Water Quantity and Quality Assessment in the Lower Mississippi River Basin

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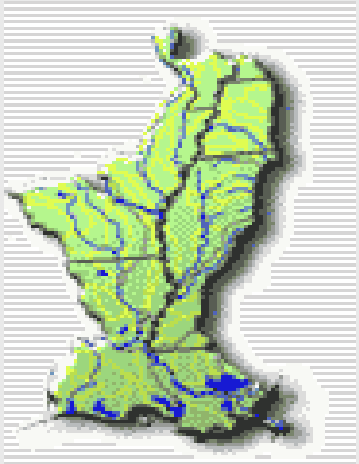
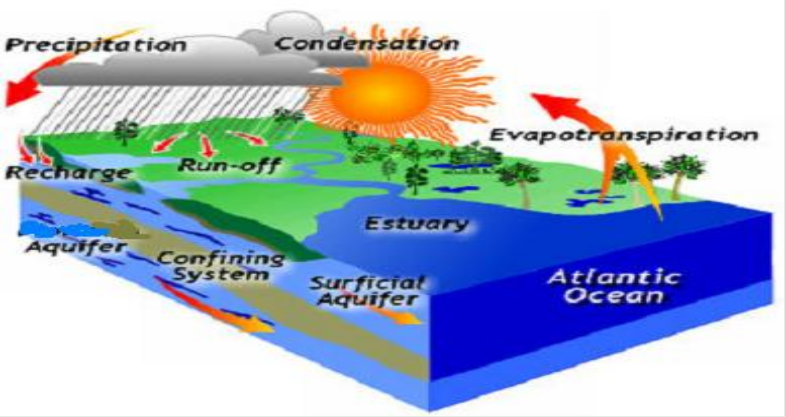




Goals

1. Analyze low flow and its response to climate change
2. Estimate water quality using BASINS-HSPF model
3. Monitor real-time variations of P in surface water using dynamic data driven application system (DDDAS)
4. Other research interests on water resource analysis

1. Low Flow and Climate Change

What is Low Flow?

- A flow of water in a stream during prolonged dry weather (WMO, 1974)
- A seasonal phenomenon and an integral component of a flow regime of any river
- Affected by climate, topography, geology, soil, and human activities
- Estimated by the 7Q10 method (Lowest average flows that occur for a consecutive 7-day period at the recurrence interval of 10 years)

Rationale

- Center to climate change investigation
- Issue discharge permits and develop water treatment plants
- Determine allowable water transfers and withdrawals in water supply
- Estimate contaminant loading and distributions in surface waters
- Assess stream flow habitats in ecosystem

Methods for Low Flow Selection

7Q10 Method

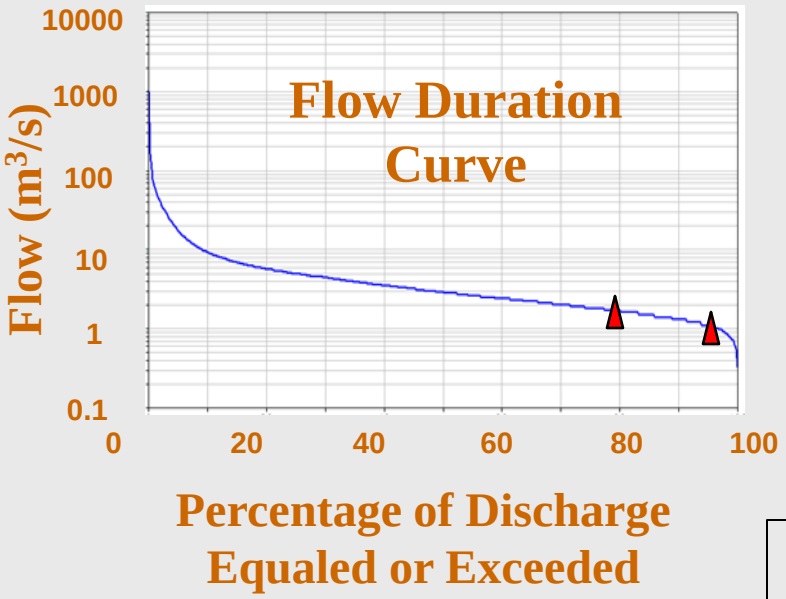
Gauge Records (>20 Years)

↓

Flow Duration Curve (FDC)

↓

Select Low Flow Value Based on 95% (= 7Q10) Using FDC



MFLs Method

Gauge Records (>20 Years)

↓

Flow Duration Curve (FDC)

↓

Select Low Flow Value Based on MFL's Minimum Frequent Low Category (80%) Using FDC

Minimum Flows and Levels (MFLs)

Florida Water Management Districts

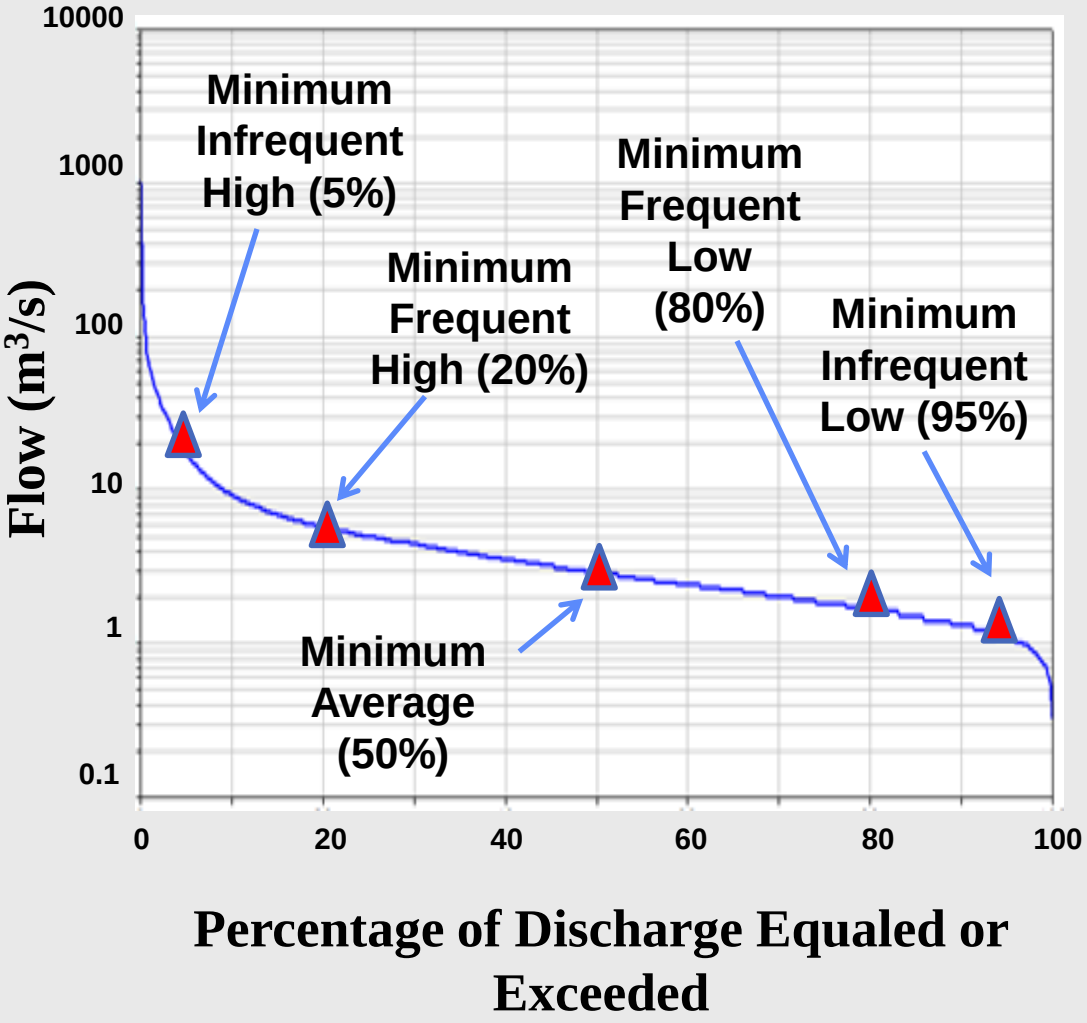
MFLs are the minimum water flows and/or levels as necessary to prevent significant harm to water resources or ecology of an area resulting from permitted water withdrawals

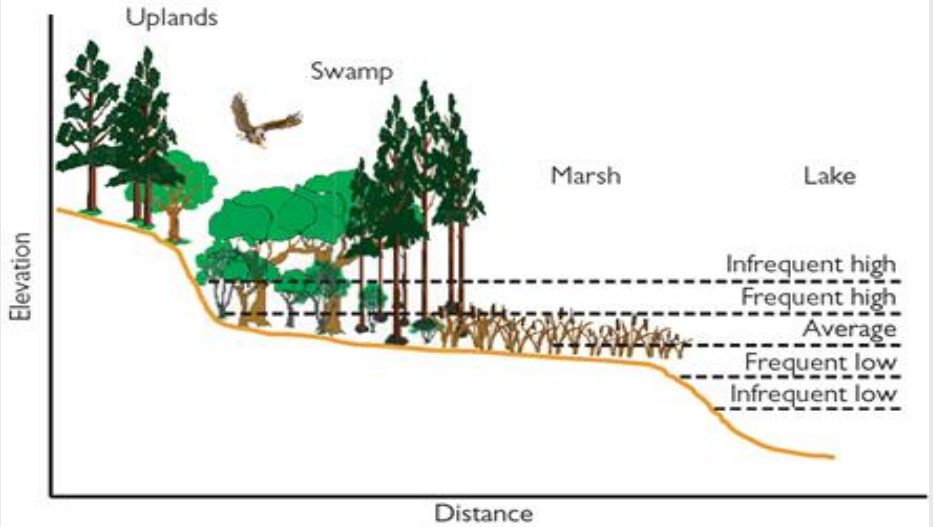
MFLs define how often and for how long the high, intermediate and low water flows and/or levels should occur to prevent significant harms

Five Categories of MFLs

1. Minimum infrequent-high (5% on FDC)
2. Minimum frequent-high (20% on FDC)
3. Minimum average (50% on FDC)
4. Minimum frequent-low (80% on FDC): A chronically low surface water level/flow that generally occurs during reduced rainfall. This category is required to prevent harmful impact on floodplain, biota, and ecosystem
5. Minimum infrequent-low (95% on FDC): An acutely low surface water level/flow with an associated frequency and duration which may occur during extreme drought below which there will be a significant negative impact on biota

FDC and MFL





- Choose MFLs method (at minimum frequent-low)
- MFLs has clearer quantified regarding the impacts of low flow on floodplain, biota, and ecosystem
- 7Q10 method is for extreme low flow conditions occurred during severe droughts with short duration and very long return intervals

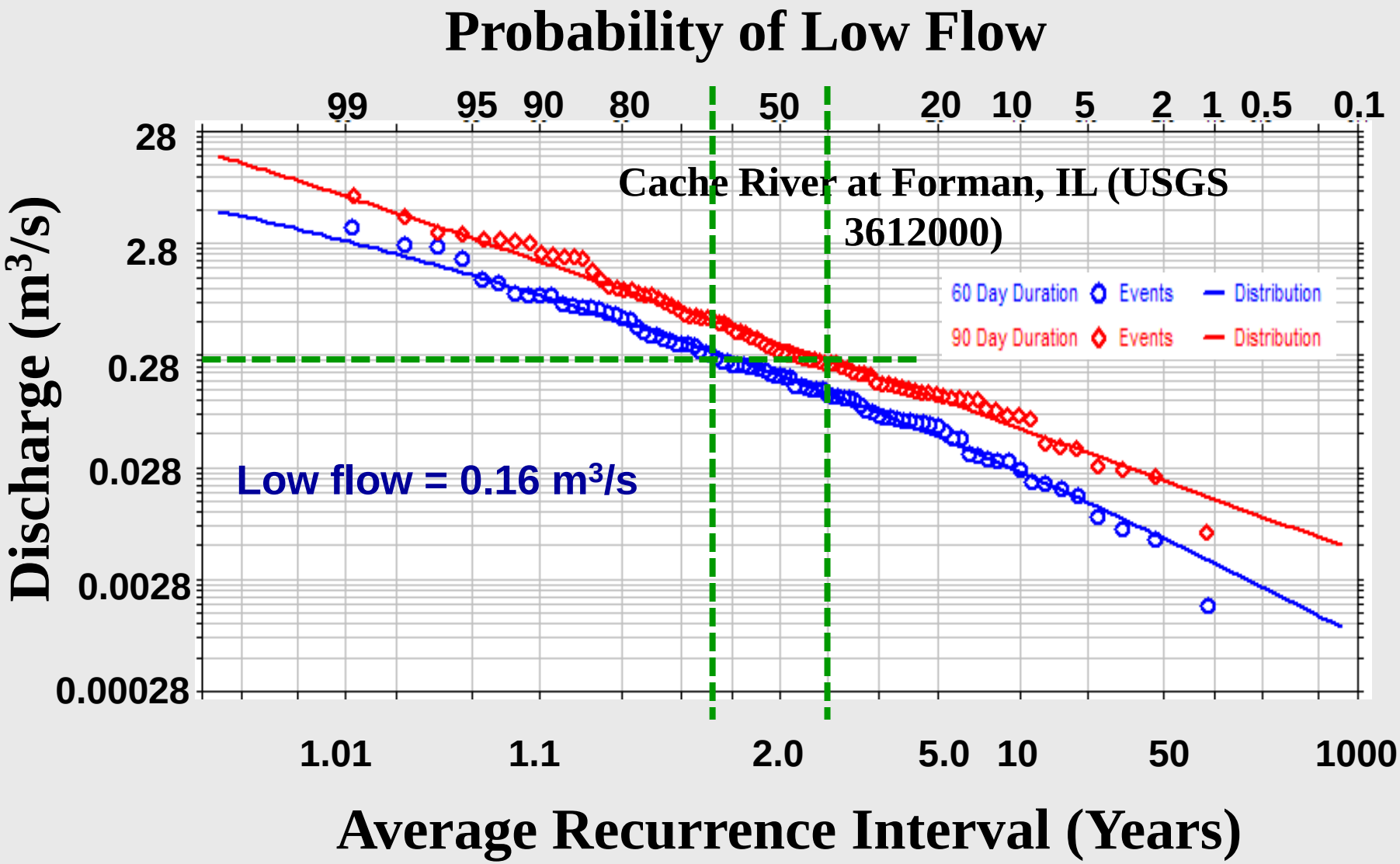
Low Flow Analysis for LMRB

- Three USGS surface water monitoring stations with 60- to 90-year periods of records (POR)
- Pristine forest lands in headwater areas
- Unique opportunity for estimating low flow response to climate change
- Divided the POR into 20-year increments to examine how climate change impact on Low Flow as time elapsed

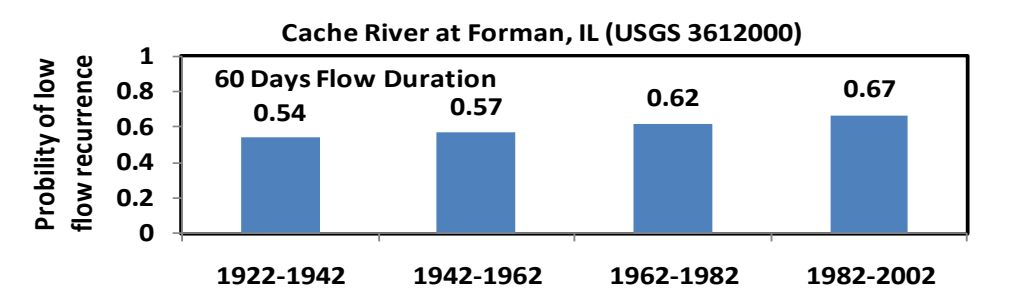
Study Site (LMRB)

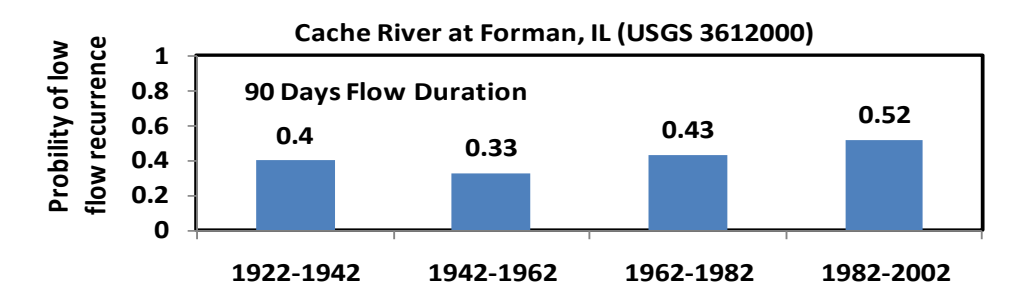
Label	USGS	Land Use	Place	POR
1	3612000	Forest deciduous	Cache River at Forman, IL	1922-2011
2	7039500	Forest deciduous	St. Francis River at Wappaello, MO	1940-2011
3	7373000	Forest evergreen	Big Creek at Pollock, LA	1942-2011

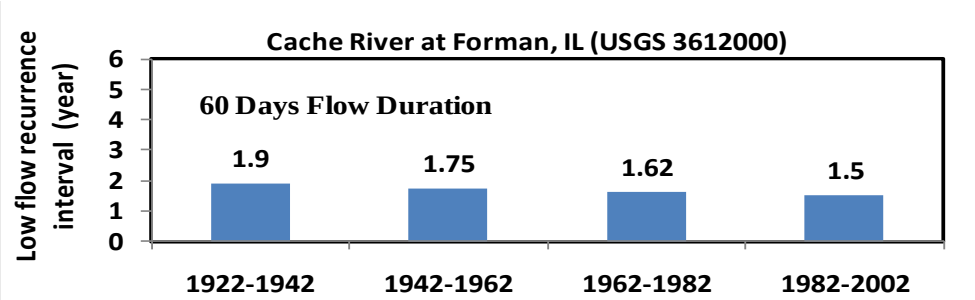
Recurrence Probability and Interval of Low Flow from Hydstra Model

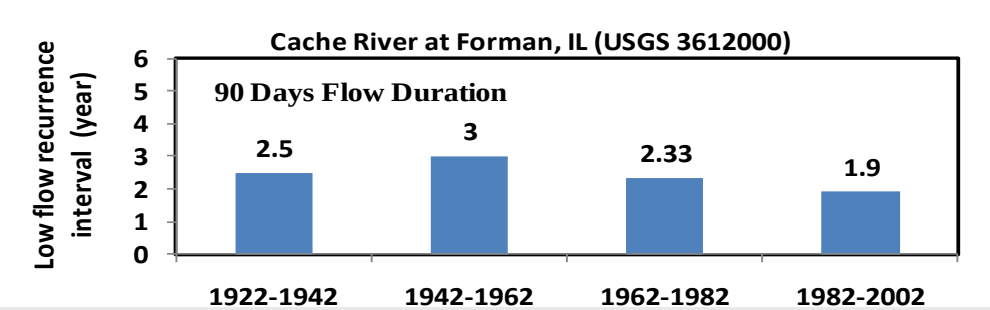


Results









- **Recurrence probability increased and recurrence interval decreased for low flow as time elapsed with a 20-year increment**
- **Low flow occurred more often as time elapsed from 1922 to present**
- **Past climate change has made the headwater areas drier**
- **Reduce water use, reclaim wastewater , and enhance GW discharge to mitigate climate change impact on low flow**
- **Approach could be applied to estimate low flow due to agricultural impacts**

2. Water Quality Assessment Using BASINS-HSPF Model

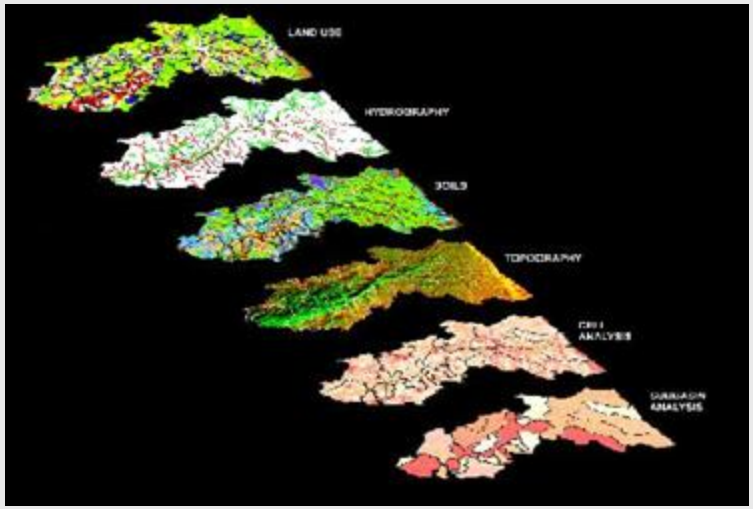
Rationale

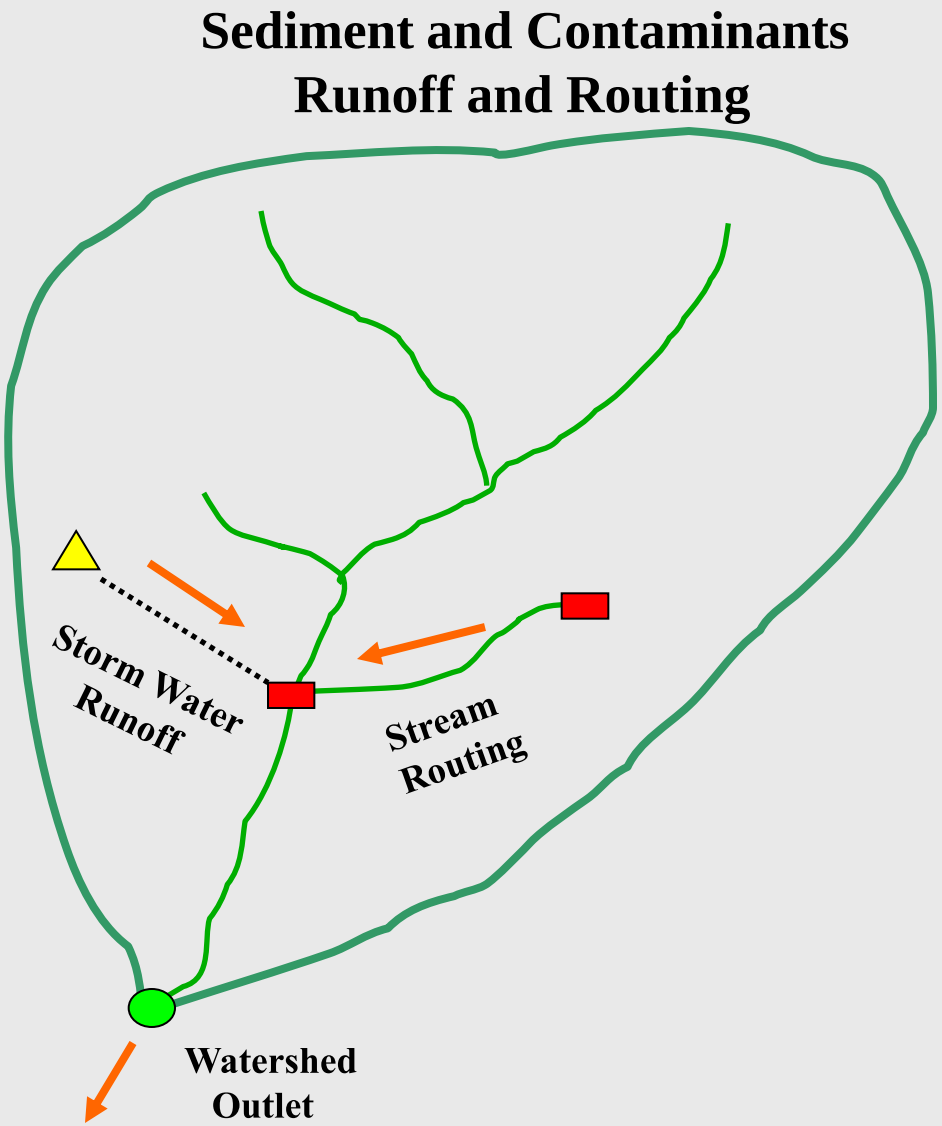
Excess nutrients, elevated sediment, and other contaminants in the LMAV due to the agricultural and forest practices

- **High BOD, low DO, fish kills, and Loss of biodiversity**
- **Toxic algal bloom**
- **Interrupt navigation**
- **Insufficient information on seasonal and annual loads of sediment, nutrients, and pesticides in the LMAV**
- **Water resource management and supply, ecosystem protection, and TMDL development/refinement**

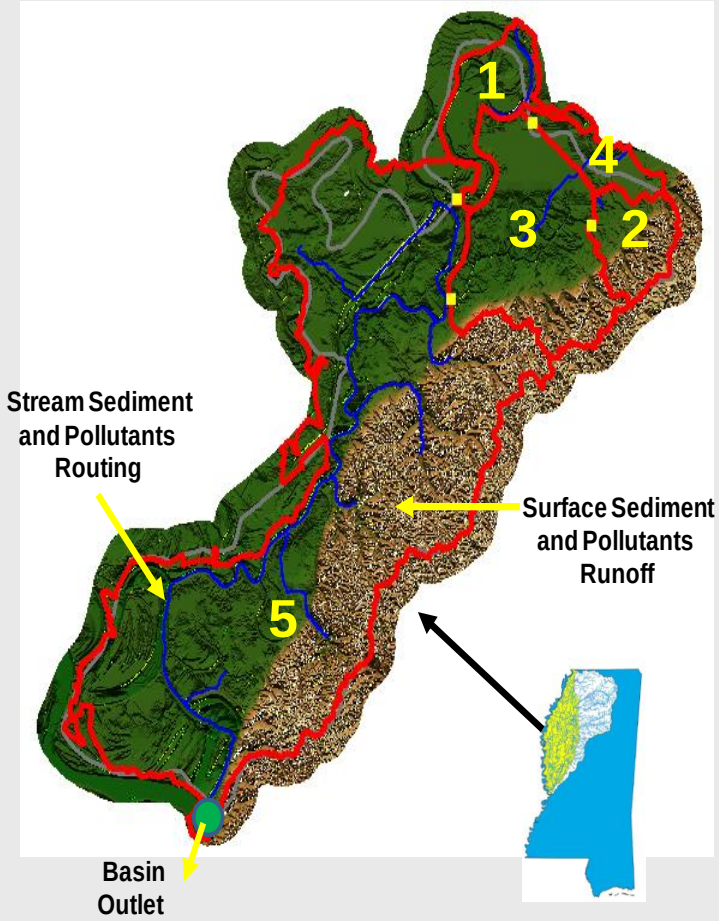
Objective

Estimate the seasonal and annual loads of sediment, nutrients, and pesticides from watersheds into rivers using BASINS-HSPF model

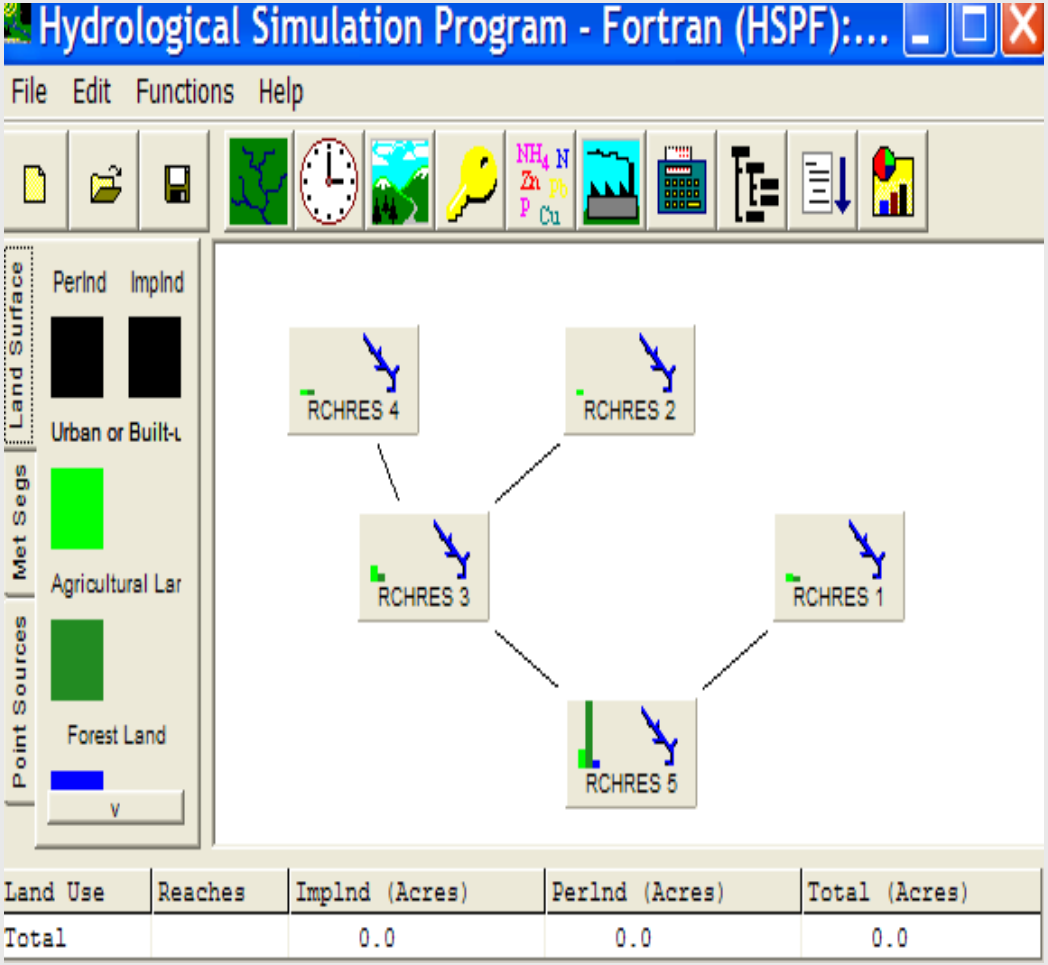




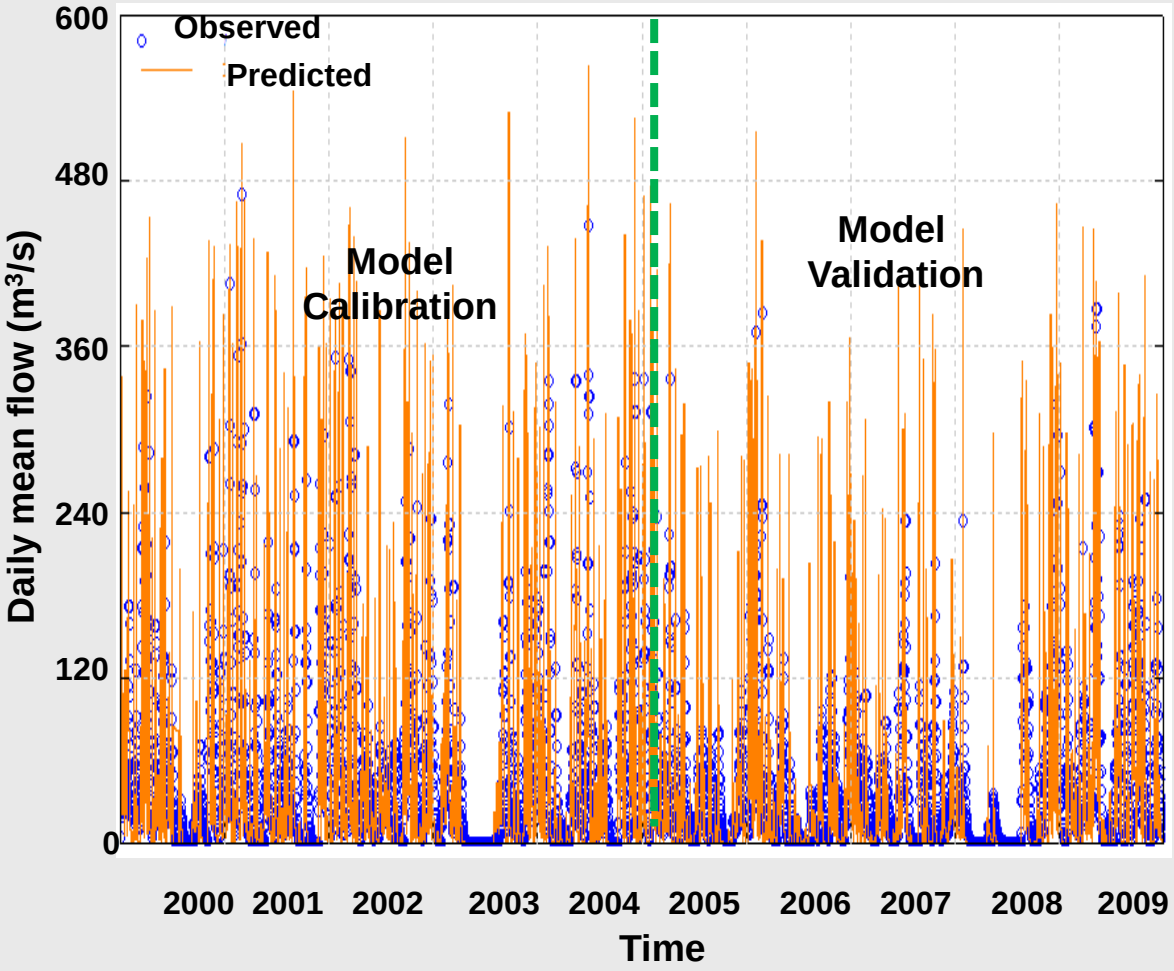
Current Progress



Yazoo River Basin



Hydrologic Calibration and Validation



Volume of Water Outflow from Watershed Outlet

Year	Simulated Outflow (m^3)	Observed Outflow (m^3)	Percent Different
Model Calibration			
2000	1.77E+09	1.75E+09	0.88
2001	2.05E+09	1.92E+09	6.34
2002	1.93E+09	1.93E+09	-0.37
2003	1.15E+09	1.16E+09	-0.34
2004	2.00E+09	1.90E+09	5.58
Total	**8.90E+09**	**8.66E+09**	**2.68**
Model Validation			
2005	1.32E+09	1.30E+09	1.64
2006	1.33E+09	1.35E+09	-2.10
2007	1.20E+09	1.19E+09	1.13
2008	9.71E+08	9.47E+08	2.54
2009	1.96E+09	1.82E+09	7.40
Total	**6.78E+09**	**6.62E+09**	**2.50**

Some Results and Further Study

Four Future Climate Change Scenarios

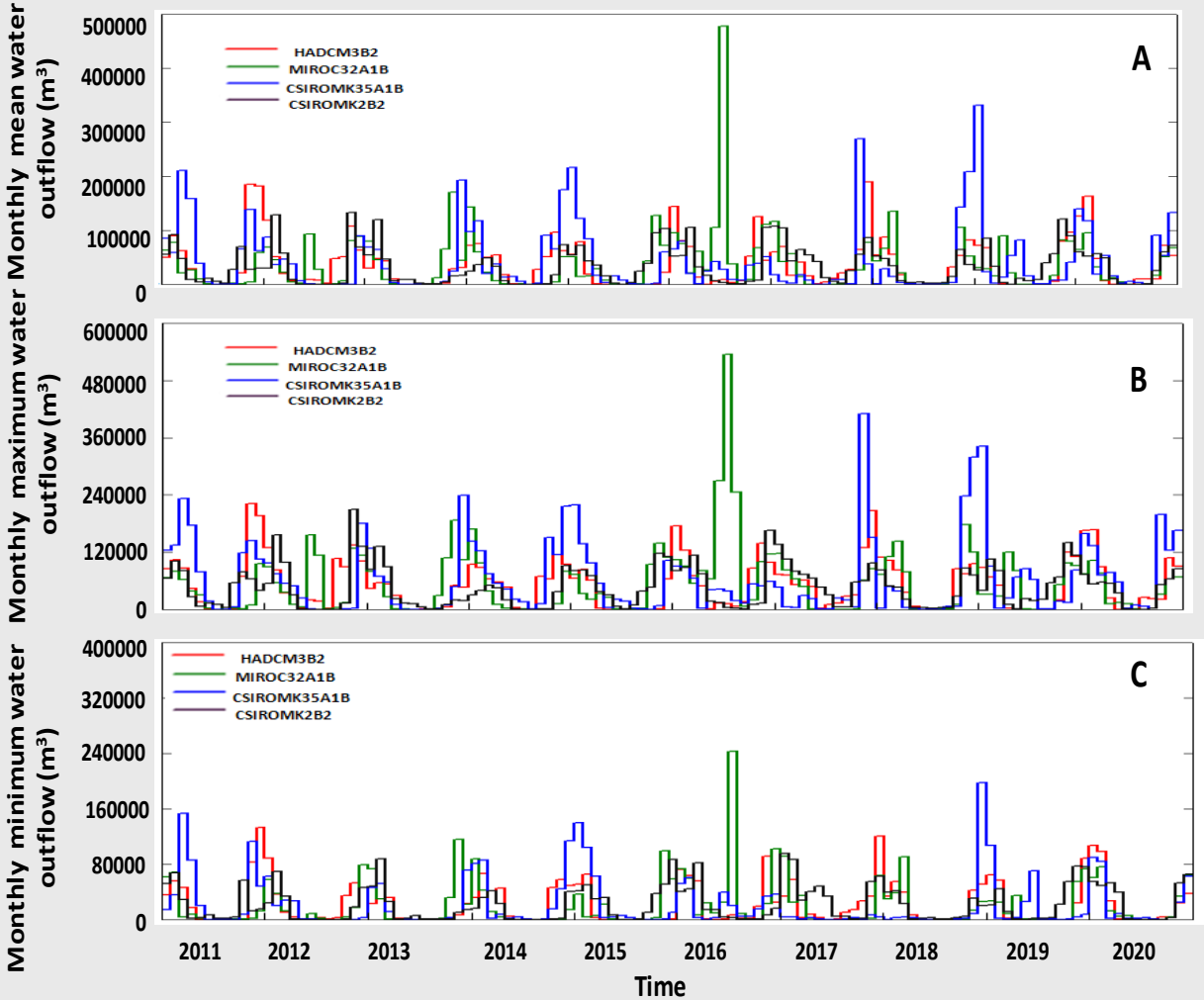


Figure 8. Simulated monthly mean (A), maximum (B), and minimum (C) evaporative loss among the four simulation scenarios.

Further Study

- **Sediment, nutrient, and pesticide calibrations and validations**
- **Seasonal and annual loads of sediment, nutrients, and pesticides from the YRB into YR and its tributaries**
- **Extend to LMAV**

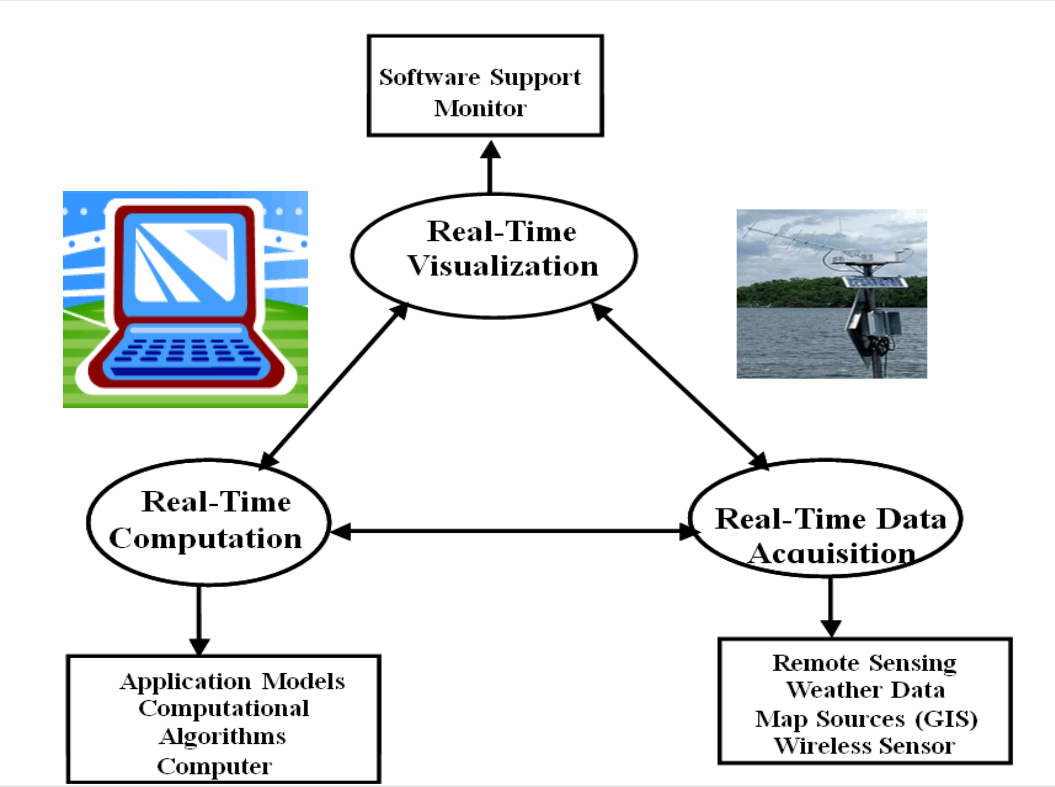
3. Real-Time Monitoring of P in Surface Water Using Dynamic Data Driven Application System

Rationale

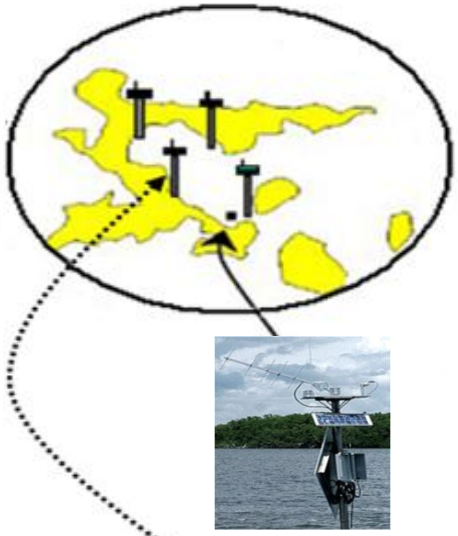
- Real-time data for chlorophyll, DO, pH, temperature, TSS, watercolor, etc in surface waters (USGS Website)
- No real-time data for P due to the lack of suitable wireless sensors
- Take a week or longer for laboratory analysis
- Human health, algal blooms, and surface water supply, the timely P information may be critical

What Is Dynamic Data Driven Application Systems (DDDAS)?

- A real-time symbiotic field measurement and computer simulation system
- Measurements provide timely data for simulations
- In reverse, simulations can guide the measurements on when and where to collect data
- Coined by National Science Foundation (NSF) in 2000



DDDAS Example: Harmful Algal Bloom



Computation Model for HAB Prediction

Automated Data Collection & Control

Wireless Sensors

GIS Map

Weather Data

Visualization & Human Interface

TP > 100 µg/L
Chl a > 40 µg/L

Why DDDAS?

Computer models fail to predict the real-time conditions

- Predict the behaviors of the fire near the Los Alamos National Laboratory in May 2000
- Computer simulations that were not geared (synchronized) to incorporate real-time changing conditions
- Using last 5-year rainfall input to predict future 5-year crop yields or water losses: Problematic
- Rainfall duration, intensity, and pattern are shifting due to global climatic change, etc.

Use today's wind speed as an input value to predict tomorrow's forest fire spreading----input value and simulation are not synchronized

Real-time monitoring of P in Streams

Objective

Real-time monitoring of P variations in streams

Basic Idea

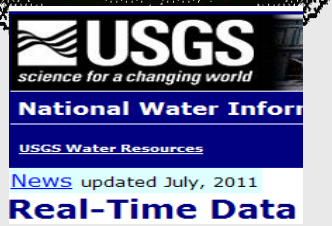
1. USGS has real-time data for TSS and discharge but not for P in the LMAV
2. Obtain relationship (P vs. TSS)

$$Y_P = aX_{TSS} + b \quad \text{or} \quad Y_P = a*Exp(X_{TSS})$$

3. Predict (indirectly) real-time variations of P in surface water

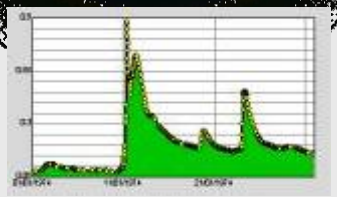
Approaches

Download USGS Real-Time Data



Predict Real-Time P Loads Using TSS and Discharge Data

Display Predictions on Computer Screen



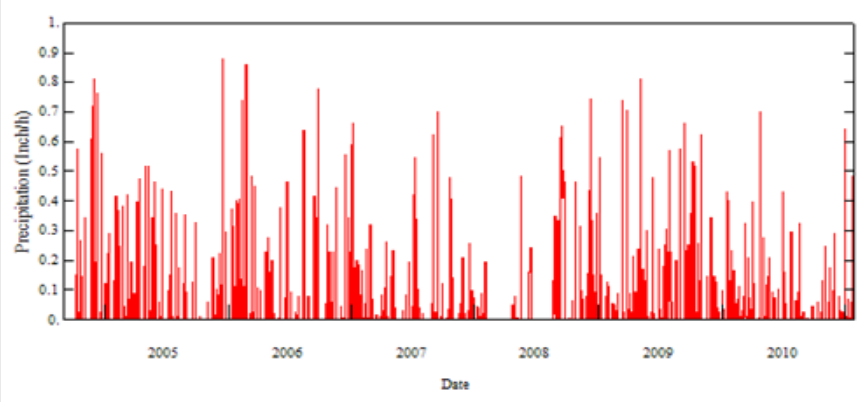
If P exceed EPA Criteria, Email Alerting

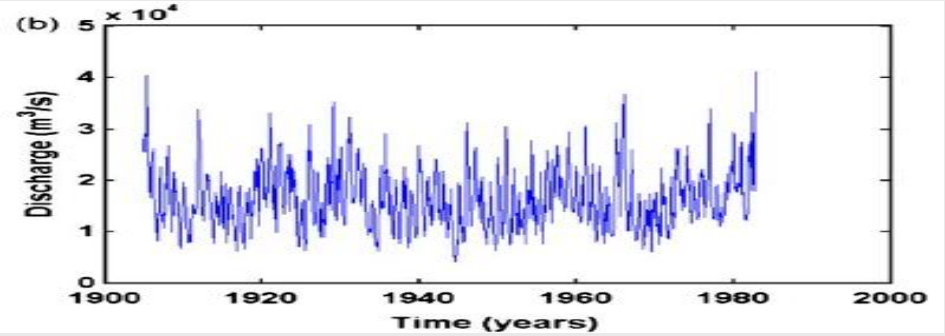
All of the above procedures can be set up with Hydstra model

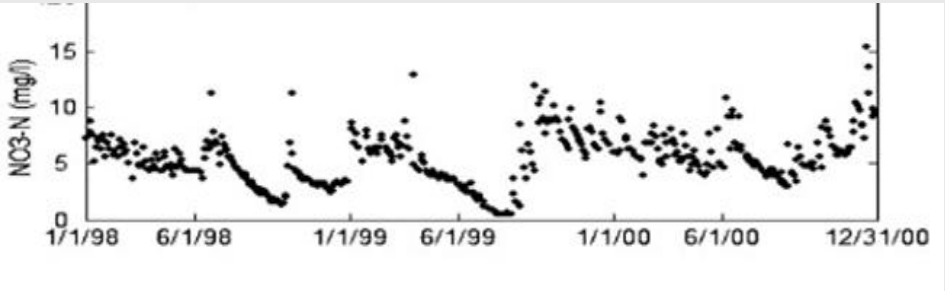
4. Other Research Interests: A. Wavelet Analysis

Rationale

- **How does the climate change affect the characteristics of precipitation, river discharge, and water quality in a large basin?**
- **Duration curve and frequency distribution analysis**
- **Wavelet analysis**

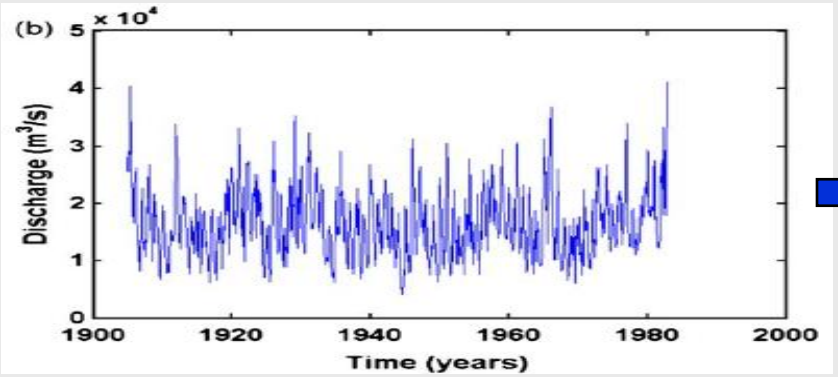




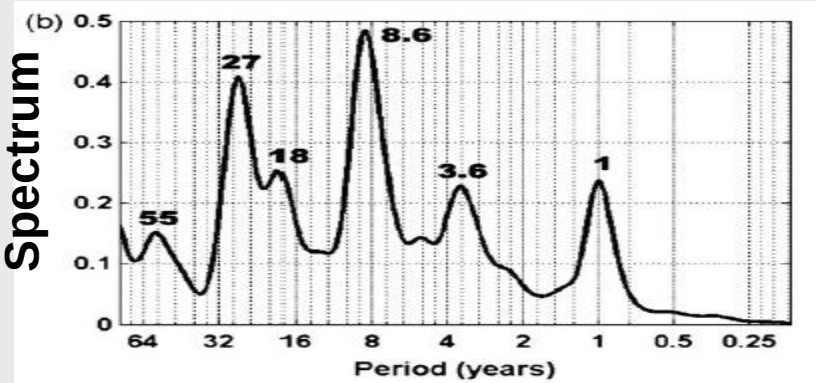


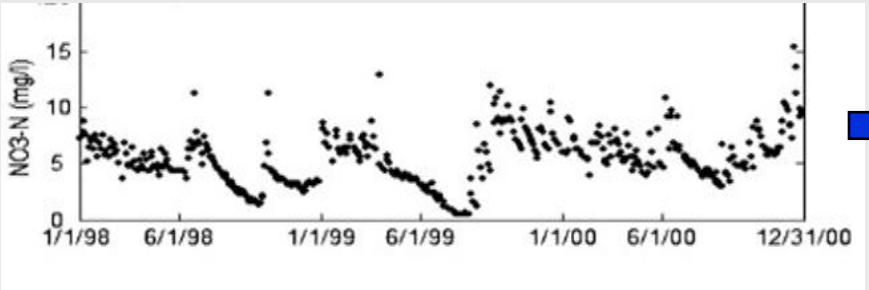
Wavelet Analysis

- **Wavelet analysis is a tool for analyzing time series (or signals) data**
- **Temporal patterns for hydrology (precipitation, stream flow, and water level), water quality, and CO_2 flux**
- **Signal analysis in medical science**

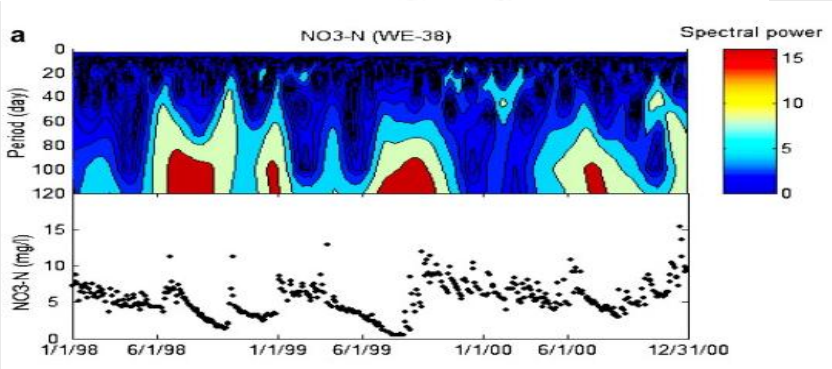


Wavelet Analysis





Wavelet Analysis

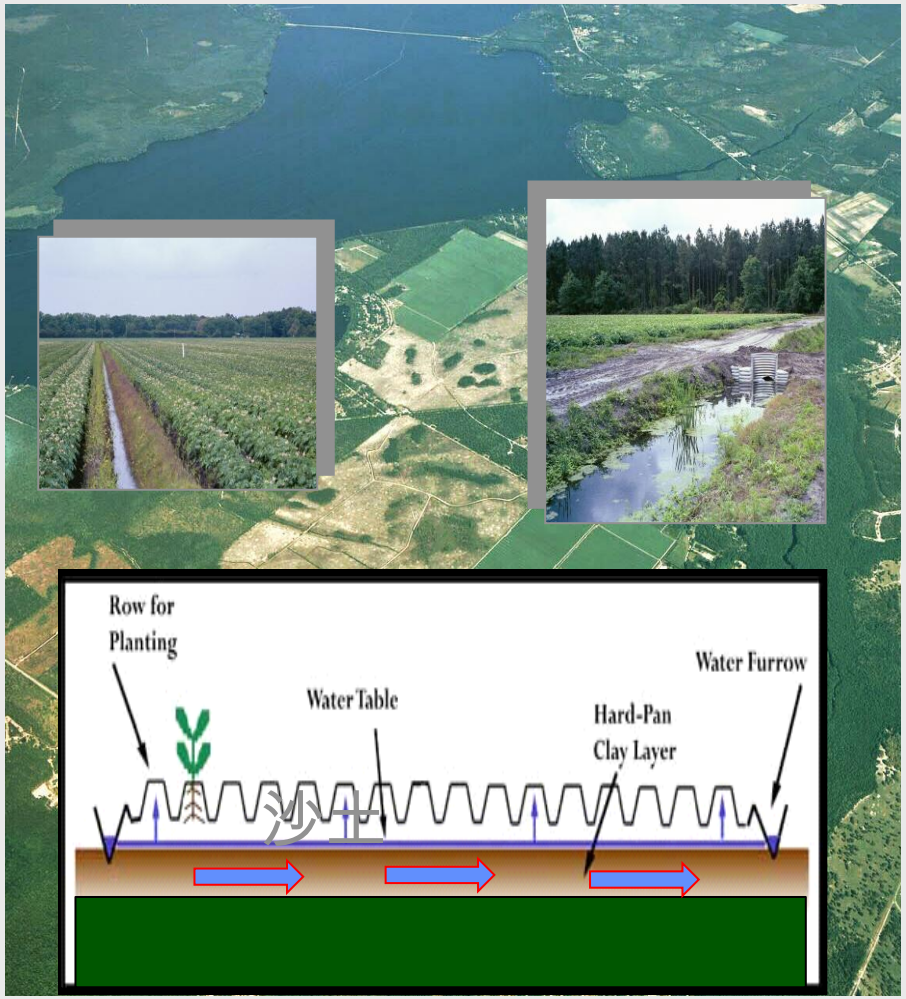


Other Research Interests: B. Optimal GW Use

Rationale

How much groundwater pumping is needed for irrigation in the Delta area?

- **Keep minimum low flow without harmful to water resource and stream ecosystem**
- **Maximize water use efficiency in a plant-soil-pond continuum**
- **Minimize adverse environmental (e.g., contaminants) impacts**



Simulation-Optimization

a. Select Simulation Models

MODFLOW (groundwater flow)
MT3D (contaminant transport)
MGO (optimization with genetic algorithm)

b. Select objective functions

Maximize crop water use efficiency
Minimize contaminant leaching

Subject to criteria

C_{con} < EPA standards
GW head, $h_{min} < h < h_{max}$, to keep minimum low flow
Irrigation rate, $Q_{min} < Q < Q_{max}$, for optimal water use

Summary

1. Method for low flow selection; Response of low flow to climate change; Past climate change has made the pristine headwater areas drier
2. Ongoing project for water quality assessment in the LMAV using BASINS-HSPF model
3. Ongoing project for monitoring real-time variations of P in surface water using DDDAS
4. Other research interests such as GW optimization and wavelet analysis