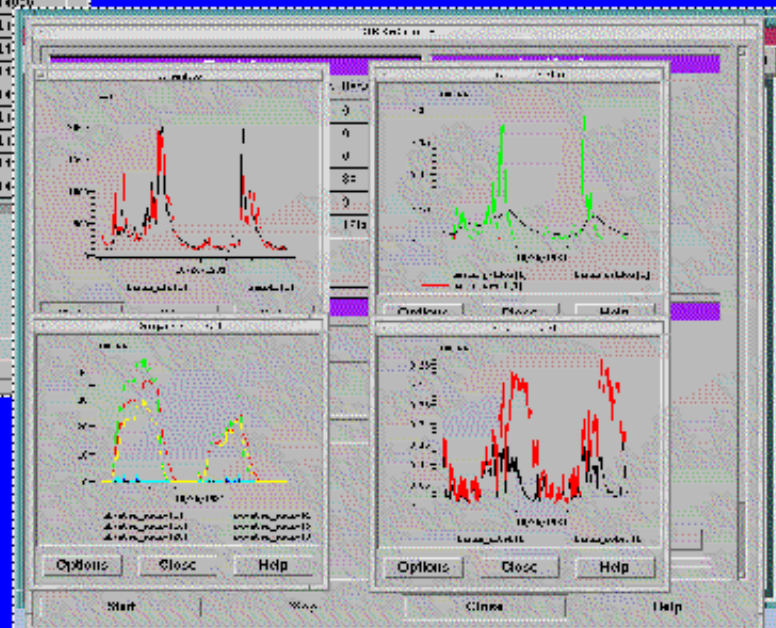
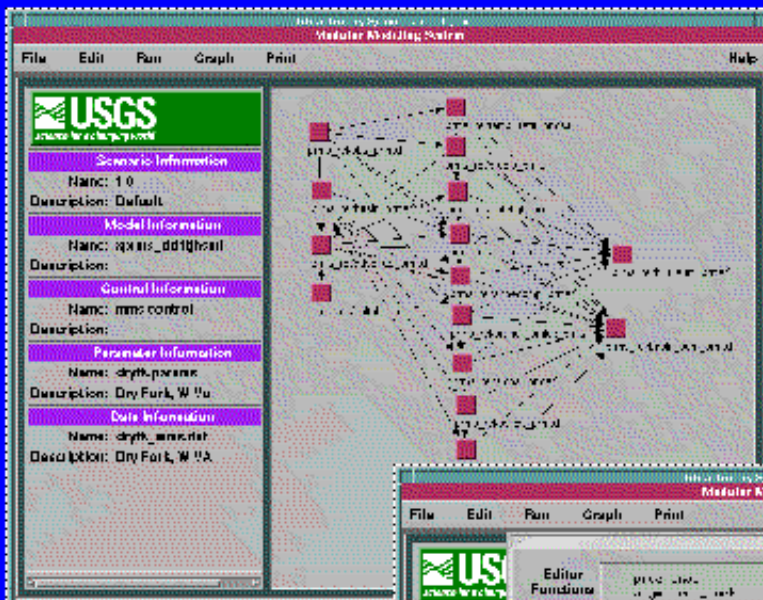


GSFLOW is distributed in

The Modular Modeling System (MMS):
A Toolbox for Water- and
Environmental Resources Management

MODULAR MODELING SYSTEM (MMS)

Model Application






MODEL BUILDING TOOL - XMBUILD

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/
- /home/mms/modules/mnt_zone/

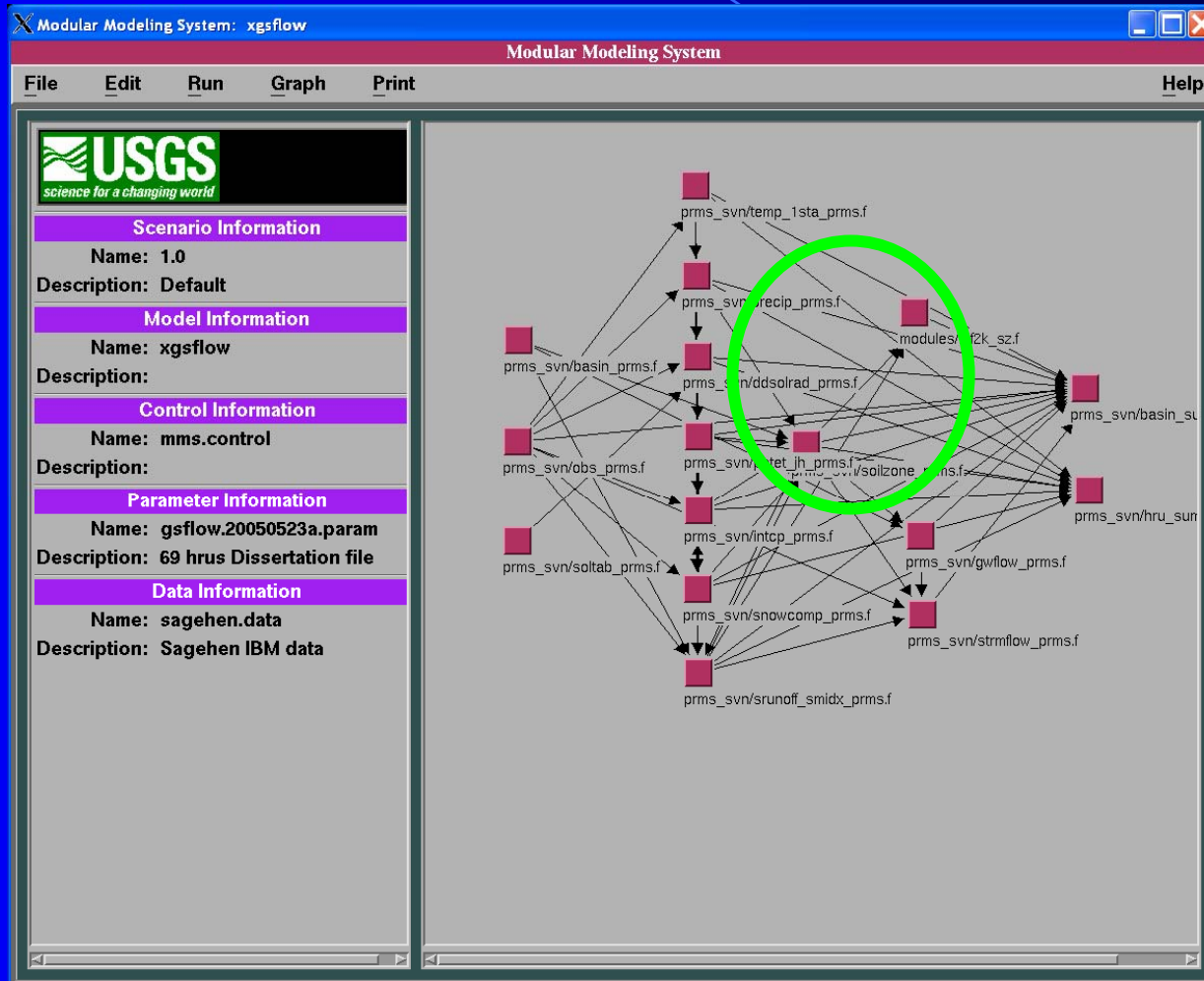
Available Modules

-  potet_jh_prms.f
-  potet_epan_prms.f
-  potet_hamon_prms.f

Current Model

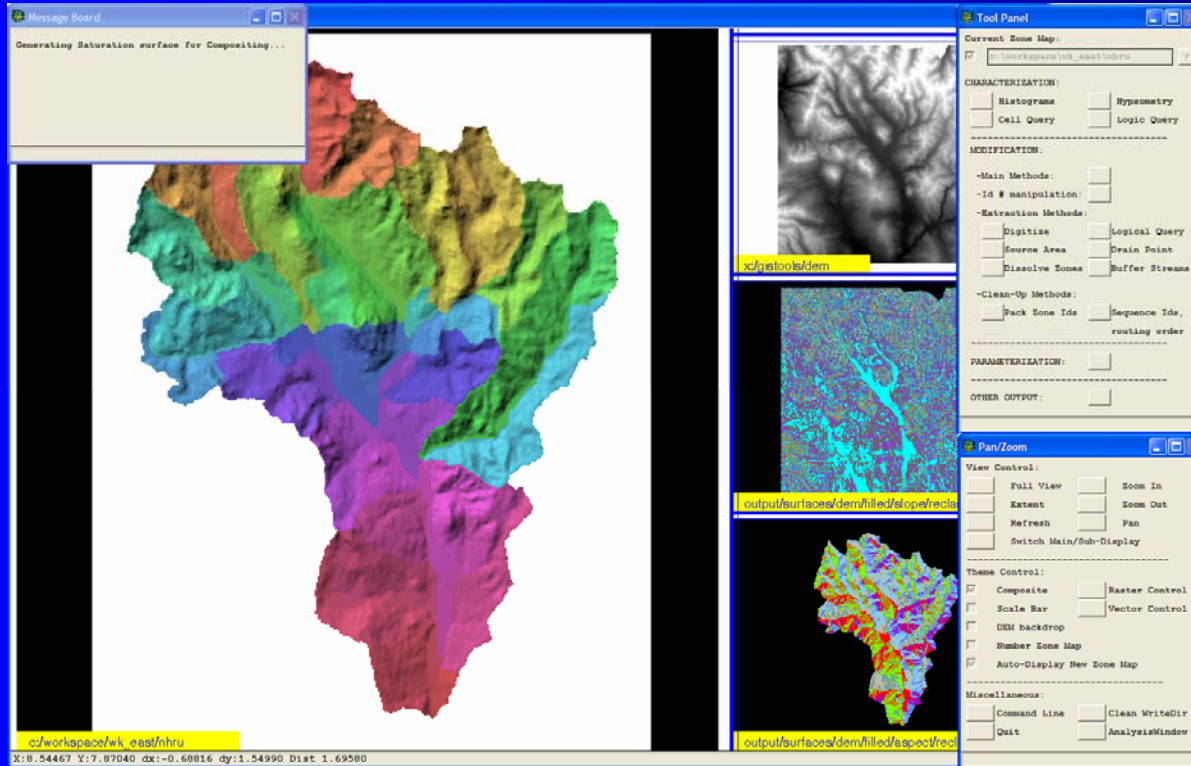
```
graph TD; A[prms_orig/basin_prms.t] --> B[prms_orig/temp_1sta_prms.f]; A --> C[prms_orig/obs_ti_prms.f]; A --> D[prms_orig/precip_prms.f]; A --> E[prms_orig/hru_sum_prms.f]; B --> F[prms_orig/potet_lh_prms.f]; C --> F; C --> G[prms_orig/ddsolred_prms.f]; C --> H[prms_orig/intop_prms.f]; C --> I[prms_orig/snowcomp_prms.f]; C --> J[prms_orig/soltab_prms.f]; D --> F; D --> G; D --> H; D --> I; D --> J; E --> K[prms_orig/srunoff_smidx_prms.f]; E --> L[prms_orig/smbal_prms.f]; E --> M[prms_orig/ssflow_prms.f]; E --> N[prms_orig/basin_sum_prms.f]; F --> O[prms_orig/gwflow_prms.f]; G --> O; H --> O; I --> O; J --> O; K --> O; L --> O; M --> O; N --> O;
```

GSFLOW



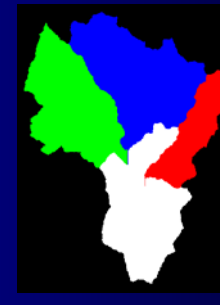
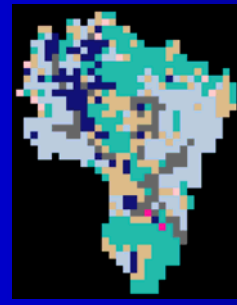
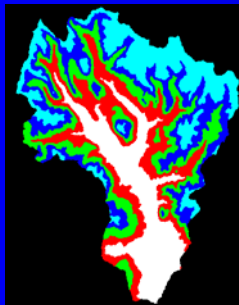


GIS WEASEL



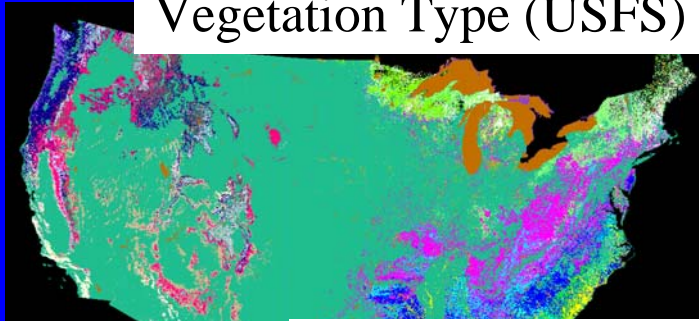
Delineation:

- Only requires elevation Grid as input
- Interactively delineate
 - Area of Interest
 - Many kinds of features
 - Streams
 - Elevation bands
 - Landuse
 - Contributing areas
 - Topographic index
 -

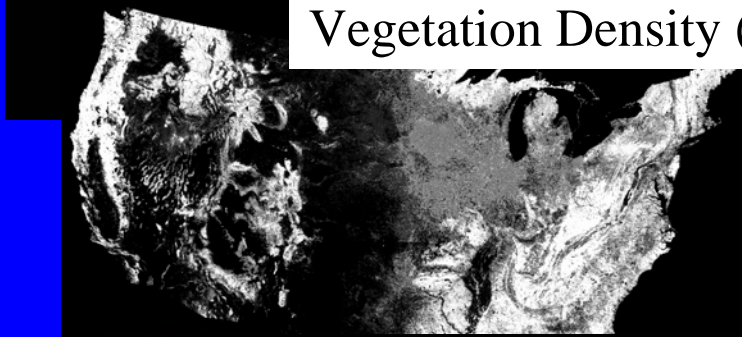


DIGITAL DATABASES

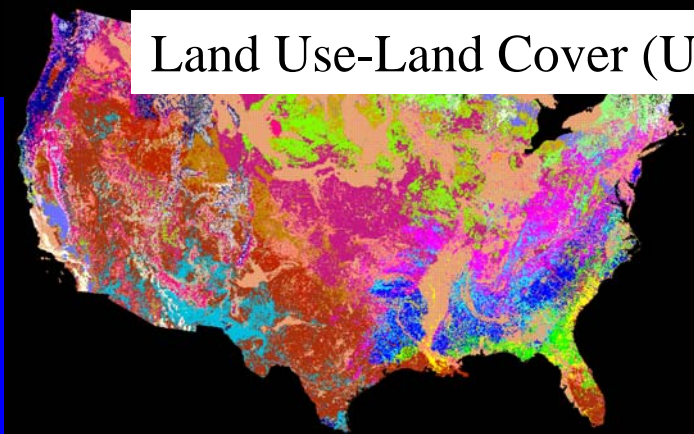
Vegetation Type (USFS)



Vegetation Density (USFS)



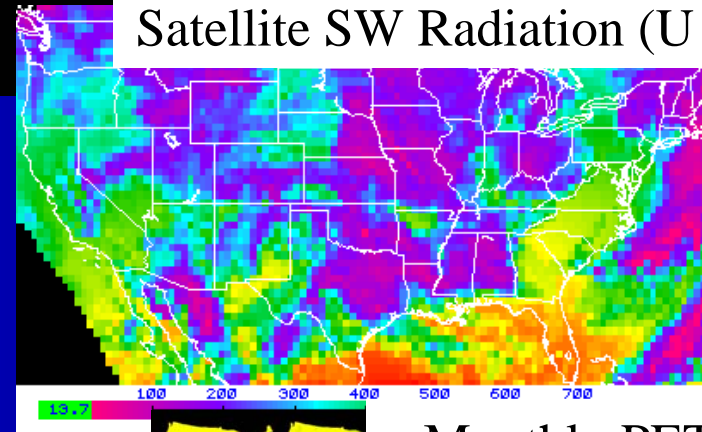
Land Use-Land Cover (USGS)



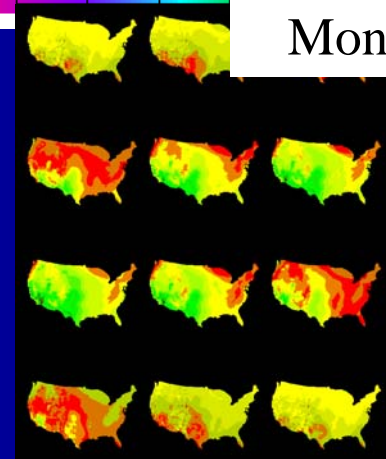
STATSGO Soils (USDA)



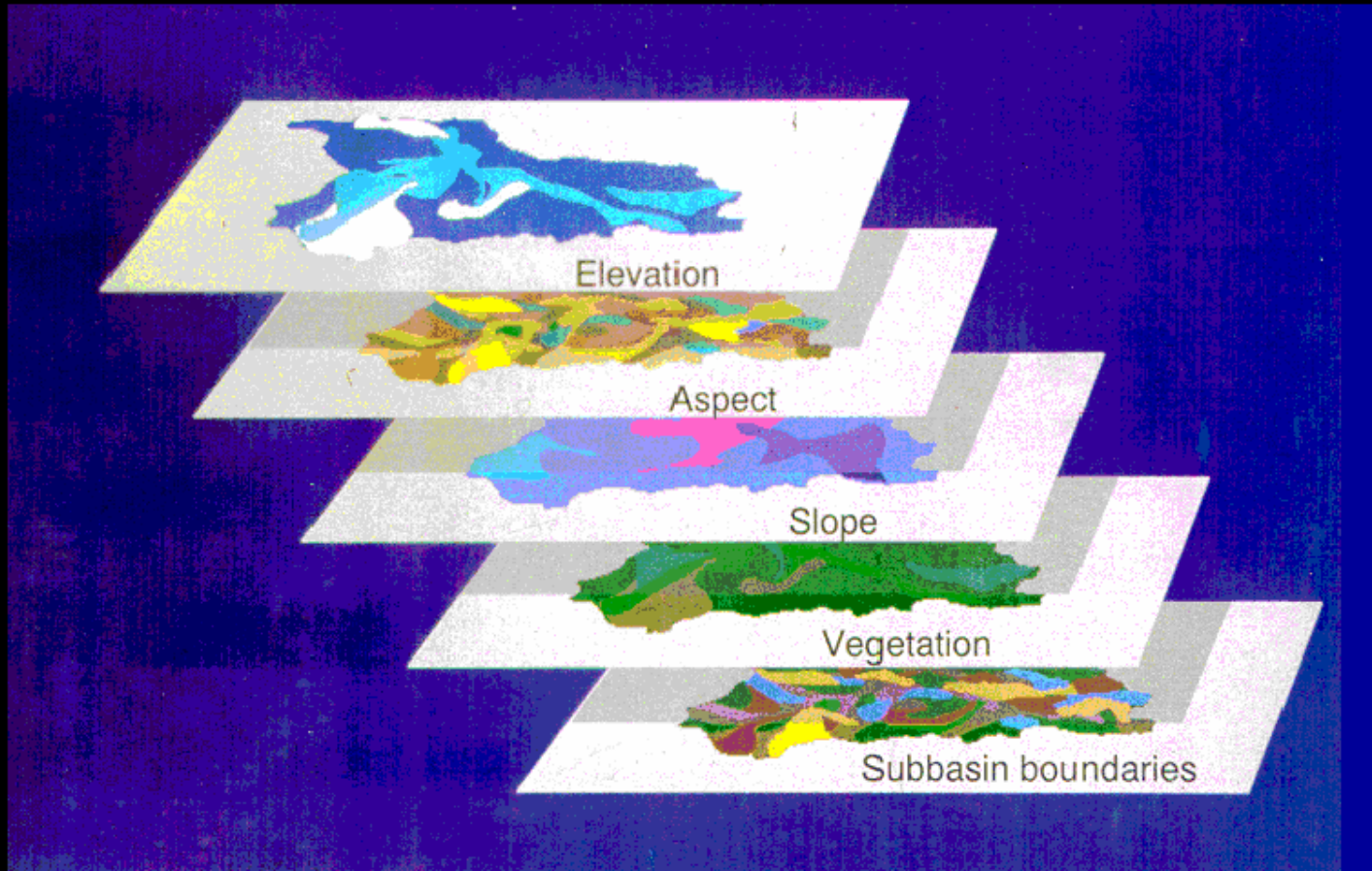
Satellite SW Radiation (U Md)



Monthly PET



AUTOMATED PARAMETER ESTIMATION USING THE GIS WEASEL





GIS WEASEL

Parameterization:

- 200+ methods available
- Easily add custom methods
- Configure recipes
- Apply to feature maps

- Exploit many types of data
- Produce maps and ASCII files of parameters

The screenshot displays the GIS WEASEL software interface. It includes several panels: 'Plugins' with a list of plugins and checkboxes; 'Parameter Settings' showing a table of parameters (Parameter Name, Dimension, Method, Interactive); 'Dimension/Method List' with a search box and a list of methods; and 'Prepared Models' with a list of model names. A central map shows a colorful, multi-classified geographical area.



A row of six maps illustrating different data types: LULC (USGS), Veg Density (USFS), Vegetation Type (USFS), STATSGO Soils (USDA), Satellite SW Radiation (U MD), and Monthly PET.

Screenshots of WordPad files generated by GIS WEASEL, showing ASCII tables of parameter values. The tables contain columns for parameter names and their corresponding values.

id	hrv_raspl	hrv_rasr	hrv_raspe	hrv_cocf_hrv	time_h3	time_h4
0	0	80	80	80	80	80
1	5	3344	0.2429000000000000	11.042000000000000	0.000000000000000	0.000000000000000
2	10	3352	0.2429000000000000	11.070000000000000	0.000000000000000	0.000000000000000
3	2	3149	0.2345000000000000	11.475000000000000	1.700000000000000	1.700000000000000
4	28	3362	0.2418000000000000	10.414000000000000	-1.000000000000000	-1.000000000000000
5	210	3474	0.4293000000000000	10.459000000000000	1.000000000000000	1.000000000000000
6	4420	3285	0.4394000000000000	11.323000000000000	0.000000000000000	0.000000000000000
7	8	3543	0.2461000000000000	10.146000000000000	0.000000000000000	0.000000000000000
8	15	3516	0.2424000000000000	10.152000000000000	1.700000000000000	1.700000000000000
9	15	3274	0.2375000000000000	11.175000000000000	0.000000000000000	0.000000000000000
10	8	3488	0.2487000000000000	10.701000000000000	0.000000000000000	0.000000000000000
11	22	3282	0.2462000000000000	11.197000000000000	0.000000000000000	0.000000000000000
12	4	2983	0.2472000000000000	12.187000000000000	0.000000000000000	0.000000000000000
13	4	3052	0.2489000000000000	11.444000000000000	1.700000000000000	1.700000000000000
14	20	3474	0.2324000000000000	10.454000000000000	-1.000000000000000	-1.000000000000000
15	2	3034	0.2485000000000000	11.107000000000000	1.700000000000000	1.700000000000000
16	2	3387	0.2470000000000000	10.144000000000000	1.000000000000000	1.000000000000000
17	18	2980	0.2487000000000000	12.119000000000000	-1.000000000000000	-1.000000000000000
18	10	3254	0.2487000000000000	11.000000000000000	0.000000000000000	0.000000000000000
19	10	2049	0.2487000000000000	11.000000000000000	1.000000000000000	1.000000000000000
20	11	1824	0.2487000000000000	11.000000000000000	1.700000000000000	1.700000000000000
21	26	3558	0.2487000000000000	11.000000000000000	-1.000000000000000	-1.000000000000000
22	27	3361	0.2487000000000000	11.000000000000000	1.000000000000000	1.000000000000000
23	26	3558	0.2487000000000000	11.000000000000000	-1.000000000000000	-1.000000000000000
24	27	3361	0.2487000000000000	11.000000000000000	1.000000000000000	1.000000000000000
25	11	9200	0.0	0.0	0.0	0.0
26	17	8943	2	270	0.2300000000000000	0.0
27	19	9062	4	220	0.2000000000000000	-1.000000000000000
28	19	2117	4	270	0.1800000000000000	-1.000000000000000
29	18	2983	4	220	0.2490000000000000	-1.000000000000000
30	18	1098	4	270	0.1490000000000000	-1.000000000000000
31	14	2297	4	270	0.1490000000000000	0.000000000000000
32	14	3632	4	270	0.1490000000000000	1.700000000000000
33	24	1133	8	270	0.1490000000000000	-1.000000000000000
34	2	1309	11	270	0.2000000000000000	1.700000000000000
35	18	3826	12	270	0.2300000000000000	-1.000000000000000
36	24	3171	19	220	0.2300000000000000	-1.000000000000000
37	24	4270	14	220	0.2300000000000000	-1.000000000000000
38	10	148	15	220	0.2300000000000000	-1.000000000000000
39	4	3423	18	130	0.2300000000000000	-1.000000000000000
40	7	6384	14	270	0.2300000000000000	-1.000000000000000
41	29	1149	19	270	0.2300000000000000	-1.000000000000000
42	7	1309	11	220	0.2300000000000000	-1.000000000000000
43	21	3278	23	220	0.2300000000000000	-1.000000000000000
44	21	4201	19	220	0.2300000000000000	-1.000000000000000
45	4	41	4	270	0.2300000000000000	-1.000000000000000
46	28	29	28	270	0.2300000000000000	-1.000000000000000
47	28	29	28	270	0.2300000000000000	-1.000000000000000
48	28	29	28	270	0.2300000000000000	-1.000000000000000
49	28	29	28	270	0.2300000000000000	-1.000000000000000
50	28	29	28	270	0.2300000000000000	-1.000000000000000

Screenshot of a WordPad file showing a table with columns for id, basin_area, and values.

id	basin_area	
1	One	1
2	1.84940.0000000000	

Forecast Methodologies

- Historic data as analog for the future

Ensemble Streamflow Prediction (ESP)

- Synthetic time-series

Weather Generator

- Atmospheric model output

Dynamical Downscaling

Statistical Downscaling

Socio-Economic Factors

(University of New Mexico, Desert Research Institute, University of Arizona)

- **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.

OBJECT USER INTERFACE (OUI)

The screenshot displays the OUI software interface, which is divided into several main sections:

- File Browser:** A tree view on the left shows the project structure under "Upper Rio Grande Project". It includes folders for "Basin Maps" (Subbasins, Streams, Cities, States, DEM, Slope, Aspect) and "Models & Data" (Input, Update MMS D, MMS Parameters, ESP Run, Animation Demo). A table below lists the loaded themes.
- Map Mode:** A large window on the right shows a 2D map of the basin. It features a red outline of the basin boundary, blue stream networks, and a grey shaded area representing the DEM. Controls for "Select", "Zoom In", and "Zoom Out" are visible at the top.
- 3D Animator:** A smaller window in the bottom-left corner shows a 3D perspective view of the terrain. It includes a color key for elevation, playback controls, and a timeline for the animation.

Name	Description	Theme	Type
Subbasins	Subbasin outline	prmsSubbasins	ESRI Shape File
Streams	Streams	streams_v	ESRI Shape File
Cities	Cities	cities	ESRI Shape File
States	States	states2m	ESRI Shape File
DEM	El Paso 1000 meter DEM	dem1 kfc	ESRI ASCII Grid
Slope	El Paso 1000 meter Slope	dem1 kfs1pc	ESRI ASCII Grid
Aspect	El Paso 1000 meter Asp...	dem1 kfaspc	ESRI ASCII Grid
Update MMS D			
Climate Da		ClimateDataStations	Shape w/MMS Data File
Streamflow		prmsSubbasinSeeds	Shape w/MMS Data File
MMS Paramete			
PRMS Para			
Xroute Pars	Edit the Xroute Paramete...		MMS Parameter Editor
ESP Run			
ESP Del Norte		prmsSubbasinSeeds	Shape w/MMS ESP Serie...
Single Run			MMS Model
Animation Demo	Demonstration of OUI's ...		MMS Model
Del Norte		prmsSubbasinSeeds	Animation w/MMS GIS O...

Name	Visible	Labels	Active	Query	Attributes
Streams	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Streamflow Data	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Key:

- 0E0 - 1.42E0
- 1.42E0 - 2.84E0
- 2.84E0 - 4.26E0
- 4.26E0 - 5.69E0
- 5.69E0 - 7.11E0
- 7.11E0 - 8.53E0
- 8.53E0 - 9.95E0
- 9.95E0 - 1.14E1
- 1.14E1 - 1.28E1
- 1.28E1 - 1.42E1
- 1.42E1 - 1.56E1
- 1.56E1 - 1.71E1
- 1.71E1 - 1.85E1
- 1.85E1 - 1.99E1
- 1.99E1 - 2.13E1
- 2.13E1 - 2.27E1

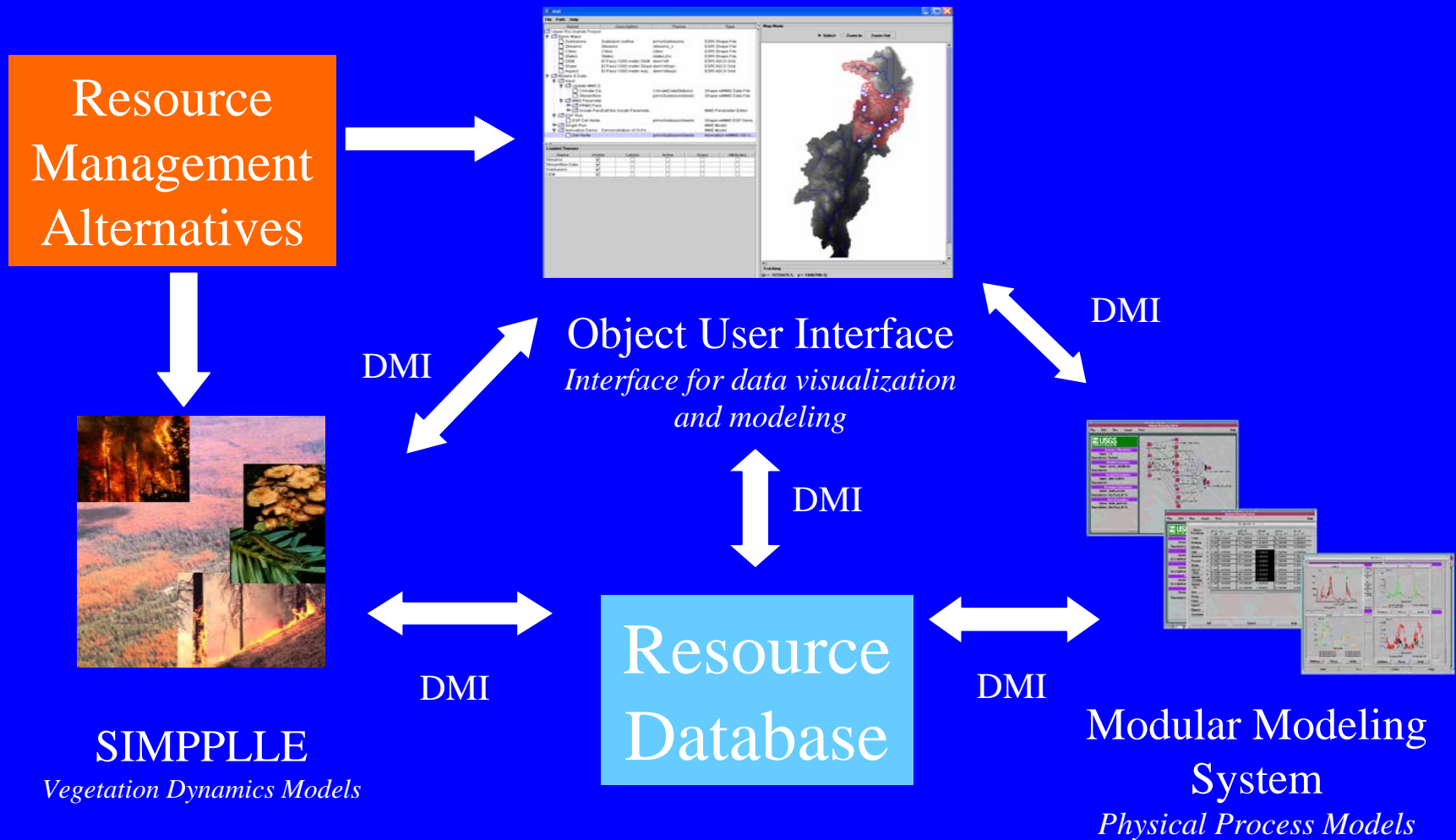
Map Date: Oct 1, 1994 to Sep 30, 1995

Z Scale: 0% to 1000% (Fast to Slow)

Animation Speed: Fast to Slow

Tracking: [x = -1233475.1, y = 1406700.1]

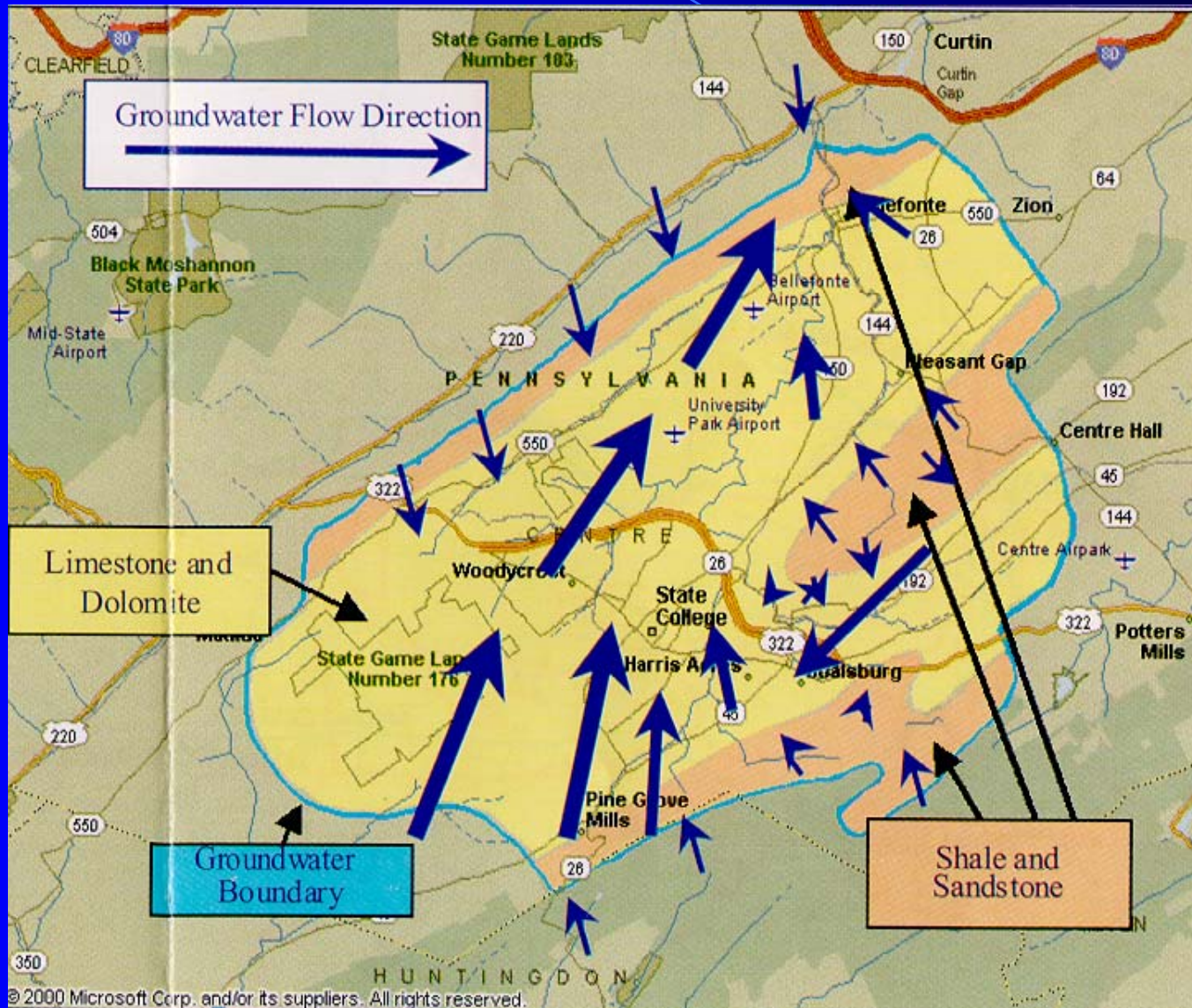
Database-Centered Decision Support System



GSFLOW Test Sites

- **Sagehen Creek, California**
- **Spring Creek, Pennsylvania**
- **Trout Creek, Wisconsin**
- **Middle Rio Grande, New Mexico**
- **Esperstedter Ried, Thuringen, Germany**

Spring Creek Basin, PA GSFLOW Model



GSFLOW

Capabilities

- 1. Any PRMS climate distribution modules**
- 2. Any PRMS ET modules**
- 3. MODFLOW lake package**
- 4. MODFLOW well package**
- 5. MODFLOW boundary conditions**
- 6. MODFLOW transport**

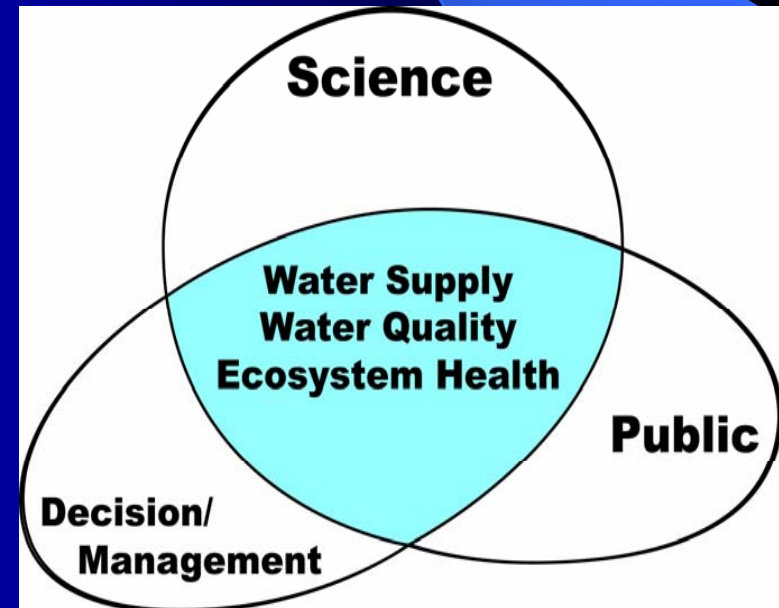
GSFLOW

Future Enhancements

- **Unsaturated zone vertical and lateral flow**
- **Calibration and uncertainty tools**
- **2D (or 3D) hydraulic routing**
- **MODFLOW / SWAT integration in MMS**
- **Temperature / Chemistry / Transport**
- **Economics: water banking and water trading**
- **Add ecosystems modules**
- **Expanded user interface and scenario generation GUI**

Integrated Modeling and Decision-Support Systems

- Facilitates multi-disciplinary integration of models and tools to address the issues of water and environmental-resource 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.



SUMMARY

- Toolbox approach to model and system development
- Supports multi-disciplinary model integration for decision support systems
- Open source software design allows many to share resources, expertise, knowledge, and costs
- Flexible framework approach enables the incorporation of continuing advances in science, databases, and computer technology

MORE INFORMATION

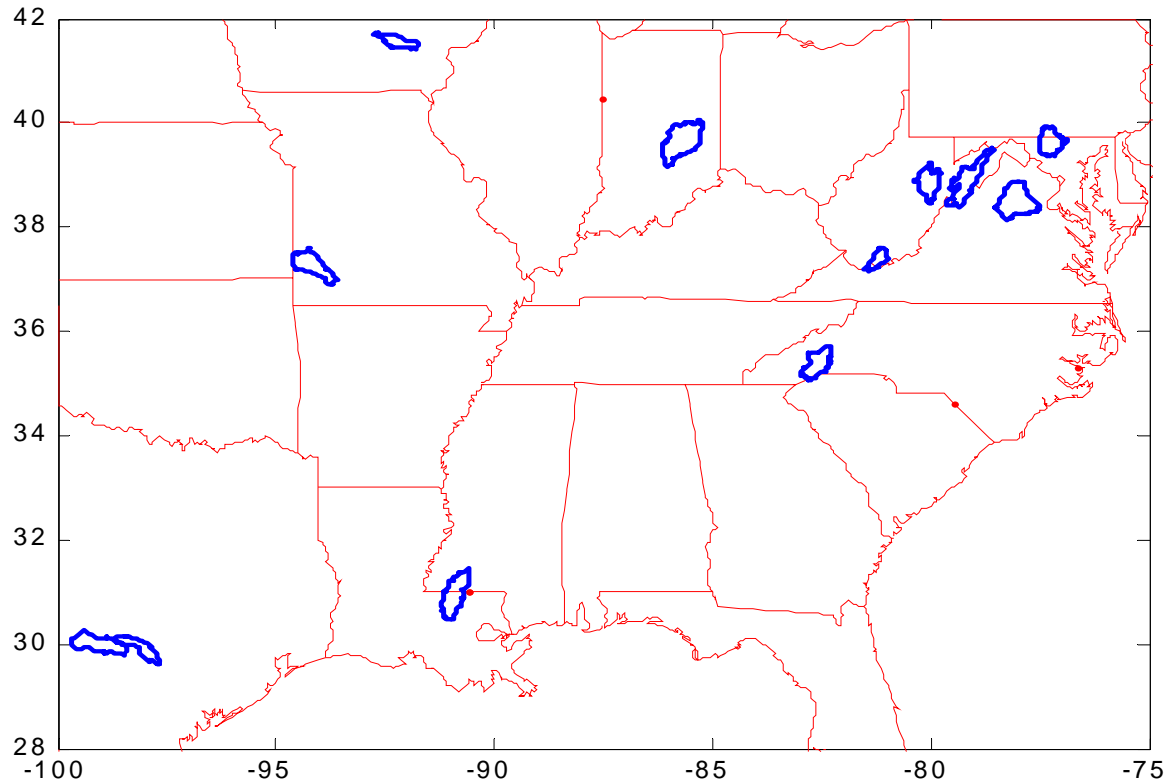
<http://wwwbrr.cr.usgs.gov/mms>

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

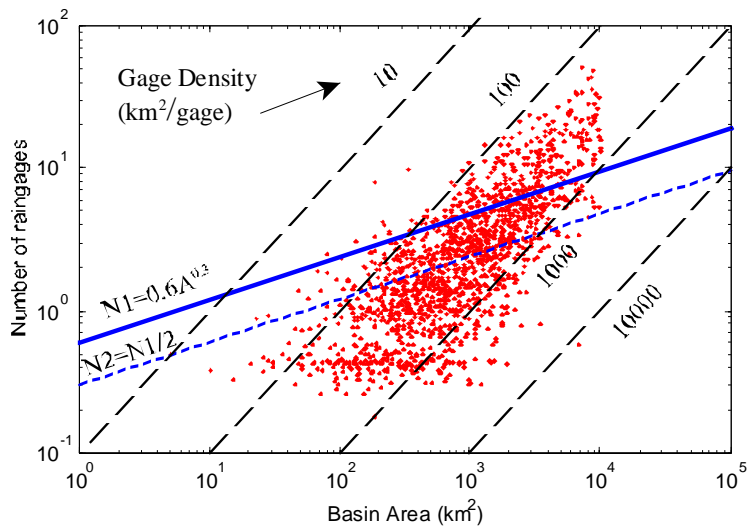
Model Parameter Estimation Experiment (MOPEX)

Location of MOPEX Basins – Workshop I

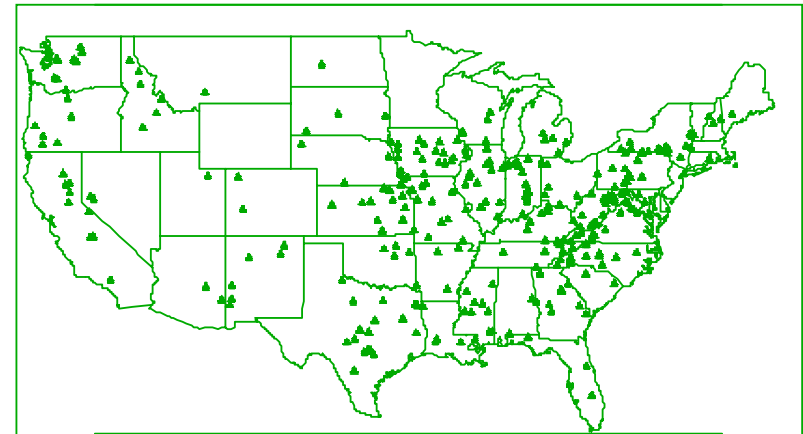
Location of 12 Basins for 2nd MOPEX workshop in Tucson



438 U.S. Basins Meet Criteria for MOPEX Basin Selection



Gage Density vs Basin Size



LOCATION OF NATURAL FLOW STREAM GAGES
WITH ADEQUATE PRECIPITATION DATA

Location of basins with
Adequate gage density