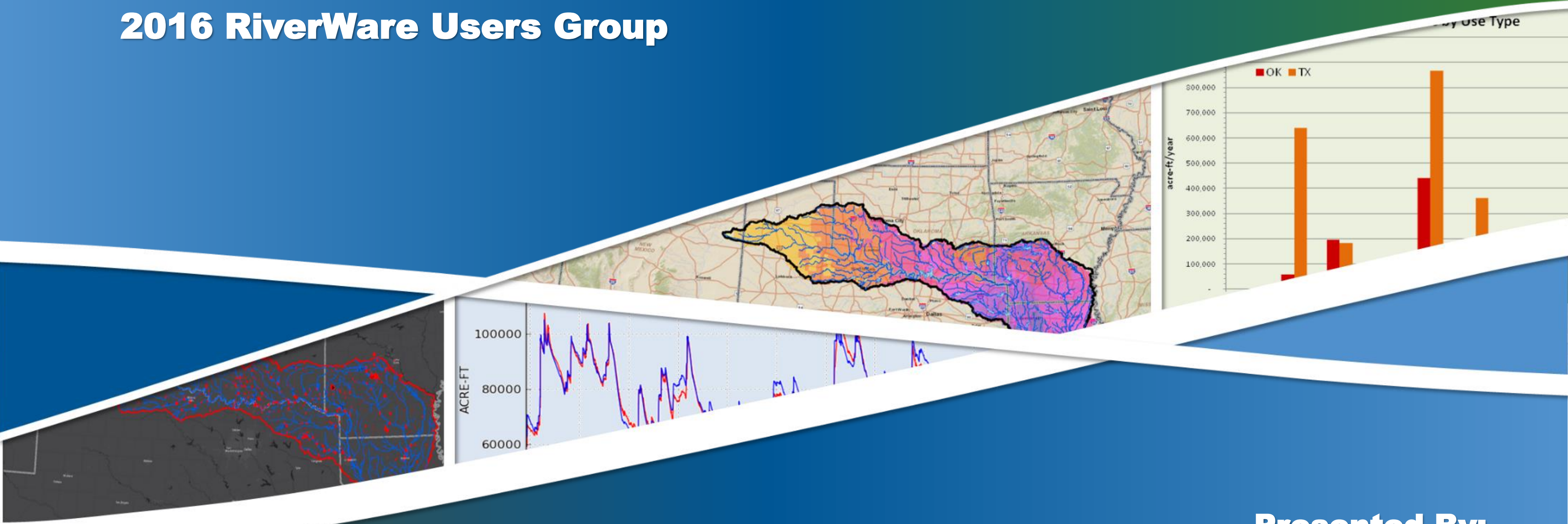
Modeling Climate Change in the Red River Basin: Results and Discussion

A Presentation To:

2016 RiverWare Users Group



Presented By:
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INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

August 23rd, 2016

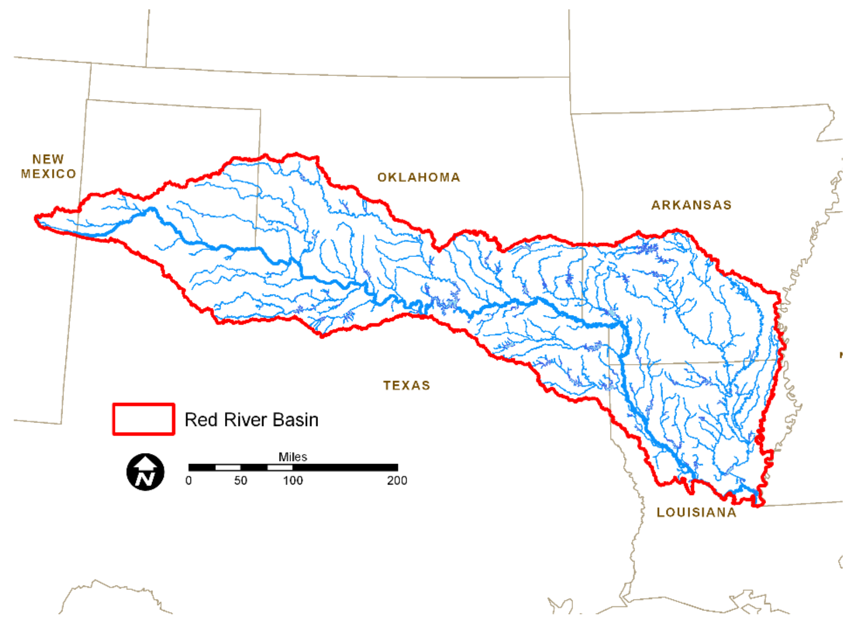
Background

- **Funding**
  - South Central Climate Science Center
- **Project Timeline**
  - Sept. 2013 to Dec. 2015
- **Partners**
  - Chickasaw & Choctaw Nations
  - University of Oklahoma

USGS science for a changing world

SOUTH CENTRAL CLIMATE SCIENCE CENTER

www.southcentralclimate.org



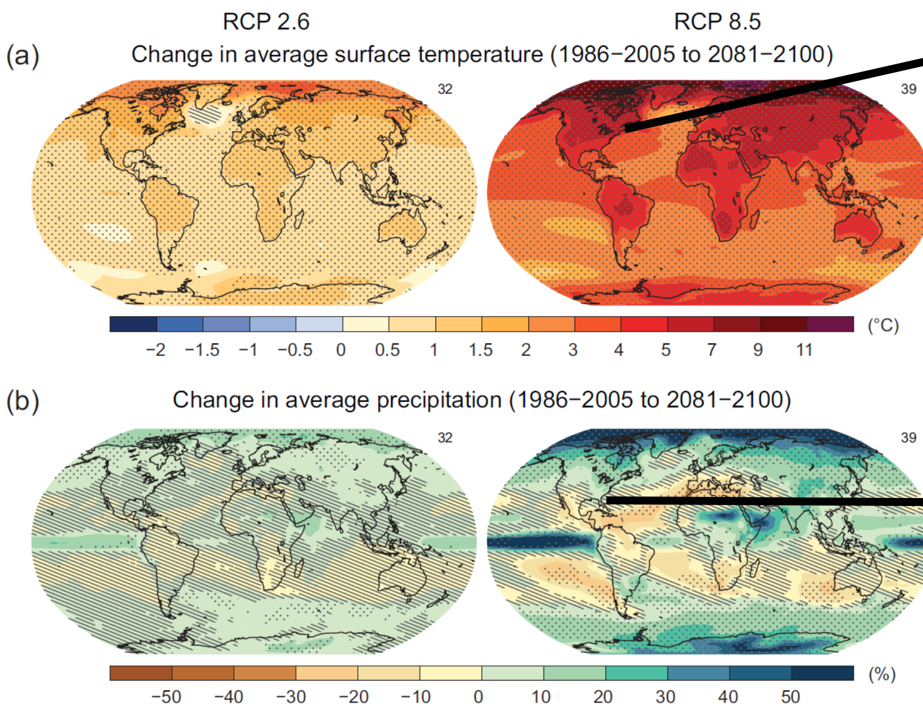
Method

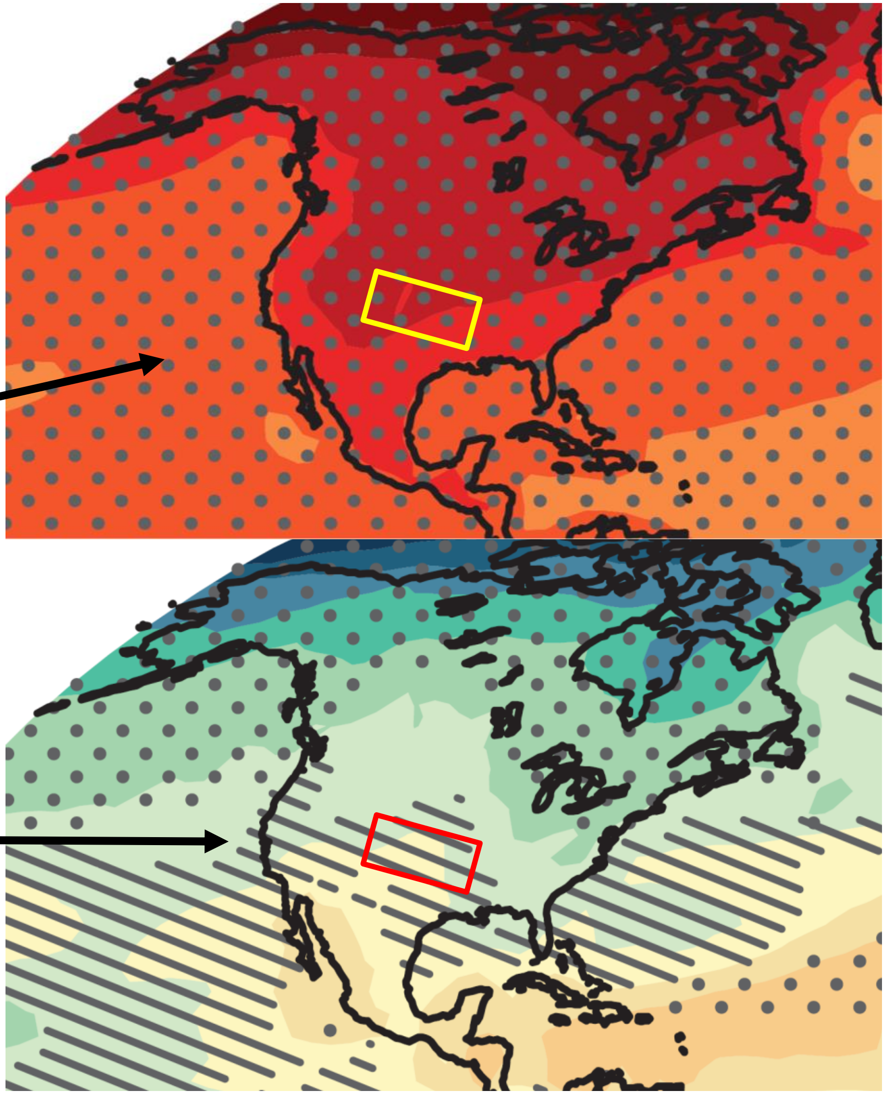
- 27 Climate Simulations + 1 Historical
  - 3 Climate Scenarios (RCPs) x 3 GCMs x 3 Downscaling Methods
  - Daily climate output from 2006 – 2099
- Runoff Modeling
  - Variable Infiltration Capacity (VIC) Hydrologic Model
  - Climate Data → Flows
- RiverWare Modeling
  - Water Users / Accounting
  - Reservoir Operations
  - Flows → Water Availability

Climate Scenarios

- **Representative Concentration Pathways (RCP)**
  - **IPCC 5th Assessment Report**
  - **RCP 8.5, scenario leading to an increase of 8.5 W/m2 in 2100**
  - **Modeled RCP 2.6, 4.5 and 8.5**

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





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

Global Climate Models

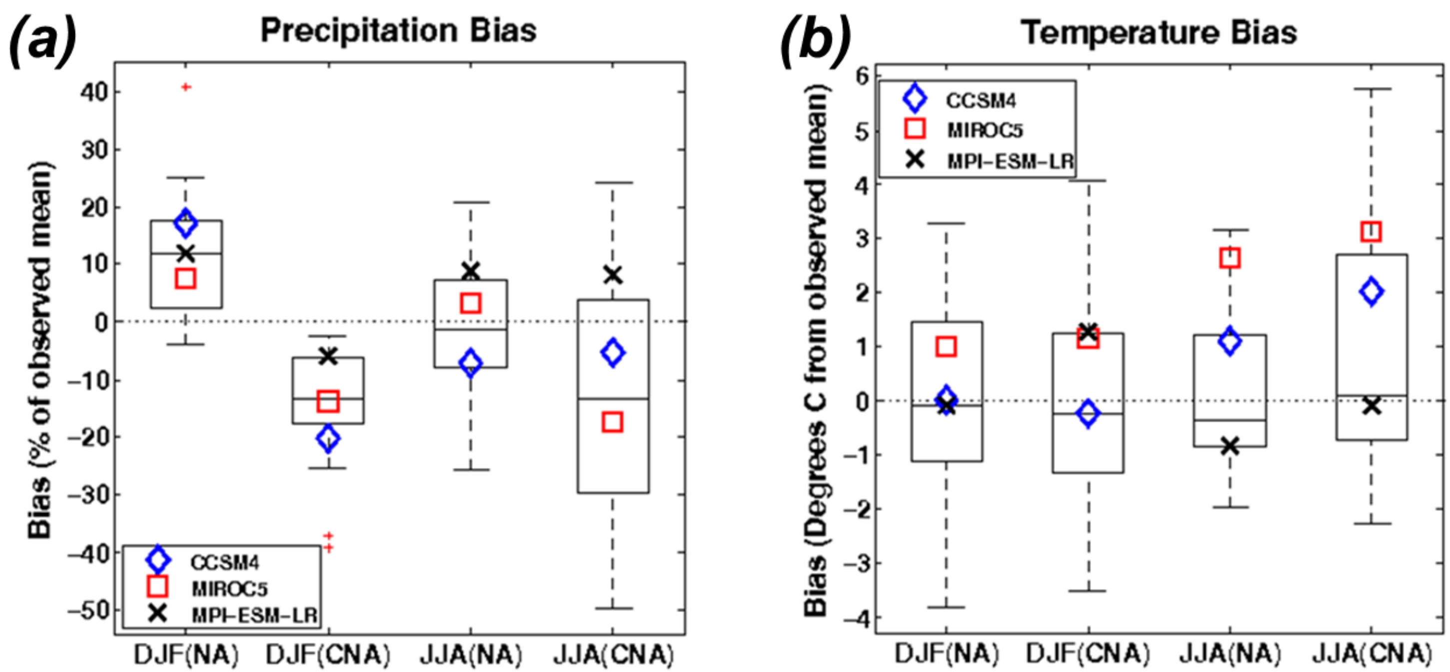
- **>50 GCMs from 20 research centers used in CMIP5**
- **3 selected that represented area and model uncertainty**

Model	Research Center	Resolution
CCSM4	U.S. National Center for Atmospheric Research (NCAR)	0.90° x 1.25°
MIROC5	University of Tokyo	1.41° × 1.41°
MPI-ESM-LR	Max Planck Institute for Meteorology Earth System Model	1.80° x 1.80°

NA –North America

CNA – Central North America

DJF – Dec/Jan/Feb
JJA – Jun/Jul/Aug



Adapted from: Sheffield, J., Barrett, A. P., Colle, B., Nelun Fernando, D., Fu, R., Geil, K. L., ... & Lombardo, K. (2013). North American climate in CMIP5 experiments. Part I: evaluation of historical simulations of continental and regional climatology*. *Journal of Climate*, *26*(23), 9209-9245.

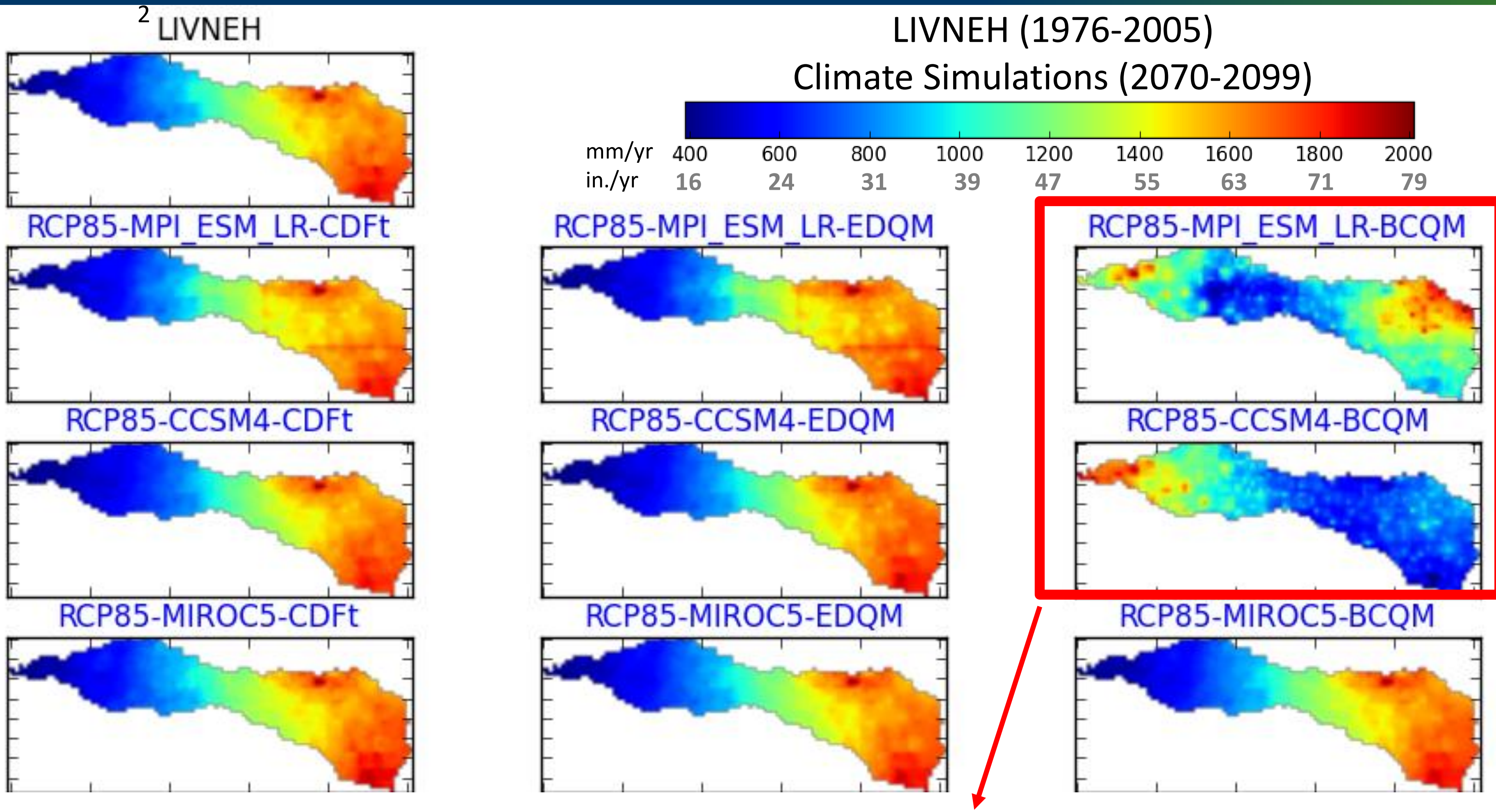
Downscaling Methods

- **3 Quantile Mapping Methods**
  - **CDFt - Cumulative Density Function Transform**
    - $F_{LF}(x)=F_{LH}(F^{-1}_{CH}(F_{CF}(x)))$
  - **EDQM - Equi-Distant Quantile Mapping**
    - $F_{LF}(x)=CF+F^{-1}_{LH}(F_{CF}(x)) - F^{-1}_{CH}(F_{CF}(x))$
  - **BCQM - Bias Correction Quantile Mapping**
    - **CDFt without post-processing refinements to improve the tail behavior of the projections**

LF= Local Future
LH= Local Historical
CF= Coarse Future
CH=Coarse Historical

Data Link:
http://data.cybercommons.org/dataset/red-river-project

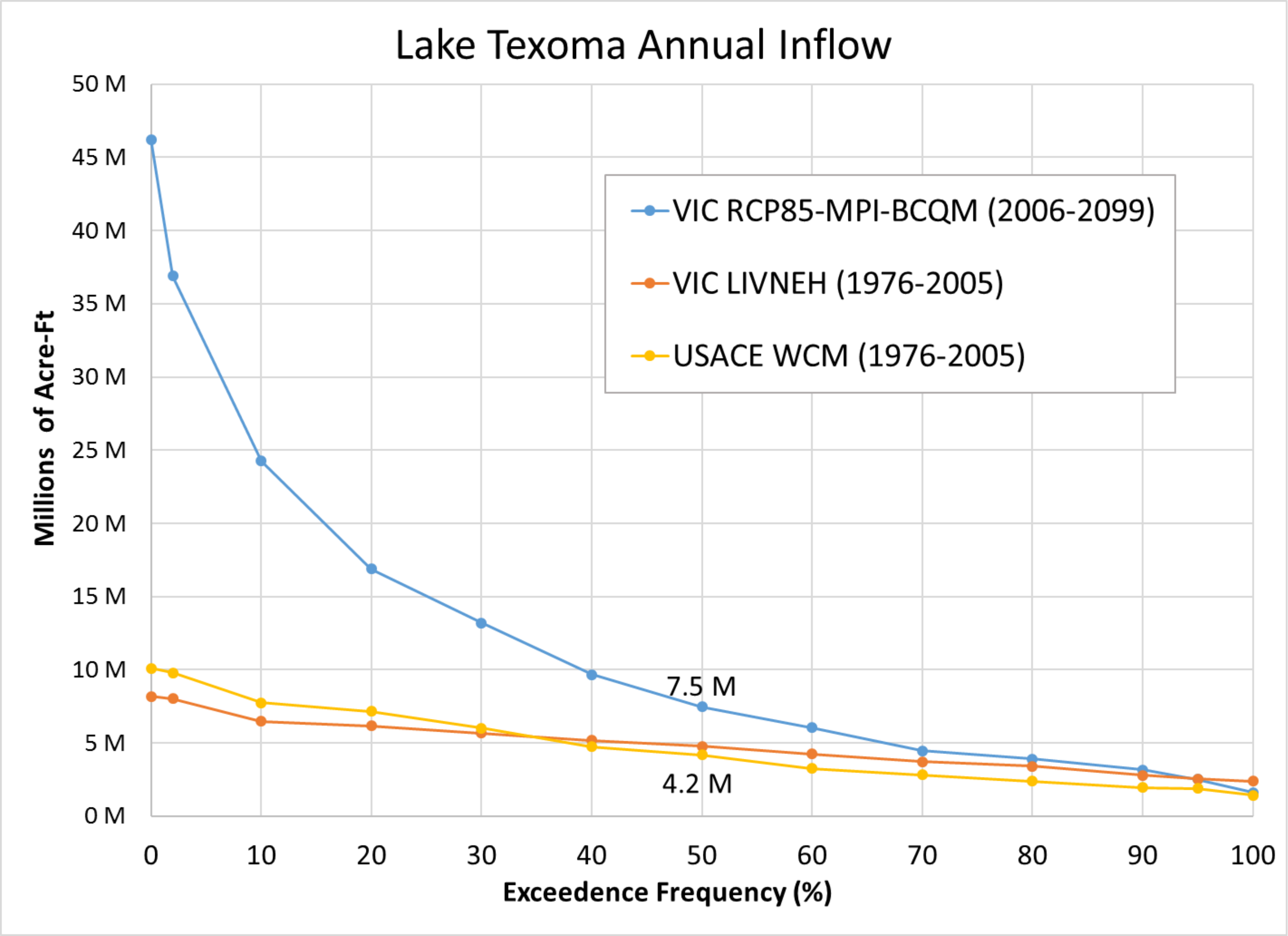
Future Rainfall (RCP 8.5)



Cannon AJ, Sobie SR, Murdock TQ (2015) Bias Correction of GCM Precipitation by Quantile Mapping: How Well Do Methods Preserve Changes in Quantiles and Extremes? Journal of Climate:150722131126009. doi:10.1175/jcli-d-14-00754.1.

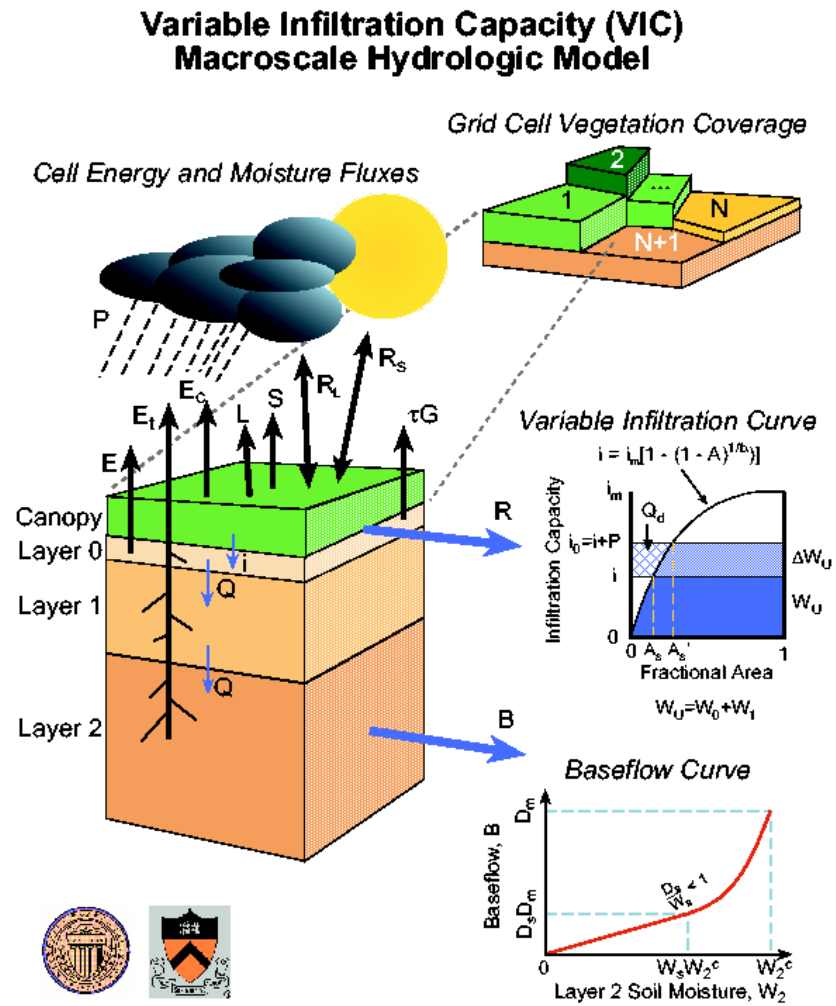
1) Rainfall Maps generated by Xianwu Xue for this project.
2) Livneh, B. et al., 2013. A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States: Update and Extensions*. Journal of Climate, 26(23): 9384-9392.

Lake Texoma Inflows from VIC



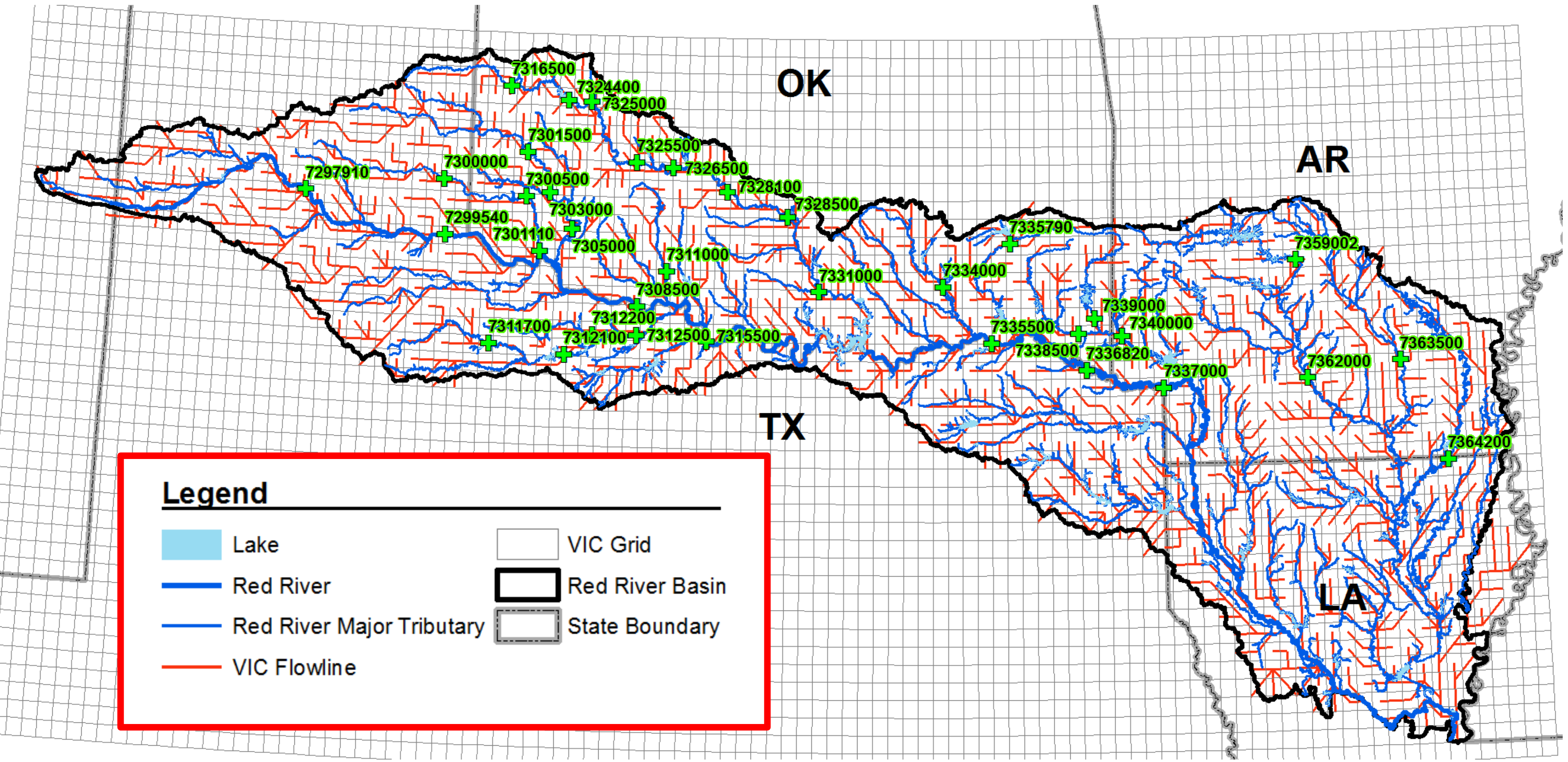
VIC Modeling

- **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 LIVNEH data (1981-2013)**



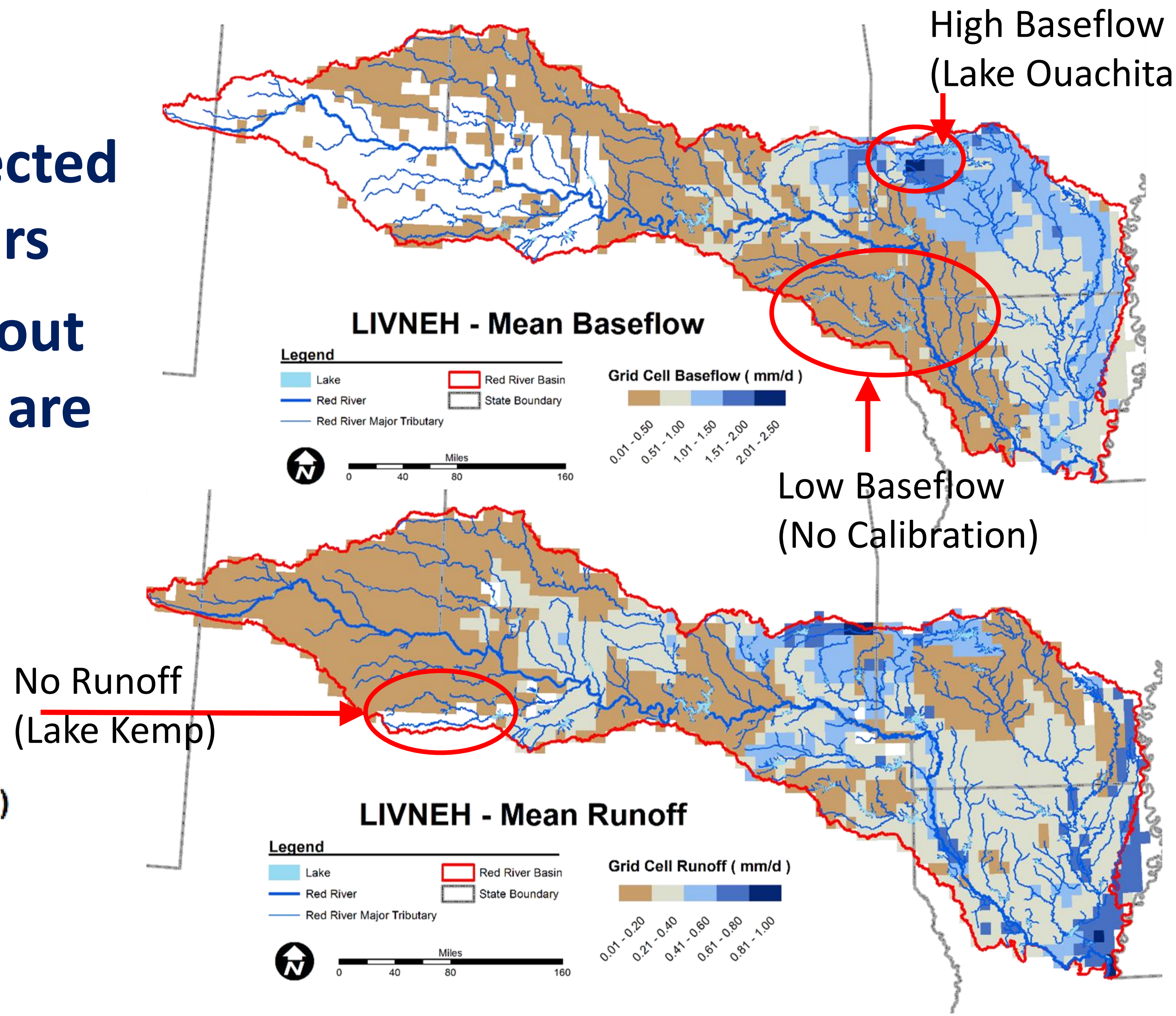
Source:
http://www.hydro.washington.edu/Lettenmaier/Models/VIC/Overview/ModelOverview.shtml

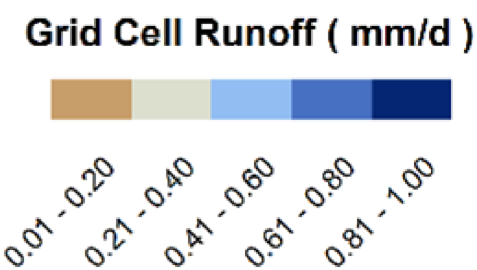
VIC Calibration



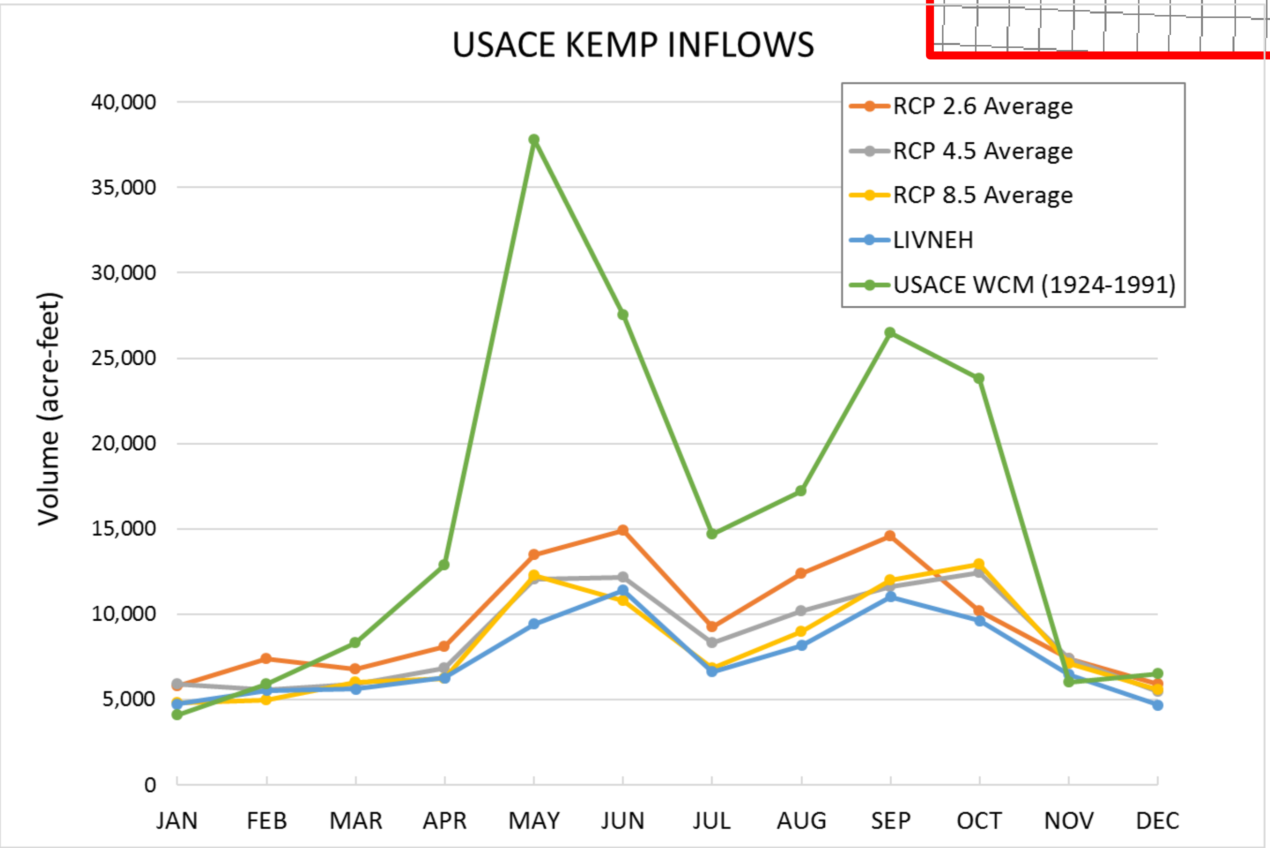
VIC Output

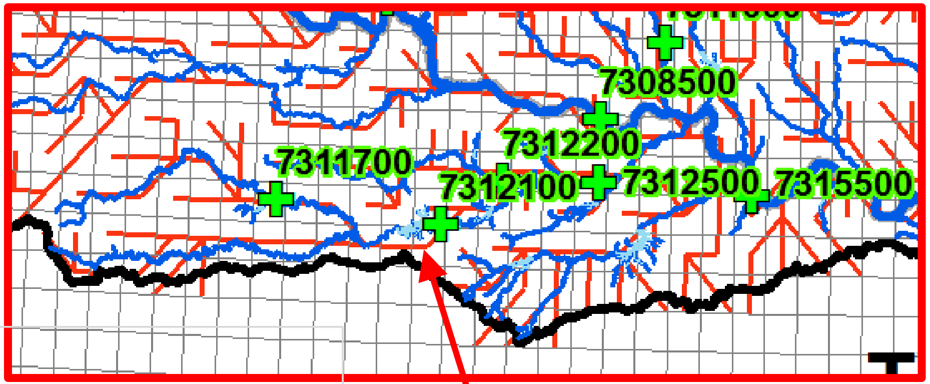
- **Calibration results effected by reservoirs**
- **Areas without calibration are suspect**





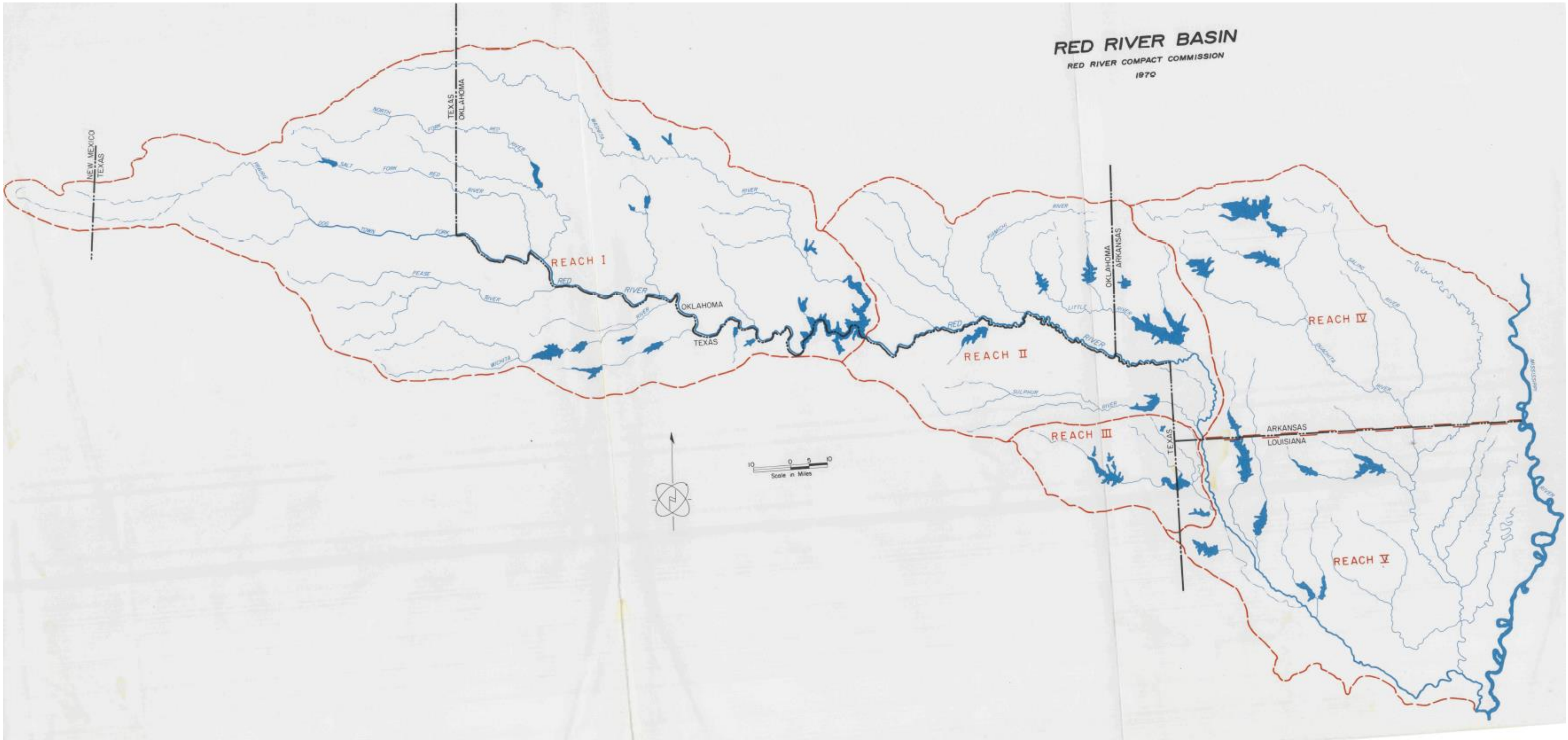
Lake Kemp Monthly Inflows from VIC





Red River Compact

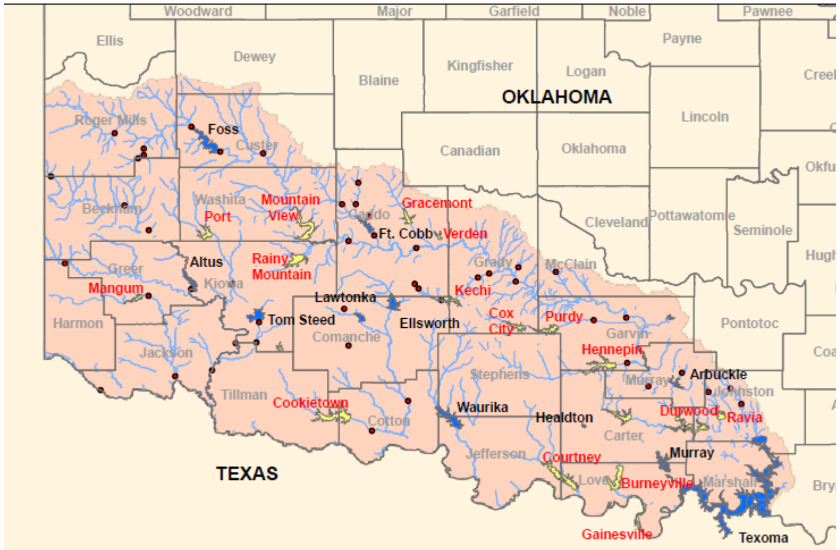
- **Splits the basin into 5 reaches**
- **Reaches further split into sub-basins**
- **Defines water ownership and sets minimum flows**



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.**

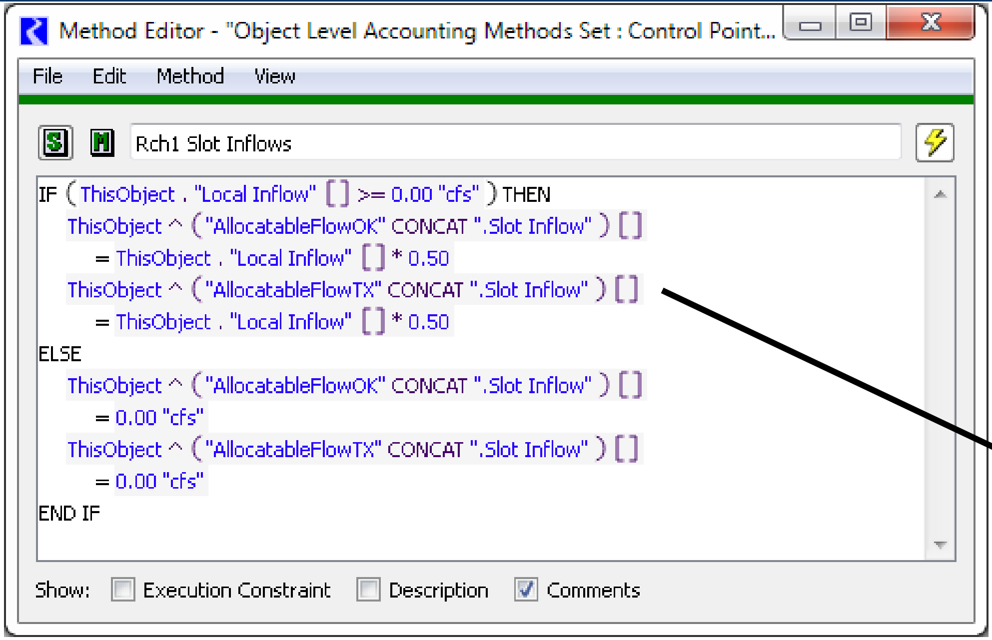
Red River Compact - Reach I, Subbasin 2

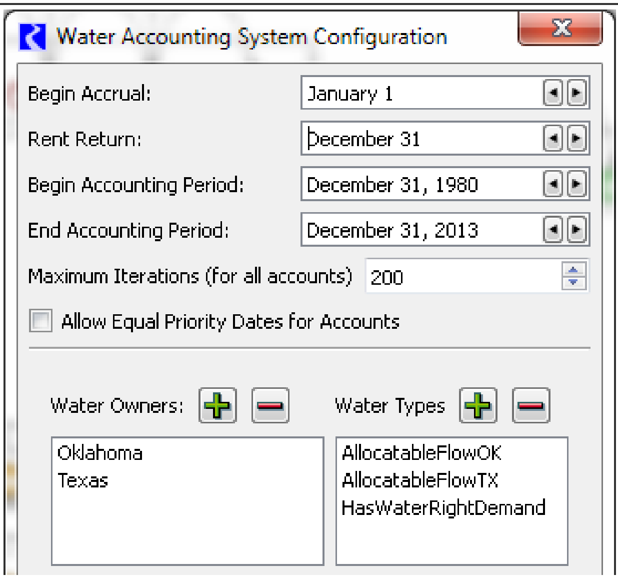


Red River Compact - Reach I, Subbasin 3

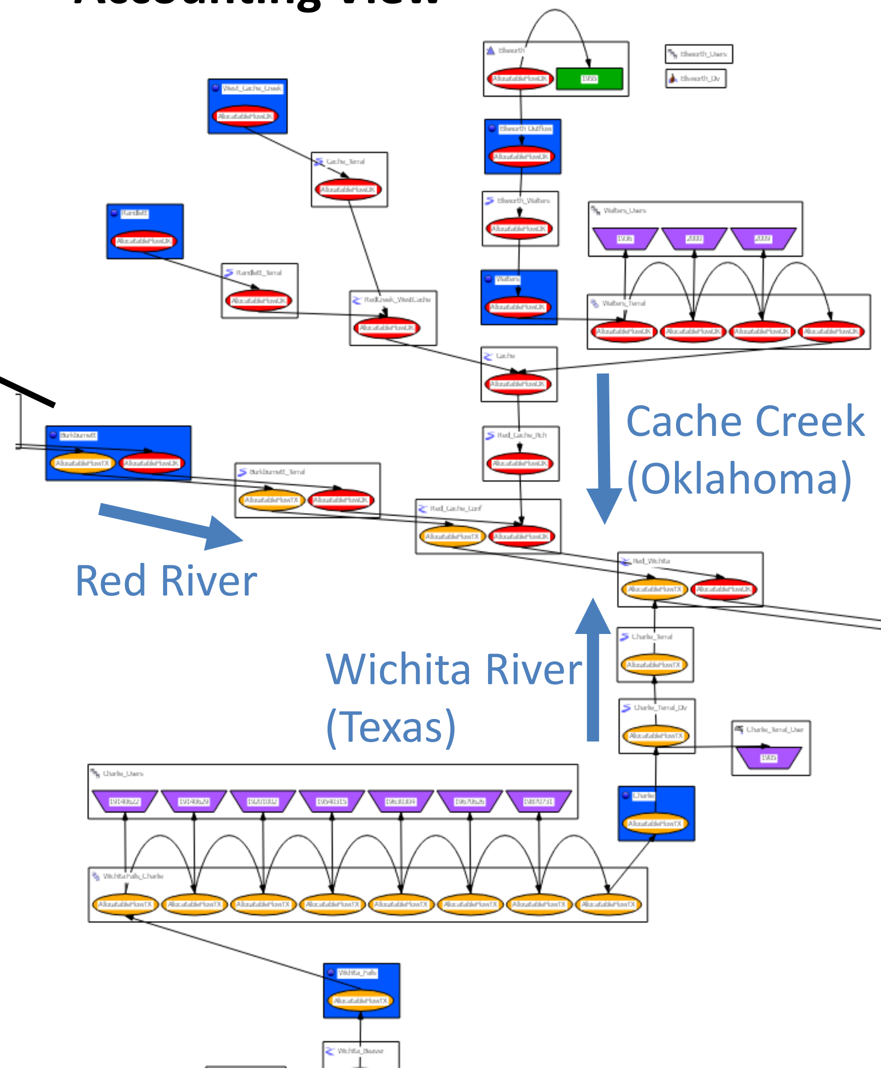
Maps provided by: Wayne Kellogg, Environmental Engineer, P.E., P.G., CSP, Chickasaw Nation

Accounting in Reach I



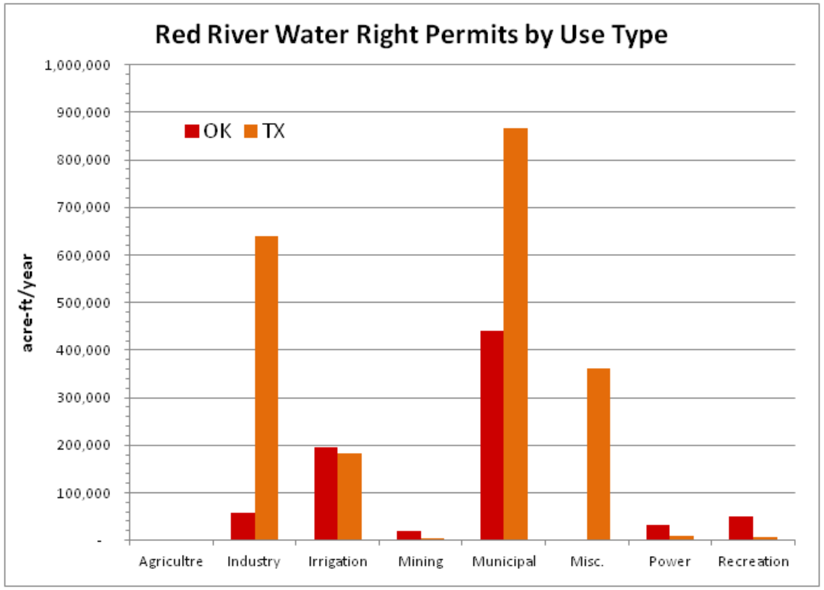


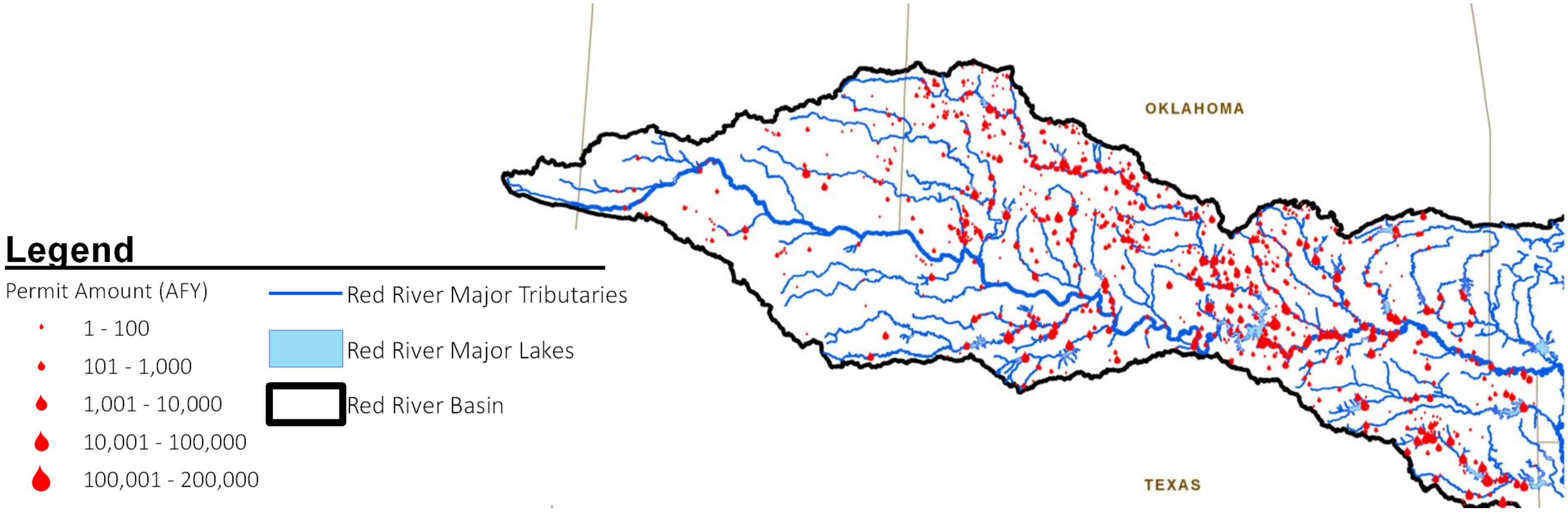
Accounting View



Water Rights (TX & OK)

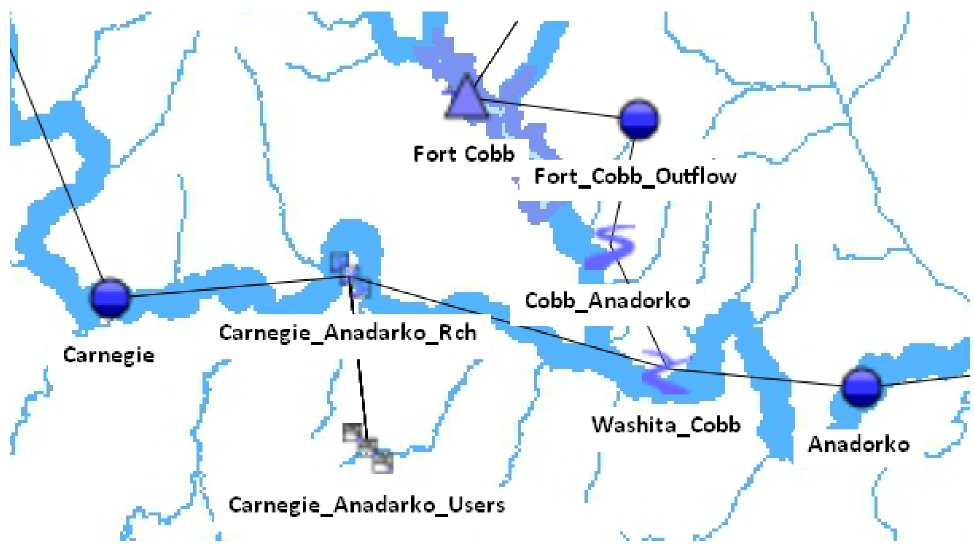
- **Prior Appropriation**
- **Data Sources**
  - (TCEQ) Texas Commission on Environmental Quality
  - (OWRB) Oklahoma Water Resources Board





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**



RiverWare Geospatial View

RCL and Python

- Used Python to run in Batch Mode using RCL
- Text files for every object stored in folder for each simulation
  - DMI Input
    - RCP26-CCSM4-EDQM
      - EVAP
      - PREC
      - Det. Inflow
      - Inc. Inflow
  - DMI Output
    - RCP26-CCSM4-EDQM
      - Outflow
      - Storage
      - Elevation
      - Diversion

PythonShell.py

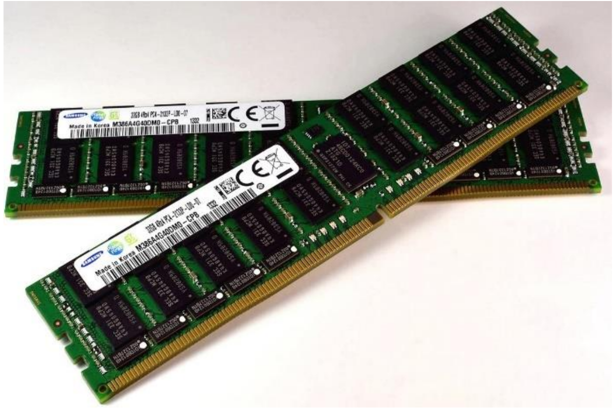
```python
#!/usr/bin/env python
import subprocess, os, datetime

VICpath="S:\Projects\OKCCT.C001.CCT\RiverWare\RedRiverBasin\VIC\DataProcessing\GridData"
VICfolders=os.walk(VICpath).next()[1]
for folder in VICfolders[:]:
    model='MainRed_CC.mdl.gz'
    ### Modify RCL file to run model
    RCLfile=open('RW.rcl','r')
    RCLlines=RCLfile.readlines()
    tmpRCL=open('tmp.rcl','w')
    for line in RCLlines:
        if line.find('LoadModel.mdl.gz')>0:
            print>>tmpRCL,line.rstrip().replace('LoadModel.mdl.gz',model)
        elif line.find('SaveModel.mdl.gz')>0:
            print>>tmpRCL,line.rstrip().replace('SaveModel.mdl.gz',folder+'.mdl.gz')
        elif line.find('SaveDiagnostics.txt')>0:
            print>>tmpRCL,line.rstrip().replace('SaveDiagnostics.txt',folder+'.txt')
        else:
            print>>tmpRCL,line.rstrip()
    tmpRCL.close()
    
    ### Modify input DMI Input contol file for current model in loop
    ctrlFile=open('VIC_INPUT.control','r')
    ctrlLines=ctrlFile.readlines()
    tmpCtrlFile=open('tmpVICinput.control','w')
    for line in ctrlLines:
        newLine=line.rstrip().replace("LIVNEH",folder)
        print>>tmpCtrlFile,newLine
    tmpCtrlFile.close()
    
    ### Modify output DMI Output contol file for current model in loop
    ctrlFile=open('ModelOutput.control','r')
    ctrlLines=ctrlFile.readlines()
    tmpCtrlFile=open('tmpModelOutput.control','w')
    for line in ctrlLines:
        newLine=line.rstrip().replace("LIVNEH",folder)
        print>>tmpCtrlFile,newLine
    tmpCtrlFile.close()
    
    ### Run Model
    start=datetime.datetime.now()
    print  "*** Started Running " +model[:-7]+'_'+folder+" ***"
    print  start
    p=subprocess.call(["C:\\CADSWES\\RiverWare666\\riverware" ,"--batch", 
                        "C:\\CADSWES\\Models\\RedRiverStudy\\tmp.rcl"])
    end=datetime.datetime.now()
    delta=end-start
    minutes=delta.total_seconds()/60
    print "Run Time = " +str(round(minutes,2))+' minutes'
    print "*** Done Running " +model[:-7]+'_'+folder+" ***\n"
```

Model

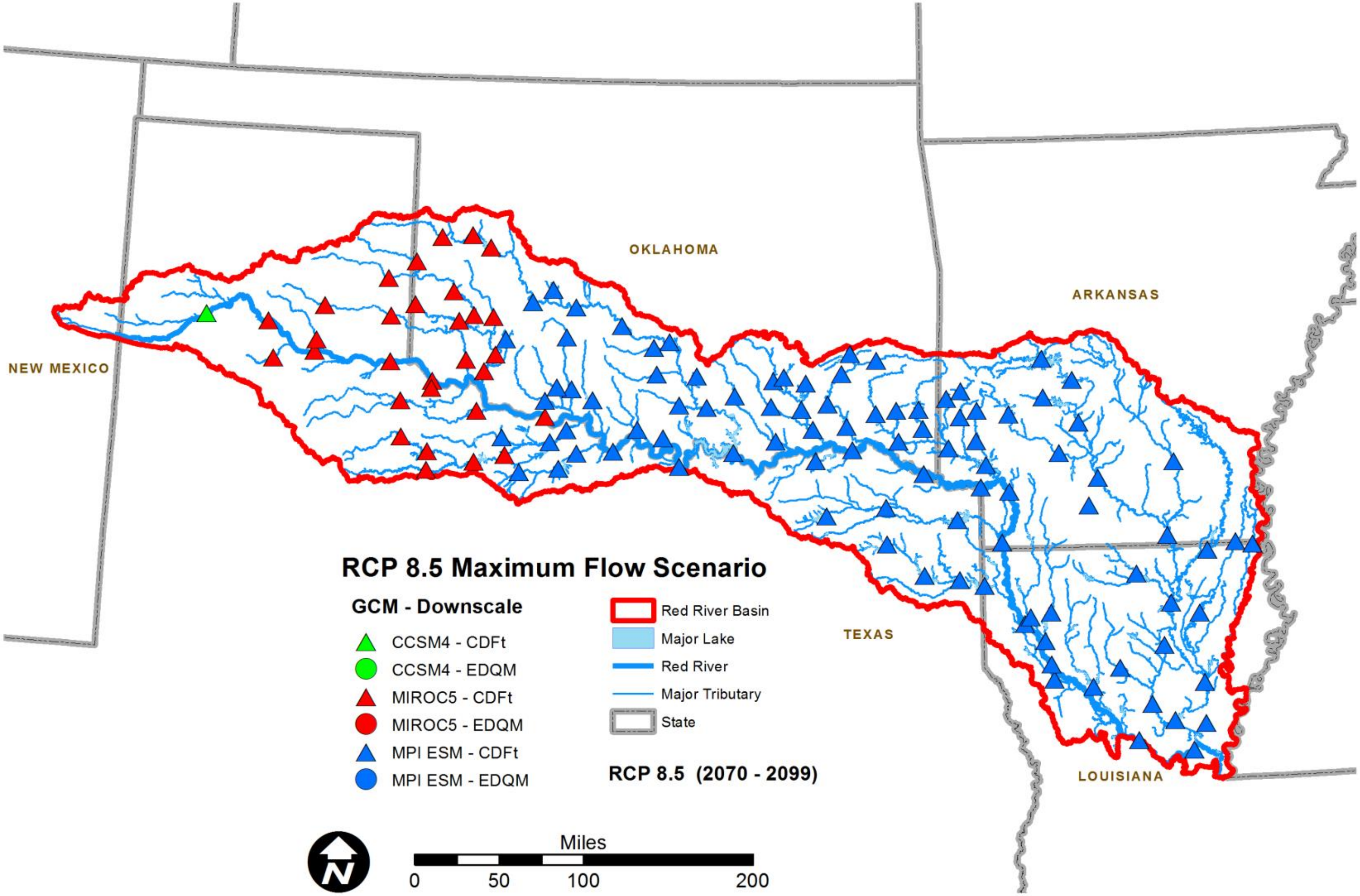
- ≈5 hrs runtime
- ≈30 min. initialization
- 4 days to run 19 models
- Computer Specs.

Processor	Intel(R) Xeon(R) CPU E5-1620 v2 @ 3.70GHz 3.70 GHz
Installed RAM	16.0 GB
System type	64-bit operating system, x64-based processor

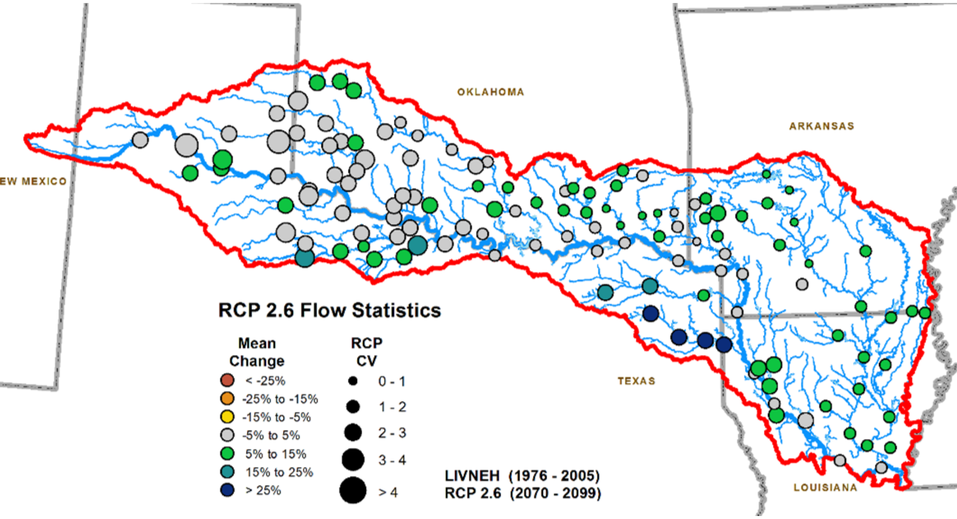
- 17 Subbasins
- 353 Water Users
  - >250 AFY
- 38 Reservoirs
- 89 Control Points

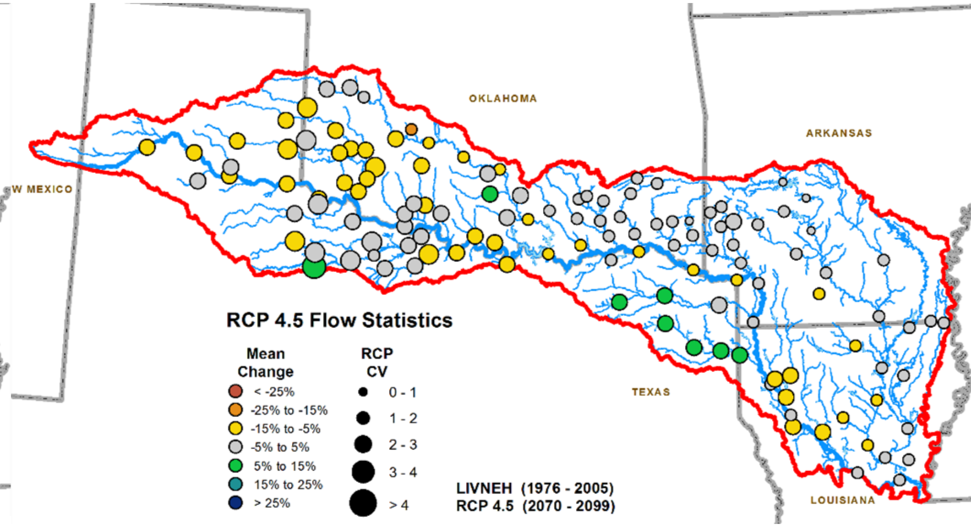


Max Flow Scenario

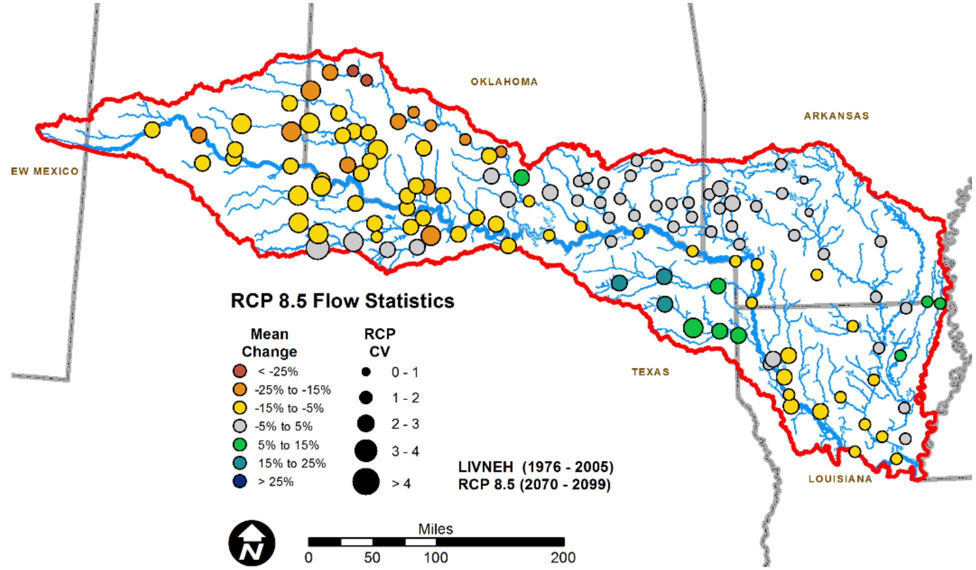


Flows

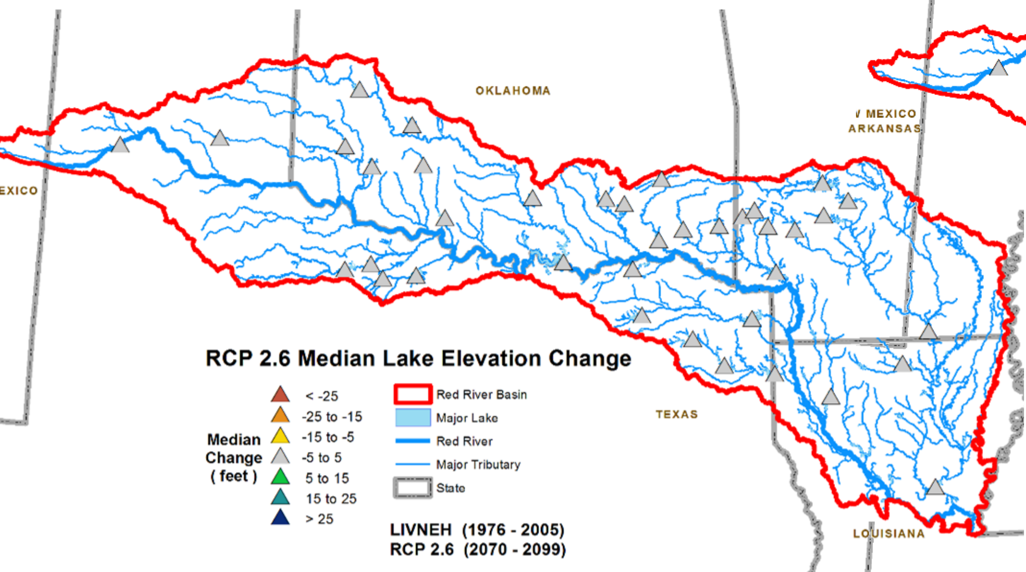


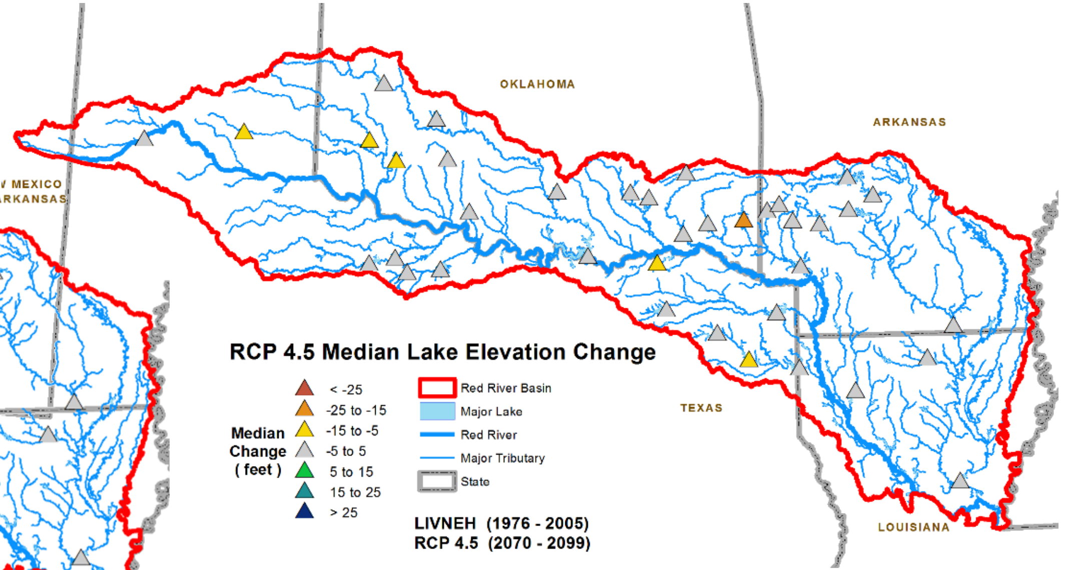


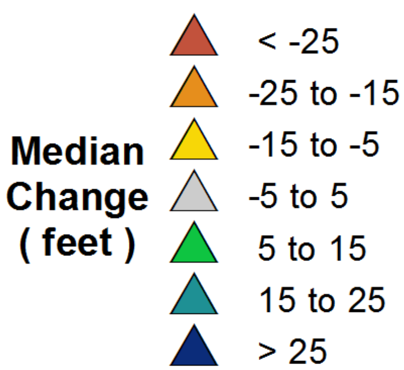
Mean Change	RCP CV
< -25%	0 - 1
-25% to -15%	1 - 2
-15% to -5%	2 - 3
-5% to 5%	3 - 4
5% to 15%	> 4
15% to 25%	
> 25%	

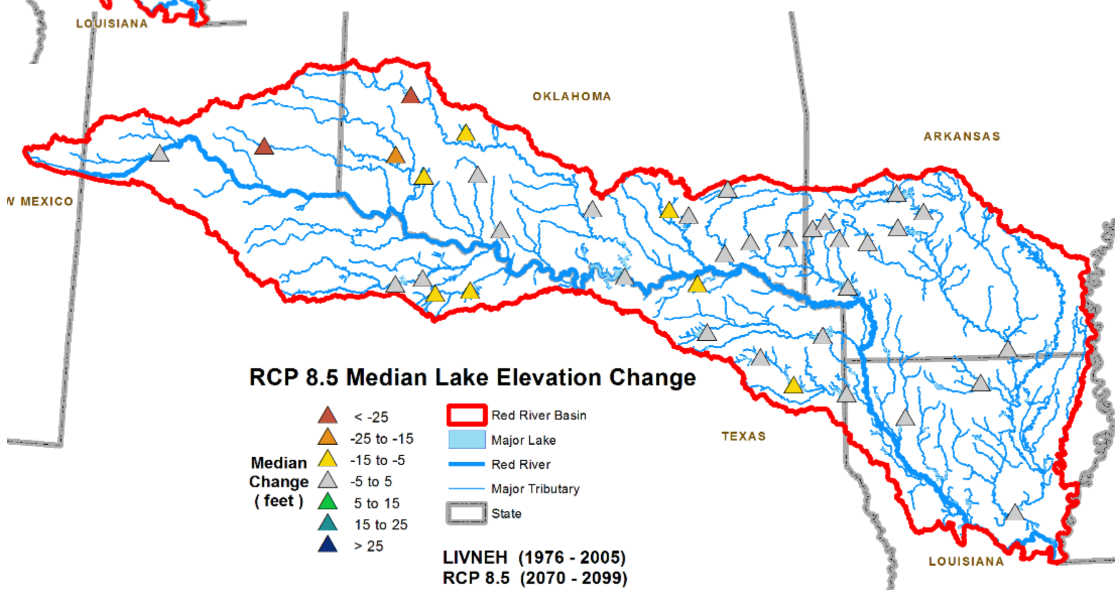


Reservoirs


OKLAHOMA
ARKANSAS
TEXAS
LOUISIANA
RCP 2.6 Median Lake Elevation Change
Median Change (feet)
< -25
-25 to -15
-15 to -5
-5 to 5
5 to 15
15 to 25
> 25
Red River Basin
Major Lake
Red River
Major Tributary
State
LIVNEH (1976 - 2005)
RCP 2.6 (2070 - 2099)


OKLAHOMA
ARKANSAS
TEXAS
LOUISIANA
RCP 4.5 Median Lake Elevation Change
Median Change (feet)
< -25
-25 to -15
-15 to -5
-5 to 5
5 to 15
15 to 25
> 25
Red River Basin
Major Lake
Red River
Major Tributary
State
LIVNEH (1976 - 2005)
RCP 4.5 (2070 - 2099)


Median Change (feet)
< -25
-25 to -15
-15 to -5
-5 to 5
5 to 15
15 to 25
> 25


OKLAHOMA
ARKANSAS
TEXAS
LOUISIANA
RCP 8.5 Median Lake Elevation Change
Median Change (feet)
< -25
-25 to -15
-15 to -5
-5 to 5
5 to 15
15 to 25
> 25
Red River Basin
Major Lake
Red River
Major Tributary
State
LIVNEH (1976 - 2005)
RCP 8.5 (2070 - 2099)

Questions?