Scale Effects in Large Scale Watershed Modeling

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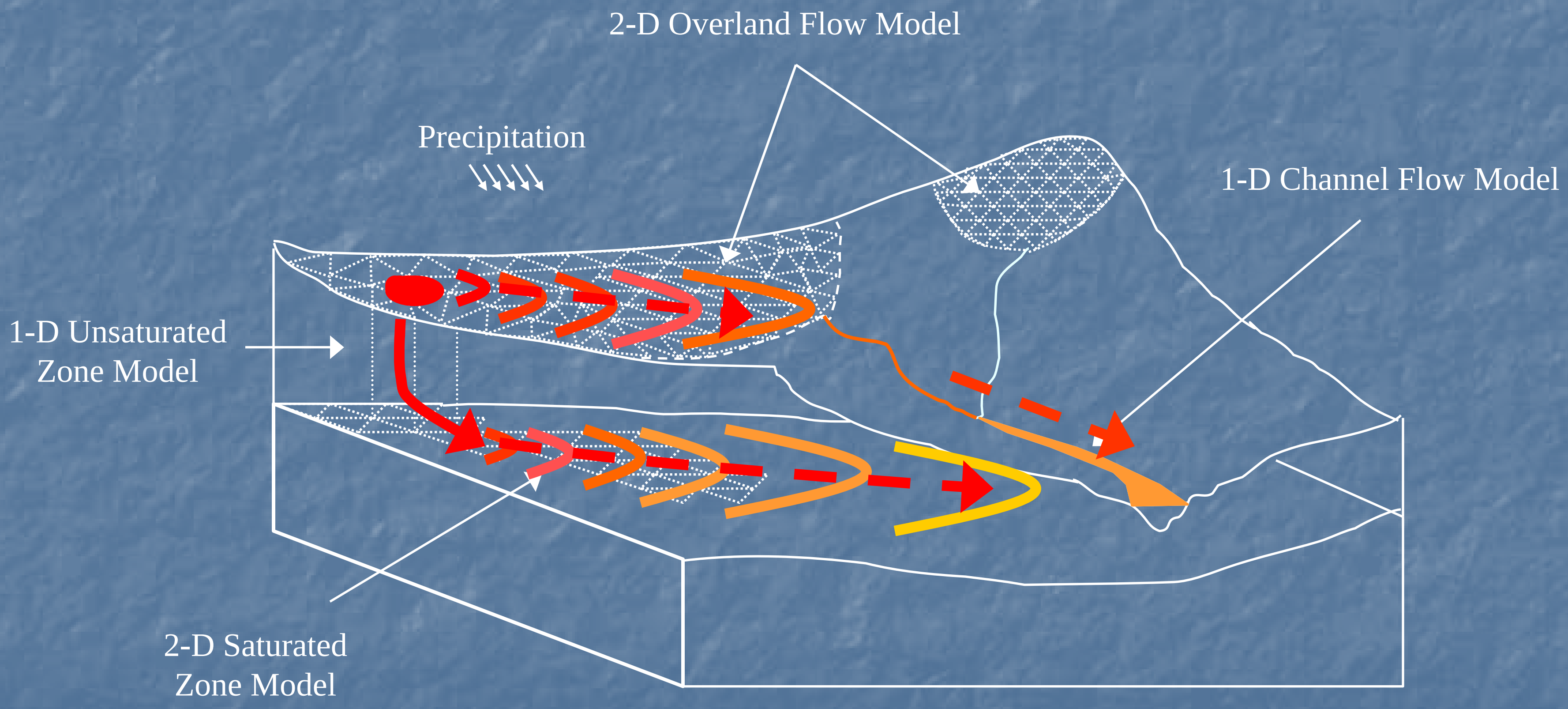
SCHEMATIC OF AN INTEGRATED WATERSHED MODEL



COMPLEXITIES………

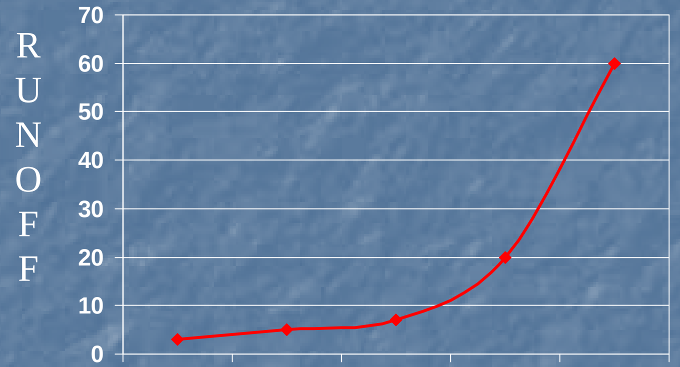
- Multi-pathway flow and contaminant transport problem.
- Integrated modeling of all pathways is the key.
- Each process pathway has its own characteristic scale.
- What should be the optimal scale of a fully integrated model?

MODELING TOOLS

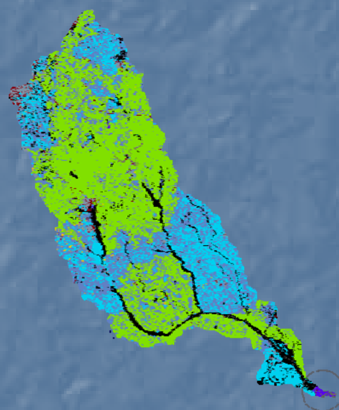
- Lumped parameter models
- Distributed parameter models

MAP ALGEBRA

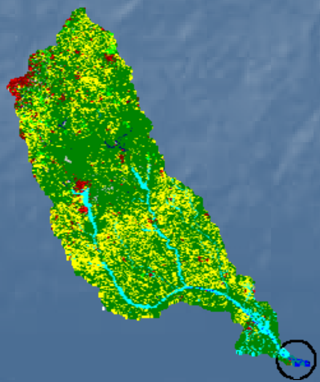
Regional Response Curve



Precipitation

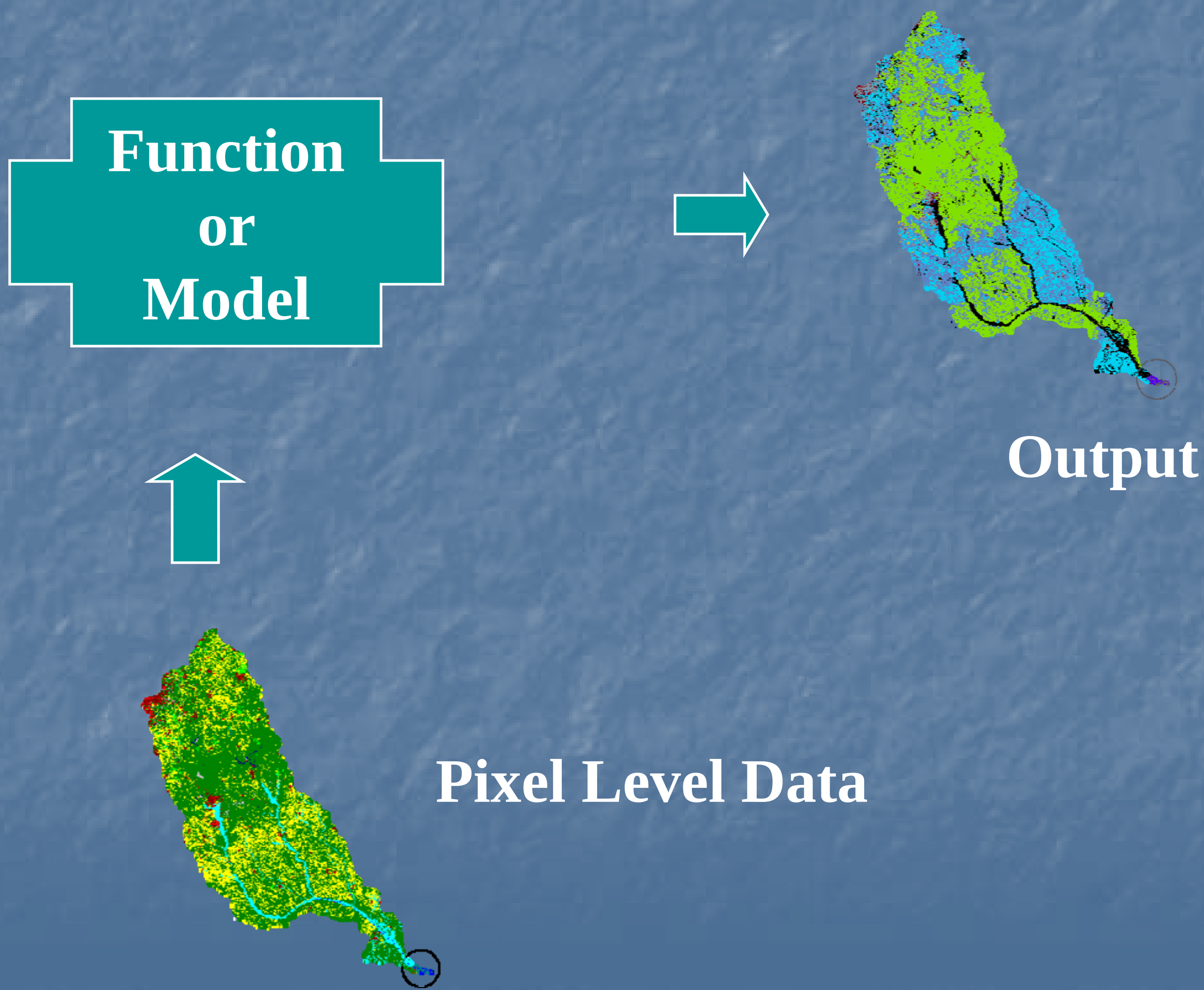


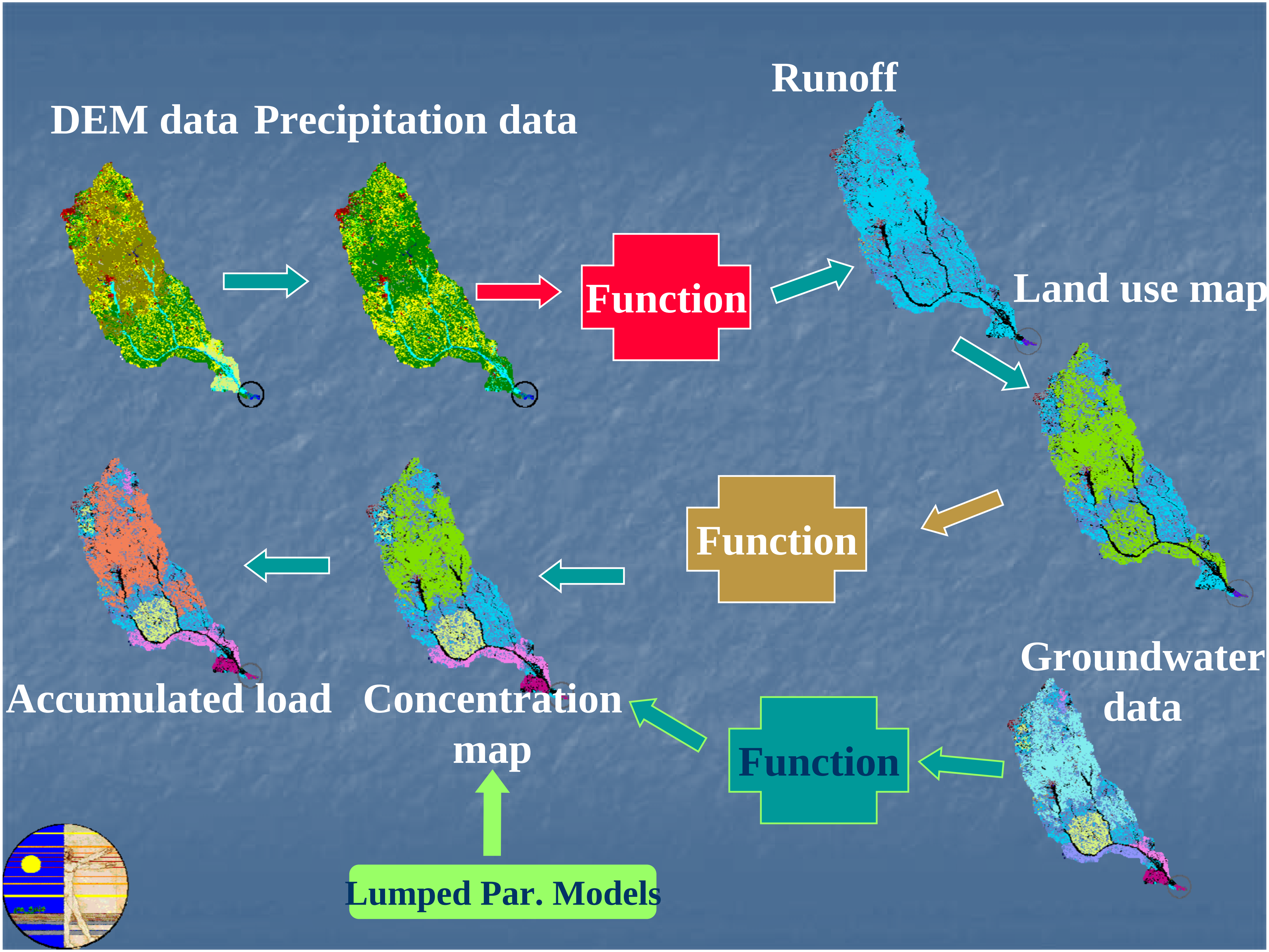
Runoff data map



Precipitation data map

MAP CALCULUS





DEM data
Precipitation data
Function
Runoff
Land use map
Function
Groundwater data
Function
Accumulated load
Concentration map
Lumped Par. Models

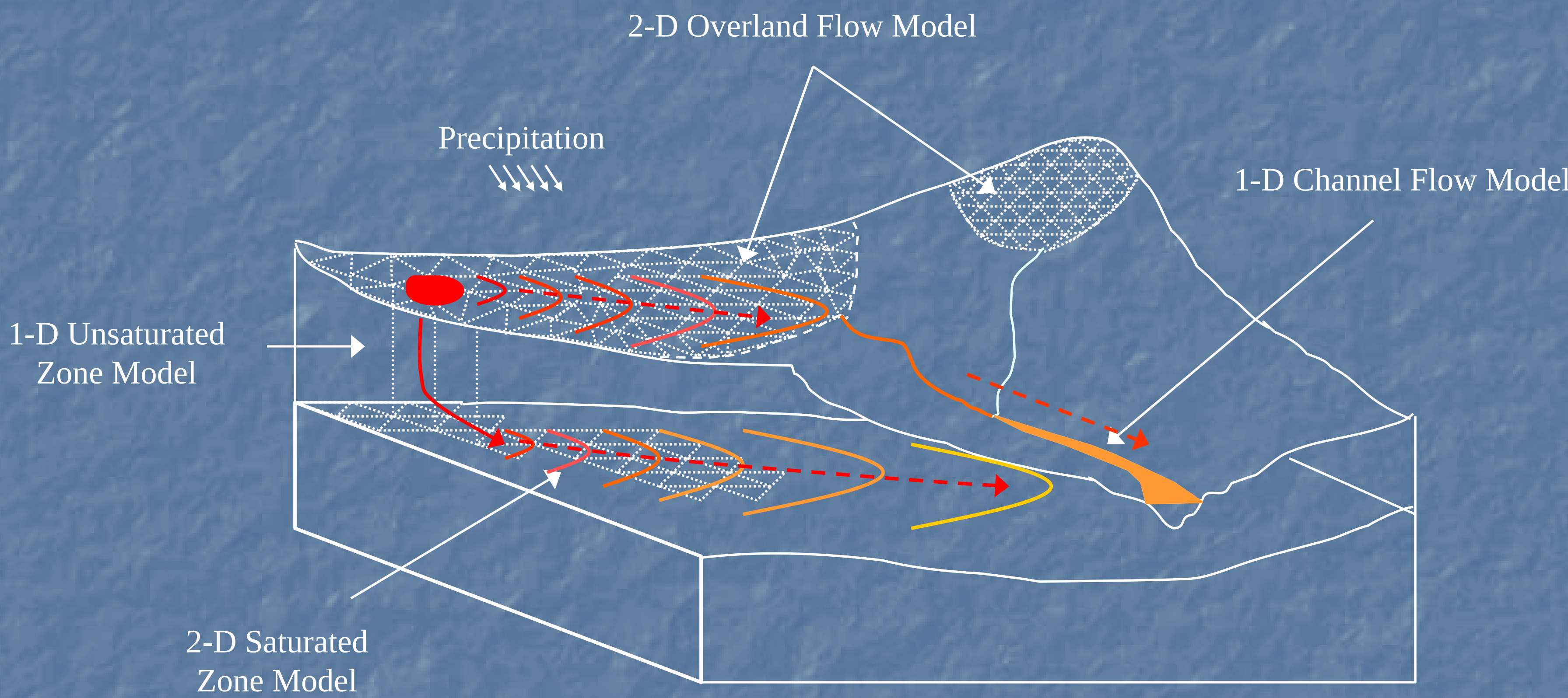
WHAT IS A SCALE?

- **Spatial or temporal dimensions at which entities, patterns, and processes can be observed and characterized to capture the important details of a hydrologic/hydrogeologic process.**

SCALING

- **The transfer of data or information across scales or linking sub-process models through a unified scale is referred to as “scaling.”**

FRAME OF REFERENCE



- Absolute and Relative frame of reference

SCALE EFFECTS

- **Heterogeneity.**
- **Sub-process scales.**
- **Nonlinearity.**

SCALING PROBLEMS

- When large-scale models are used to predict small-scale events, or when small-scale models are used to predict large-scale events, problems may arise.

- Problems also arise when integrated models are used across scales.

FUNCTIONAL SCALE

- **At what spatial and temporal scale does the final model performs optimally; and,**
- **What scale should be selected to implement the final integrated model?**

SUB-PROCESSES

- **Integrated river channel flow and groundwater flow.**

- **Integrated overland flow, unsaturated and saturated groundwater flow.**

- **Integrated watershed model.**

COUPLED SURFACE WATER AND GROUNDWATER FLOW MODEL

Channel flow

Interaction parameter between two domains

$$\frac{\partial s_c (A + A_o)}{\partial t} + \frac{\partial Q}{\partial x} - \boxed{q} = 0$$

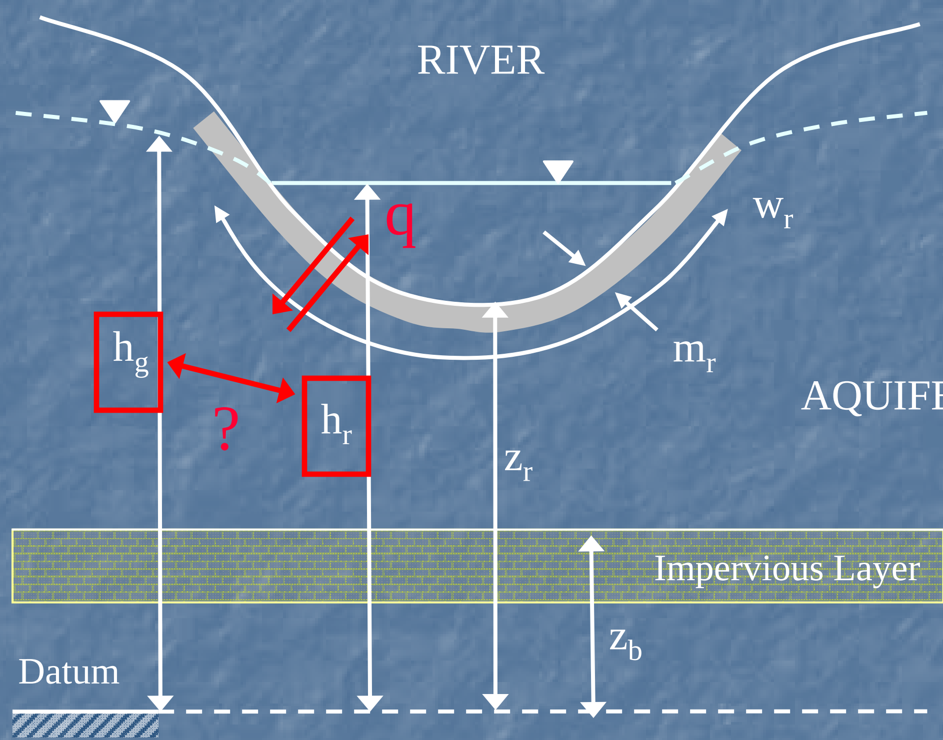
$$\frac{\partial s_m Q}{\partial t} + \frac{\partial (\beta Q^2 / A)}{\partial x} + gA\left(\frac{\boxed{\partial h_r}}{\partial x} + S_f + S_e \right) + L = 0$$

Groundwater flow

Key parameters of interest

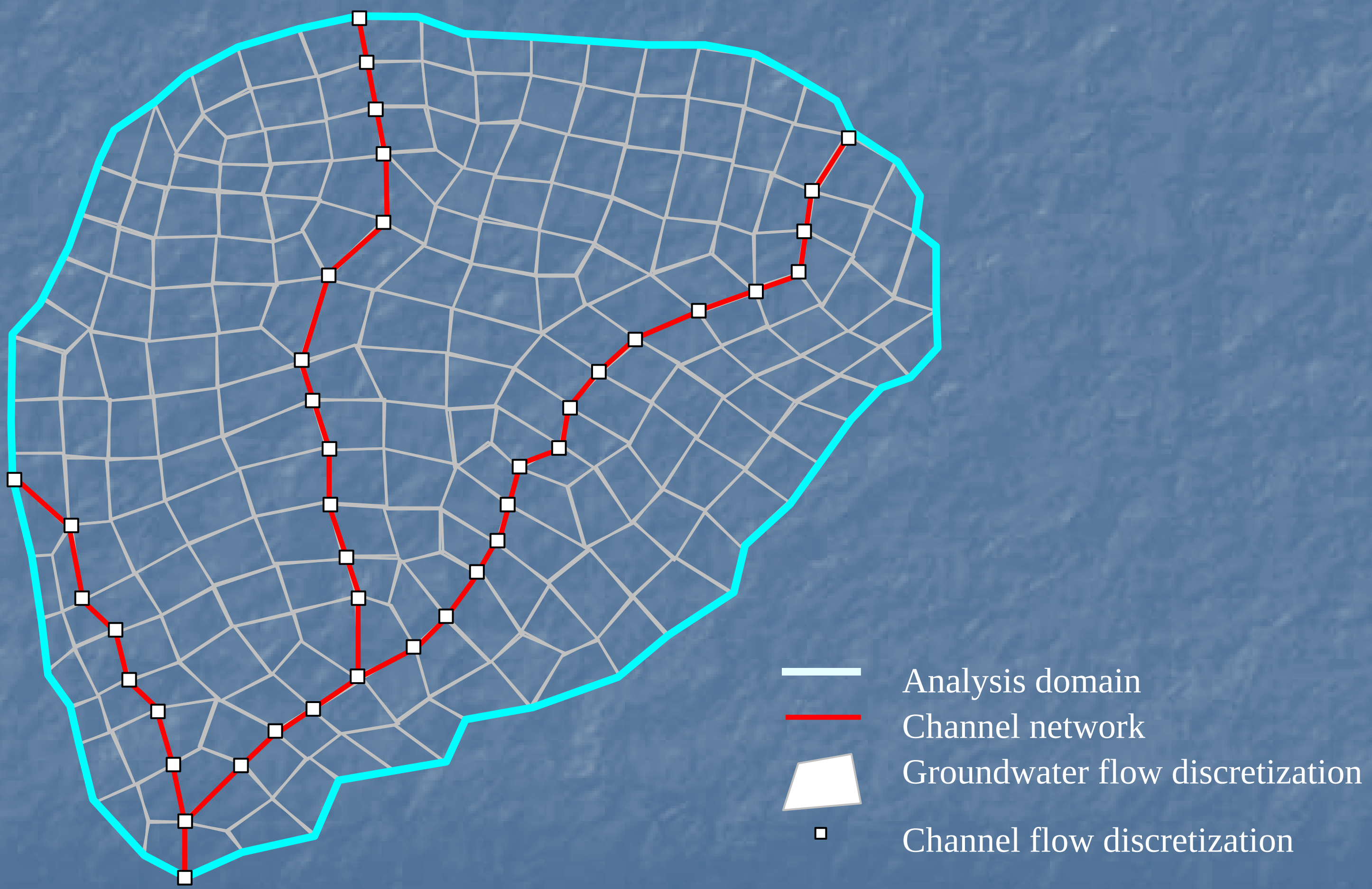
$$\frac{\partial}{\partial x}\left[(h_g - z_b) K_x \frac{\partial h_g}{\partial x} \right] + \frac{\partial}{\partial y}\left[(\boxed{h_g} - z_b) K_y \frac{\partial h_g}{\partial y} \right] + \sum_{k=1}^{n_w} Q_{w_k} + I = S_y \frac{\partial h_g}{\partial t}$$

COUPLING OVER THE INTERFACE



Type-3 boundary condition of the groundwater flow model couples with the lateral inflow/outflow term in the stream flow equation

COUPLED SYSTEM

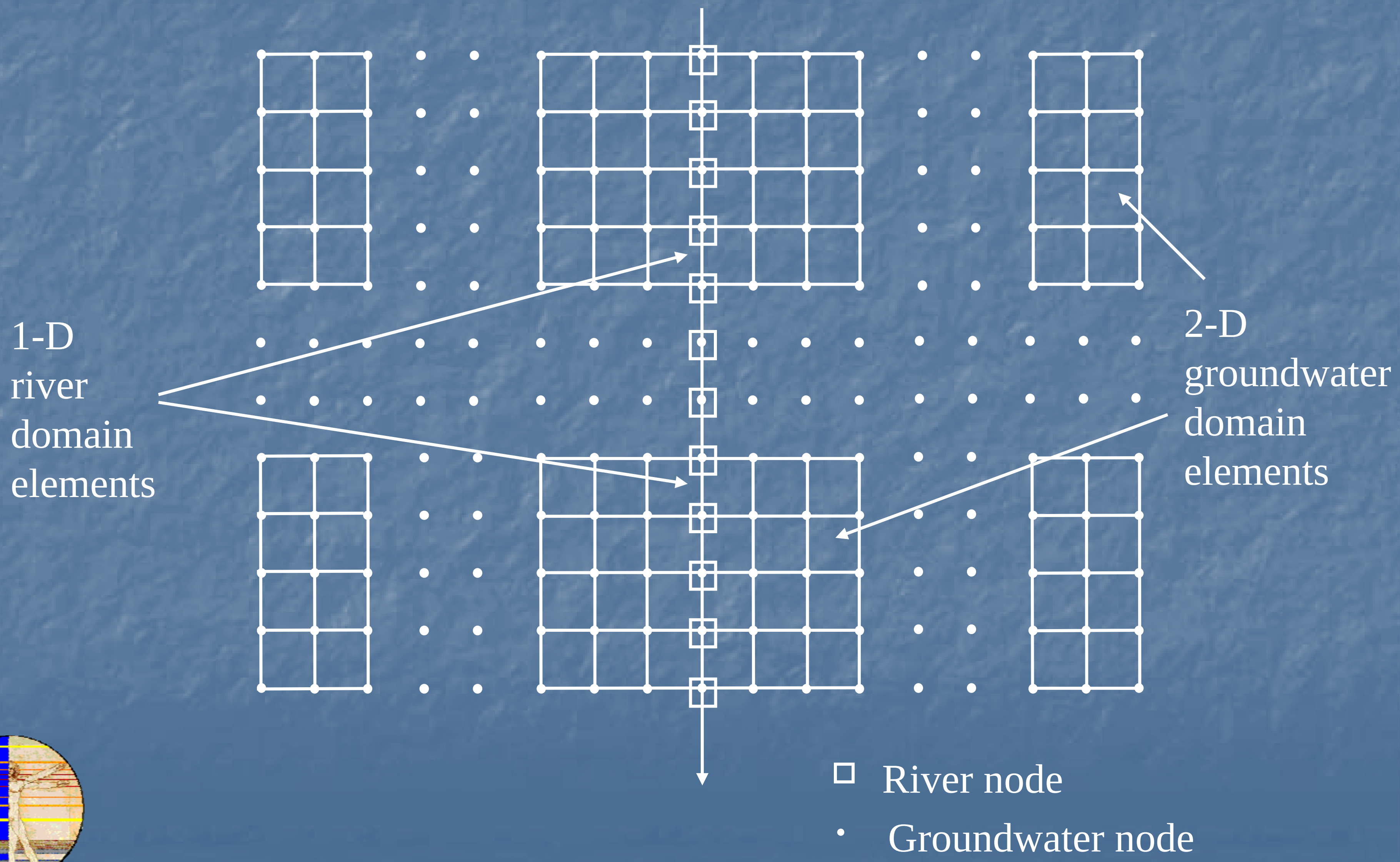


GLOBAL MATRIX EQUATION

$$\mathbf{A} \cdot \mathbf{x} = \mathbf{B}$$

$$\left[\begin{array}{c:c} \left[\;\mathbf{A}^{\mathrm{GW}}\;\right] & \mathbf{0} \\ \hdashline \mathbf{0} & \left[\;\mathbf{A}^{\mathrm{RIVER}}\;\right] \end{array}\right] \left\{\begin{array}{c} \mathbf{x}^{\mathrm{GW}} \\ \hdashline \mathbf{x}^{\mathrm{RIVER}} \end{array}\right\} = \left\{\begin{array}{c} \mathbf{B}^{\mathrm{GW}} \\ \hdashline \mathbf{B}^{\mathrm{RIVER}} \end{array}\right\}$$

DISCRETIZATION OF DOMAIN



APPLICATION

Simulation scenarios:

- Two set of runs are done to simulate:
  - ✓ lateral flow from stream to groundwater and from groundwater to stream
  - ✓ Time lag between the timing of stream flow peak and groundwater head peak
  - ✓ Flow reversal conditions

RUN-1: Lateral flow towards groundwater flow domain

RUN-2: Lateral flow towards stream flow domain

APPLICATION

Groundwater flow model

- Initial conditions: RUN-1: h_g = 32 m

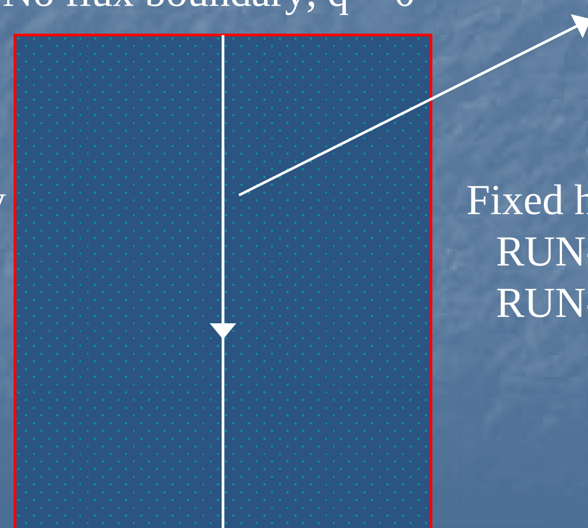
  RUN-2: h_g = 35 m

- Boundary conditions:

No flux boundary, q = 0

Head-dependent boundary

Fixed head boundary
RUN-1: h = 32 m
RUN-2: h = 35 m



Fixed head boundary
RUN-1: h = 32 m
RUN-2: h = 35 m

No flux boundary, q = 0

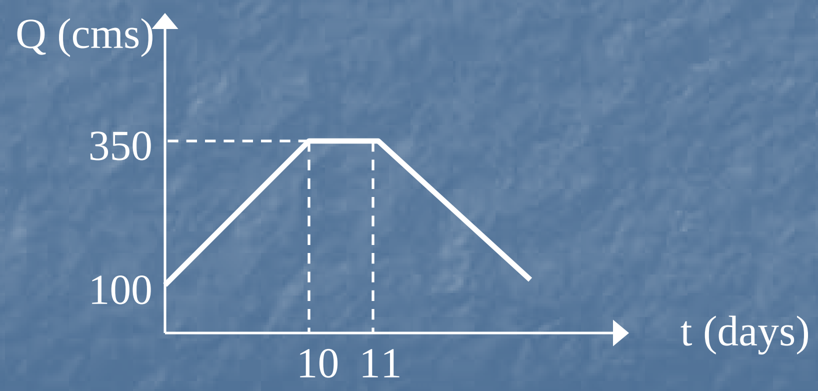
APPLICATION

Boundary and Initial Conditions:

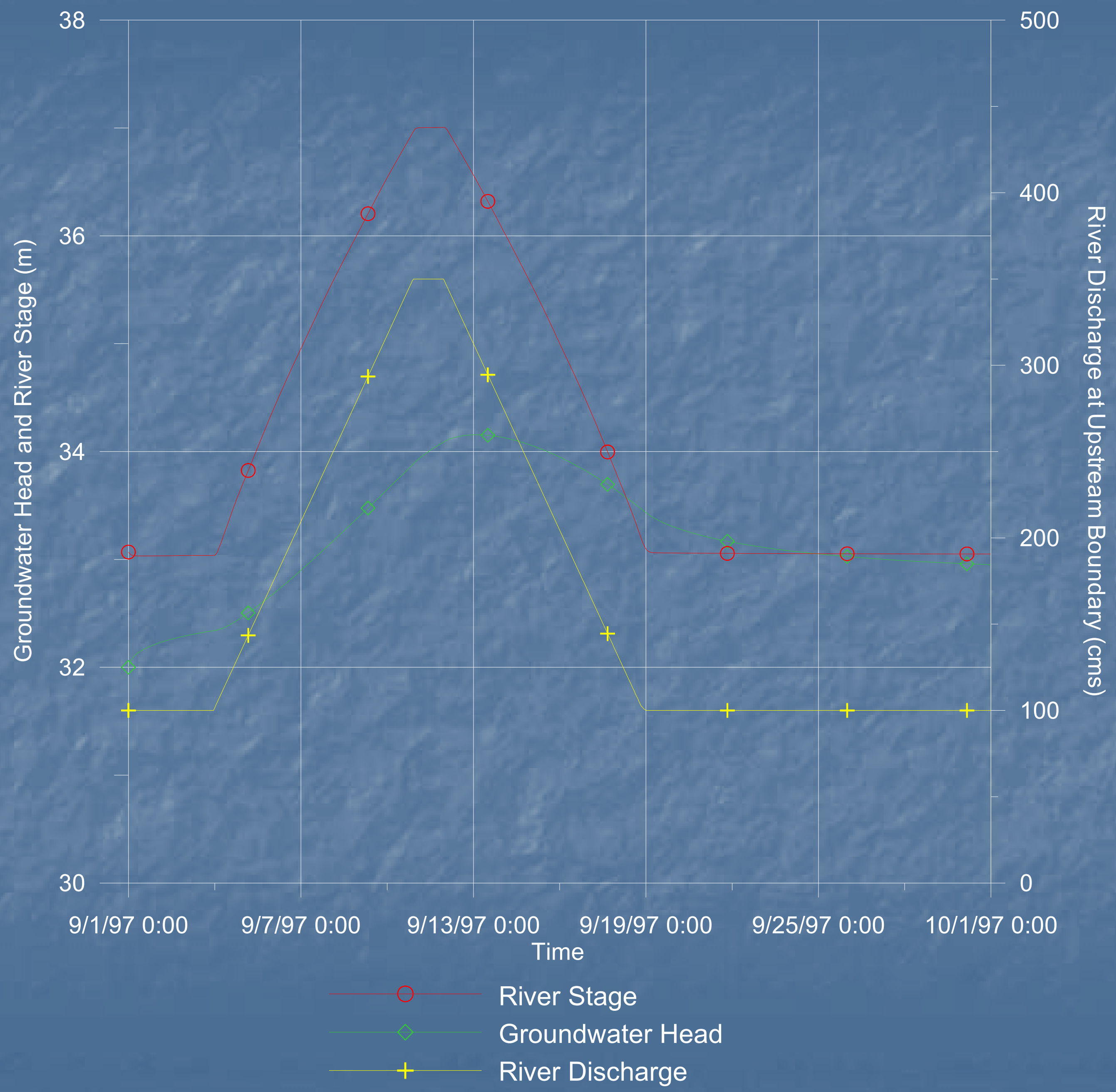
Stream flow model

- Initial conditions: Uniform flow discharge Q = 100cms
  Uniform flow depth d = 3.57m

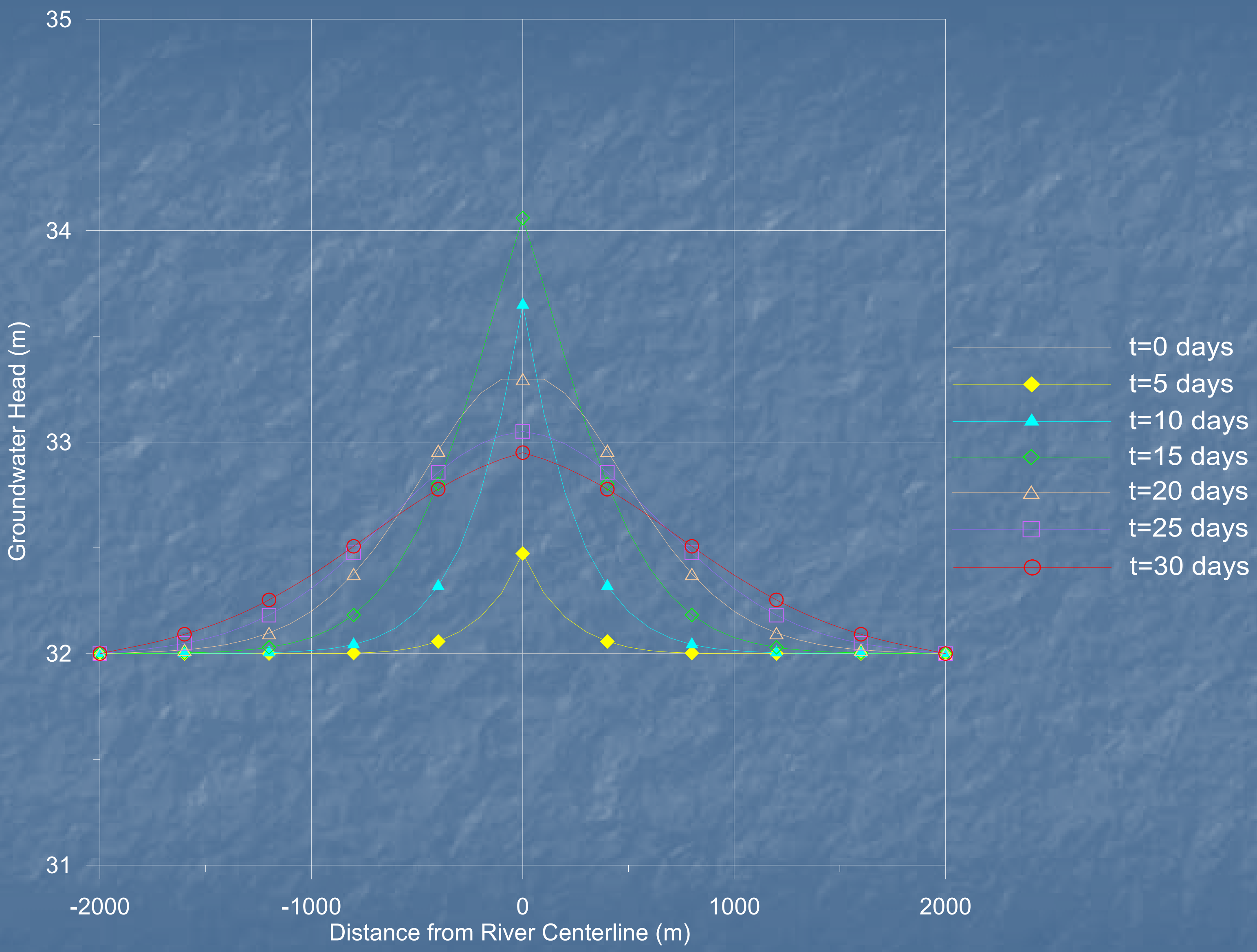
- Upstream BC: Trapezoidal discharge hydrograph



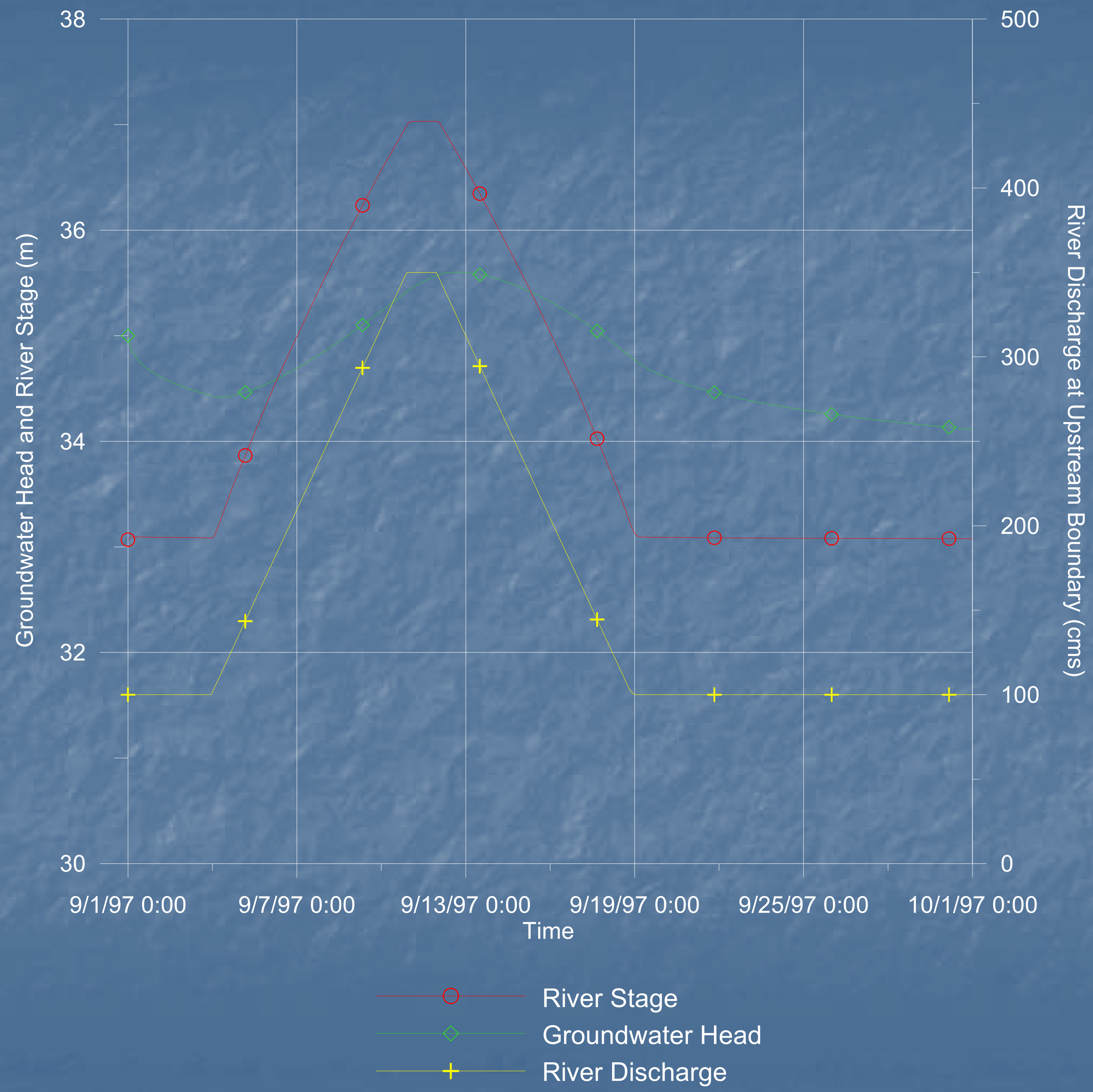
- Downstream BC: Single-valued rating curve that maps the discharge to its uniform flow depth



38
36
34
32
30
500
400
300
200
100
0
Groundwater Head and River Stage (m)
River Discharge at Upstream Boundary (cms)
9/1/97 0:00
9/7/97 0:00
9/13/97 0:00
9/19/97 0:00
9/25/97 0:00
10/1/97 0:00
Time
River Stage
Groundwater Head
River Discharge



35
34
33
32
31
Groundwater Head (m)
-2000
-1000
0
1000
2000
Distance from River Centerline (m)
t=0 days
t=5 days
t=10 days
t=15 days
t=20 days
t=25 days
t=30 days



38
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0
Groundwater Head and River Stage (m)
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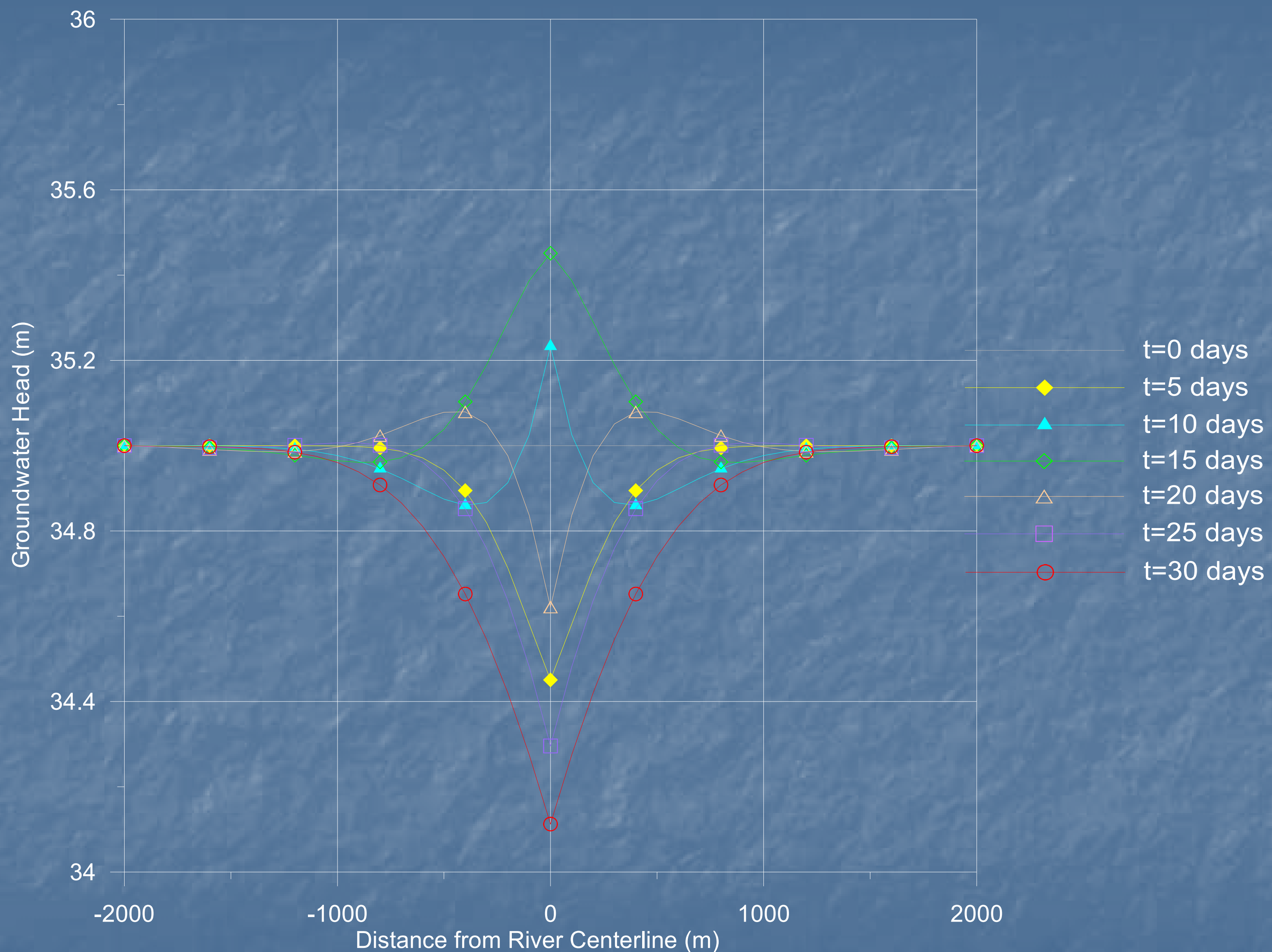
9/1/97 0:00
9/7/97 0:00
9/13/97 0:00
9/19/97 0:00
9/25/97 0:00
10/1/97 0:00
Time
River Stage
Groundwater Head
River Discharge


36
35.6
35.2
34.8
34.4
34
Groundwater Head (m)
-2000
-1000
0
1000
2000
Distance from River Centerline (m)
t=0 days
t=5 days
t=10 days
t=15 days
t=20 days
t=25 days
t=30 days

COUPLED OVERLAND FLOW AND SAT/UNSAT GROUNDWATER MODEL

Overland Flow Zone

$$\frac{\partial h_o}{\partial t} = \frac{\partial}{\partial x}\left(K_{ox}\frac{\partial h_o}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{oy}\frac{\partial h_o}{\partial y}\right) + R - I$$

Overland flow surface

Soil surface

Unsaturated Flow Zone

$$S_w S_s \frac{\partial \psi}{\partial t} + \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K_u\left(\frac{\partial \psi}{\partial z} + 1\right)\right)$$

Key parameters of interest

Groundwater table

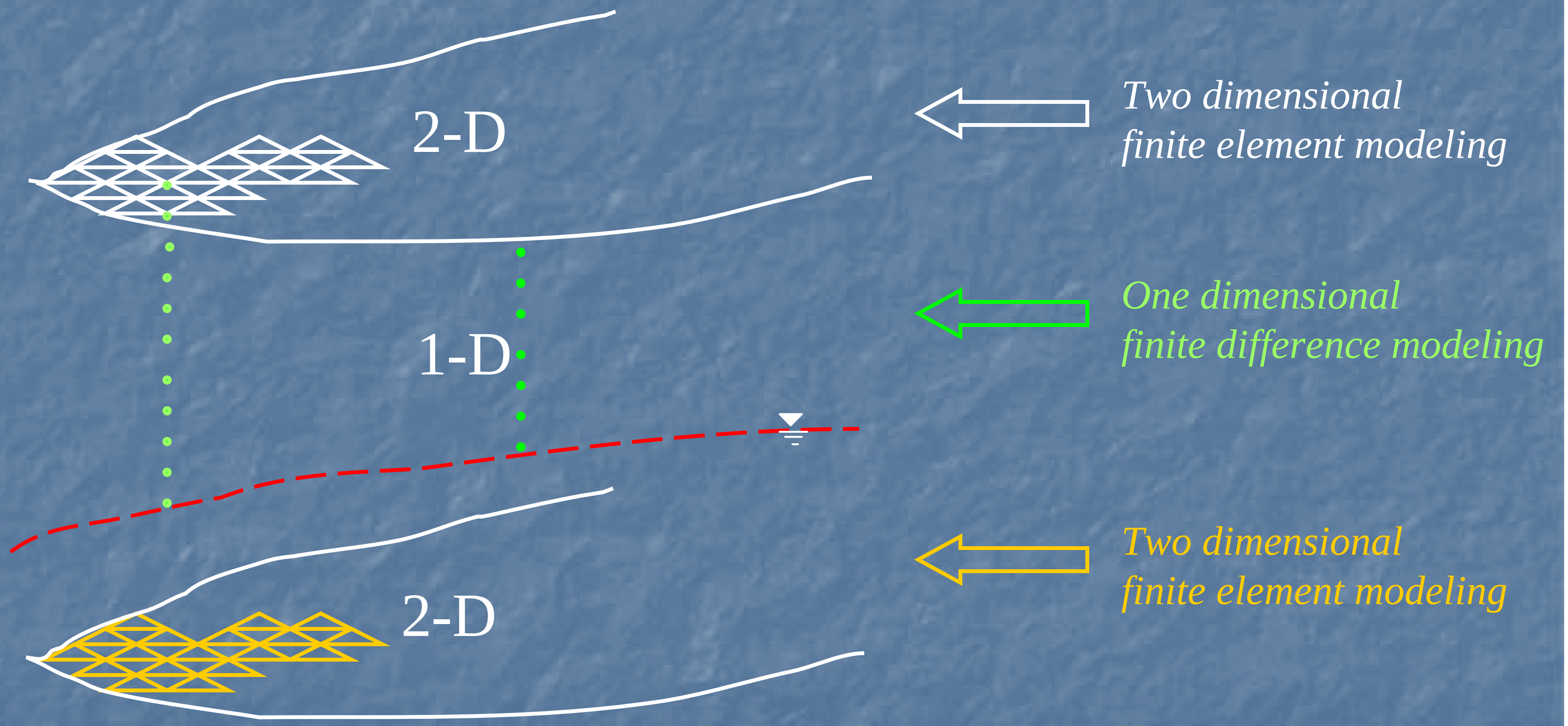
Saturated Flow Zone

$$S_y \frac{\partial h_g}{\partial t} = \frac{\partial}{\partial x}\left(K_{gx}\left(h_g - z_b\right)\frac{\partial h_g}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{gy}\left(h_g - z_b\right)\frac{\partial h_g}{\partial y}\right) + \sum_{k=1}^{n_w} Q_{w_k} + I$$

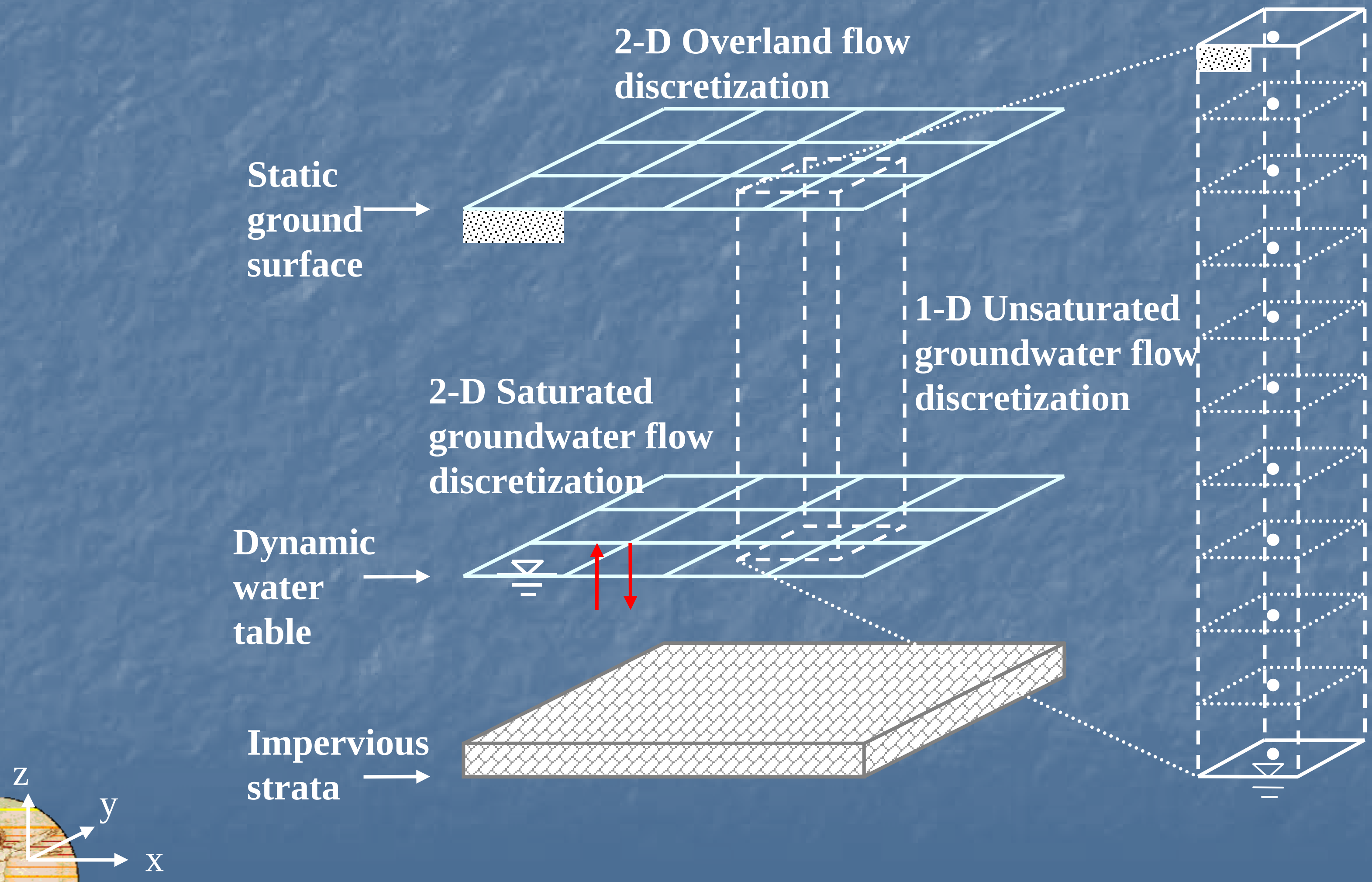
Impervious layer

Note: Figure not to scale

INTEGRATED MODEL



OVERLAND, UNSATURATED and SATURATED GROUNDWATER MODEL STRUCTURE



COUPLING OVER INTERFACES

- **At the ground surface, overland flow and unsaturated zone models are coupled via the infiltration flux.**
- **Infiltration flux becomes a sink/source term in overland flow model.**
- **The top boundary condition for the unsaturated column depends on the presence of overland flow.**

Present

✓ **Head condition**

Not present

✓ **Flux condition**

APPLICATION

Simulation scenarios:

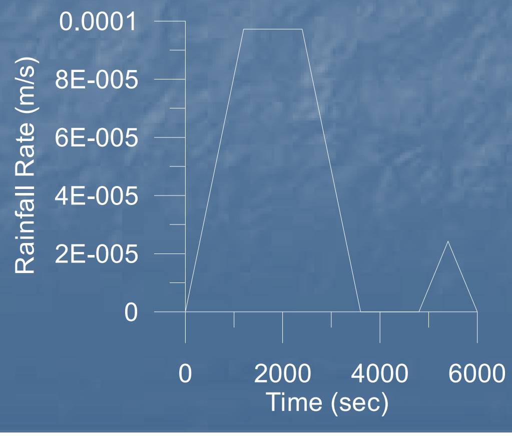
- **Response of clay and sand soils to a two-peaked precipitation event to simulate:**
  - ✓ **Response of overland flow generation to different soil types**
  - ✓ **Response of groundwater recharge to different soil types**
  - ✓ **Response of unsaturated column moisture migration to intermittent rainfall**
  - ✓ **Response of groundwater levels to arbitrary precipitation events over different soils**
  - ✓ **Interactions between different pathways**

RUN-1: Clay soil
RUN-2: Sand soil

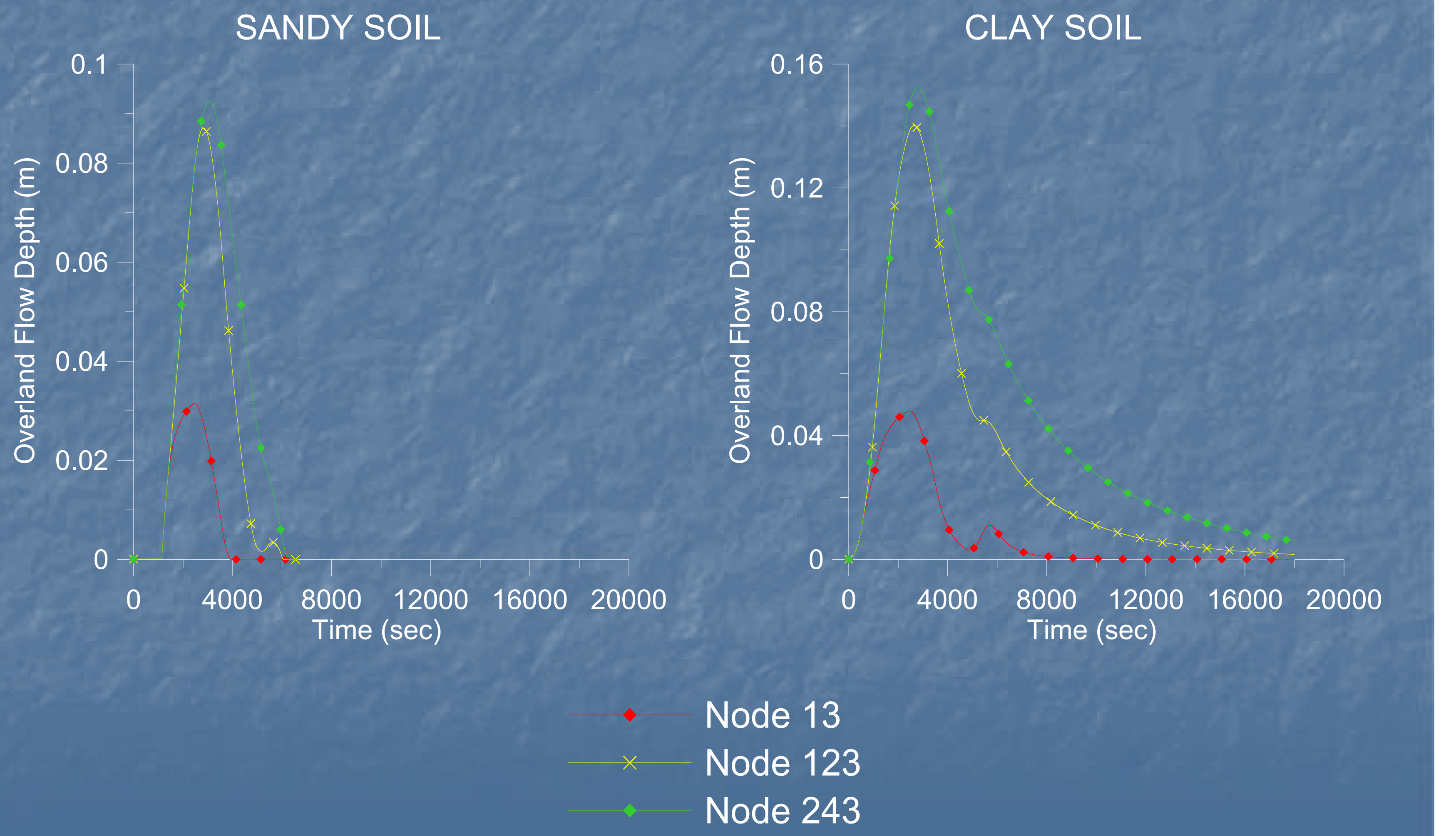
APPLICATION

Physical Setup:

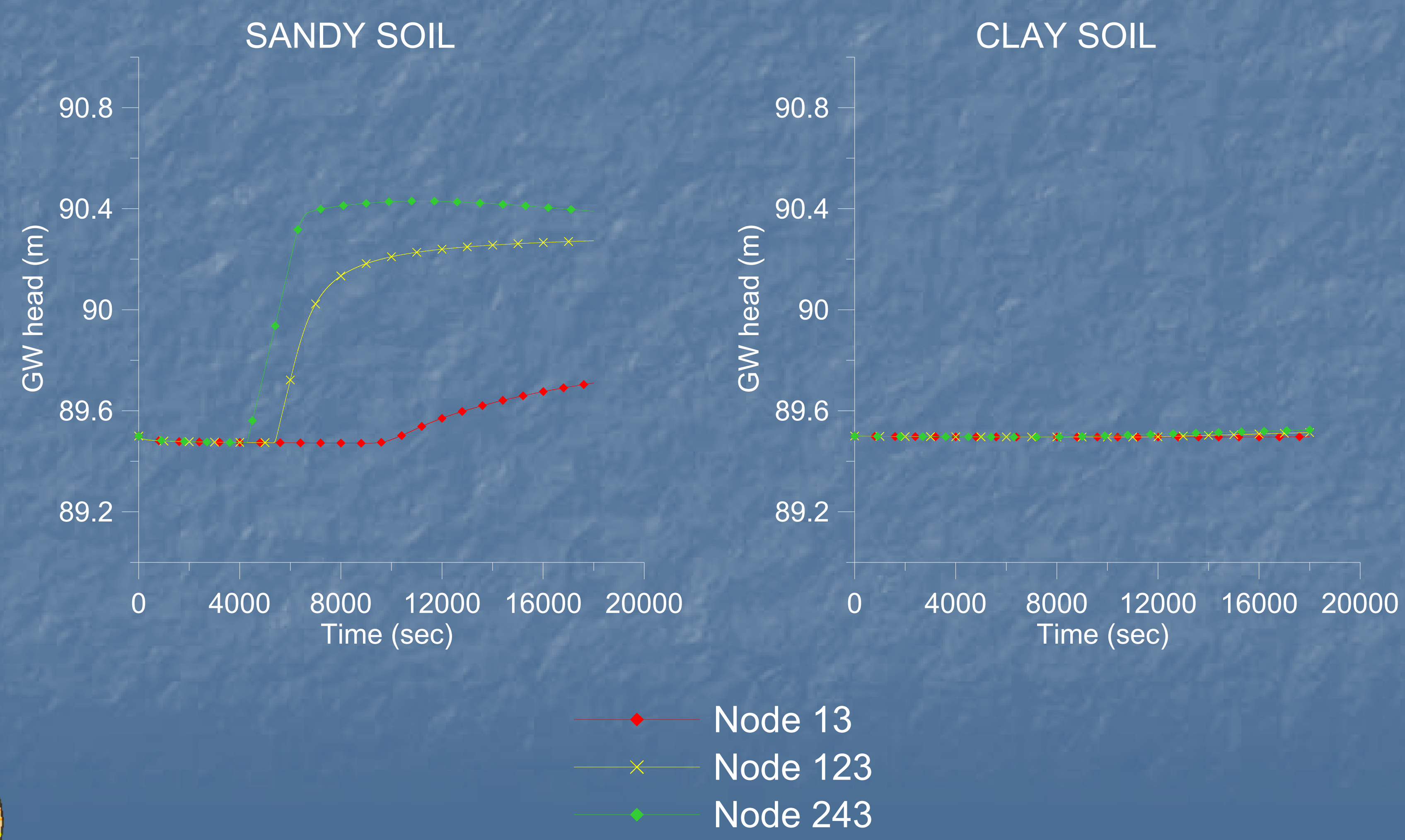
- **40 m wide X 500 m long hypothetical rectangular plot**
  $0 < x < 500$ m and $0 < y < 40$ m
- **Uniform slope in x-direction, $S_{ox} = 0.001$ m/m**
- **No slope in y-direction, $S_{oy} = 0.0$ m/m**
- **Essentially one-dimensional flow**
- **Response to a two-peaked precipitation event:**



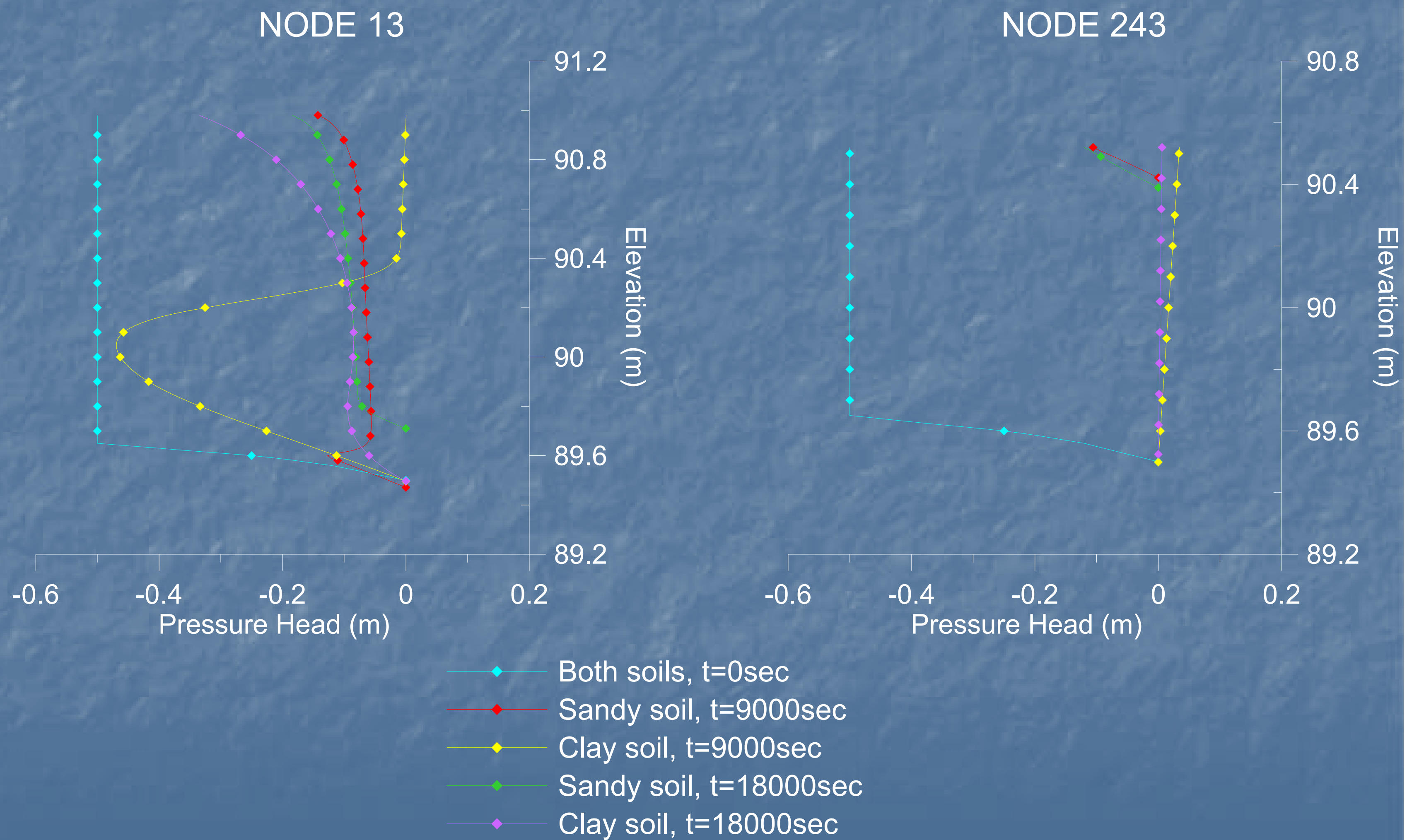
RESULTS – Overland flow depth time series



RESULTS – Groundwater head time series



RESULTS – Unsaturated zone moisture distribution



SCALES OF IMPORTANCE

	Space (cm)	Time (sec)
Unsaturated GW zone	**0.01 - 10**	**0.1 - 10^2**
Overland flow	**10 - 10^4**	**0.1 - 10^2**
River Channel flow	**10^3 - 10^6**	**10^2 - 10^5**
Saturated GW zone	**10^3 - 10^6**	**10^3 - 10^6**

HYBRID MODELS ARE THE SOLUTION TO INTEGRATED WATERSHED MODELING SYSTEMS

APPLICATION:

Analysis of Coastal Georgia Ecosystem Stressors Using GIS Integrated Remotely Sensed Imagery and Modeling:
A Pilot Study for Lower Altamaha River Basin
Georgia Sea Grant College Program of the National Sea Grant Program.

http://groups.ce.gatech.edu/Research/MESL/research/altamaha/index.htm

ALTAMAHA APPLICATION

ALTAMAHA RIVER SYSTEM

Data Available

- **Topography data**
- **Gage discharge data**
- **Precipitation data**
- **Cross-section data at bridges**

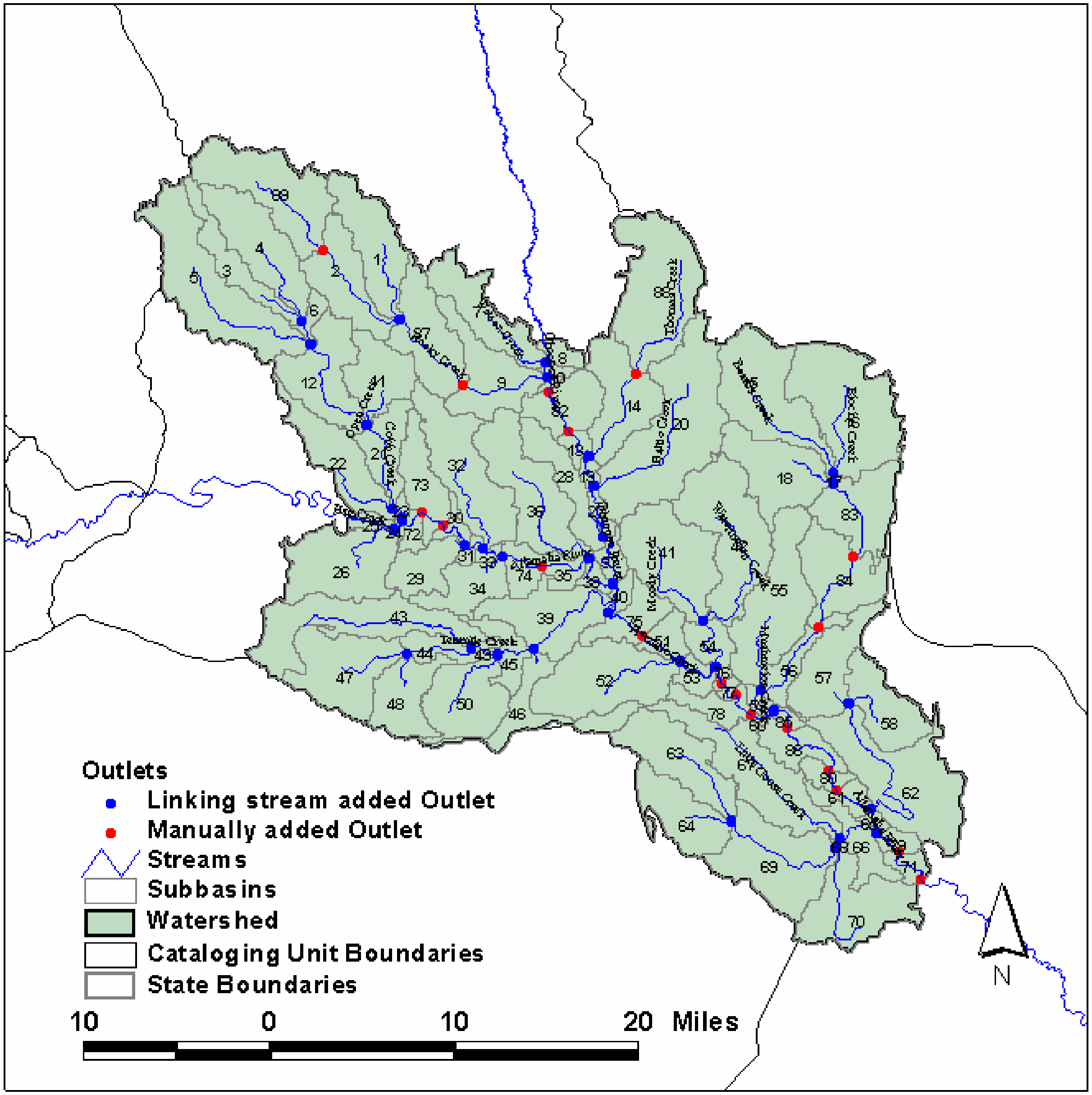
Data Required

- **Channel slopes, bottom elevations, cross-section top width vs depth data**
- **Roughness coefficients**
- **Discharge hydrographs at upstream BCs**
- **Rating curve at downstream exit point**
- **Groundwater BCs data**
- **Unconfined aquifer thickness data**
- **Aquifer conductivity data**
- **Infiltration data**
- **Well data**
- **River bottom sediment conductivity and thickness data**

BASIN REPRESENTATION for LUMPED PARAMETER PROCESES

- Land discretization
  - BASINS automatic delineation tool
  - National Hydrographic Dataset (NHD) reach file and Digital Elevation Model (DEM) data
  - 89 sub-watersheds
  - 352 PERLN
  - 30 IMPLND

BASINS Automatic Delineation



Basins Representation

- Land discretization
  - Land Use

Land Use	Area (acres)	%
Urban or Build-up Land	10,776	1.7
Cropland and Pasture	196,084	30.7
Evergreen Forest Land	285,147	44.6
Mixed Forest Land	72,631	11.4
Water	5,164	0.8
Forested Wetlands	67,345	10.5
Barren Land	2,125	0.3
TOTAL	639,272	100

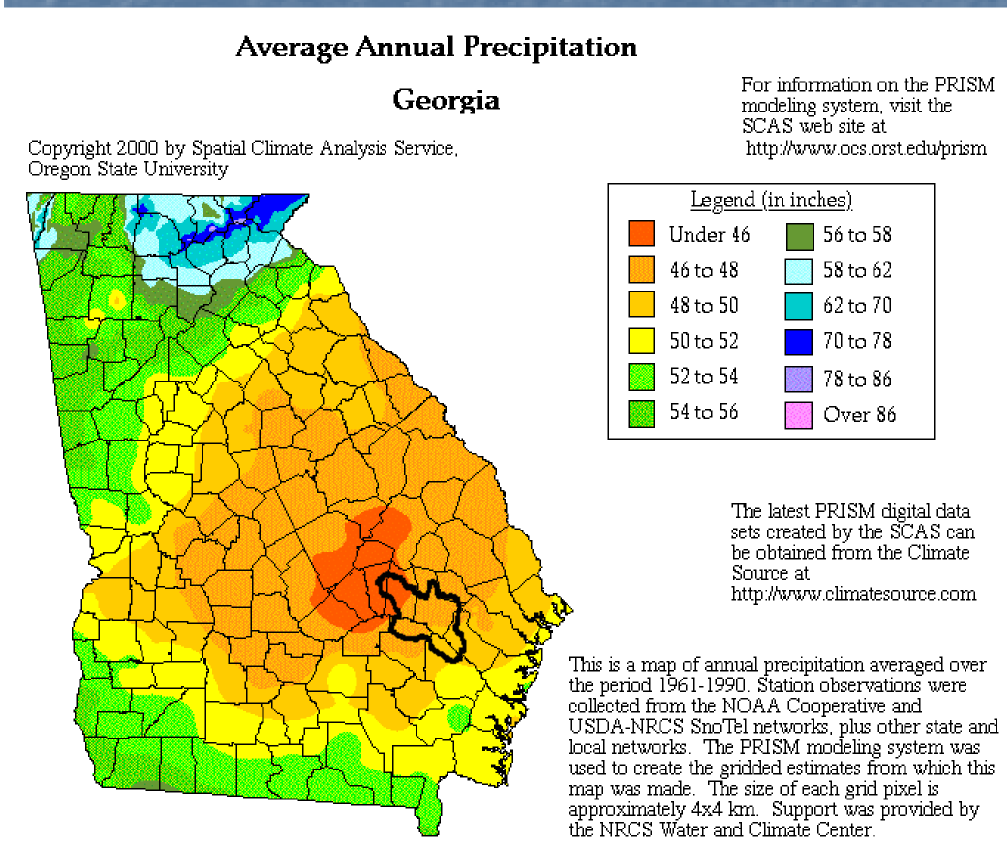
Meteorological Data

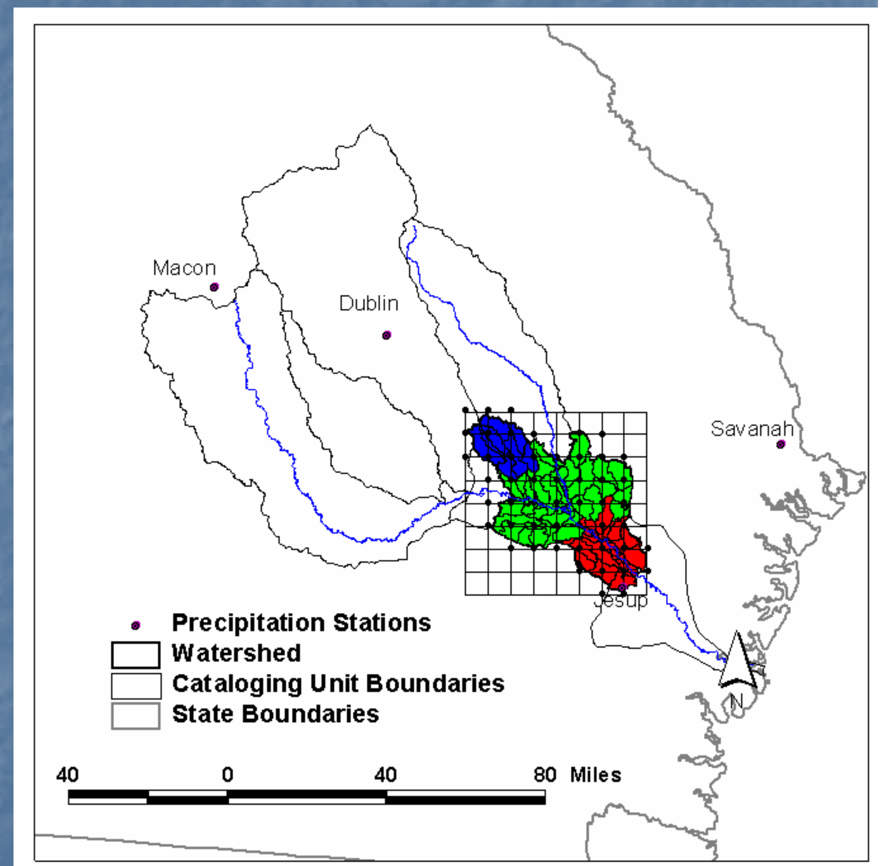
- Precipitation (PREC)
  - Stations: Jesup and Dublin
  - Fill in missing data – Normal Ratio Method

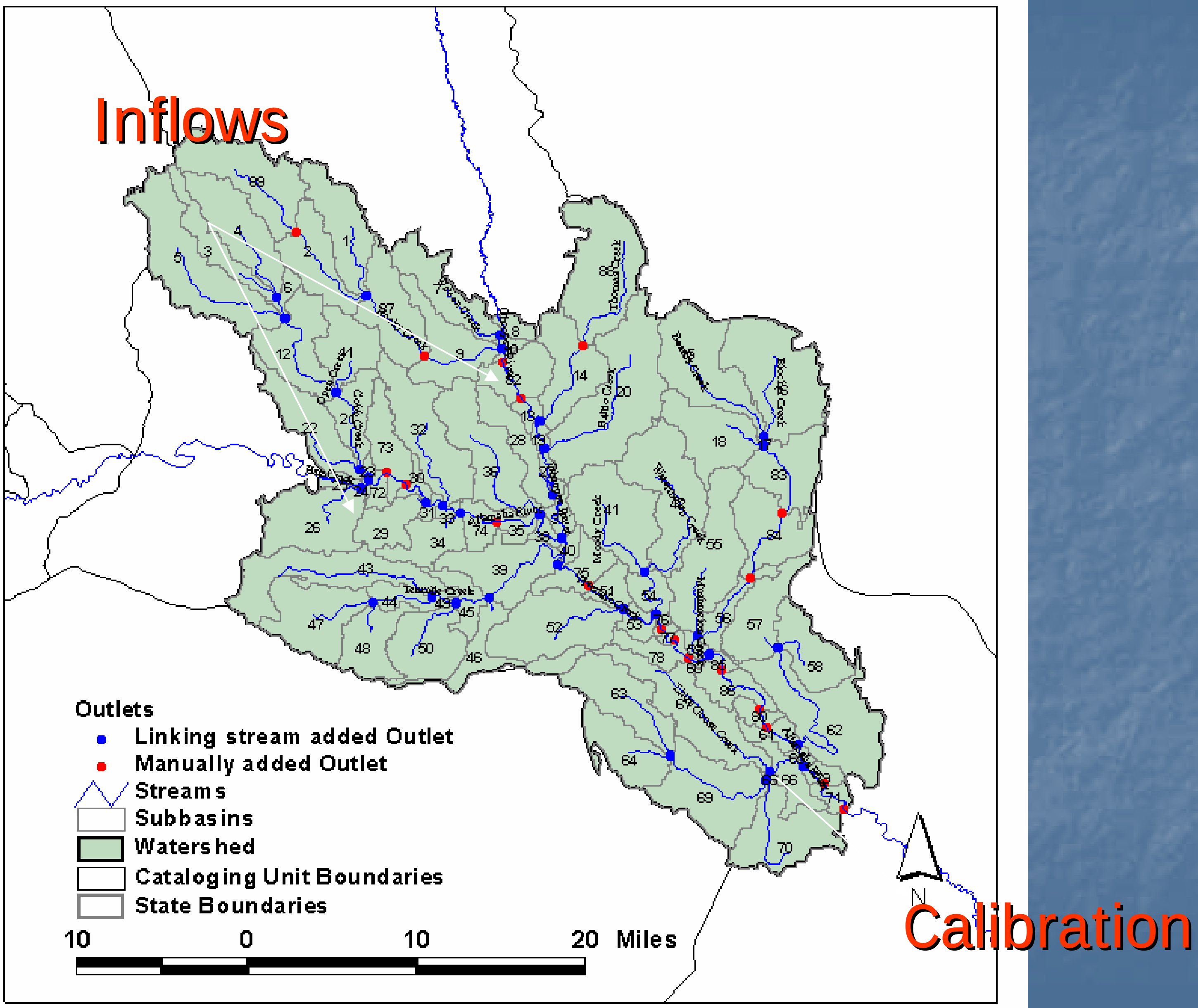
    Jesup → Jacksonville-Savannah-Dublin

    Dublin → Macon
- Potential Evapotranspiration (PETINP)
  - Jesup
- Potential Evaporation (POTEV)
  - Jesup

For modeling: Jesup and Dublin

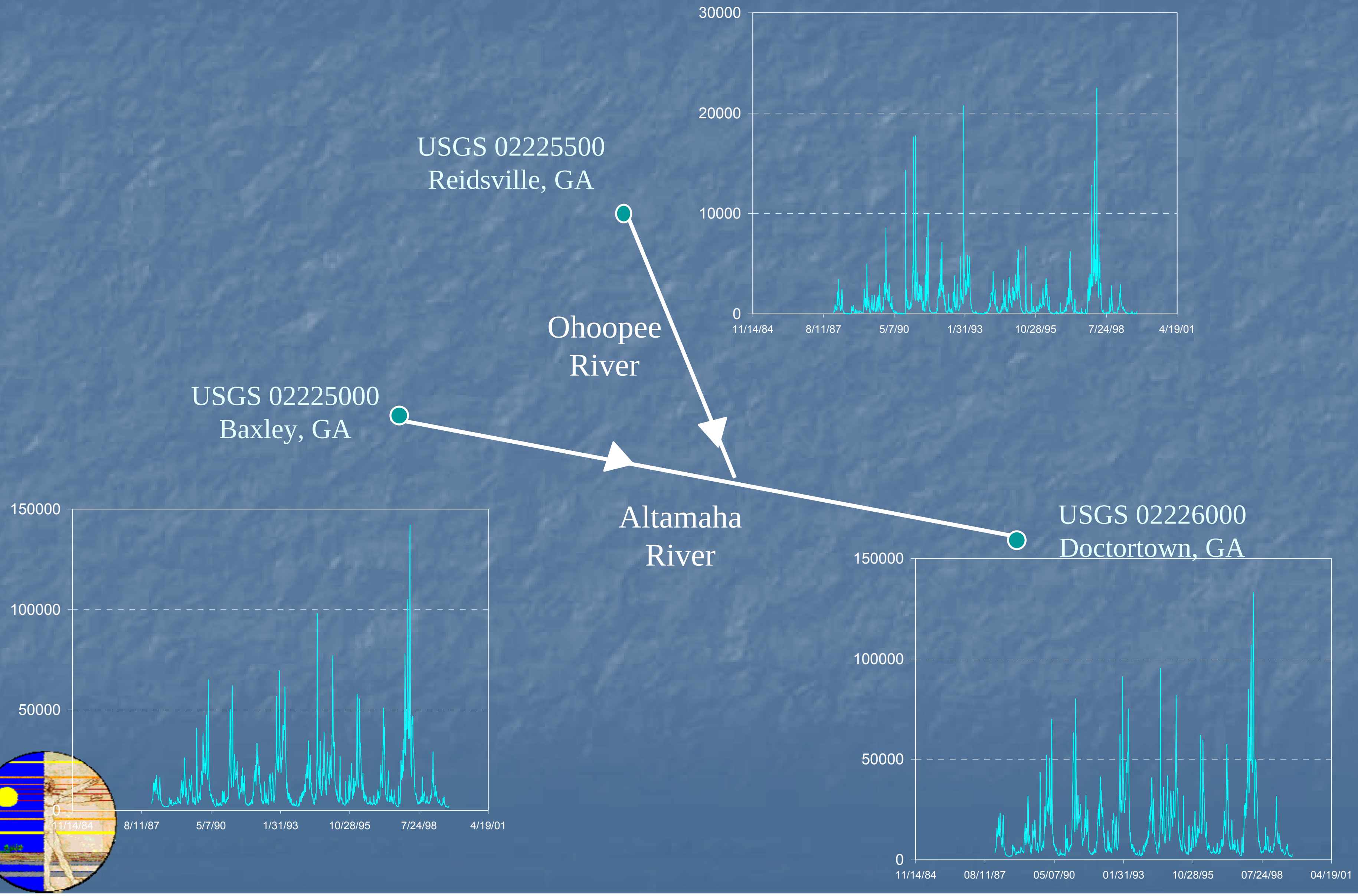


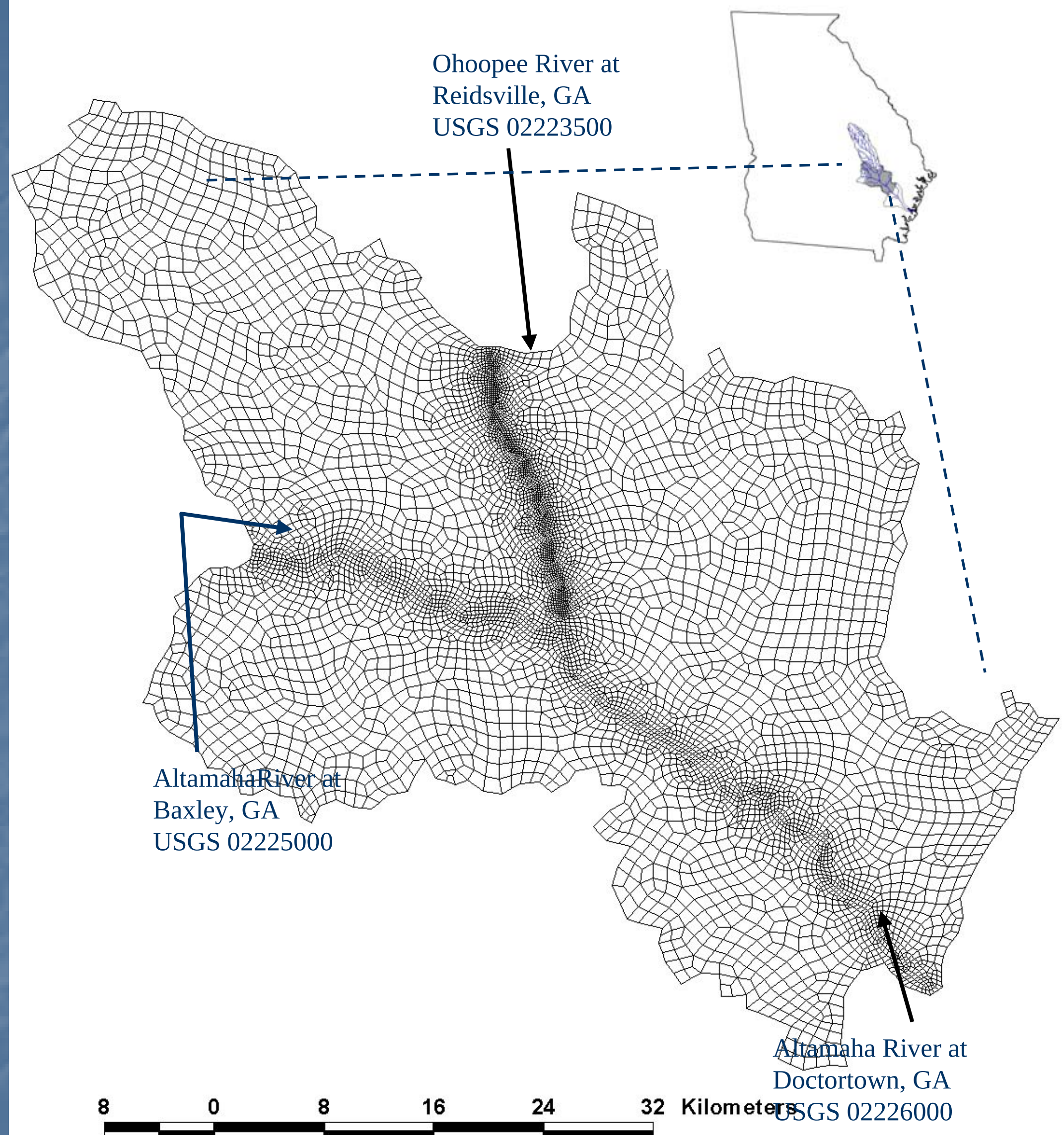




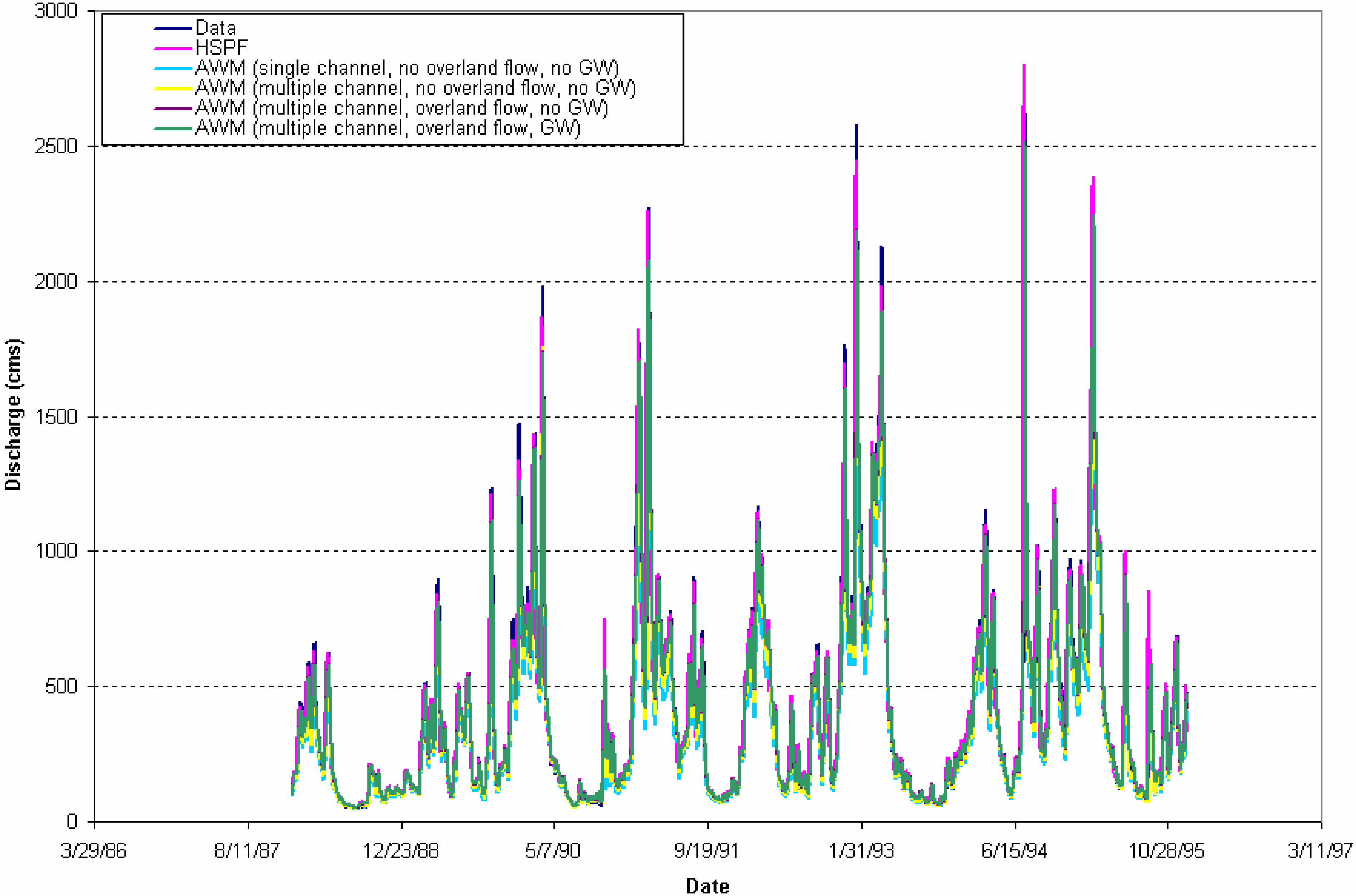
Inflows
Outlets
Linking stream added Outlet
Manually added Outlet
Streams
Subbasins
Watershed
Cataloging Unit Boundaries
State Boundaries
10 0 10 20 Miles
N
Calibration

ALTAMAHA RIVER SYSTEM

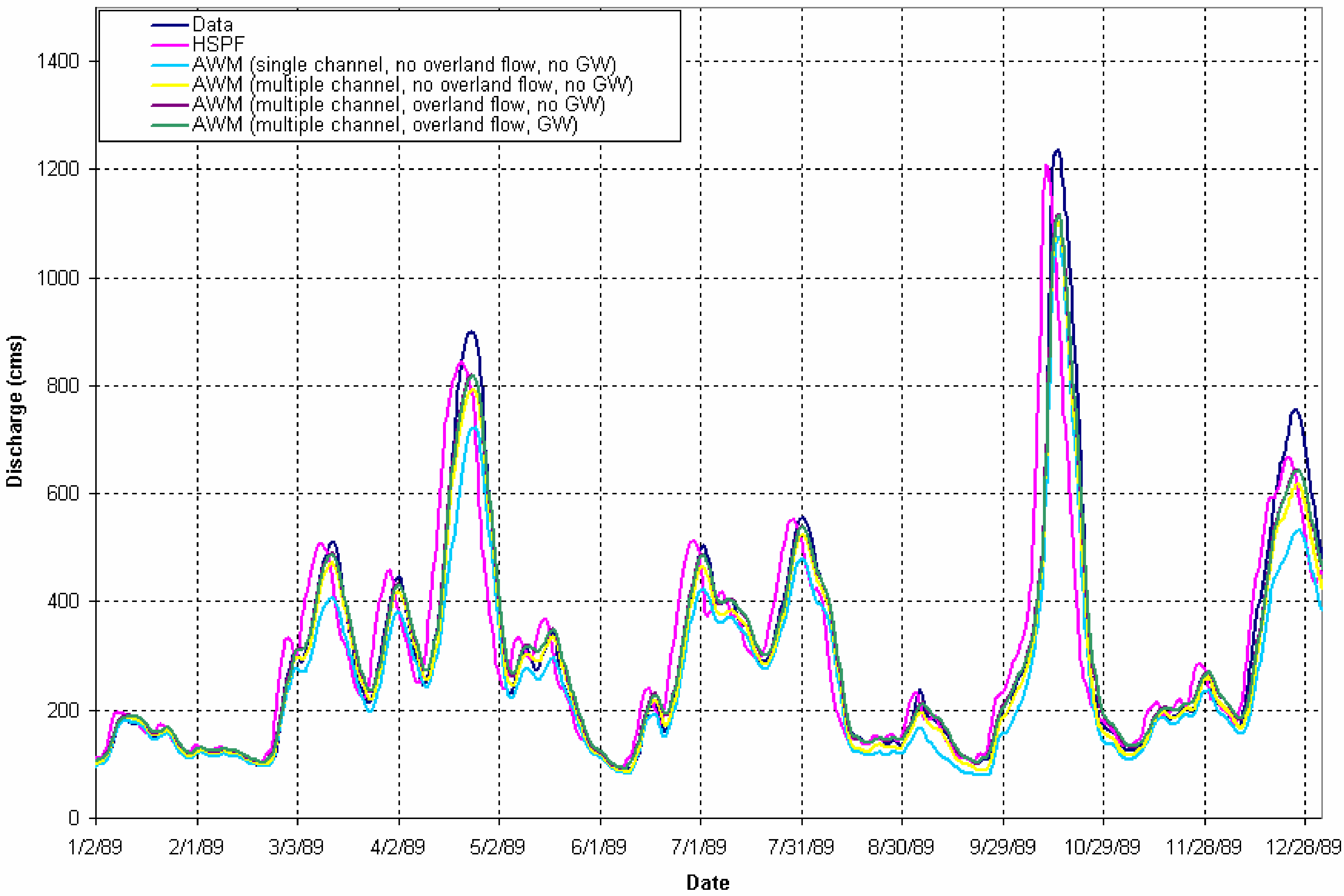



Ohoopee River at
Reidsville, GA
USGS 02223500
AltamahaRiver at
Baxley, GA
USGS 02225000
Altamaha River at
Doctortown, GA
USGS 02226000
8 0 8 16 24 32 Kilometers

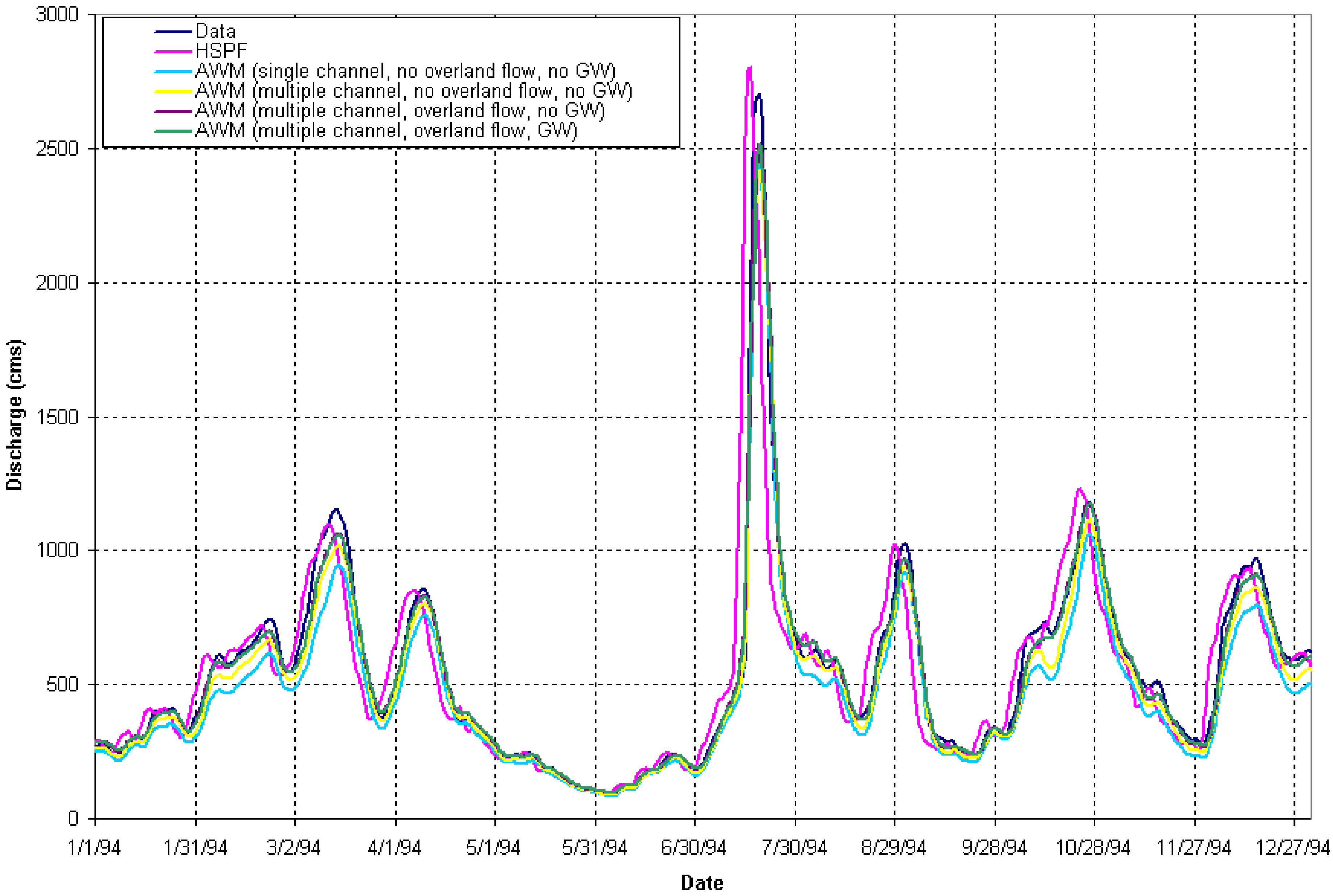
Comparison of results for 1988-1995



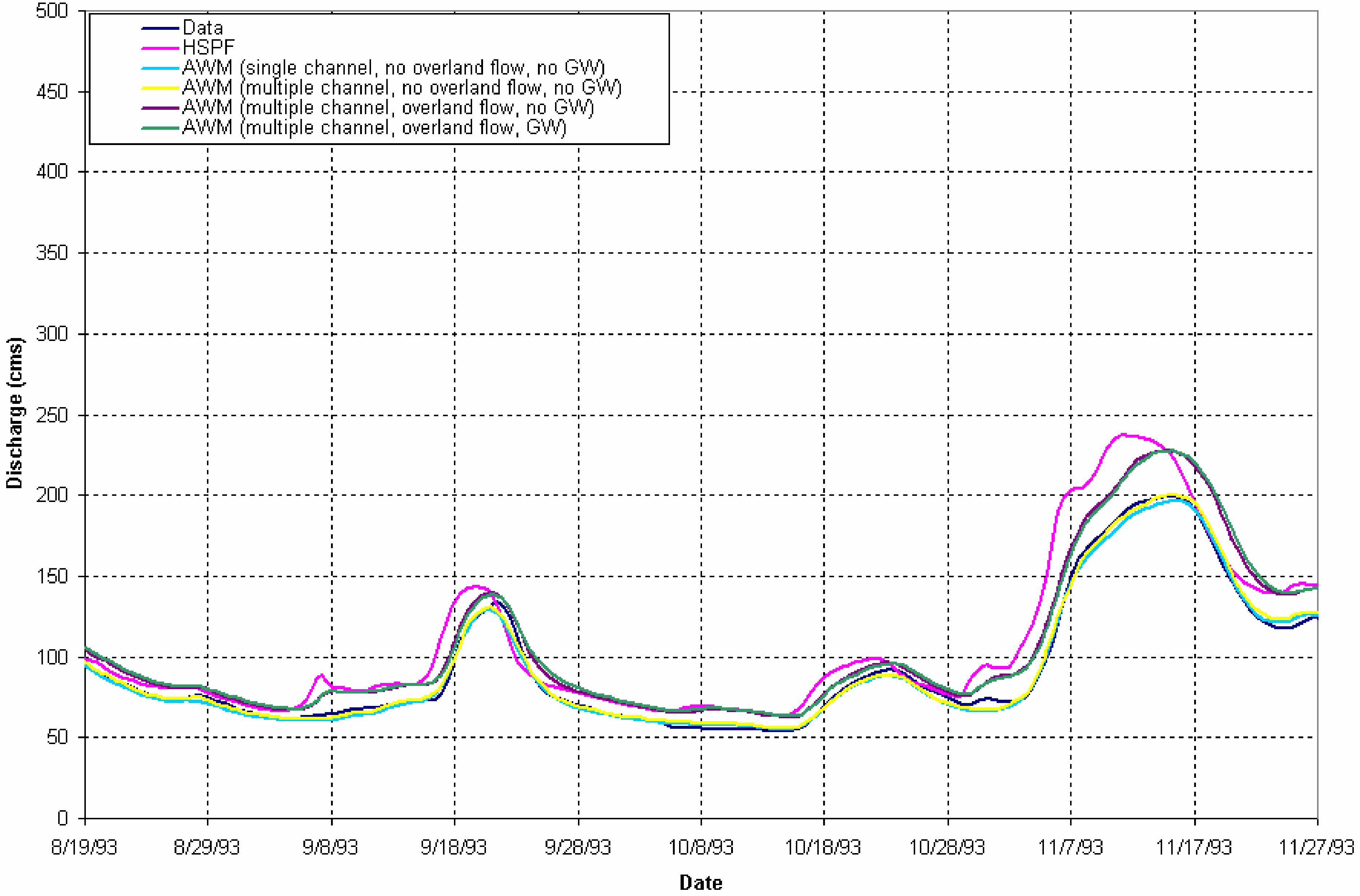
Detailed comparison of results for 1989



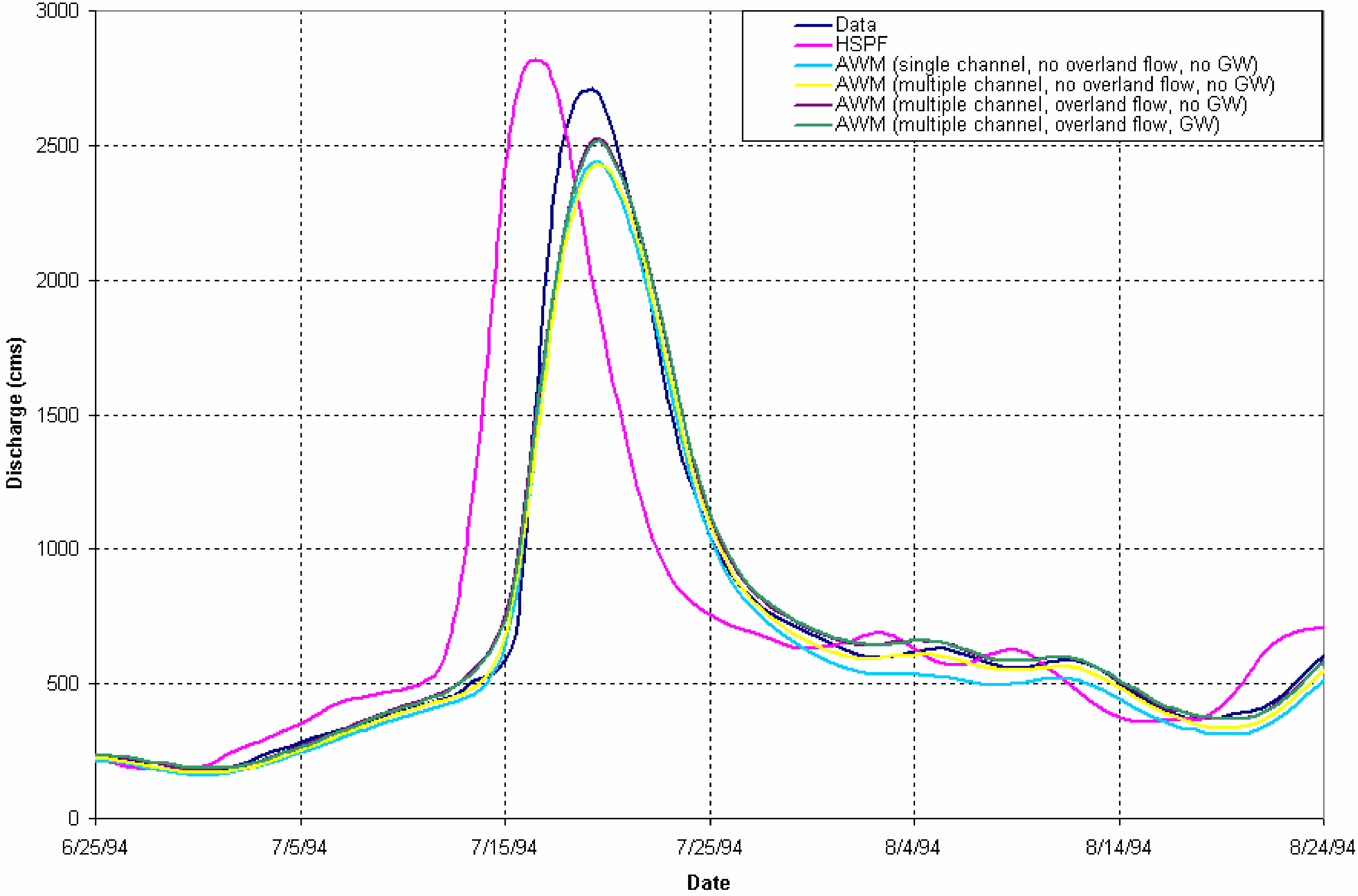
Detailed comparison of results for 1994



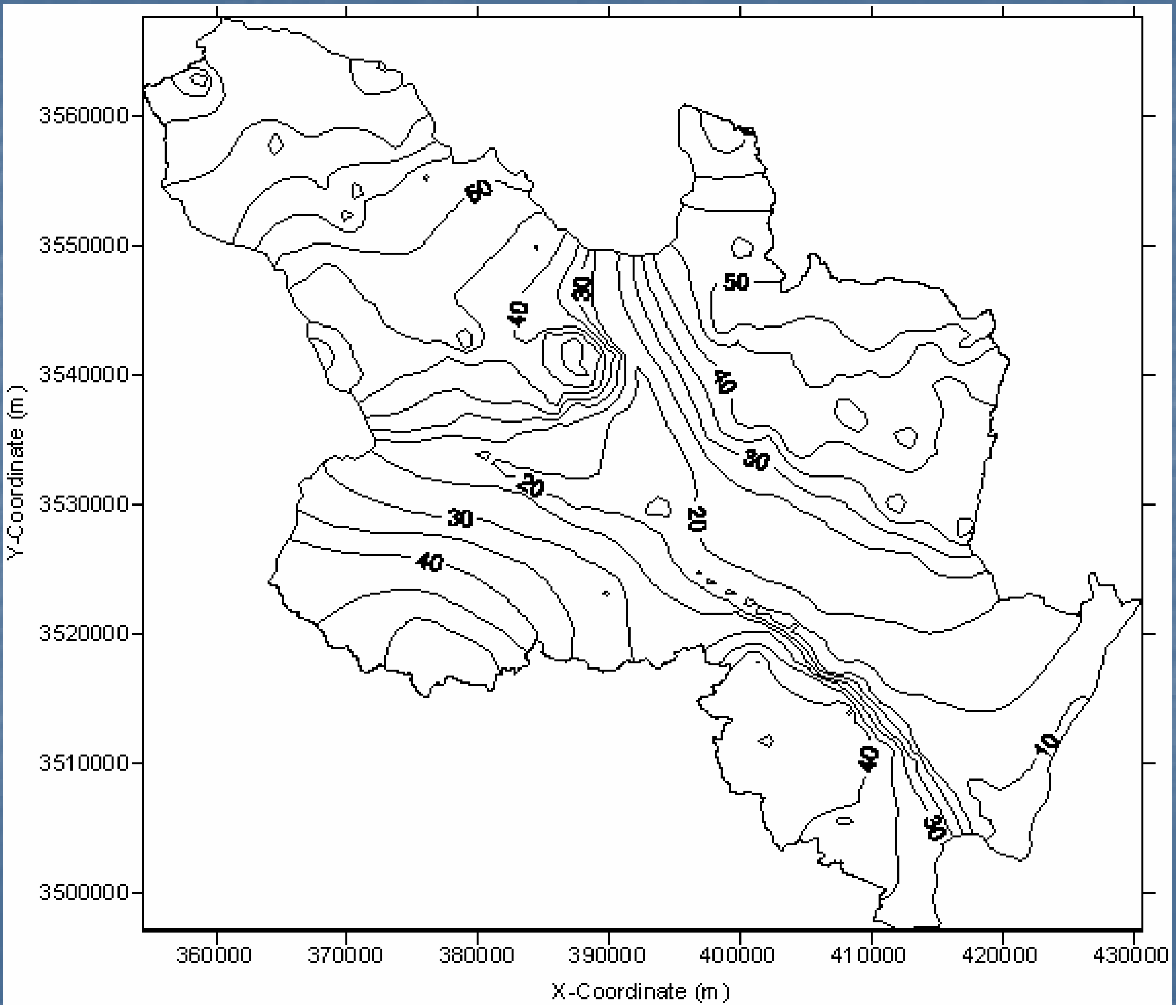
Comparison of results for a low flow period



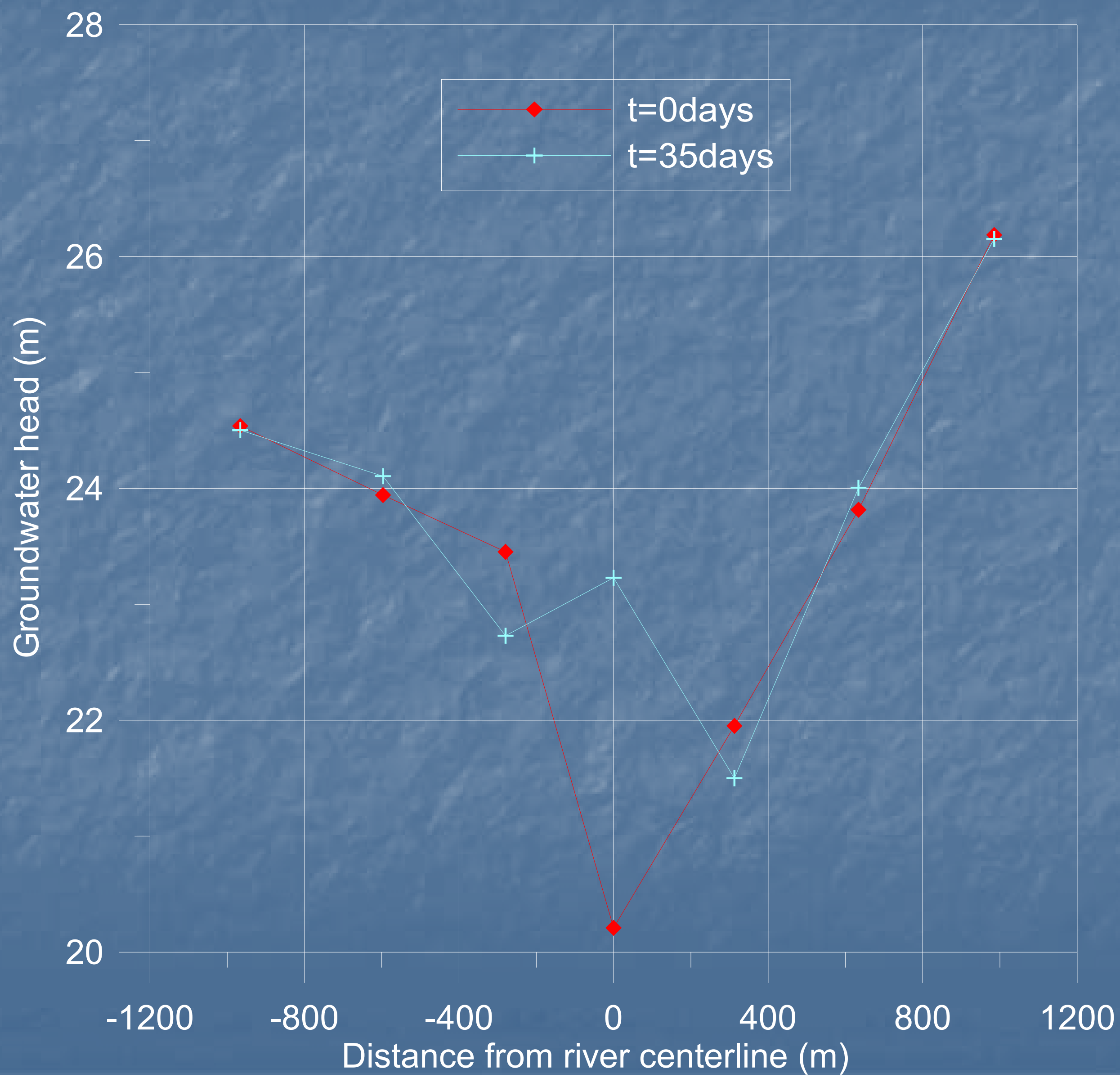
Comparison of results for a high flow period



GROUNDWATER



GW CROSS SECTION



CONCLUSIONS

- Order of importance of the sub-process;
- Domain of importance;
- Functional scales; and,
- Hybrid modeling concepts

CONCLUSIONS

- Selection of the smallest scale in an integrated model as functional scale is not possible.
- Hybrid modeling approach is necessary.
- Functional scale based on …..

ACKNOWLEDGEMENTS

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We would like to express our gratitude to *Dr. Mac Rawson*, Director of Georgia Sea Grant College Program for his continuous support throughout this study.

For additional information or questions, you may contact:

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http://groups.ce.gatech.edu/Research/MESL/

MESL