USGS Watershed Model Evolution – RRM(1972) to GSFLOW(2012)

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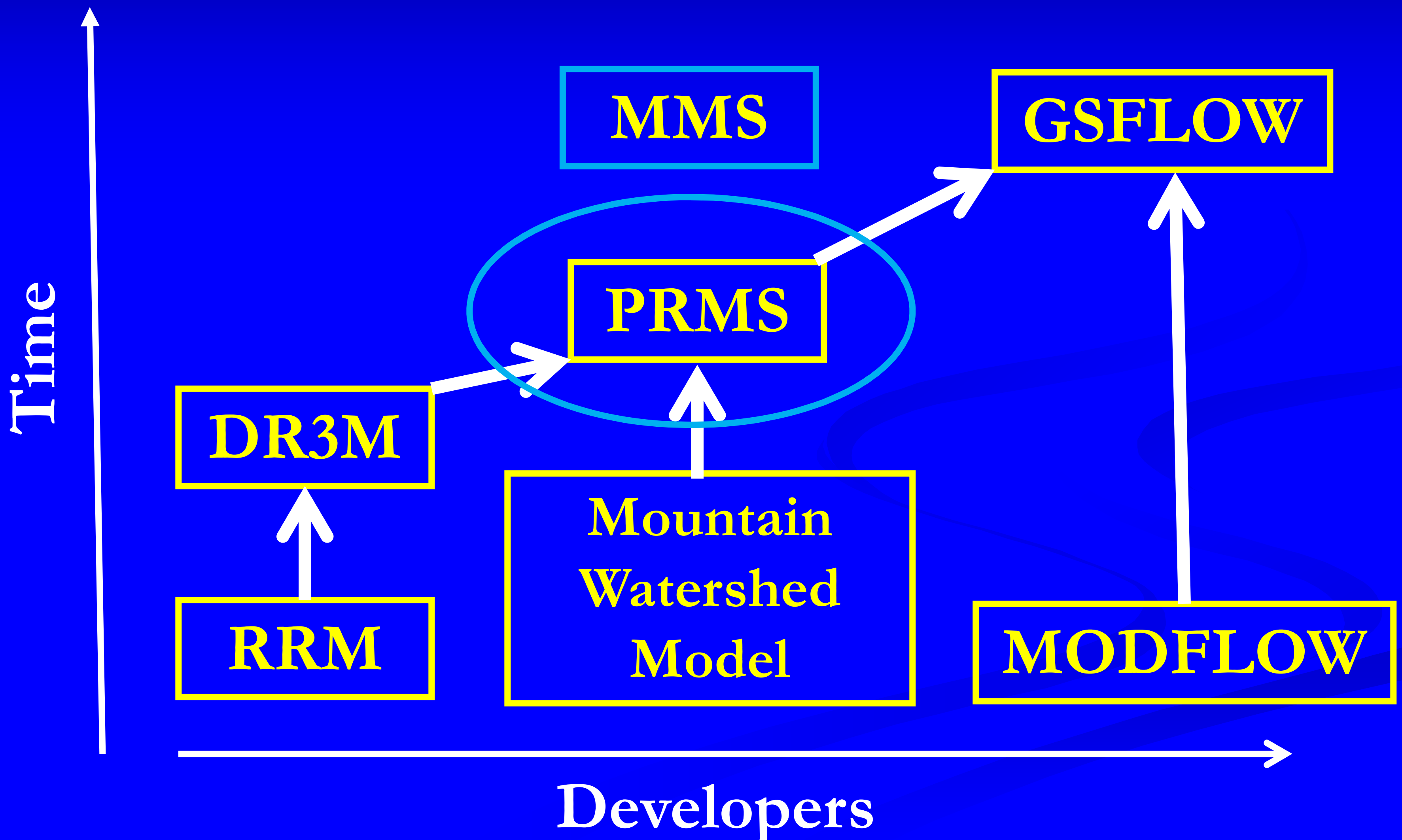
Steve Markstrom, USGS, Denver

Model Evolution

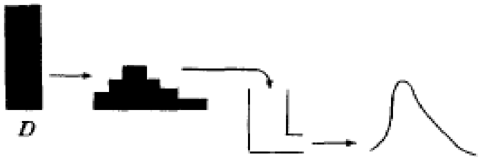


Guiding Principles – Integrated Model and System Development

- Multi-disciplinary integration of models and tools
- Incorporation of new science advances
- Open source
- Modular approach to model development
  - Model composition is function of problem objectives, data constrains, time-space of application
  - Credit Dave Dawdy for planting the seeds of modular design during a grad level class at CSU in early 1970's

Rainfall Runoff Model (RRM)

Model Components

ANTECEDENT-MOISTURE ACCOUNTING COMPONENT	INFILTRATION COMPONENT	ROUTING COMPONENT
Saturated-unsaturated soil moisture regimes	**Philip infiltration equation**	**Clark instantaneous unit hydrograph**
	$di/dt = K\,(1. + (P(m-m_0) / i))$	
<u>Vars & Params</u> Daily rainfall Daily pan evaporation Initial conditions	<u>Vars & Params</u> Storm rainfall Initial conditions Ksat and P	<u>Vars & Params</u> Rainfall excess Time-area curve Linear reservoir coeff

Dawdy, D.R., Lichty, R.W., and Bergmann, J.M., 1972, A rainfall- runoff simulation model for estimation of flood peaks for small drainage basins: U.S. Geological Survey Professional Paper 506-B, 28 p.

Model Evolution

DR3M (Distributed)

ENHANCEMENTS

- Green-Ampt infiltration
- Flow planes and channels
- Kinematic routing
  - Leclerc, Guy, and Schaake, J.C., Jr., 1973, Methodology for assessing the potential impact of urban development on urban runoff and the relative efficiency of runoff control alternatives: Ralph M. Parsons Laboratory Report no. 167, Massachusetts Institute of Technology, 257 p.

RRM (Lumped)

Time

Developers

Distributed Routing Rainfall Runoff Model (DR3M)

Model Features

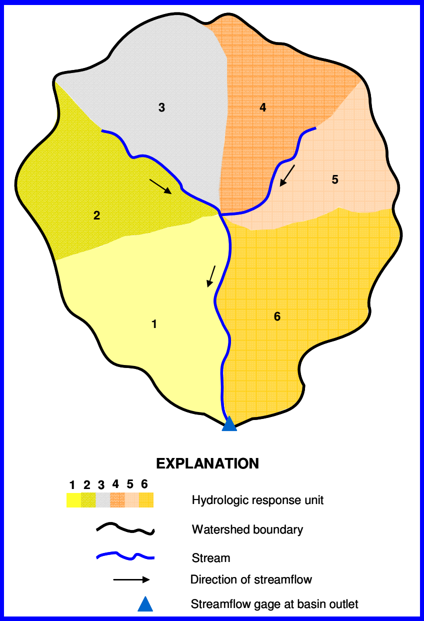
- Pervious and impervious area rainfall excess
- Green-Ampt infiltration equation for rainfall excess
- Kinematic routing for flow planes and channels
- Multiple solution techniques for kinematic routing
- Soil moisture accounting between storms
- Interflow and baseflow not simulated
- Snow accumulation and melt are not simulated

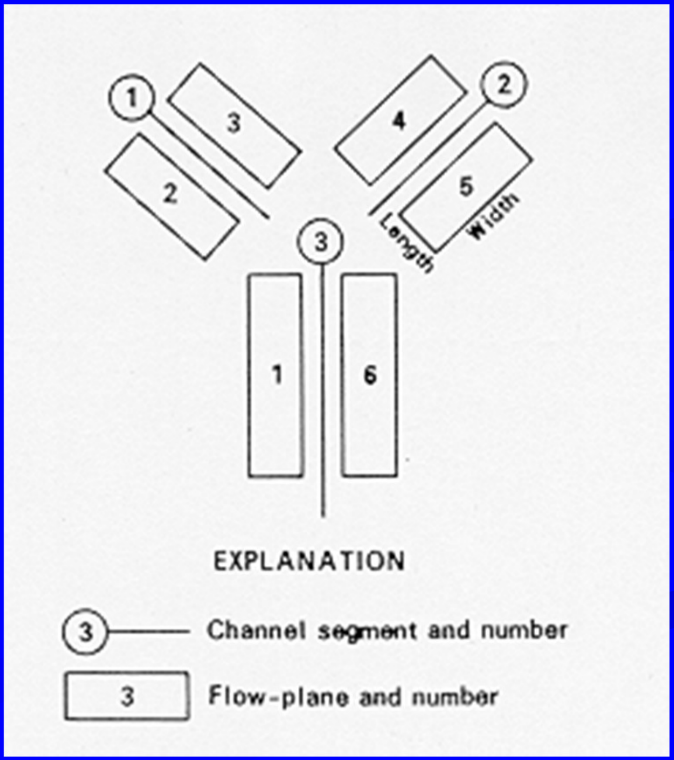
Dawdy, D.R., Schaake, J.C., Jr., and Alley, W.M., 1978, User's guide for distributed routing rainfall-runoff model: U.S. Geological Survey Water-Resources Investigations Report 78-90, 146 p.

Alley, W.M., and Smith, P.E., 1982, Distributed routing rainfall- runoff model--version II: U.S. Geological Survey Open-File Report 82-344, 201 p.

Distributed Routing Rainfall Runoff Model (DR3M)

Flow Planes and Channels





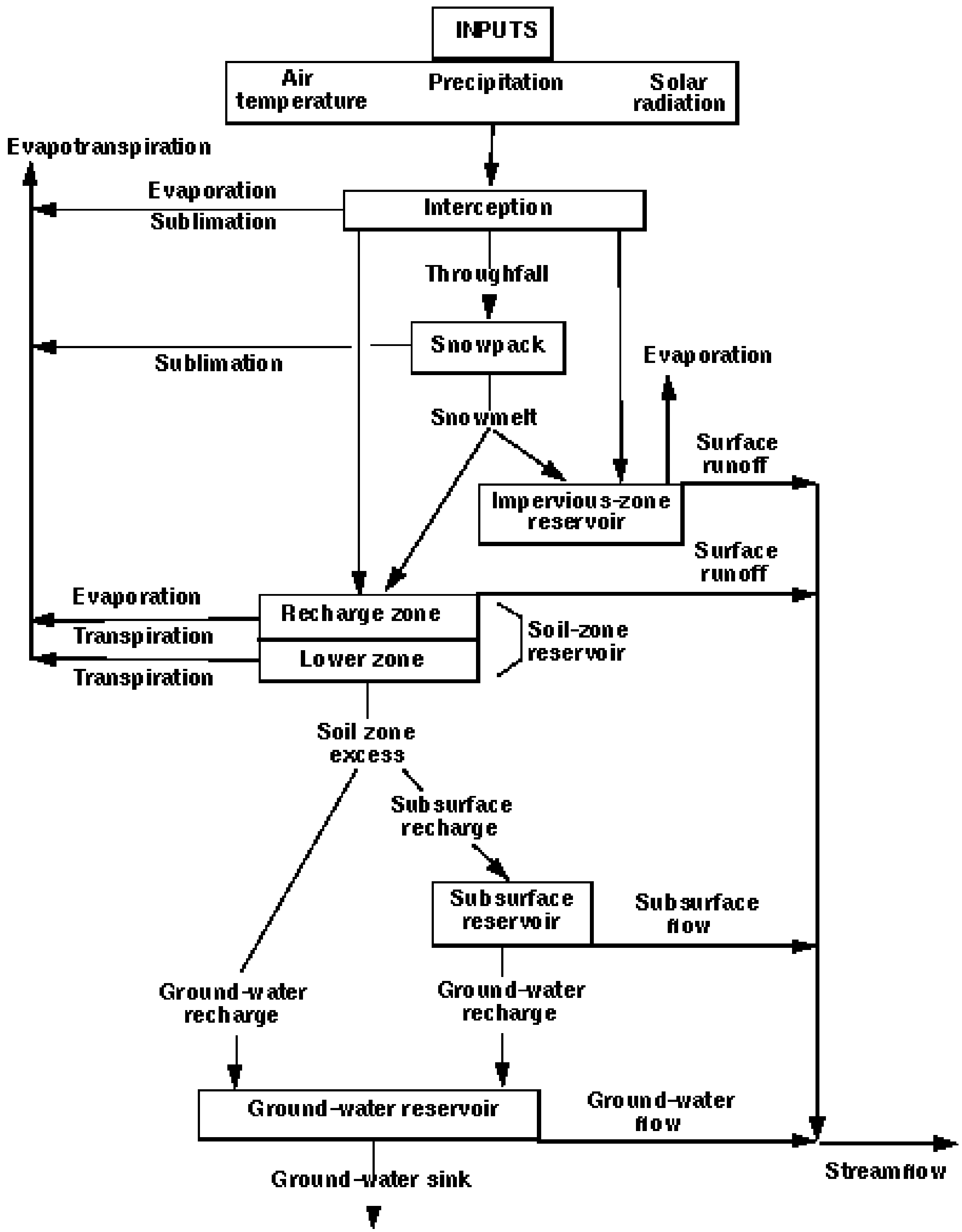
Mountain Watershed Model

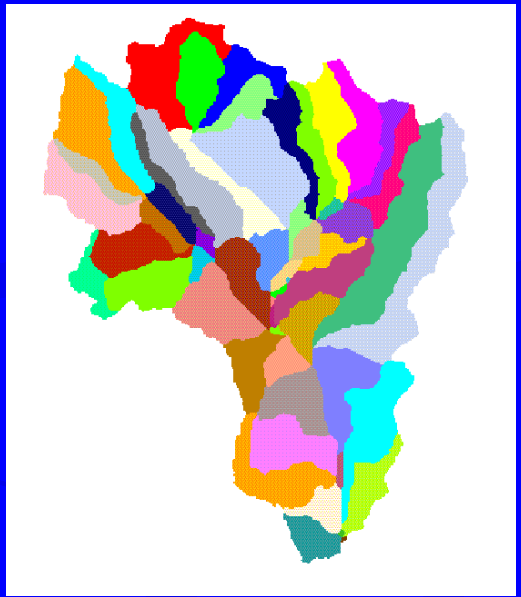
Model Features

- Daily time step
- Distributed hydrologic response unit (HRU) based
- Surface runoff computed using contributing area concept
- Subsurface and groundwater flows computed as nonlinear and linear reservoirs
- Snow accumulation and melt computed using an energy budget approach

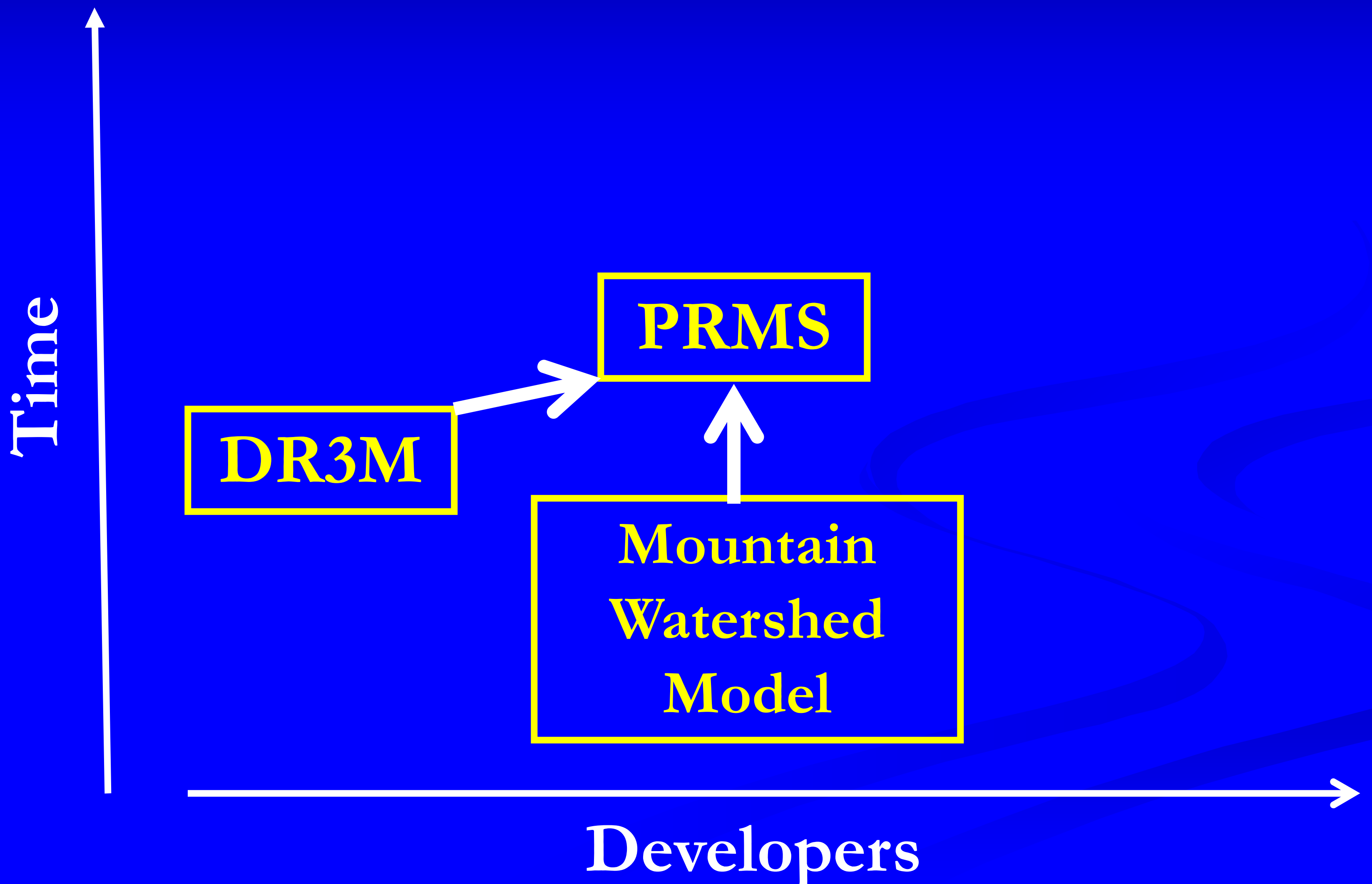
Leavesley, G.H., 1973, A mountain watershed simulation model: Fort Collins, Colorado, Colorado State University, Ph. D. dissertation, 174 p.

Mountain Watershed Model





Model Evolution

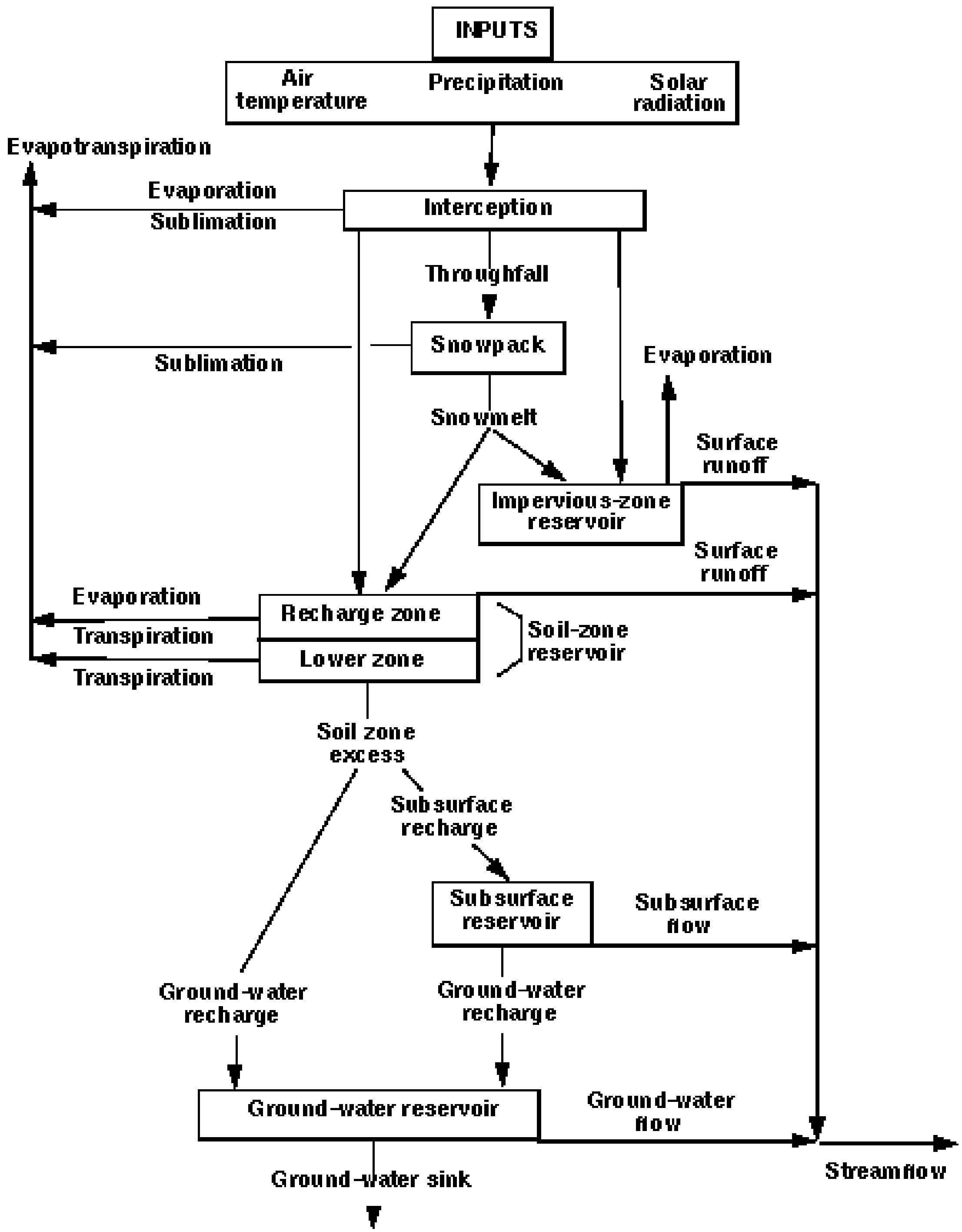


Precipitation-Runoff Modeling System (PRMS)

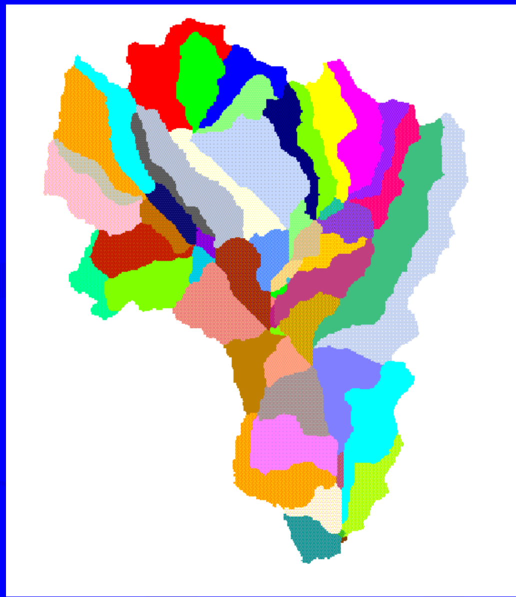
Model Features

- Modular design
- Integrates daily and storm mode time steps
- Computes surface, subsurface, and groundwater flow at all time steps
- User selectable components for ET, precip and temp distribution, surface runoff, and solar radiation computations
- Includes optimization and sensitivity analysis tools

Leavesley, G.H., Lichty, R.W., Troutman, B.M., and Saindon, L.G., 1983, Precipitation-runoff modeling system—User's manual: U.S. Geological Survey Water-Resources Investigations Report 83-4238, 207 p.


INPUTS
Air temperature
Precipitation
Solar radiation
Evapotranspiration
Evaporation
Sublimation
Interception
Throughfall
Snowpack
Sublimation
Evaporation
Snowmelt
Surface runoff
Impervious-zone reservoir
Surface runoff
Evaporation
Recharge zone
Transpiration
Lower zone
Transpiration
Soil-zone reservoir
Soil zone excess
Subsurface recharge
Subsurface reservoir
Subsurface flow
Ground-water recharge
Ground-water recharge
Ground-water reservoir
Ground-water flow
Ground-water sink
Streamflow

PRMS



PRMS Modular Design

- **Conceptually a great idea**
- **Implementation in PRMS, less than desirable**
  - **Few support tools**
  - **Coding complexity**
  - **Spaghetti coding**

Enter the Modular Modeling System (MMS)

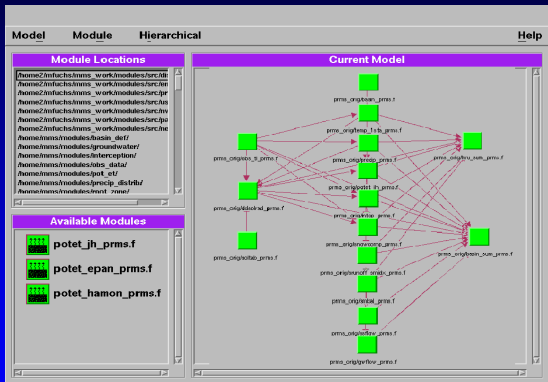
- **Developed in collaboration with the Center for Advanced Decision Support in Water and Environemental Systems (CADSWES), Univ of Colorado, Boulder, CO**

Leavesley, G.H., Restrepo, P.J., Markstrom, S.L., Dixon, M., and Stannard, L.G., 1996b, The Modular Modeling System (MMS): User's manual: U.S. Geological Survey Open-File Report 96-151, 142 p.

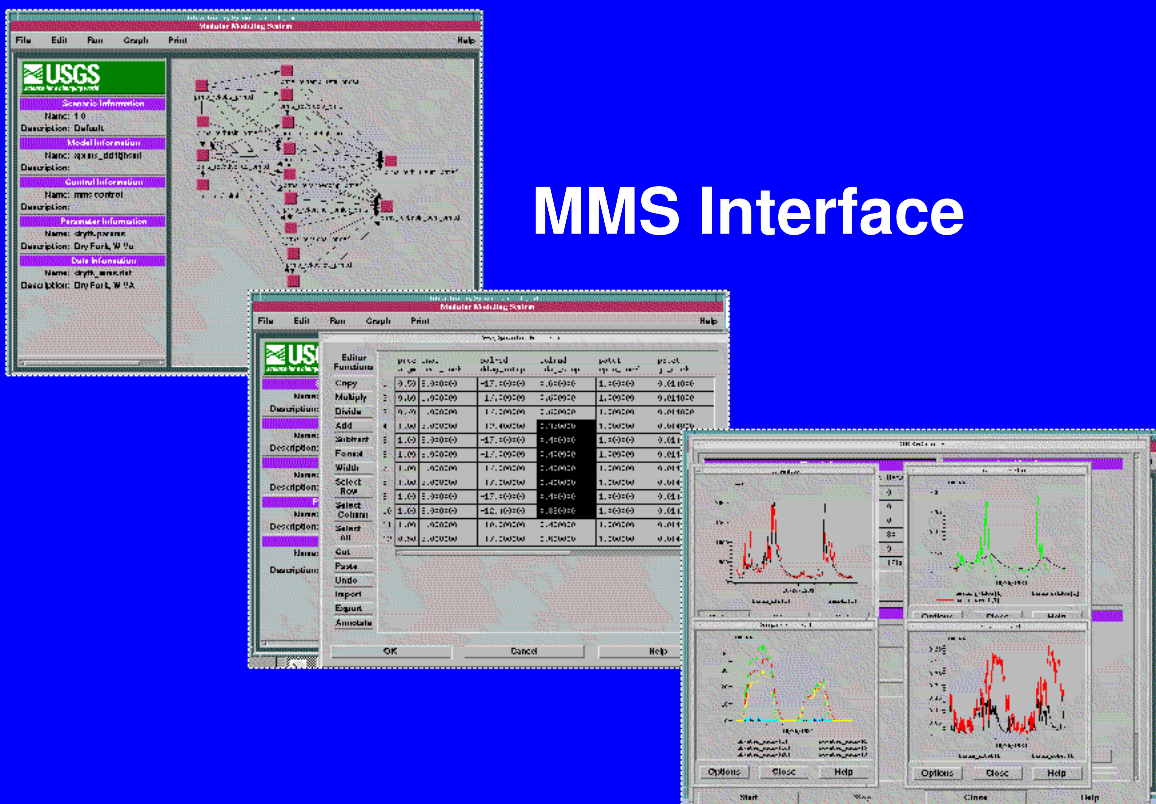
MMS Developed to Address a Range of Modular Design Levels

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

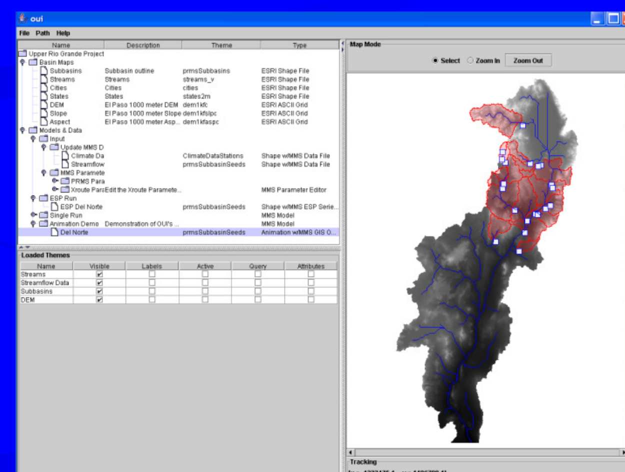
MODULAR MODELING SYSTEM (MMS)



Model Builder



MMS Interface

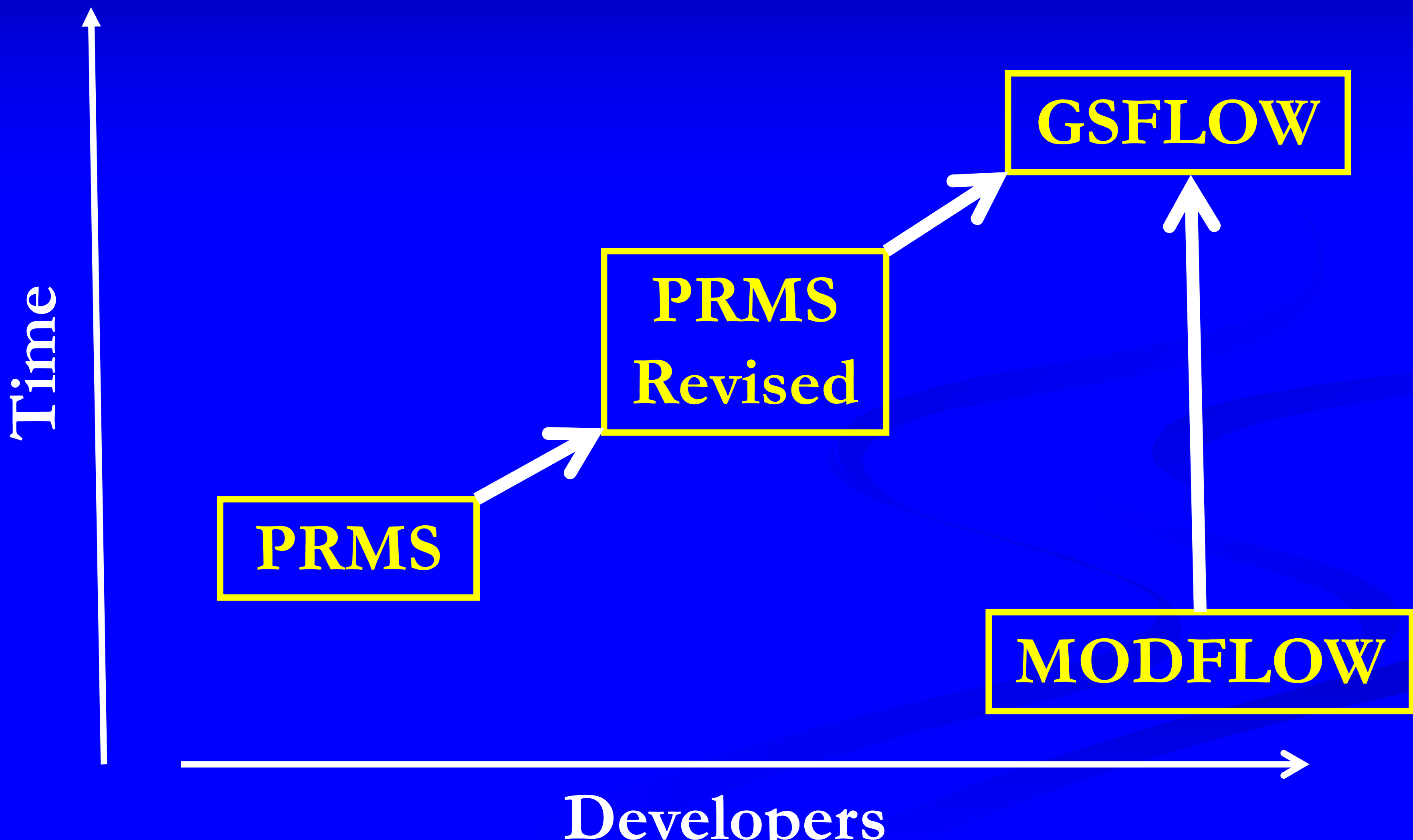


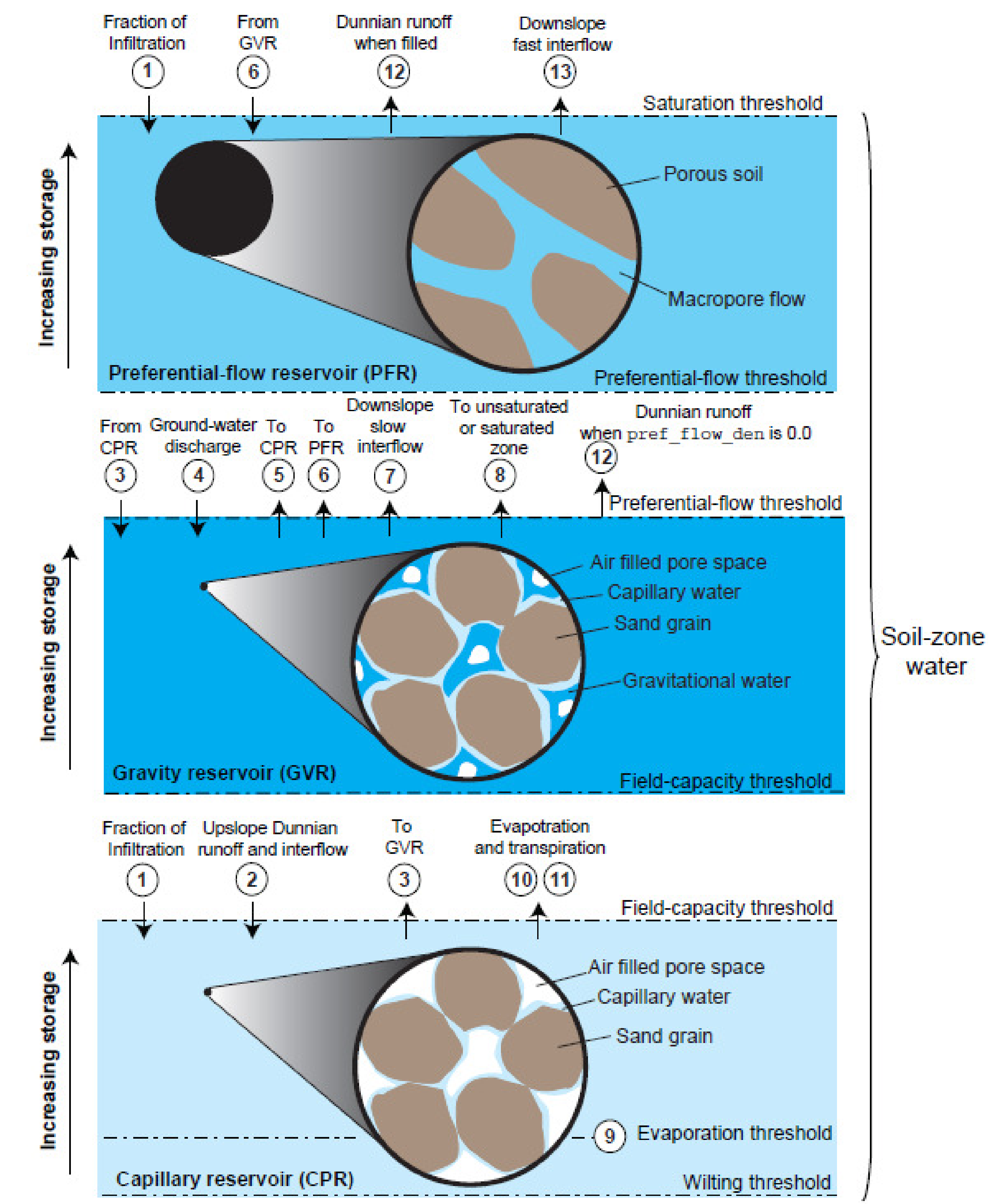
Object User Interface

Analysis and Support Tools Integrated with MMS and PRMS

- The GIS Weasel
- LUCA – A Multi-step multi-objective calibration tool
- Esemble Streamflow Prediction
- Data retrieval Downsizer

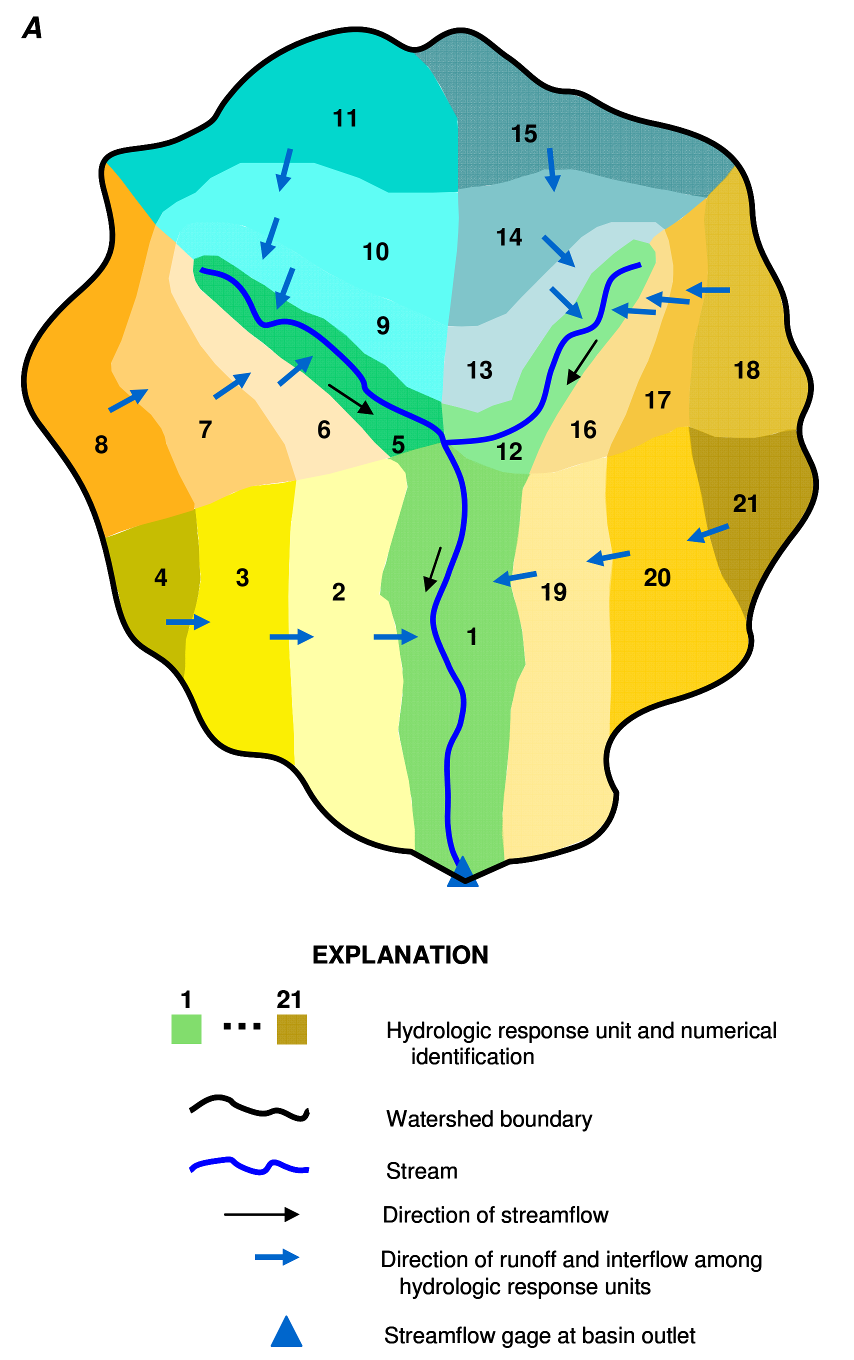
Model Evolution



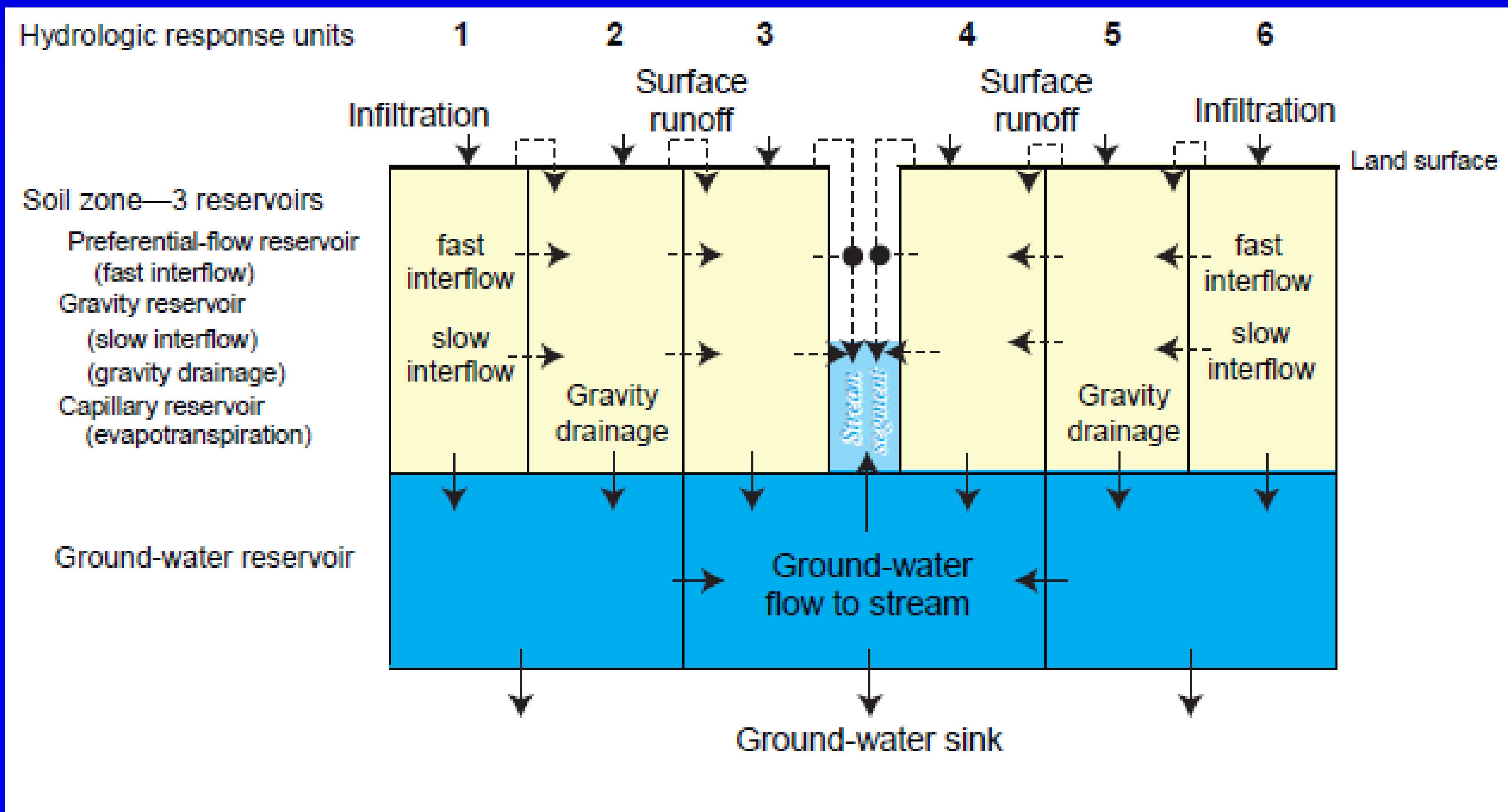


Conceptual Revised Soil Zone Structure and Flow Computation Sequence

Revision Adds Cascading HRU Flow Paths



Revised PRMS Conceptualization



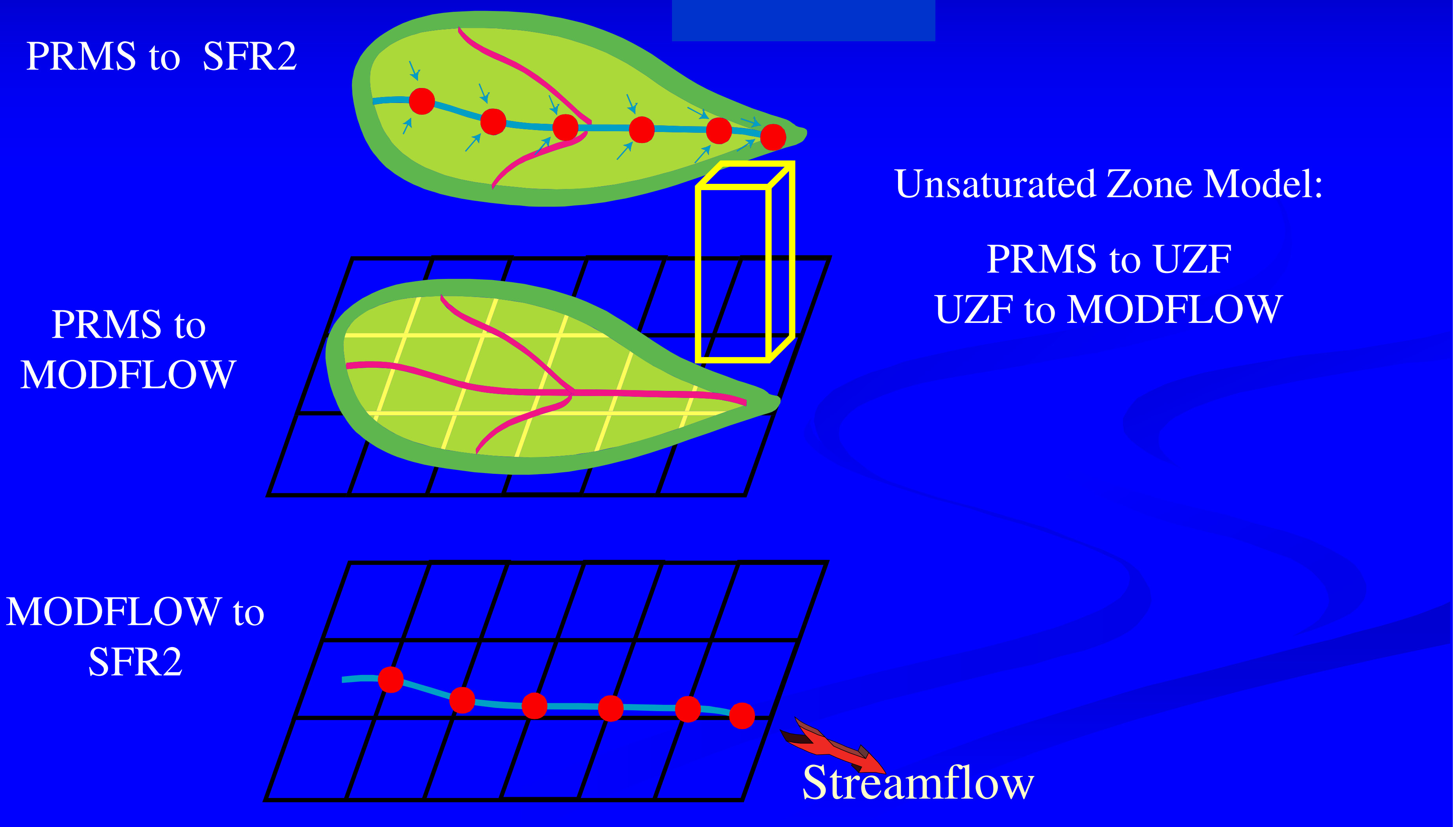
Coupled Groundwater Surface-Water Flow Model (GSFLOW)

Model Features

- **Daily time step**
- **Simultaneously simulates flow across the land surface, within subsurface saturated and unsaturated materials, and within streams and lakes**
- **3 simulation modes (integrated, PRMS only, MODFLOW only) allow incrimental setup and calibration**

Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW—Coupled ground-water and surface-water flow model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods 6-D1, 240 p.

GSFLOW -- Coupled PRMS, MODFLOW, SFR, and Unsaturated Zone Models



Model Developer Credits

Alley, W.M.
Barlow, P.M.
Bergman, J.M.
Dawdy, D.R.
Dixon, M.
Hay, L.E.
Harbaugh, A.W.
Lichty, R.W.
Markstrom, S.L.
Niswonger, R.G.
Prudic, D.E.
Regan, R.S.
Restrepo, P.J.
Schaake, J.W. Jr
Smith, P.E.
Stannard, L.G.
Troutman, B.M.

In Conclusion

- Legacy of watershed model development and application that goes back 40 years
- Responds to the technology and need of the time
- Many people have contributed