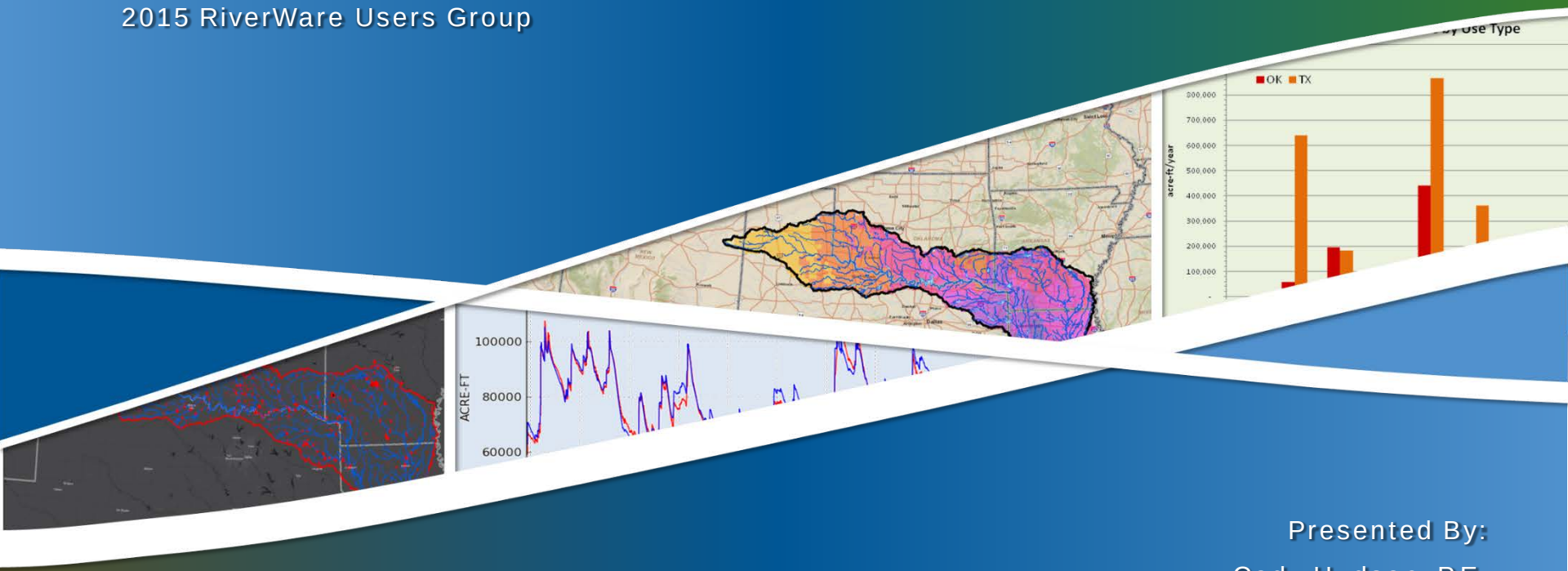
Modeling the impacts of Climate Change to Reservoirs, Water Users, and Environmental Flows in the Red River Basin

A Presentation To:

2015 RiverWare Users Group



Presented By:

Cody Hudson, P.E.

INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

February 3rd, 2015

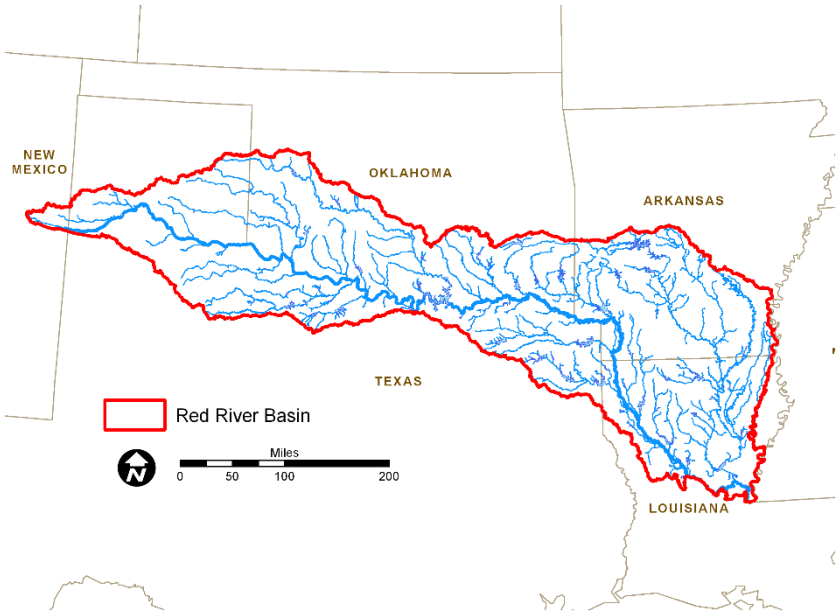
Background

- **Funding**
  - South Central Climate Science Center
- **Project Timeline**
  - Sept. 2013 to Sept. 2015
- **Partners**
  - Chickasaw & Choctaw Nations
  - University of Oklahoma
- **Model Extent**
  - Entire Red River Basin
  - 28 USACE Reservoirs

USGS science for a changing world

SOUTH CENTRAL CLIMATE SCIENCE CENTER

www.southcentralclimate.org



Procedure

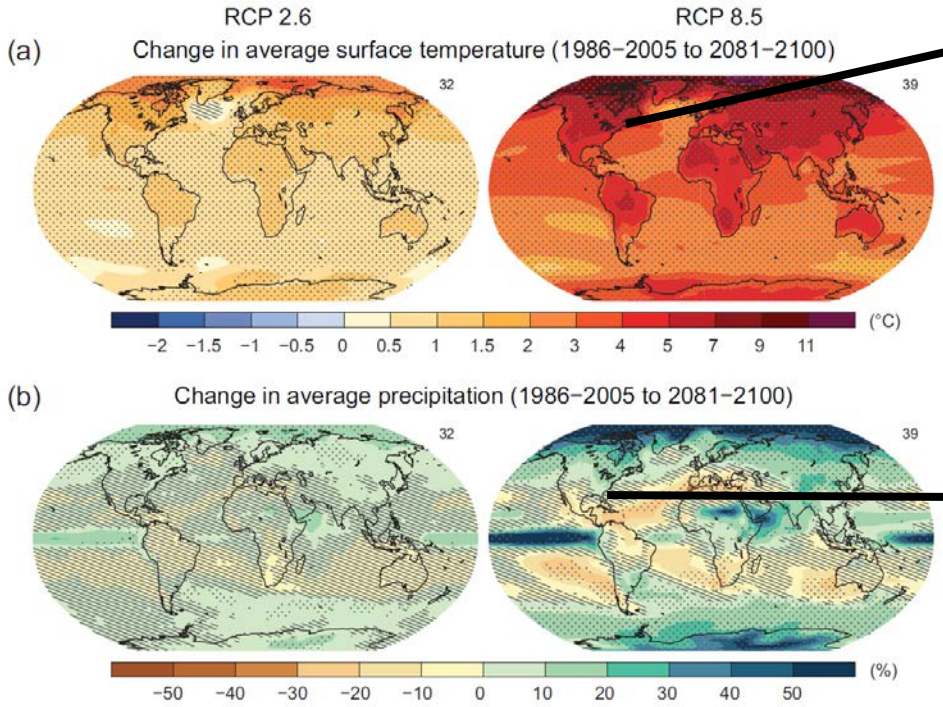
- Global Climate Model Downscaling
  - 6 Different Model/Climate Scenarios

- Runoff Modeling
  - VIC Model
  - Climate Output to Flows

- RiverWare Modeling
  - Water Users / Accounting
  - Reservoir Operations

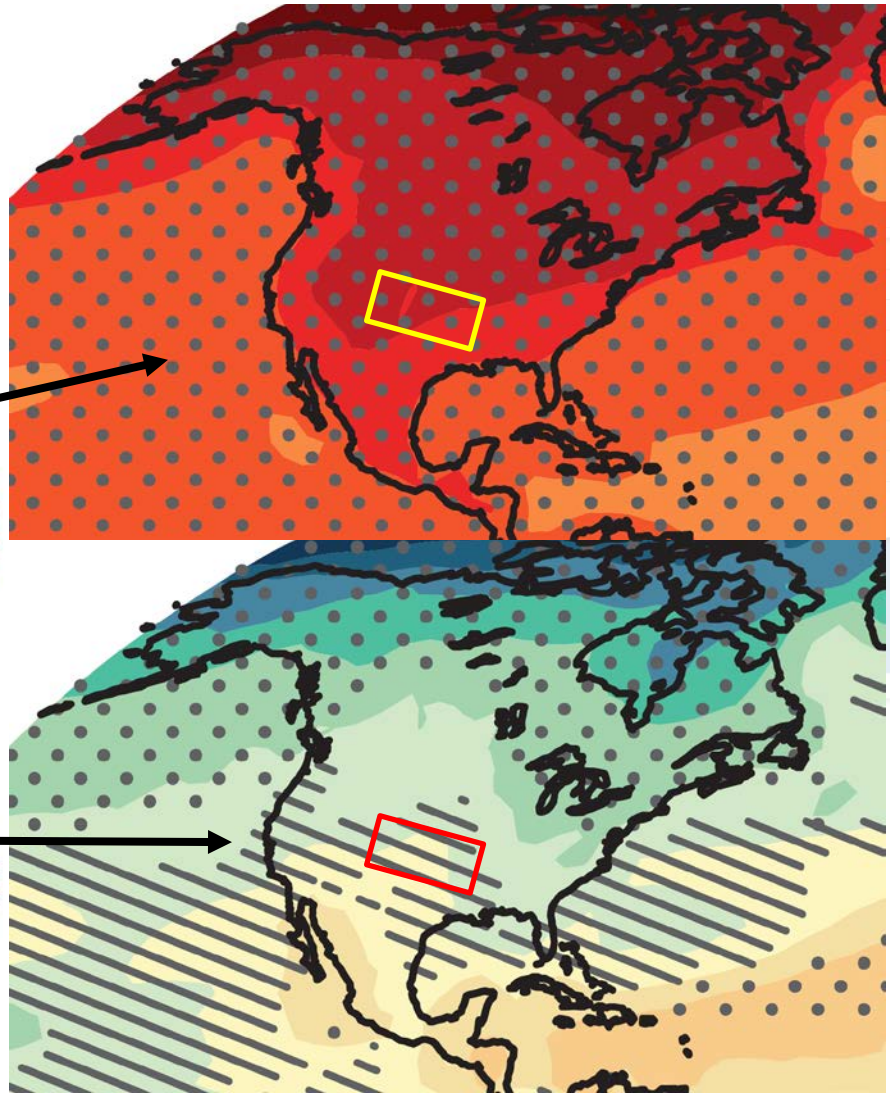
Climate Change Scenarios

- **Representative Concentration Pathways**
  - **IPCC 5th Assessment Report**
  - **RCP 8.5, scenario leading to 8.5 W/m2 in 2100**

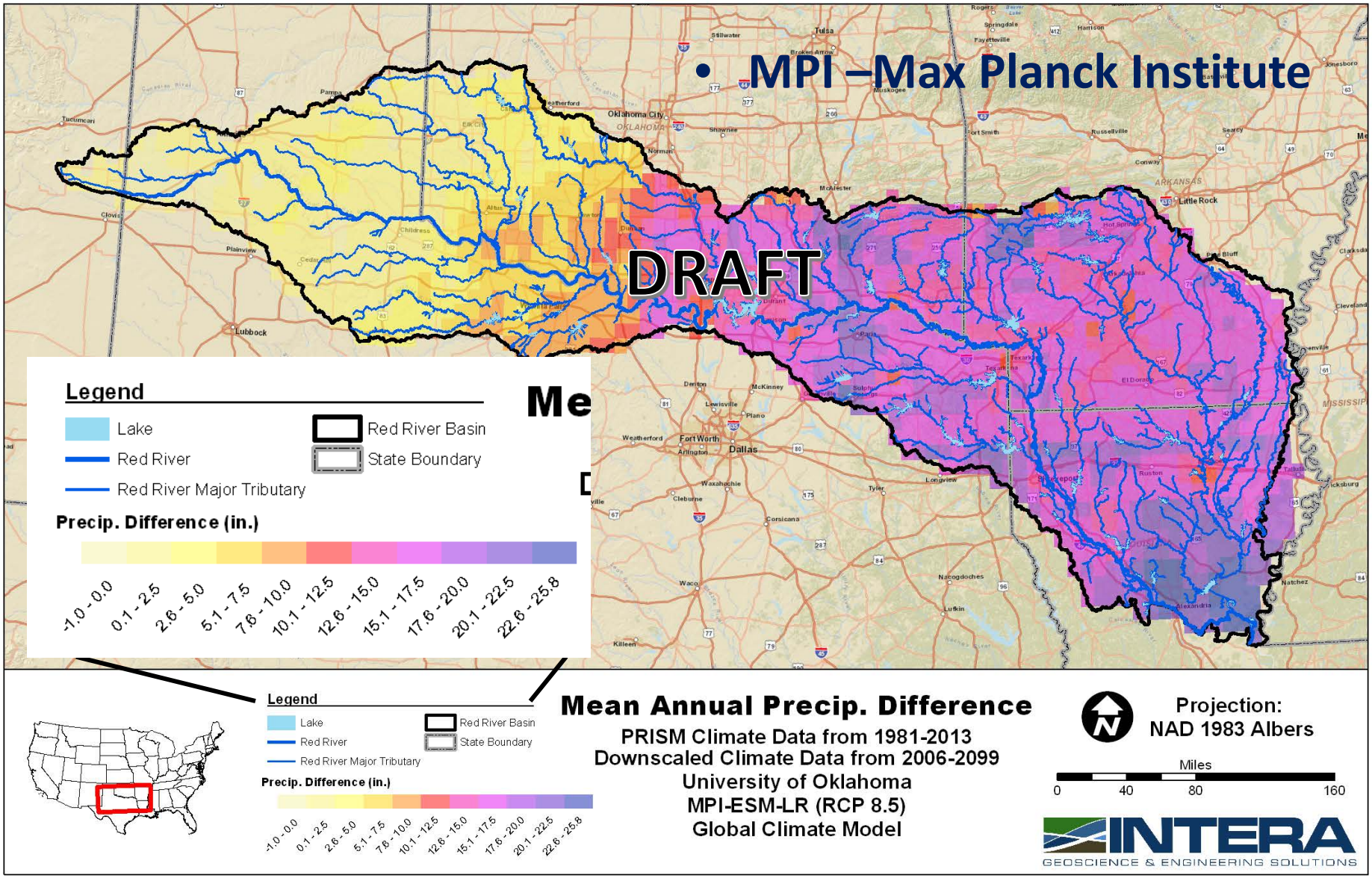


IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

Hatching (i.e., diagonal lines) shows regions where the projected change is less than one standard deviation of the natural internal variability

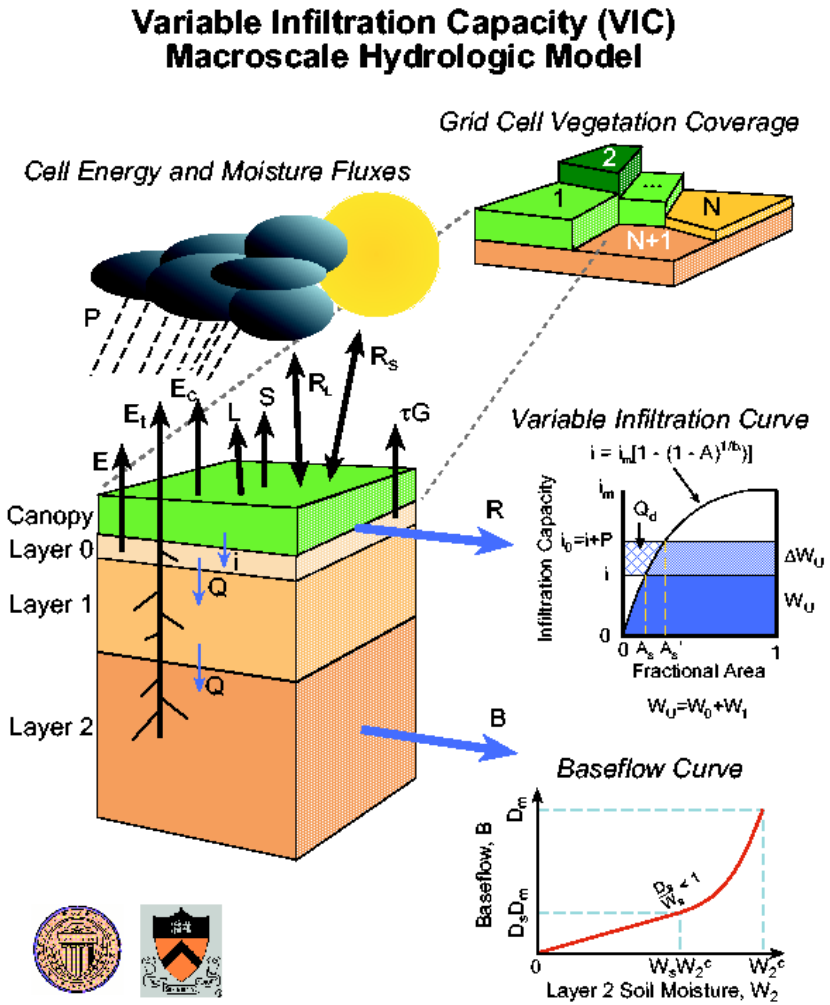


Future Rainfall (MPI RCP 8.5)



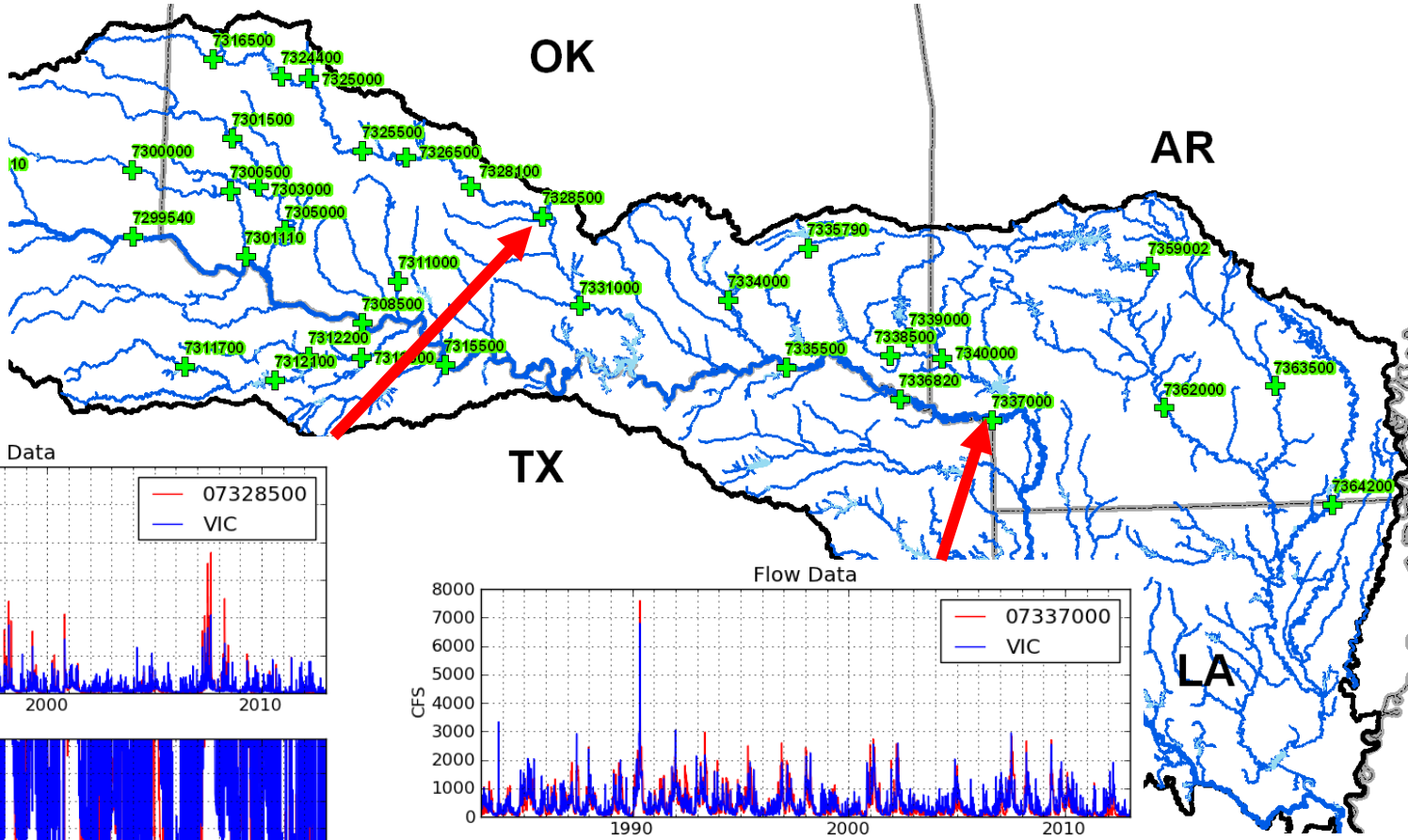
VIC Modeling

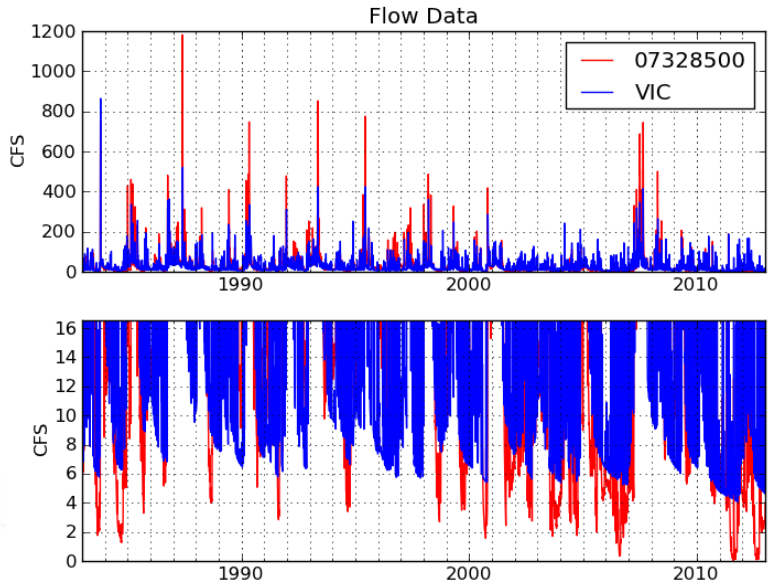
- Macro-Scale Model
- Solves grid based water balance
- Inputs
  - Precip., Temp, Wind,…
- Flow Routing
  - multi-site cascading calibration (MSCC)
  - Developed by Xianwu Xue at University of Oklahoma as part of this project
  - Calibration with daily PRISM data (1981-2013)



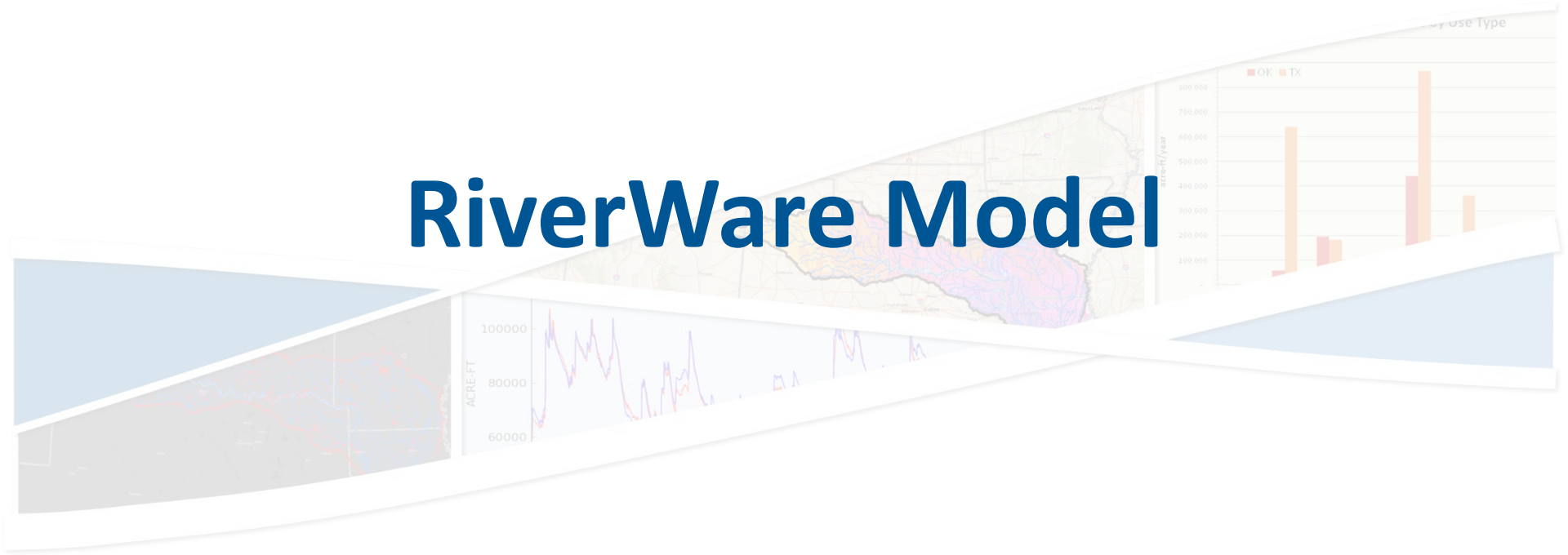
Source:
http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Overview/ModelOverview.shtml

VIC Preliminary Results





RiverWare Model



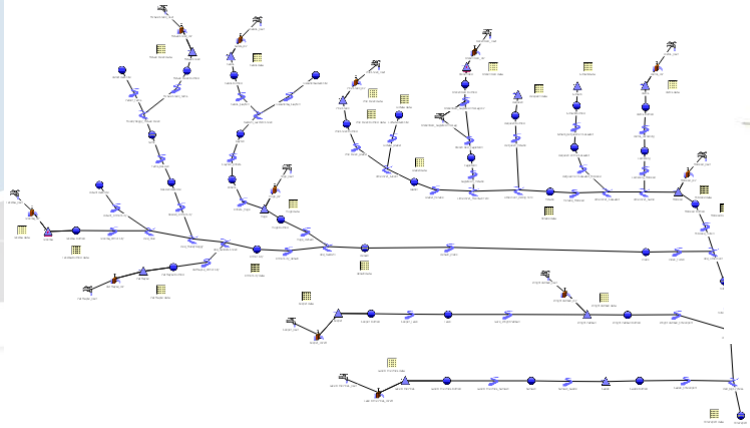
Data Acquisition

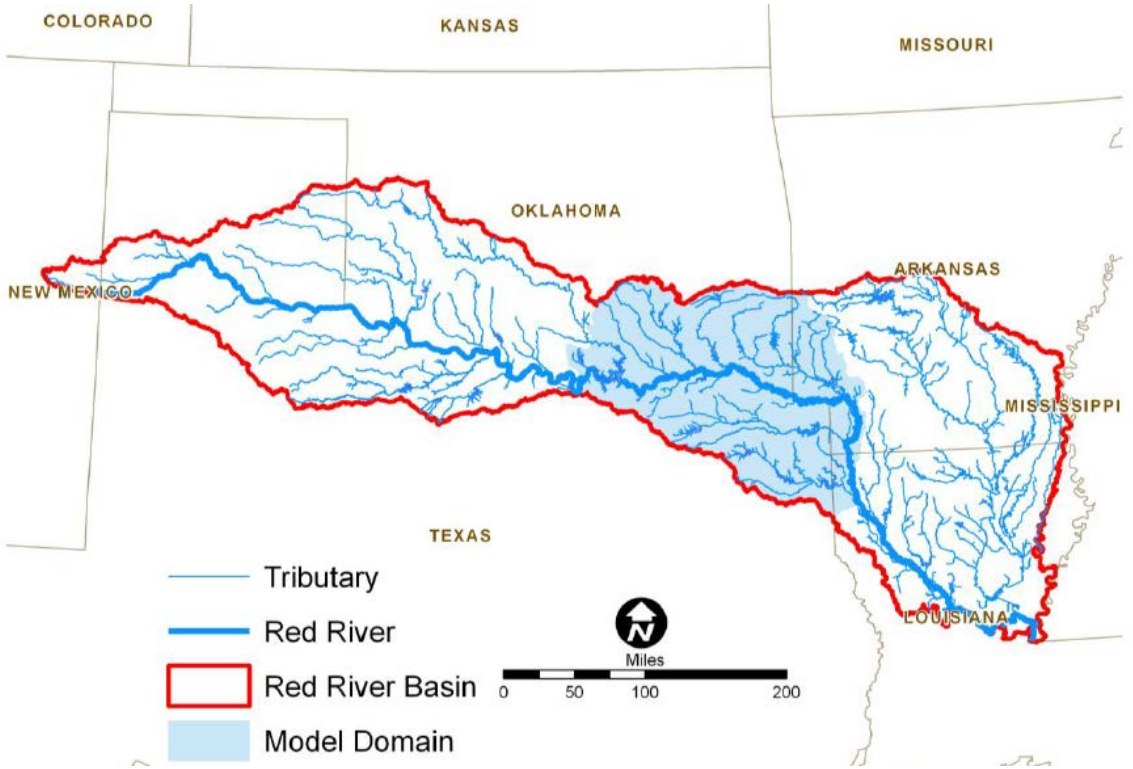
- 2 Existing Models in Basin
  - Red River & Wichita River
  - 16 Reservoirs Modeled
- FOIA Request
  - Received 35 Water Control Manuals for USACE operated facilities in the Red River Basin
- Water User Data
  - Water Rights in OK & TX
  - Water Use data in AR & LA

http://www.usace.army.mil/Locations.aspx

Existing RiverWare Models

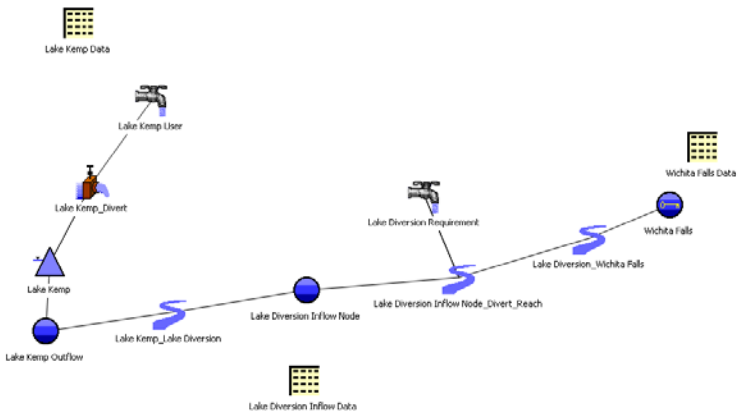
- **Red River**
  - **Lake Texoma to Shreveport, LA**
  - **Rulebased Model**
  - **15 Reservoirs**

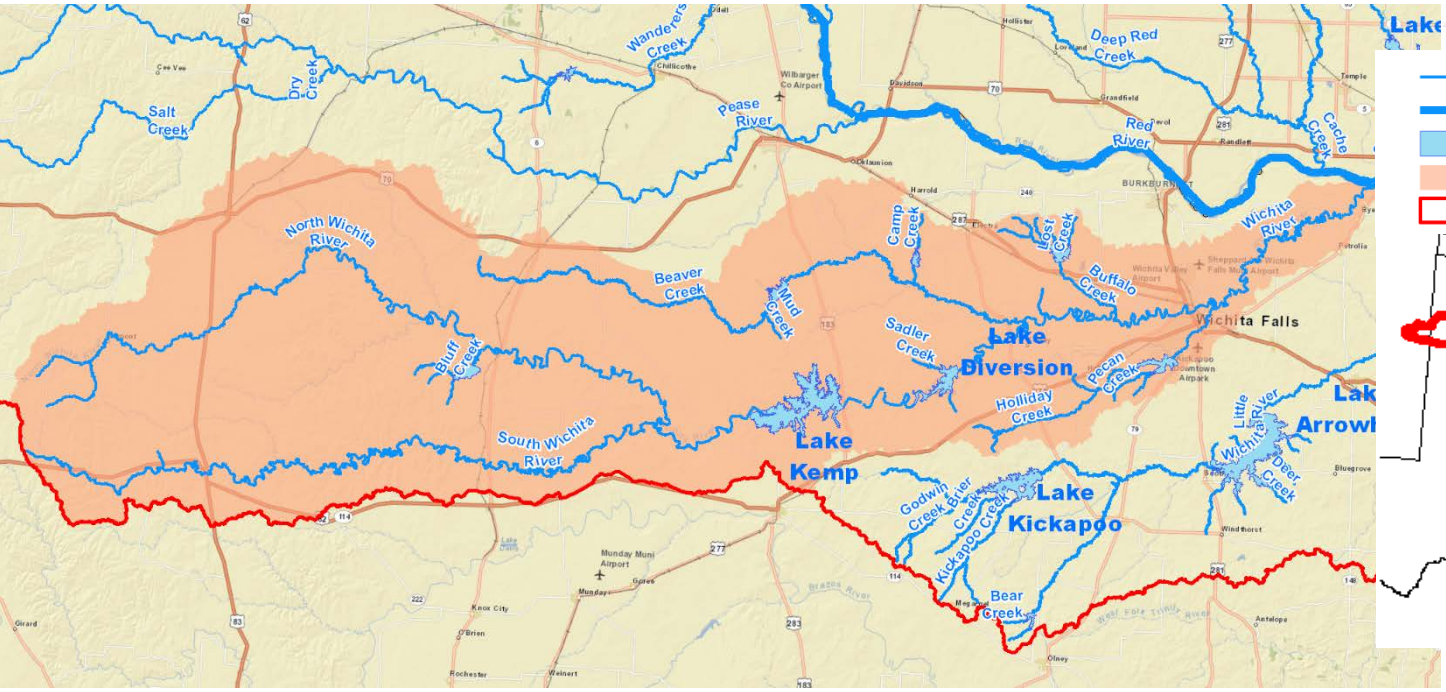




Existing RiverWare Models

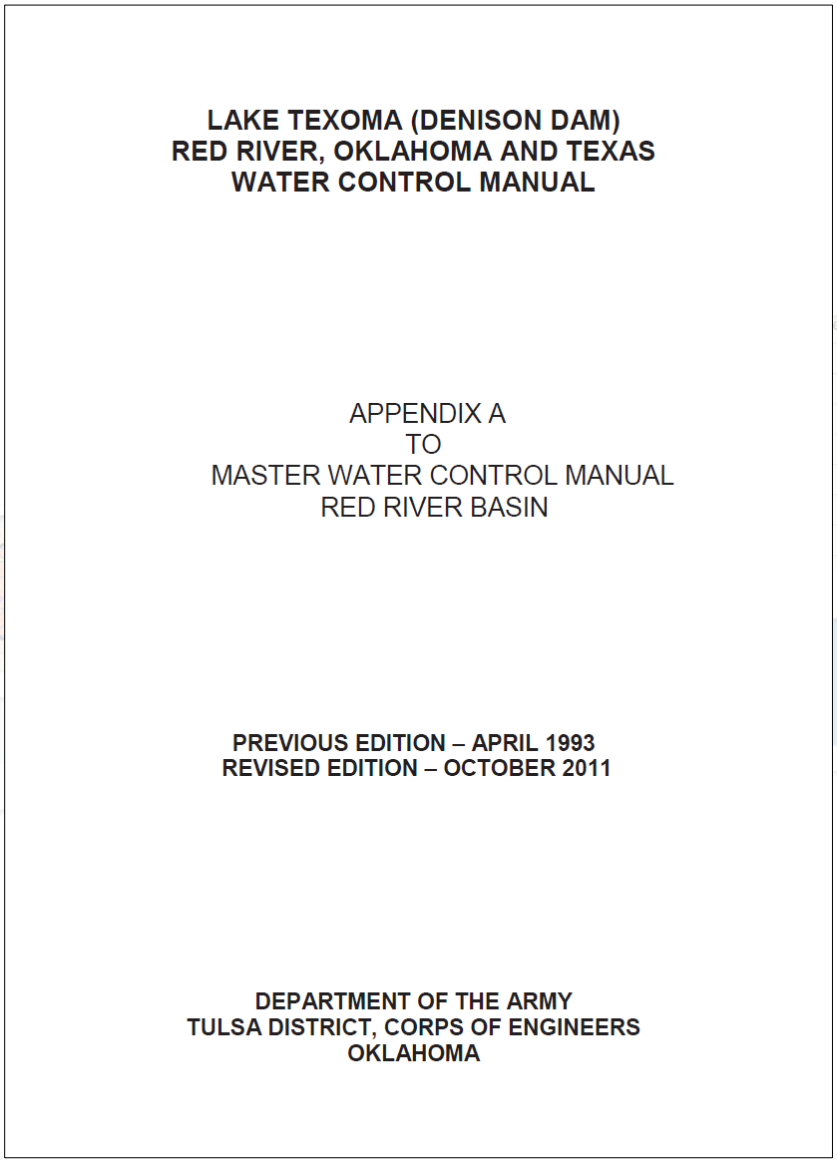
- **Wichita River**
  - **Rulebased Model**
  - **1 Reservoir (Lake Kemp)**





Water Control Manuals

- Elevation-Area-Capacity
- Outlet Rating Curves
- Emergency Flood Control Schedule
- Operational Levels
- Low Flow / WQ Releases
- Contracted Water Use
- Flood Flow Routing



LAKE TEXOMA (DENISON DAM)
RED RIVER, OKLAHOMA AND TEXAS
WATER CONTROL MANUAL

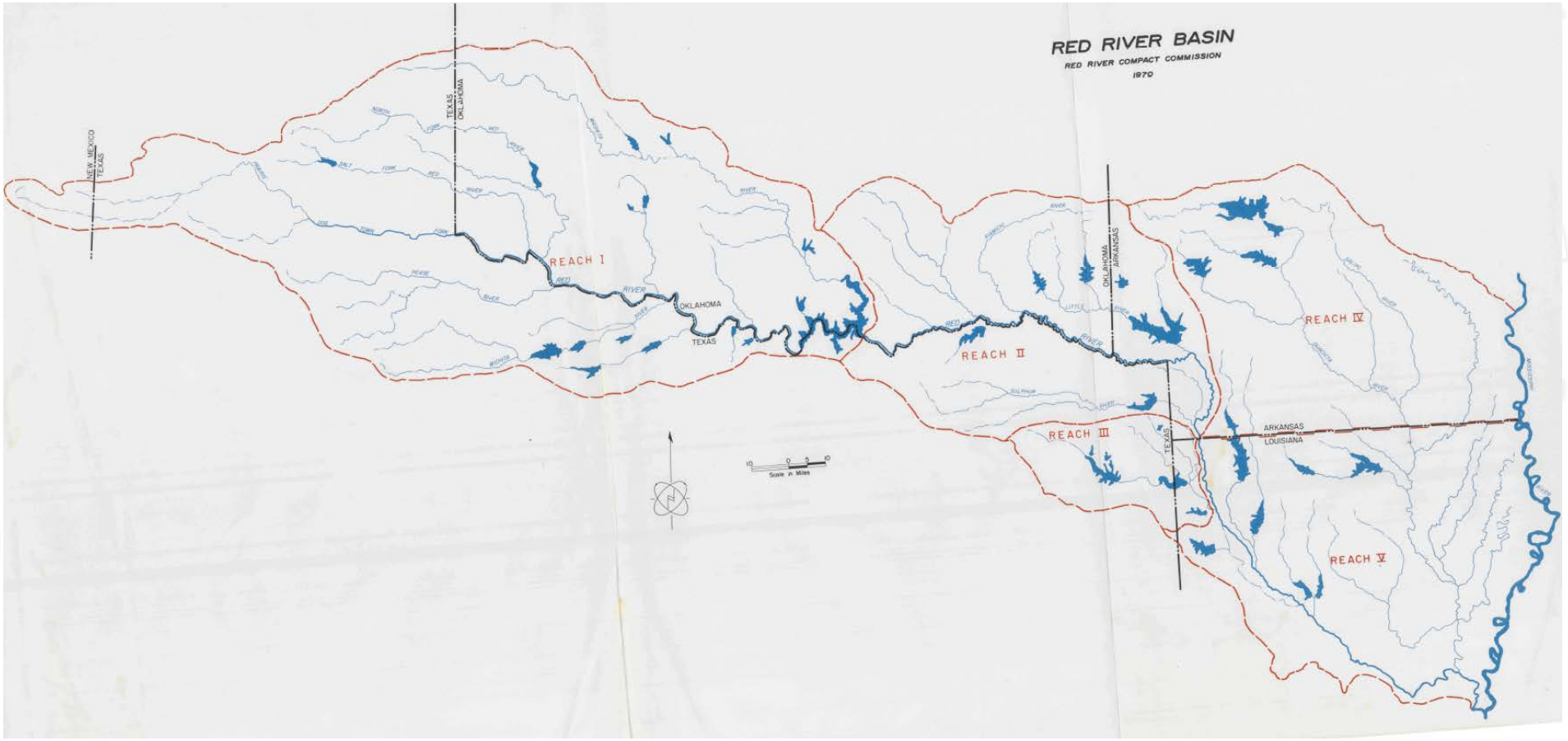
APPENDIX A
TO
MASTER WATER CONTROL MANUAL
RED RIVER BASIN

PREVIOUS EDITION – APRIL 1993
REVISED EDITION – OCTOBER 2011

DEPARTMENT OF THE ARMY
TULSA DISTRICT, CORPS OF ENGINEERS
OKLAHOMA

Red River Compact

- Splits the basin into 5 reaches
- Reaches further split into sub-basins
- Defines water ownership and sets minimum flows

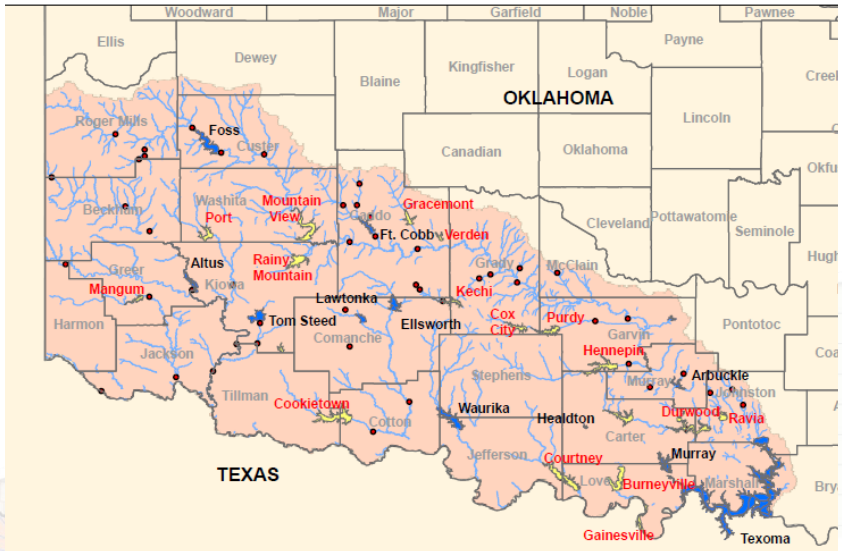


Accounting in Reach I

- **Compact**
  - **Oklahoma shall have free and unrestricted use of the water in Subbasin 2**
  - **Texas shall have free and unrestricted use of the water in Subbasin 3**
  - **Mainstem of the Red River and Lake Texoma.**
    - **Oklahoma shall be apportioned 200,000 ac-ft/year**
    - **Texas shall be apportioned 200,000 ac-ft/year.**
    - **Additional quantities may be apportioned in a ratio of 50% Oklahoma and 50% Texas.**

Maps provided by: Wayne Kellogg, Environmental Engineer, P.E., P.G., CSP, Chickasaw Nation

Red River Compact - Reach I, Subbasin 2



Red River Compact - Reach I, Subbasin 3

Accounting in Reach I

Method Editor - "Object Level Accounting Methods Set : Control Point...

File Edit Method View

Rch1 Slot Inflows

```
IF ( ThisObject . "Local Inflow" [ ] >= 0.00 "cfs" ) THEN
   ThisObject ^ ( "AllocatableFlowOK" CONCAT ".Slot Inflow" ) [ ]
      = ThisObject . "Local Inflow" [ ] * 0.50
   ThisObject ^ ( "AllocatableFlowTX" CONCAT ".Slot Inflow" ) [ ]
      = ThisObject . "Local Inflow" [ ] * 0.50
ELSE
   ThisObject ^ ( "AllocatableFlowOK" CONCAT ".Slot Inflow" ) [ ]
      = 0.00 "cfs"
   ThisObject ^ ( "AllocatableFlowTX" CONCAT ".Slot Inflow" ) [ ]
      = 0.00 "cfs"
END IF
```

Show: Execution Constraint Description Comments

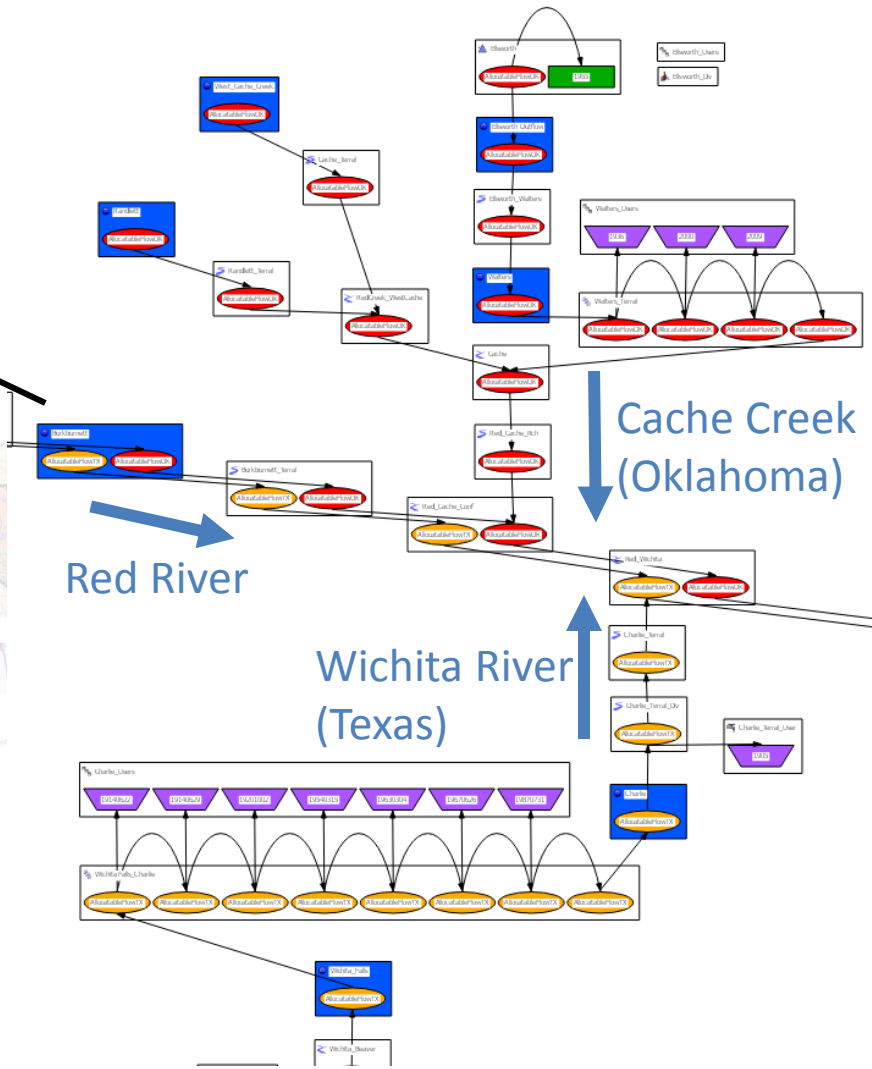
Water Accounting System Configuration

Begin Accrual:	January 1
Rent Return:	December 31
Begin Accounting Period:	December 31, 1980
End Accounting Period:	December 31, 2013
Maximum Iterations (for all accounts)	200

Allow Equal Priority Dates for Accounts

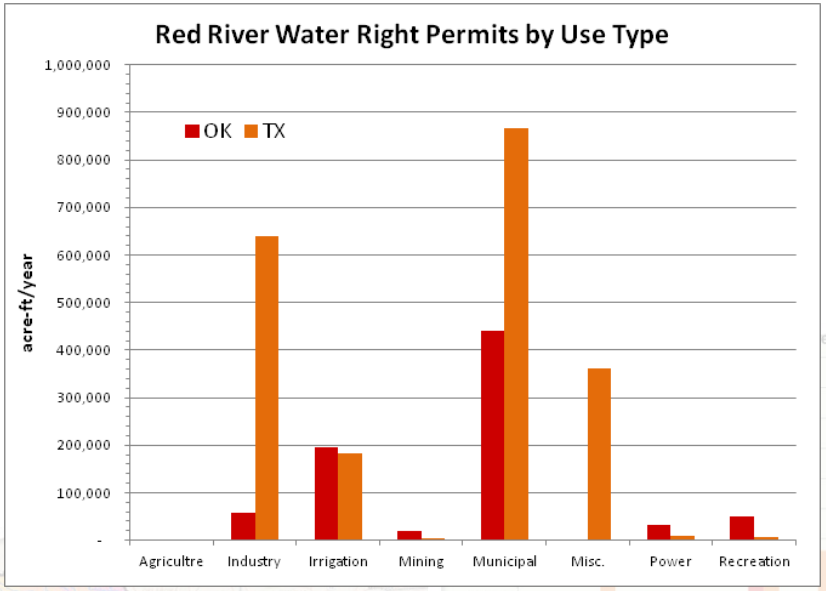
Water Owners: Oklahoma, Texas

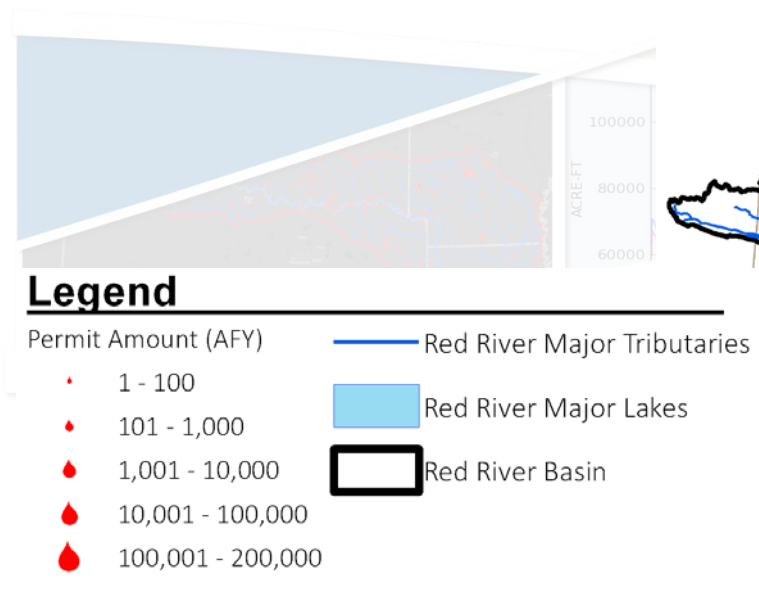
Water Types: AllocatableFlowOK, AllocatableFlowTX, HasWaterRightDemand



Water Rights (TX & OK)

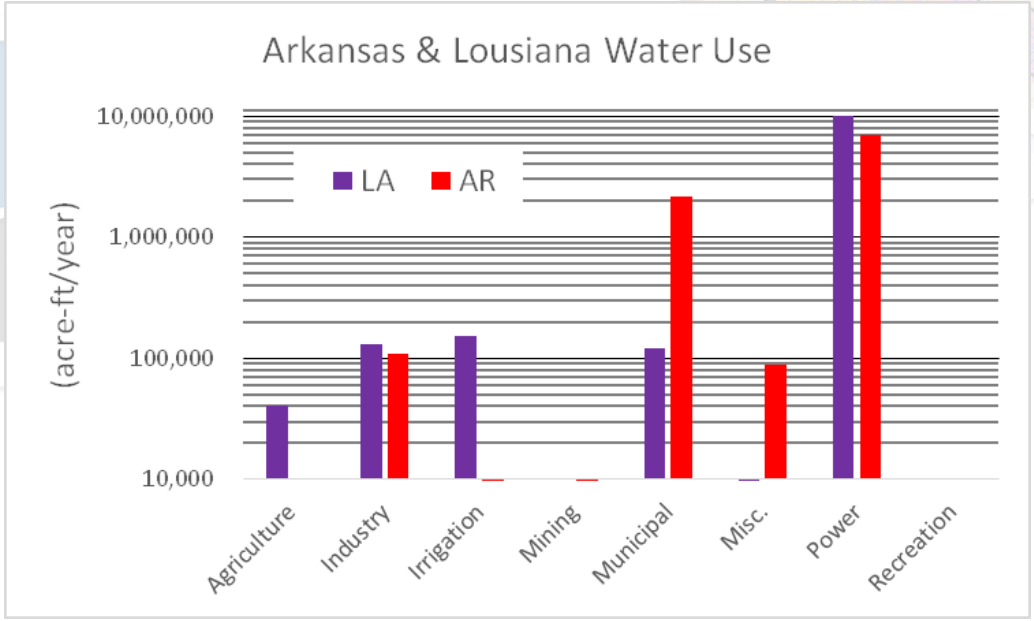
- **Prior Appropriation**
- **Data Sources**
  - **(TCEQ) Texas Commission on Environmental Quality**
  - **(OWRB) Oklahoma Water Resources Board**

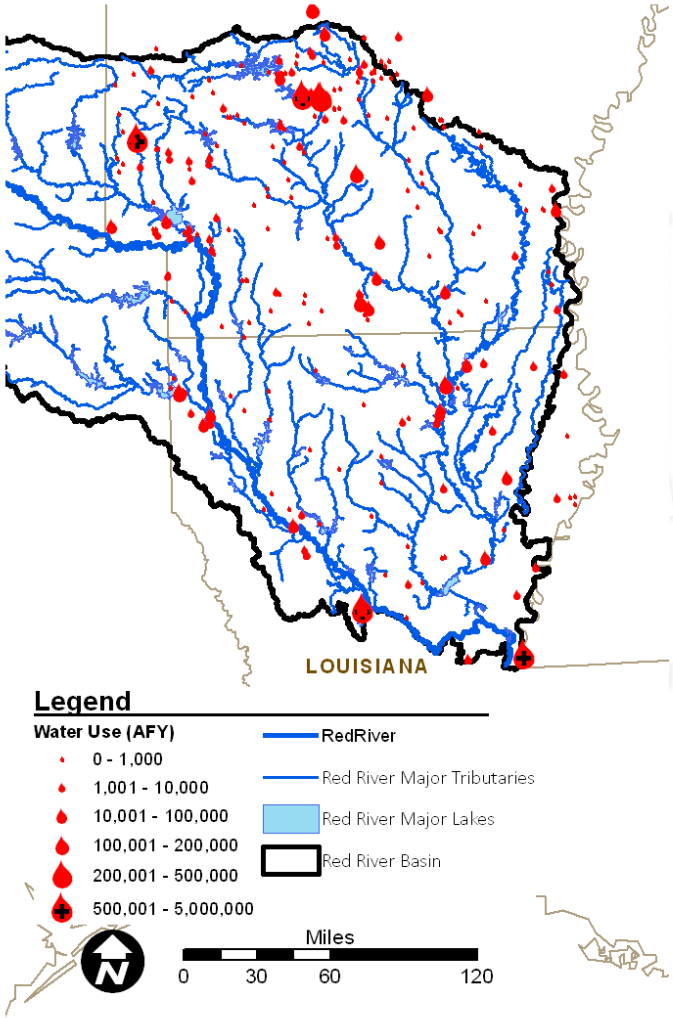




Water Use (AR & LA)

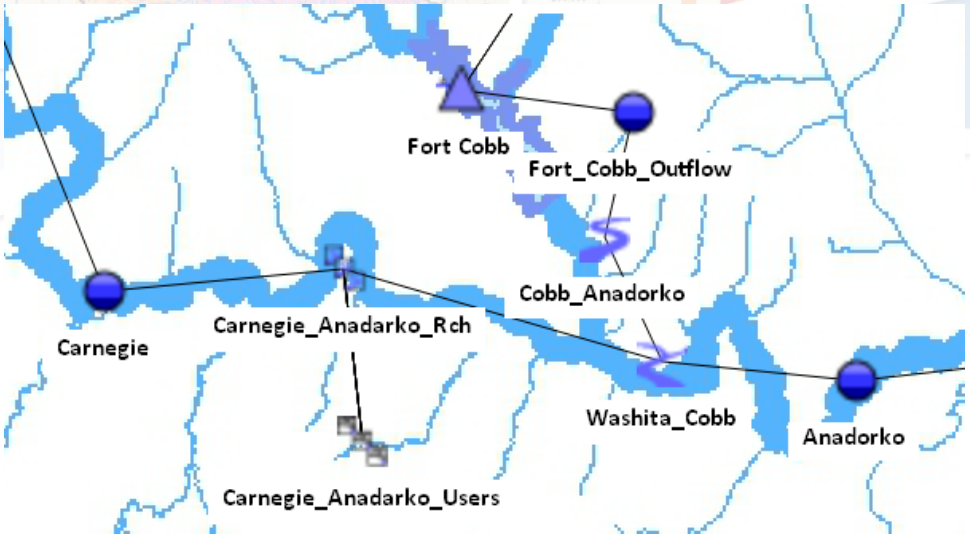
- Riparian Doctrine
- Data Sources
  - Collection
    - (ANRC) Arkansas Natural Resources Commission
    - (LDNR) Louisiana Dept. of Natural Resources
  - Database
    - USGS





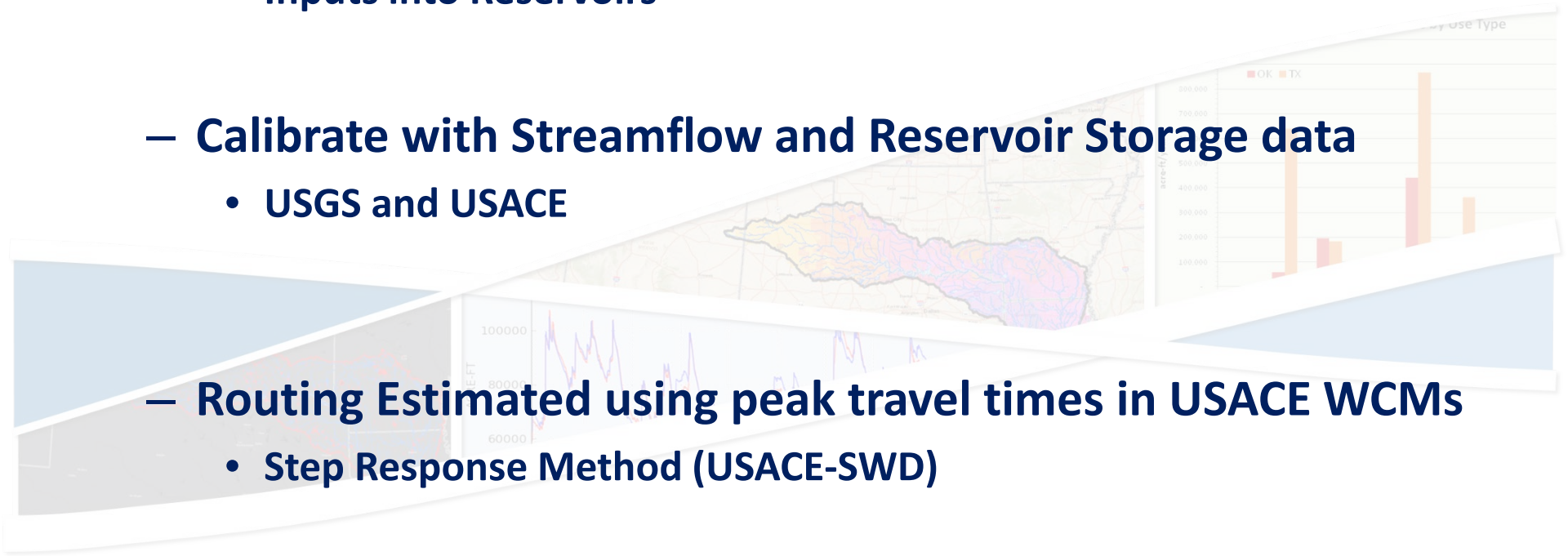
Water Users

- >1,500 Water Users!!!!
- Needed to develop a way to automate
  - python script takes water user information in a database and creates objects for import in model
  - Makes Aggregate Diversion and Aggregate Reach Objects
  - Creates links, accounts, sets methods, and slots
  - Data Required
    - Monthly Water Demand
    - Reach Name
    - Water Right Priority Date



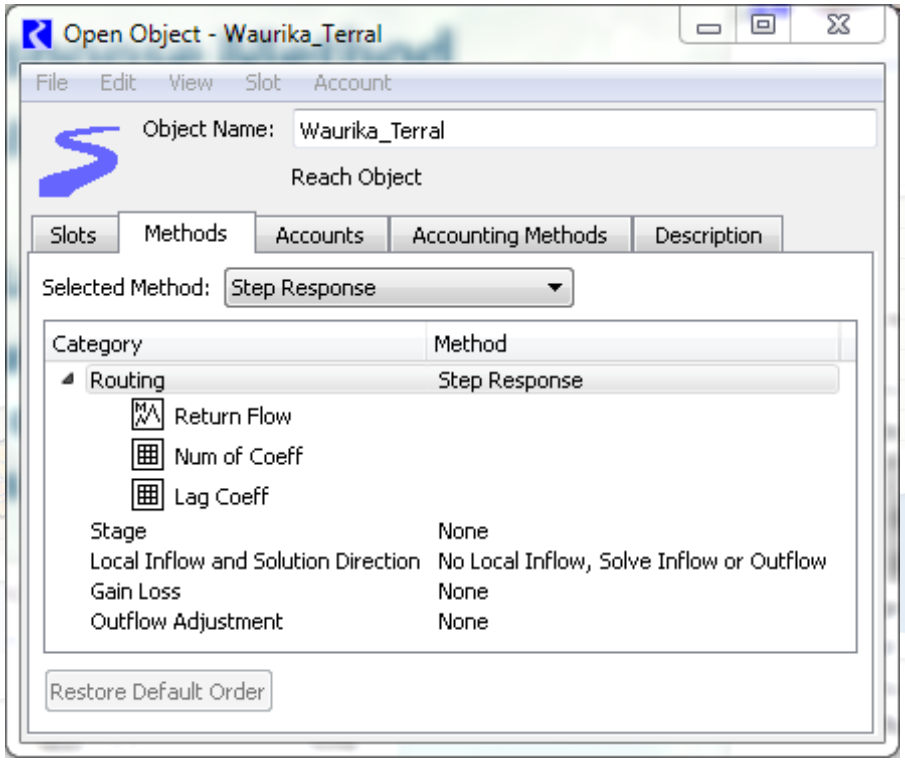
Model Calibration/Checks

- **Develop Calibration Model with data from (1981-2013)**
  - **Precipitation and Evaporation Data used in VIC calibration**
    - **Inputs into Reservoirs**
  - **Calibrate with Streamflow and Reservoir Storage data**
    - **USGS and USACE**
  - **Routing Estimated using peak travel times in USACE WCMs**
    - **Step Response Method (USACE-SWD)**



Flow Routing

- **Step Response Method**
  - **Input Lag Coefficients (C_i)**
  - **Coefficients sum must = 1**
  - **Calculates downstream flow based on current and previous flows**



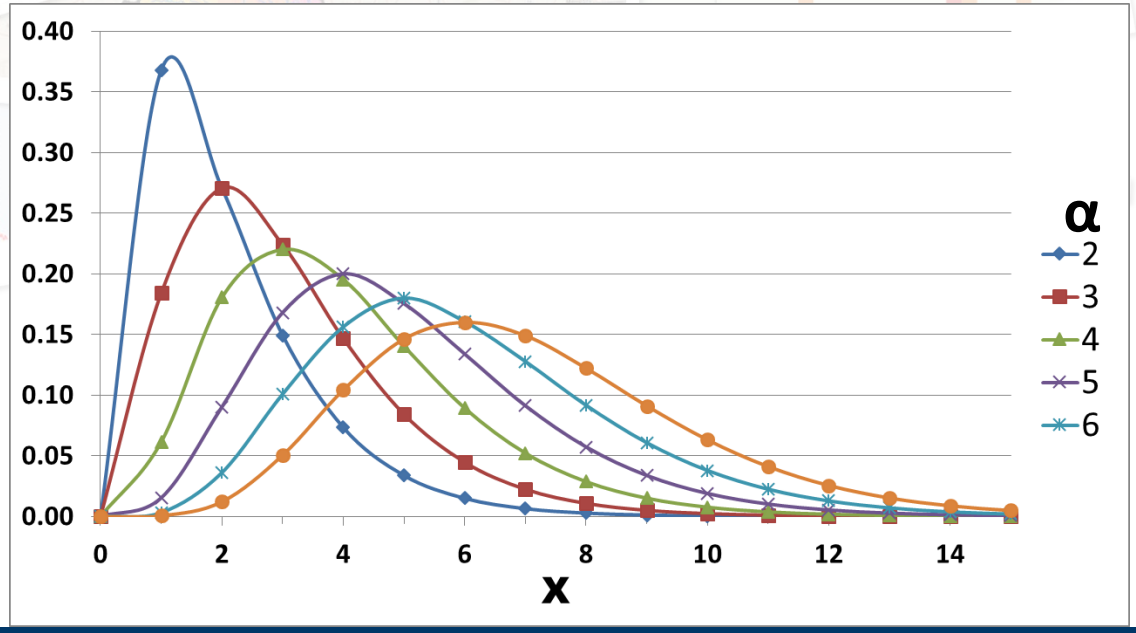
$$Outflow = C_0 Inflow_t + C_1 Inflow_{t-1} + \ldots + C_{ncoeff-2} Inflow_{t-(ncoeff-2)} + C_{ncoeff-1} Inflow_{t-(ncoeff-1)} + TotalGainLoss$$

Flow Routing

- **Gamma Distribution**
  - **alpha (α)**
    - **Used to represent peak flow time**
    - **Mode = (α-1)/β**
  - **beta (β)**
    - **Set to 1, standard gamma distribution**
  - **Area under curve = 1**

$$f(x;\alpha,\beta) = \begin{cases} \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}, x \geq 0 \\ 0, \qquad \text{otherwise} \end{cases}$$

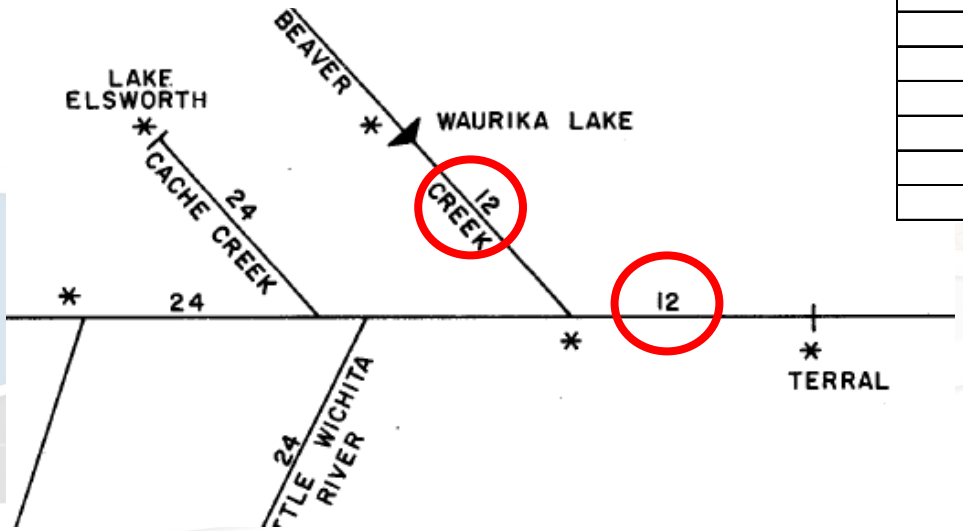
If $\beta = 1$ then we have the **standard gamma distribution**.



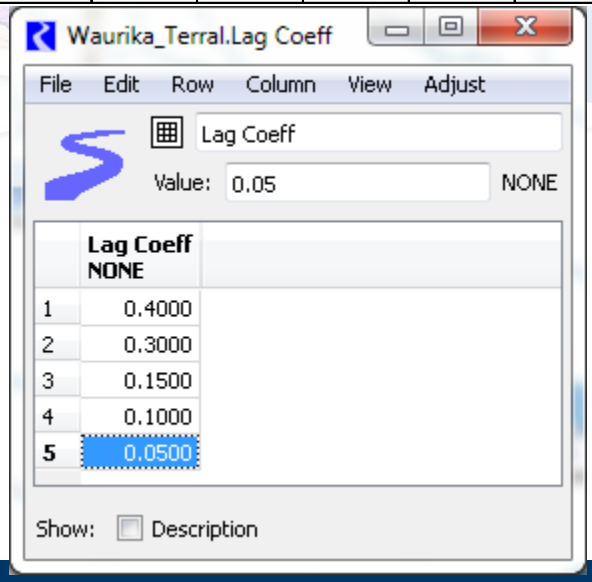
Flow Routing

- **Waurika WCM**
  - **Crest Travel Times (hours)**

	Peak Day (α-1)							
X	0.5	1	1.5	2	3	4	5	6
0	0	0	0	0	0	0	0	0
1	0.5	0.40	0.30	0.20	0.05	0.02	0.01	0.00
2	0.3	0.30	0.30	0.30	0.20	0.09	0.04	0.01
3	0.15	0.15	0.20	0.20	0.25	0.17	0.10	0.06
4	0.05	0.10	0.10	0.15	0.20	0.20	0.16	0.11
5	0	0.05	0.05	0.10	0.15	0.18	0.18	0.15
6	0	0.00	0.03	0.05	0.10	0.13	0.16	0.16
7	0	0.00	0.02	0.00	0.05	0.09	0.13	0.15
8	0	0.00	0.00	0.00	0.00	0.06	0.09	0.12
9	0	0.00	0.00	0.00	0.00	0.03	0.06	0.09
10						0.02	0.04	0.07
11						0.01	0.02	0.05
12						0.00	0.01	0.02
13							0.00	0.01
14								0.00
15								

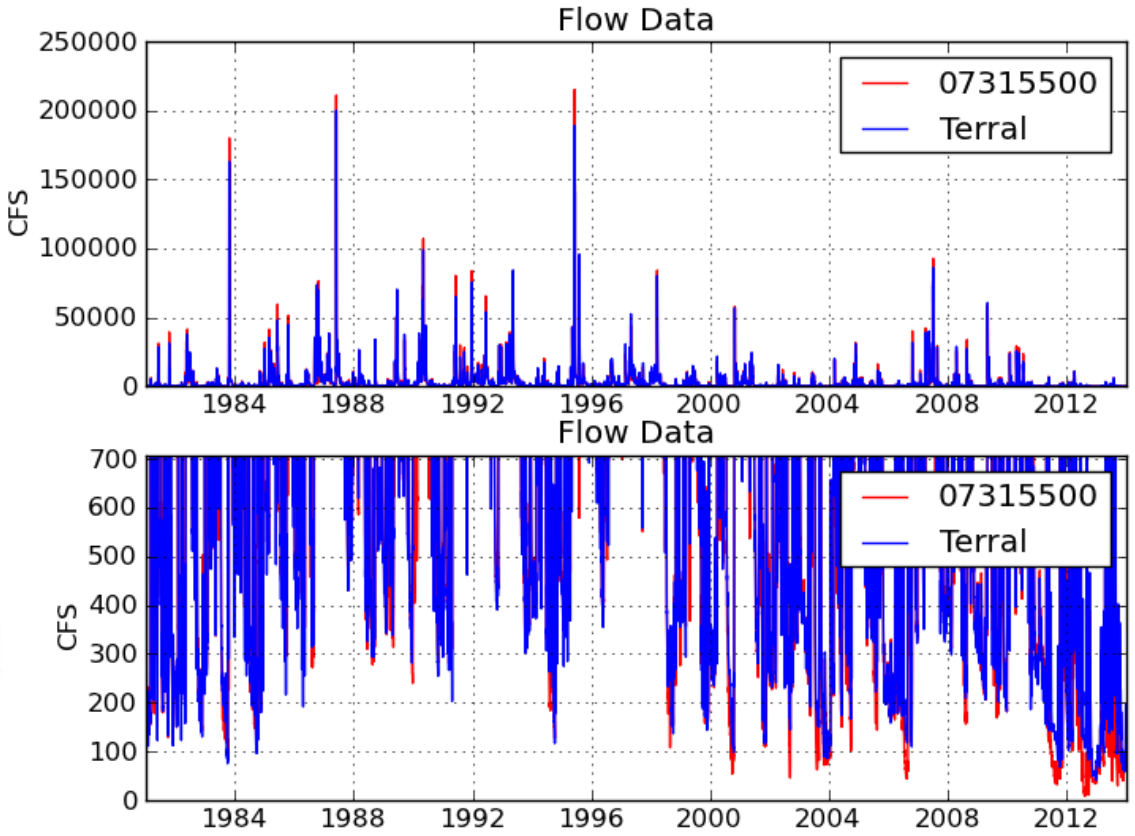


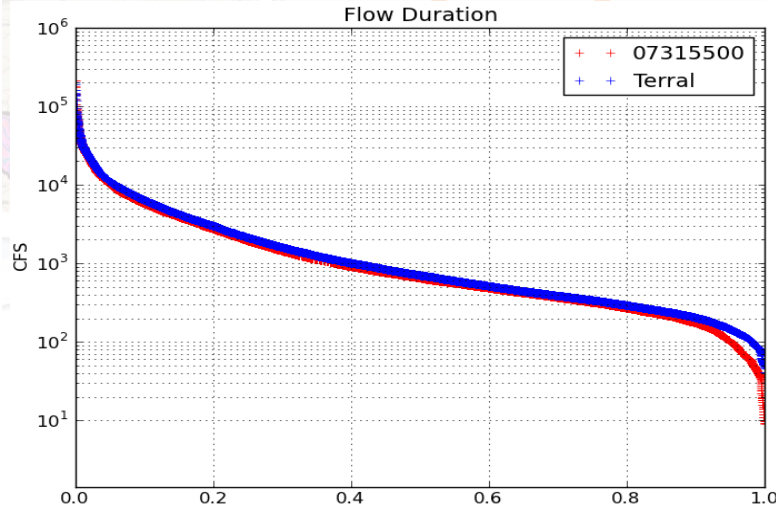
Waurika Lake Water Control Manual (2004)



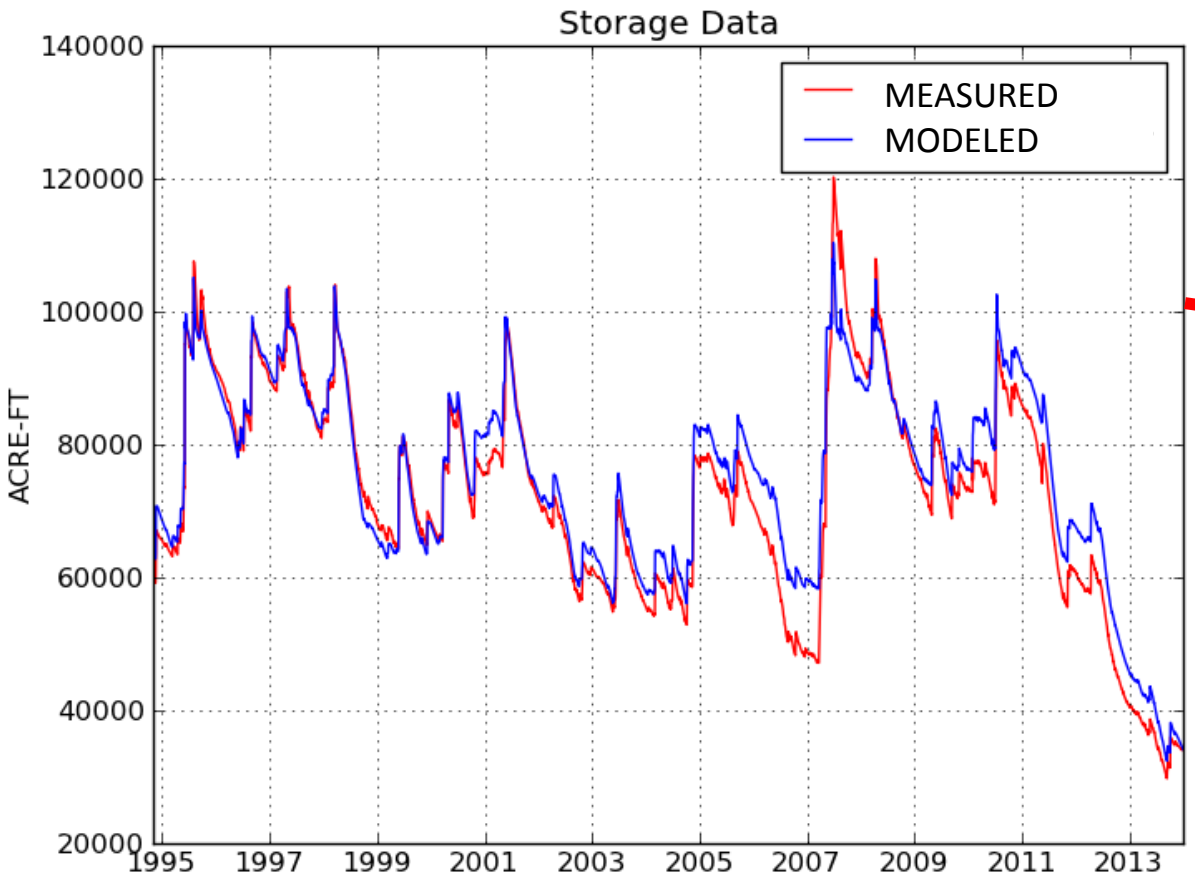
Calibration

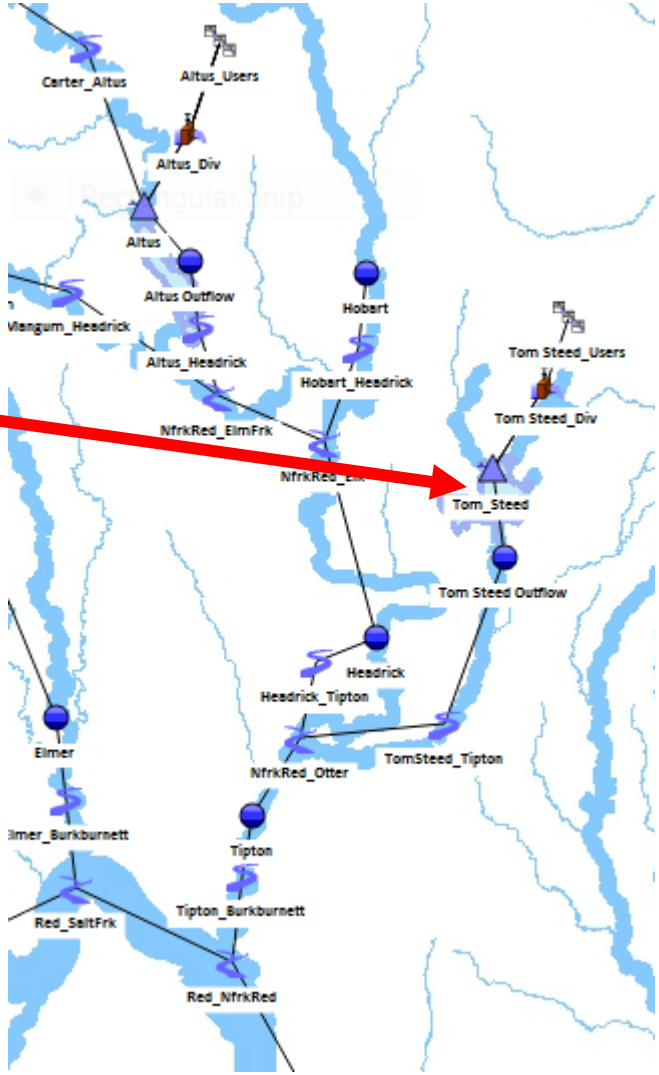
- **Developed Python scripts to create calibration plots and generate calibration statistics**
- **Script reads DMI output and Measured Gage Data**





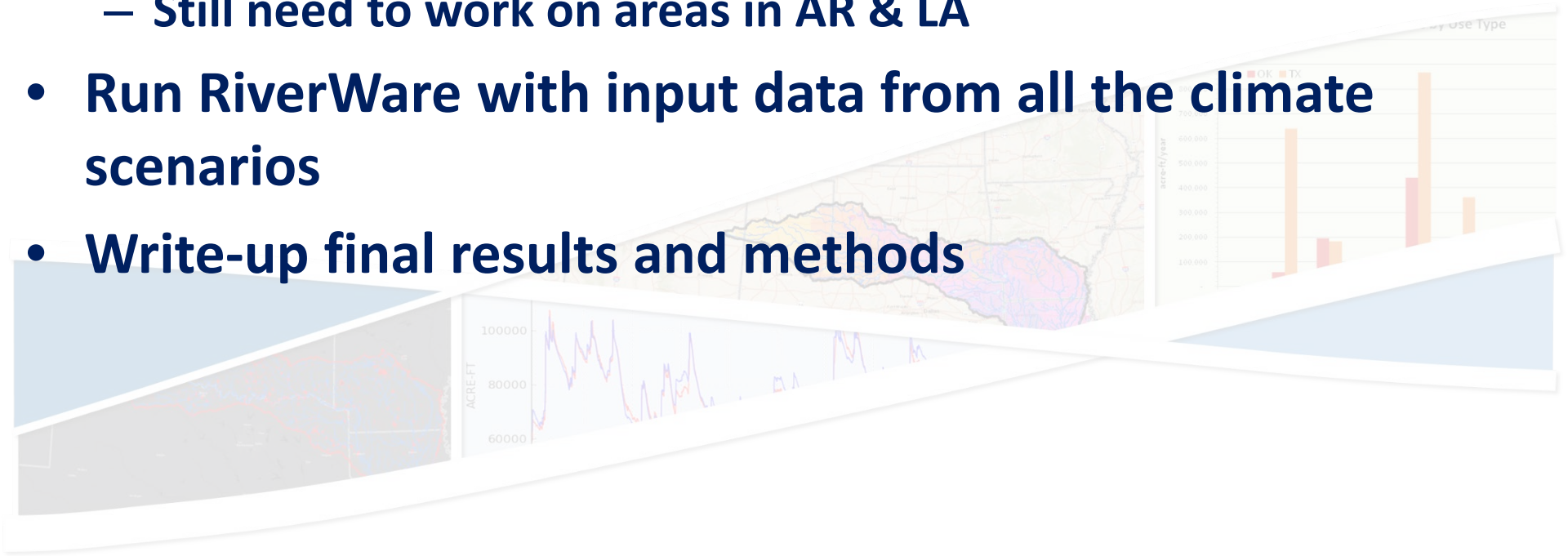
Storage Calibration





Future Work

- **Project End Date in September ‘15**
- **Currently calibrating the model upstream to downstream**
  - **Still need to work on areas in AR & LA**
- **Run RiverWare with input data from all the climate scenarios**
- **Write-up final results and methods**



Questions?