HSPF Modeling of the Illinois River Watershed – Technical Update

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Illinois River Watershed Modeling
and TMDL Development Project
Informational Meeting
Armory Municipal Center
Tahlequah, OK

April 26, 2012

Presentation Topics

- Project Tasks
- US EPA HSPF Watershed Model
- Model Setup and Overview
- P sources and F/T
- Calibration and Validation Status
- Sensitivity and Uncertainty Analyses
- Scenarios for TMDL Development

Remaining Project Tasks

- Watershed/WQ model and development
  - Phase I – Simulation Plan Development (Drafted), Modeling QAPP Development (Drafted)
  - Phase II – Model setup and Calibration/Validation
  - Phase III – Sensitivity and Uncertainty Analyses
- Scenario development, simulation, and TMDL development
- Peer Review

Models Selected for the IRW TMDL

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

HSPF

Hydrological Simulation Program - FORTRAN

- It is a comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil runoff processes with in-stream hydraulic and sediment-chemical interactions.

•Physically based

•Sub-daily timesteps

•Surface and subsurface hydrology

•Stream/reservoir routing included

•User-defined WQ, sediment, nutrients, toxics/pesticides, metals, BOD, and bacteria

- Outputs: a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in a watershed.
- Development sponsored by US EPA and USGS; core watershed model in US ACOE Watershed Modeling System (WMS)

HSPF is currently one of the most comprehensive and flexible models of watershed hydrology and water quality available (Singh and Frevert, 2006).

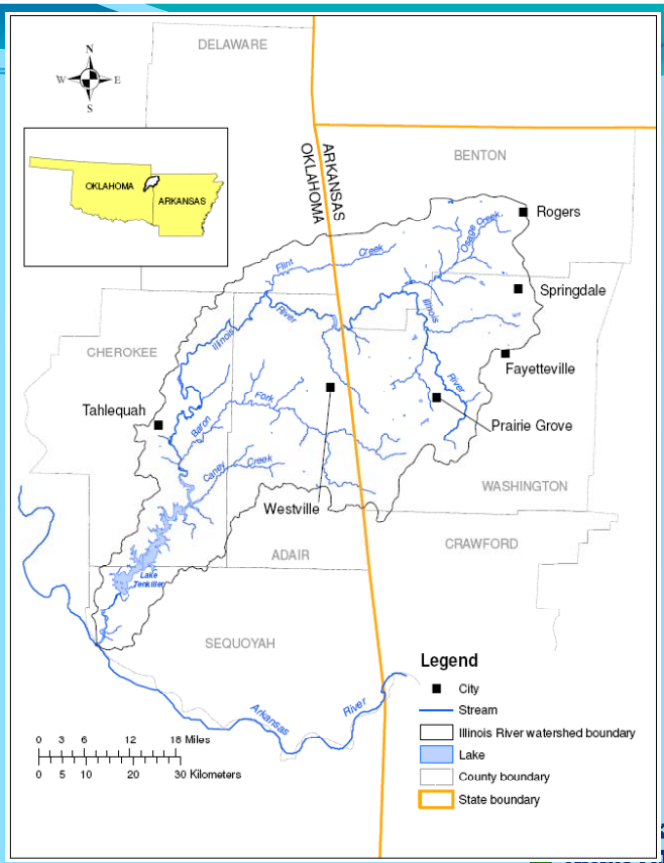
Constituents Modeled

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

Volume of Reports/Data Received

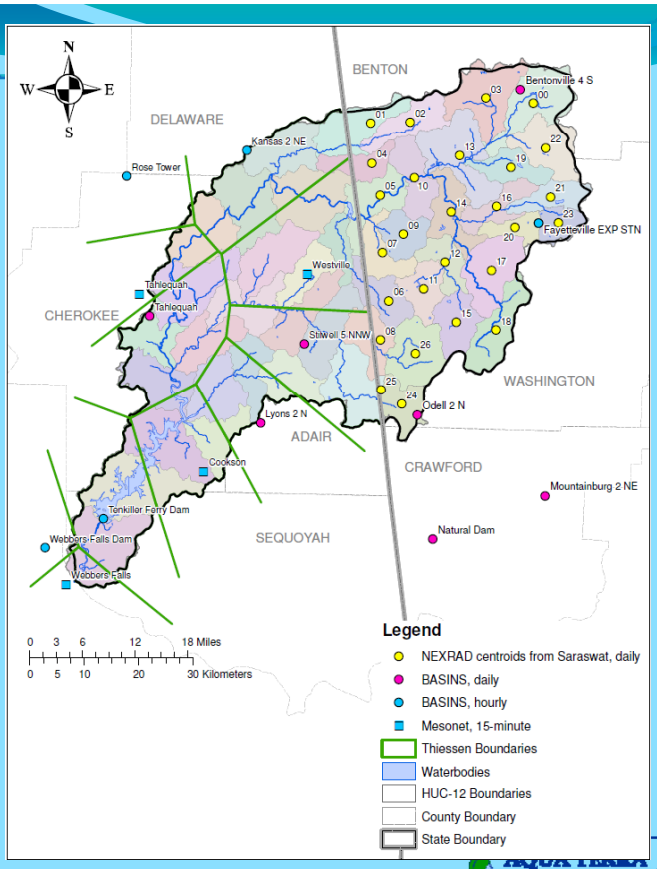
- AQUA TERRA Consultants was provided, or located, ~200 relevant publications related to the IRW.
- More than ~5,000 data files have been received and/or downloaded (20,000+ from Mesonet alone)
- Almost 130 GIS coverages were received and/or downloaded
- Reports/data provided by 20+ Federal, State, Tribal, and local agencies, and private organizations

Illinois River Watershed in AR and OK



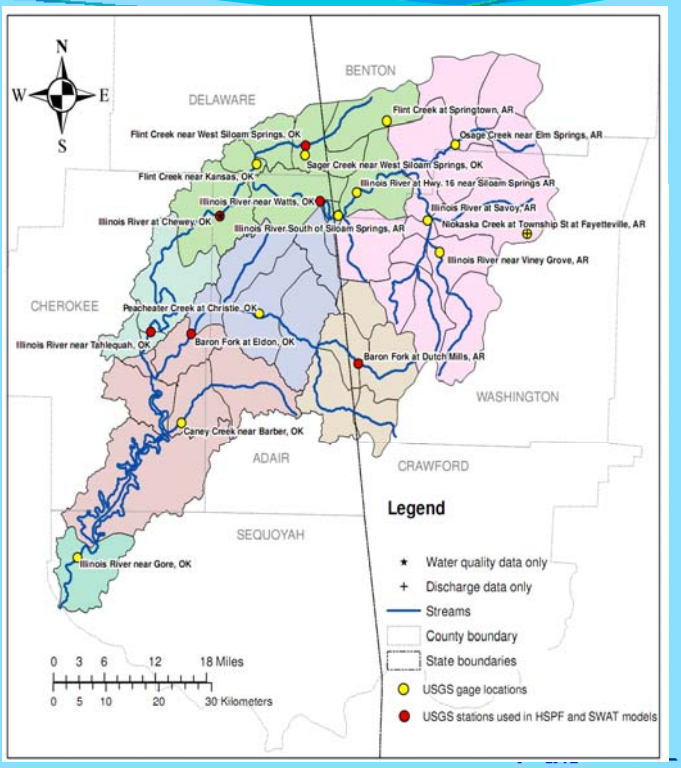
Planned Approach for Rainfall Inputs

- 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



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

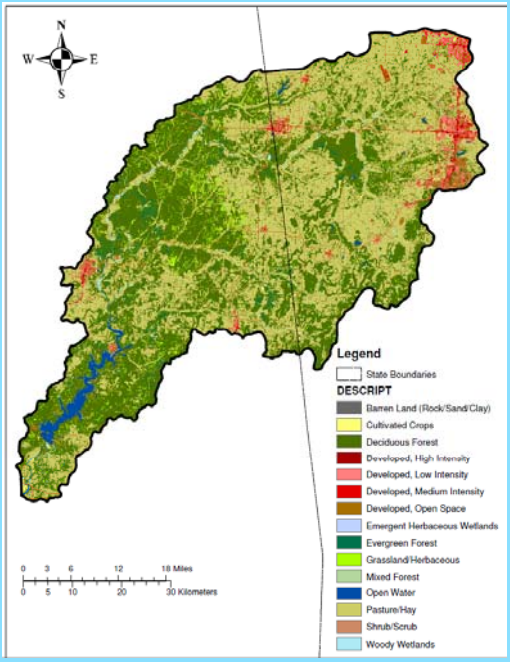
Key: Pink – Border sites; Yellow – OK; Green - AR

Tentative Calibration Sites

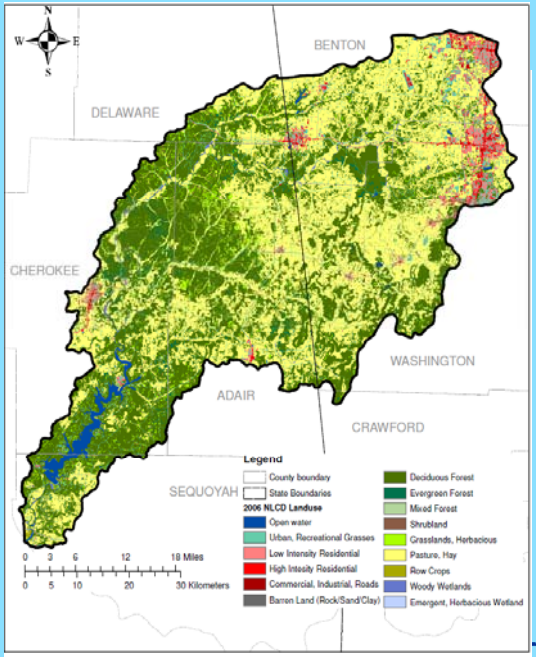
- AR –
  - Barren Fork at Dutch Mills
  - Osage Cr near Elm Springs
  - IR at Savoy
  - ~~IR near Viney Grove~~, Sager Cr, nr West Siloam Springs
- Border sites:
  - IR south of Siloam Springs (HY 59)
  - IR near Watts
- OK –
  - Barren Fork at Eldon
  - Flint Creek near Kansas
  - Caney Creek near Barber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

NLCD Land Use – 2001 and 2006

2001



2006

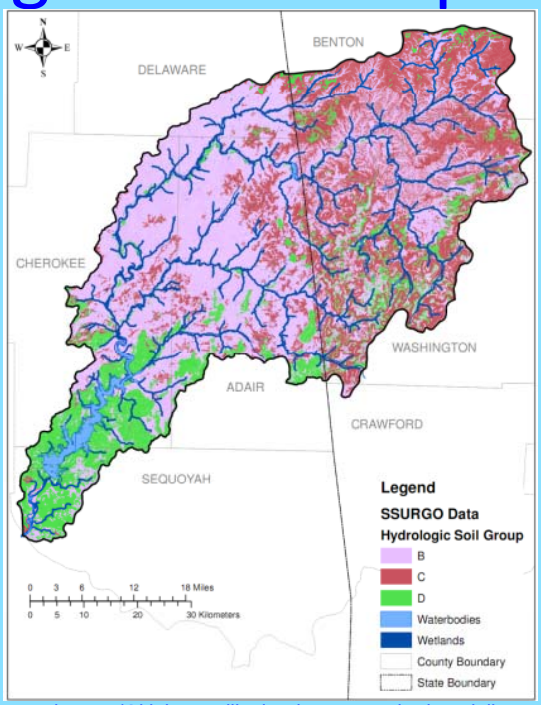


NLCD Aggregation to Model Categories

NLCD Class (2001, 2006)	2001 Percent	2006 Percent	Aggregated Model Categories	2001 Percent	2006 Percent
Deciduous Forest	41.40%	41.11%	Forest	43.09%	42.78%
Evergreen Forest	1.20%	1.19%			
Mixed Forest	0.49%	0.49%			
Pasture/Hay	41.92%	41.08%	Pasture/Hay	41.92%	41.08%
Grassland/Herbaceous	3.41%	3.63%	Grass/Shrub/Barren	3.99%	4.33%
Shrub/Scrub	0.47%	0.50%			
Barren Land (Rock/Sand/Clay)	0.11%	0.19%			
Developed, Open Space	5.61%	5.93%	Developed, Open Space	5.61%	5.93%
Developed, Low Intensity	2.16%	2.42%	Developed, Open/Low Intensity	2.16%	2.42%
Developed, Medium Intensity	0.74%	0.92%	Developed, Medium/High Intensity (includes Commercial/Industrial)	1.03%	1.27%
Developed, High Intensity	0.29%	0.35%			
Woody Wetlands	0.59%	0.59%	Wetlands	0.60%	0.60%
Emergent Herbacious Wetlands	0.01%	0.01%			
Cultivated Crops	0.15%	0.15%	Cultivated Crops	0.15%	0.15%
Open Water	1.46%	1.46%	Open Water	1.46%	1.46%
Totals	100%	100%	Totals	100%	100%

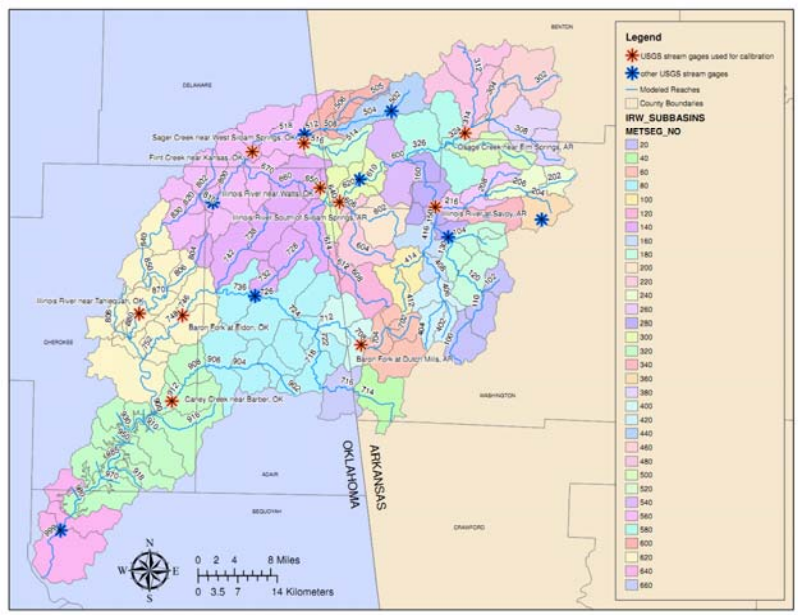
Note: Open Water modeled as a water surface (stream/lake), not as a land component.

Hydrologic Soil Groups



IR Watershed Segmentation

- Final Segmentation
- HUC12 starting point
- Adjusted for:
  - Gage locations
  - Stateline
  - Impaired segments
- Current detail:
  - 133 subbasins
  - 126 reachs



P Sources and Contributions to be Considered in the Model (Planned)

- WWTPs – Point sources (input to the model)
- Animal Wastes – Poultry, cattle, swine, wildlife
- Commercial Fertilizers
- Urban Stormwater – urban fertilizers, pets, etc.
- Others – Septic systems, nurseries, industrial sources, recreational users, etc.
- Atmospheric deposition – negligible (?)

WWTP Point Sources Discharges

- Need timeseries of loadings for <u>all</u> constituents
- Prefer daily loadings, if available, but weekly/monthly are OK
- Current values developed from data obtained in previous studies and DMR reports
- Earlier time periods 'estimated' from earliest available data
- Use of just DMR data tends to under-estimate loads
- Still waiting for data for a few dischargers (highlighted)

Facility	State	Typical Flow (MGD)	TP Load 1990-2000 (lb/year)	TP Load 2001-2009 (lb/year)	Period of TP Data
Springdale	AR	12	140,000	77,100	4/04-12/09
Rogers	AR	6.5	7,410	11,300	1/03-12/09
Fayetteville - Noland & Westside	AR	4.5/5.8	5,100	5,650	1/93-12/09
Siloam Springs	AR	3	29,500	25,900	4/02-12/09
Gentry	AR	0.45	5,430	5,430	5/06-12/09
Lincoln	AR	0.45	2,390	1,950	8/02-12/09
Prairie Grove	AR	0.3	3,550	3,950	8/04-12/09
SWEPCO Flint Ck Power Plant	AR	5/400	n/a *	n/a *	n/a *
USDA FS - Lake Wedington	AR	0.0013	1.2	2.3	8/02-12/09
Tahlequah	OK	2.7	11,900	2,790	1/90-12/09
Stilwell	OK	0.85	2,040	2,370	1/02-12/09
Westville	OK	0.2	1,440	720	1/01-12/09

* SWEPCO - no significant TP discharges

Constituents Modeled – Point Source Data Needed

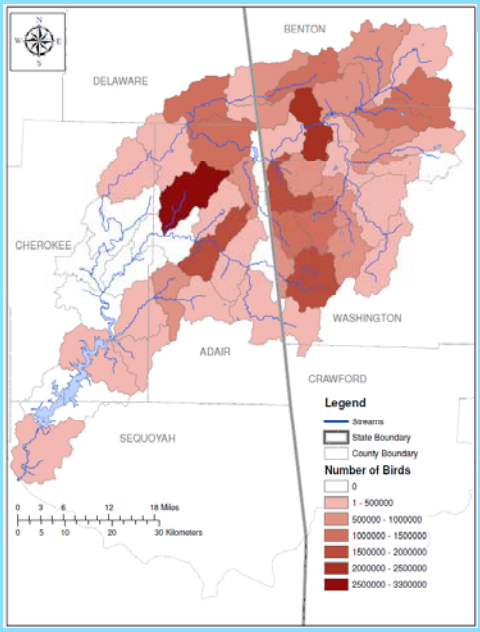
- Flow/discharge
- Sediment/TSS
- Water temperature
- DO
- BOD ultimate or total BOD/Organics
- NO3/NO2, combined
- NH3/NH4
- Total N
- PO4
- Total P
- ~~Phytoplankton as Chl a~~
- ~~Benthic algae~~

P Sources Modeling Approaches and Issues (Planned)

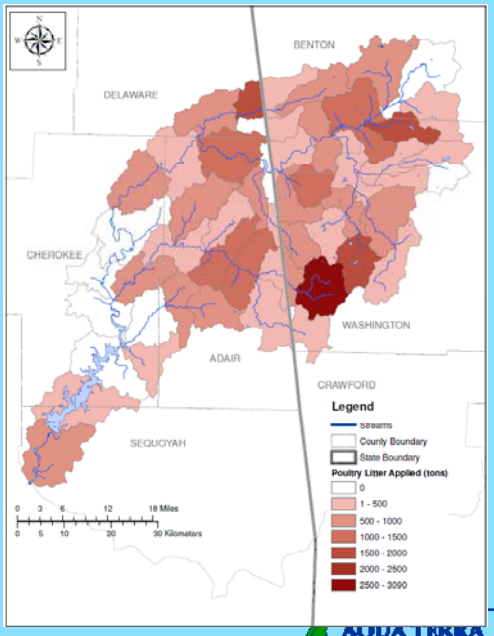
- Goal – distinguish contributions from each source
- Animal Wastes –
  - Use AGCHEM on pasture lands receiving wastes
  - Define alternative categories of pasture, e.g. pasture, pasture-littered, pasture-comm.fert
  - For other land uses, apply simplier appoaches (e.g. accumulation-washoff)
- For other sources, consider 'pseudo-point source' representation (e.g., AFO/CAFOs)

Sample data on Poultry Litter (Preliminary)

Bird Populations



Litter Applied, tons



WATERSHED MODEL CALIBRATION/VALIDATION

Tentative Simulation Periods:

Calibration: 2002 – 2009 (8 years)

Validation: 1994 – 2001 (8 years)

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)

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).

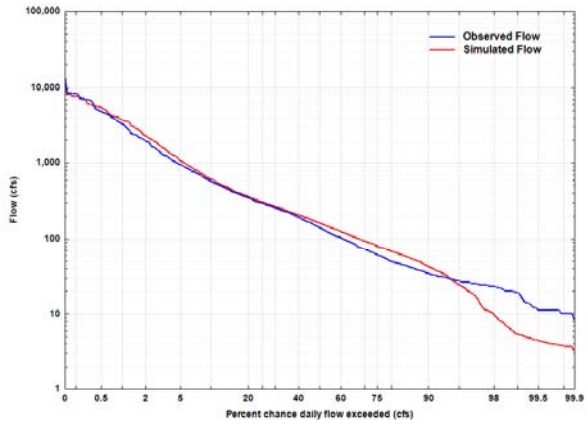
Source: Donigian, 2000

‘Preliminary’ Hydrology Calibration Results

Site	Flow (in)			Daily		Monthly			NSE	
	Sim	Obs	% Vol error	R	R^2	R	R^2	Daily Peaks % Diff	Daily	Monthly
150 (Illinois River at Savoy, AR)	14.4	13.8	4.6	0.72	0.51	0.87	0.76	-7.8	0.38	0.76
523 (Flint Creek near Kansas, OK)	13.8	12.3	12.2	0.76	0.58	0.87	0.75	35.1	0.26	0.70
630 (Illinois River South of Siloam Springs, AR (USGS *)	17.6	14.1	25.3	0.75	0.56	0.83	0.69	58.8	-0.41	0.55
640 (Illinois River near Watts, OK (USGS gage))	17.0	13.6	25.2	0.77	0.60	0.85	0.73	66.0	-0.28	0.59
706 (Baron Fork at Dutch Mills, AR (USGS gage))	13.2	15.1	-12.9	0.73	0.54	0.84	0.70	-23.2	0.52	0.69
746 (Baron Fork at Eldon, OK (USGS gage))	14.8	13.7	7.8	0.87	0.76	0.94	0.89	-2.1	0.76	0.88
870 (Illinois River near Tahlequah, OK (USGS gage))	16.1	13.7	16.8	0.64	0.41	0.89	0.80	52.6	-0.24	0.77
912 (Caney Creek near Barber, OK (USGS gage))	15.7	13.2	19.1	0.76	0.57	0.90	0.81	14.2	0.45	0.77
316 (Osage Creek near Elm Springs, AR (USGS gage))	15.8	17.1	-7.4	0.77	0.60	0.84	0.71	26.7	0.06	0.64
516 (Sager Creek near West Siloam Springs, OK (USGS ga*)	15.8	18.0	-12.6	0.67	0.45	0.80	0.64	-27.4	0.35	0.63

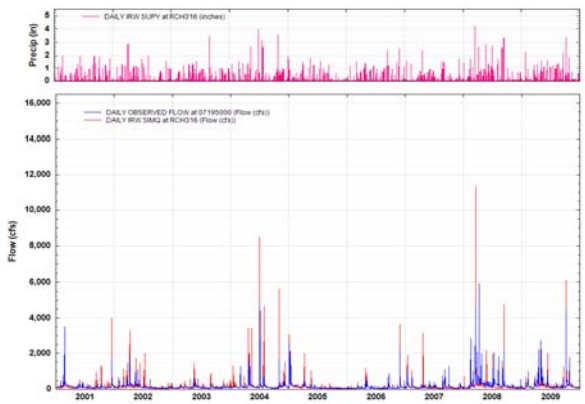
Preliminary Hydrology Calibration Results

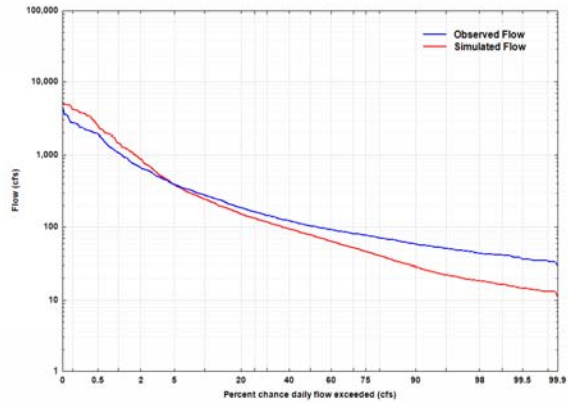
Baron Fork at Eldon, OK (RCH 746, USGS 07197000)



Preliminary Hydrology Calibration Results

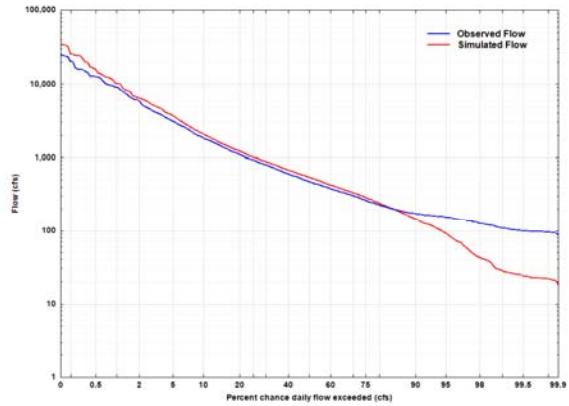
Osage Creek near Elm Springs, AR (RCH 316, USGS 07195000)





Preliminary Hydrology Calibration Results

Illinois River near Tahlequah, OK (RCH 870, USGS 07196500)



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

Watershed Model Sensitivity Analyses

- Objective: Identify/quantify impacts of most sensitive model parameters
- Steps –
  - Select target inputs/parameters for analysis
  - Define reasonable perturbations from calibration values
  - Perform multi-year model runs with changes
  - QA and process model results
  - Rank input/parameters by sensitivity metrics

Sensitivity Factor

Sensitivity Factor:

$$S\ (\%) = \frac{[\mathrm{abs}(\Delta\mathrm{metric}_{-,\%}) + \mathrm{abs}(\Delta\mathrm{metric}_{+,\%})\ ]\ /\ 2}{[\mathrm{abs}(\Delta\mathrm{parm}_{-,\%}) + \mathrm{abs}(\Delta\mathrm{parm}_{+,\%})\ ]\ /\ 2} * 100$$

where:

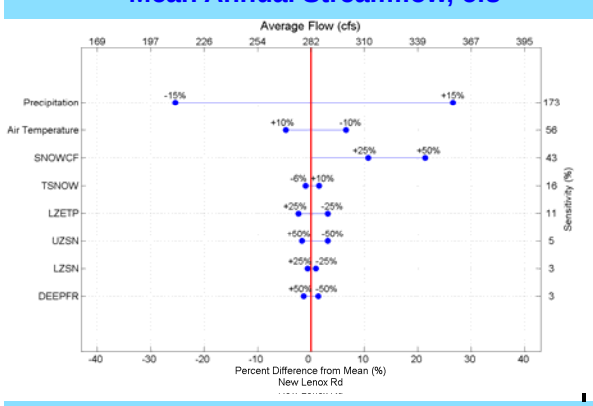
$\Delta\mathrm{metric}_{+\ \mathrm{OR}\ -,\%}$ - is the percent change from the base metric resulting from the % increase (+) or decrease (-) of parameter i

$\Delta\mathrm{parm}_{+\ \mathrm{OR}\ -,\%}$ - is the % increase (+) or decrease (-) of parameter i

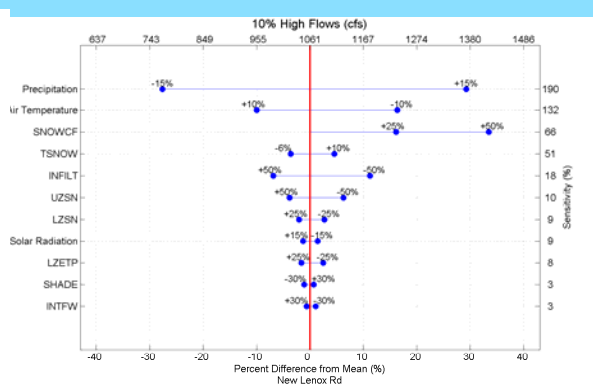
S		Δparm	to	Δmetric
200%	→	1	:	2
100%	→	1	:	1
10%	→	1	:	0.1

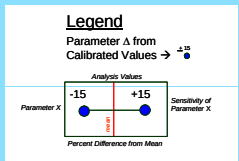
Tornado Diagrams for Flow Sensitivity

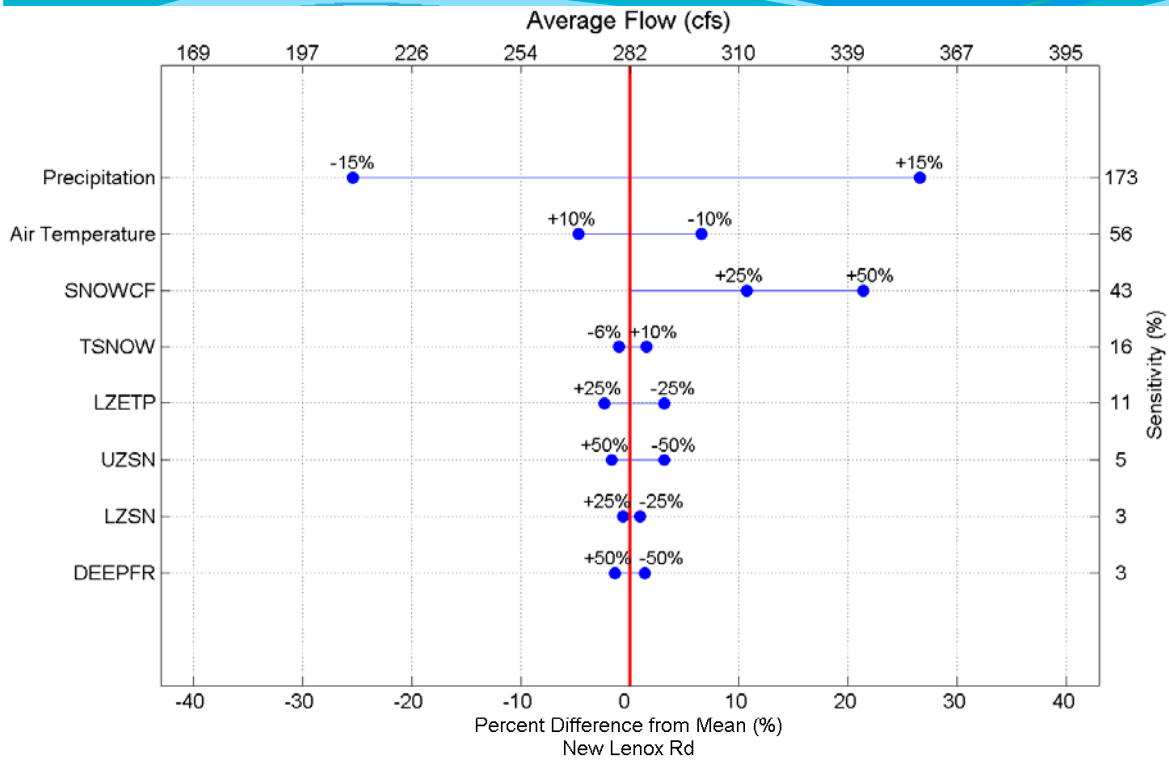
Mean Annual Streamflow, cfs



10% Highest Flows, cfs

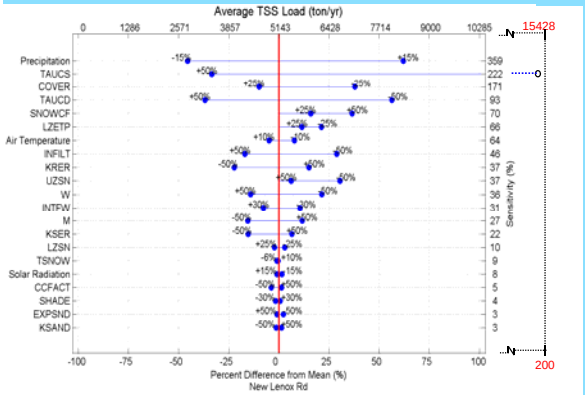




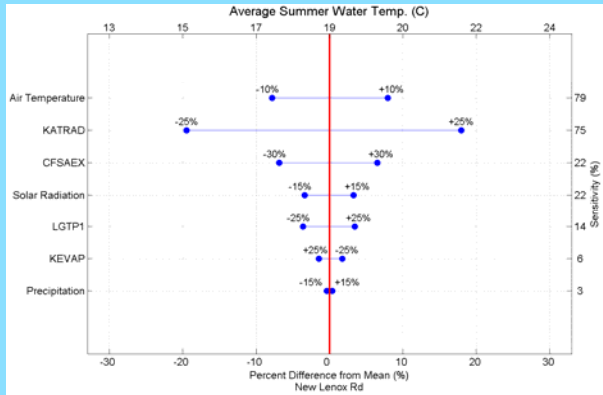


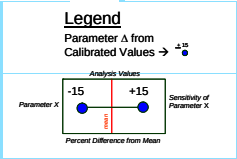
Tornado Diagrams for Sediment and Water Temperature

Mean Annual TSS Loading, tons/yr



Mean Summer Water Temperature, C

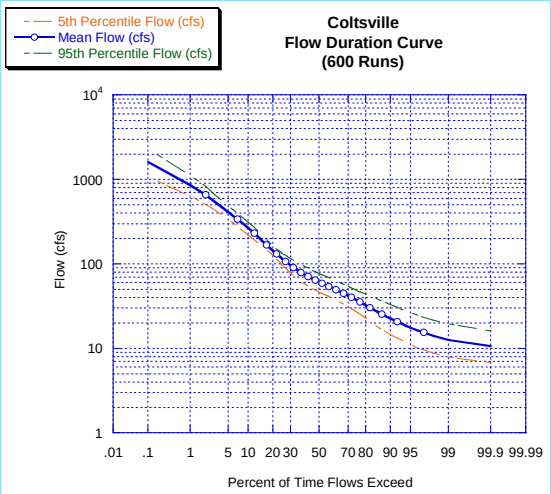


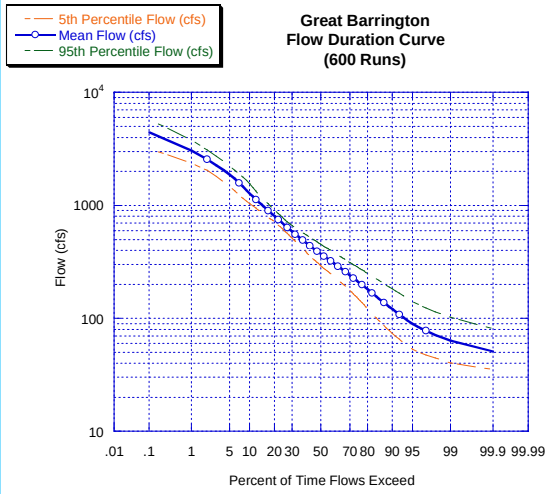


Watershed Model Uncertainty Analyses

- Monte Carlo approach used
- ~500-1000 HSPF multi-year runs performed
- Parameter values selected from assigned NO and LN distributions
- Model output analyzed for same quantities as the SA
- 5th and 95th percentile values generated to represent 90% confidence intervals

Flow Duration Curves with CIs





Scenarios for TMDL Development

- Model runs to identify/quantify loadings and contributions
- Adjusted model runs to meet WQ standards at the Stateline and Lake Tenkiller
- Runs will be long-term simulations of ~30 years, with met database of ~1980 – 2009
- Additional and alternative scenarios to be determined jointly with State agencies and other Stakeholders

QUESTIONS/DISCUSSION

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

Rationale for HSPF Selection

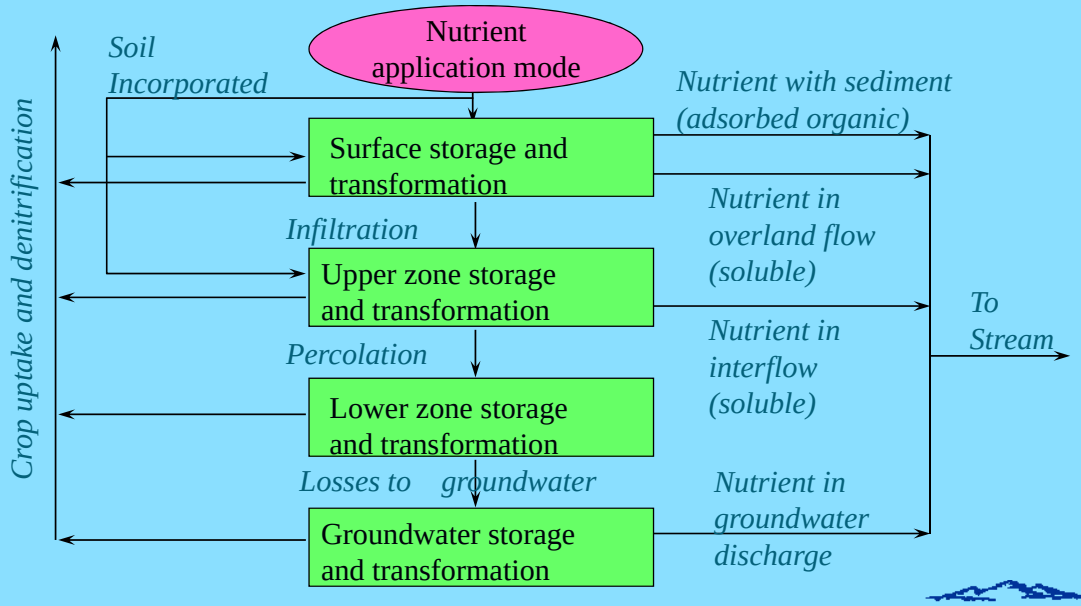
- HSPF provides a stronger hydrologic model commonly run on an hourly (or less) timestep
- HSPF provides an improved instream sediment transport and sediment-nutrient interaction capability
- The hourly output from HSPF supports a more robust and compatible linkage with the EFDC hydrodynamic model for Lake Tenkiller
- HSPF soil nutrient models are comparable to SWAT, and include some additional details for inorganic forms
- The linked soil nutrient models and improved instream fate/transport capability in HSPF provides an improved overall capability to relate watershed sources to down stream impacts

MODEL/DATA COMPARISONS

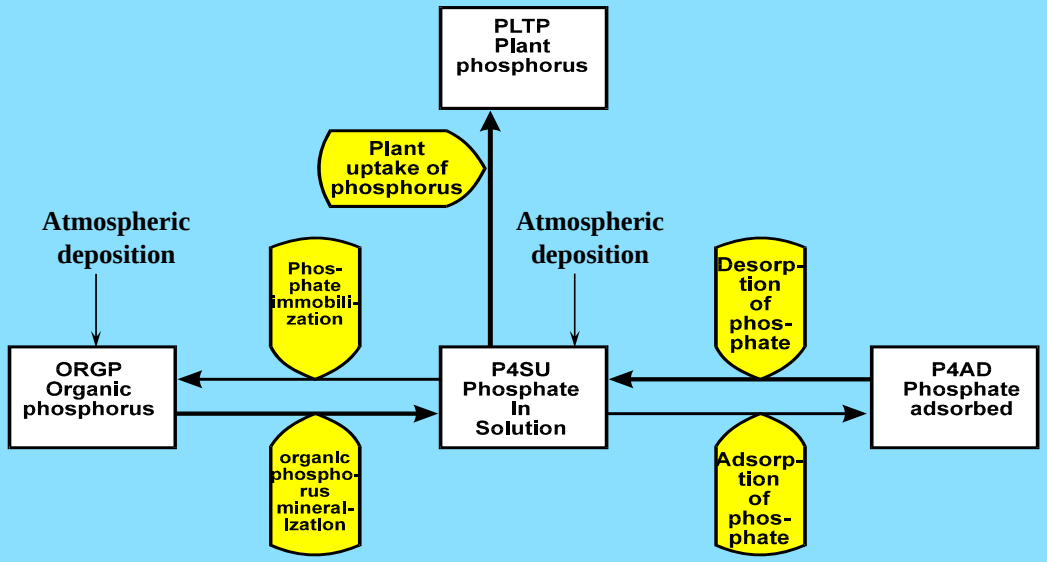
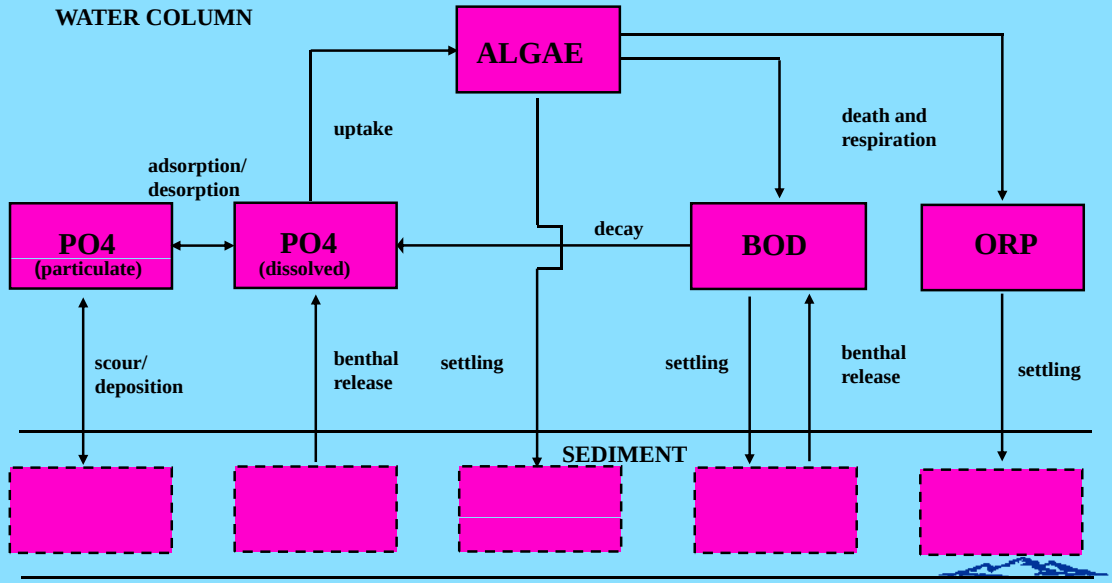
Water Balance Components

- 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

Nutrient Storages and Transport Modeled by HSPF AGCHEM



Phosphorus Transformations Simulated by HSPF/AGCHEM



Summary of Instream Phosphorus Cycle in HSPF RCHRES