US EPA ARCHIVE DOCUMENT

# Development of Predictive SWAT to Assess Global Change Impacts on U.S. Water Quality

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Consequences of Global Climate and Emissions Changes on U.S. Water Quality: An Integrated Modeling Assessment

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# Objective

**To quantify and understand the impacts of global climate and emission changes from the present to 2050 on U.S. water quality, focusing on the nitrogen cycle.**

# Approach

- The objective will derive from the application of a unique, state-of-the-art, integrated modeling system that couples a global climate-chemical transport component with a mesoscale regional climate-hydrology-air quality-water quality component over North America.
- The system predicts the interactive dynamical, physical and biogeochemical processes that govern the movement of water and pollutants in the air and on land (surface, subsurface, streams, plants, human).
- The system incorporates multiple alternative model configurations representing the likely range of climate sensitivity and biogeochemistry response under the conceivable anthropogenic emissions scenarios to rigorously assess the result uncertainty for improving risk analysis.

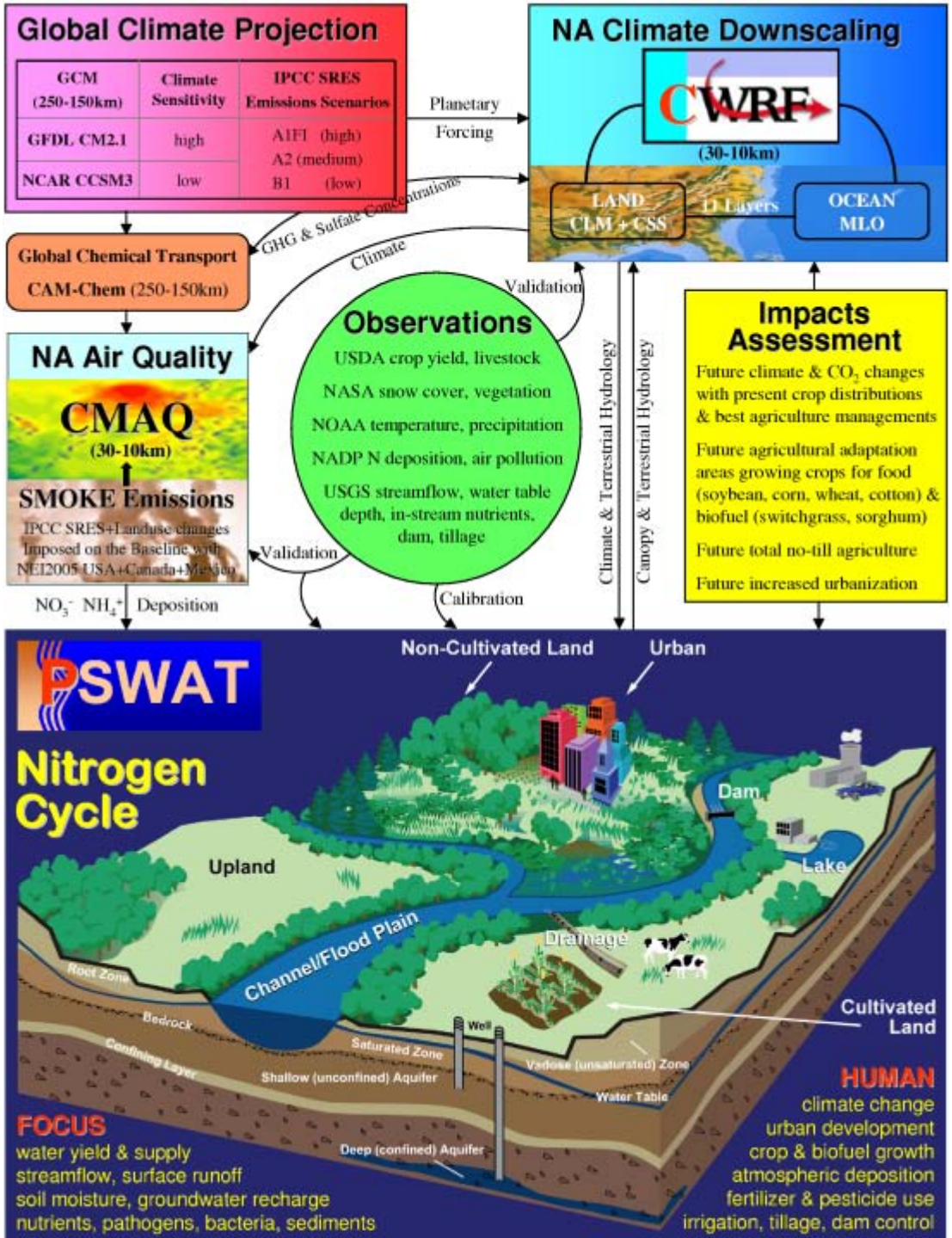
**EPA STAR 2003-2011**

**FOCUS**

Consolidate $O_3$

Elaborate PM

Explore Hg




**EPA STAR 2009-2012**

**FOCUS**

**Nutrients**

**Pathogens**

**Bacteria**

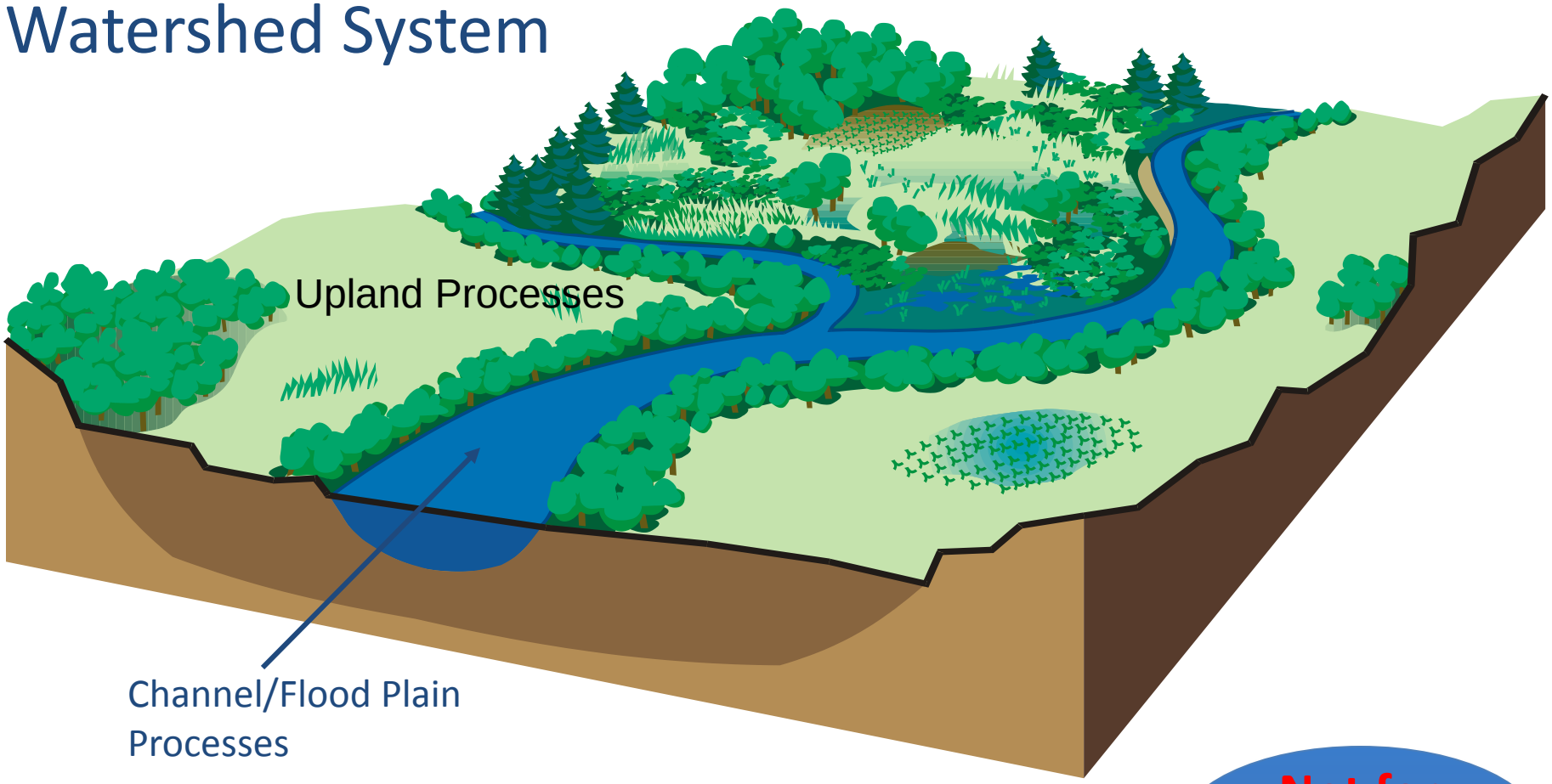
**Sediments**

**Agriculture**

**Urban**

SWAT

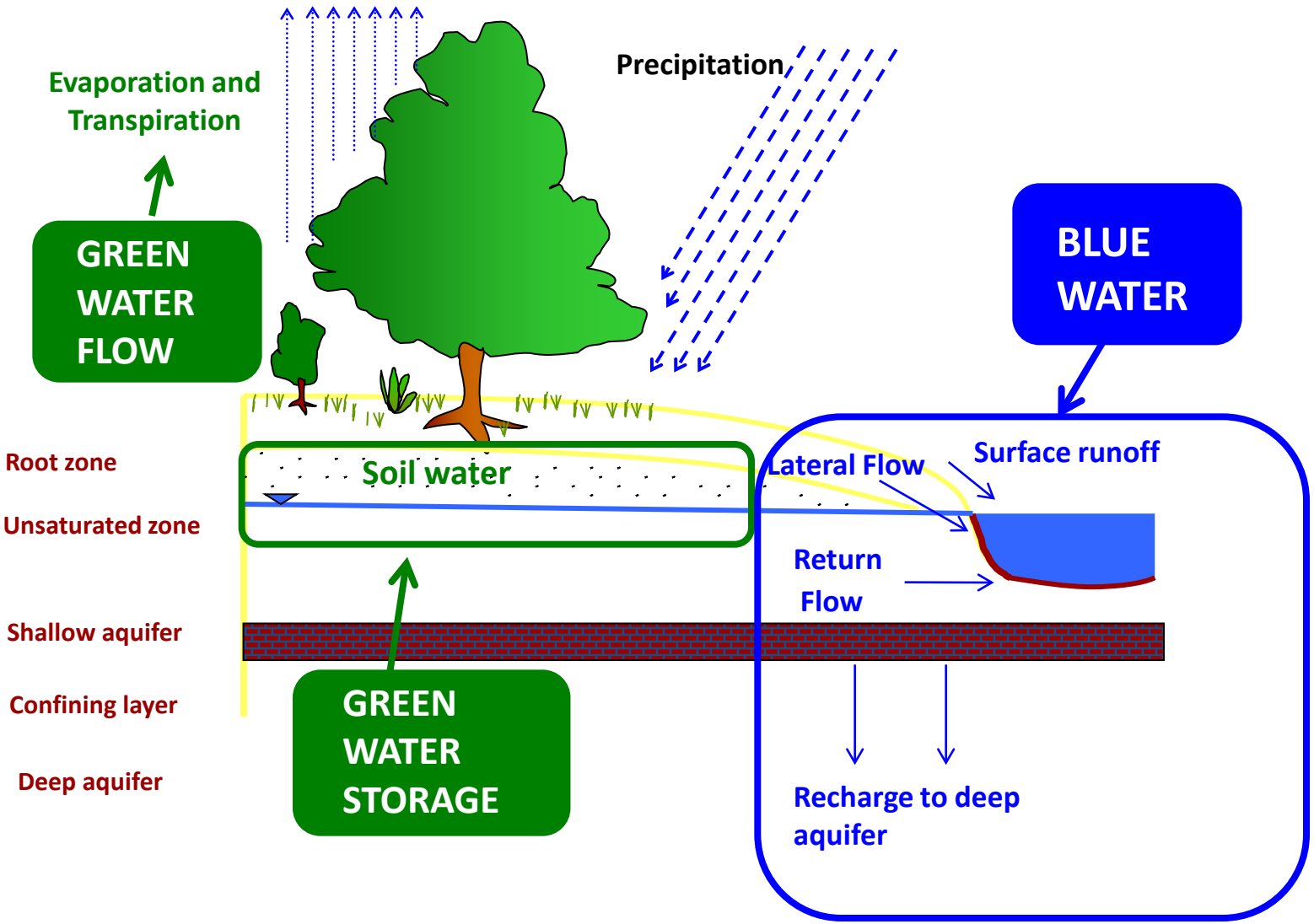
# Watershed System




**Soil and Water Assessment Tool**

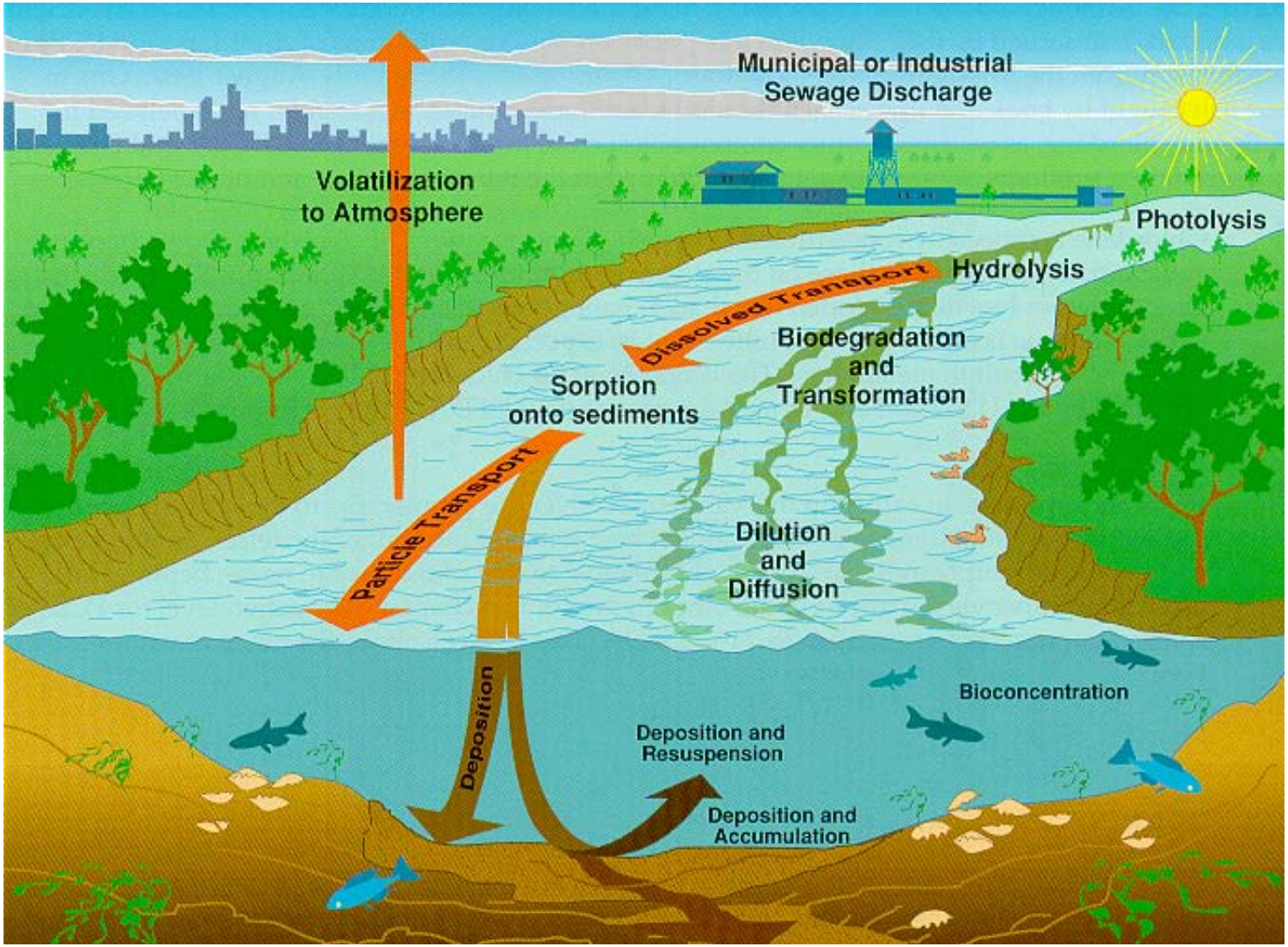
Not for Prediction

# Hydrologic Cycle Simulated by SWAT



SWAT

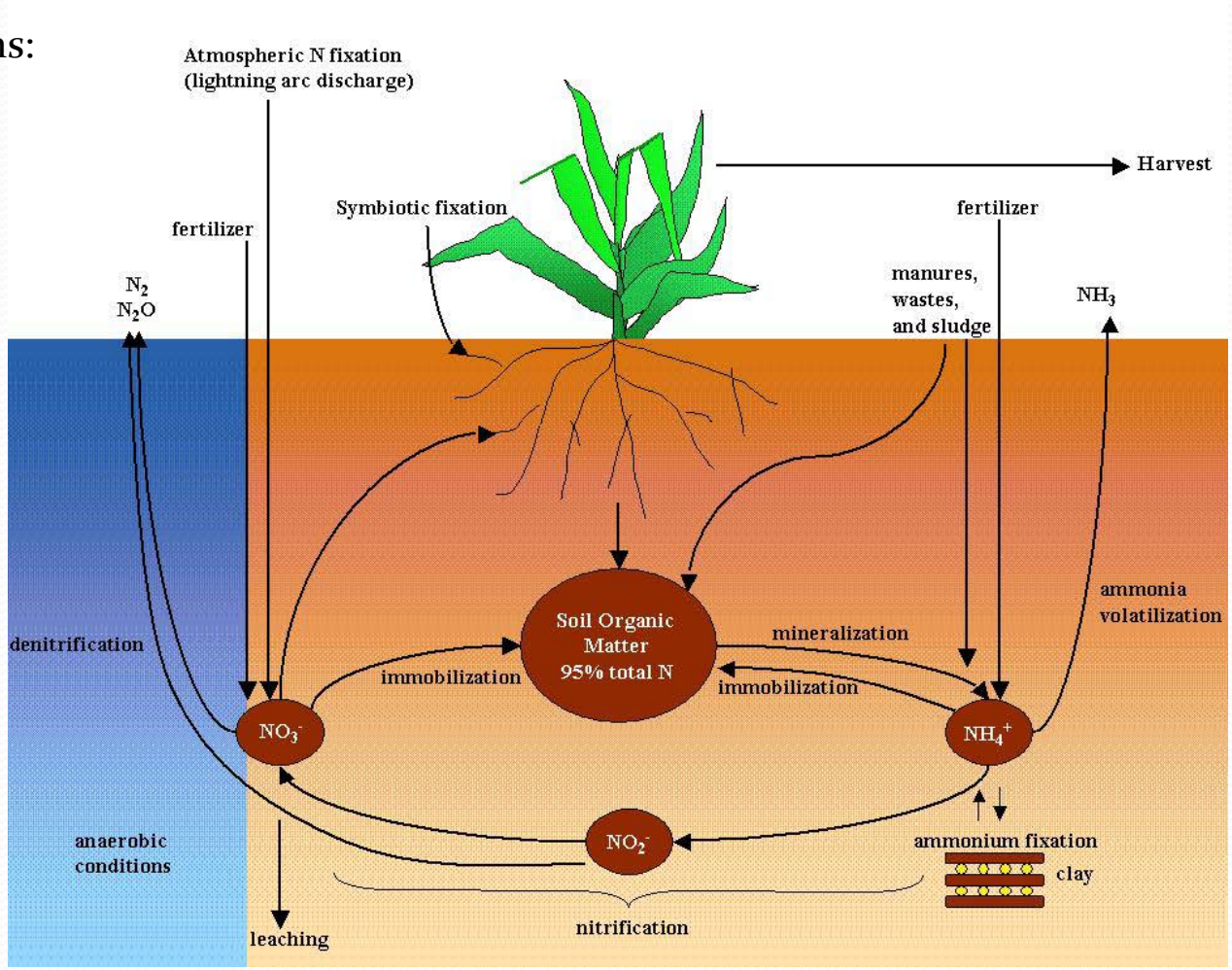
# Channel Processes




GREY WATER

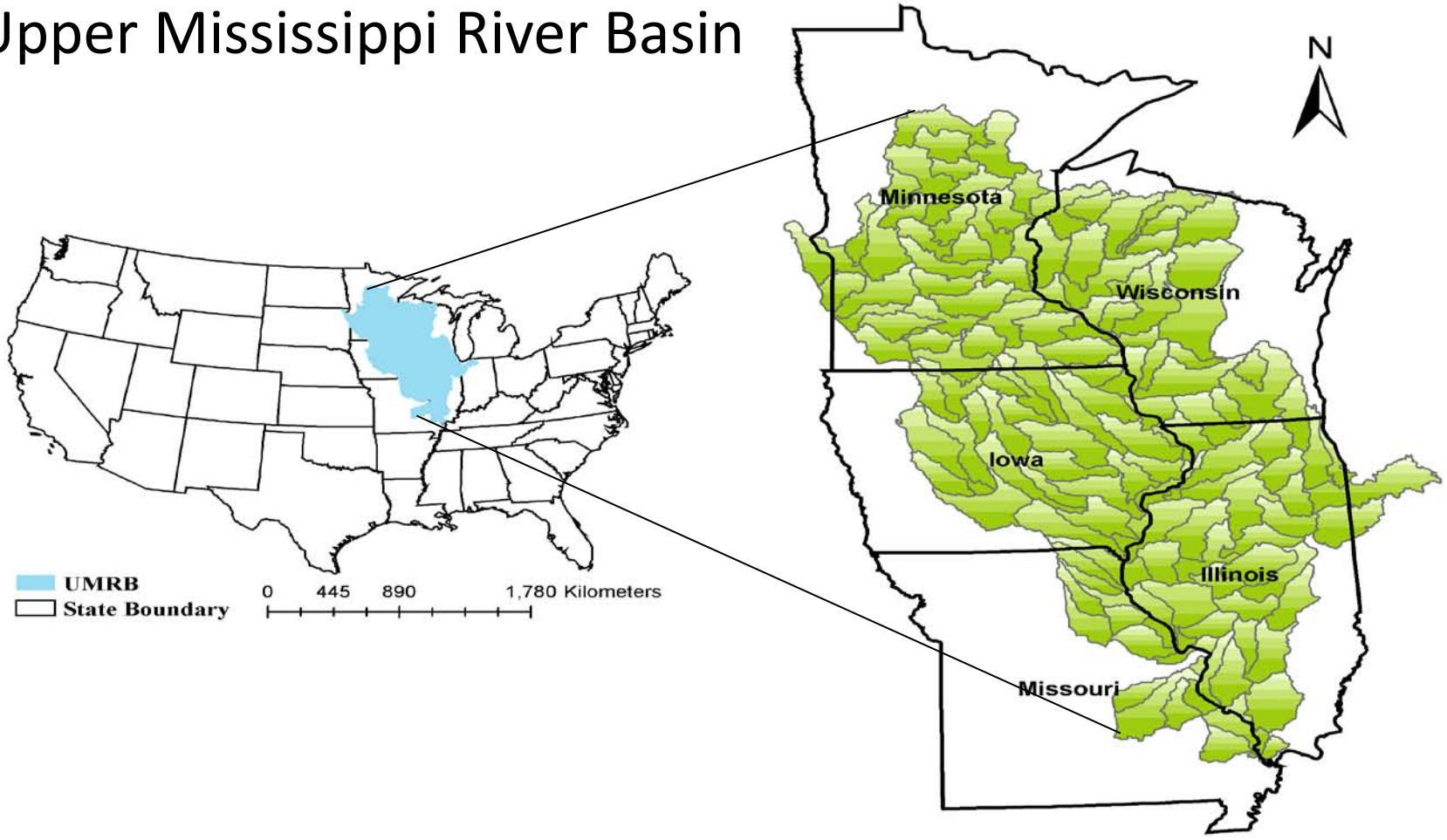
# Nitrogen Cycle

- Nitrogen include 4 forms:
  -Ammonia ($NH_3$)
  -Nitrite ($NO_2^-$)
  -Nitrate ($NO_3^-$)
  -Nitrogen gas ($N_2$)

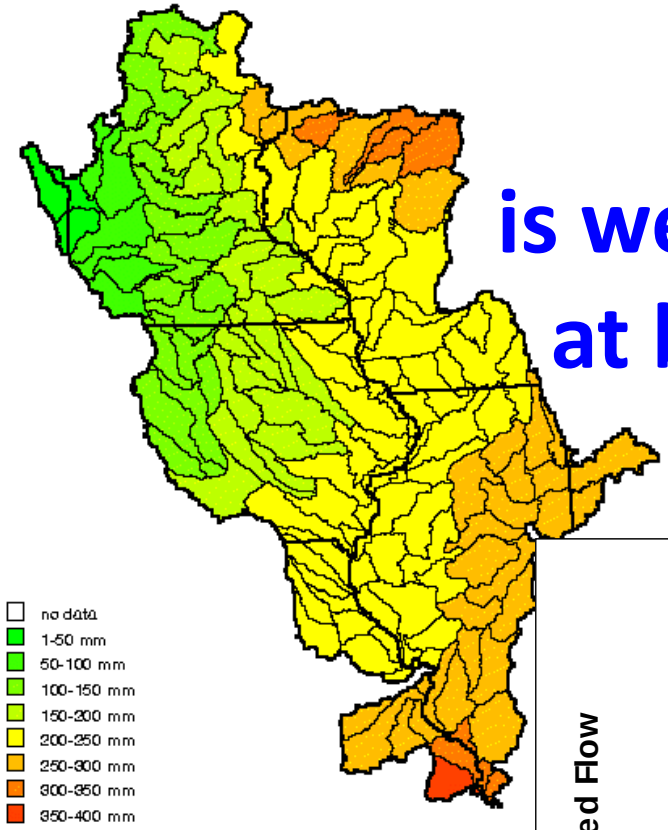


# SWAT Application in Watershed Basin

Upper Mississippi River Basin

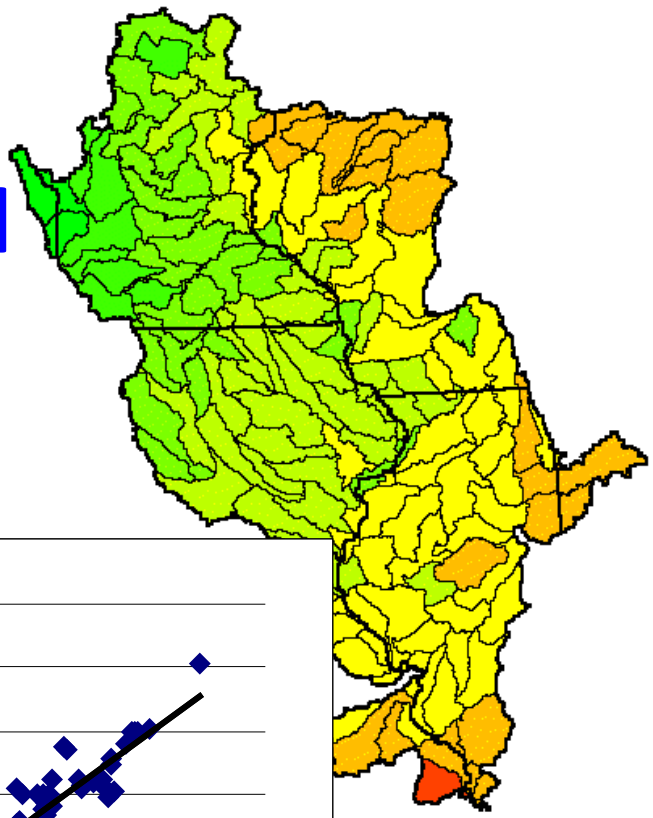


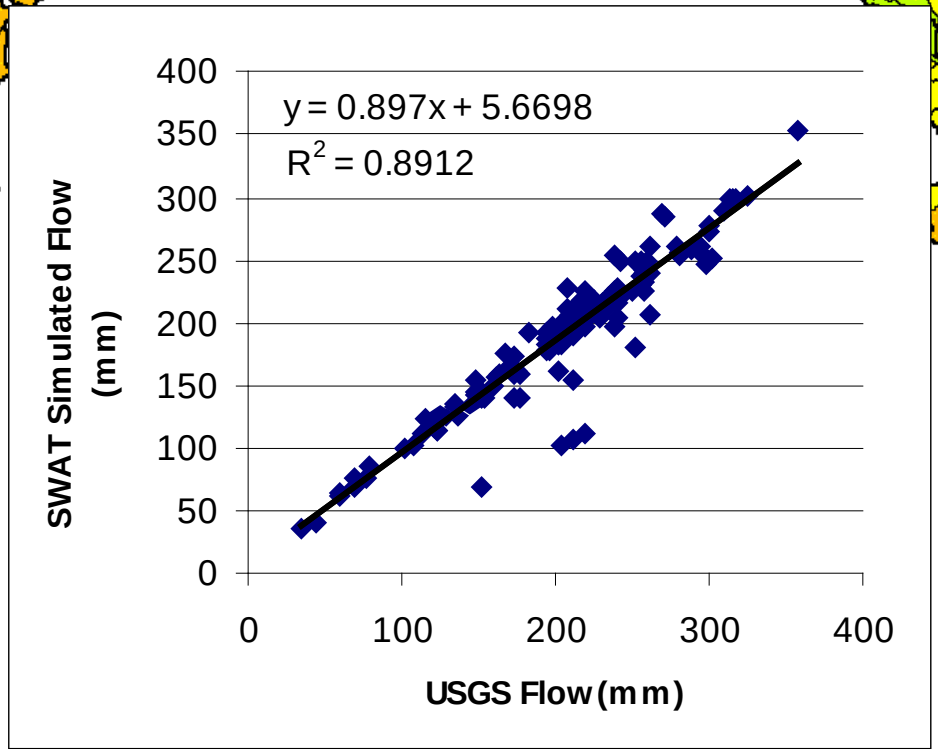
Upper Mississippi Water Resource Region
Average Annual Observed (USGS) Total Flow
By 8-digit HUA




# SWAT is well validated at basin scale

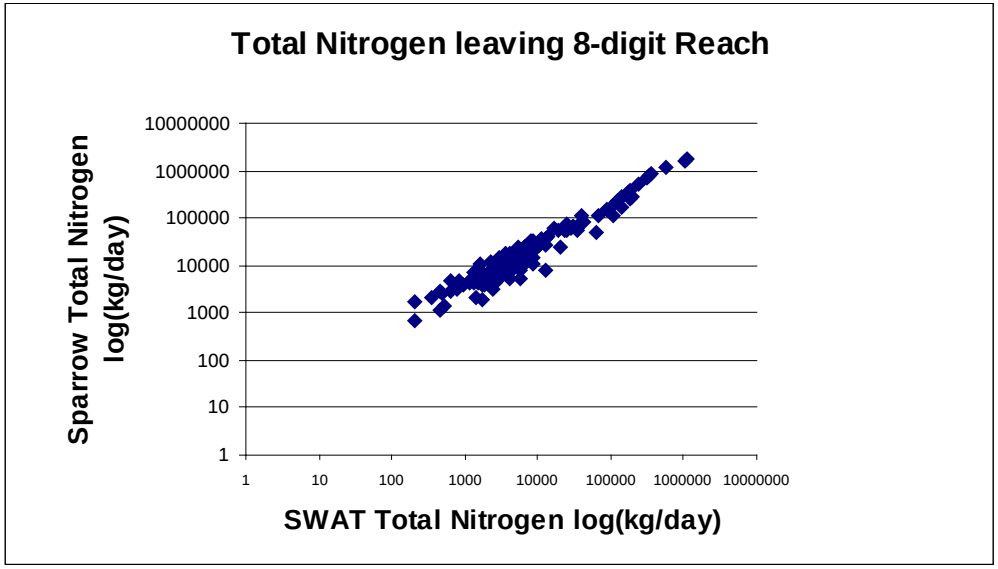
Upper Mississippi Water Resource Region
Average Annual SWAT Simulated Total Flow
By 8-digit HUA



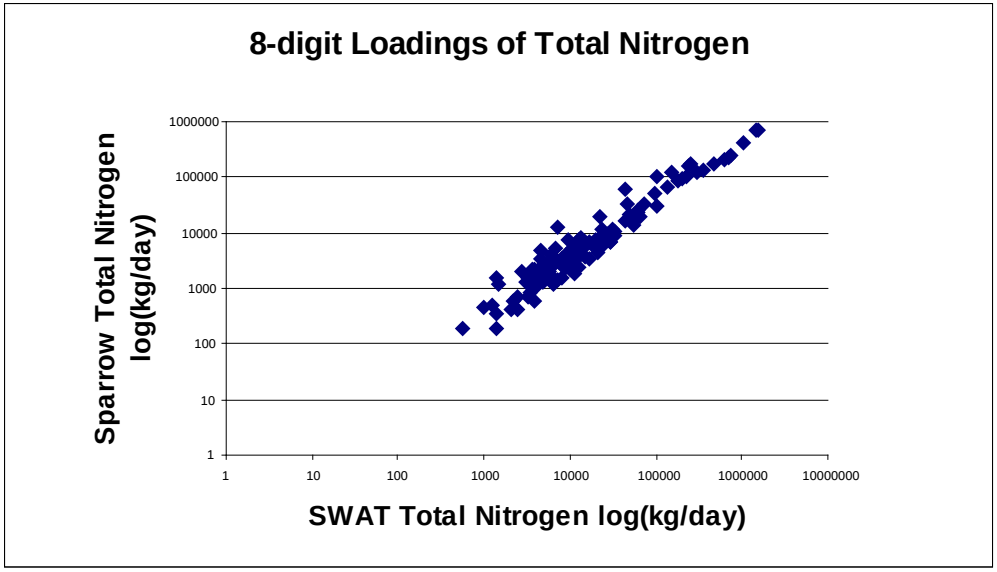


# Upper Mississippi (131 8-digits)

**8-digit Transport**

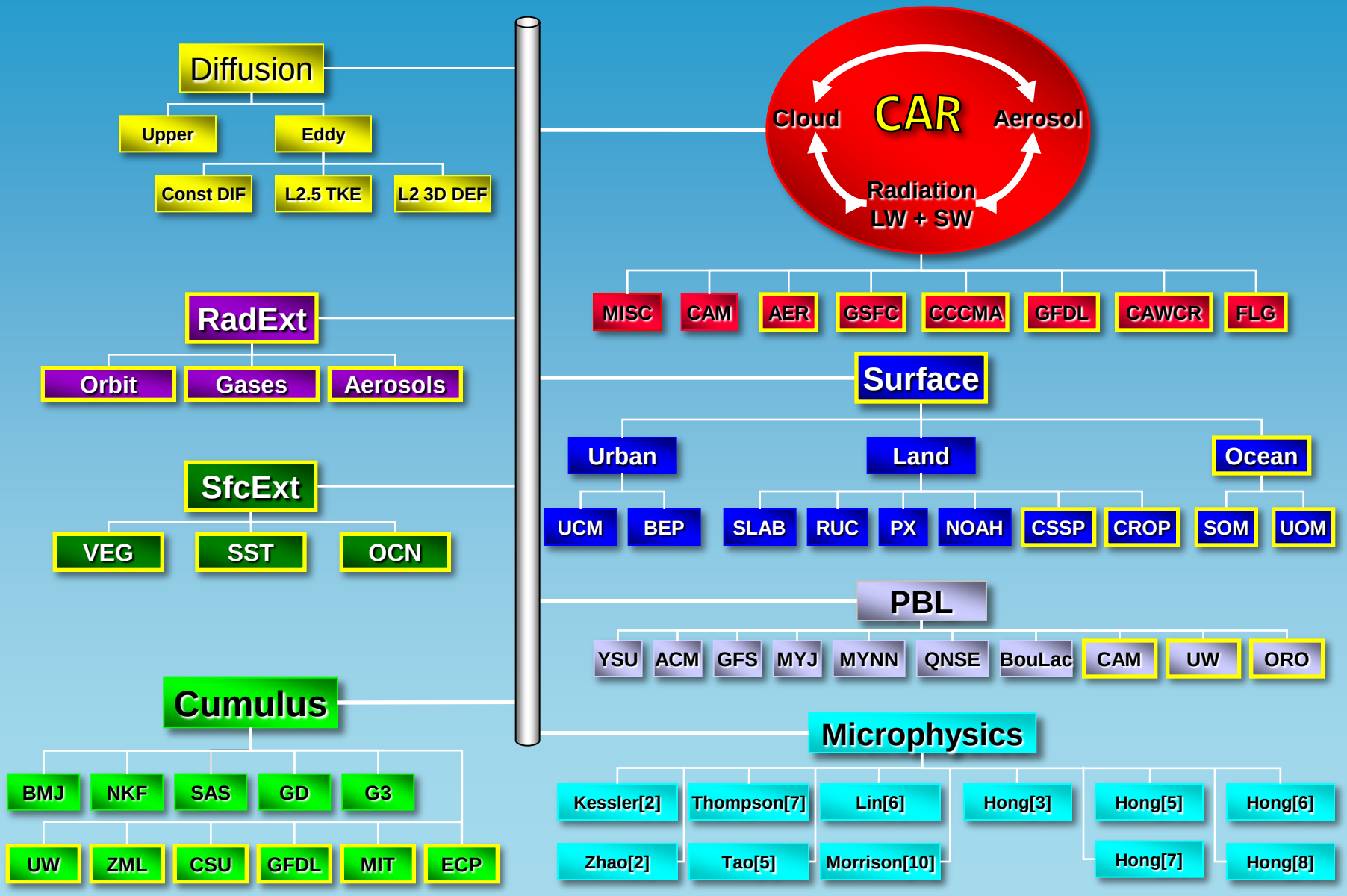



**8-digit Loadings**

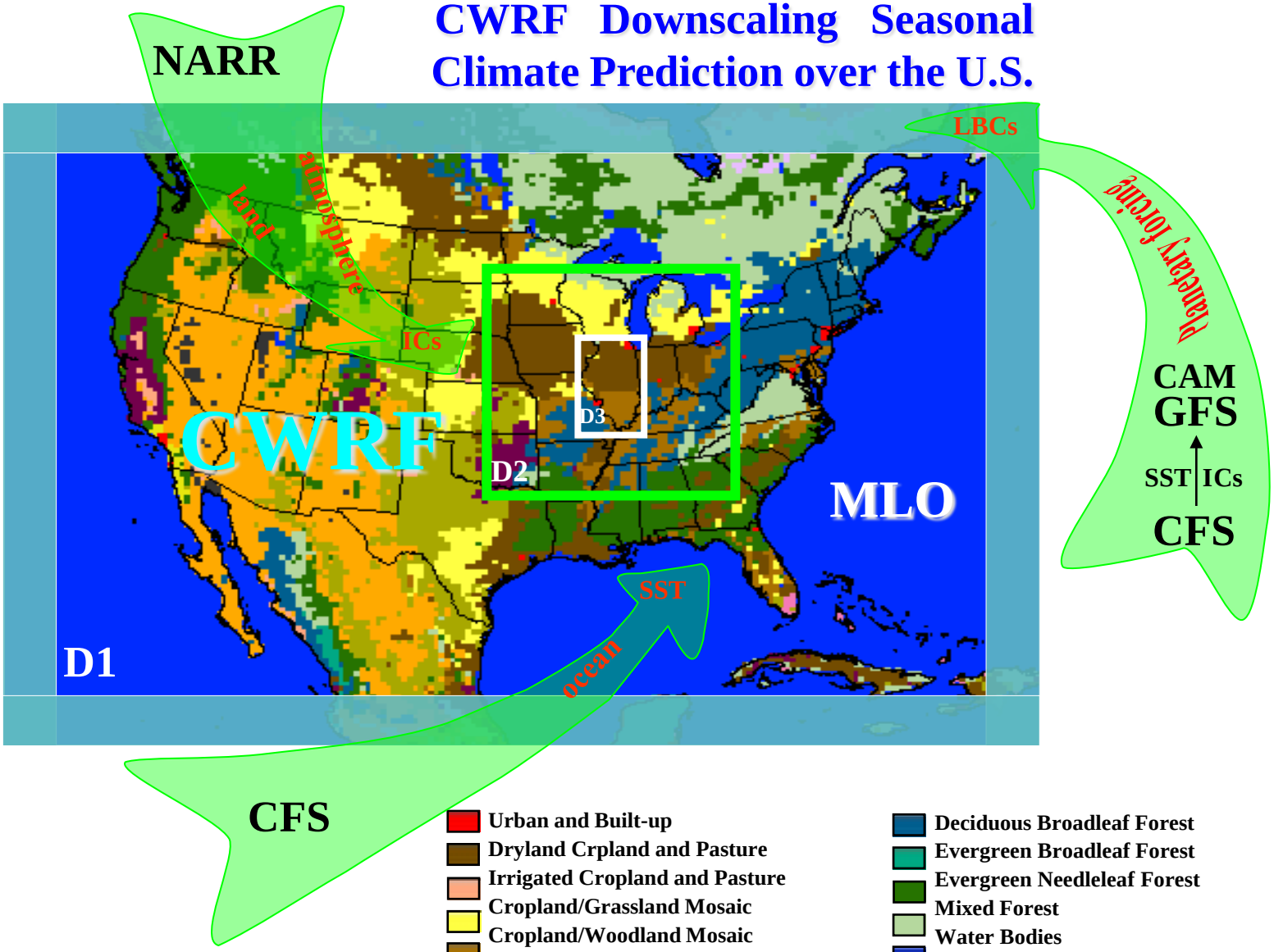



**Sparrow Comparison USGS Regression Model**

# CWRF Physics Options



# CWRF Downscaling Seasonal Climate Prediction over the U.S.



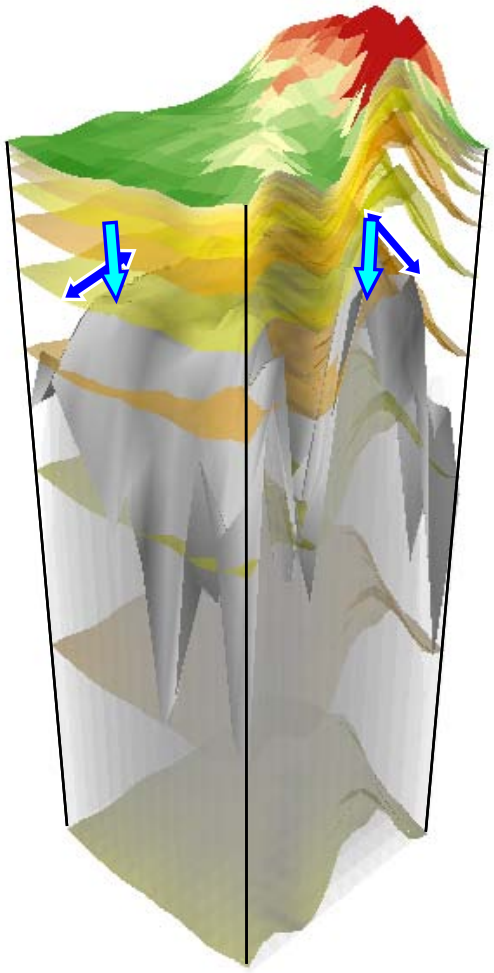

**NOAA**

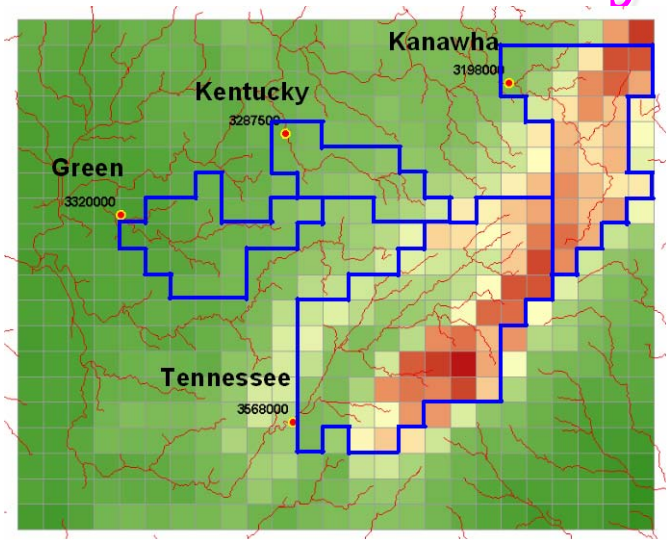
**2008-2011**

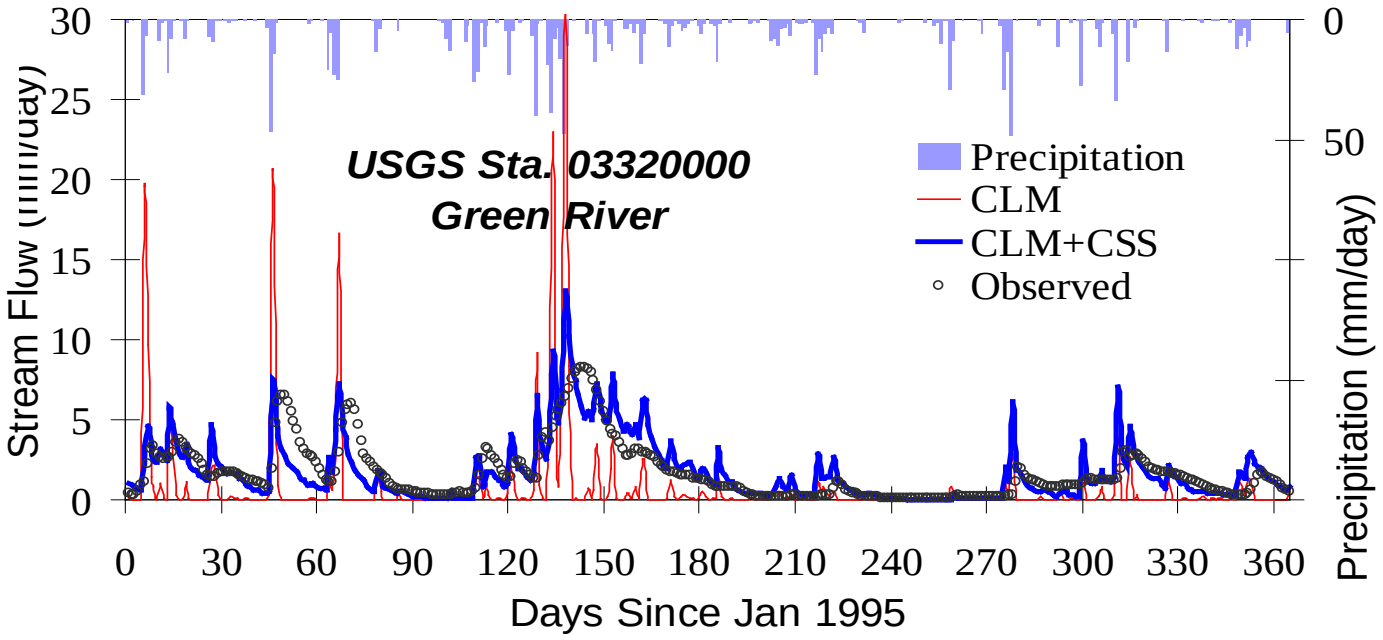
# CWRF Downscaling Seasonal Climate Prediction over the United States

Frequency distribution of root mean square errors (RMSE, mm/day) for the interannual variations of seasonal precipitation over land predicted by the CFS and CWRF based on 5 ensemble members during wintertime of 1982-2008. Seasonal precipitation is binned at an interval of 0.1 mm/day. After Yuan and Liang (2011, GRL).

# CWRF Terrestrial Hydrology

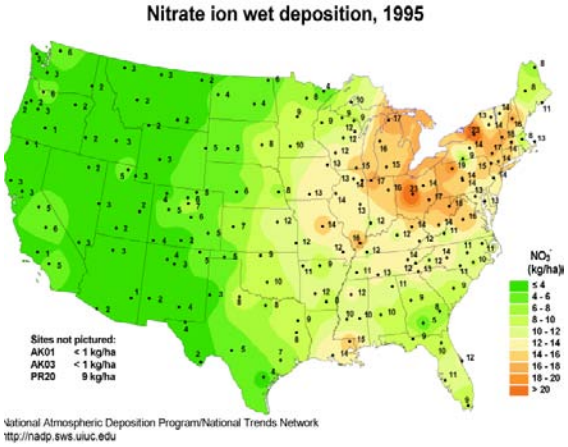


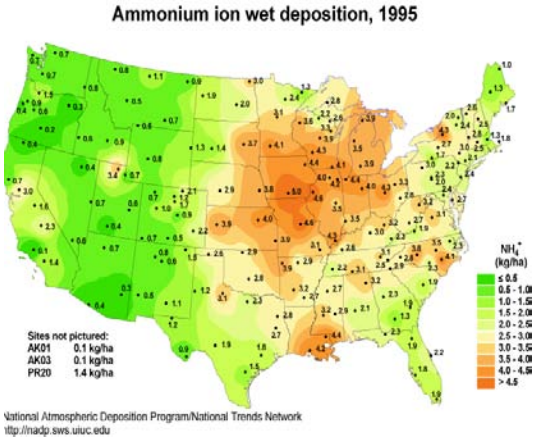


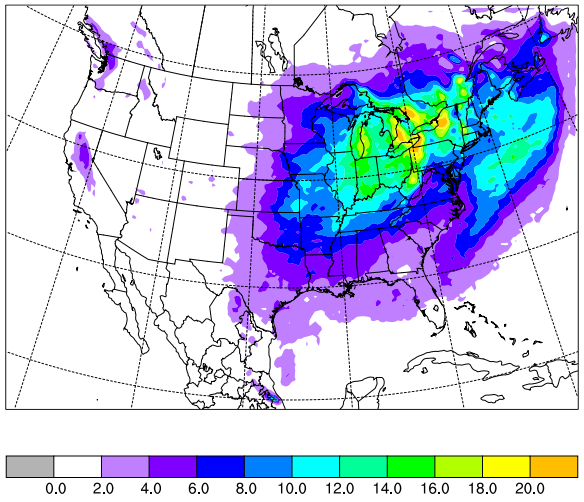

Choi 2006; Choi et al. 2007; Choi and Liang 2010; Yuan and Liang 2010; Liang et al. 2010d

# CMAQ Captures Depositions

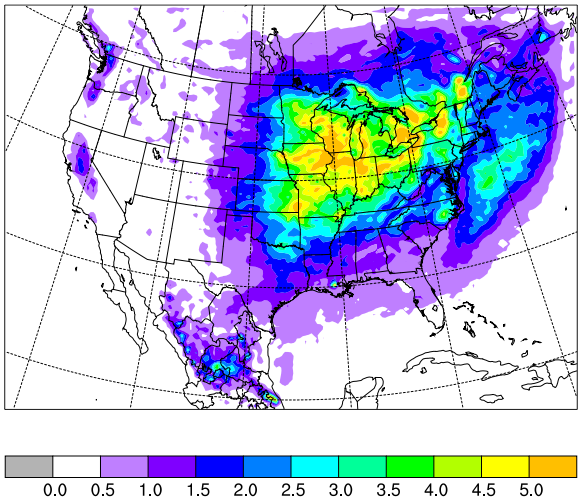



Nitrate wet deposition (kg/ha),1995



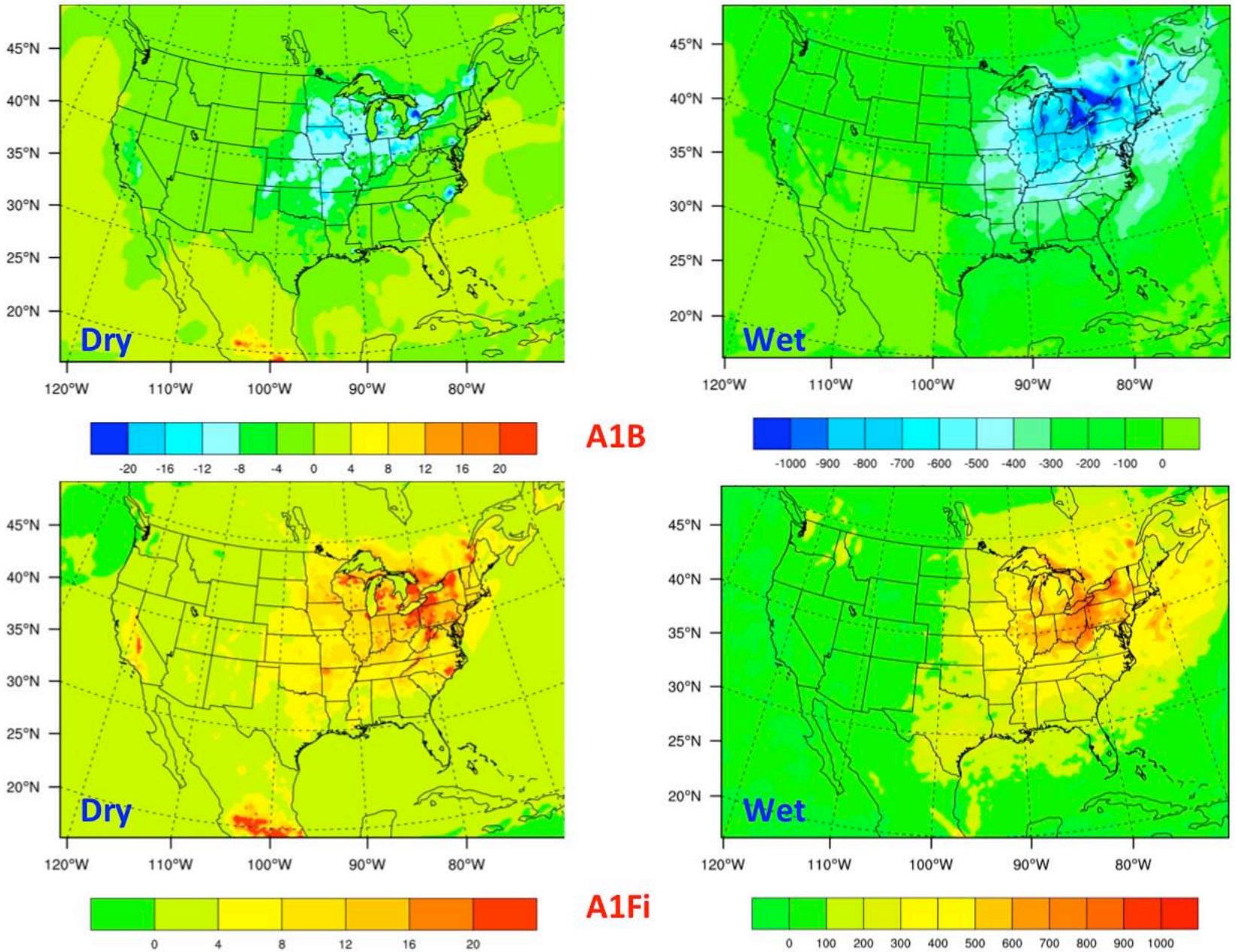

Ammonium wet deposition (kg/ha),1995



# CMAQ Projected N Deposition Change

When changes in both climate and emissions are incorporated, the two scenarios project opposite changes of nitrate wet deposition in the Midwest and Northeast: increases under A1Fi but decreases under A1B with similar magnitudes of 400-1000 mg/m2/year.

The wet deposition changes resemble dry deposition in spatial pattern but with substantially larger magnitudes by a factor of 40-50. Thus the wet deposition is the predominant sink for nitrate aerosols.

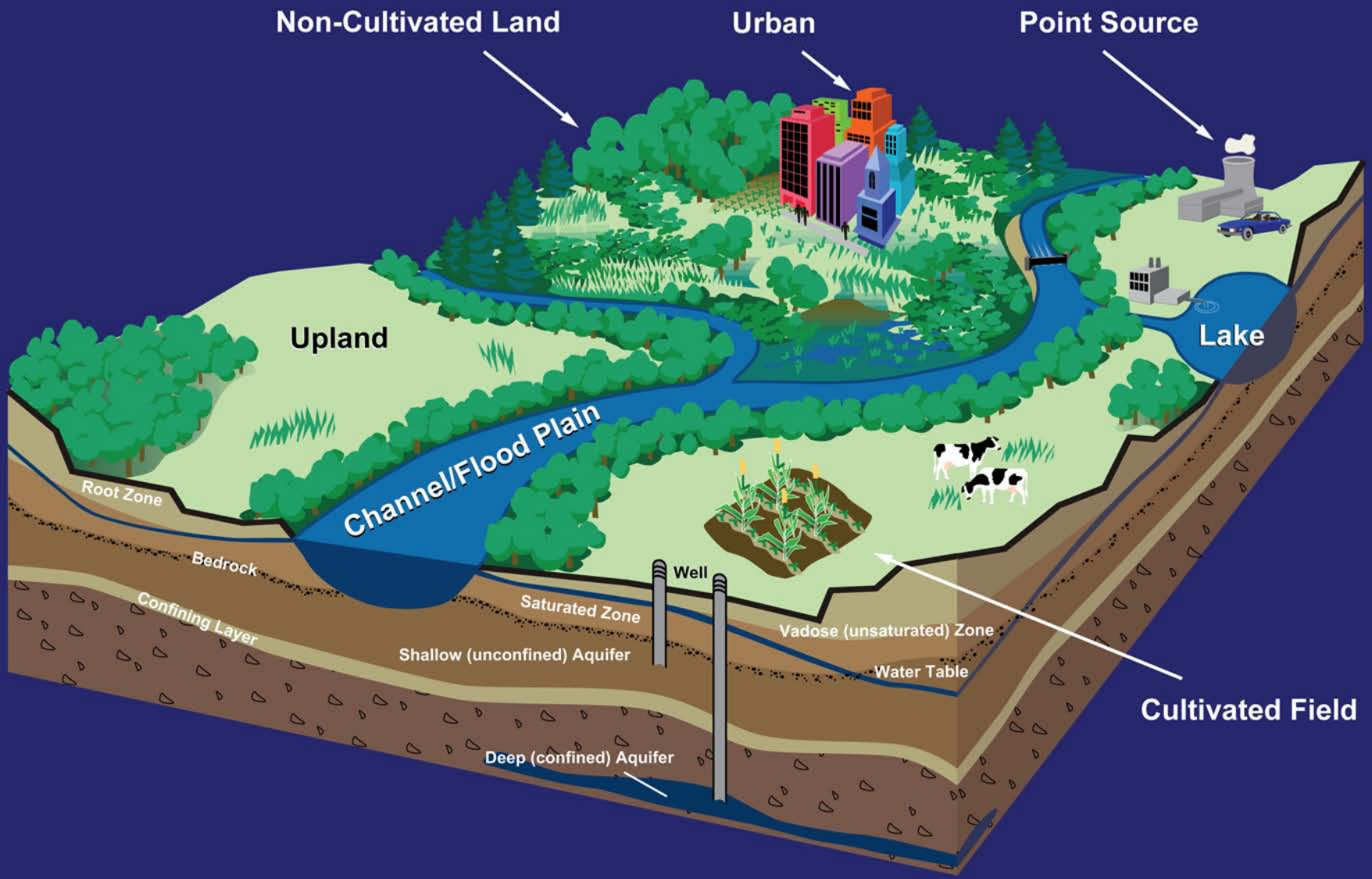



CMAQ projected differences in annual total nitrate deposition (mg/m$^2$/year) between future (2048-2052) and present (1995-1999)

# PSWAT

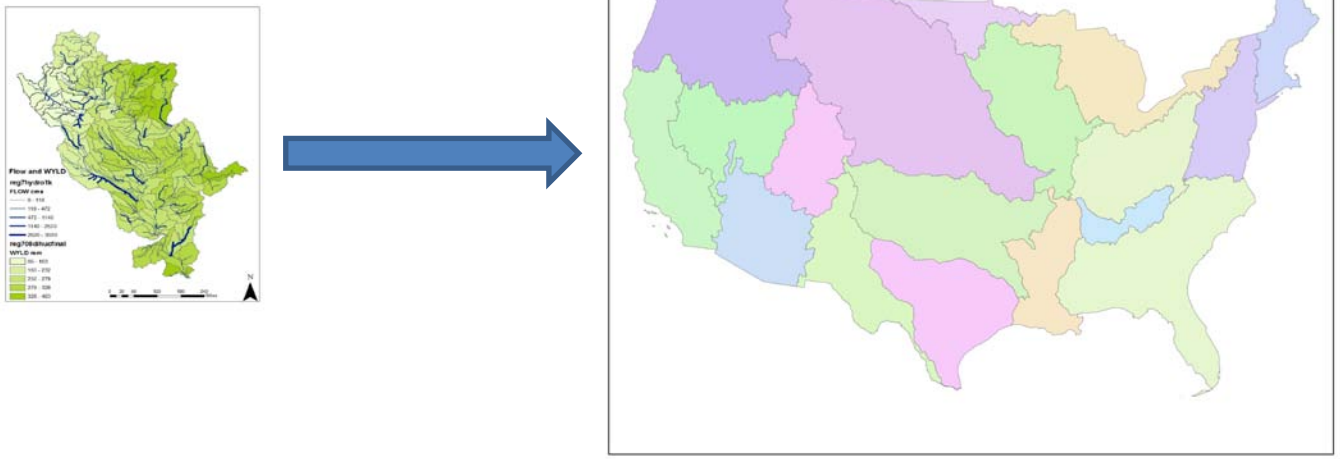
# Predictive Water Quality Modeling System

CWRF

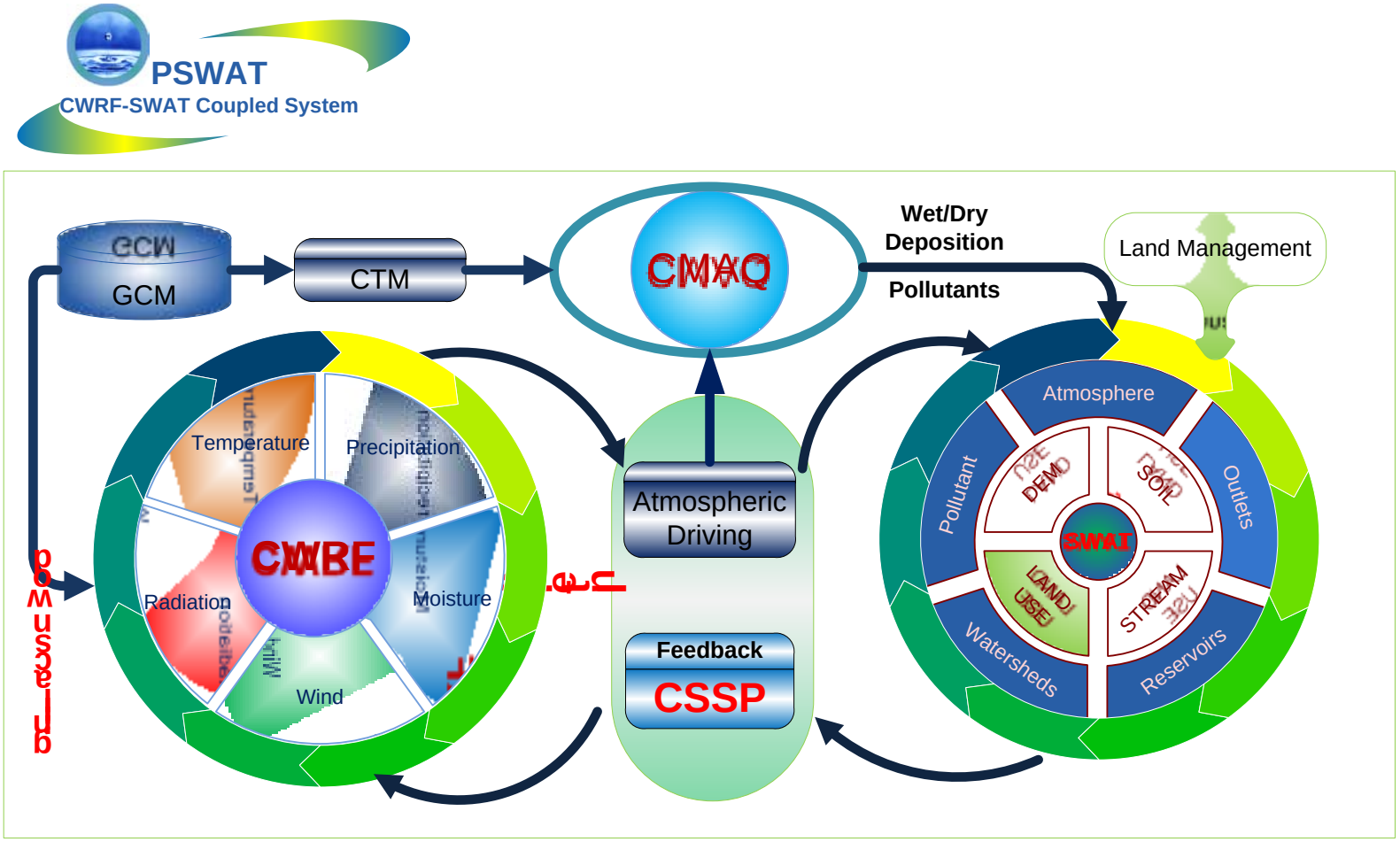


# Build National Predictive Capability

SWAT → PSWAT



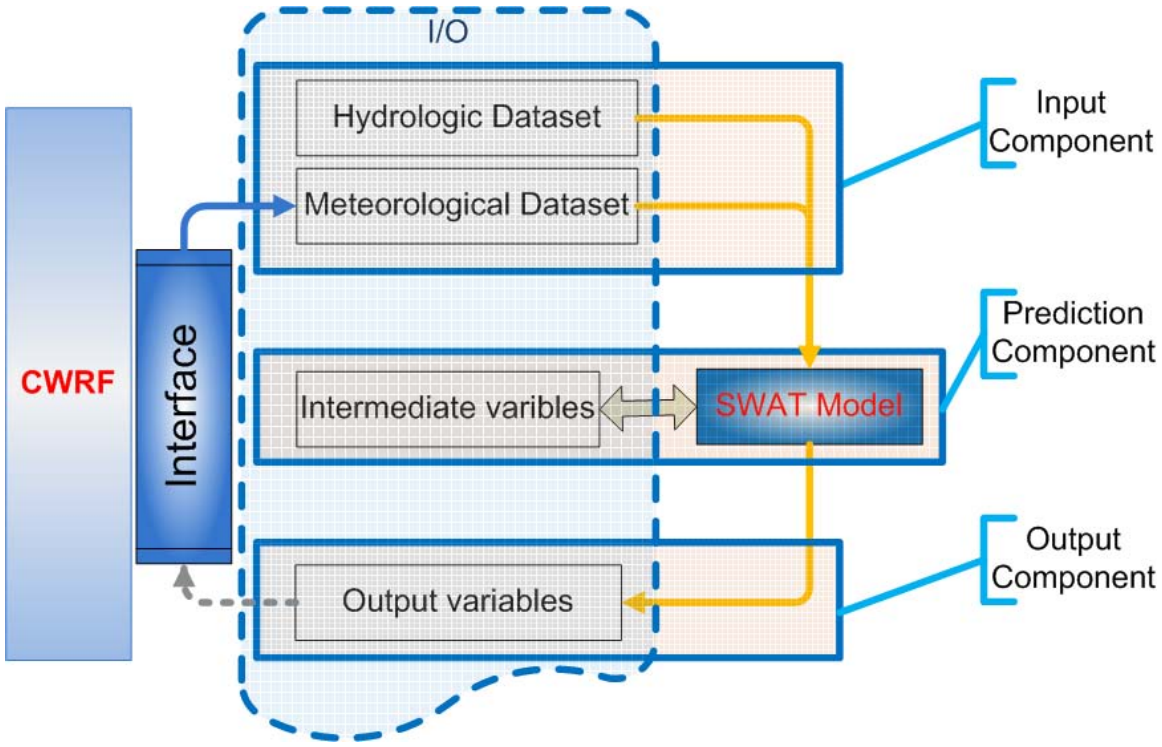
# Couple the System Components



# Build I/O Data Processor

SWAT requires diversity information with thousands of data files. This prohibits effective coupling with CWRF for parallel computing. Intensive and careful re-engineering work has been done to solve this problem. We first classified all input and output variables according to their function and the order of their usage in the program, and then wrote all categories in the sequential order into one binary file.

There are three categories: variables that will be initialized by reading operation, variables that are not used in the I/O operation, and variables that are output. As such, only a reading interface is needed between input data processing and model predicting component.



# Basin⇔Grid Information

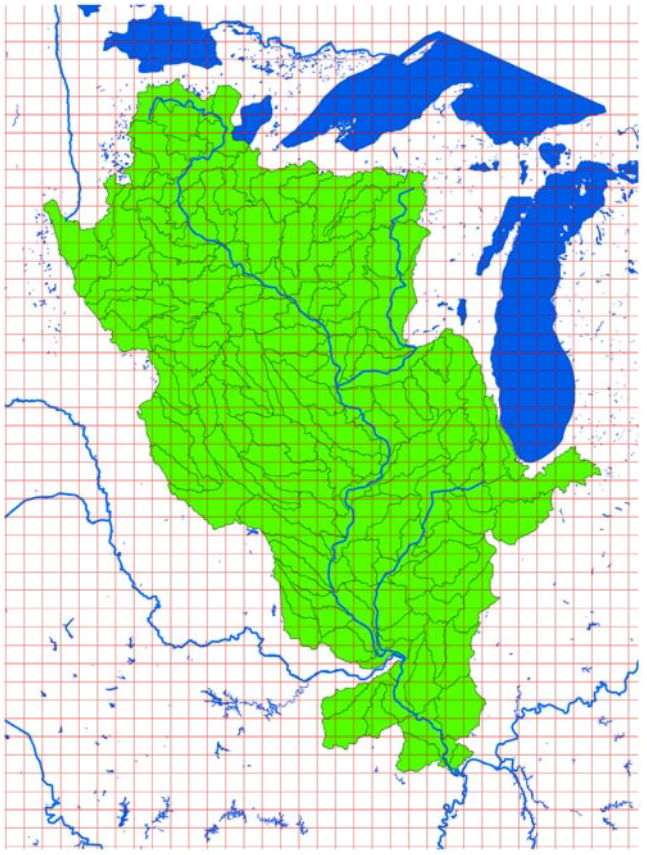
Develop the transmissive interface between the basin based SWAT and gridded CWRF

Requirement:

- Conservation of intensity or flux
- Real-time transaction
- High effectiveness

Solution:

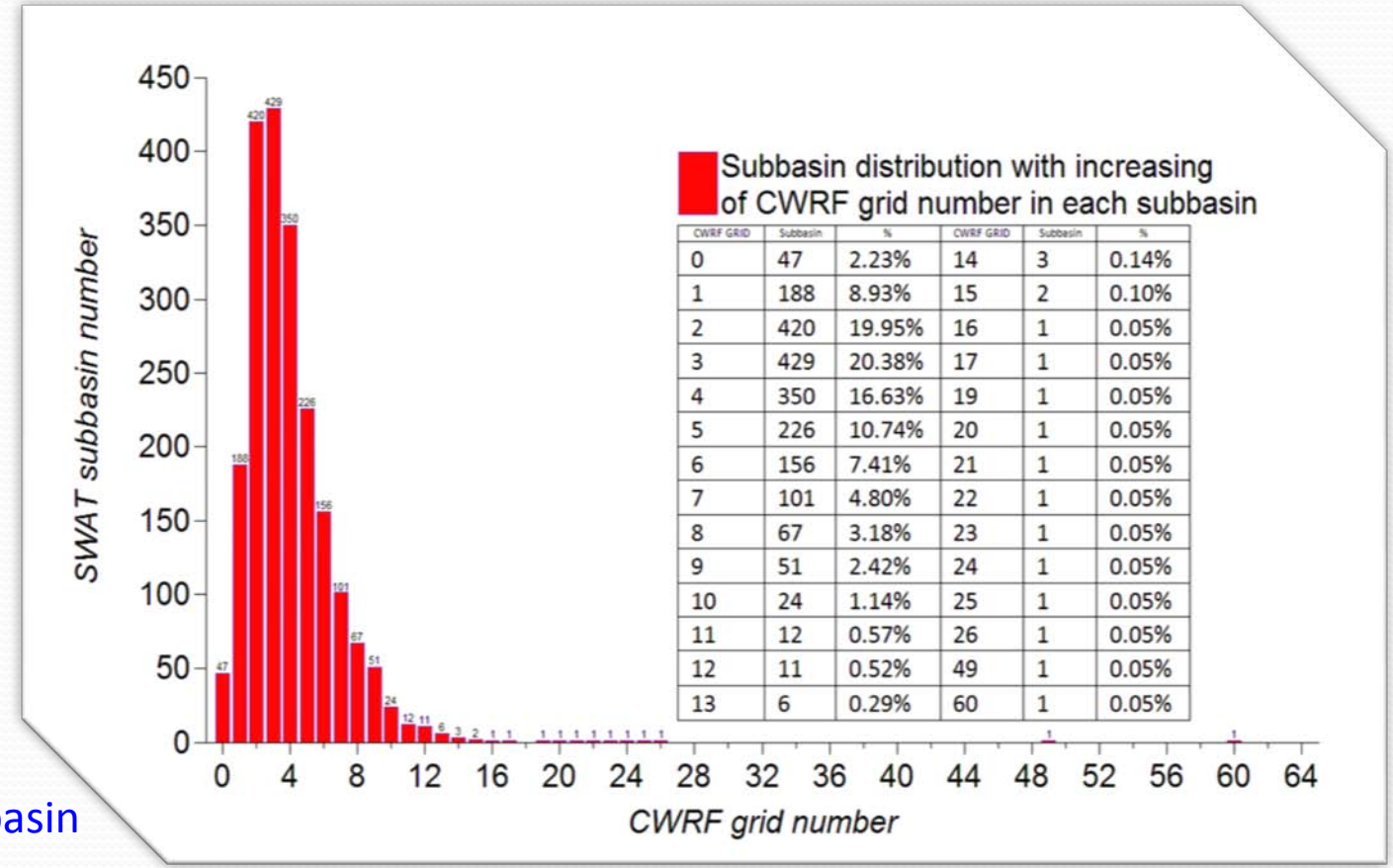
- Area weighted method (now)
- Flux coupler approach (future)



# SWAT Subbasins Distribution with CWRF grids

- More than 70% subbasin have 2 or more CWRF grids

Resolution can be refined



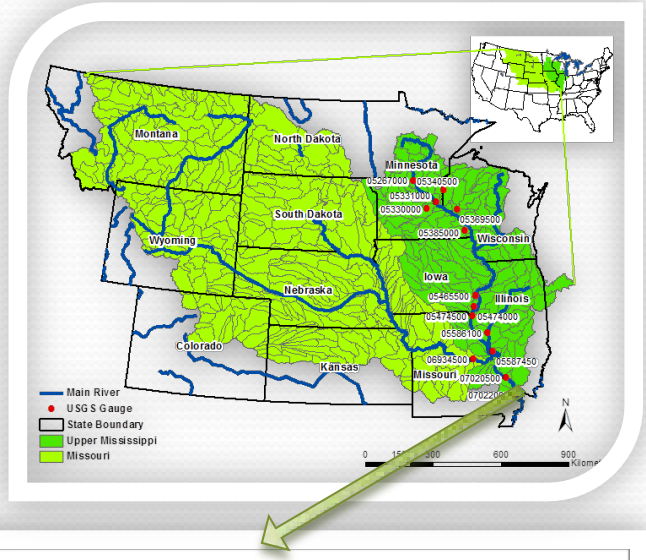

Subbasin distribution with increasing of CWRF grid number in each subbasin

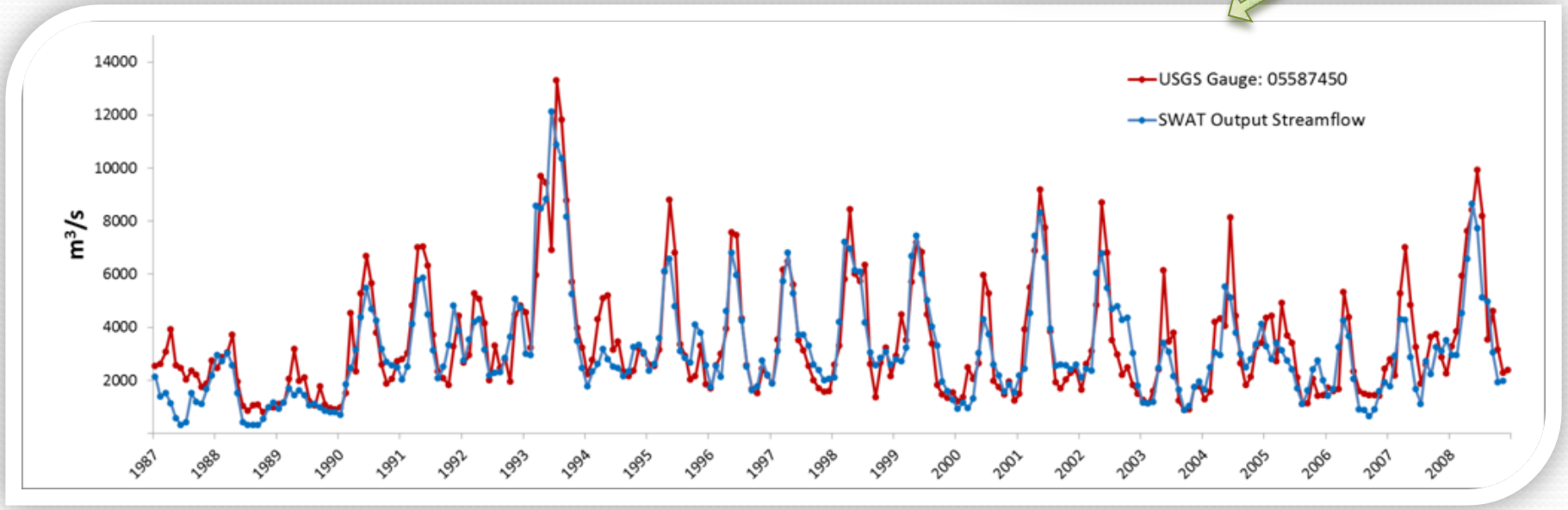
| CWRF GRID | Subbasin | % | CWRF GRID | Subbasin | % |
|---|---|---|---|---|---|
| 0 | 47 | 2.23% | 14 | 3 | 0.14% |
| 1 | 188 | 8.93% | 15 | 2 | 0.10% |
| 2 | 420 | 19.95% | 16 | 1 | 0.05% |
| 3 | 429 | 20.38% | 17 | 1 | 0.05% |
| 4 | 350 | 16.63% | 19 | 1 | 0.05% |
| 5 | 226 | 10.74% | 20 | 1 | 0.05% |
| 6 | 156 | 7.41% | 21 | 1 | 0.05% |
| 7 | 101 | 4.80% | 22 | 1 | 0.05% |
| 8 | 67 | 3.18% | 23 | 1 | 0.05% |
| 9 | 51 | 2.42% | 24 | 1 | 0.05% |
| 10 | 24 | 1.14% | 25 | 1 | 0.05% |
| 11 | 12 | 0.57% | 26 | 1 | 0.05% |
| 12 | 11 | 0.52% | 49 | 1 | 0.05% |
| 13 | 6 | 0.29% | 60 | 1 | 0.05% |

CWRF 30km is comparable to SWAT 8-digit subbasin

# Streamflow Comparison

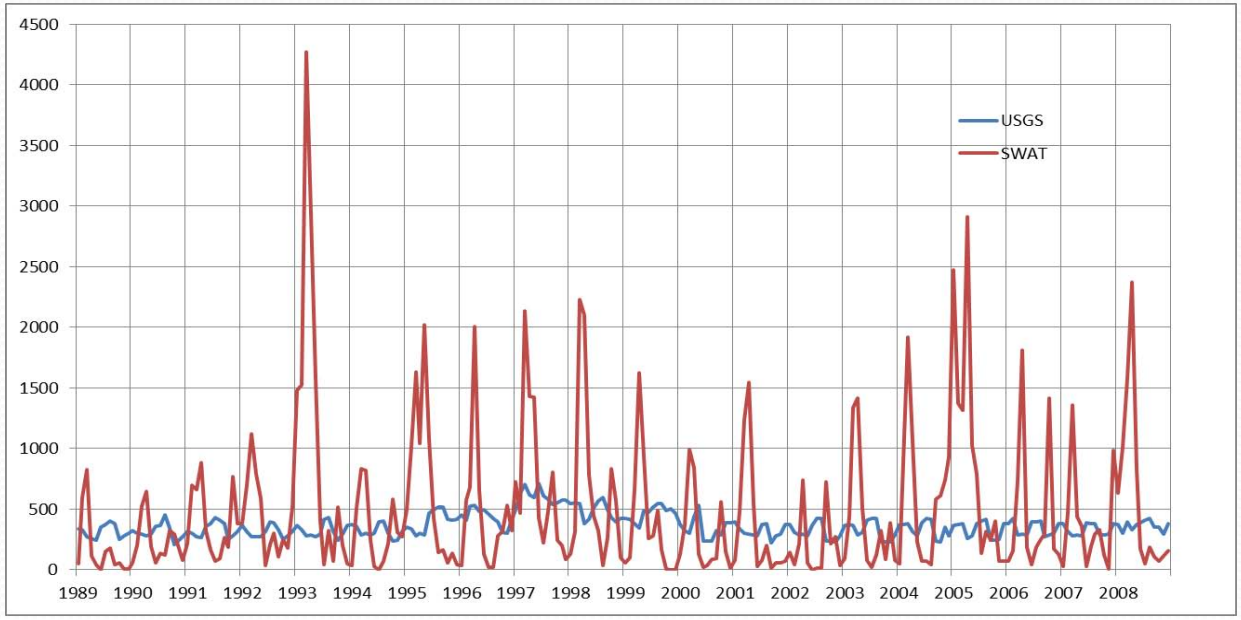
Correlation coefficient of PSWAT streamflow with USGS observations is 0.88



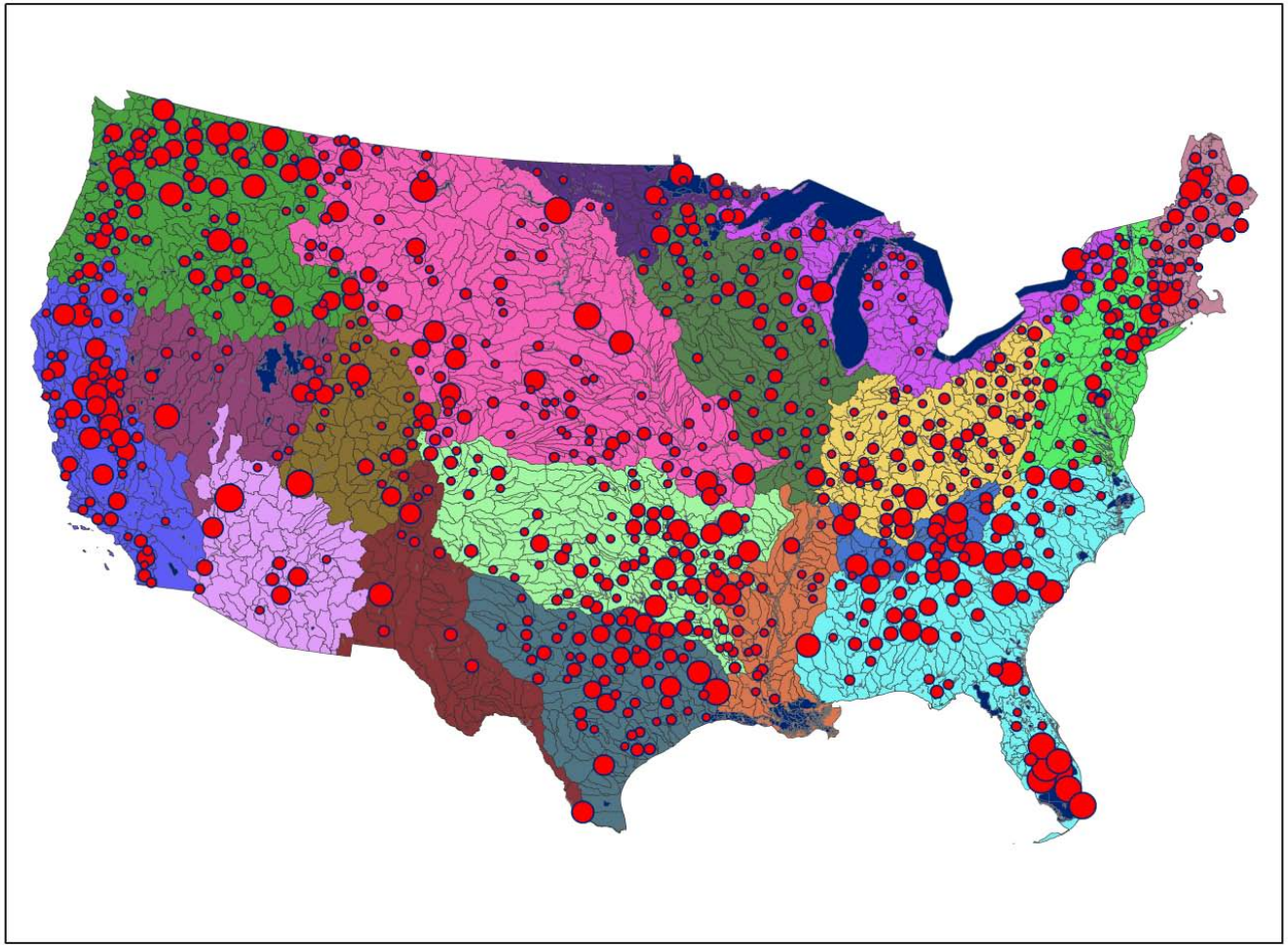



# Streamflow at the Colorado River

**The original SWAT simulates it very poorly**

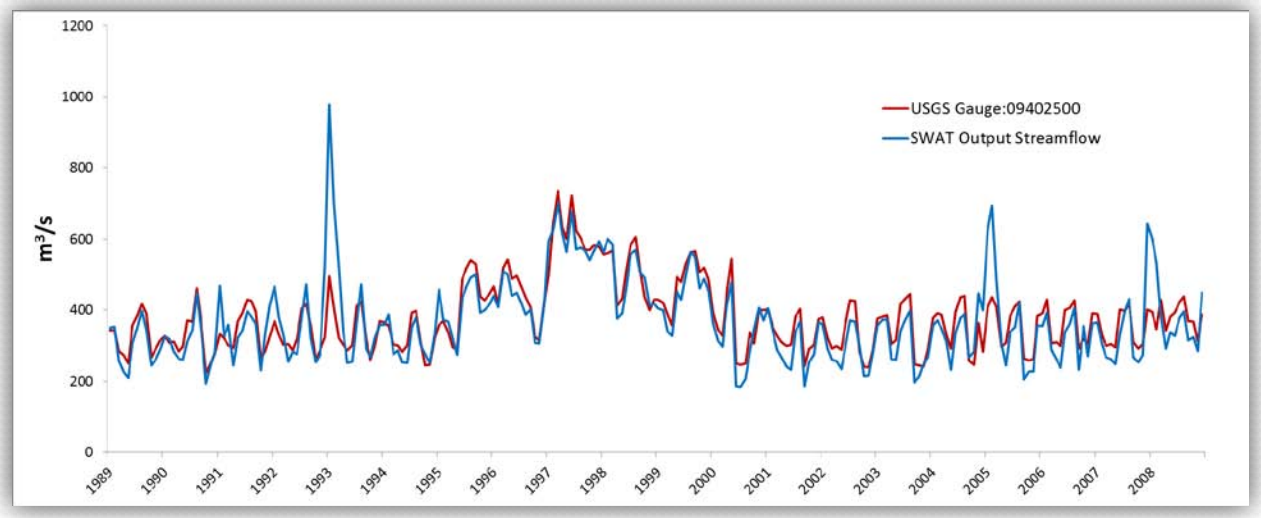


# Reservoir volume distribution in each subbasin



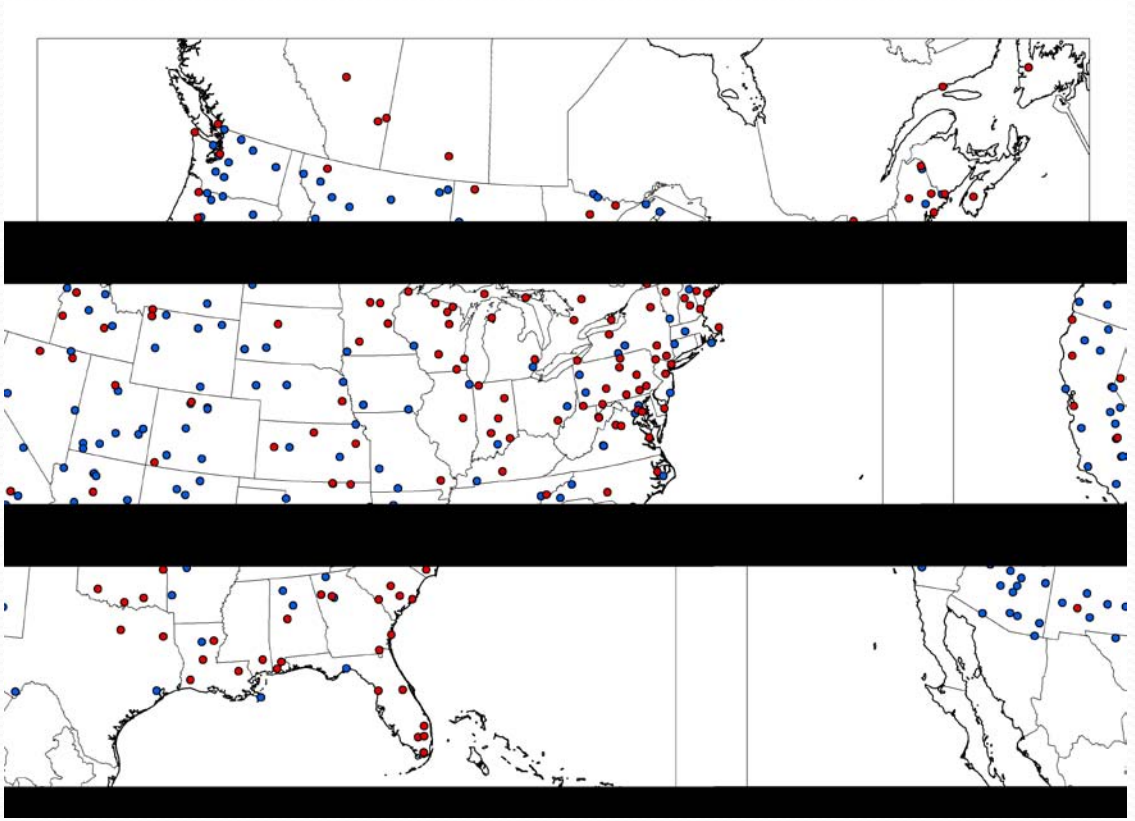
# Streamflow at the Colorado River

After incorporating the reservoir effects, the streamflow is improved remarkably. But large errors still exist in 3 abundant precipitation years, indicating that the reservoir module need to be further refined.



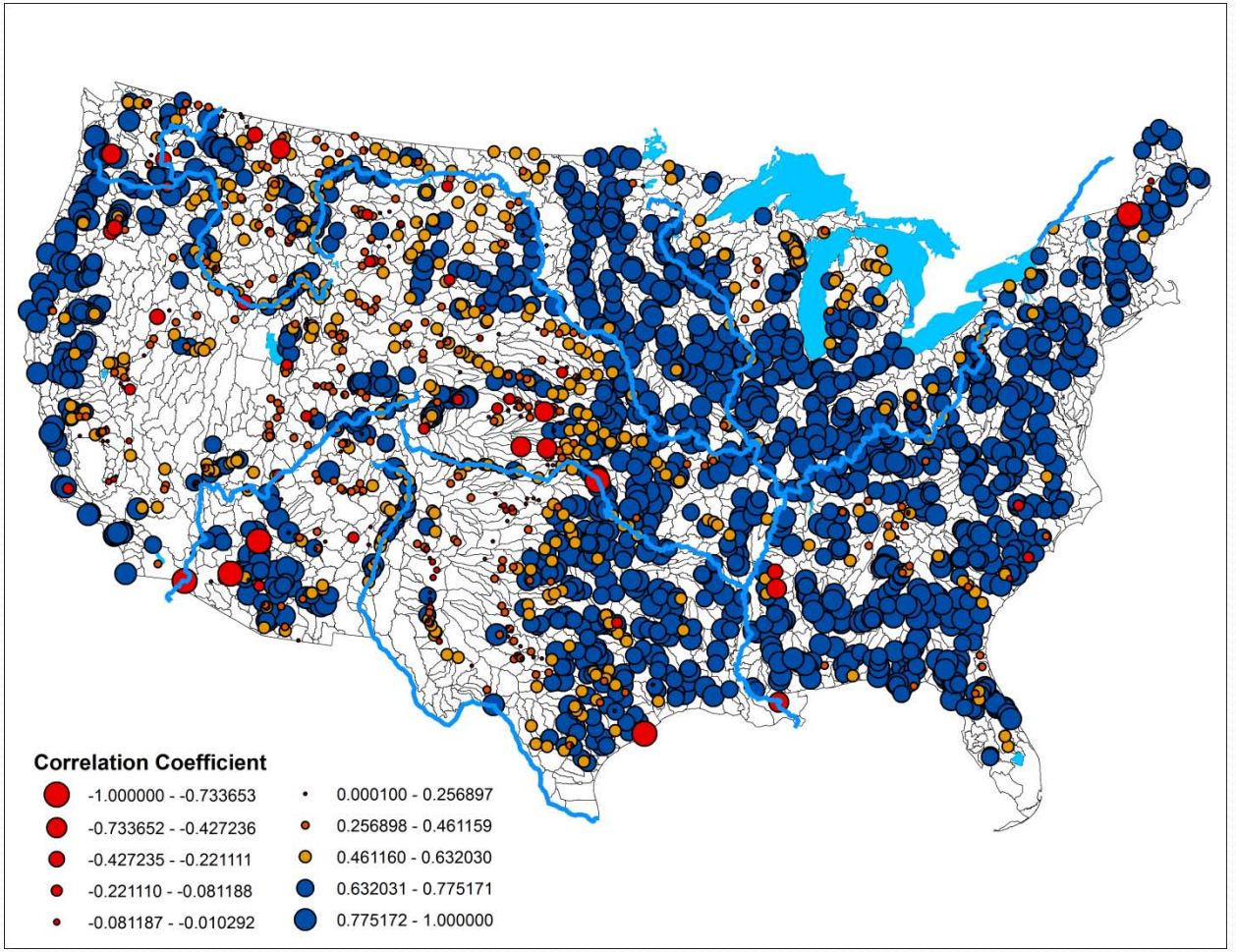
# Streamflow Stations from USGS

- For examination of the performance of the PSWAT running over the continuous U.S., we collected the USGS streamflow historic dataset more than 1500 stations
- Extracted the stations with monthly data records of >20 days, and calculated the correlation coefficient between observed and simulated interannual streamflow variations

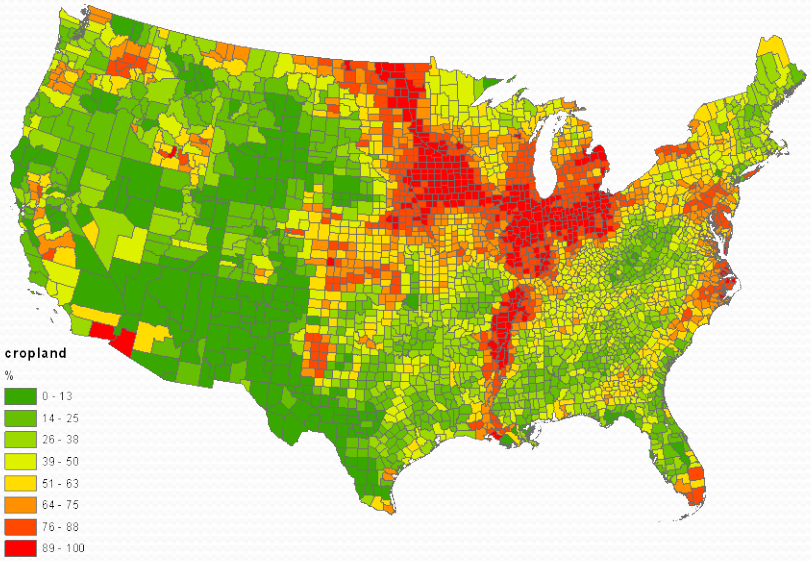


# Streamflow Correlation Distribution

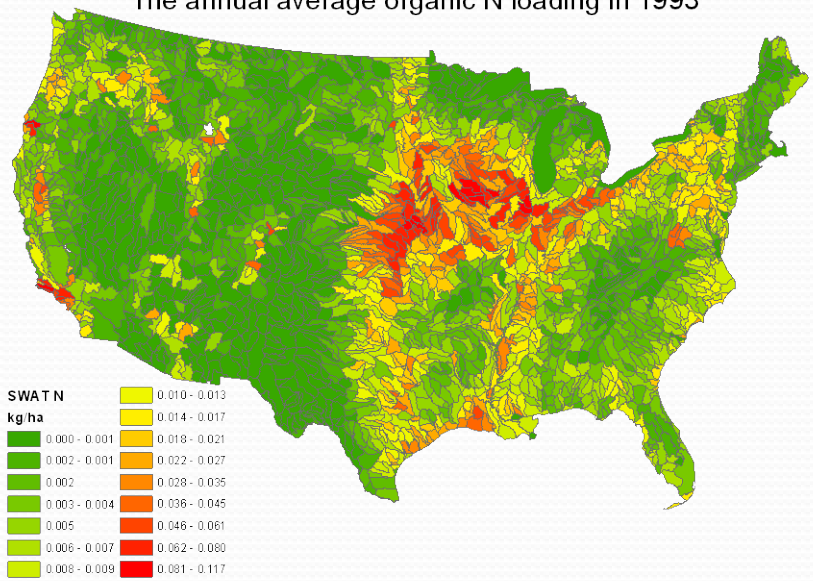
- The performance in the eastern and central U.S. is better than the western mountain semi-arid region
- The poor skill may partially result from precipitation observational data uncertainty



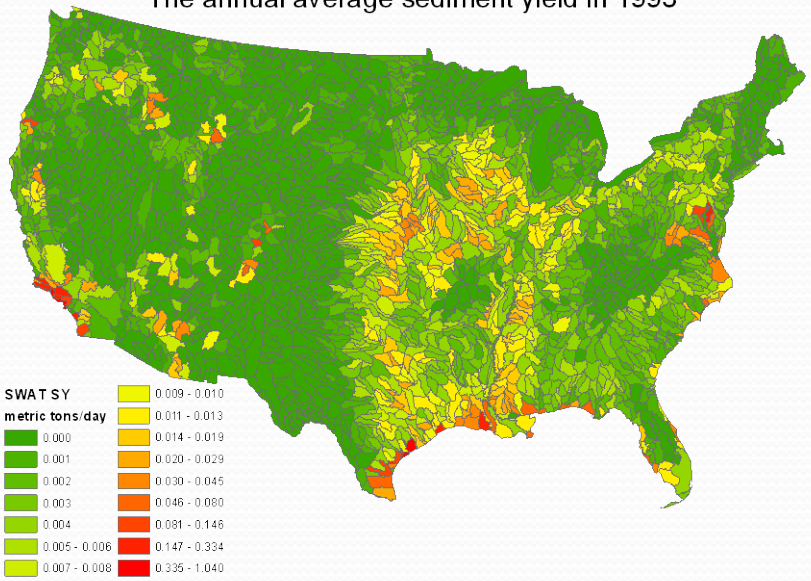
Total cropland as a percentage of land area



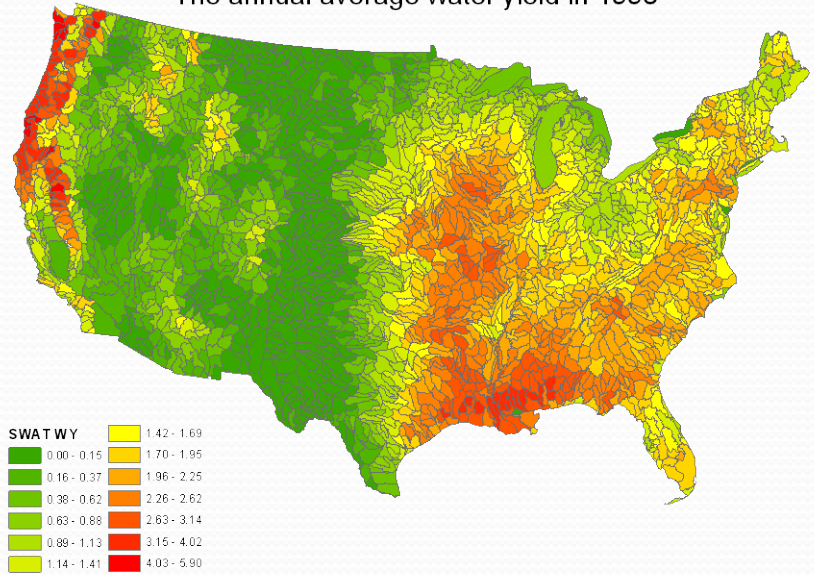

The annual average organic N loading in 1993




The annual average sediment yield in 1993

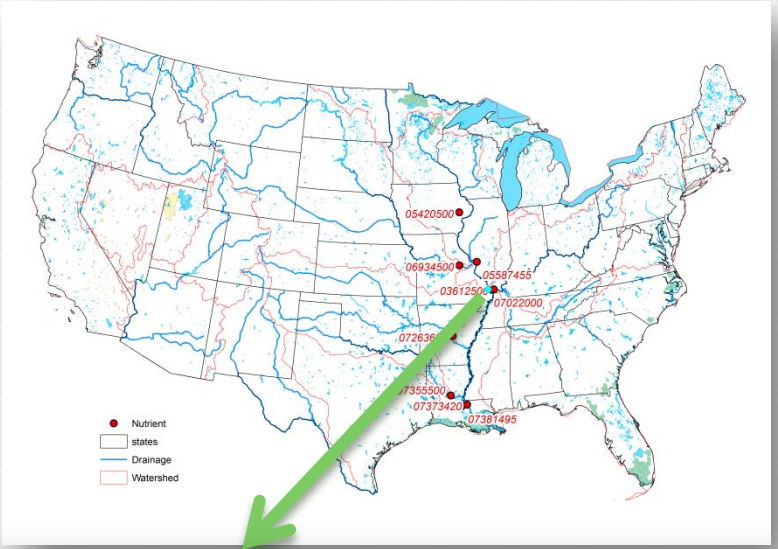


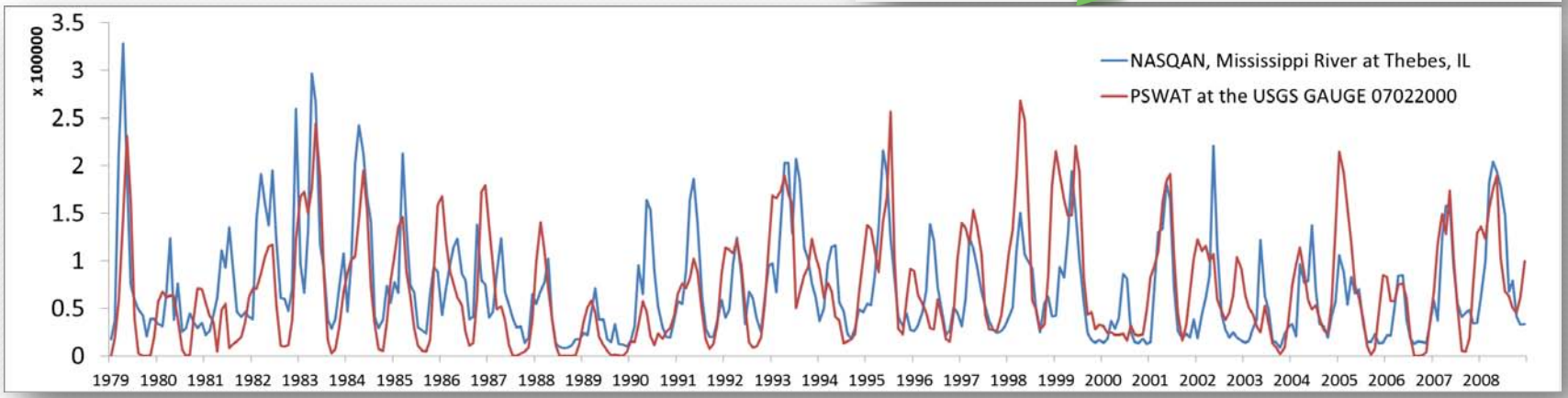

The annual average water yield in 1993



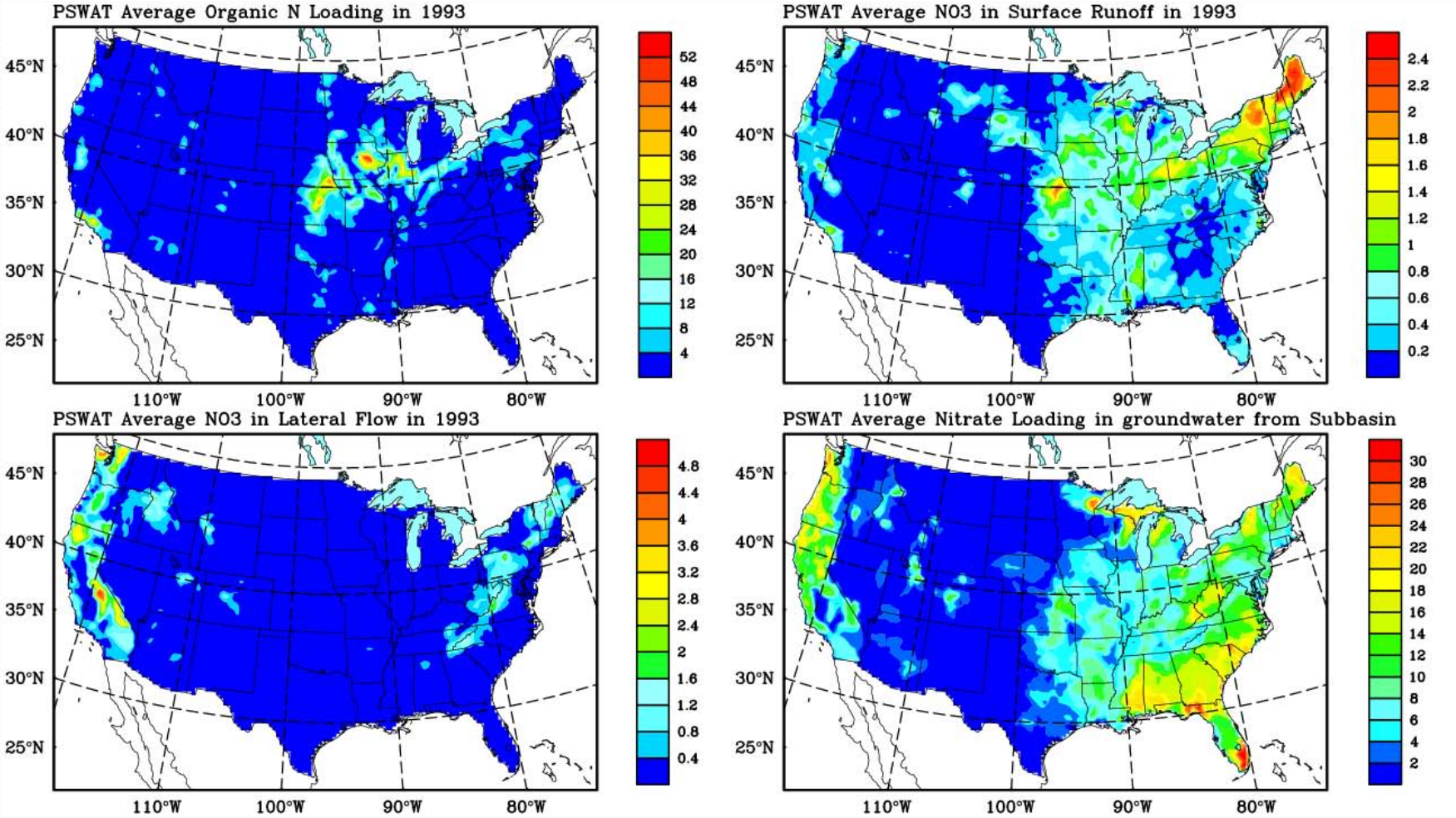
# Simulated and Observed Nitrogen

The observed data from monitoring large rivers in the national stream quality accounting network (NASQNA)



# PSWAT Nitrogen Distribution



# PSWAT is Built to Predict Water Change

- Predictive SWAT (PSWAT) has been developed, tested, and is ready for online coupling with CWRF, further refinement and system optimization
- It incorporates atmospheric information (precipitation, temperature, radiation, wind, humidity, and nitrogen deposition) and point sources and management strategies
- It captures the streamflow characteristics in most regions of the U.S.
- It provides a unique modeling tool to better understand and predict potential consequences of climate change on hydrologic processes
- Its application next will enable us to identify, at the national scale, relative vulnerabilities of U.S. water resources to global change and provide scientific guidance for developing adaptive strategies