Water Quality Modeling and TMDL Development for the Illinois River Watershed

Sponsored by
EPA Region 6
Dallas, TX

Performed by
AQUA TERRA Consultants (Prime Contractor)
Mountain View, CA
and
Dynamic Solutions, LLC
Knoxville, TN

Public Meeting
Rogers, AR
May 19, 2011

Presentation Topics

- Update on Simulation Plan
- Update on Modeling QAPP

Project Tasks

- Work plan development and project management
- Quality assurance project plan development
- Data compilation and assessment
- GIS/geospatial database development
- Watershed/WQ model selection and development
  - Phase I – Simulation Plan Development,
    Modeling QAPP Development
  - Phase II – Model setup and calibration/validation
- Scenario development, simulation, and TMDL development

THE MODELING PROCESS

Phase I

- Data collection
- Model input preparation
- Parameter evaluation

Phase II

- Calibration
- Validation
- (Post-audit)

Model Testing/ Performance Evaluation

Phase III

- Analysis of alternatives

Simulation Plan – Draft Table of Contents

- Introduction
- Time-series Data Needs
- Segmentation and Characterization of the IRW
- Calibration/Validation
- Lake Tenkiller EFDC Application
- Special Issues & Consideration

Models Selected for the IRW TMDL

- Watershed Domain:
  - HSPF – Hydrologic Simulation Program FORTRAN
- Lake Tenkiller
  - EFDC – Environmental Fluid Dynamics Code

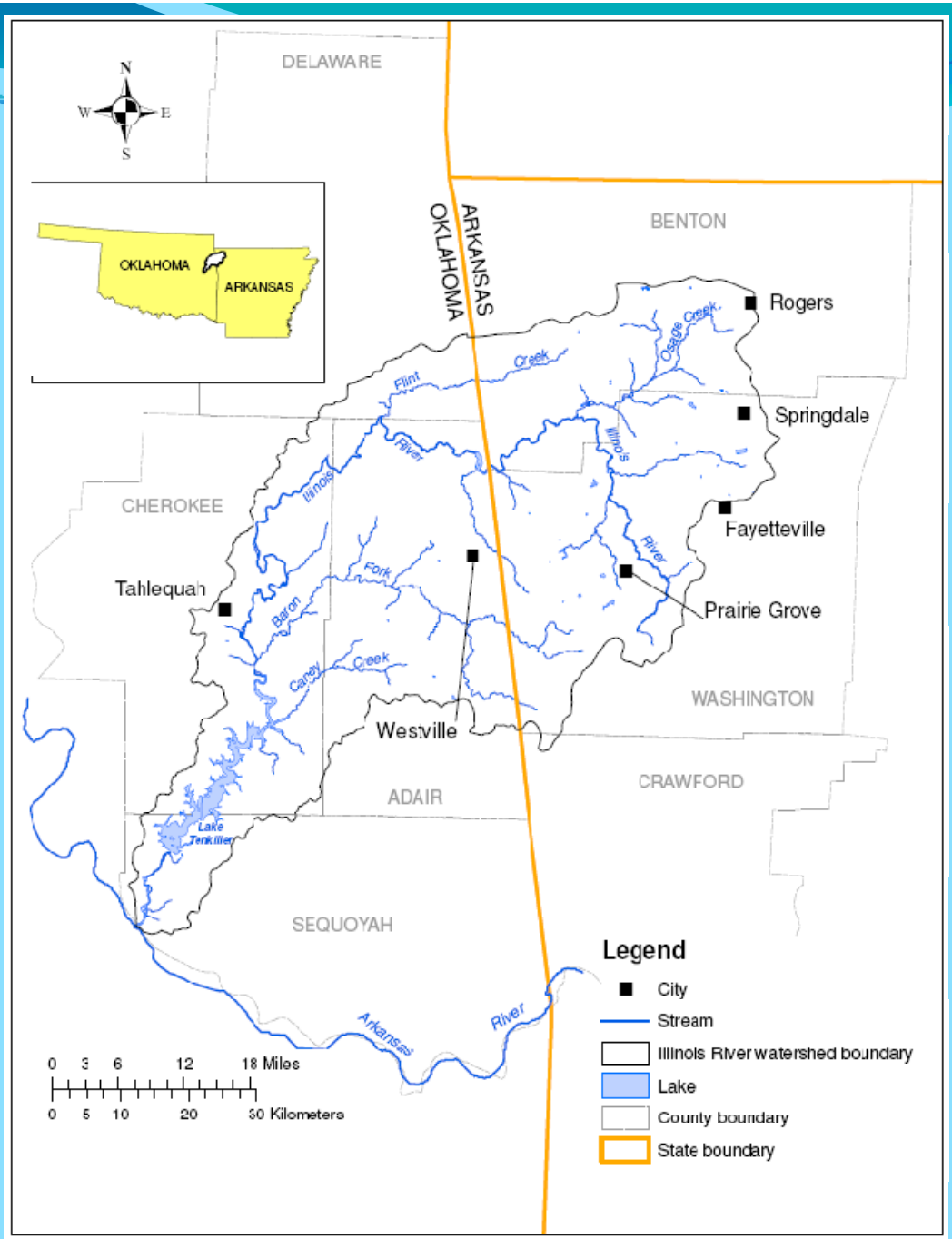
Constituents Modeled

- Flow/discharge
- Sediment/TSS
- Water temperature
- DO
- BOD ultimate or total BOD
- NO3/NO2, combined
- NH3/NH4
- Total N
- PO4
- Total P
- Phytoplankton as Chl a
- Benthic algae

Data Needs for Modeling

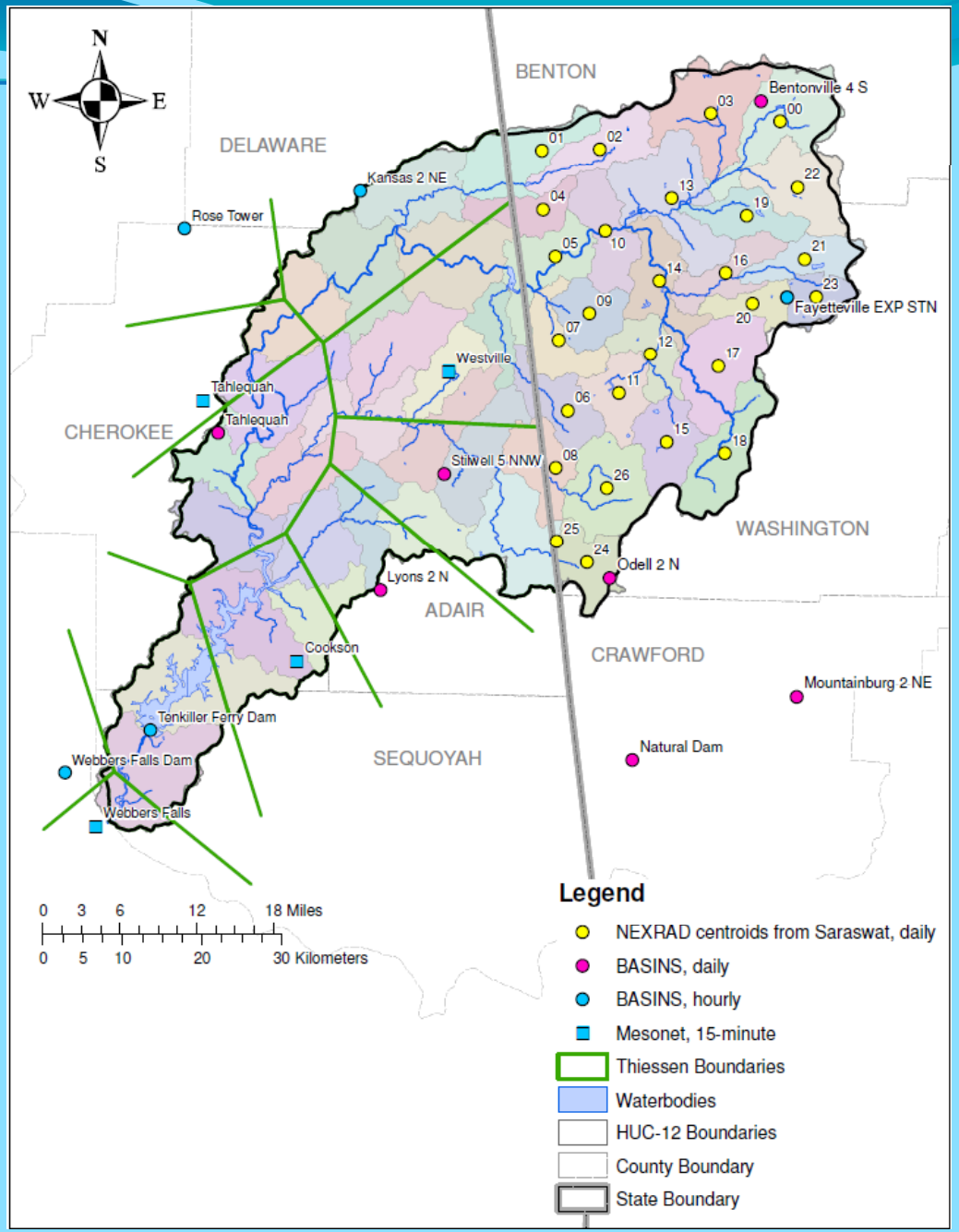
- Precipitation and meteorologic data
- Monitoring program observations
- Watershed land use/land cover and other GIS data
- Hydrography and geomorphological data
- Other nutrient source data/information
- Prior investigations and modeling studies

Illinois River Watershed in AR and OK



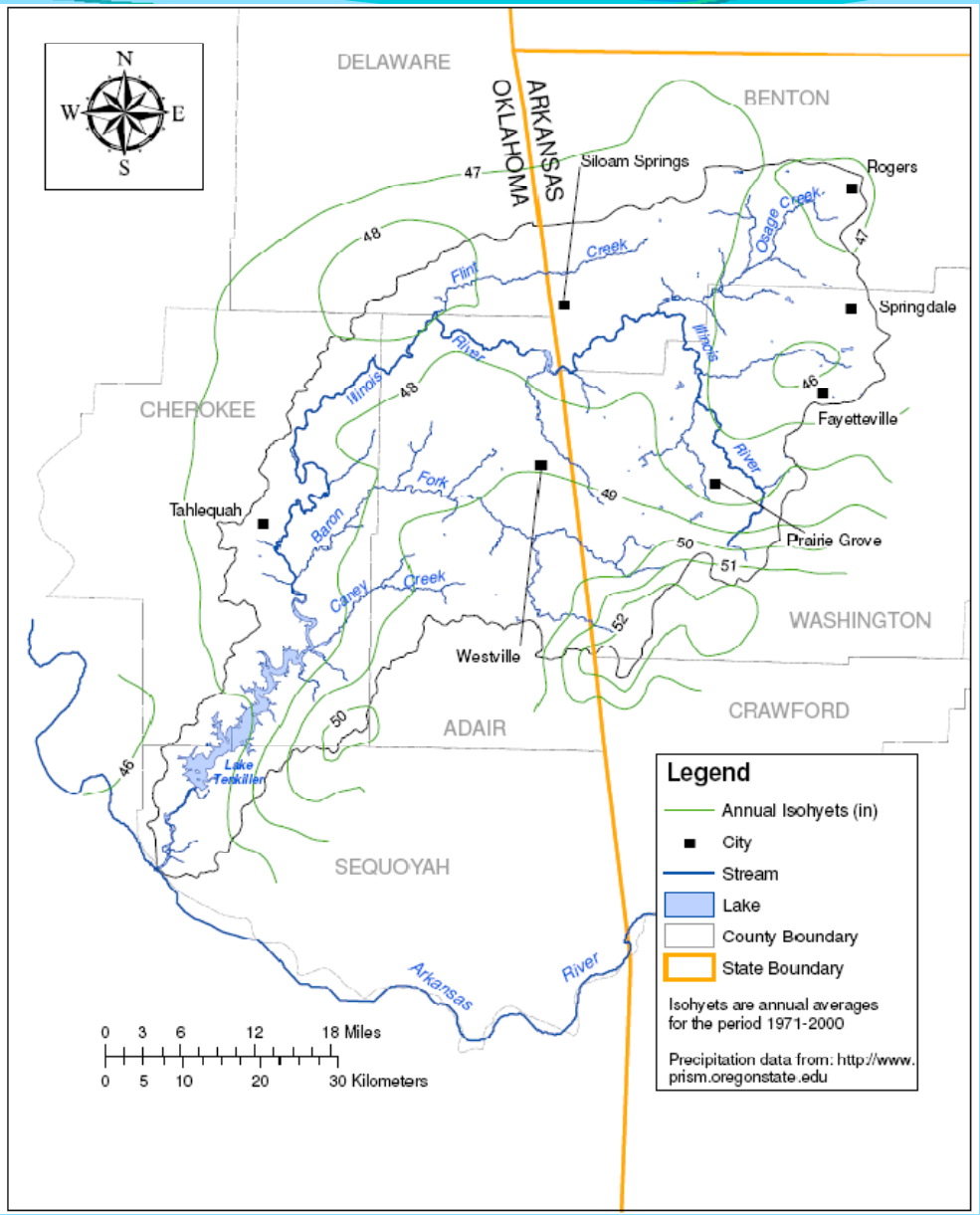
Planned Approach for Rainfall Inputs

- For OK – 11 gages using NWS/BASINS and Mesonet data
- For AR – NEXRAD data from Saraswat for 27 subwatersheds
- Daily data to be disaggregated to hourly values



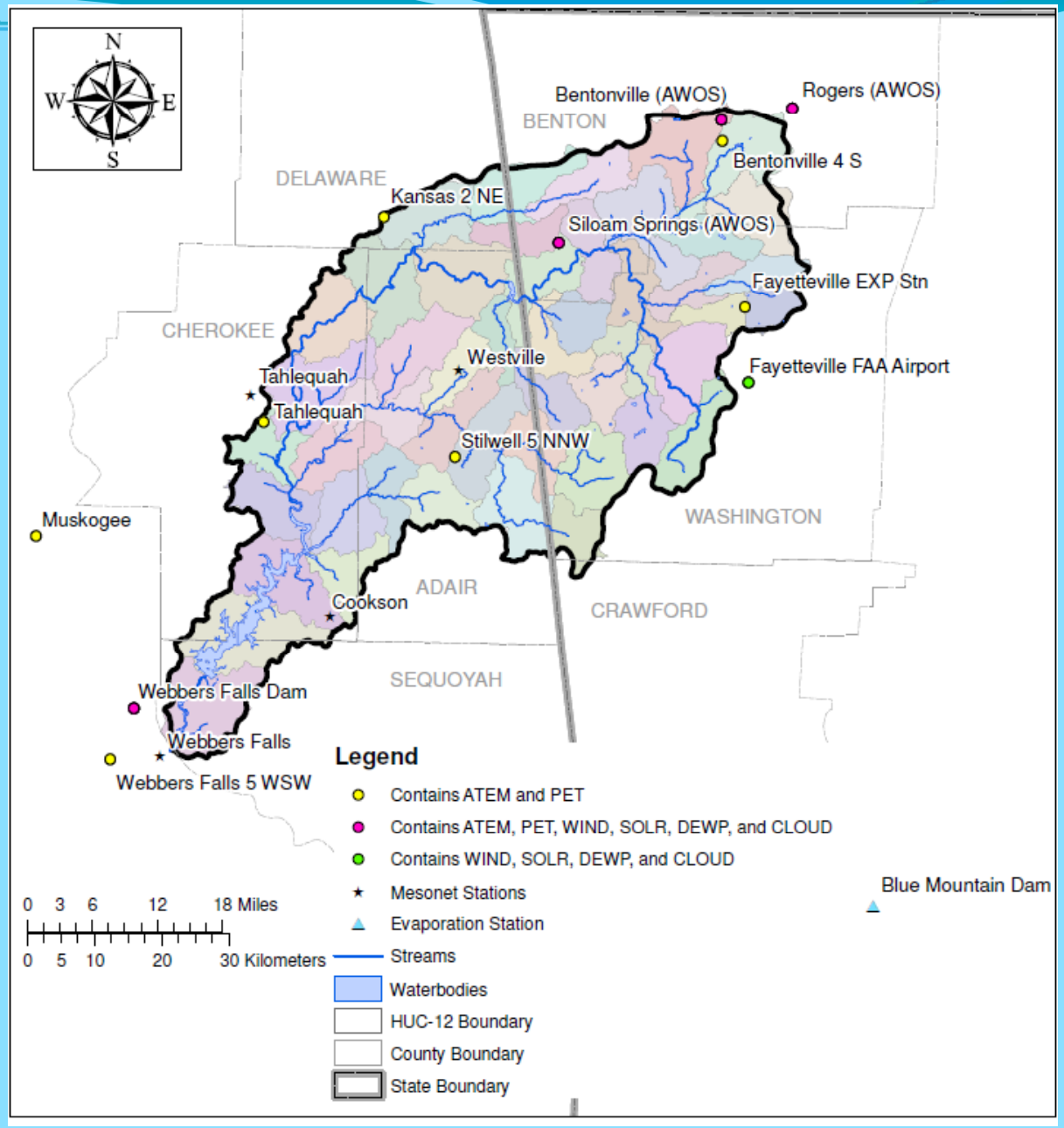
IRW Isohyetal Map from PRISM data

- PRISM – **P**arameter-elevation **R**egressions on **I**ndependent **S**lopes **M**odel
- Derived from point data, DEM, and other GIS data to produce gridded estimates
- Processed in GIS to provide isolines of equal values
- www.ocs.orst.edu/prism/



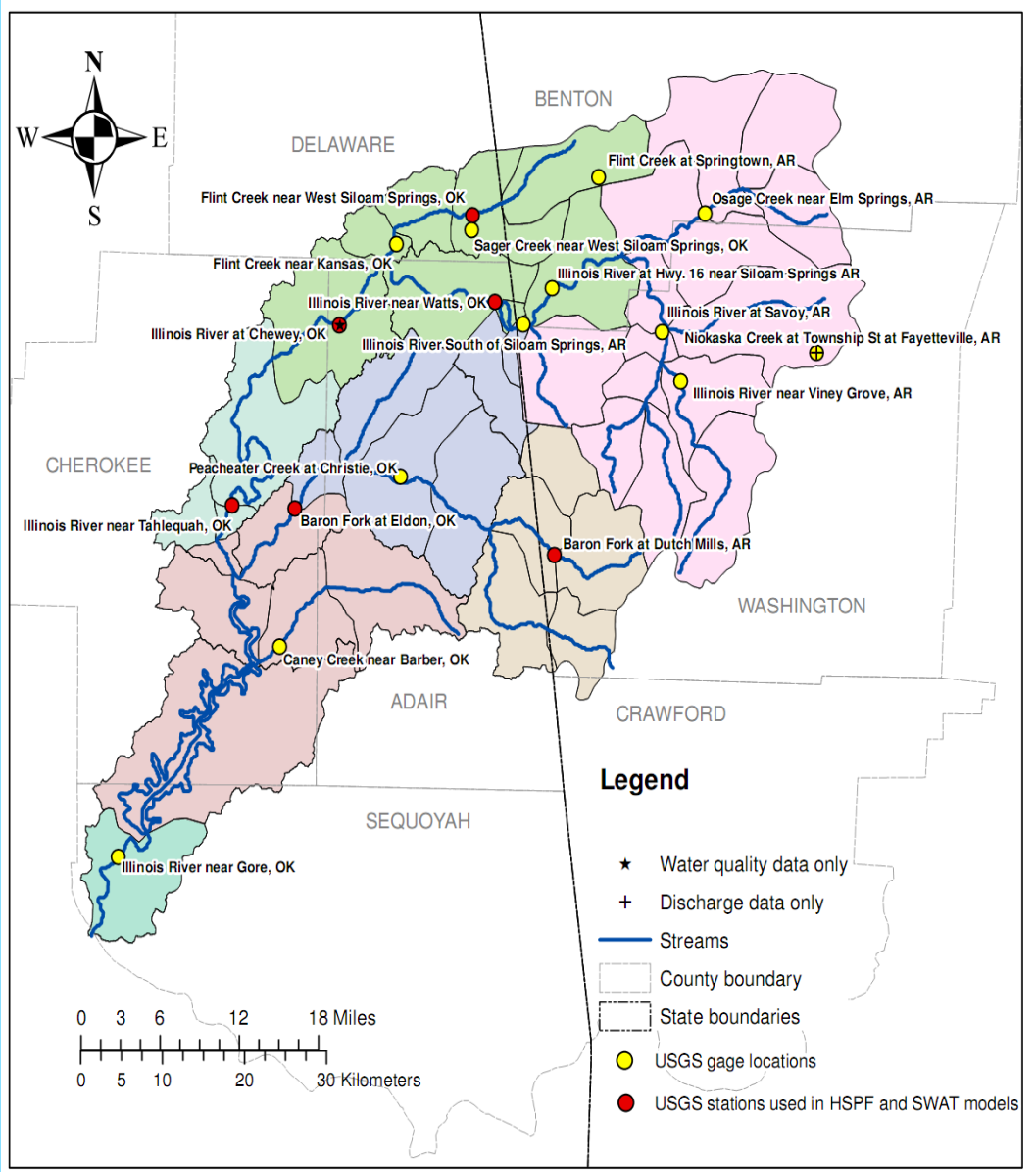
Other Met Data Inputs

- NWS/BASINS and Mesonet sites
- Types:
  - Air Temp
  - PET
  - Wind
  - Solar Rad
  - Dewpoint Temp
  - Cloud Cover



USGS Stream Gage Locations within the IRW

- 17 sites
- 10 sites in OK, 7 in AR
- 10 sites with WQ data through 2009



IRW Gage Stations for Calibration/Validation (tentative)

Location	Gage Station	Water Quality		Tributary Area (mi²)	Elevation (ft)
Illinois River near Tahlequah, OK	7196500	8/23/1955	12/15/2009	959	664.14
Baron Fork at Eldon, OK	7197000	5/7/1958	12/14/2009	307	701.14
Baron Fork at Dutch Mills, AR	7196900	3/17/1959	8/25/2009	40.6	986.47
Illinois River near Watts, OK	7195500	9/12/1955	10/26/2009	635	893.78
Illinois River near Viney Grove, AR	7194760	9/6/1978	7/19/2007	80.7	
Illinois River at Savoy, AR	7194800	9/11/1968	8/25/2009	167	
Osage Creek near Elm Springs, AR	7195000	9/10/1951	8/25/2009	130	1052
Illinois River at Hwy. 16 near Siloam Springs AR	7195400	9/8/1978	9/20/1994	509	
Illinois River South of Siloam Springs, AR	7195430	10/3/1972	8/25/2009	575	
Flint Creek at Springtown, AR	7195800	10/15/1975	7/1/1996	14.2	1173.47
Flint Creek near West Siloam Springs, OK	7195855	7/11/1979	8/28/1996	59.8	
Sager Creek near West Siloam Springs, OK	7195865	5/24/1991	10/21/2009	18.9	960
Flint Creek near Kansas, OK	7196000	9/7/1955	10/26/2009	110	854.59
Peacheater Creek at Christie, OK	7196973	8/6/1991	5/16/1995	25	801.72
Caney Creek near Barber, OK	7197360	8/25/1997	10/27/2009	89.6	
Illinois River at Chewey, OK	7196090	7/16/1996	10/27/2009		
Illinois River near Gore, OK	7198000	4/12/1940	8/16/1995	1626	468

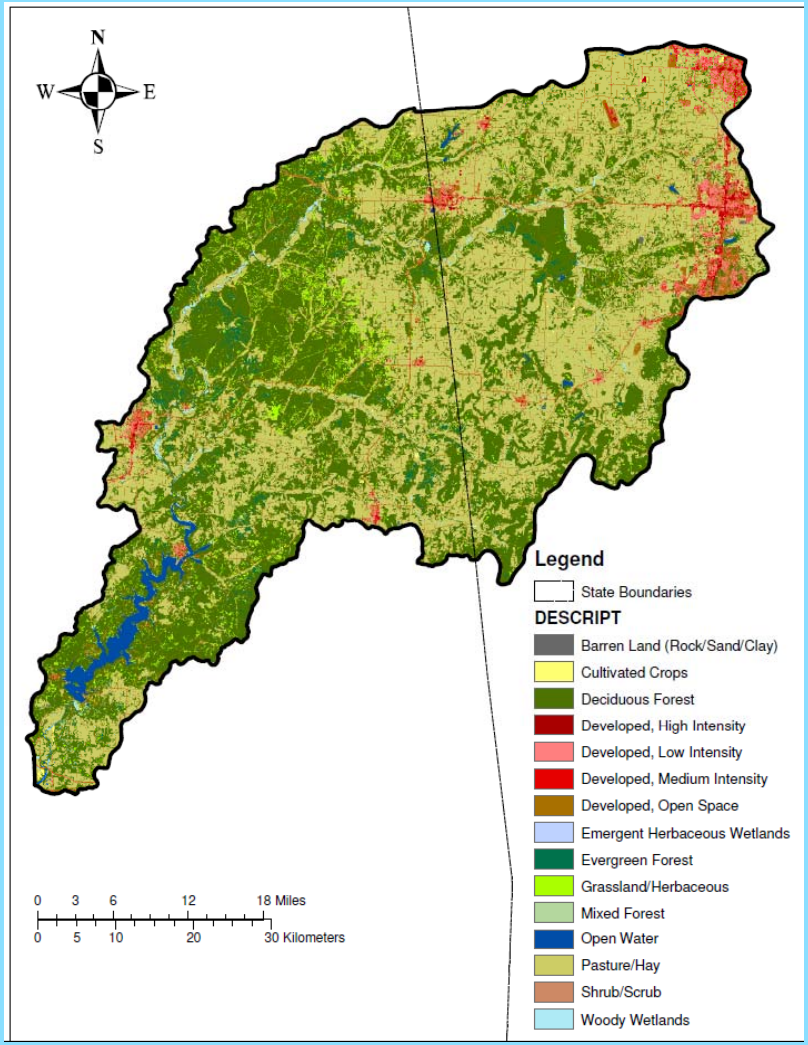
Key: Pink – Border sites; Yellow – OK; Green - AR

Tentative Calibration Sites

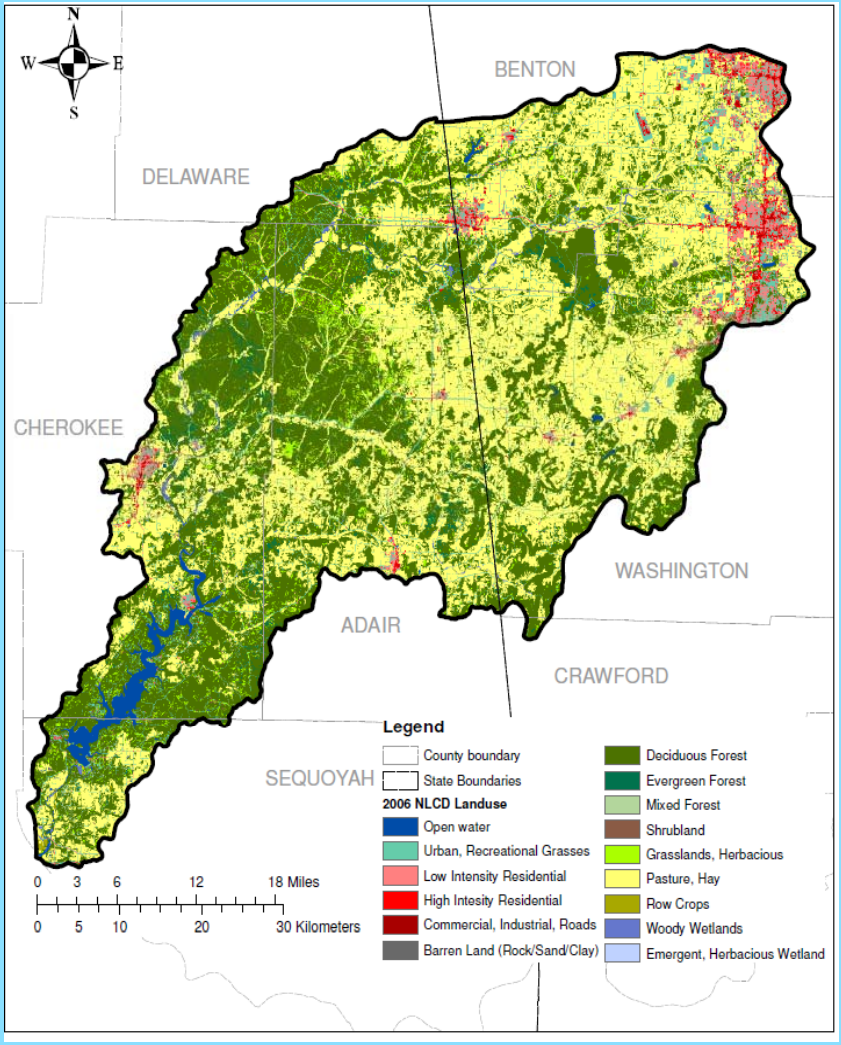
- AR –
  - Barren Fork at Dutch Mills
  - Osage Cr near Elm Springs
  - IR at Savoy
  - IR near Viney Grove
- Border sites:
  - IR south of Siloam Springs (HY 59)
  - IR near Watts
- OK –
  - Barren Fork at Eldon
  - Flint Creek near Kansas
  - Caney Creek near Barber
  - IR at Tahlequah

NLCD Land Use – 2001 and 2006

2001



2006



Land Use Distributions for NLCD Coverages

	1992		2001		2006	
Description	Area (Sq. Mi.)	Percent land use	Area (Sq. Mi.)	Percent land use	Area (Sq. Mi.)	Percent land use
open water	32.25	1.96	24.15	1.47	24.16	1.47
urban, recreational grasses	7.41	0.45	91.67	5.58	97.23	5.91
low intensity residential	27.91	1.70	34.01	2.07	38.52	2.34
high intensity residential	13.38	0.81	11.89	0.72	14.70	0.89
commercial, industrial, roads	12.24	0.74	4.66	0.28	5.63	0.34
Barren land (rock/sand/clay)	3.30	0.20	1.86	0.11	3.01	0.18
deciduous forest	554.83	33.75	681.70	41.46	678.47	41.27
evergreen forest	34.01	2.07	19.78	1.20	19.64	1.19
mixed forest	114.86	6.99	8.16	0.50	8.09	0.49
shrubland	13.55	0.82	7.61	0.46	8.26	0.50
grassland, herbaceous	0.13	0.01	55.41	3.37	59.90	3.64
pasture, hay	763.31	46.43	691.06	42.03	674.55	41.03
row crops (small grains/fallow)	60.45	3.68	2.39	0.15	2.16	0.13
woody wetlands	4.96	0.30	9.59	0.58	9.68	0.59
emergent, herbaceous wetland	1.49	0.09	0.12	0.01	0.12	0.01

WATERSHED MODEL CALIBRATION/VALIDATION

Tentative Simulation Periods:
Calibration: 2002 – 2009
Validation: 1994 – 2001

CALIBRATION/VALIDATION ISSUES

'Basic Truths' in modeling Natural Systems

- Models are approximations of reality; they can not precisely represent natural systems
- There is no single, accepted statistic or test that determines whether or not a model is valid
- Both graphical comparisons and statistical tests are required in model calibration and validation
- Models cannot be expected to be more accurate than the errors (confidence intervals) in the input and observed data
- A 'weight-of-evidence' approach is becoming the preferred practice for model calibration and validation

MODEL/DATA COMPARISONS

"Weight-of-Evidence" Approach

- Annual and monthly runoff volume (inches)
- Mean runoff volume for simulation period (inches)
- Daily flow timeseries (cfs)
  - observed and simulated daily flow
  - scatter plots
- Flow frequency (flow duration) curves (cfs)
- Storm hydrographs, hourly or less, (cfs)

MODEL/DATA COMPARISONS

Water Balance Components

- Precipitation (+ irrigation, other sources)
- Total Runoff (sum of following components)
  - Overland flow
  - Interflow
  - Baseflow
- Total Actual Evapotranspiration (ET) (sum of following components)
  - Interception ET
  - Upper Zone ET
  - Lower Zone ET
  - Baseflow ET
  - Active Groundwater ET
- Deep Groundwater Recharge/Losses

MODEL/DATA COMPARISONS

Graphical/Statistical Procedures & Tests

Graphical Comparisons:

- Timeseries plots of observed and simulated values for fluxes (e.g., flow) or state variables (e.g., stage, sediment concentration, biomass concentration)
- Observed and simulated scatter plots, with 45° linear regression line displayed, for fluxes or state variables
- Cumulative frequency distributions of observed and simulated fluxes or state variable (e.g., flow duration curves)

Statistical Tests:

- Error statistics, e.g., mean error, absolute mean error, relative error, relative bias, standard error of estimate, etc.
- Correlation tests, e.g., correlation coefficient, coefficient of model-fit efficiency, etc.
- Cumulative Distribution tests, e.g., Kolmogorov-Smirnov (KS) test

ROUGH CALIBRATION/VALIDATION TARGETS

% Difference Between Simulated and Recorded Values

	VERY GOOD	GOOD	FAIR
Hydrology/Flow	< 10	10 - 15	15 - 25
Sediment	< 20	20 - 30	30 - 45
Water Temperature	< 7	8 - 12	13 - 18
Water Quality/Nutrients	< 15	15 - 25	25 - 35
Pesticides/Toxics	< 20	20 - 30	30 - 40

CAVEATS:
1.) Relevant to monthly and annual values; storm peaks may differ more.
2.) Quality and detail of input and calibration data.
3.) Purpose of model application.
4.) Availability of alternative assessment procedures.
5.) Resource availability (i.e. time, money, personnel).

Source: Donigian, 2000

R and R^2 VALUE RANGE FOR MODEL PERFORMANCE

Criteria

R	← 0.75 — 0.80 — 0.85 — 0.90 — 0.95 →
R^2	← 0.6 — 0.7 — 0.8 — 0.9 →
Daily Flows	Poor Fair Good Very Good
Monthly Flows	Poor | Fair | Good | Very Good

HIERARCHY OF WATERSHED MODEL CALIBRATION

- Hydrology / Hydraulics
- Water Temperature
- Sediment Loadings and Instream Sediment Fate / Transport
- Nonpoint Loadings
- Instream Water Quality Processes

Lake Tenkiller Modeling

- US EPA EFDC – Environmental Fluid Dynamics Code

EFDC Application to Lake Tenkiller

- EFDC includes the following sub-models:
  - Hydrodynamic model
  - Sediment transport model
  - Water quality and eutrophication model
  - Sediment flux model

EFDC Lake Model

- EFDC state variables include:
  - Hydrodynamics: water surface elevation, water temperature (thermal stratification: 10 layers)
  - Sediment transport: total suspended solids (TSS)
  - Water Quality: Organic C,N,P, inorganic N,P, algae (Chl-a) & dissolved oxygen
  - Sediment Flux: sediment oxygen demand, nutrient release (N,P), sediment bed organic matter (C,N,P) and porewater nutrients (N,P)

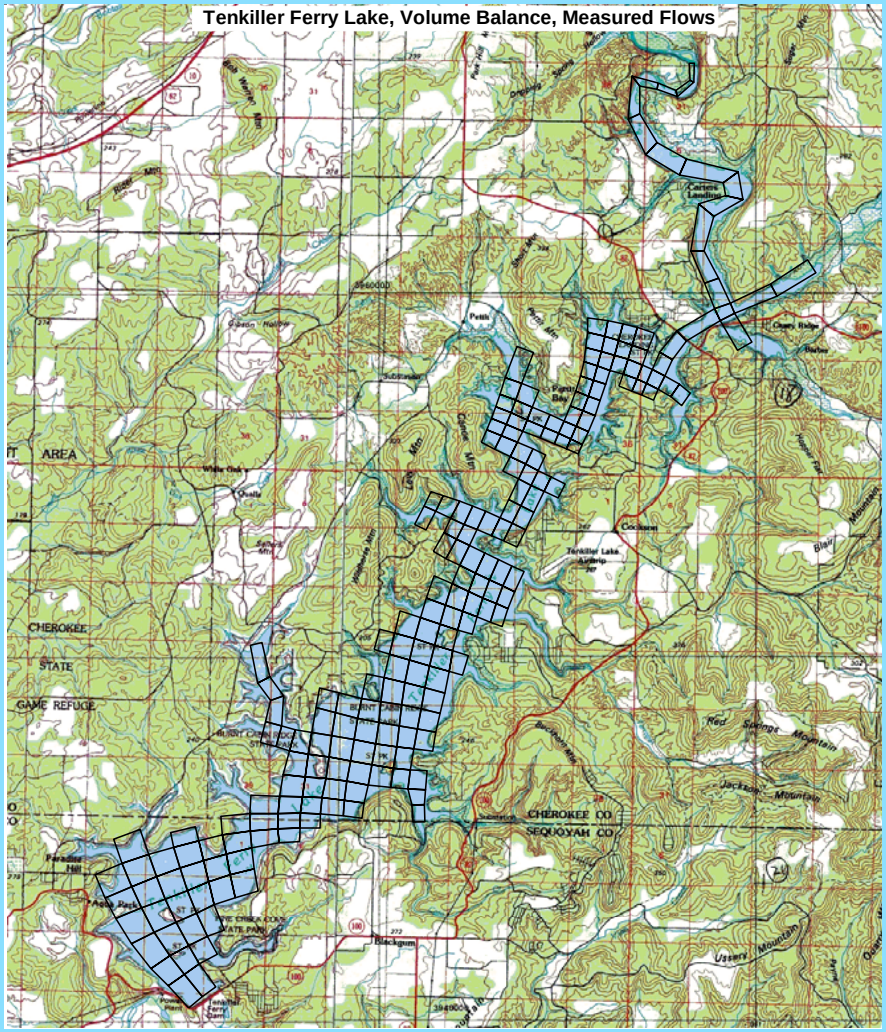
Data Requirements for Lake Model

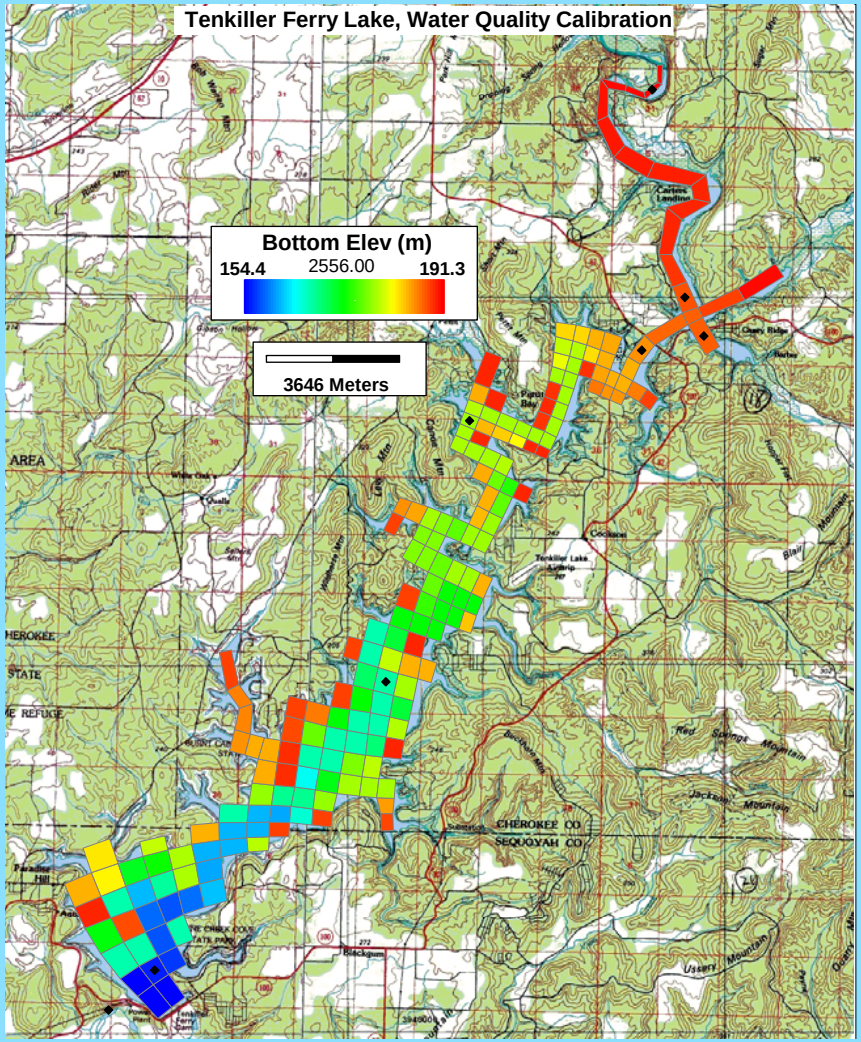
- Shoreline/bathymetry of lake and tributaries
- Winds/atmospheric forcing (e.g., solar radiation, air temperature, humidity etc.)
- Watershed flows/loads of TOC, TN, TP and TSS
- Flow withdrawals from the lake
- Water level at the dam; in-lake station data for water temperature, TSS, TN, TP, Chl-a and oxygen
- Sediment bed properties: solids content, grain size, organic matter (TOC,TON,TOP) and porewater (N,P)

Previous EFDC Model

- Calibrated to Clean Lakes Program data from 1992-1993
- Represented vertical profiles of water temperature and dissolved oxygen
- Represented seasonal trends of water temperature, oxygen, algae (Chl-a) and nutrients (TN,TP)
- Oxygen results used to determine seasonal trends in anoxic volume of the lake
- Model demonstrated importance of sediment flux model for good agreement of model dissolved oxygen with observed data

EFDC Grid & Lake Bathymetry





Plan for Improving Lake Model

- Increase grid resolution in deep areas of lake & in upper reservoir/transition zone to enhance mixing and circulation processes
- Use updated watershed flow and loading of TOC, TN, TP and TSS
- Sediment bed core data now available from Fisher et al. survey in 2005
- Re-calibrate hydrodynamic and water quality model using OWRB data for 8 in-lake stations from 2005-2006

MODELING QAPP

Quality Assurance Project Plan for Modeling

Modeling QAPP TOC

(Organized in response to EPA QA/G-5M)

- Preamble
- Project organization
- Problem definition and background
- Project description and schedule
- Quality objectives and criteria
- Documentation and records
- Modeling approach and calibration/validation
- Data Acquisition
- Hardware/software configuration
- References

Modeling QAPP

- Companion document to the IRW TMDL Project QAPP
- Focuses on use of data in the modeling effort
- Assesses quality of data to be used in the modeling effort
- Discusses the overall modeling approach
- Describes calibration/validation procedures
- Includes model performance and acceptance criteria
- Closely related to the Simulation Plan

Data Quality Screening/Assessment

- Function of data type and use in the modeling
  - Types – weather, flow, WQ, soils, DEM, land use, etc.
  - Model setup vs. model application (calib/valid)
- Majority of data is from agencies with established QA/QC procedures
- Data from others will be evaluated for QA/QC if used for either setup or application
- Significant amount of data has been received; <u>not ALL</u> will be used directly in the model, due to differences in temp/space scales, QA/QC, etc.
- QA/QC assessment will be performed as part of model setup effort

Special Issues and Considerations

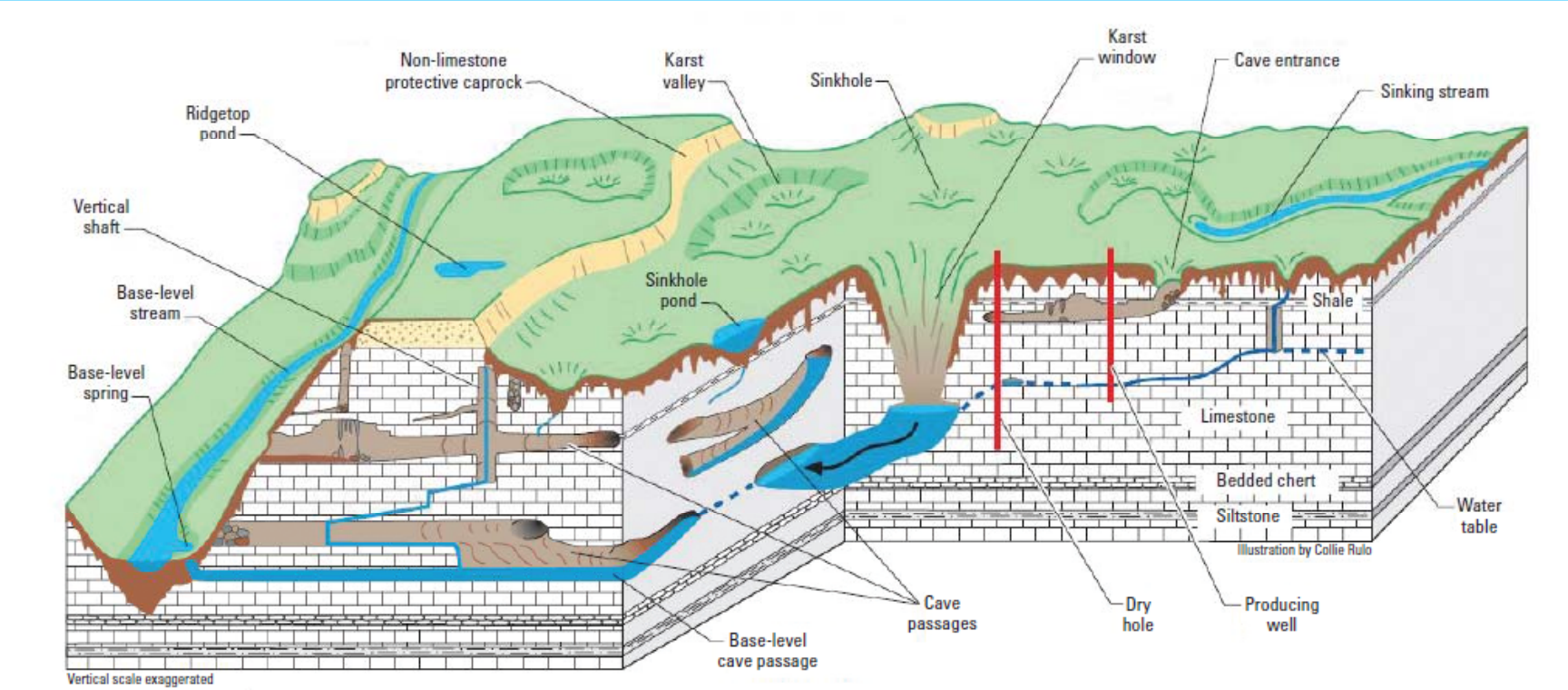
- Karst conditions and representation in the model
- Comprehensive view of P sources and mass balances
- Poultry litter representation, including export practices
- Consistency and interpretation of model outputs with respect to the OK WQ standard at the AR/OK stateline
- Sensitivity and Uncertainty Analyses
- Scenarios for TMDLs - Issues

QUESTIONS/DISCUSSION

Modeling Karst Conditions

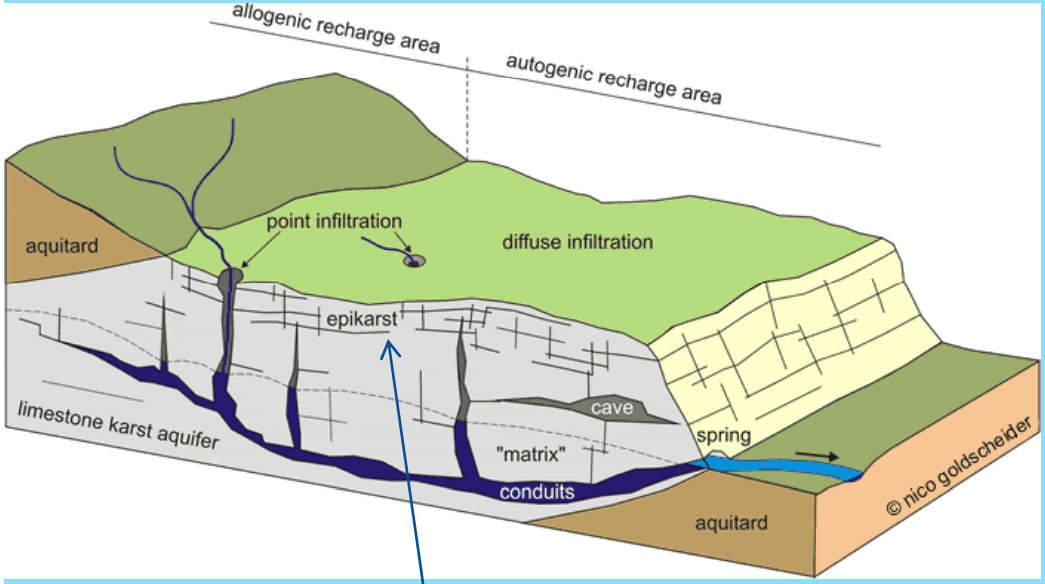
- Distinctive Features
- Definitions
- National Karst Map
- Karst Impacts on Hydrology
- Karst Drainage Basin
- Conceptual Model
- Parameter Adaptation

Distinctive Features of Karst Terrain



Physiographic and hydrologic features typical of a well-developed karst terrain (*Taken from USGS Document, Techniques and Methods 4–D2)*

Definitions



Three Functional Hydrologic Groups

Overflow allogenic basins - the trunk (master) conduit is recharged mostly by subsurface piracy of a surface stream(s), but because of limited hydraulic capacity, the surface channel is maintained as a losing stream reach or as an intermittent, storm-overflow route.

Underflow allogenic basins - the hydraulic capacity of the trunk conduits has increased to the point that the surface flow is completely diverted underground through streambed swallets, and the surface valley becomes blind.

Epikarst - The uppermost weathered zone of carbonate rocks with substantially enhanced and more homogeneously distributed porosity and permeability, as compared to the bulk rock mass below.

Local autogenic basin - surface flow has been captured by subsurface piracy, and the trunk conduit is recharged almost exclusively by infiltration through the soil and internal sinkhole drainage.

Pseudokarst - resembles karst but that is not formed by the dissolution of limestone; usually a rough-surfaced lava field in which ceilings of lava tubes have collapsed.

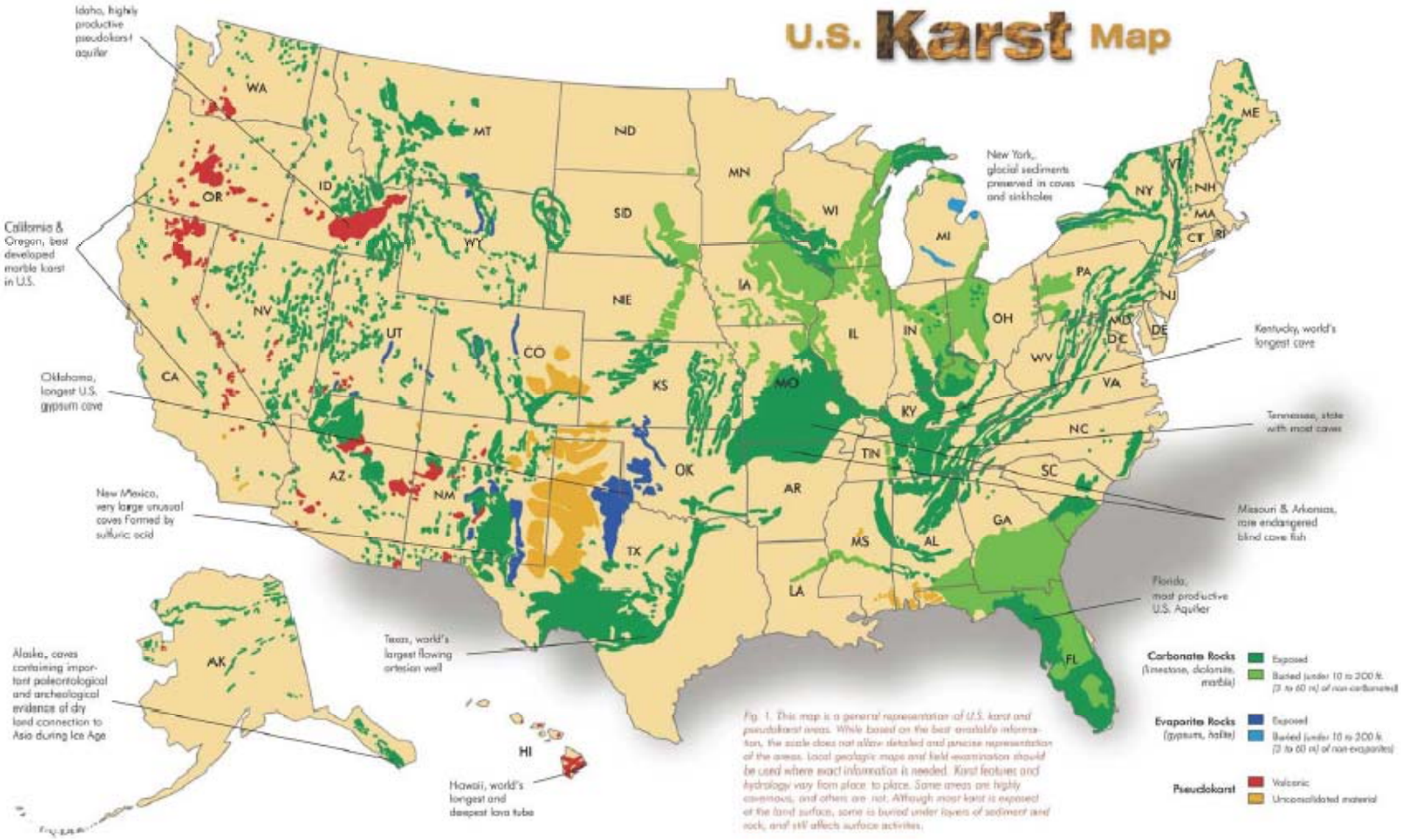
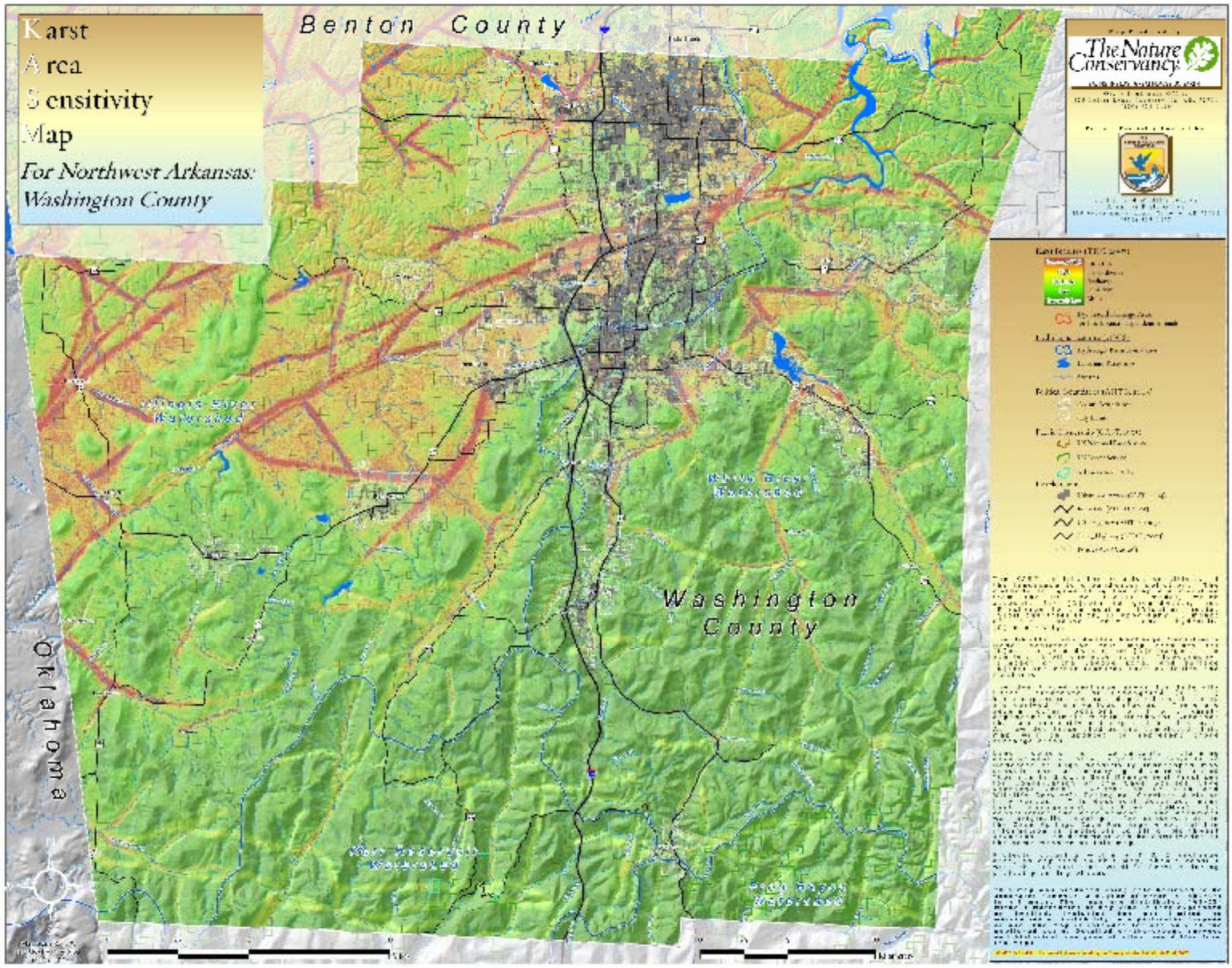


Fig. 1. This map is a general representation of U.S. karst and pseudokarst areas. While based on the best available information, the scale does not allow detailed and precise representation of the areas. Local geologic maps and field examination should be used where exact information is needed. Karst features and hydrology vary from place to place. Some areas are highly cavernous, and others are not. Although most karst is exposed at the land surface, some is buried under layers of sediment and rock, and still affects surface activities.

Karst of the US published by AGI (*Veni et al, 2001)*

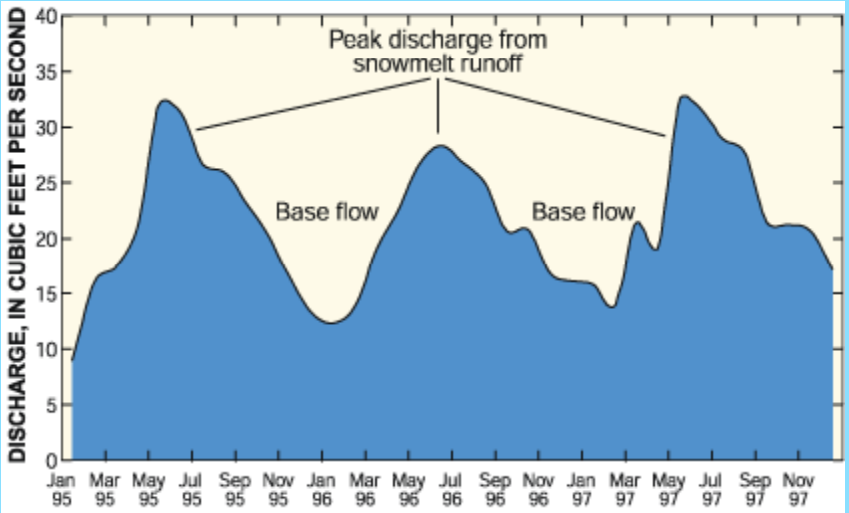
Arkansas/Oklahoma Illinois River Watershed Modeling

Karst Area Sensitivity Map for NW AR



Karst Impacts on Watershed Hydrology

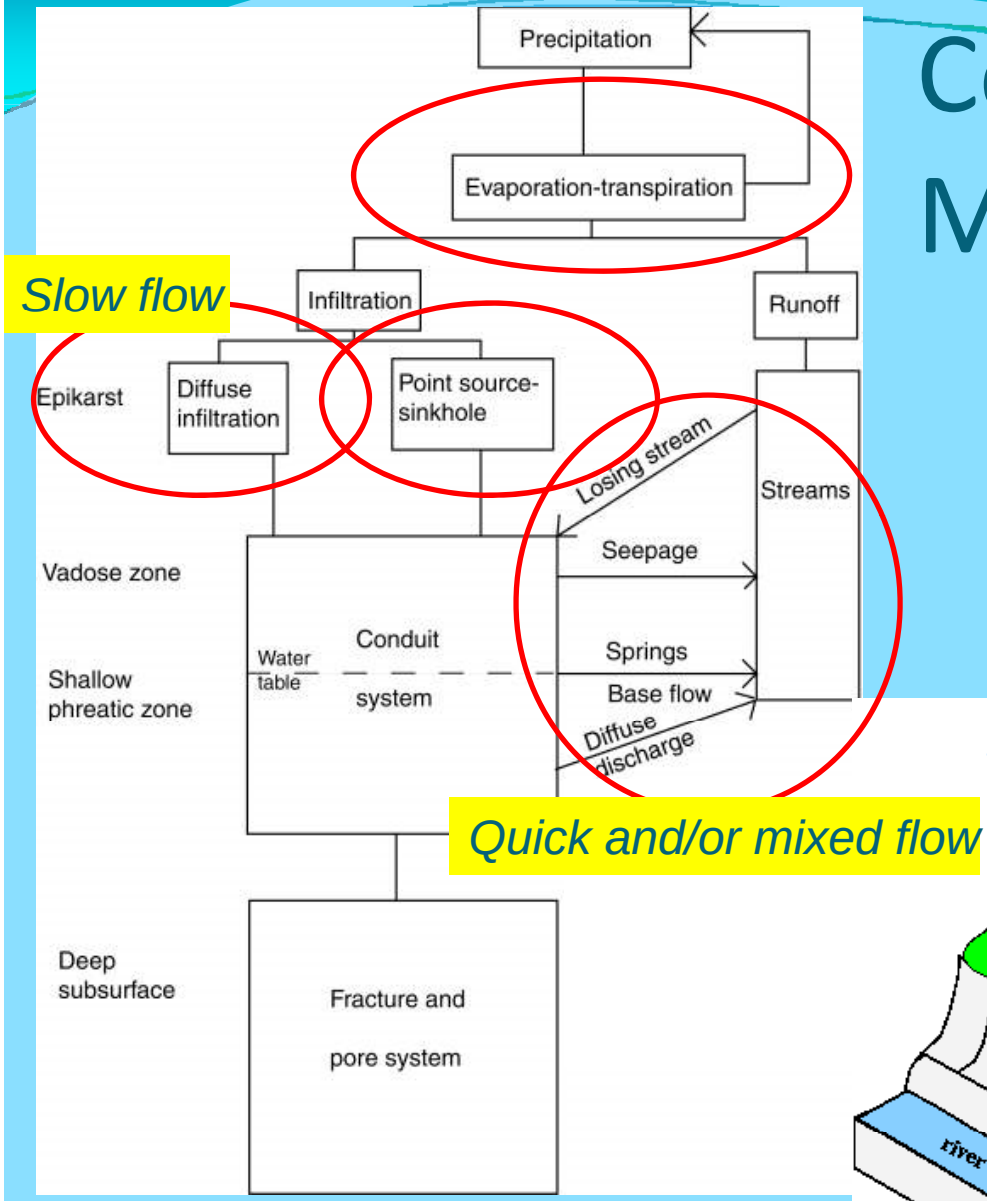
- **Highly interconnected** groundwater-surface water interactions
- **Highly variable** flow rates both spatially and temporally
- **Triple or Double-peak Hydrograph** – "Quick flow," "slow flow," and "mixed or intermediate flow"
- **Lower ET values** – due to rapid infiltration

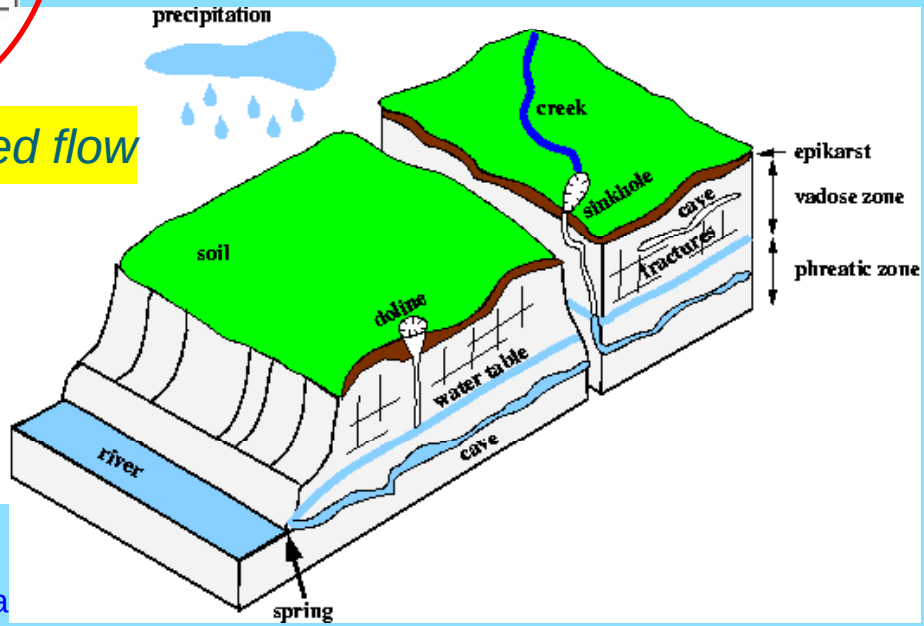


Hydrograph showing typical seasonal response of an alpine karst spring to snowmelt runoff

Conceptual Model

- ET
- Epikarst
- Point source-sinkhole
- Conduit System (discharge/recharge)

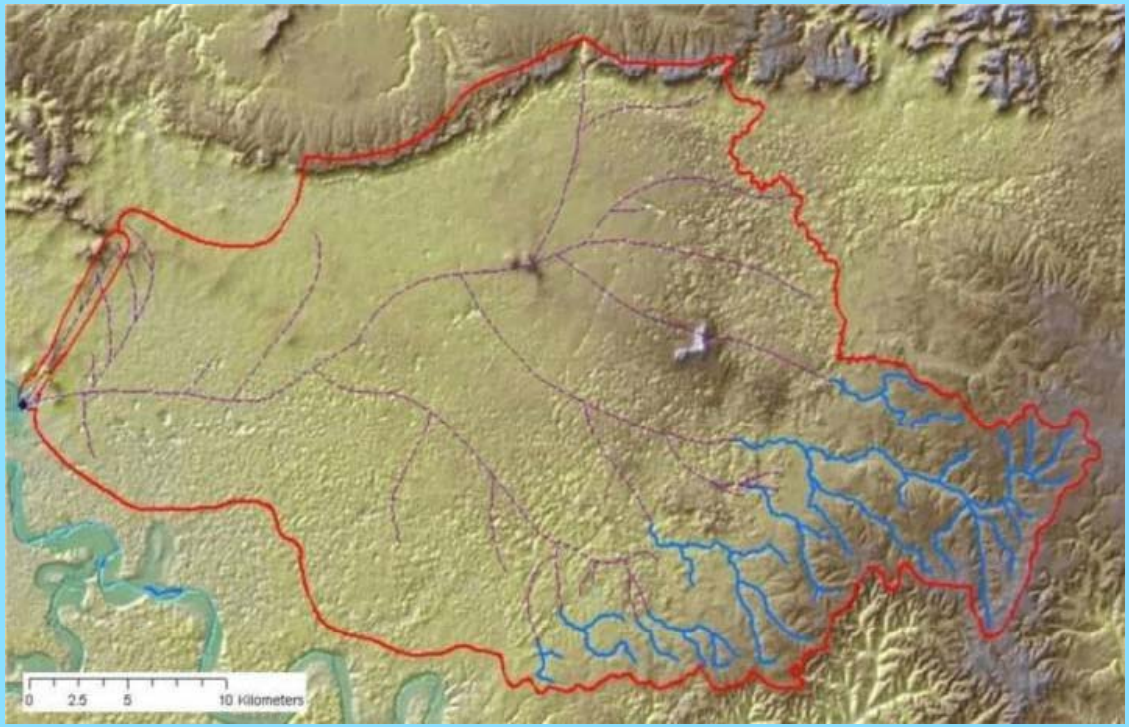




(Taken from USGS WRI Report 01-4011)

Arkansas/Oklahoma

Karst Drainage Basin



- The mapping unit defined by the total area of surface and subsurface drainage that contributes water to a conduit network and its outlet spring or springs.

- Karst basin boundaries do not always coincide with topographic drainage divides.

Model Parameter Adaptation for Karst

- INFILT - Infiltration
- AGWRC – Baseflow recession rate
- Baseflow rerouting
- INTFW - Interflow
- KVARY - Variable Recession

Data Dependent