A Spatially Variable, Physically-Based Gridded Flash Flood Guidance Model

John Schmidt, ABRFC
Tony Anderson, ABRFC
July 18, 2006

Project Goal

To provide WFOs served by ABRFC with a GIS-based gridded flash flood guidance value for FFMP-based flash flood warning operations that will reflect …

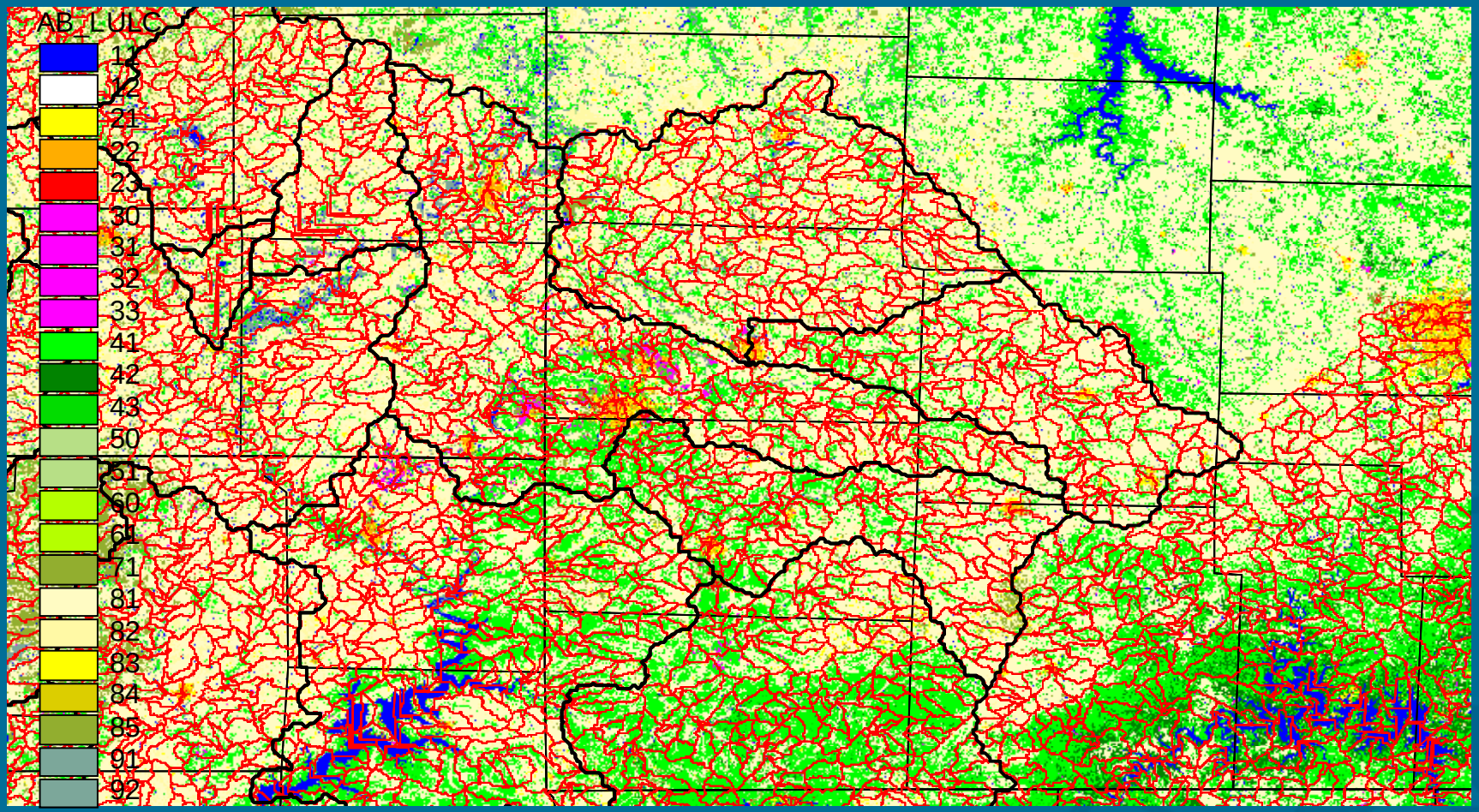
a. the spatial variability of precipitation and subsequent soil moisture,

b. the physical differences in slope, land use and soil quality that exist across a basin or county and

c. the variety of possible flash flood scenarios that exist across the ABRFC area through the application of a gridded threshold runoff value.

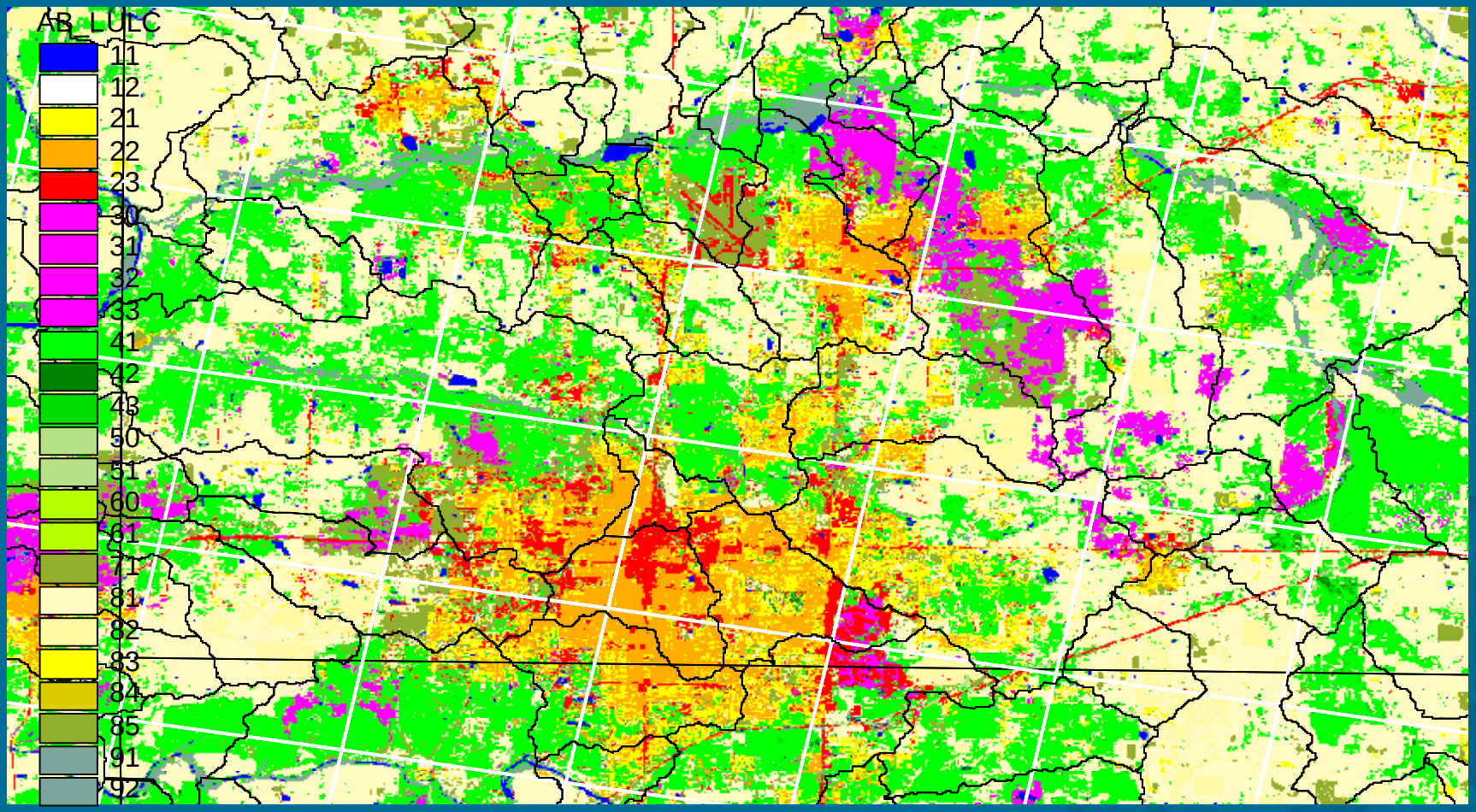
Issues of Scale

Basin/County/FFMP

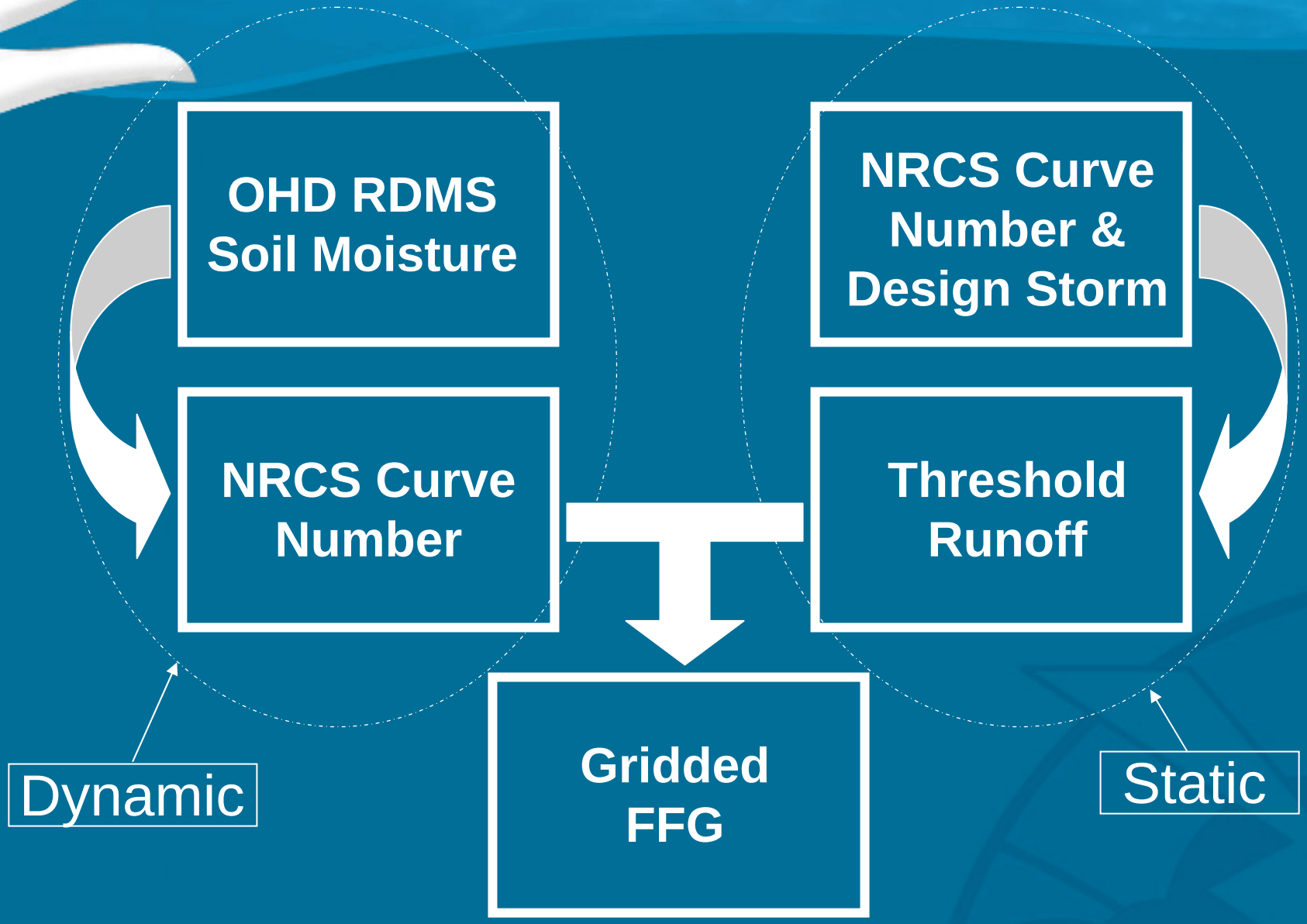


Issues of Scale

FFMP/HRAP



Gridded Flash Flood Guidance Model



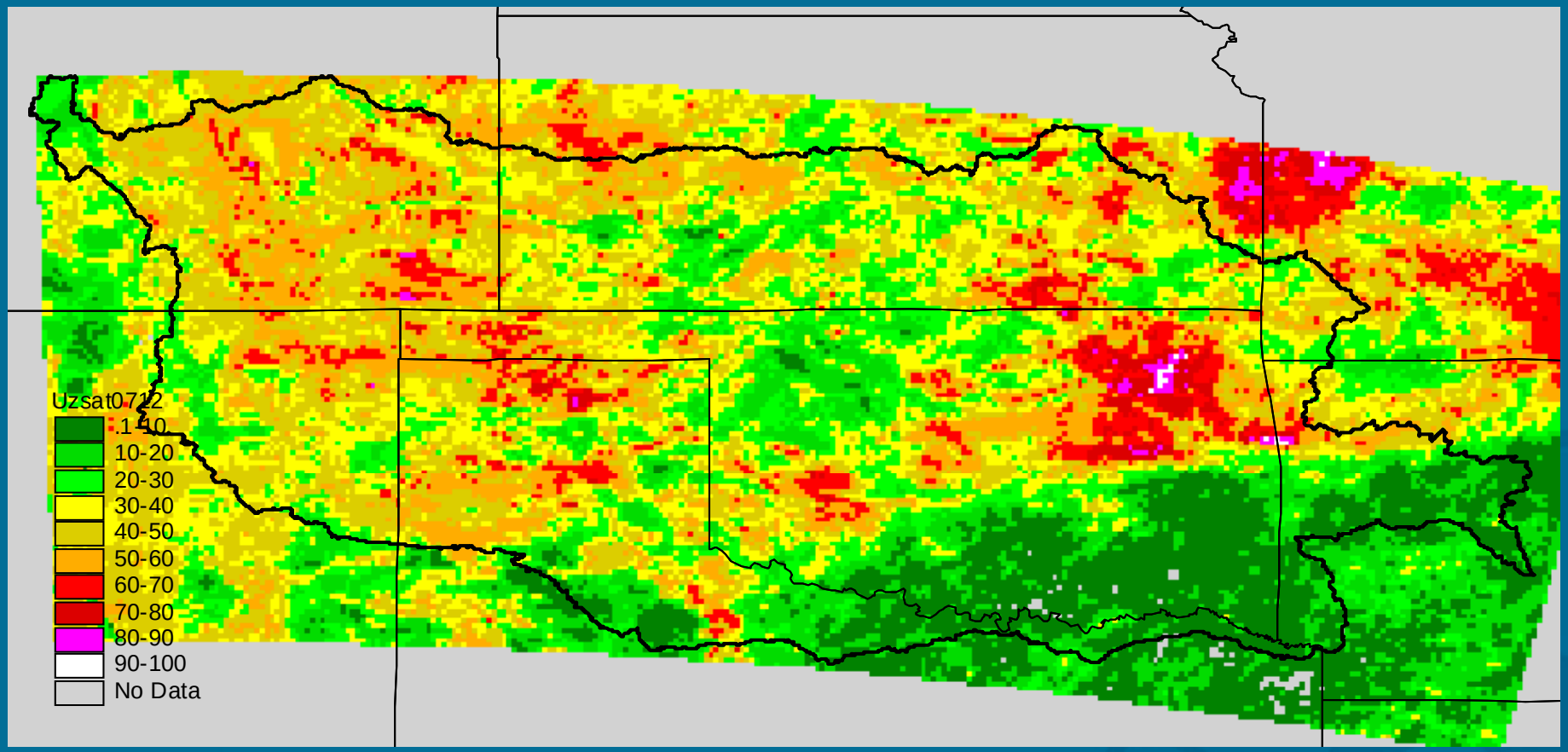
Application of Victor Koren's Research Distributed Modeling System (RDMS)

1. Run Victor's RDMS without connectivity for period of interest with hourly precipitation and evapotranspiration xmrgs.

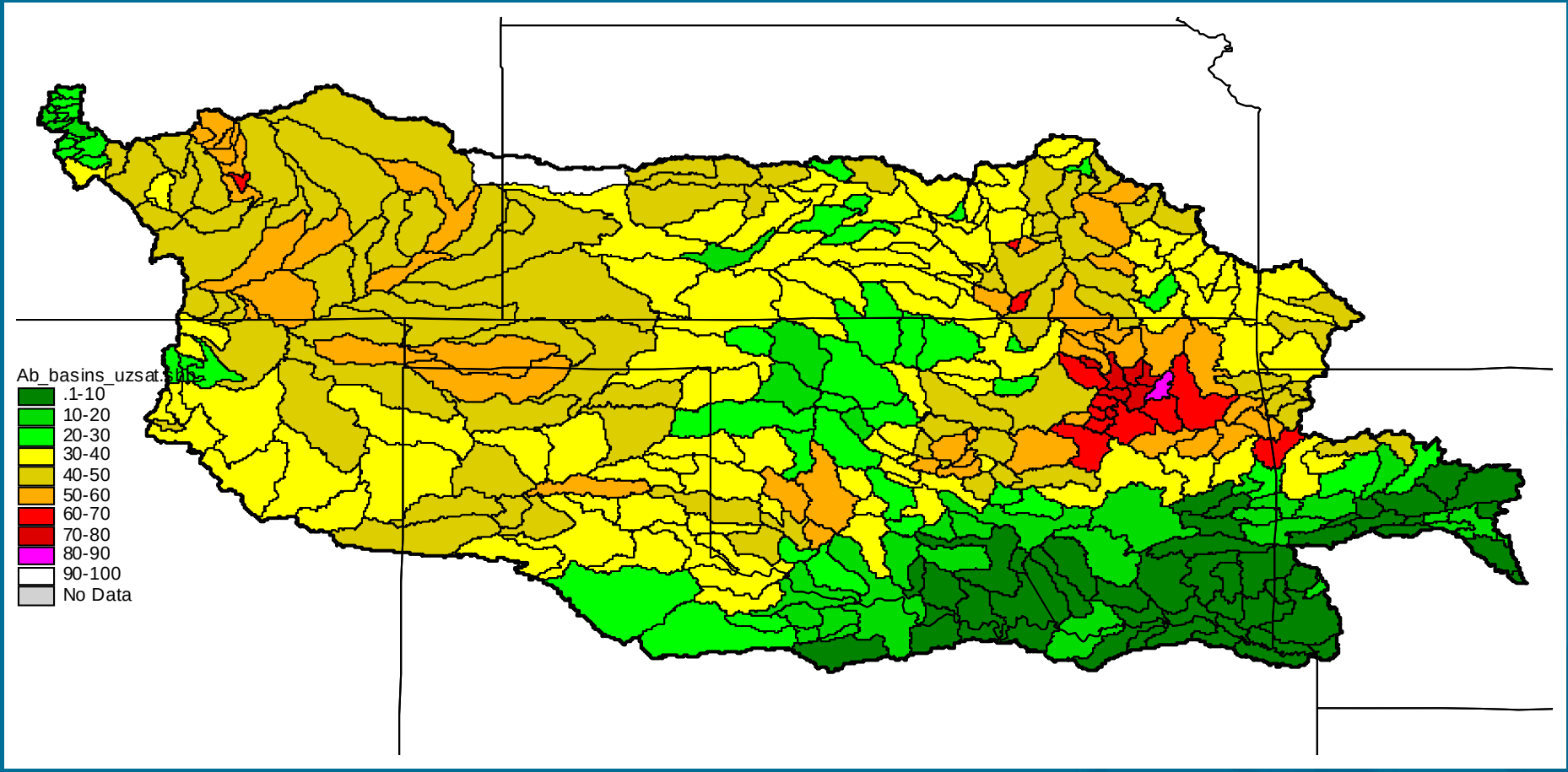
2. Output end of run gridded model states and preserve UZTWC and UZFWC.

3. Multiply UZTWC and UZFWC by their *a priori* maximum contents and divide by the sum to calculate UZ percent full.

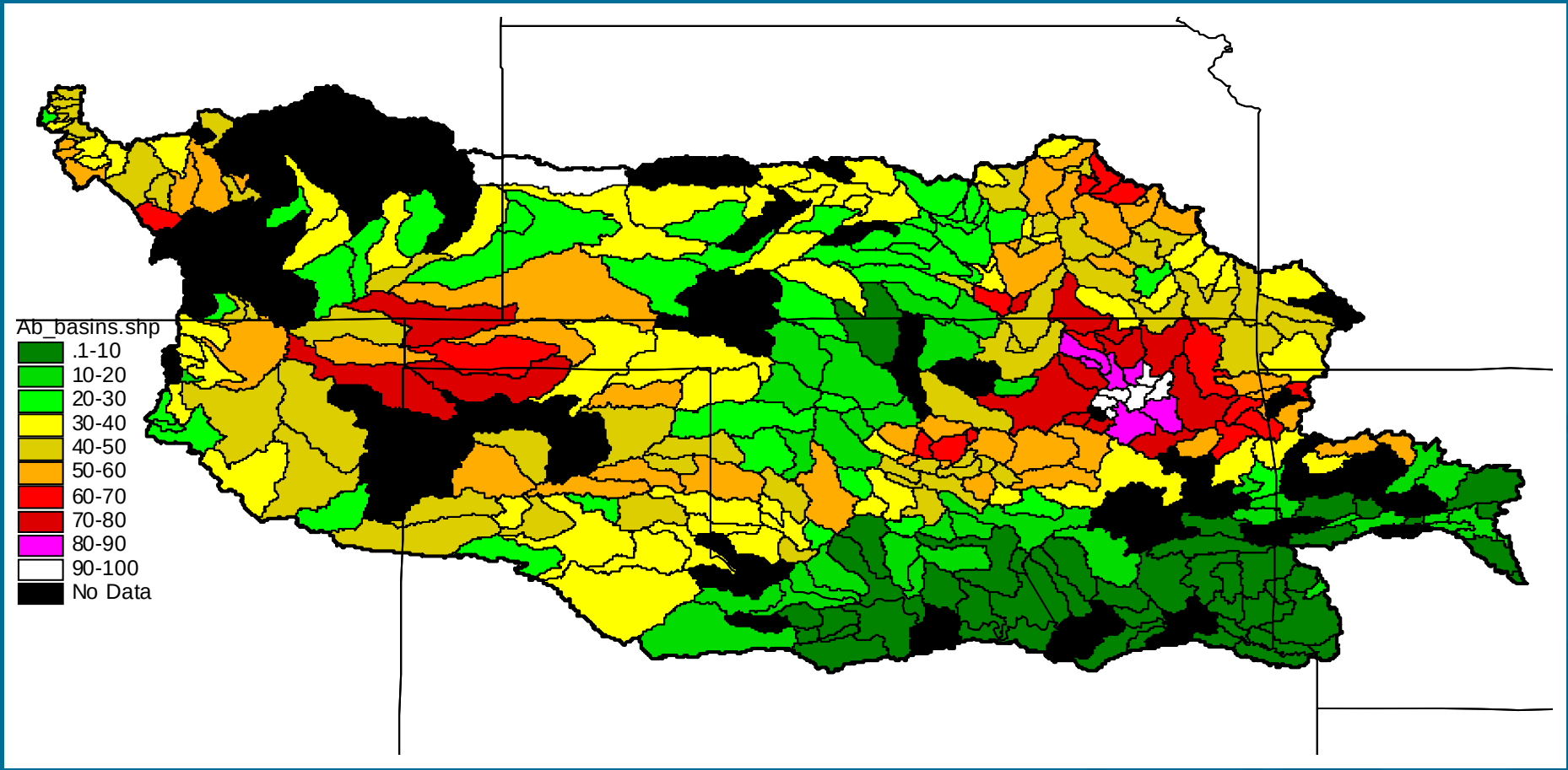
July 12, 2006 RDMS
Upper Zone Saturation



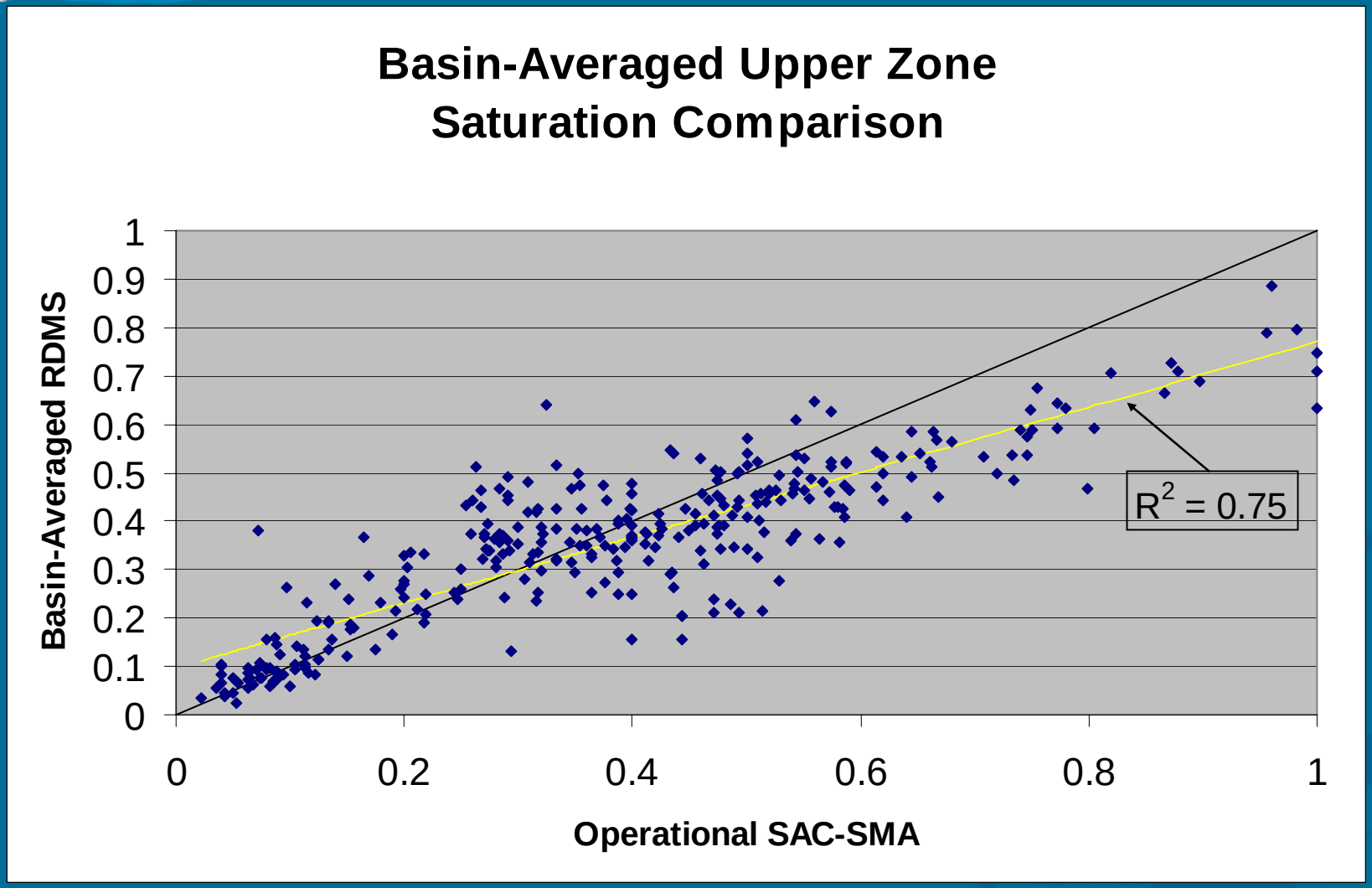
July 12, 2006 RDMS Basin-Averaged Upper Zone Saturation



July 12, 2006 Operational SAC-SMA Upper Zone Saturation



The Effect of No Run-Time Mods in the RDMS



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1. Run Victor's RDMS without connectivity for period of interest with hourly precipitation and evapotranspiration xmrgs.

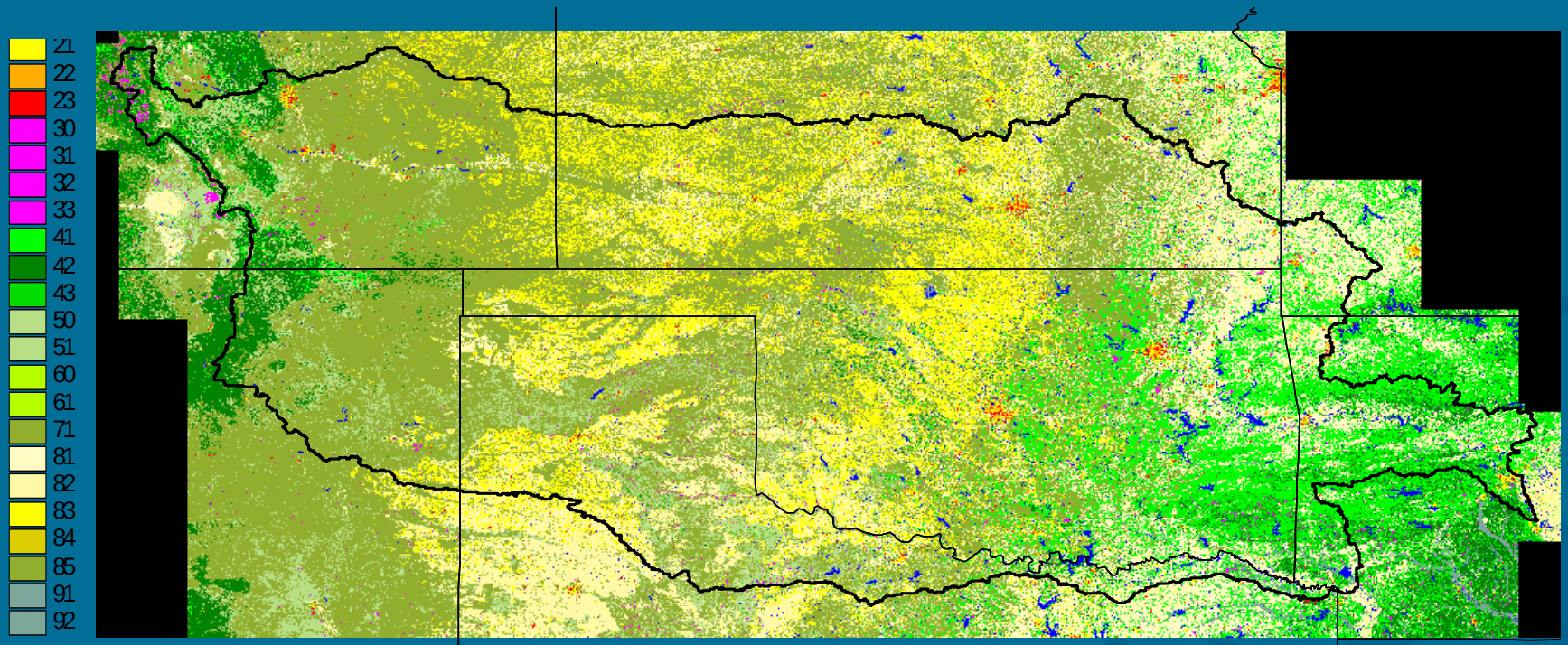
2. Output end of run gridded model states and preserve UZTWC and UZFWC.

3. Multiply UZTWC and UZFWC by their *a priori* maximum contents and divide by the sum to calculate UZ percent full.

4. Continuously modify "normal" curve numbers by applying formulas to estimate antecedent soil moisture conditions I, II and III to reflect the fullness of the UZ.

Runoff Model: NRCS Curve Number

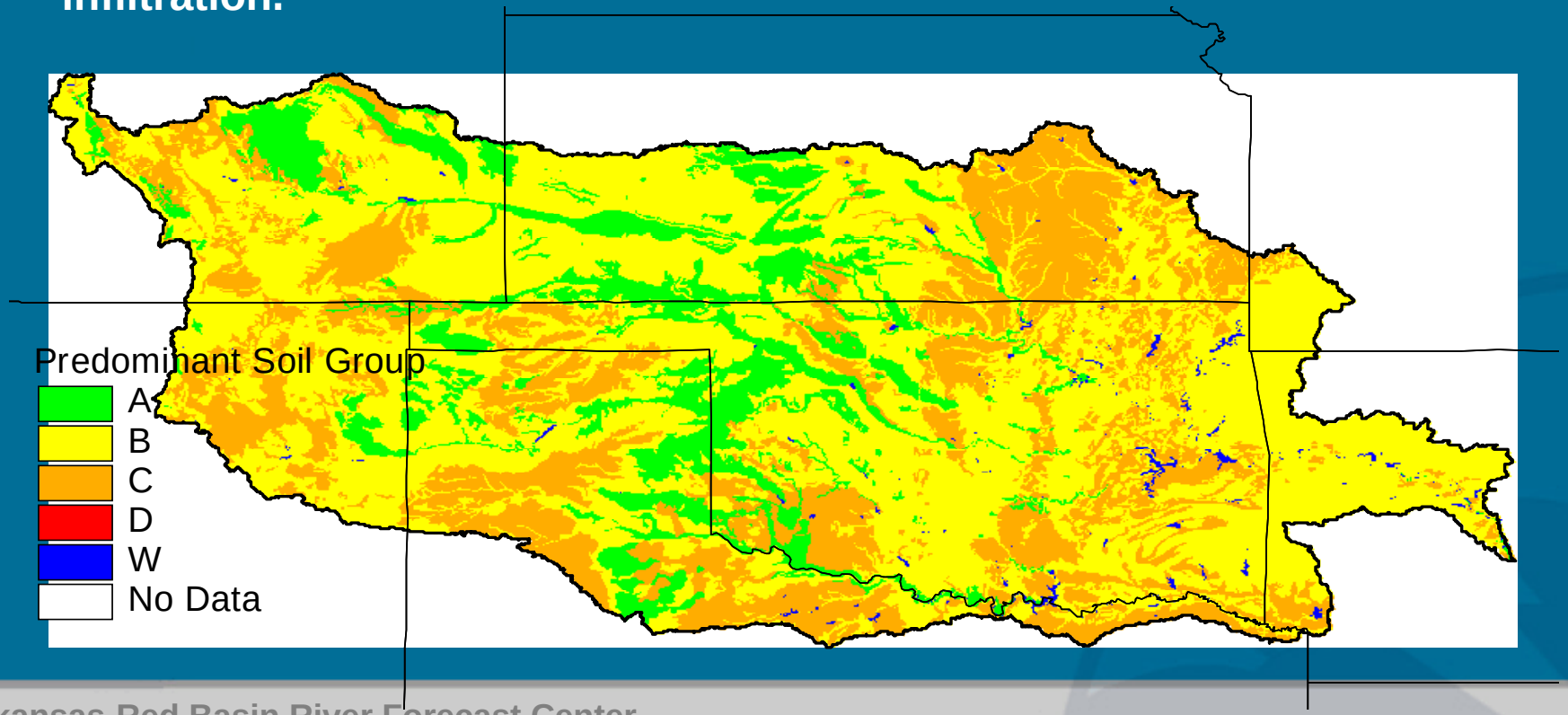
Land Use and Soil Quality can be analyzed to predict the ability of an area of interest to produce surface runoff. The NLCD divides land use/land cover into 24 categories to describe types of forestation, cultivation, urbanization, etc.



NLCD Land Cover Classes

Runoff Model: NRCS Curve Number

One of the multitude of STATSGO data sets, predominant soil group, describes the ability of the soil to allow infiltration. Group A describes a sandier soil which allows significant infiltration, while Group D describes a clayey soil which does not allow significant infiltration.

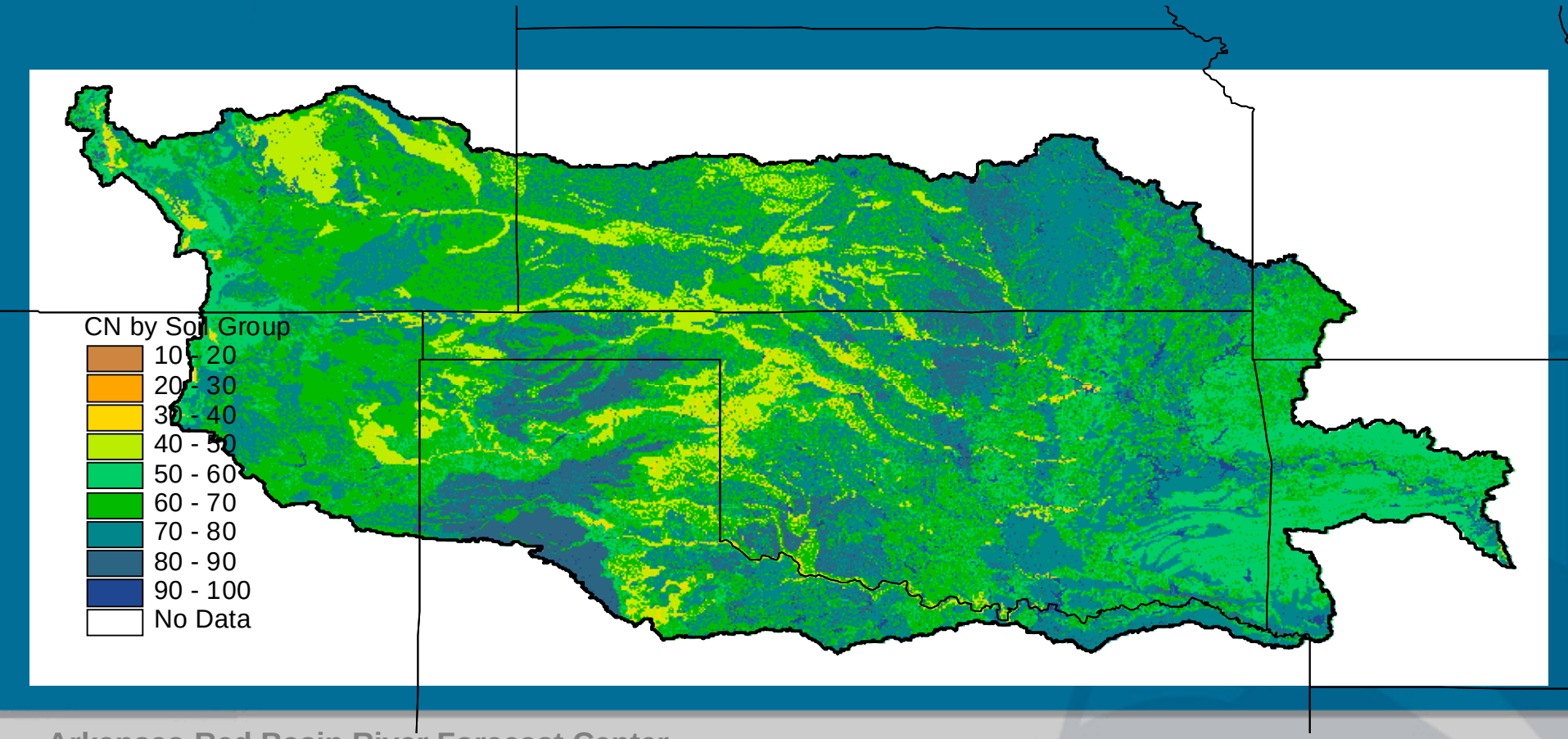


Studies have been performed by comparing land use and soil quality of basins to empirically determine average rainfall-runoff relationships. The resultant curve numbers for these combinations are represented in this table.

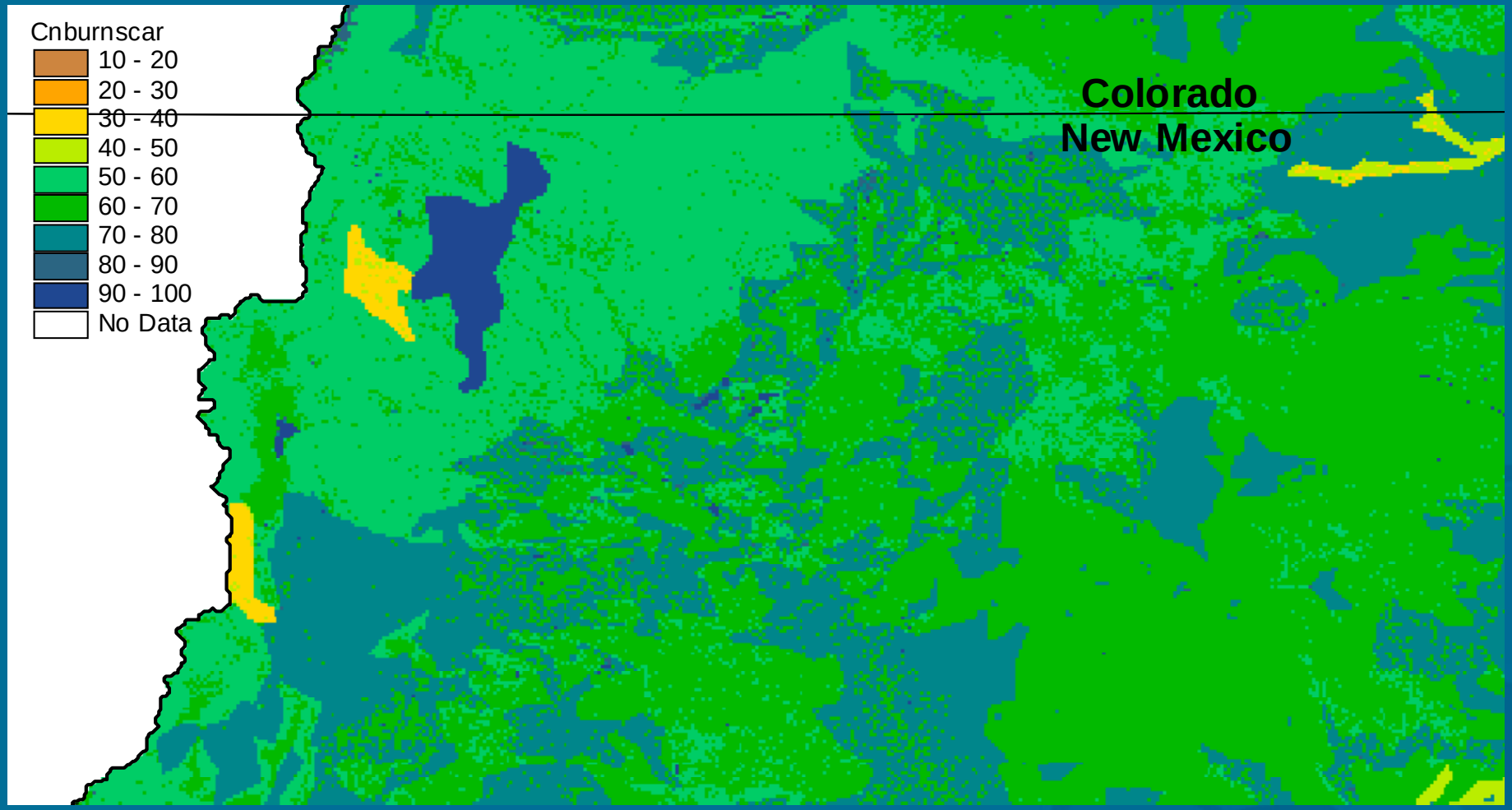
CLASS	DESCRIPTION	A	B	C	D
11	Open Water	100	100	100	100
12	Perennial Ice/Snow	100	100	100	100
21	Low Intensity Residential	57	72	81	86
22	High Intensity Residential	61	75	83	87
23	Commercial/Industrial/Transportation	89	92	94	95
30	Barren	77	86	91	94
31	Bare Rock/Sand/Clay	77	86	91	94
32	Quarries/Strip Mines/Gravel Pits	77	86	91	94
33	Transitional	43	65	76	82
41	Deciduous Forest	36	60	73	79
42	Evergreen Forest	36	60	73	79
43	Mixed Forest	36	60	73	79
50	Shrubland	35	56	70	77
51	Shrubland	35	56	70	77
60	Non-Natural Woody	35	58	71	78
61	Orchards/Vineyards/Other	35	58	71	78
71	Grasslands/Herbaceous	49	69	79	84
81	Pasture/Hay	49	69	79	84
82	Row Crops	67	78	85	89
83	Small Grains	63	75	83	87
84	Fallow	76	85	90	93
85	Urban/Recreational Grasses	39	61	74	80
91	Woody Wetlands	36	60	73	79
92	Emergent Herbaceous Wetlands	49	69	79	84

Runoff Model: NRCS Curve Number

The application of the relationships on the previous slide to the land use and soil quality datasets results in this "normal" curve number grid.



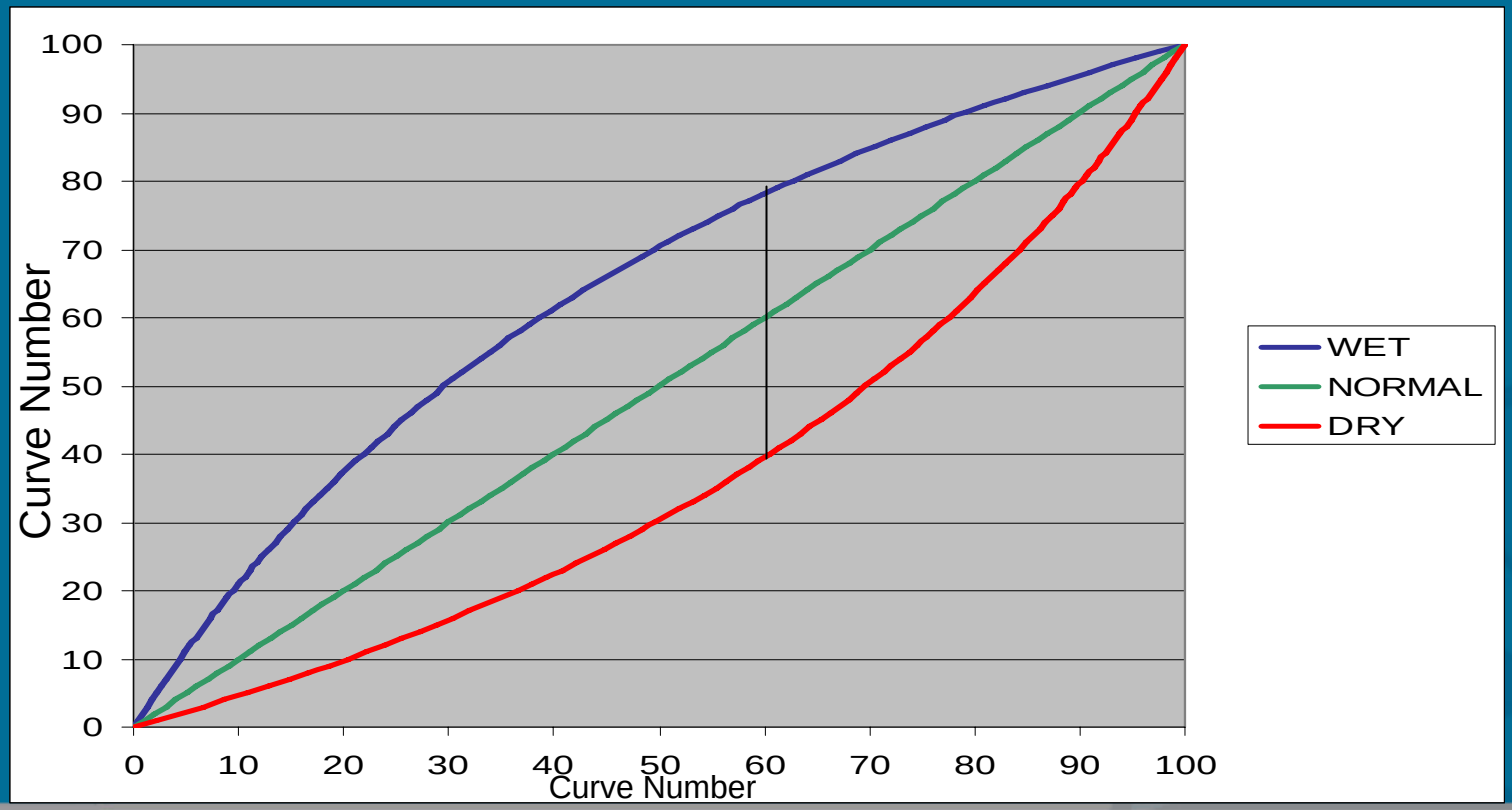
Possible Enhancement:
Burn Scars (or other land use changes)



Runoff Model: NRCS Curve Number

NRCS CN wrapup

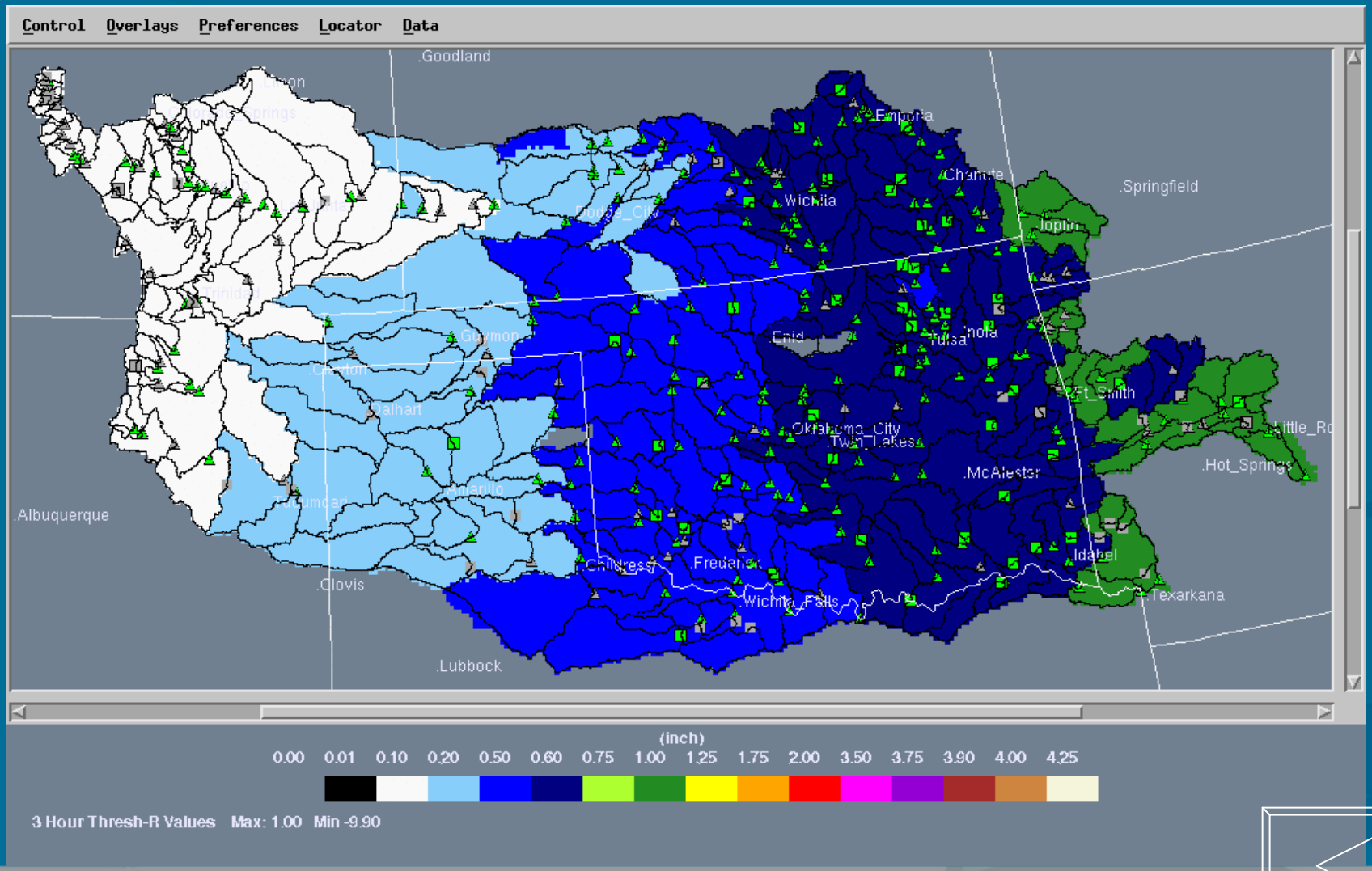
- Each grid cell has a range of possible CN values from "saturated" to "bone dry".
- Each day, a different ABRFC-wide CN grid is calculated based on relative soil moisture from the distributed model.



Threshold Runoff (Thresh R)

ThreshR is supposed to represent the amount of run-off, in inches, necessary to fill small headwater channels to bank-full flow.

Current ABRFC "Gridded" Thresh R Values



Thresh R equations from NRCS Unit Hydrograph Methods

$$ThreshR = \frac{Q_s}{\frac{Q_p}{V}} = \frac{Q_{s(cfs)}}{Q_p\left(\frac{cfs}{in}\right)} = ThreshR(in)$$

- **Qs – a discharge value of concern or consideration,**
  - » *Current Qs is supposed to represent bankfull discharge in small headwater streams of a basin. Gridded Qs can be varied specifically to reflect local flash flood scenarios.*
- **Qp – peak flow from a hydrograph representative of the basin**
  - » *The hydrograph is used to distribute the run-off through time.*
- **V = volume of runoff for a given event**

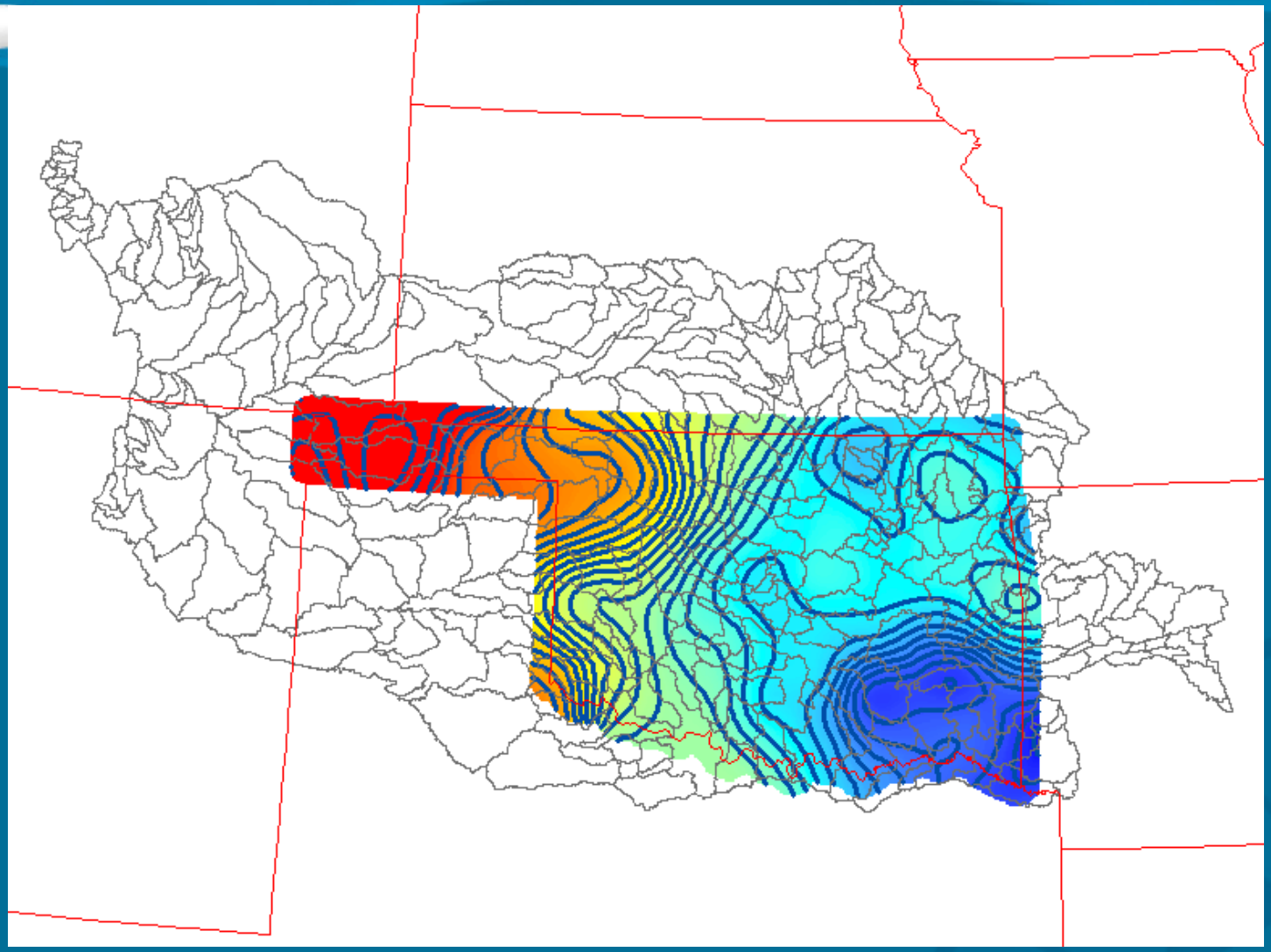
Estimating and Calculating Qs

1. NRCS Curve Number
2. Design storm

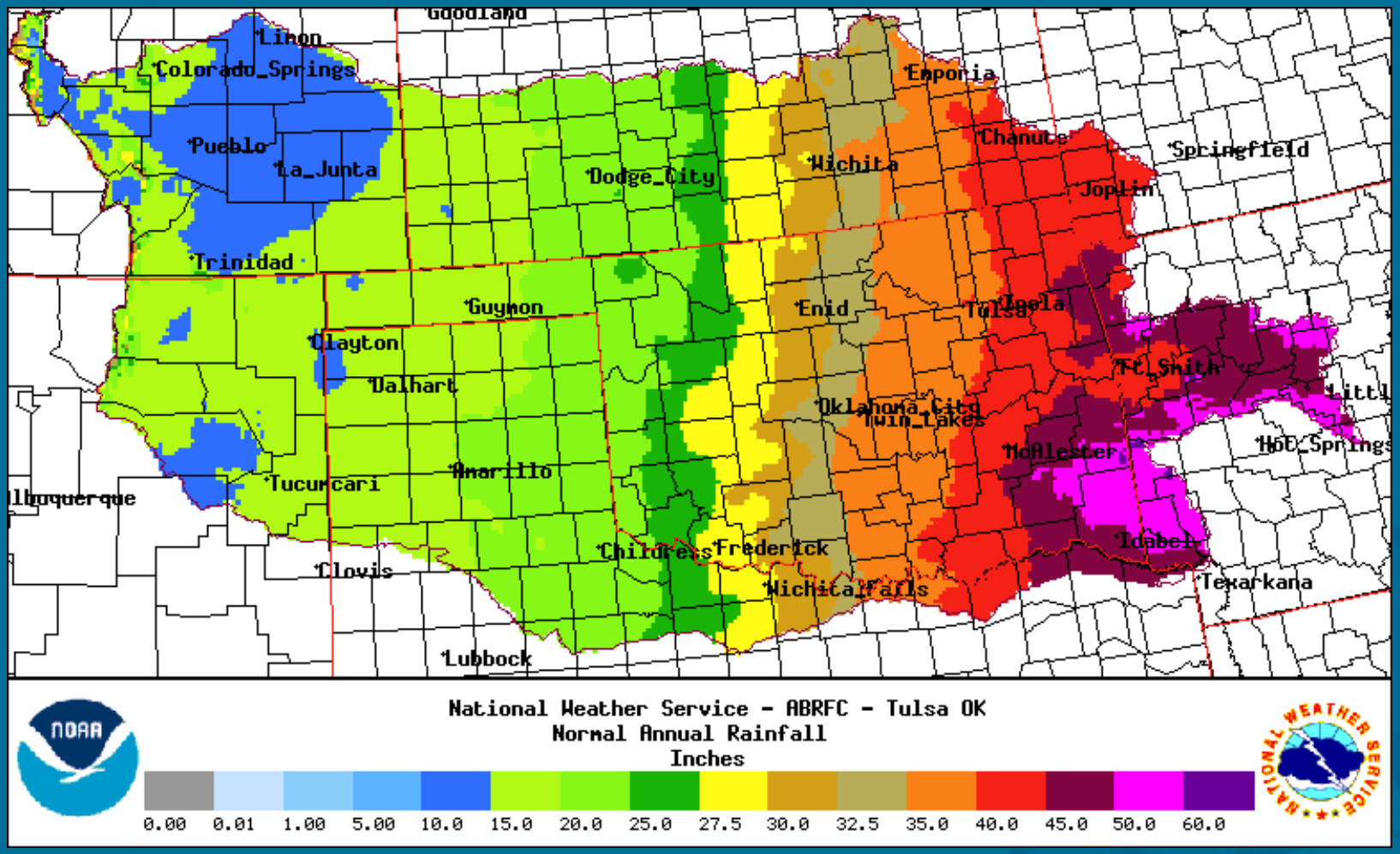
NRCS Curve Number Method

1. Can be used to calculate run-off for a given amount of rainfall
2. 16 km^2 (HRAP scale) may be small enough to use precipitation depth duration frequency to estimate a flow of desired recurrence interval.
3. Gridded DDF precipitation available for OK and TX.

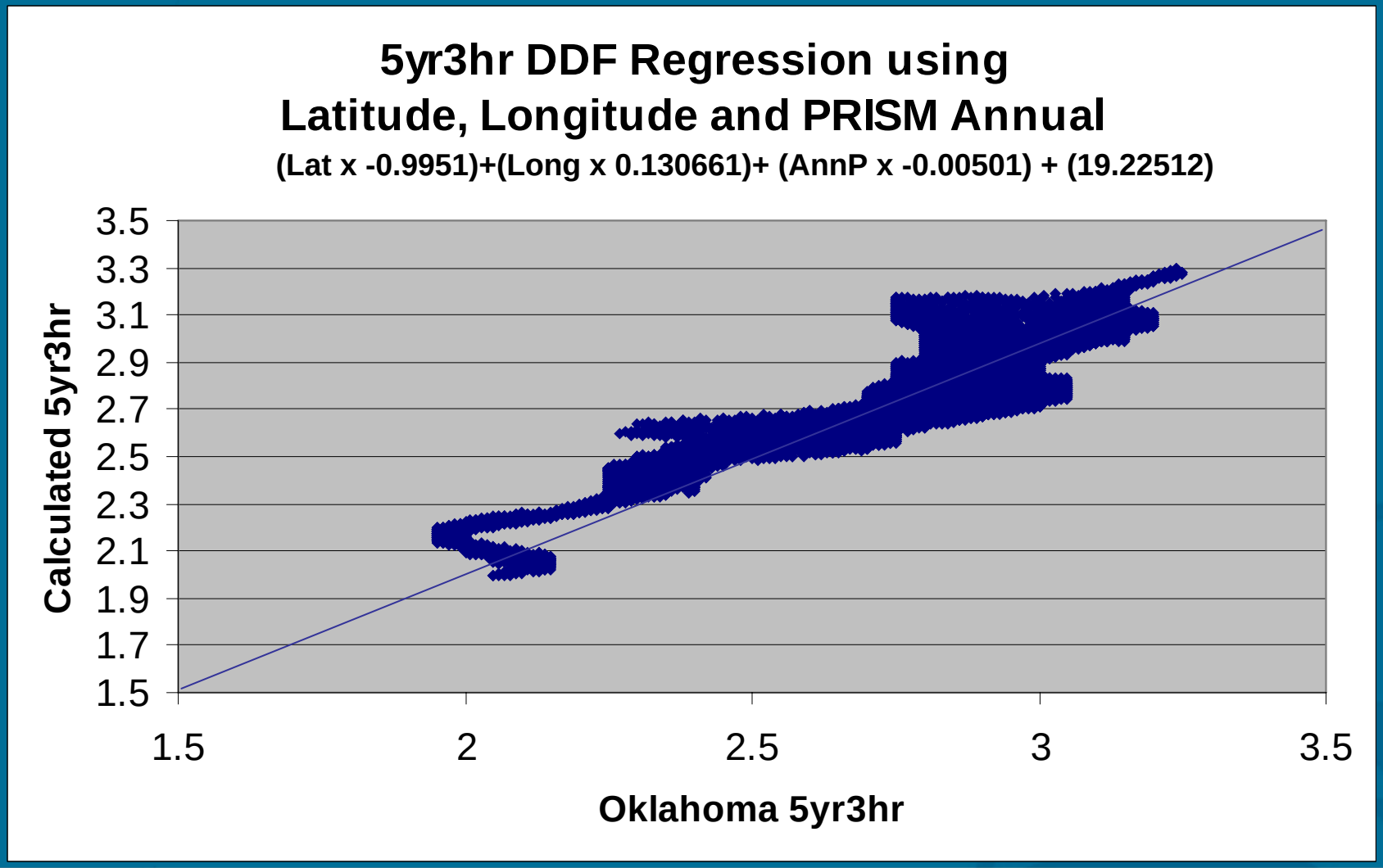
Gridded 5-Year, 3-Hour Precipitation for OK



PRISM Mean Annual Precipitation
ABRFC



5-year 3-hour precipitation predicted v. observed R^2=0.80



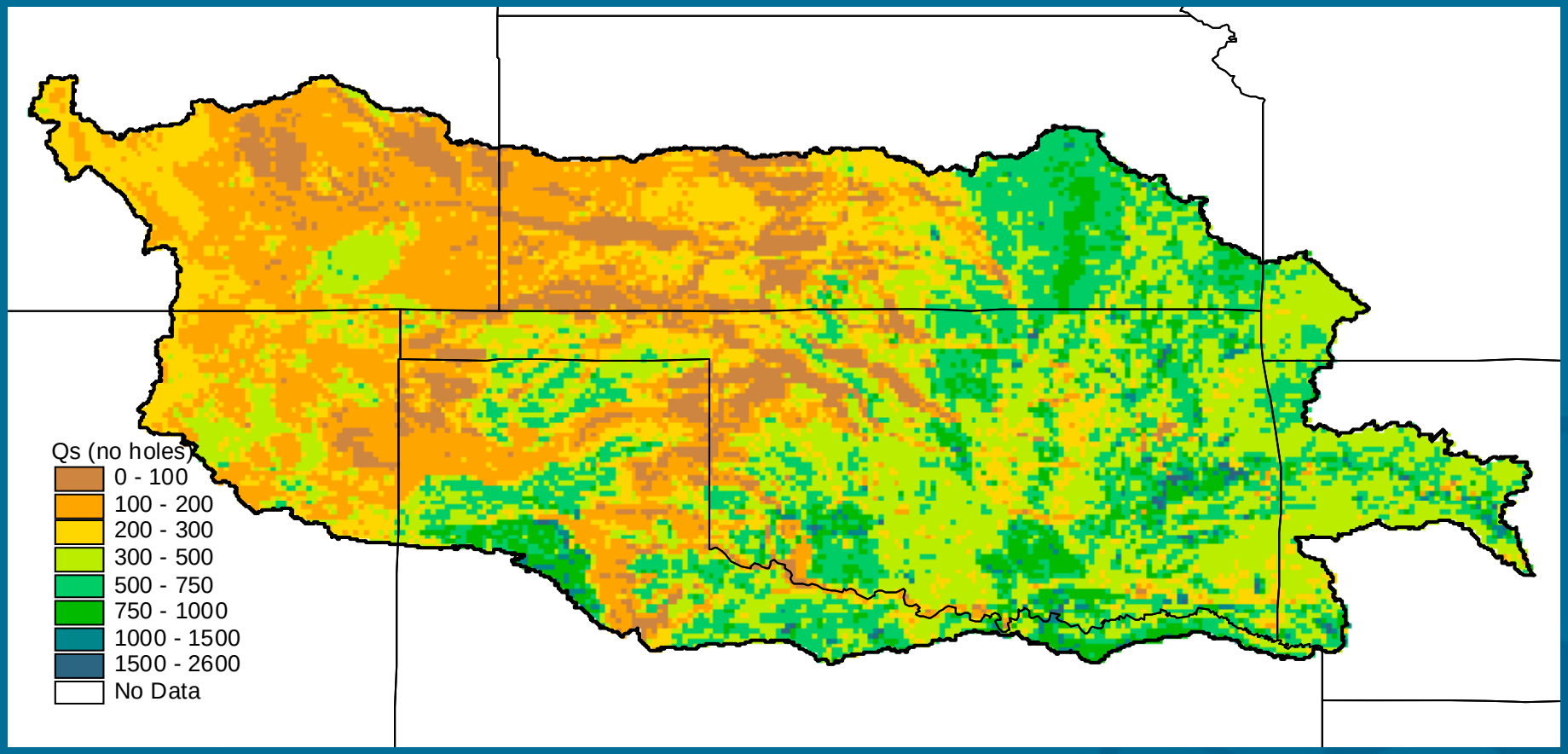
NRCS Method for Estimating Runoff for a given amount of Precipitation

$$Runoff = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Where:

- Runoff is in inches
- P is Precipitation in inches
- S=(1000/CN)-10

Q_s

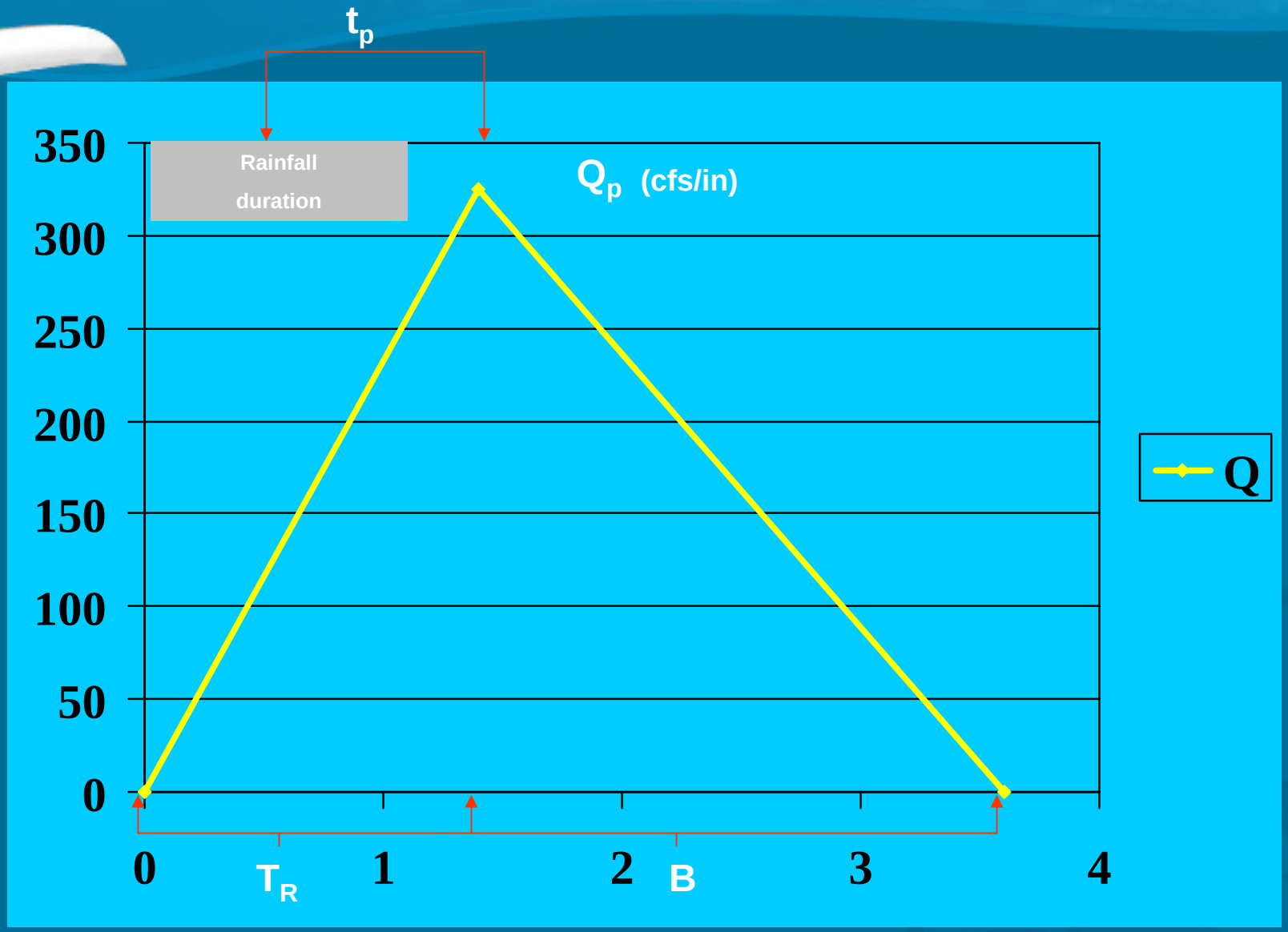

Qs (no holes)
0 - 100
100 - 200
200 - 300
300 - 500
500 - 750
750 - 1000
1000 - 1500
1500 - 2600
No Data

Estimating and Calculating Q_p

- Estimating peak flow Q_p requires distribution of the run-off through time.

- NRCS methods also allow us to distribute the runoff through time and calculate a theoretical peak flow for a given land area with a consistent NRCS Curve Number

SCS Triangular Unit Hydrograph Method



NRCS Triangular Hydrograph Variables

Known Variables

CN= NRCS Curve Number

S=Abstraction = (1000/CN)-10

l = length to divide

y=average watershed slope

A = drainage area

D= duration of rainfall (1 Hour for unit Hydrograph)

$$t_p = \frac{l^{0.8}(S+1)^{0.7}}{1900y^{0.5}}$$

$$T_R = D/2 + t_p$$

$$Q_p = \frac{484 * A}{T_R}$$

Calculated Variables

tp= lag time (time from center of mass of rainfall to Qp)

Tr = time to Qp from beginning of rainfall

Qp= peak discharge from unit hydrograph

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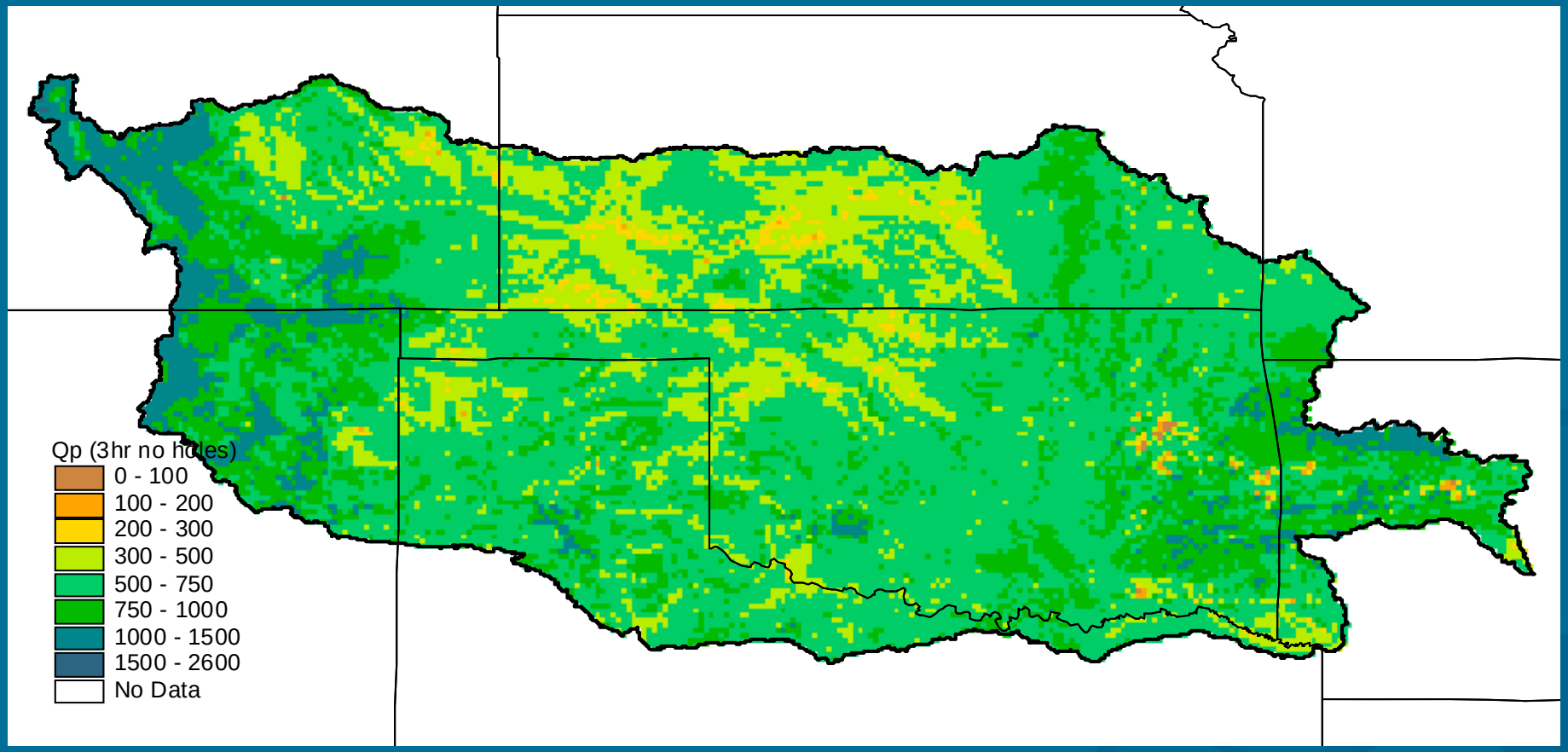
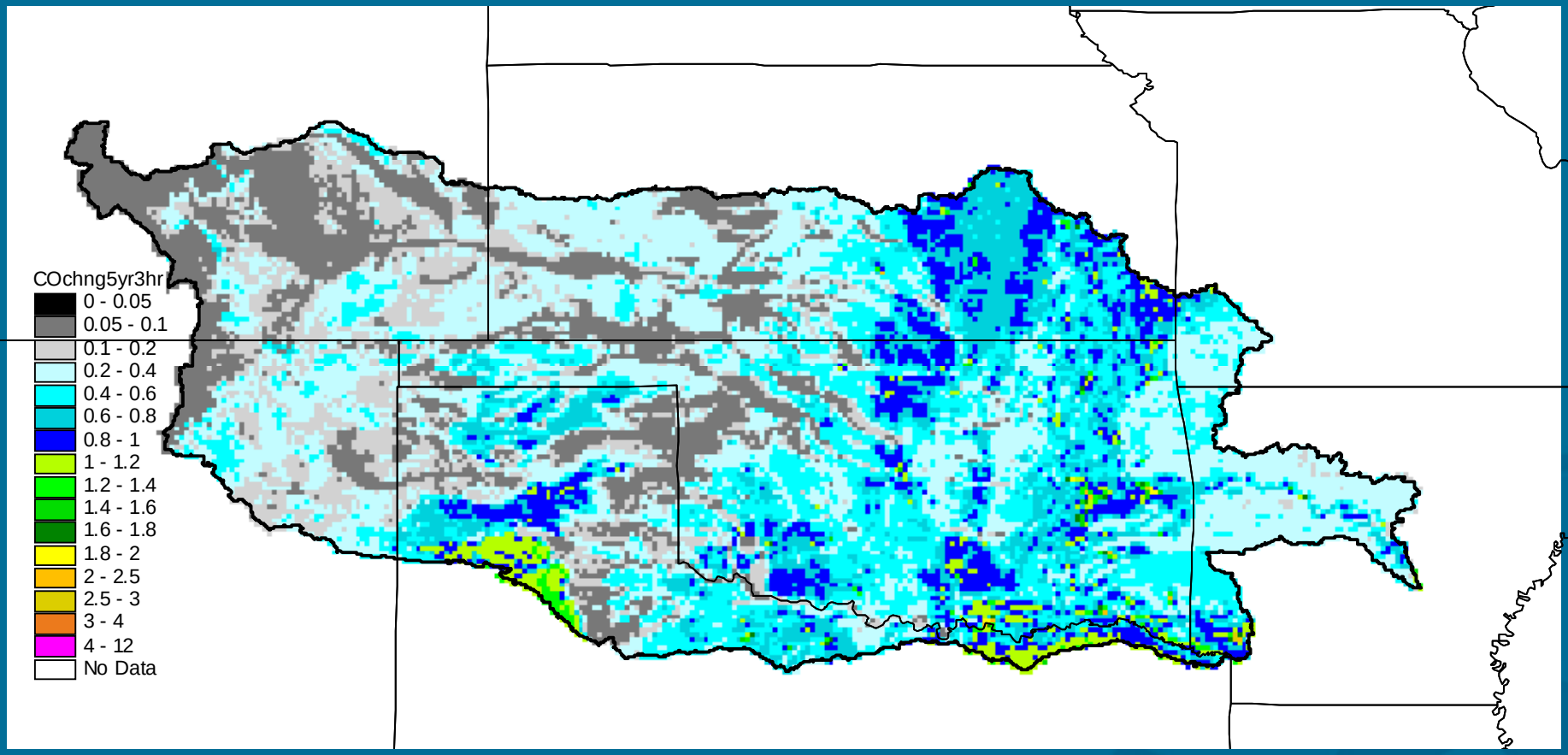
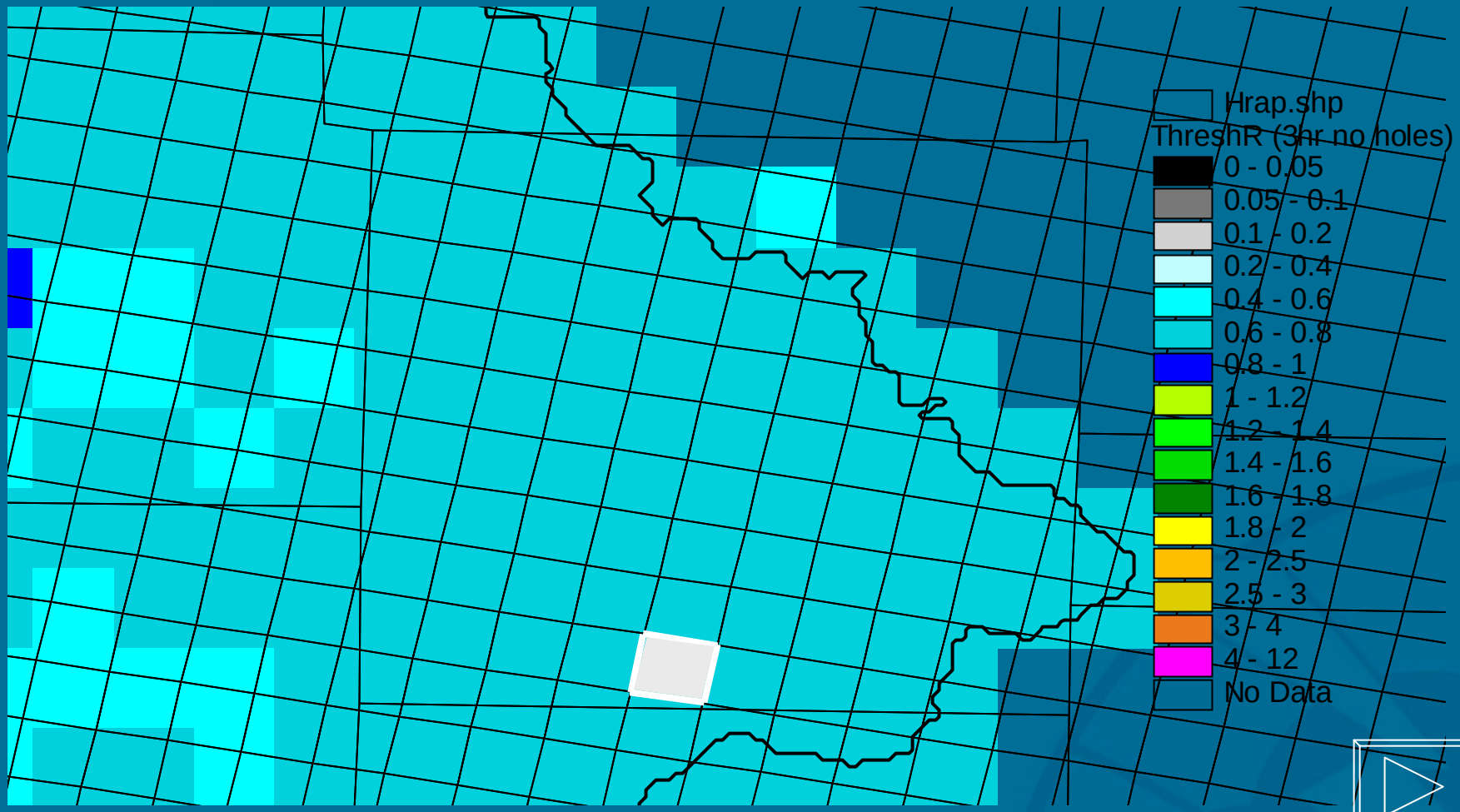
Q_p


Qp (3hr no holes)
0 - 100
100 - 200
200 - 300
300 - 500
500 - 750
750 - 1000
1000 - 1500
1500 - 2600
No Data

5yr-3hr Q_S/Q_P = ThreshR



Possible Enhancement: Thresh R Customization



Calculating Flash Flood Guidance Using NRCS Curve Number and ThreshR

- Once CN is found, the potential abstraction 'S' is calculated using $S=1000/CN - 10$.

- CN is usually used to calculate runoff 'Q' and estimate a hydrologic response. FFG requires that we find what precipitation will *generate* 'Q'.

so… $Q=(P-Ia)^2 * (P+Ia+S)^{-1}$, solved for P….

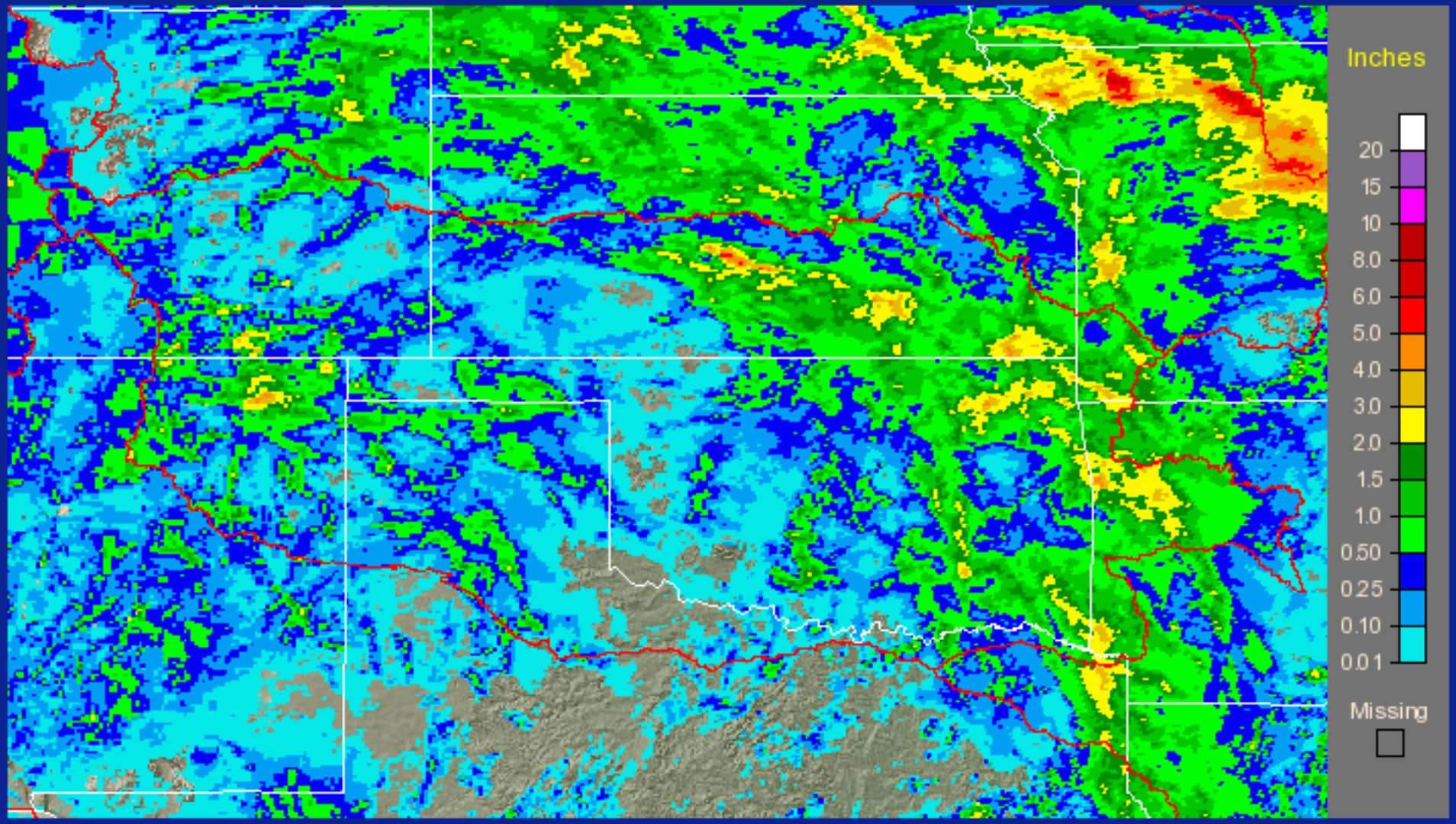
$$P = (.4S + Q +- (Q^2+2QS)^{0.5})/2$$

If we let Ia = 0.2S and Q equal our runoff of interest, or ThreshR, then

$$P = FFG$$

Arkansas-Red Basin RFC Tulsa, OK
14-Day Observed Precipitation - Valid 6/15/2006 1200 UTC

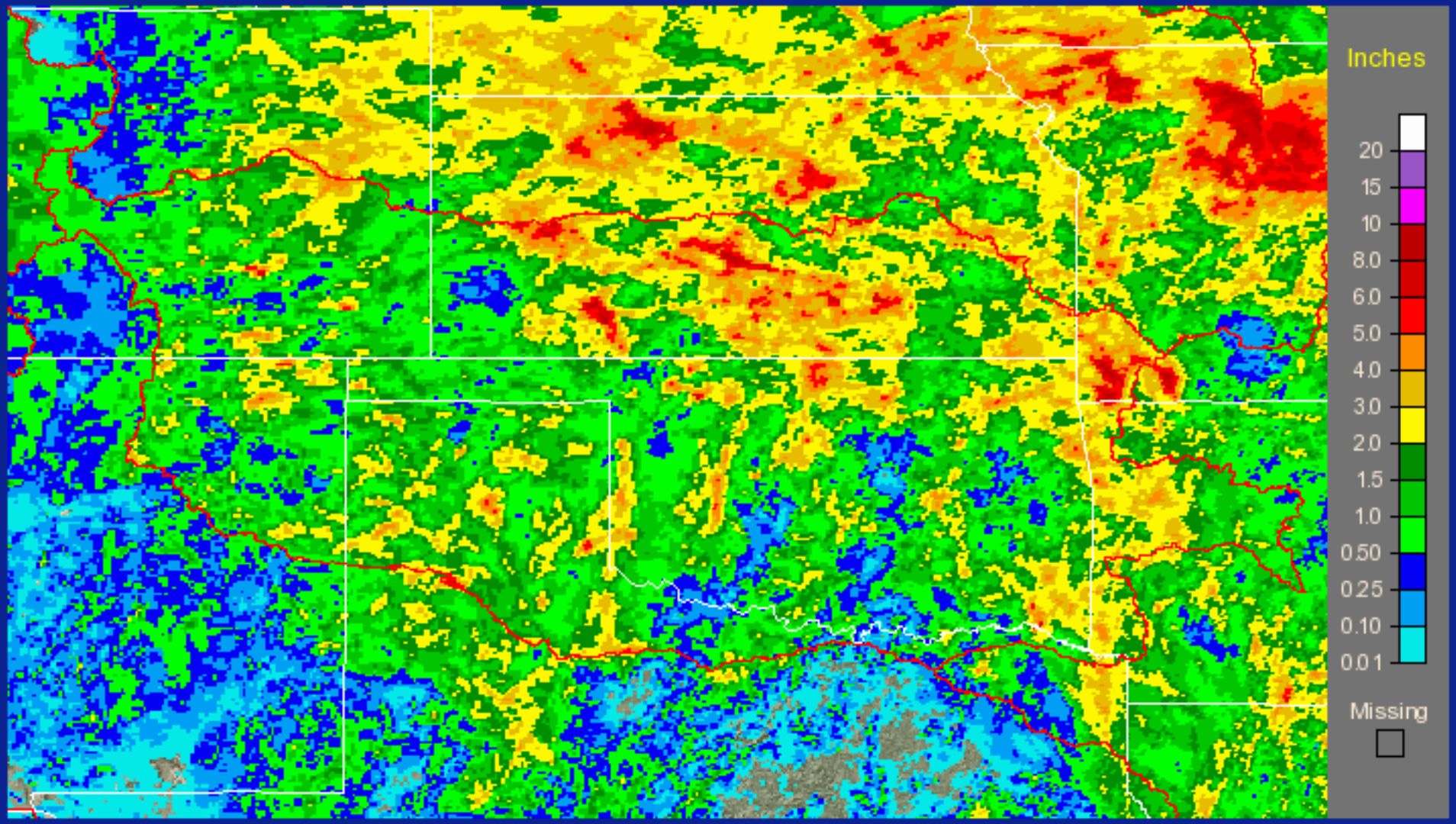
Click on the image to zoom in
Click on "States" to zoom out



☑ Topo ☑ Pcpn Amount ☐ Counties ☐ Rivers ☑ States ☐ Highway/City ☑ RFC Boundary Last Update: 6/15/2006 1735 UTC

Arkansas-Red Basin RFC Tulsa, OK
30-Day Observed Precipitation - Valid 6/15/2006 1200 UTC

Click on the image to zoom in
Click on "States" to zoom out



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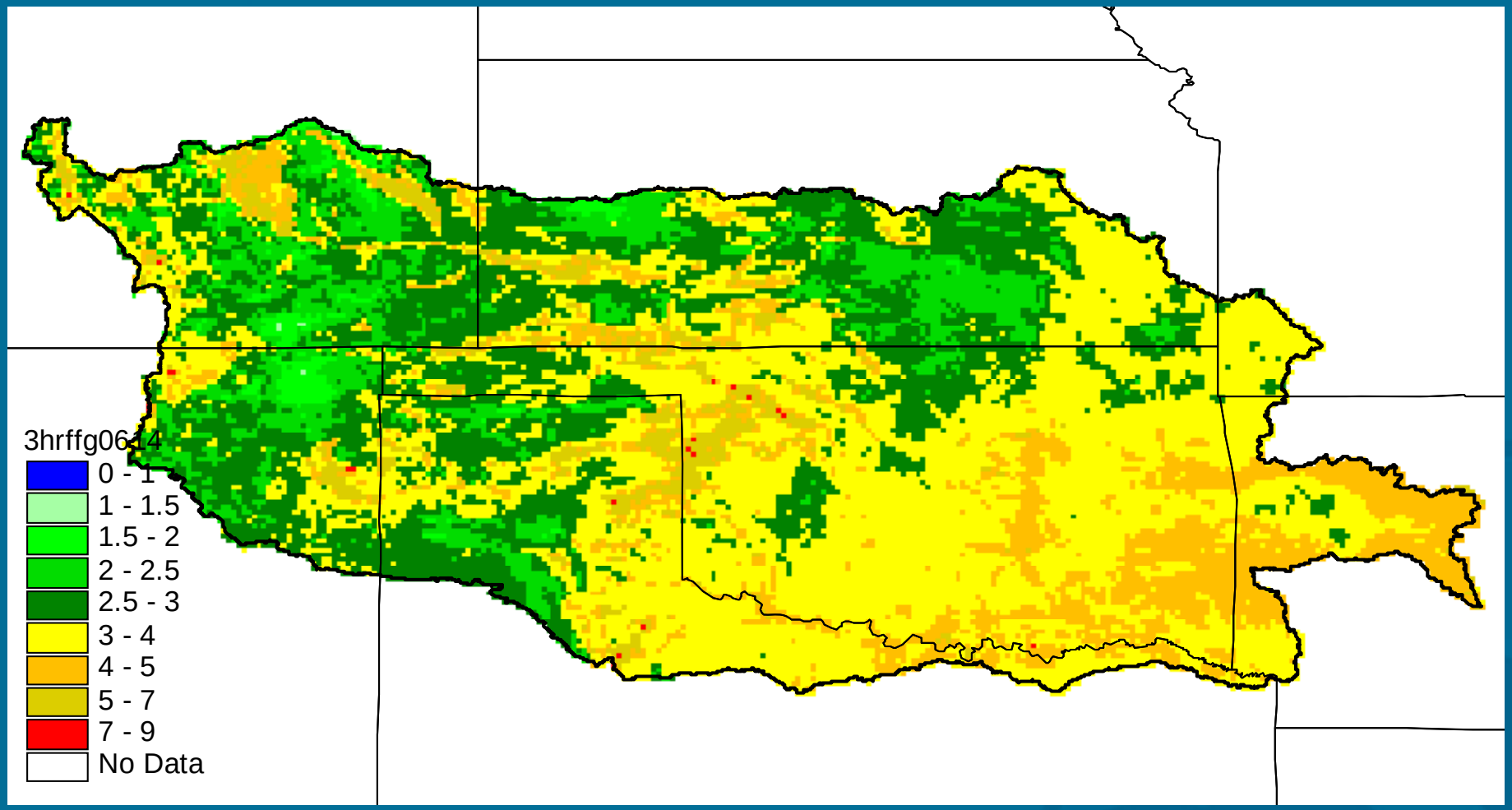
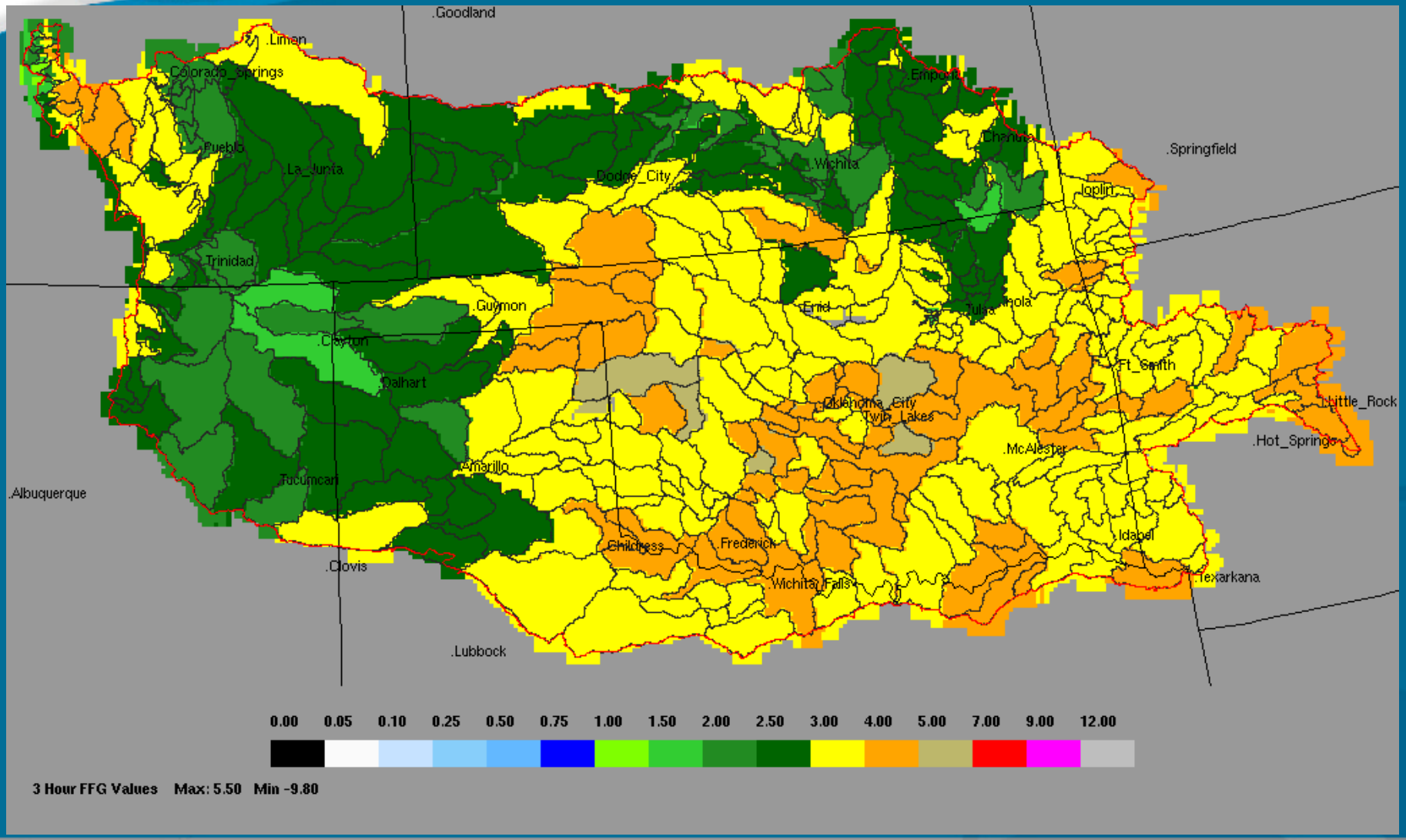
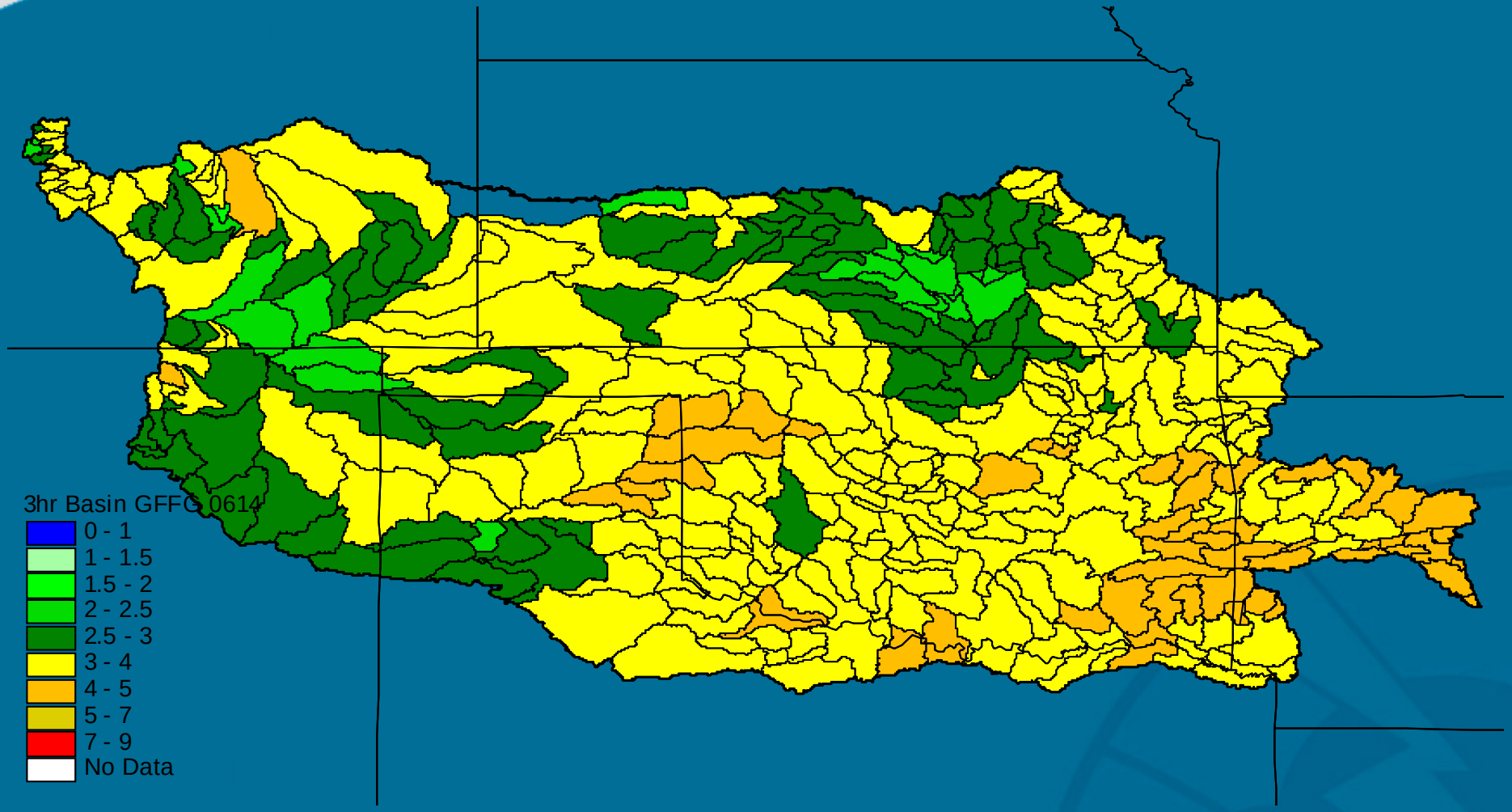
June 14, 2006 Gridded 3-Hour Flash Flood Guidance



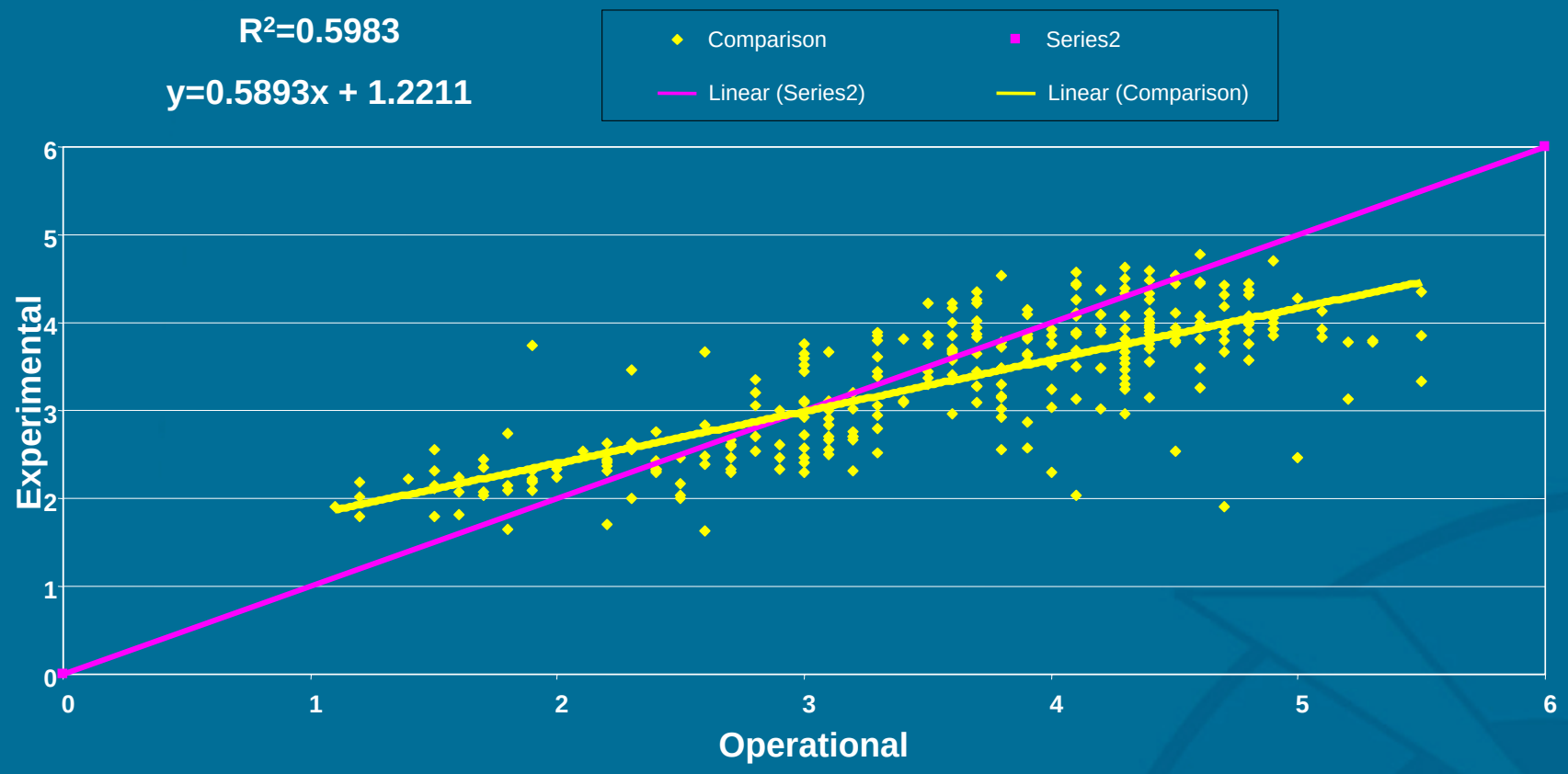
June 14, 2006 Basin 3-Hour Flash Flood Guidance



June 14, 2006 Basin-Averaged Gridded 3-Hour Flash Flood Guidance



Basin Averaged 3-Hour FFG
Operational vs. Experimental
July 10, 2006 12Z



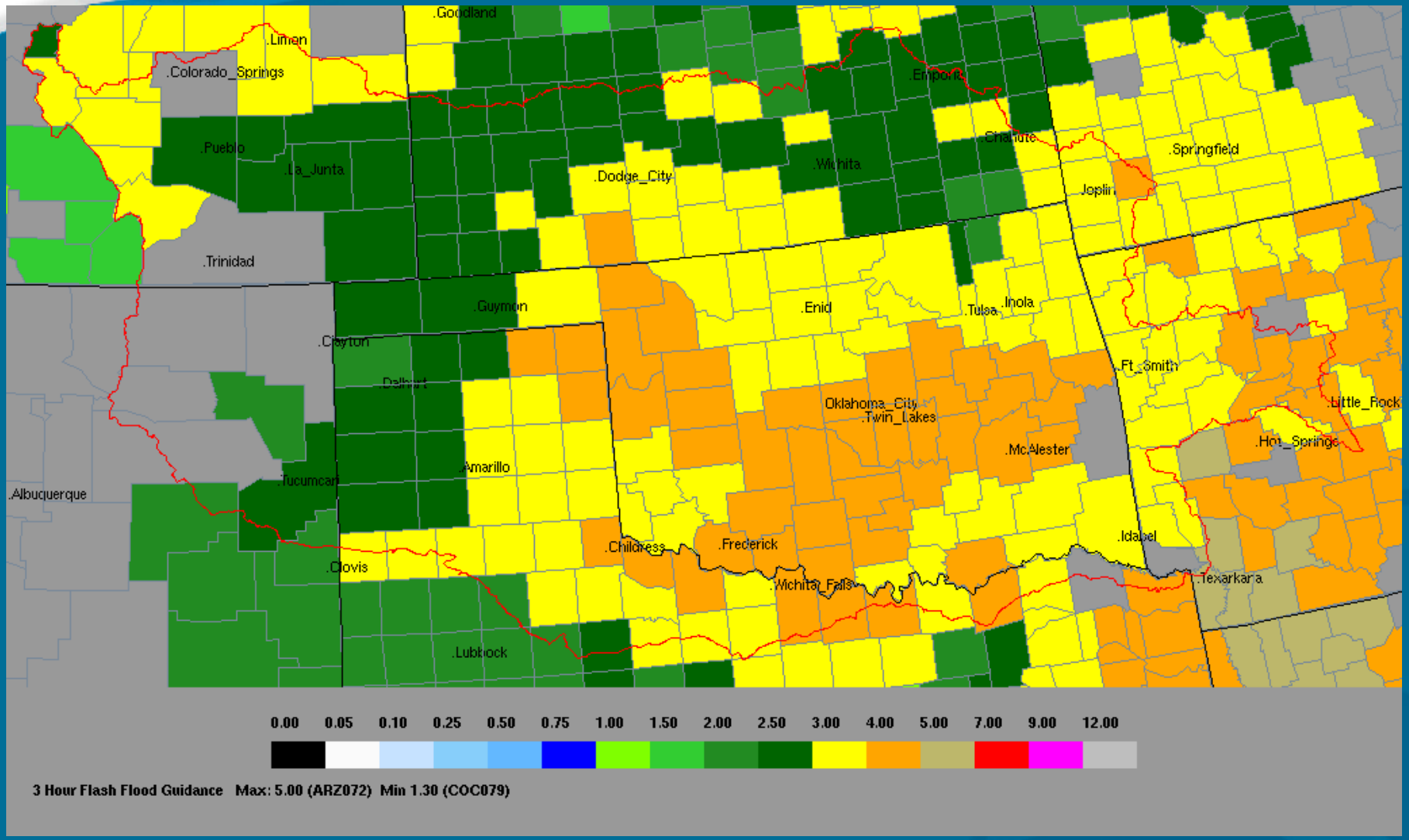
“Verification”

Experimental gridded ThreshR values are initially calibrated to reflect a similar range of values* as the current operational gridded ThreshR.

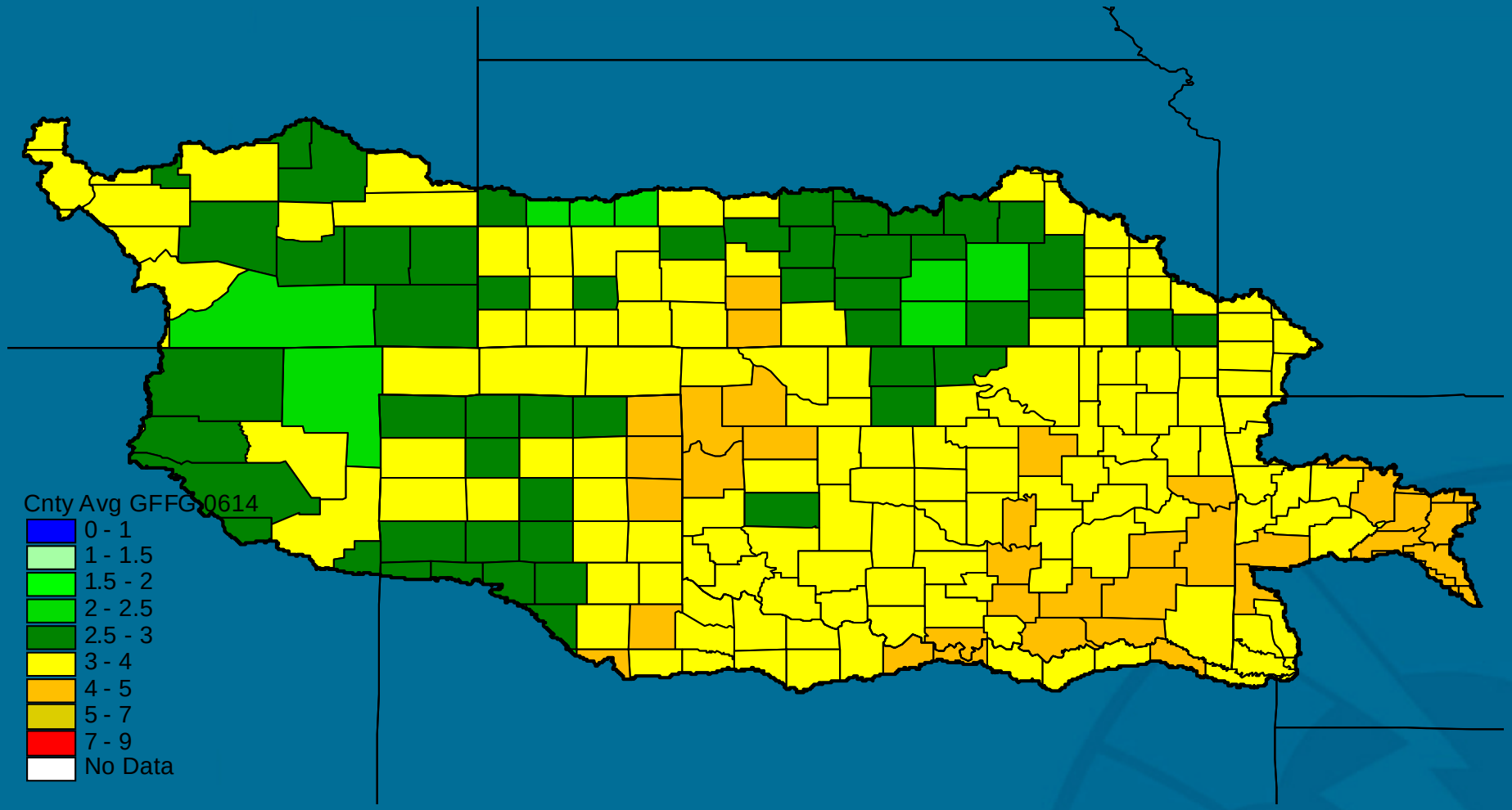
*Experimental ThreshR values range from .10 to about 1.50 inches and operational values range from .10 to 1.00 inches.

Experimental FFG is initially loosely validated such that basin-averaging of gridded FFG is similar to current operational, lumped-parameter FFG.

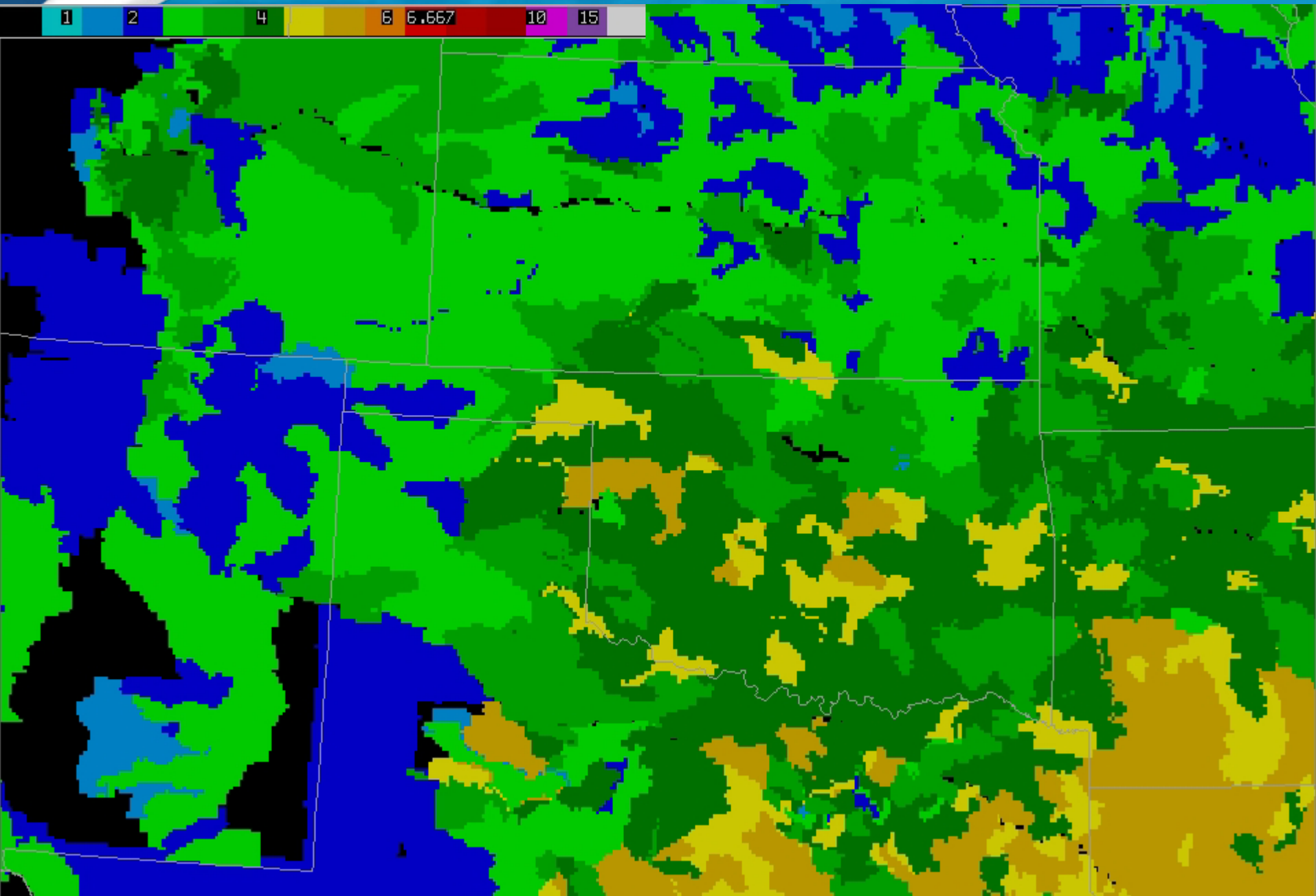
June 14, 2006 County 3-Hour Flash Flood Guidance



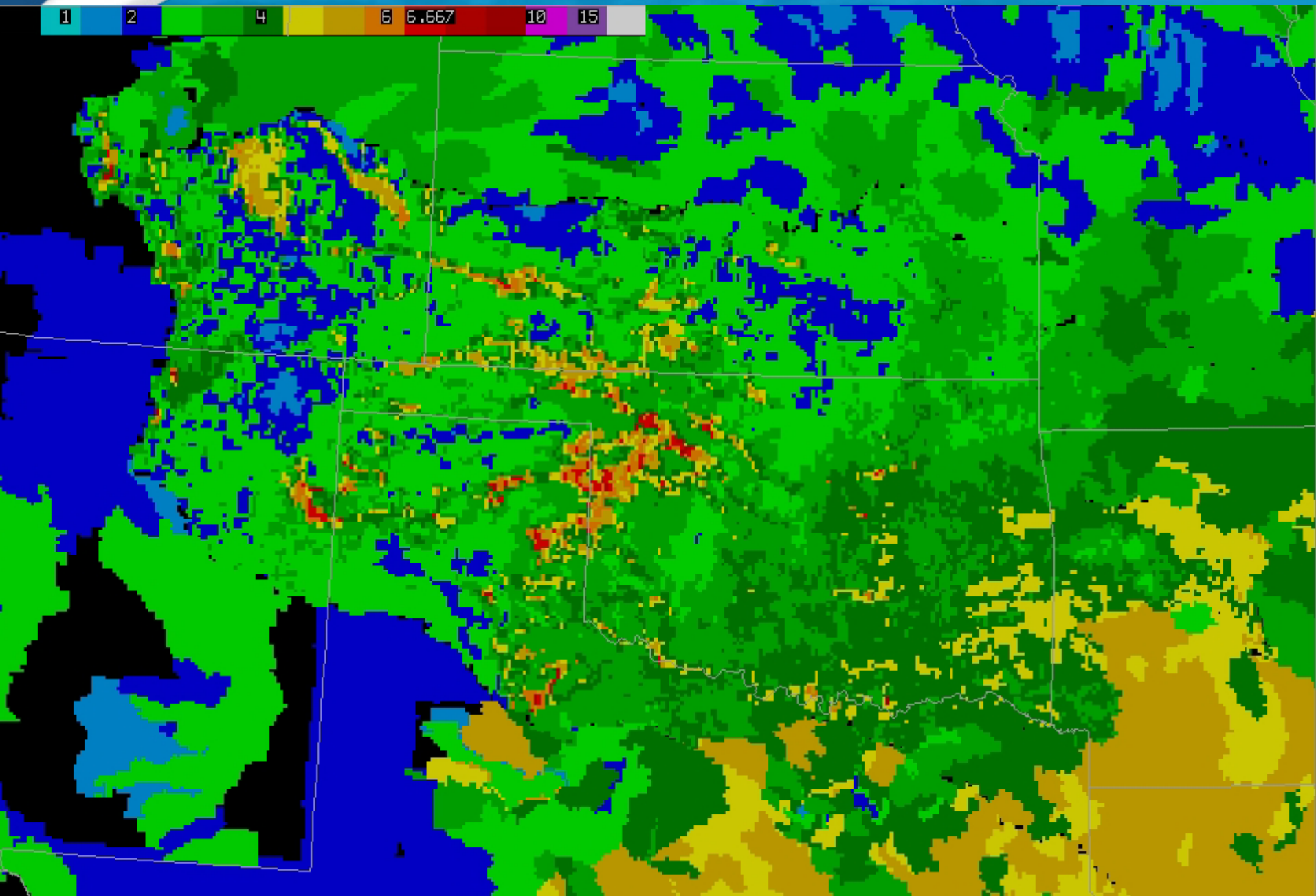
June 14, 2006 County-Averaged Gridded 3-Hour Flash Flood Guidance



June 15, 2006 3-hr Operational FFG



June 15, 2006 3-hr Experimental FFG



Gridded FFG Production Process

1. Run RDMS and generate output text files of UZT and UZF. (~2.5 min/24 hrs)

2. Run ArcView Avenue script to ingest UZT and UZF text files, convert to gridded data, apply appropriate formulas and convert resultant gridded flash flood guidance to text format for output. (~2 min/product)* * currently working on replacing this step with C program (< 2 sec/product).

3. Run data manipulation scripts and programs to convert text information to grib format for WAN transmission. (< 30 sec)

4. WFO ingests grib data where it is converted to netCDF for FFMP ingest.

Questions, concerns and future plans….

- How do we know which method is best, most accurate, most useful?
CONSISTENT VERIFICATION and OPERATIONAL USE

- Are 1, 3 and 6 hour FFG still ideal? How about ½ hour, 2 hour?
OPERATIONAL USE

- How often should we update the values? Daily? Hourly? 3-hourly?
Use Site Specific Concept?
OPERATIONAL USE

- What spatial resolution should we produce? HRAP for now, FFMP in the future?

Questions, concerns and future plans….

FUTURE….

- **Automate production of gridded FFG for entire ABRFC.**
- **Operational deployment to ABRFC WFOs by end of August 2006.**
- **Enhance ThreshR values through integration of WFO FF database and/or hydrologic studies and analyses.**
- **Calculate PE grid instead of using climatology.**
- **Resolve GRIBIT offset error.**
- **Investigate the use of various AMC conditions to account for flash flood guidance durations.**
- **Expansion of project eastward.**

Acknowledgements

Assistance in implementing Research Distributed Hydrologic Model: Victor Koren and Zhengtao Cui

Programming Assistance: James Paul

Contacts

john.schmidt@noaa.gov

tony.anderson@noaa.gov

(918) 832-4109

Feedback from COMET presentation…

Comments:

Great work in the field, would like to see this implemented nationwide, or at least east of the Rockies. Would like to see additional testing of Qp and Qs methodology.

The first presentation I've seen on this approach. Looks promising compared to current methods.

Well done presentation on information I was not aware of. I am somewhat uncomfortable with some of the approaches being used in their modeling process, but I believe it is a step in the right direction.

Limited application due to unavailability of DHM at RFCs.

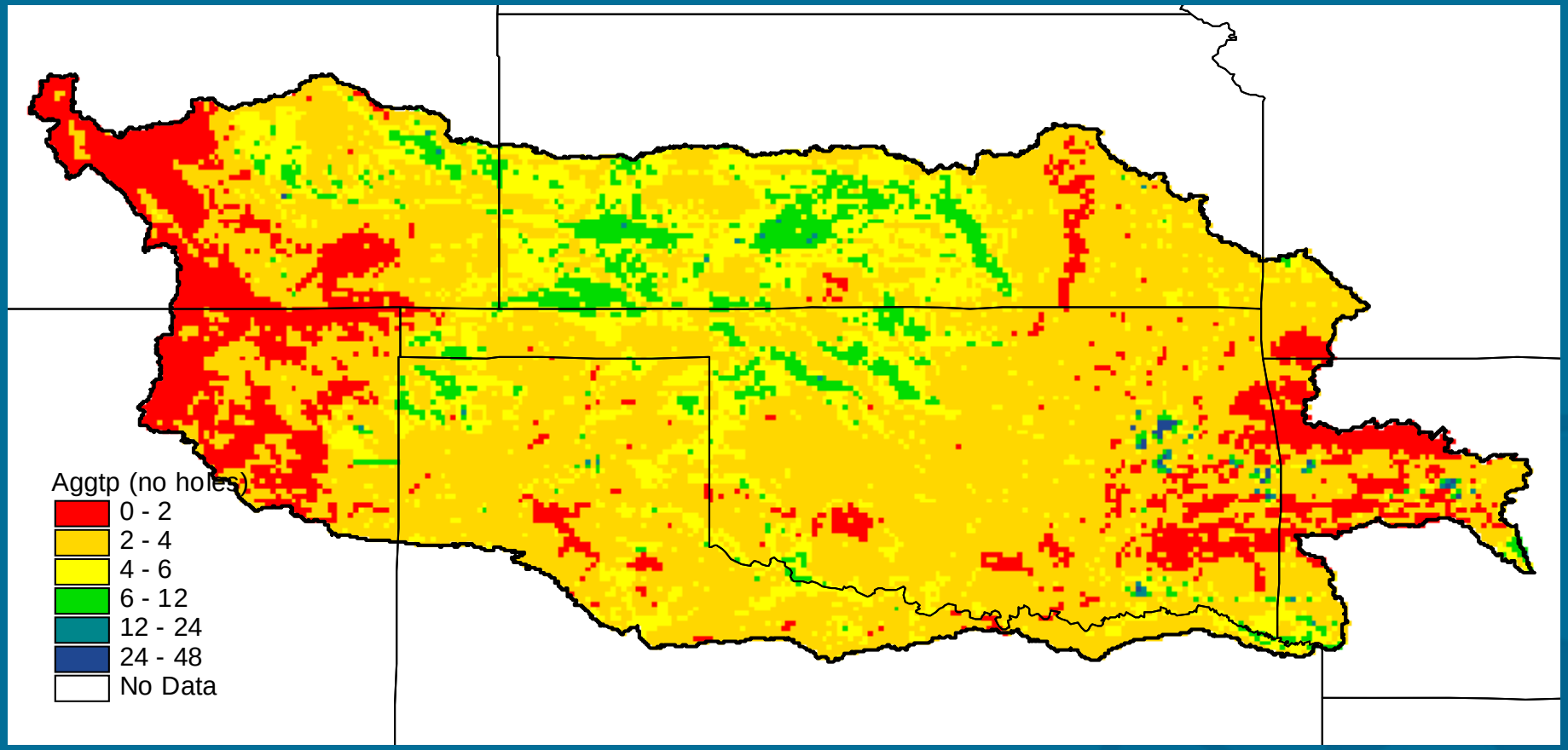
Good idea of how to look at FFG differently, but requires running distributed model without manual intervention and innovative work to relate guidance to curve number.

This application for Gridded FFG needs to become a nationwide effort.

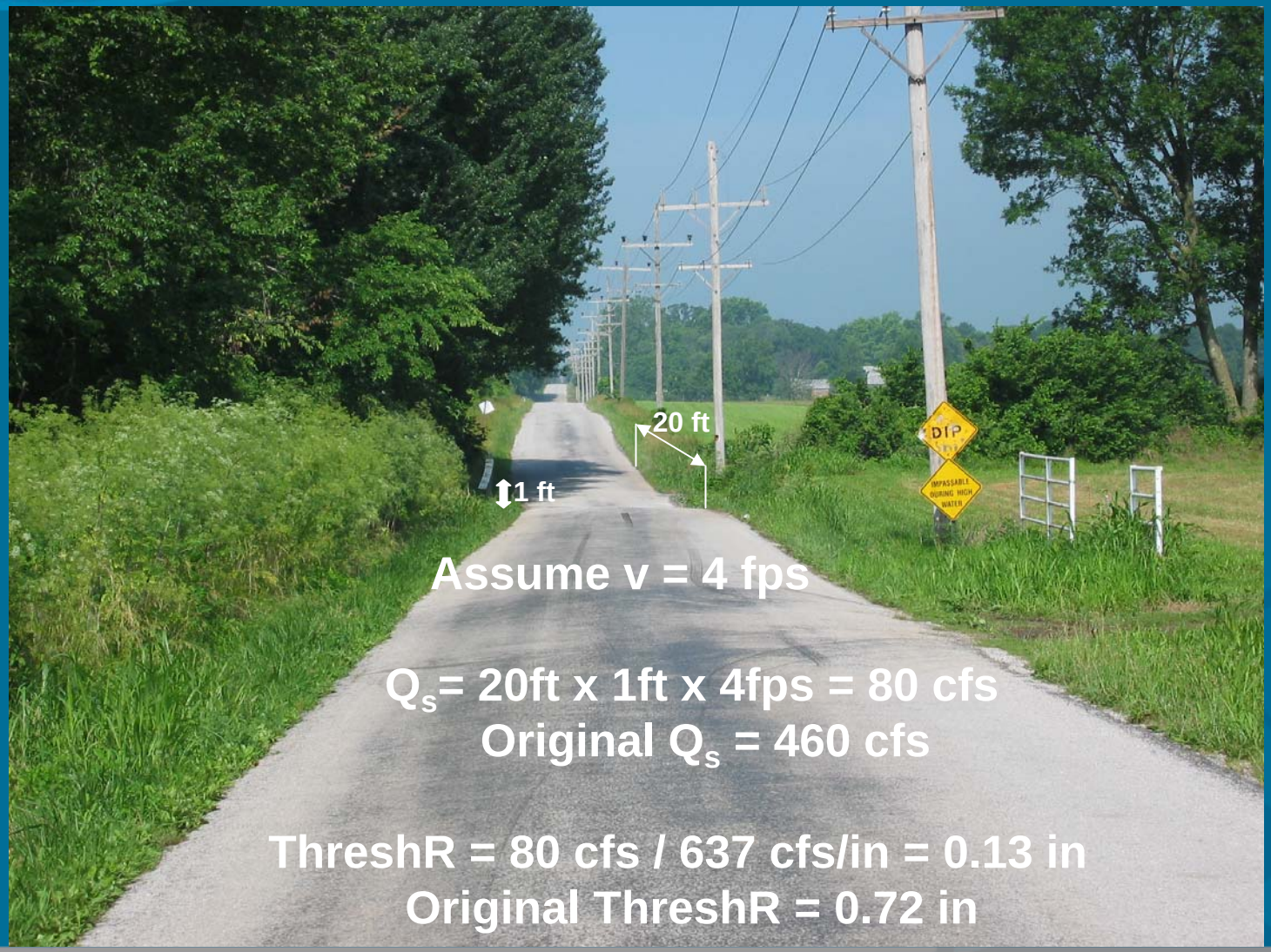
Great material, look forward to it's continued integration with the field.

Very useful to see what other RFCs are trying to do.

t_p



Possible Enhancement: ThreshR Customization



Assume v = 4 fps

Q_s= 20ft x 1ft x 4fps = 80 cfs
Original Q_s = 460 cfs

ThreshR = 80 cfs / 637 cfs/in = 0.13 in
Original ThreshR = 0.72 in

WFO Flash Flood Verification

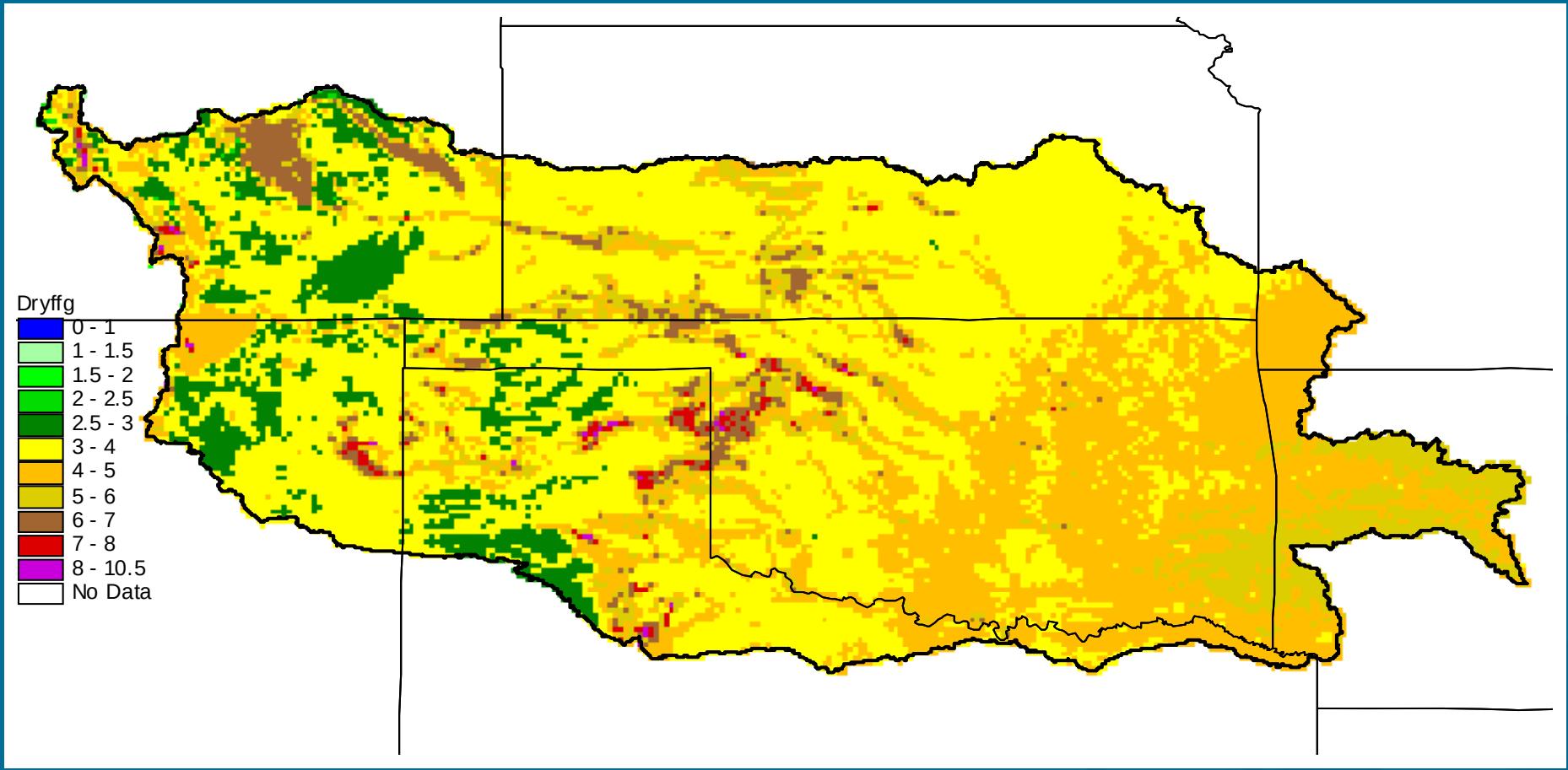
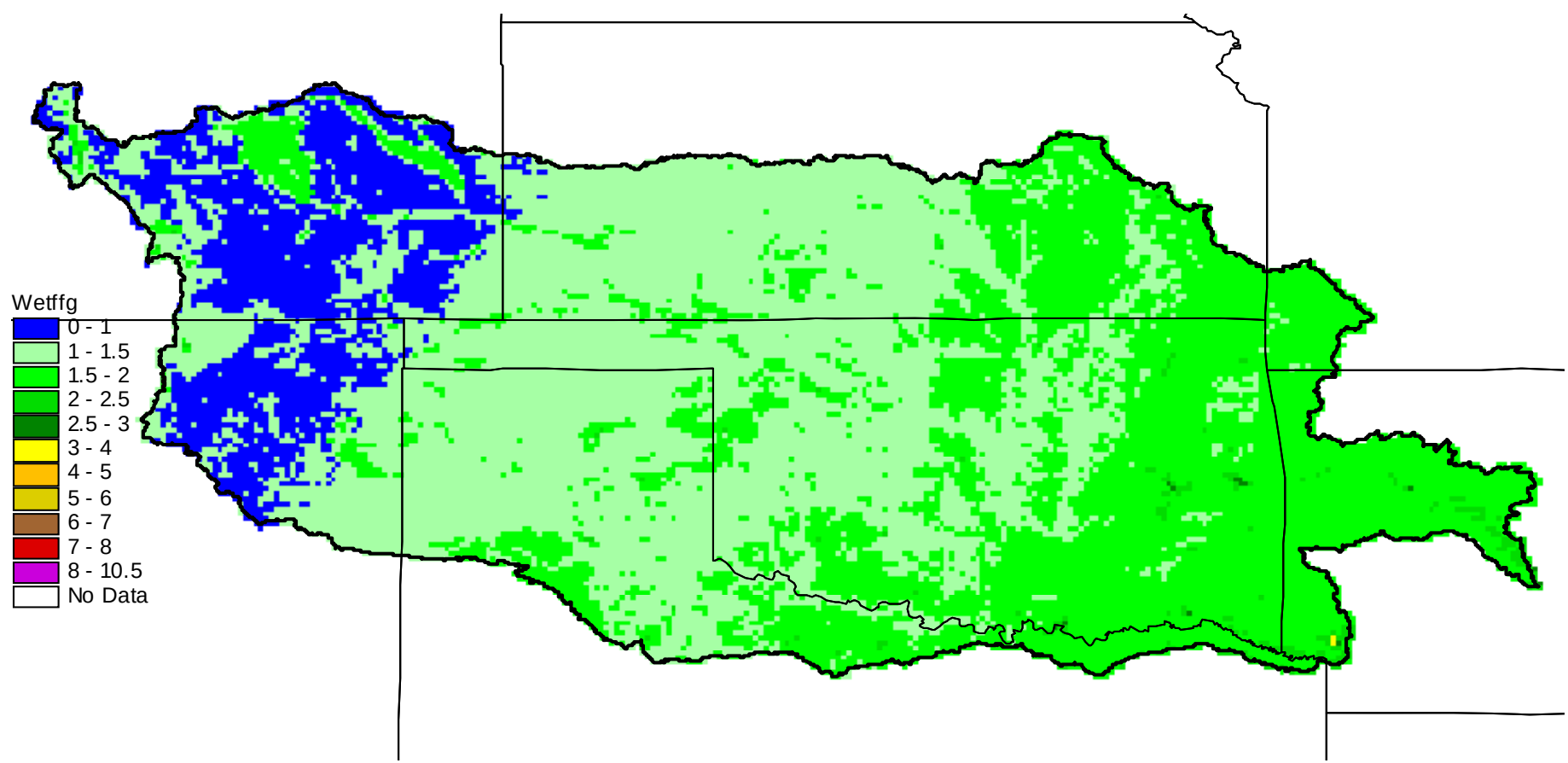
..TIME... ..DATE...	...EVENT... ....MAG.... ..REMARKS..	...CITY LOCATION... ..COUNTY LOCATION..ST..		...LAT.LON... ...SOURCE....
0211 AM 07/10/2006	FLASH FLOOD	2 NE COURTLAND REPUBLIC	KS	39.80N 97.87W LAW ENFORCEMENT
DEPUTY REPORTED WATER UP TO 5 INCHES DEEP OVER HIGHWAY 266 ABOUT 2 MILES NORTHEAST OF COURTLAND.				
0534 PM 07/09/2006	FLASH FLOOD	8 N PUEBLO PUEBLO	CO	38.38N 104.62W LAW ENFORCEMENT
VEHICLES REPORTED STUCK IN HIGH WATER AT EXIT 108 ON I-25. ONE FOOT OF WATER OVER OVERTON ROAD AT 1800 AND 1900 BLOCKS				
0957 PM 07/11/2006	FLASH FLOOD	ANY CITY ANY COUNTY	XX	3X.07N 9X.04W BROADCAST MEDIA
5.23 INCHES OF RAIN AT ANY CITY MIDDLE SCHOOL. REPORTED BY XXX.				

Basin Averaged 3-Hour FFG Operational vs. Experimental July 10, 2006 12Z

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	3.562033898	3.32039322
Variance	1.002499251	0.574624541
Observations	295	295
Pearson Correlation	0.778421342	
Hypothesized Mean Difference	0	
df	294	
t Stat	6.599442312	
P(T<=t) one-tail	9.60481E-11	
t Critical one-tail	1.28443772	
P(T<=t) two-tail	1.92096E-10	
t Critical two-tail	1.650052985	

UZSat = 0%



UZSat = 100%