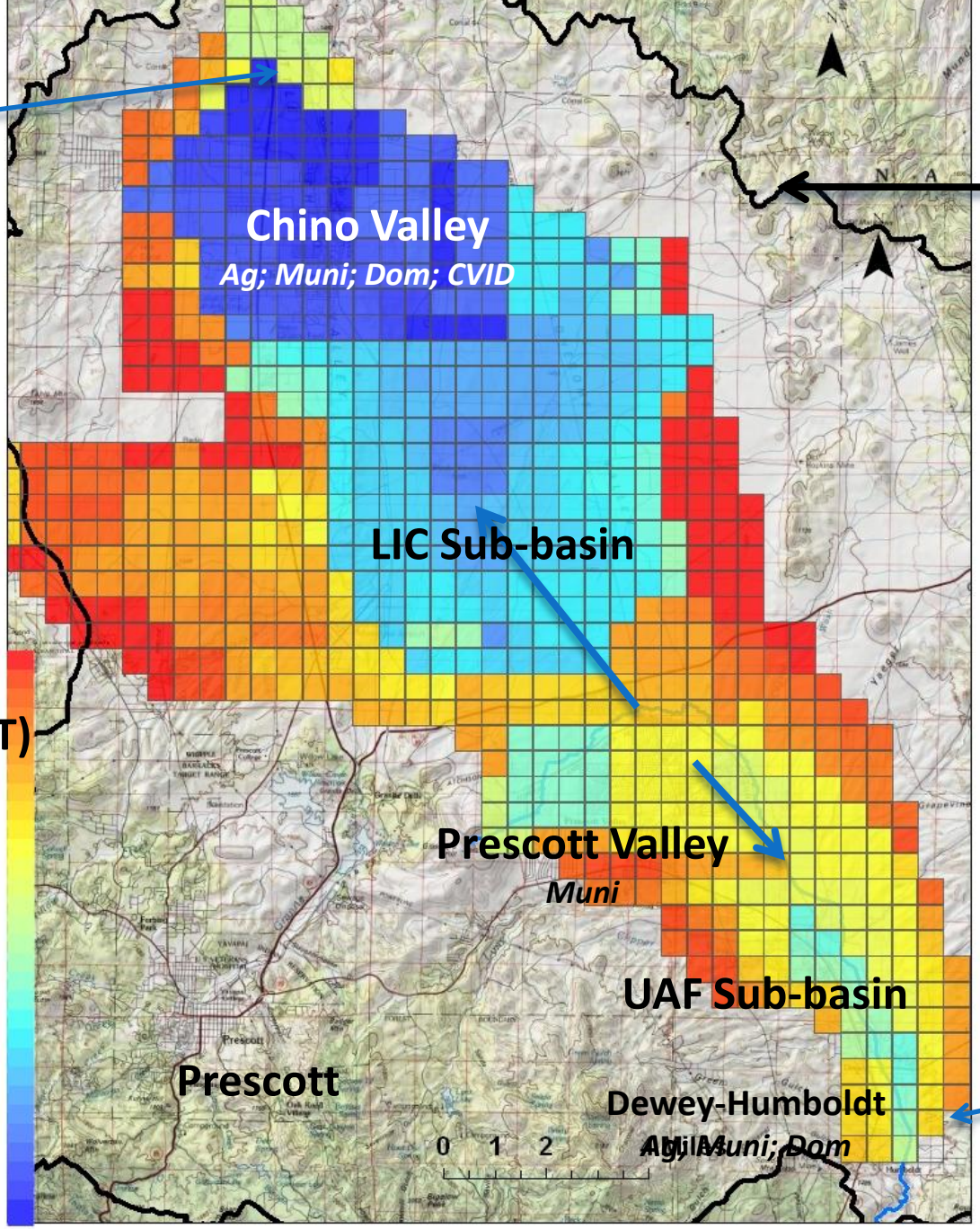
# *Provisional ADWR Prescott AMA Groundwater Flow Model*

## *Natural Recharge Discussion*

1) Regional & Local Hydrology
2) ADWR Model History / Safe - yield
3) Model Estimated Natural Recharge Rates
4) Observed Streamflow Scaled to Contributing Areas
   Granite Creek 228 miles$^{2;}$ Upper Agua Fria Sub-basin 175 miles$^{2}$
5) Simulated Water budgets 1939-2011; 1941-65; 1965-95; 1995-2011
6) Observed and Simulated Heads & Flows
7) Alternative Conceptual Models (K & RCH)
8) Parameter reliability

Del Rio Springs

Prescott
AMA Boundary

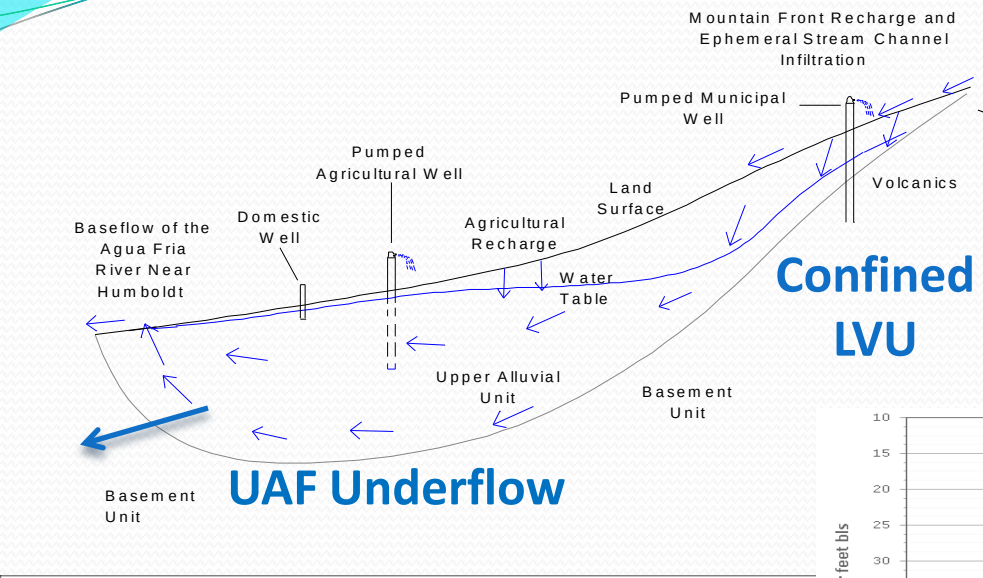


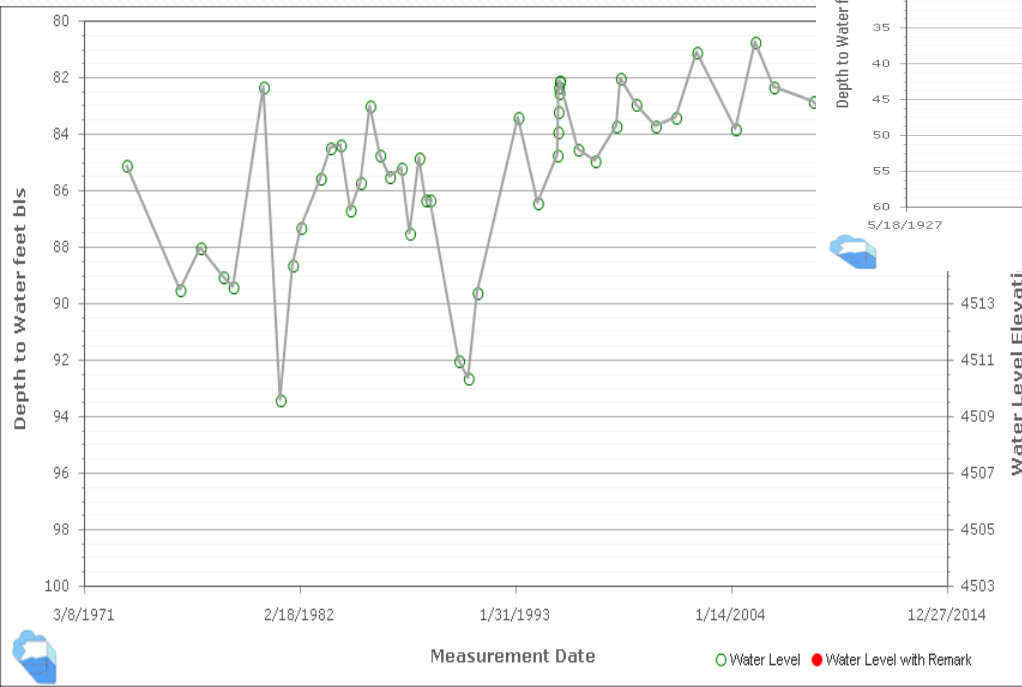

Map Shows
Simulated Total
Transmissivity (T)
Low T in red
High T in Blue

Agua Fria
River
Baseflow

# Conceptual Model of Groundwater Flow in the Prescott AMA Model Area

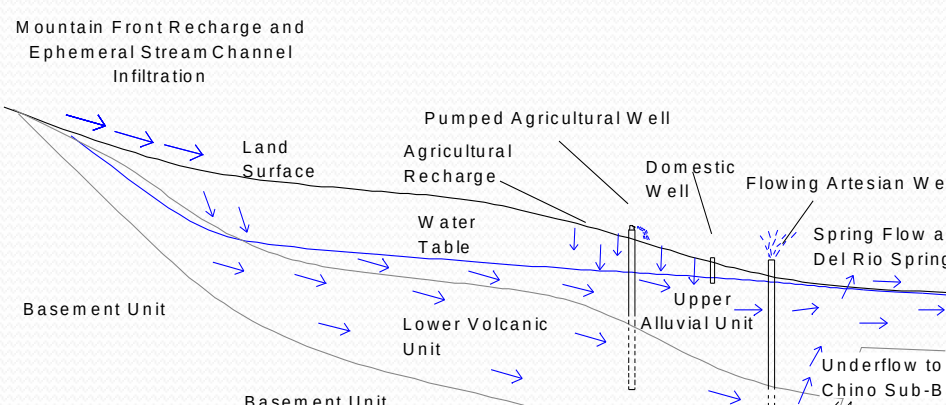
## Upper Agua Fria Sub-Basin

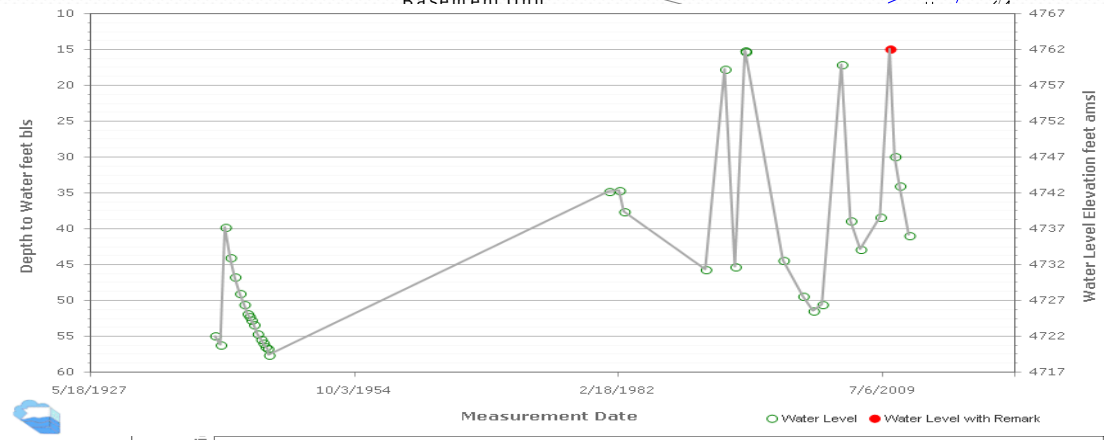



# Conceptual Model of Groundwater Flow in the Prescott AMA Model Area

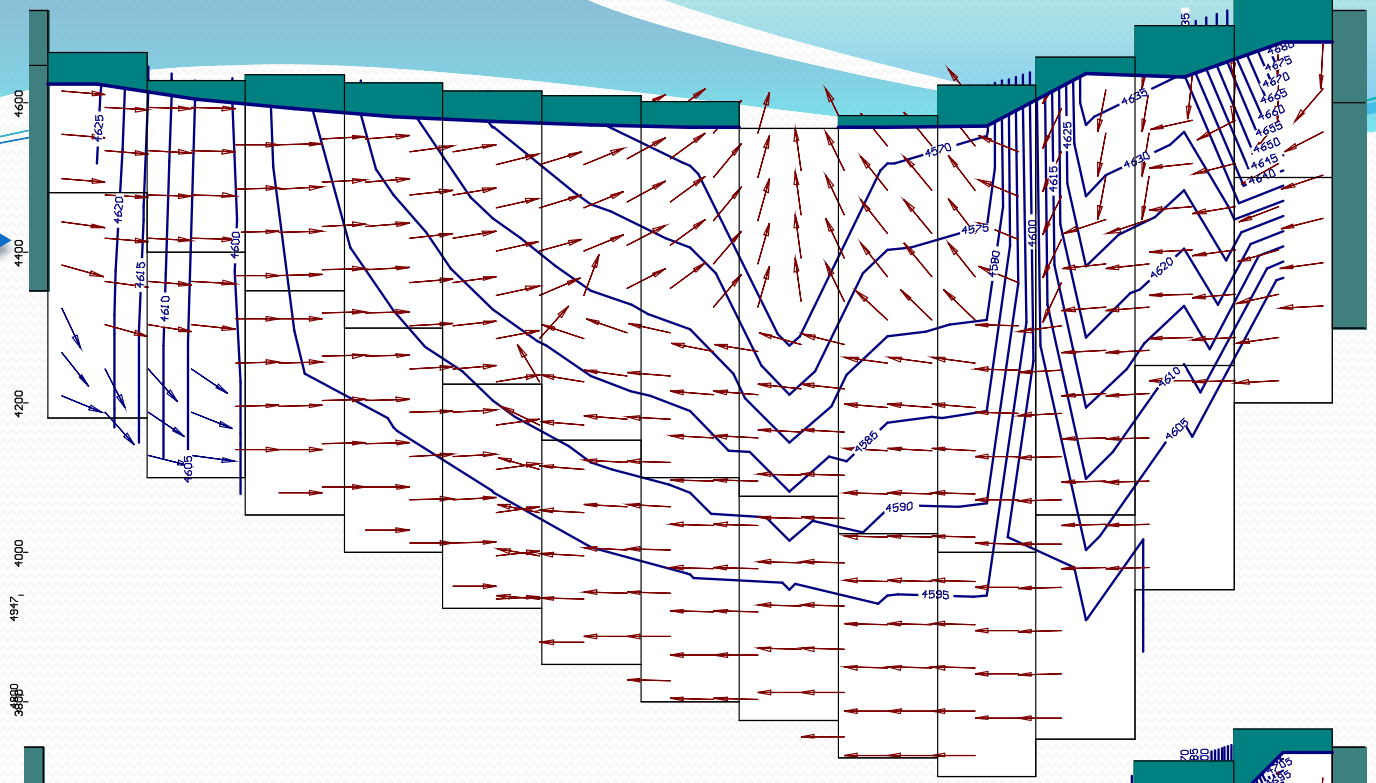
## Little Chino Sub-Basin



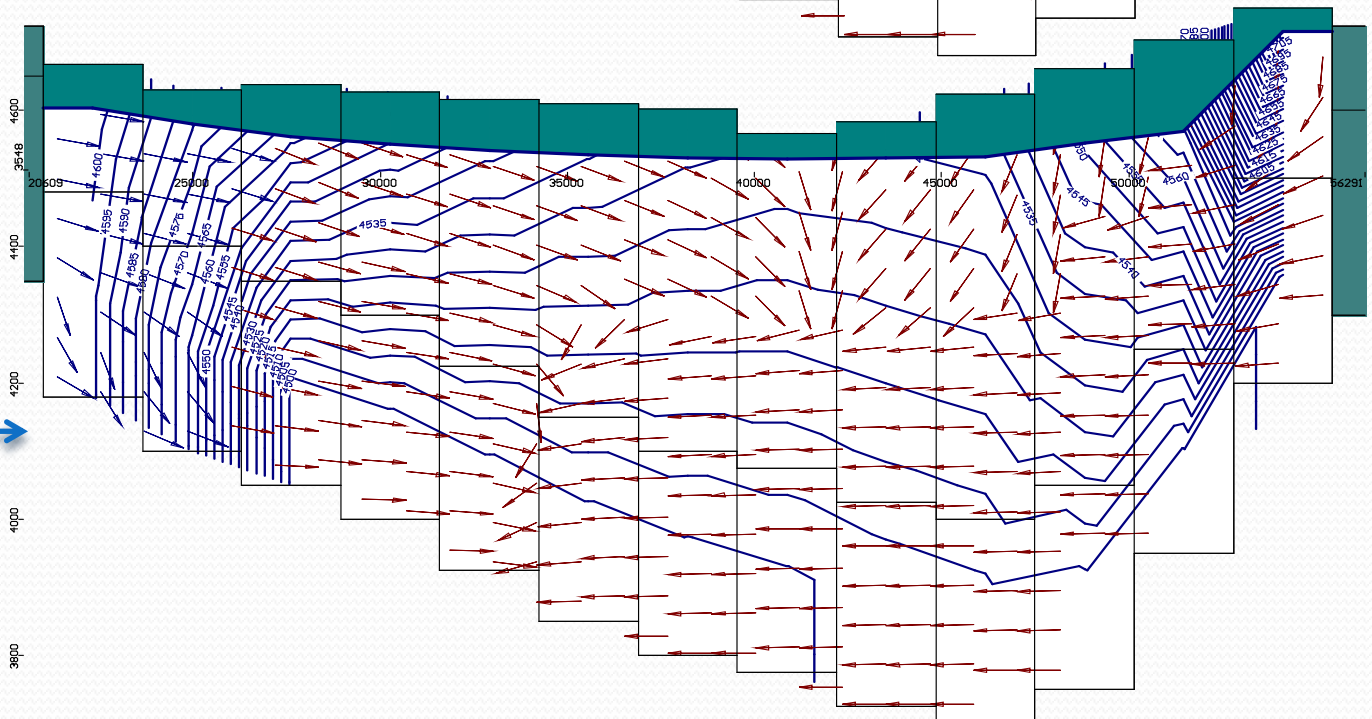
# 1940

**Row 7**
**Road 4N**
**Chino Valley**



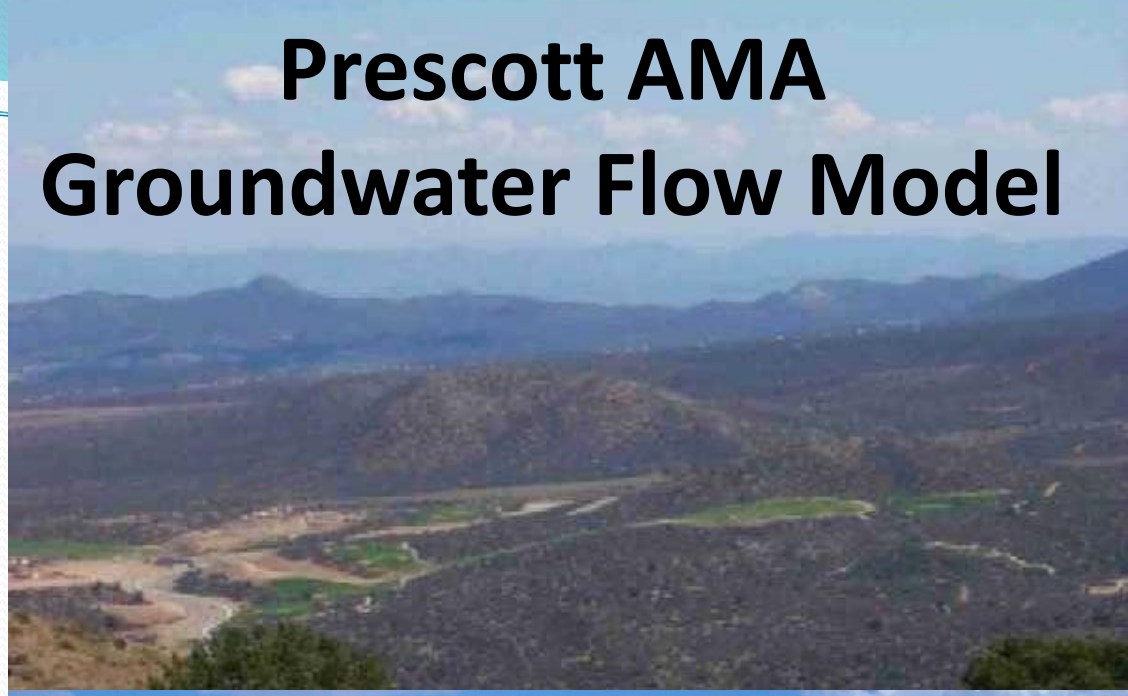

# 2010

**Row 7**
**Road 4N**
**Chino Valley**



# Prescott AMA Groundwater Flow Model

- ✓ **Corkhill and Mason, 1995**
  - Prescott AMA
  - LIC & UAF Sub-basin Aquifers
  - 2 Layer Model (3-D flow)
  - L1 –Upper Alluvial Unit (UAU)
  - L2 –Lower Volcanic Unit (LVU)
- ✓ **SW Groundwater, 1998**
  - Natural Recharge 22,000 AF/yr
- ✓ **Nelson, 2002**
  - Added Confined LVU to UAF
  - Episodic Recharge to UAF
- ✓ **Timmons & Springer, 2006**
  - Expanded Model Mint Wash
  - Geologic Updates to L1 & L2
- ✓ **Provisional Update, 2012**
  - -Alternative Conceptual Models (K, Recharge, etc)
  - -Expanded Aquitard
  - -Inversion Stats: Transparency



# Prescott AMA Groundwater Flow Model

## Tested Dozens of Alternative Conceptual Models (ACM):

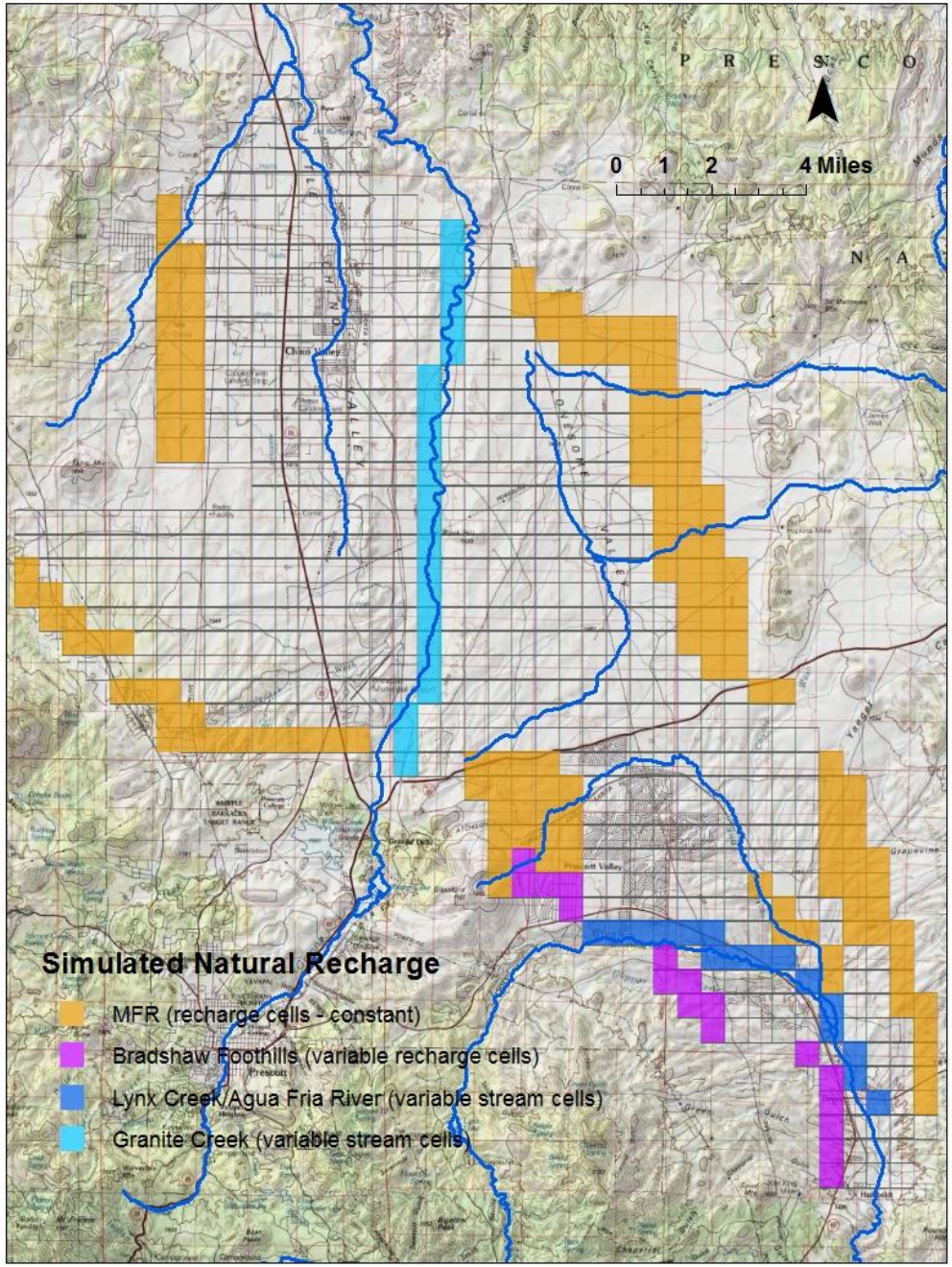
**Hydraulic Conductivity (K) & Natural Recharge Distributions; Alternative Initialization; Boundary Conditions, etc.**

## Inverse Model Statistics

**Transparency; Better Understanding of ACM's & Model Parameters**

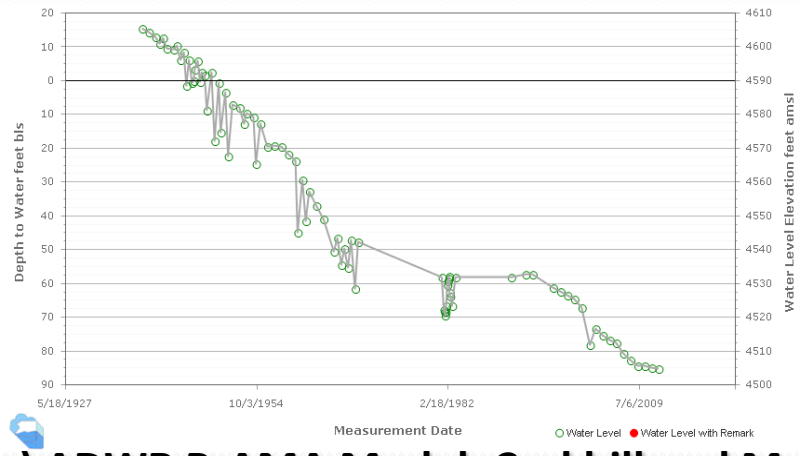
## Natural Recharge Rates

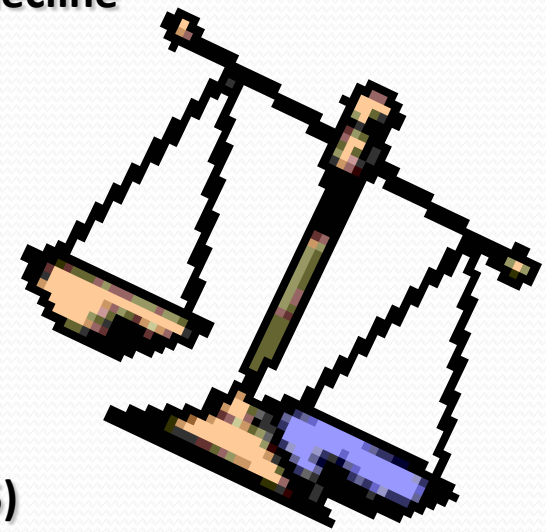
**Plausible Long-Term Rate: 7,500–12,000 AF/yr**
**Central Tendency ≈ 10,000 AF/yr**
**Highest Rates Along Major Streams & Tribs During "Wet" periods (~10%: 1939-2011)**
**Natural Recharge Annual Variability**
**from < 3,000 AF/yr to > 25,000 AF/yr**
**Natural Recharge Extended-Period Variability**
**1941-1965: ≈ 4,000 AF/yr**
**1965-1995: ≈ 15,000 AF/yr**



# *ADWR Prescott AMA Safe-Yield Decision (1998-99)*

**1) Observation data late 1930's-1999 Long-term decline**



**2a) ADWR PrAMA Model: Corkhill and Mason (1995)**

Steady Flow Natural Recharge *7,000 AF/yr*

Transient Natural Recharge *(1940-1993) 4,600 AF/yr*

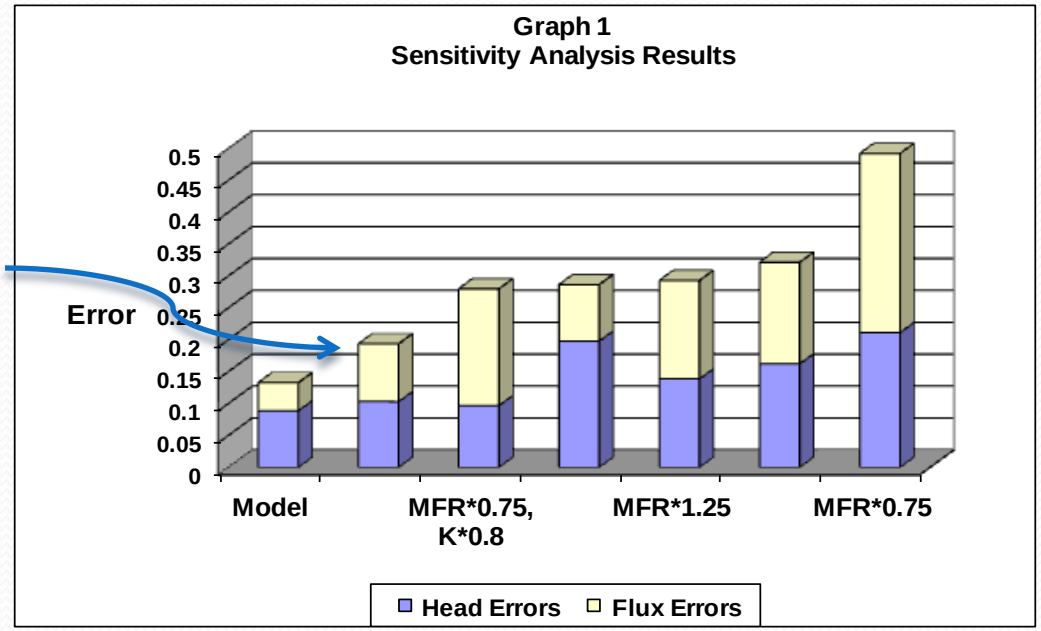
**2b) Southwest Groundwater Model (1998):** Nat Rch *22,000 AF/yr*

**Comparison of Prescott Models (ADWR & Southwest Groundwater by Woesner (1998),** *"ADWR model provided an overall more reasonable representation of the hydrogeology and associated water balance….",* Woesner also suggested including *"confidence intervals for recharge (+/- 50%)".ADWR Model SS Recharge CI Range:* ***3,500-10,500 AF/yr***

*ADWR Model Transient Recharge CI Range: 2,300- 6,900 AF/yr*

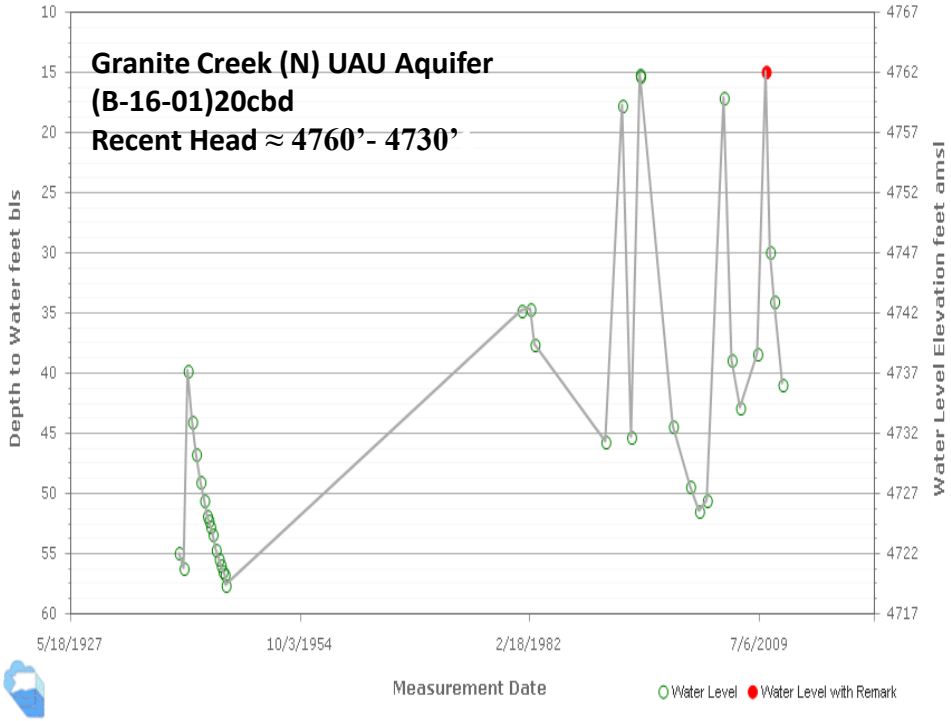
**ADWR Model Updates (2002 and 2006) applied transient natural recharge ≈ MFR 5,800 AF/yr + Long-term mean Flood 700 AF/yr ≈ 6,500 AF/yr**

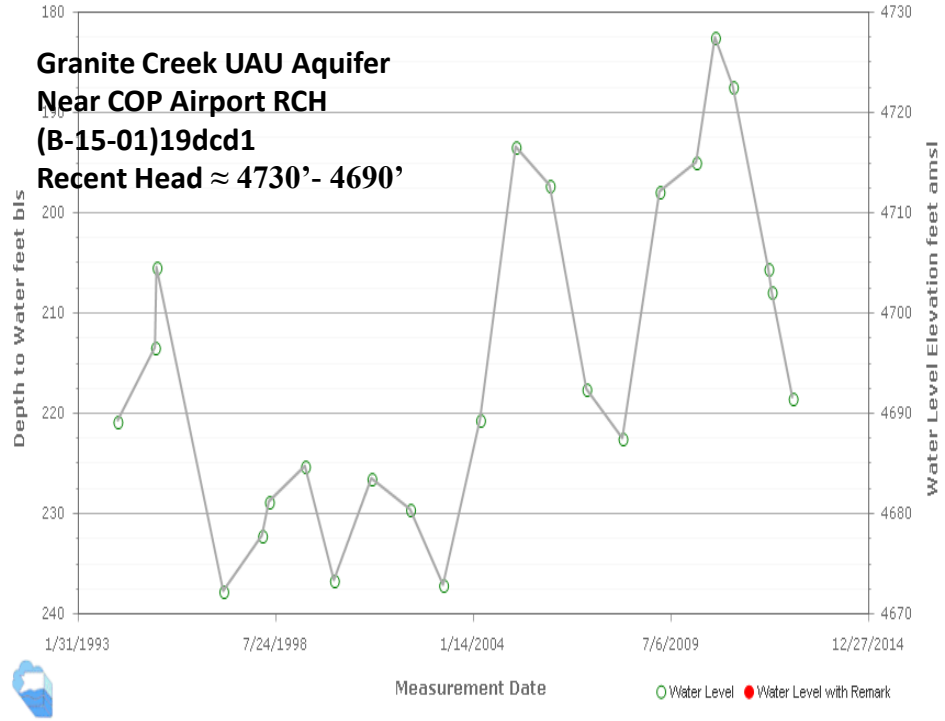
**Prescott Model Update (2002)**
**Plausible ACM Solution**
**Low Model Error**
**Transient: 1.2*K combined w/ 1.25*natural Recharge**
**=>Natural recharge = 8,125 AF/yr**

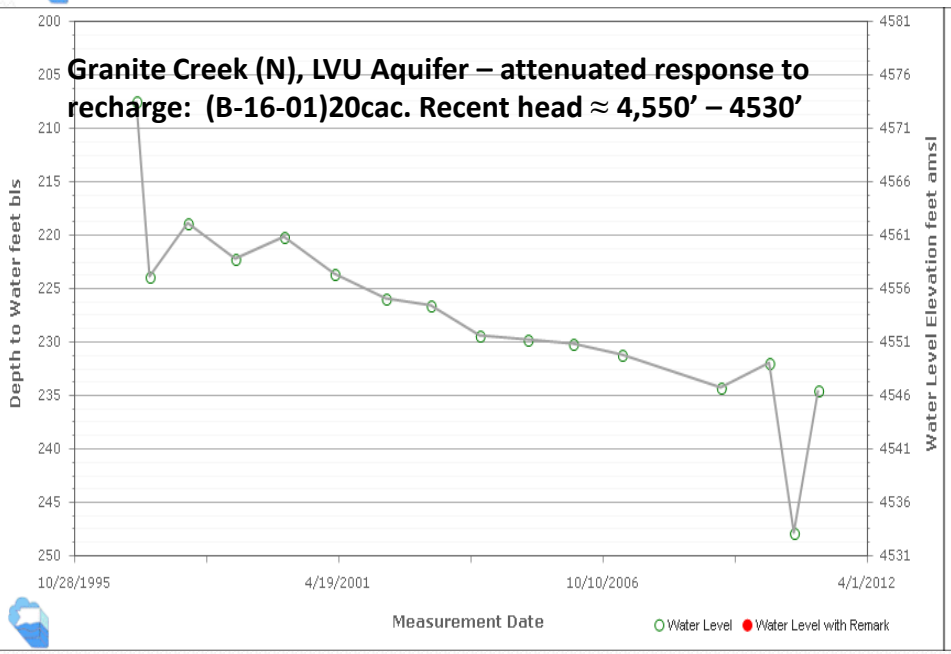


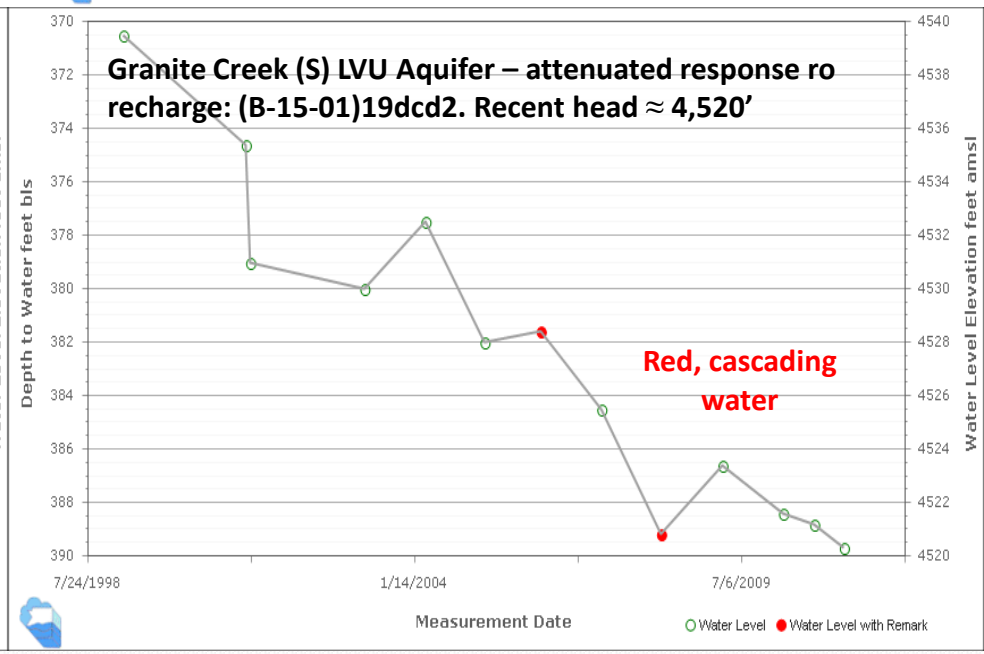

**Prescott Model Update (2006): Observed – Simulated = +10.8 feet (2,324 head targets)**
***Synopsis: Model was undersimulating groundwater***

GRANITE CREEK RD


Granite Creek (N) UAU Aquifer
(B-16-01)20cbd
Recent Head ≈ 4760'- 4730'
Depth to Water feet bls
Water Level Elevation feet amsl
Measurement Date
5/18/1927
10/3/1954
2/18/1982
7/6/2009
Water Level
Water Level with Remark


Granite Creek UAU Aquifer
Near COP Airport RCH
(B-15-01)19dcd1
Recent Head ≈ 4730'- 4690'
Depth to Water feet bls
Water Level Elevation feet amsl
Measurement Date
1/31/1993
7/24/1998
1/14/2004
7/6/2009
12/27/2014
Water Level
Water Level with Remark


Granite Creek (N), LVU Aquifer – attenuated response to recharge: (B-16-01)20cac. Recent head ≈ 4,550' – 4530'
Depth to Water feet bls
Water Level Elevation feet amsl
Measurement Date
10/28/1995
4/19/2001
10/10/2006
4/1/2012
Water Level
Water Level with Remark

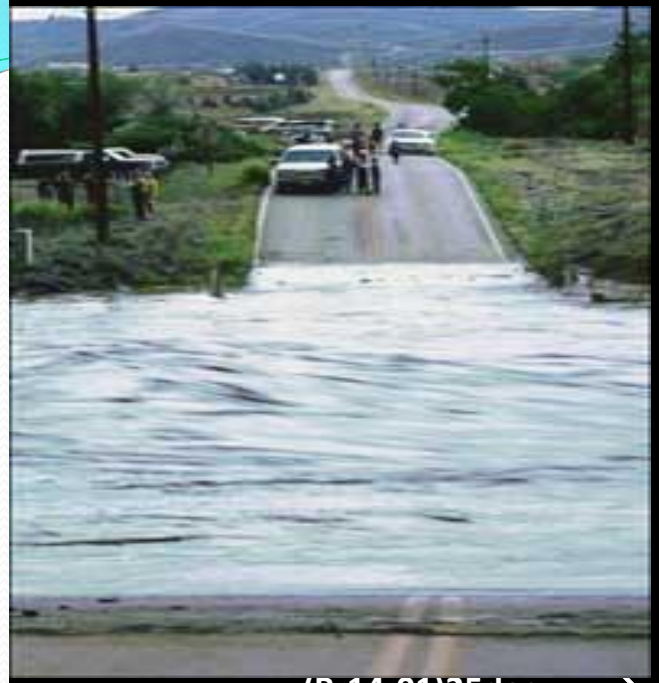

Granite Creek (S) LVU Aquifer – attenuated response ro recharge: (B-15-01)19dcd2. Recent head ≈ 4,520'
Red, cascading water
Depth to Water feet bls
Water Level Elevation feet amsl
Measurement Date
7/24/1998
1/14/2004
7/6/2009
Water Level
Water Level with Remark

Re-evaluate how the UAU Aquifer was filling-up during stream recharge

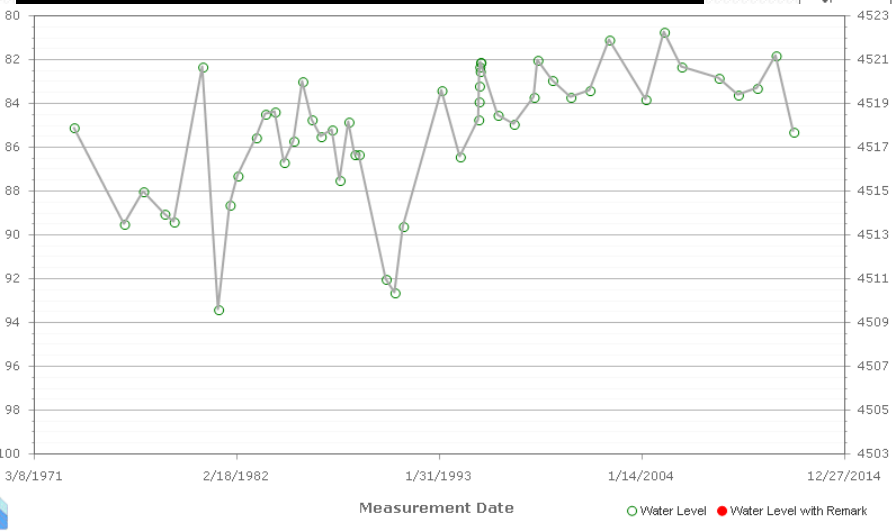
← Flood Recharge March 2010

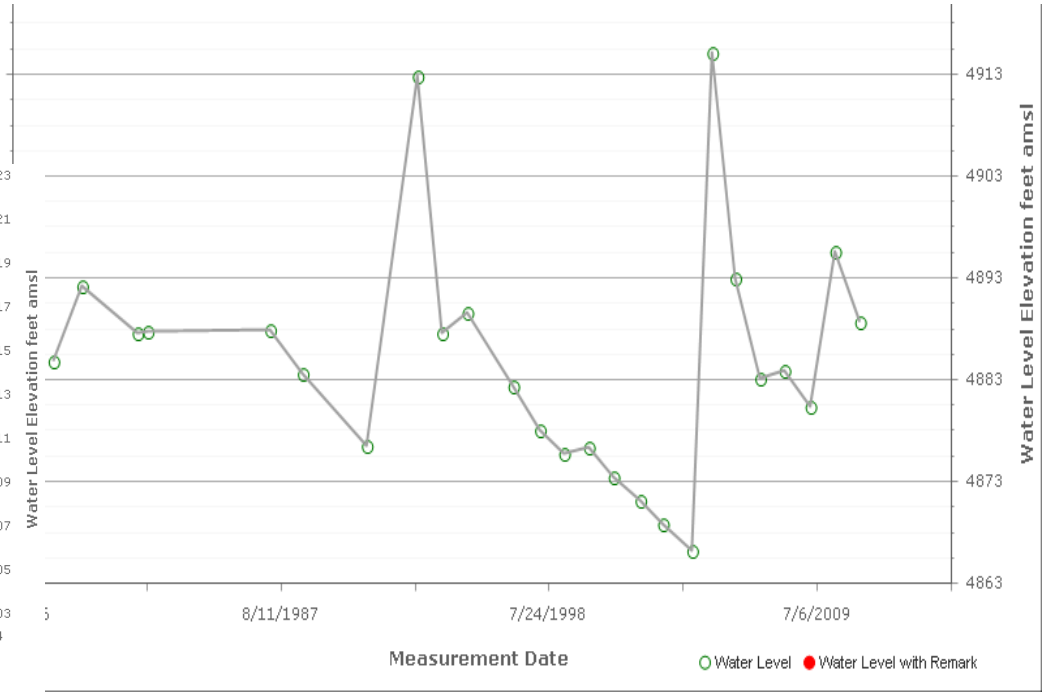
Flood Recharge Early 1995 →

**UAU Aquifer Water Levels,**
**UAF Sub-basin, (B-14-01)22ada →**

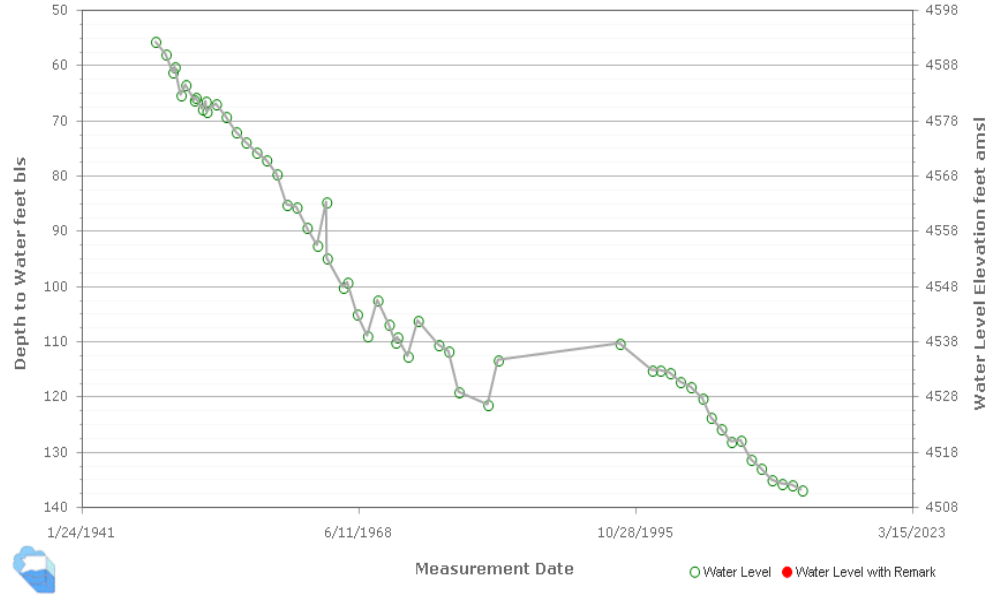


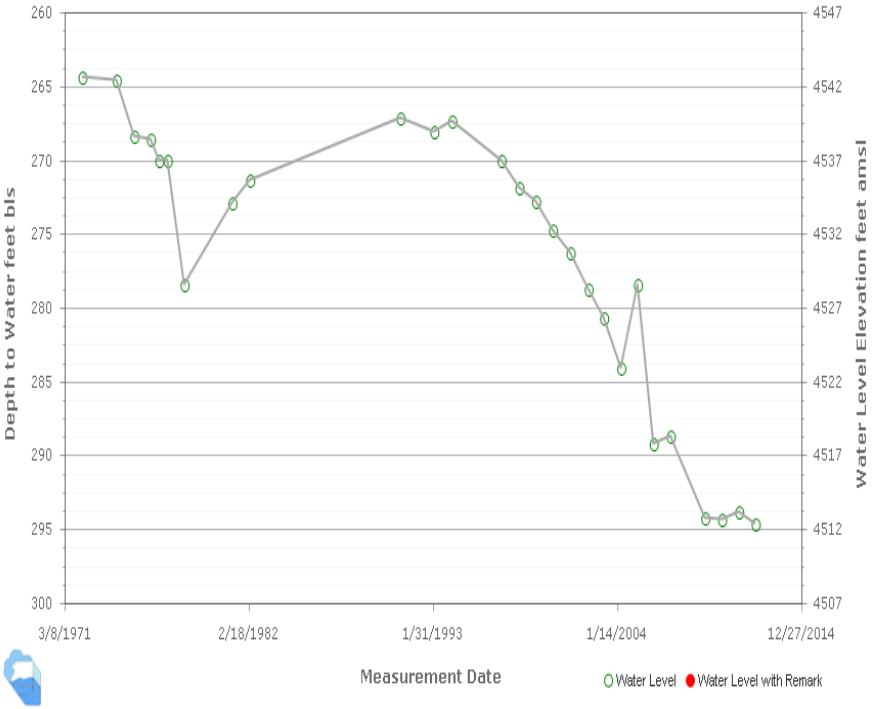
**(B-14-01)25dac -----→**
**(A-13-02)01cad, below**

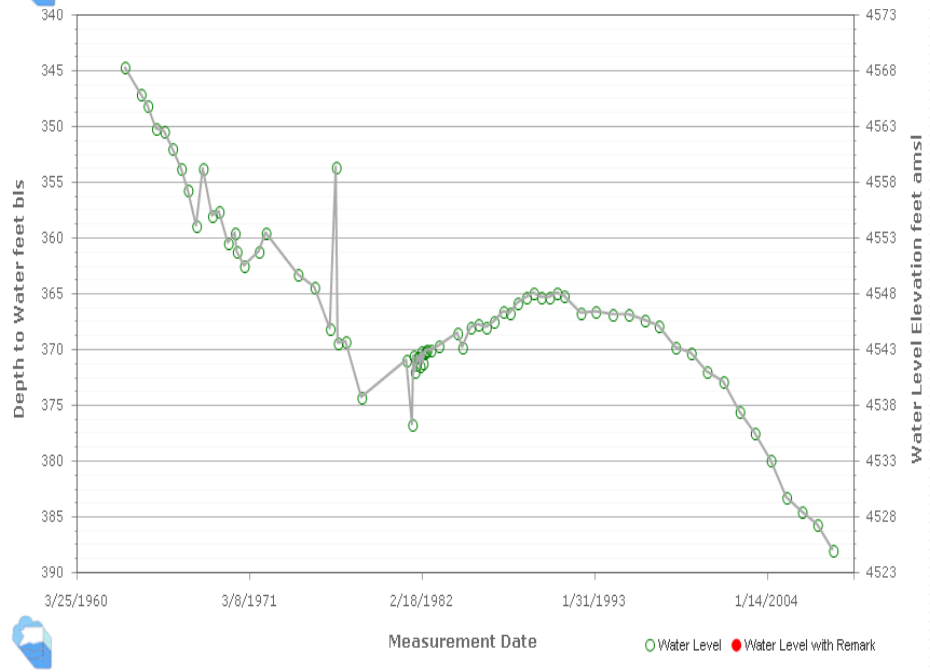


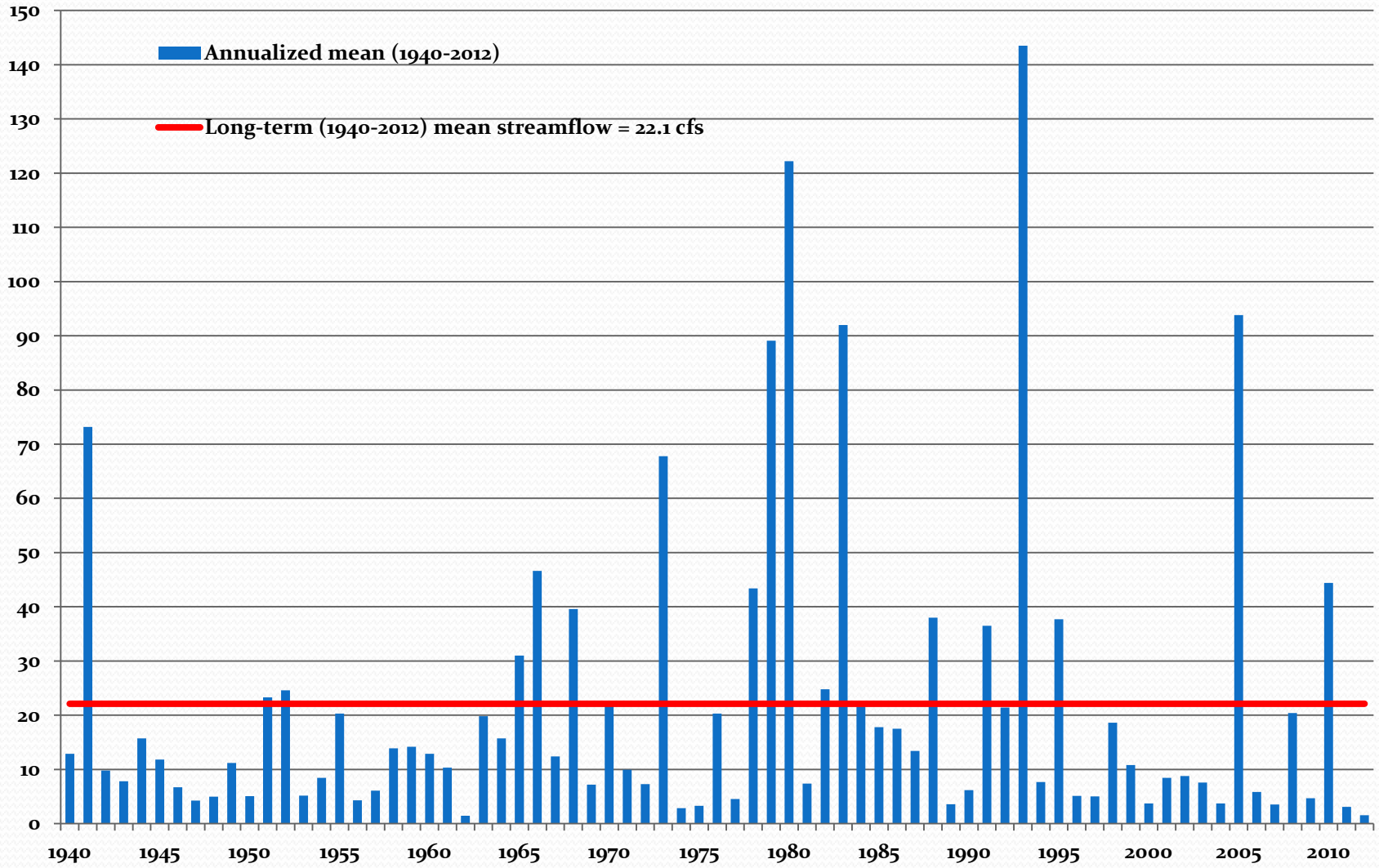
Depth to Water feet bls
Water Level Elevation feet amsl
20
10
0
10
20
30
40
50
60
70
80
90
4610
4600
4590
4580
4570
4560
4550
4540
4530
4520
4510
4500
5/18/1927
10/3/1954
2/18/1982
7/6/2009

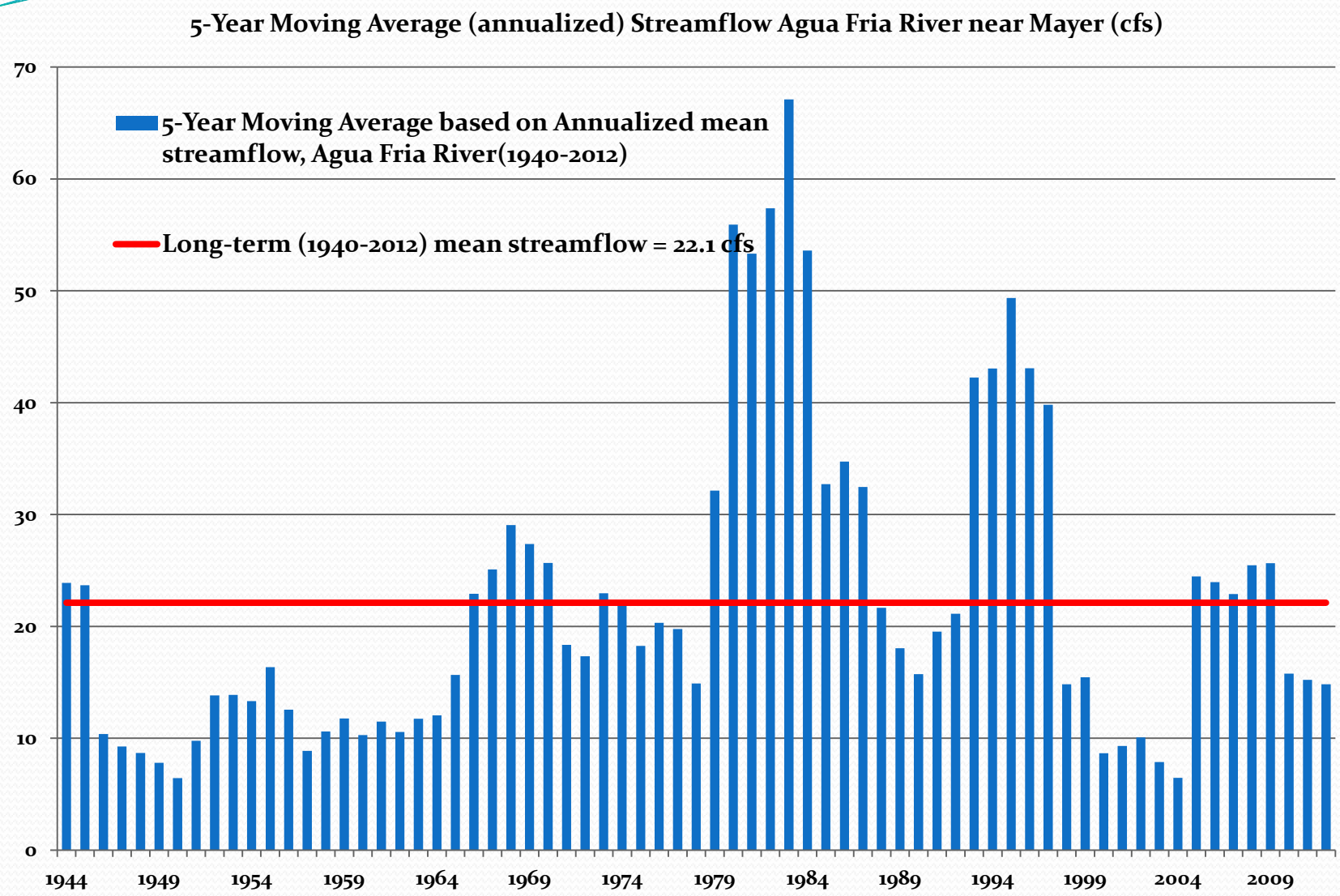

Depth to Water feet bls
Water Level Elevation feet amsl
50
60
70
80
90
100
110
120
130
140
4598
4588
4578
4568
4558
4548
4538
4528
4518
4508
1/24/1941
6/11/1968
10/28/1995
3/15/2023
Measurement Date
Water Level
Water Level with Remark

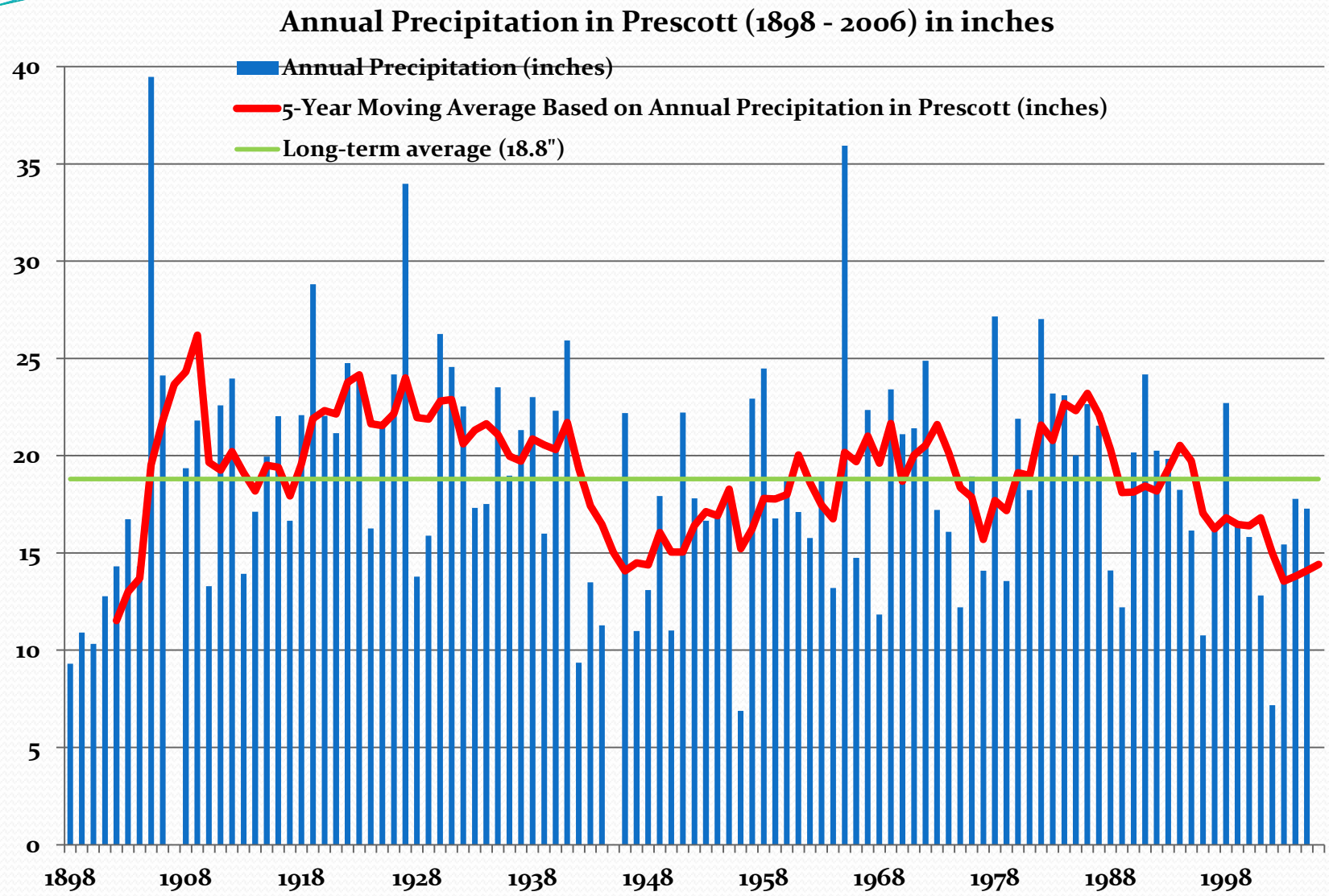

Depth to Water feet bls
Water Level Elevation feet amsl
260
265
270
275
280
285
290
295
300
4547
4542
4537
4532
4527
4522
4517
4512
4507
3/8/1971
2/18/1982
1/31/1993
1/14/2004
12/27/2014
Measurement Date
Water Level
Water Level with Remark

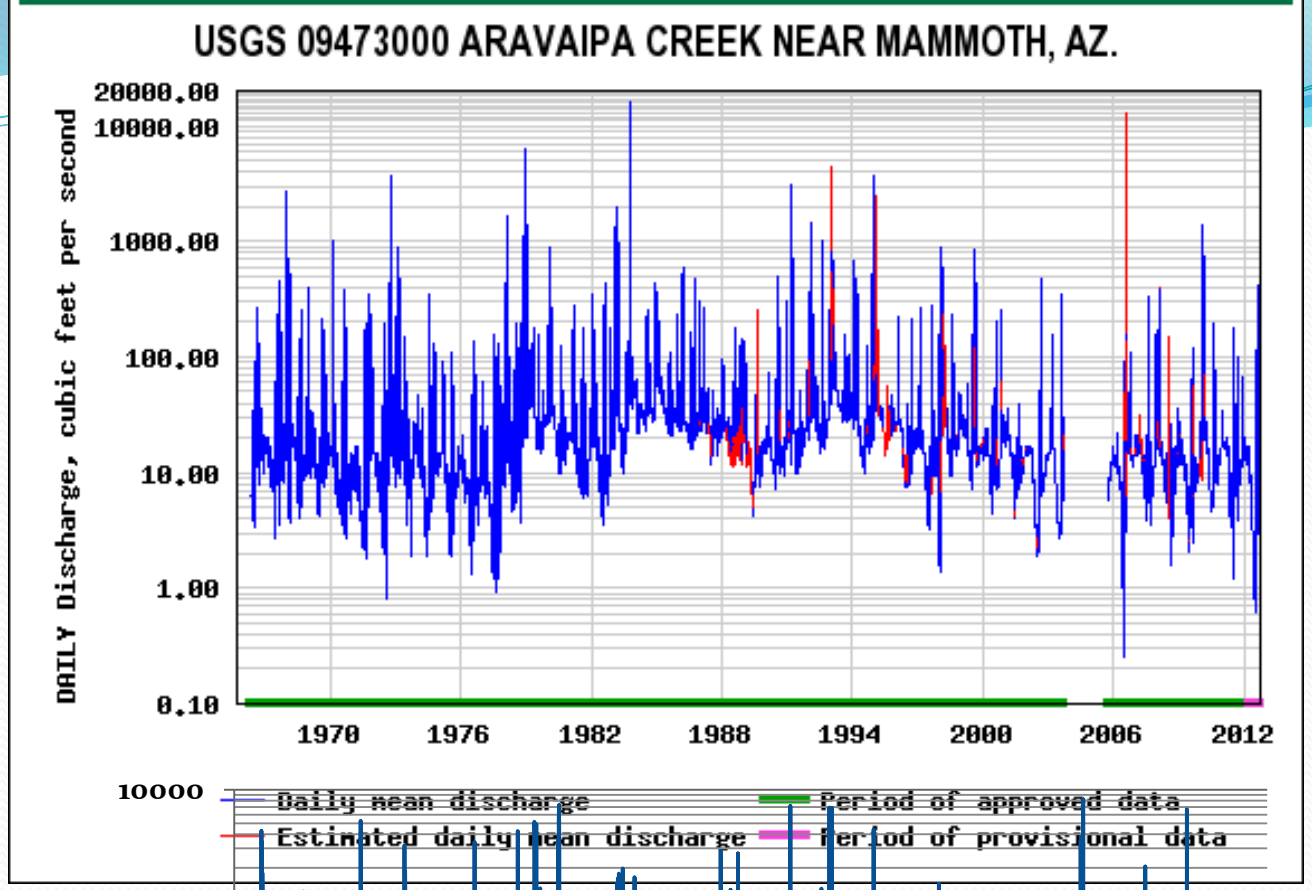

Depth to Water feet bls
Water Level Elevation feet amsl
340
345
350
355
360
365
370
375
380
385
390
4573
4568
4563
4558
4553
4548
4543
4538
4533
4528
4523
3/25/1960
3/8/1971
2/18/1982
1/31/1993
1/14/2004
Measurement Date
Water Level
Water Level with Remark

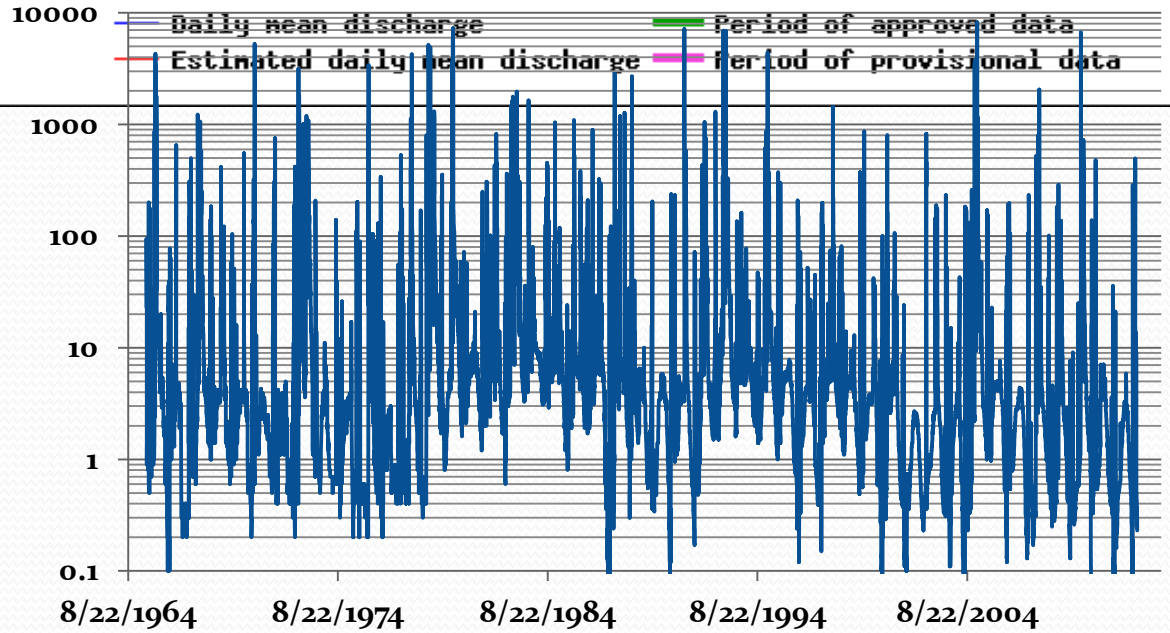
# Average Annualized Streamflow Agua Fria River near Mayer (in cfs) per year



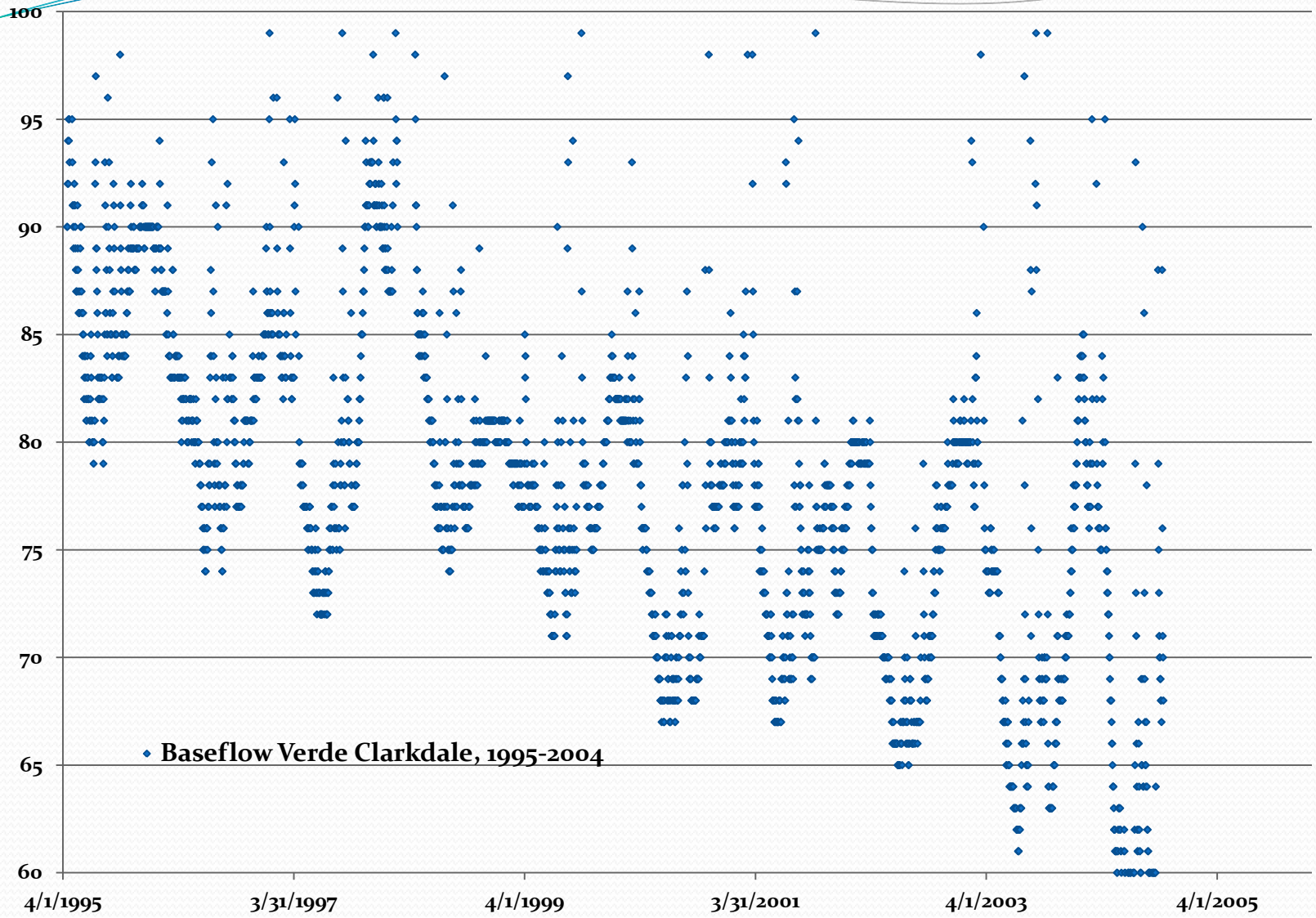

5-Year Moving Average (annualized) Streamflow Agua Fria River near Mayer (cfs)
5-Year Moving Average based on Annualized mean streamflow, Agua Fria River(1940-2012)
Long-term (1940-2012) mean streamflow = 22.1 cfs
70
60
50
40
30
20
10
0
1944
1949
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
2004
2009

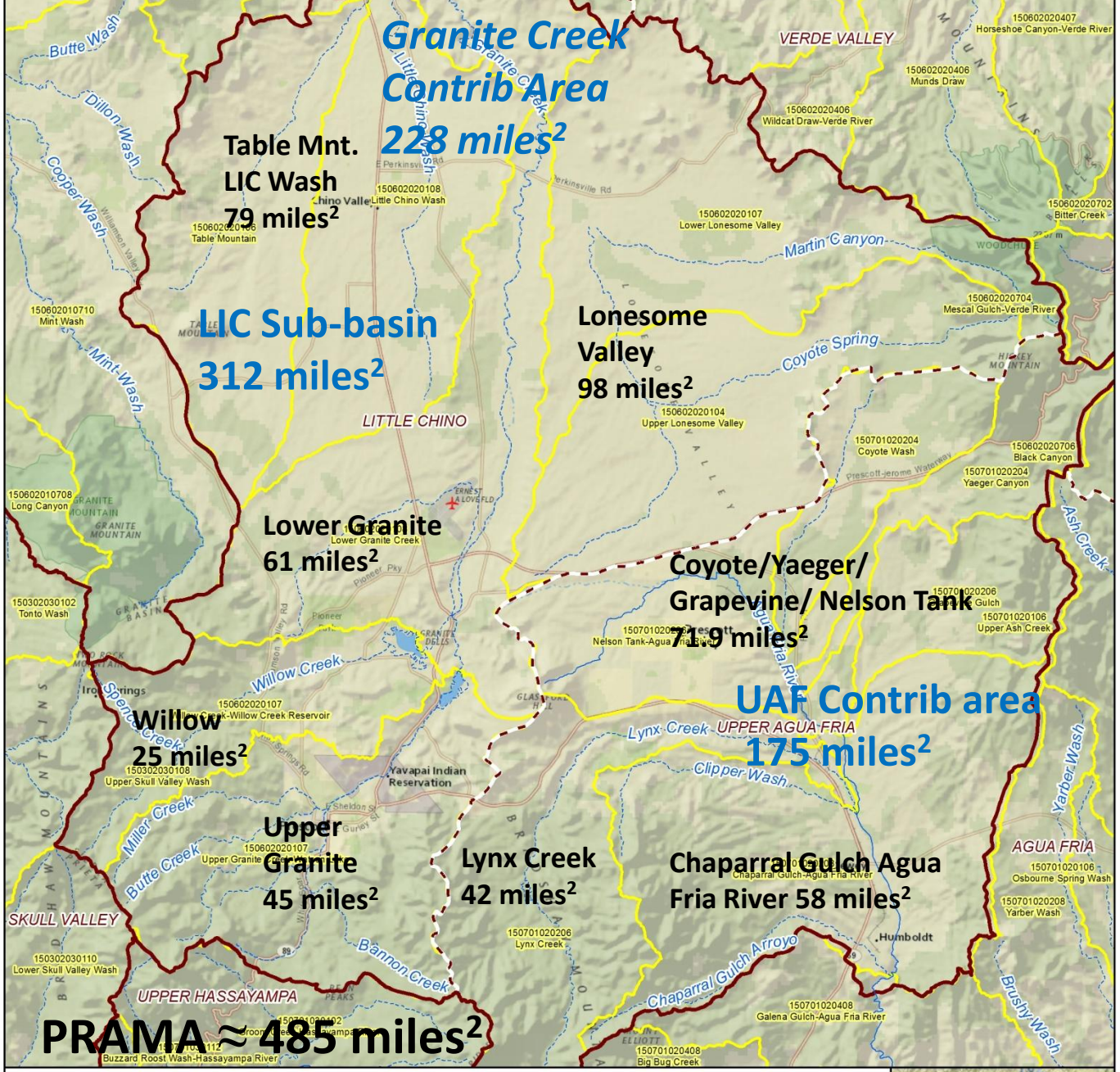

Annual Precipitation in Prescott (1898 - 2006) in inches
Annual Precipitation (inches)
5-Year Moving Average Based on Annual Precipitation in Prescott (inches)
Long-term average (18.8")
40
35
30
25
20
15
10
5
0
1898
1908
1918
1928
1938
1948
1958
1968
1978
1988
1998




Agua Fria River Mayer,
mid-1960's
2012


100
95
90
85
80
75
70
65
60
4/1/1995
3/31/1997
4/1/1999
3/31/2001
4/1/2003
4/1/2005
Baseflow Verde Clarkdale, 1995-2004

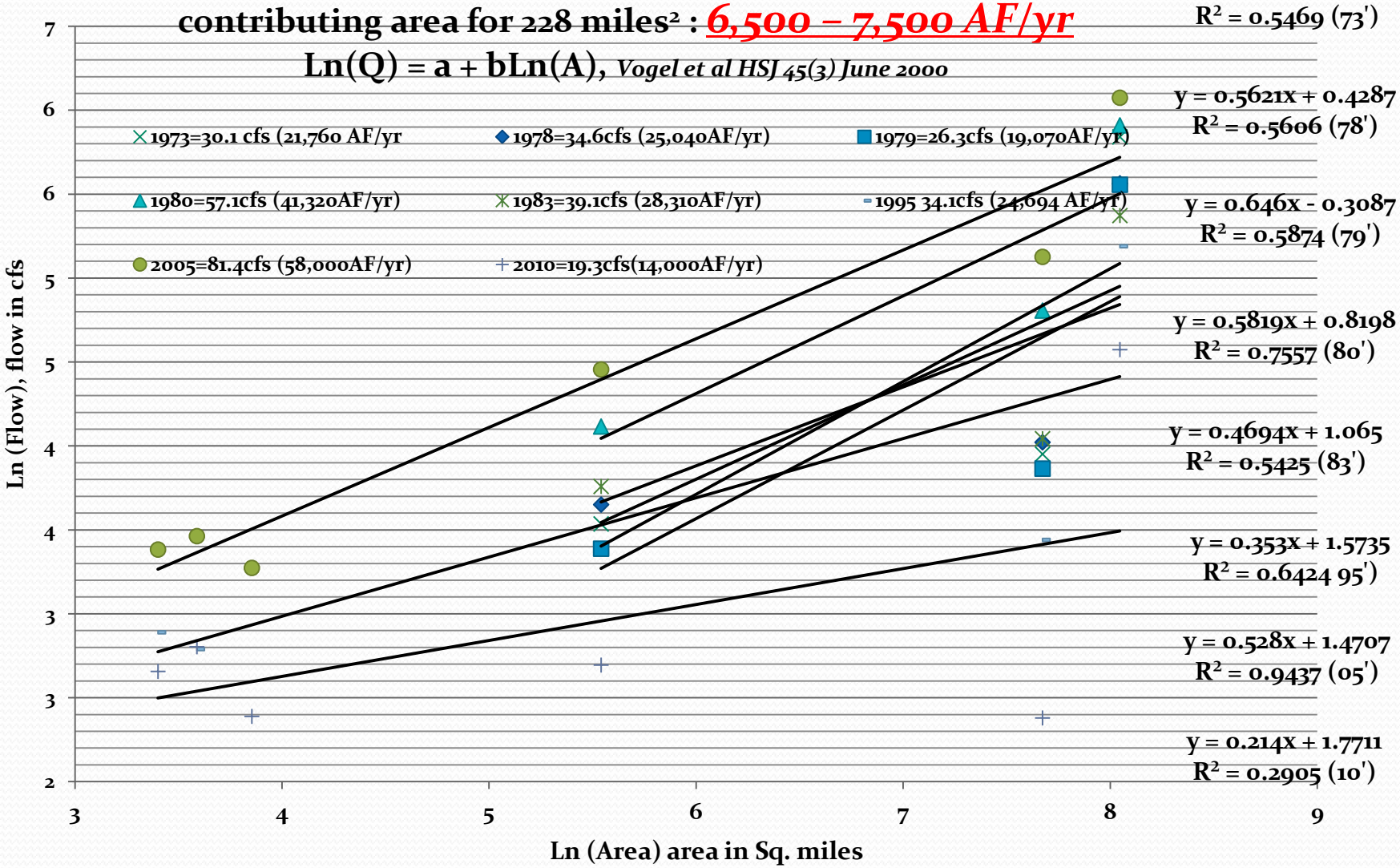



Legend

LITTLE CHINO
SUB-BASIN
USGS 12 DIGIT HUCS

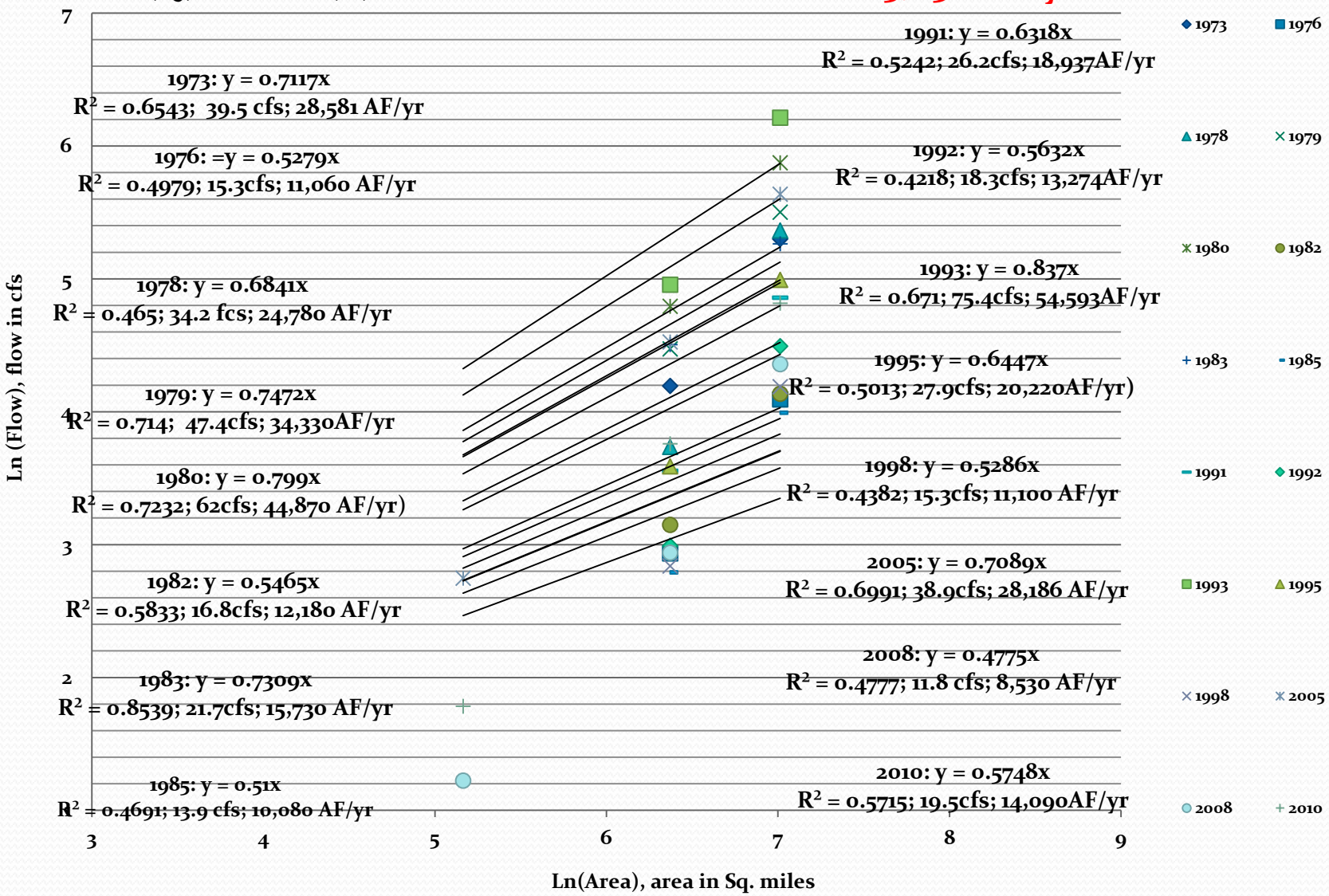
# Streamflow Scaling (1973-2011): Log-Linear Least Squares Fit for contributing area for 228 miles² : 6,500 – 7,500 AF/yr

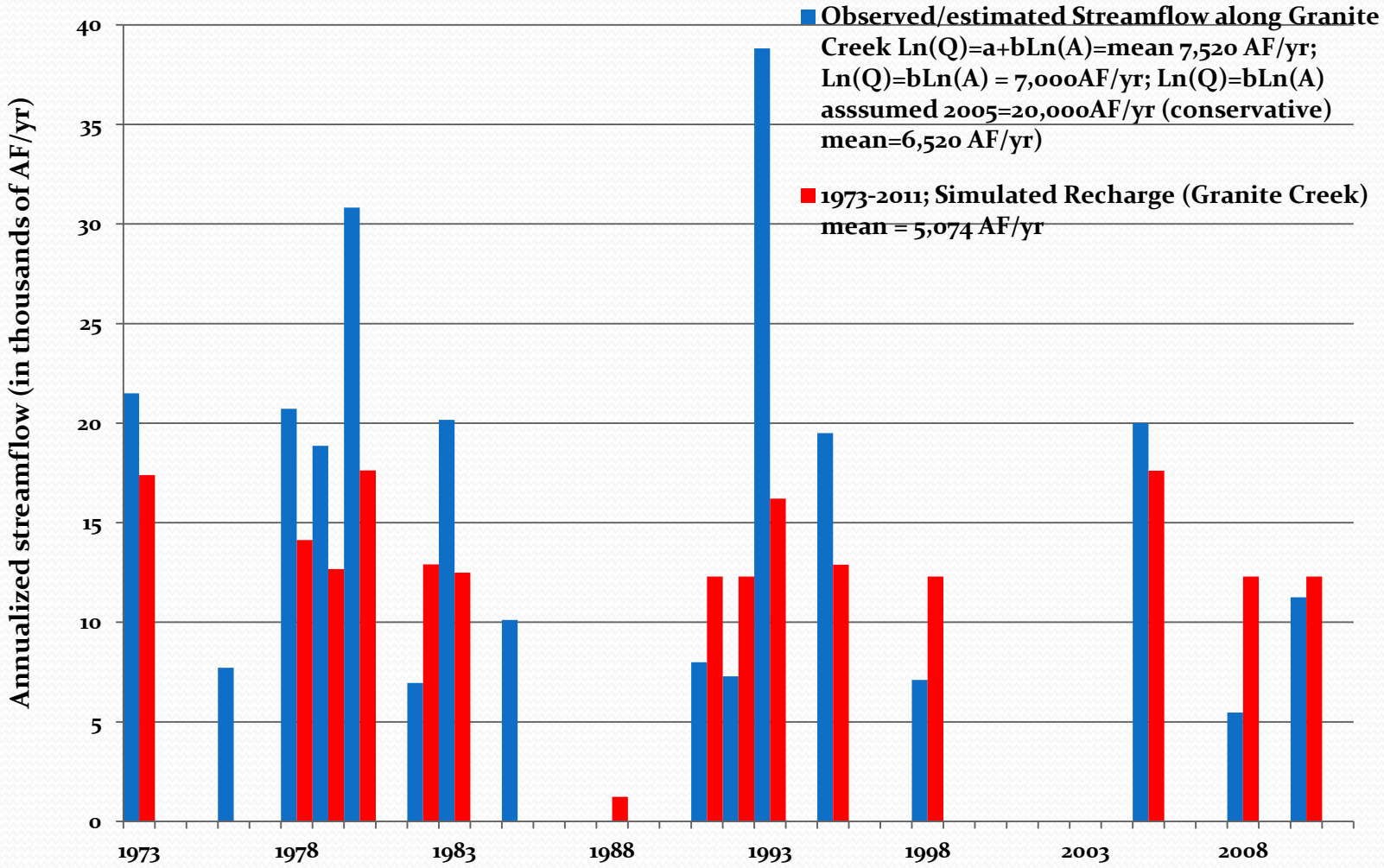
**Ln(Q) = a + bLn(A),** *Vogel et al HSJ 45(3) June 2000*

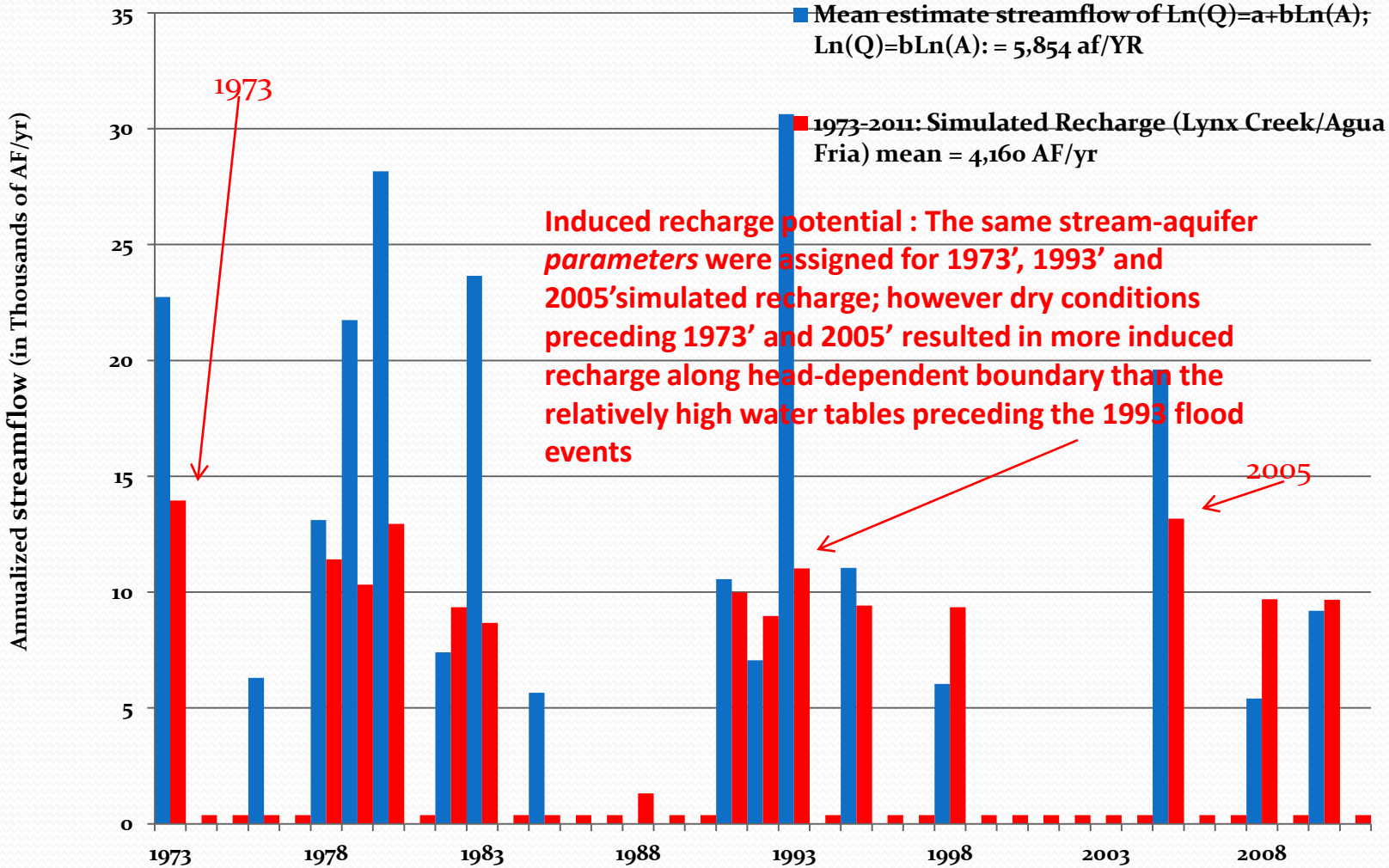


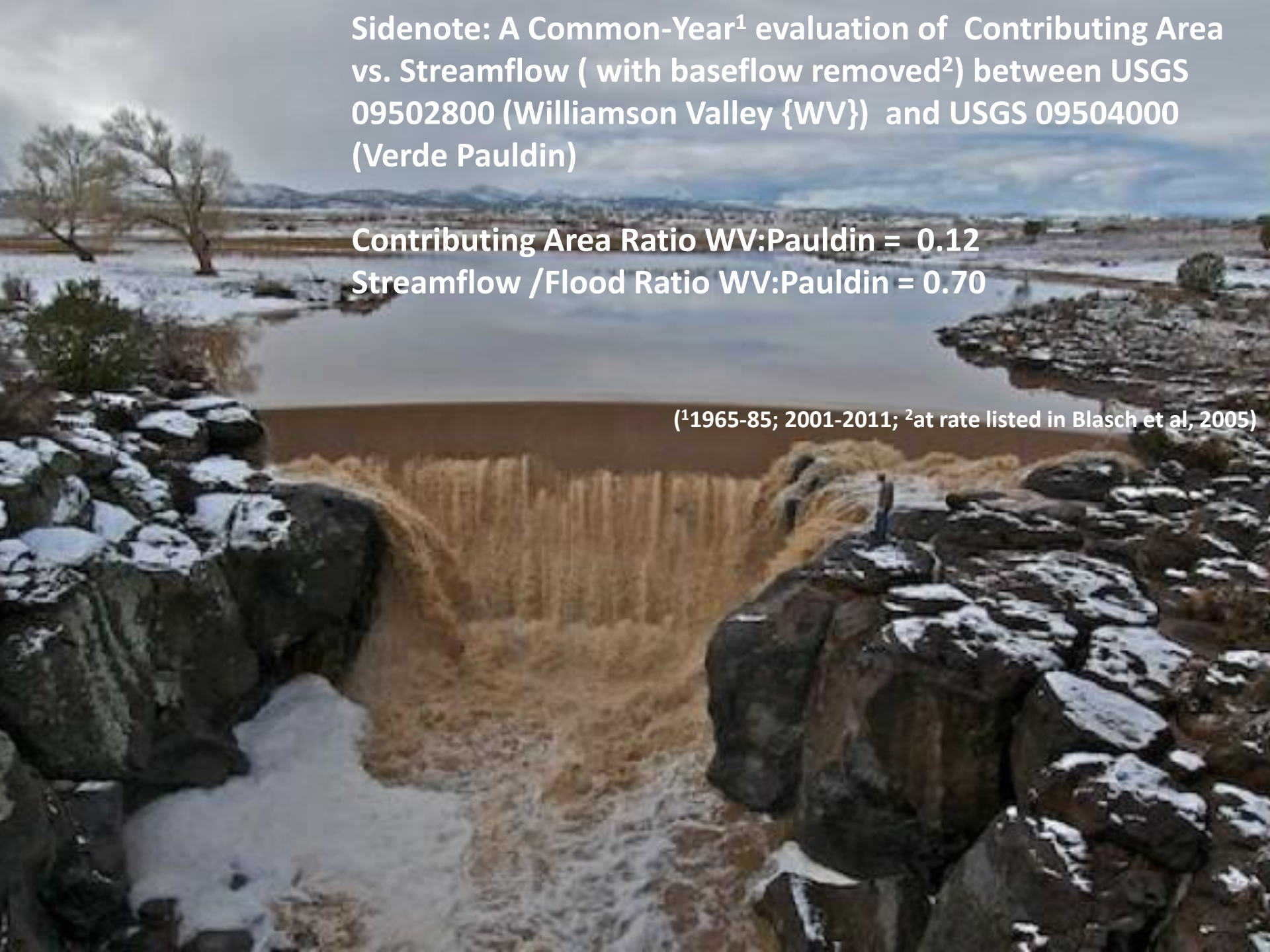
# Streamflow Scaling (1973-2011) for 175 miles²; Below:

## Ln(Q)= o+bLn(A); mean of Ln(Q)= a+bLn(A)& Ln(Q)= o+bLn(A) ->5,850 AF/yr




Observed/estimated Streamflow along Granite Creek Ln(Q)=a+bLn(A)=mean 7,520 AF/yr; Ln(Q)=bLn(A) = 7,000AF/yr; Ln(Q)=bLn(A) asssumed 2005=20,000AF/yr (conservative) mean=6,520 AF/yr)
1973-2011; Simulated Recharge (Granite Creek) mean = 5,074 AF/yr
Annualized streamflow (in thousands of AF/yr)
40
35
30
25
20
15
10
5
0
1973
1978
1983
1988
1993
1998
2003
2008


Mean estimate streamflow of Ln(Q)=a+bLn(A); Ln(Q)=bLn(A): = 5,854 af/YR
1973-2011: Simulated Recharge (Lynx Creek/Agua Fria) mean = 4,160 AF/yr
Annualized streamflow (in Thousands of AF/yr)
35
30
25
20
15
10
5
0
1973
1978
1983
1988
1993
1998
2003
2008
1973
2005
Induced recharge potential : The same stream-aquifer *parameters* were assigned for 1973', 1993' and 2005'simulated recharge; however dry conditions preceding 1973' and 2005' resulted in more induced recharge along head-dependent boundary than the relatively high water tables preceding the 1993 flood events



**Sidenote: A Common-Year[1] evaluation of Contributing Area vs. Streamflow ( with baseflow removed[2]) between USGS 09502800 (Williamson Valley {WV}) and USGS 09504000 (Verde Pauldin)**

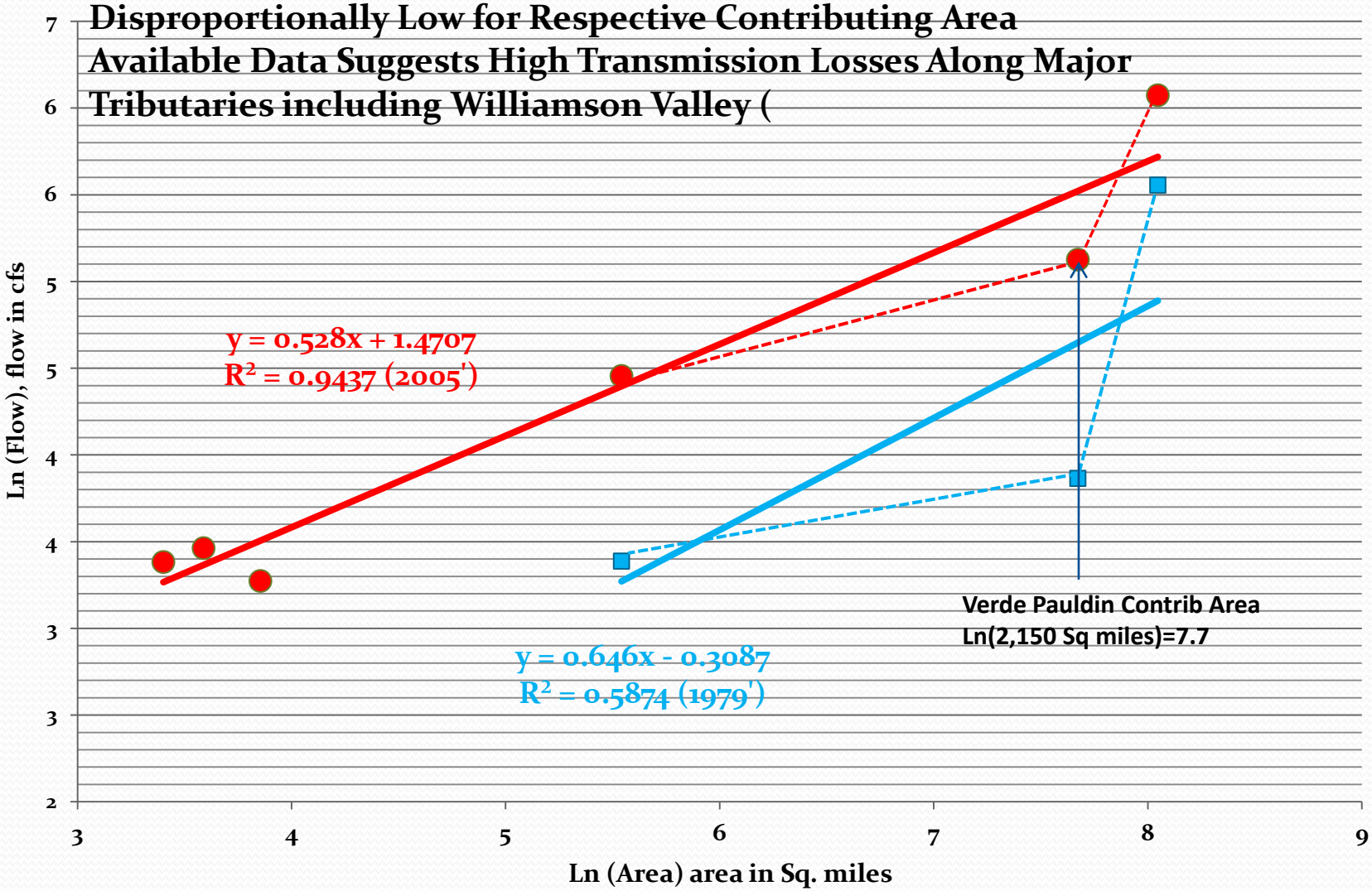
**Contributing Area Ratio WV:Pauldin = 0.12**
**Streamflow /Flood Ratio WV:Pauldin = 0.70**

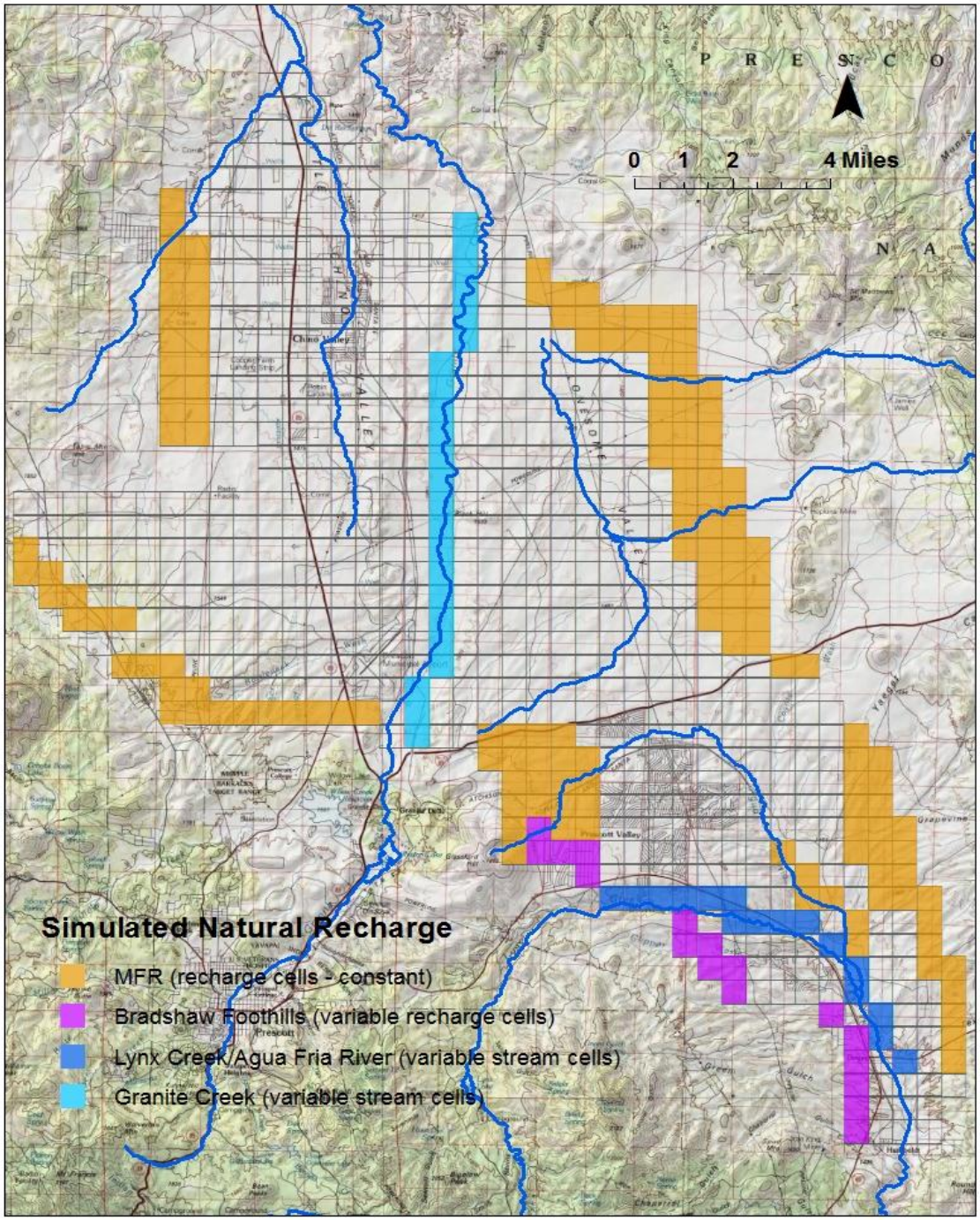
**([1]1965-85; 2001-2011; [2]at rate listed in Blasch et al, 2005)**

## Log-Linear LSR for Ln(Q) = a + bLn(A)

**Observed Streamflow (Baseflow removed) at Verde Pauldin is Disproportionally Low for Respective Contributing Area**

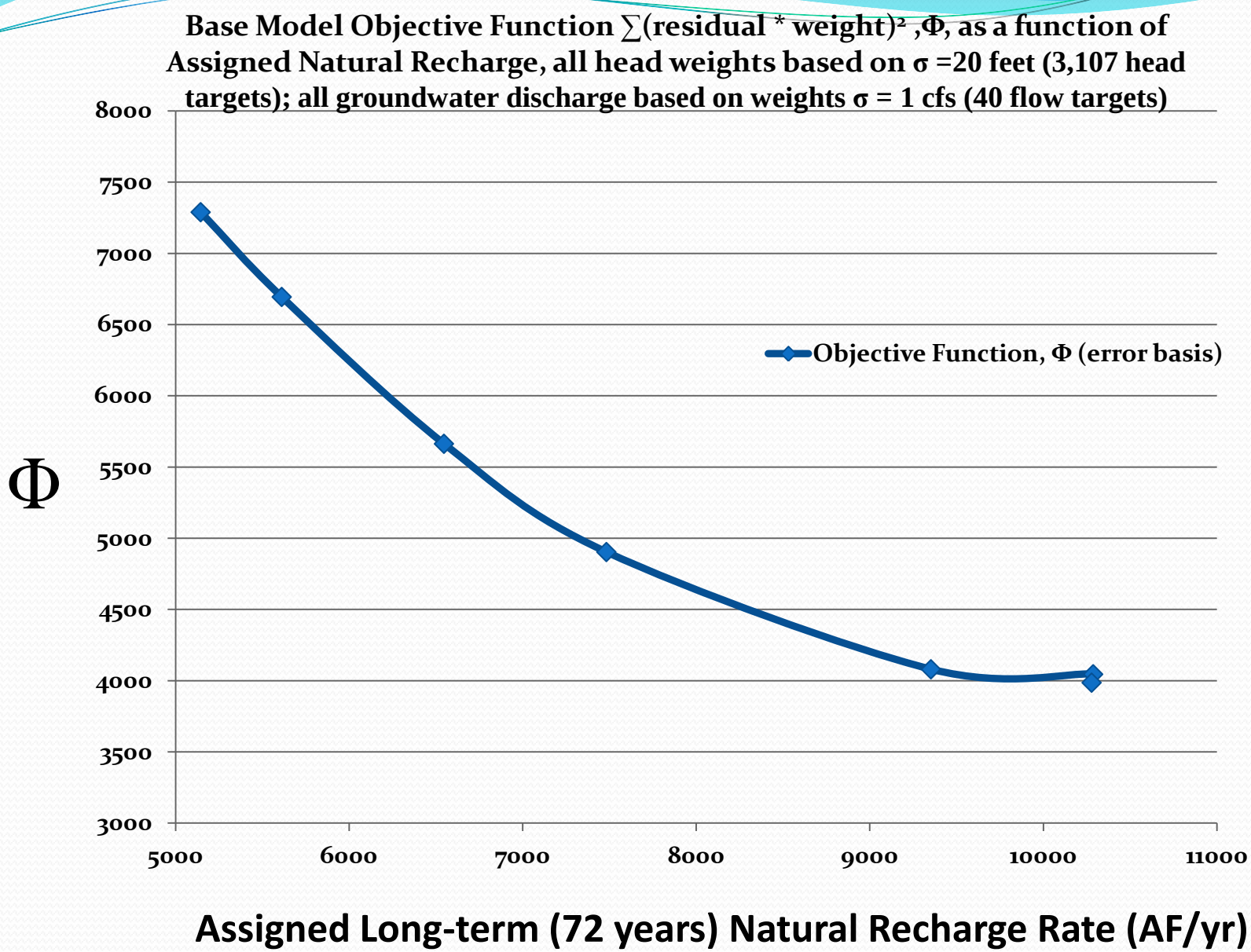
**Available Data Suggests High Transmission Losses Along Major Tributaries including Williamson Valley (**






**"Base Model"**
***Long-Term* Natural Recharge Rate: Transient 1939-2011 = 72 years**

| | | AF/yr |
|---|---|---|
| MFR | = | 2,558 |
| Granite Creek | = | 3,524 |
| Lynx/Agua Fria | = | 2,593 |
| Upper Agua Fria River | = | 379 |
| Bradshaw FootHills | = | 870 |
| Total Natural Recharge | = | 9,924 |


Base Model Objective Function ∑(residual * weight)² ,Φ, as a function of Assigned Natural Recharge, all head weights based on σ =20 feet (3,107 head targets); all groundwater discharge based on weights σ = 1 cfs (40 flow targets)
Φ
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
5000
6000
7000
8000
9000
10000
11000
Objective Function, Φ (error basis)
Assigned Long-term (72 years) Natural Recharge Rate (AF/yr)

## Table G.1. Simulated Water budget, 1939-2011

| Simulated Water Budget - *Long-term* (1939-2011):Annualized Rates in AF/yr for 1939-2011 period (72 years)<br>**Long-term (1939-2011) Natural Recharge Rate = 10,000 AF/yr** | | |
|---|---|---|
| **Simulated Inflow Component** | **IN AF/yr** | **IN AF/yr** |
| Storage | | 19070 |
| Agricultural-related Recharge | 7760 | 12700 |
| Artificial Recharge | 1210 | |
| Natural Recharge (recharge cells) | ***3700*** | |
| Natural Recharge* (stream cells[1]) | | ***6300*** |
| **Total Inflow** | | **38070** |
| **Simulated Outflow Component** | | **Out AF/yr** |
| Storage | | 13010 |
| Pumping | | 17700 |
| Evapotranspiration* (saturated zone) | | 800 |
| Underflow LIC* Sub-basin | | 1730 |
| Underflow UAF Sub-basin | | 1140 |
| Groundwater Discharge*[2] at Del Rio Springs and Baseflow, Agua Fria River | | 3630 |
| **Total Outflow** | | **38010** |
| **Net Change-in-Storage: Long-term (1939-2011) Annualized Rate of Water Lost from Storage** | | **6,060** |

*Head-dependent boundaries.**Specified flux - uniform long-term underflow rates. [1]This predominately losing reach has a small rate of groundwater discharge out contained in the streamflow out term. [2]This predominately gaining reach has a small rate of stream inflow contained within the Natural Recharge (stream cells).

## Table G.4. Simulated Water budget, 1941-1965

| Simulated Water Budget: Dry Period: 1941-1965; Annualized Rates for 1941-1965 (24-year period)<br>Annualized Natural Recharge Rate (1941-1965) = 4,030 AF/yr – "Dry" period | | |
|---|---|---|
| **Simulated Inflow Component** | **IN AF/yr** | **IN AF/yr** |
| Storage | | 18350 |
| Agricultural-related Recharge | 9640 | 12650 |
| Artificial Recharge | 0 | |
| Natural Recharge (recharge cells) | ***3010*** | |
| Natural Recharge* (stream cells[1]) | | ***1020*** |
| **Total Inflow** | | **32020** |
| **Simulated Outflow Component** | | **Out AF/yr** |
| Storage | | 8600 |
| Pumping | | 15300 |
| Evapotranspiration* (saturated zone) | | 800 |
| Underflow LIC* Sub-basin | | 1940 |
| Underflow UAF** Sub-basin | | 1140 |
| Groundwater Discharge*[2] at Del Rio Springs and Baseflow, Agua Fria River | | 4170 |
| **Total Outflow** | | **31950** |
| **Net Change-in-Storage: Annualized (1941-1965) Rate of Water Lost from Storage** | | **9,750** |

*Head-dependent boundaries. **Specified flux – uniform long-term underflow rates. [1]This predominately losing reach has a small rate of groundwater discharge out contained in the streamflow out term. [2]This predominately gaining reach has a small rate of stream inflow contained within the Natural Recharge (stream cells).

## Table G.3. Simulated Water budget, 1965-1995

| Simulated Water Budget: Wet Period: 1965-1995; Annualized Rates for 1965-1995 (30 year period)<br>Annualized Natural recharge Rate (1965-1995) = 14,940 AF/yr – "Wet" period | | |
|---|---|---|
| **Inflow Component** | **IN AF/yr** | **IN AF/yr** |
| Storage | | 19400 |
| Agricultural-related Recharge | 9320 | 14410 |
| Artificial Recharge | 550 | |
| Natural Recharge (recharge cells) | ***4540*** | |
| Natural Recharge* (stream cells[1]) | | ***10400*** |
| **Total Inflow** | | **44210** |
| **Outflow Component** | | **Out AF/yr** |
| Storage | | 18850 |
| Pumping | | 18400 |
| Evapotranspiration* (saturated zone) | | 800 |
| Underflow LIC* Sub-basin | | 1650 |
| Underflow UAF** Sub-basin | | 1130 |
| Groundwater Discharge*[2] at Del Rio Springs and Baseflow, Agua Fria River | | 3700 |
| **Total Outflow** | | **44530** |
| **Net Change-in-Storage: Annualized (1965-1995) Rate of Water Lost from Storage** | | **550** |

*Head-dependent boundaries. **Specified flux – uniform long-term underflow rates. [1]This predominately losing reach has a small rate of groundwater discharge out contained in the streamflow out term. [2]This predominately gaining reach has a small rate of stream inflow contained within the Natural Recharge (stream cells)[2].

## Table G.4. Simulated Water budget, 1995-2011

| Simulated Water Budget: 1995-2011 (Annualized Rates for 1995-2011)<br><br>Annualized Natural recharge Rate (1995-2011) = 9,380 AF/yr | | |
|---|---|---|
| **Inflow Component** | **AF/yr** | **In Af/yr** |
| Storage | | 20550 |
| Agricultural-related Recharge | 2860 | 10260 |
| Artificial Recharge | 3900 | |
| Natural Recharge (recharge cells) | ***3500*** | |
| Natural Recharge* (stream cells[1]) | | ***5880*** |
| **Total Inflow** | | **36,690** |
| **Outflow Component** | | **Out Af/yr** |
| Storage | | 8970 |
| Pumping | | 21650 |
| Evapotranspiration* (saturated zone) | | 800 |
| Underflow LIC* Sub-basin | | 1530 |
| Underflow UAF** Sub-basin | | 1130 |
| Groundwater Discharge*[2] at Del Rio Springs and Baseflow, Agua Fria River | | 2520 |
| **Total Outflow** | | **36,600** |
| **Net Change-in-Storage: Annualized (1995-2011) Rate of Water Lost from Storage** | | **11,580** |

*Head-dependent boundaries. **Specified flux – uniform long-term underflow rates. [1]This predominately losing reach has a small rate of groundwater discharge out contained in the streamflow out term. [2]This predominately gaining reach has a small rate of stream inflow contained within the Natural Recharge (stream cells)[2].

## Table G.4. Simulated Water budget, 1995-2011

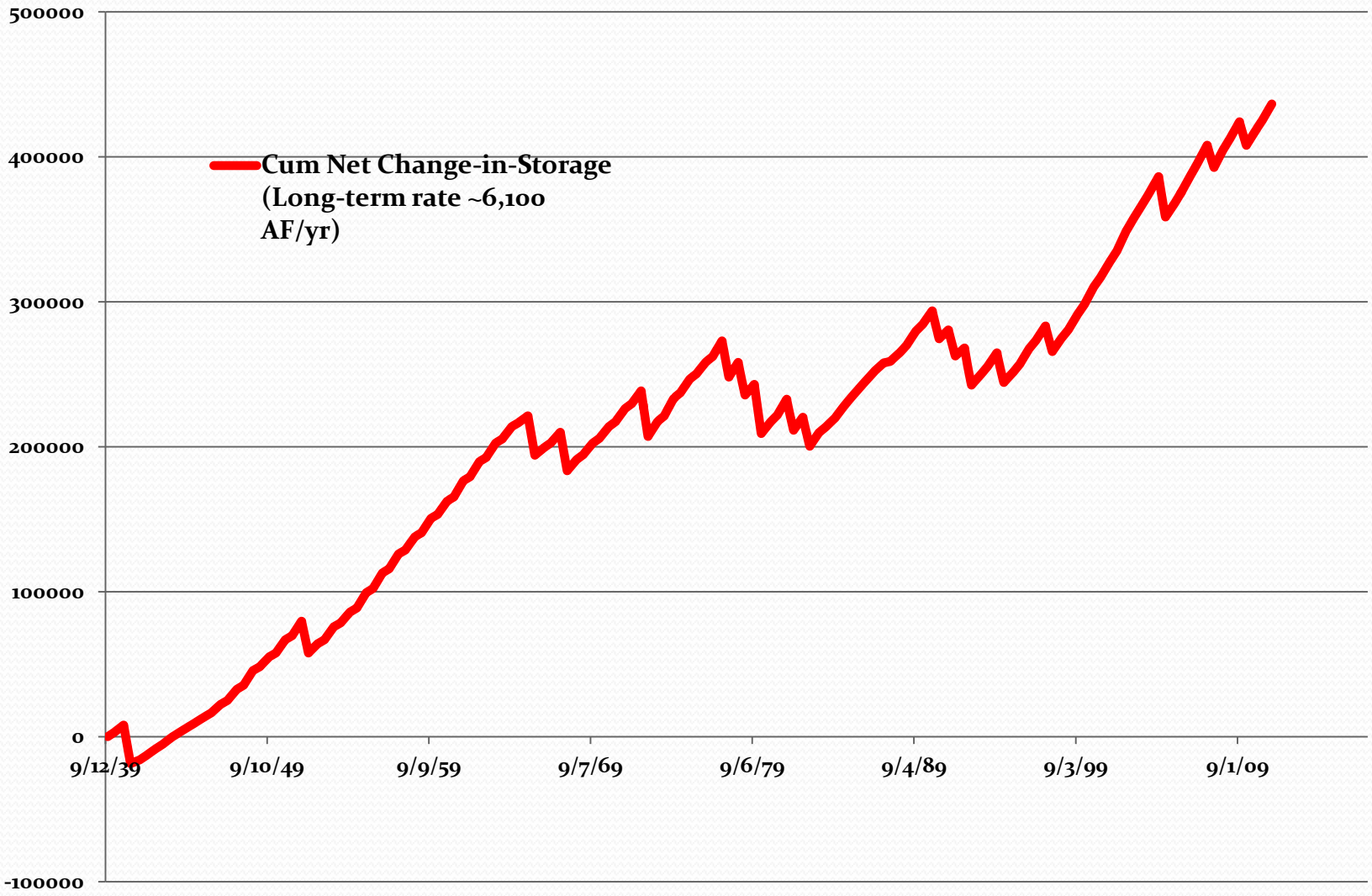
| Simulated Water Budget: 1995-2011 (Annualized Rates for 1995-2011)<br><br>Annualized Natural recharge Rate (1995-2011) = 9,380 AF/yr | | |
|---|---|---|
| **Inflow Component** | **AF/yr** | **In Af/yr** |
| Storage | | 20550 |
| Agricultural-related Recharge | 2860 | 10260 |
| Artificial Recharge | 3900 | |
| Natural Recharge (recharge cells) | ***3500*** | |
| Natural Recharge* (stream cells[1]) | | ***5880*** |
| **Total Inflow** | | **36,690** |
| **Outflow Component** | | **Out Af/yr** |
| Storage | | 8970 |
| Pumping | | 21650 |
| Evapotranspiration* (saturated zone) | | 800 |
| Underflow LIC* Sub-basin | | 1530 |
| Underflow UAF** Sub-basin | | 1130 |
| Groundwater Discharge*[2] at Del Rio Springs and Baseflow, Agua Fria River<br>(Original Net Natural Groundwater Discharge Rate, circa 1939 ≈ 6,700 AF/yr) | | 2520 |
| **Total Outflow** | | **36,600** |
| **Net Change-in-Storage: Annualized (1995-2011) Rate of Water Lost from Storage …….Plus "Hidden-Cost" of Long-term Net Capture** | **11,580 + 4,000 AF/yr ??** | |

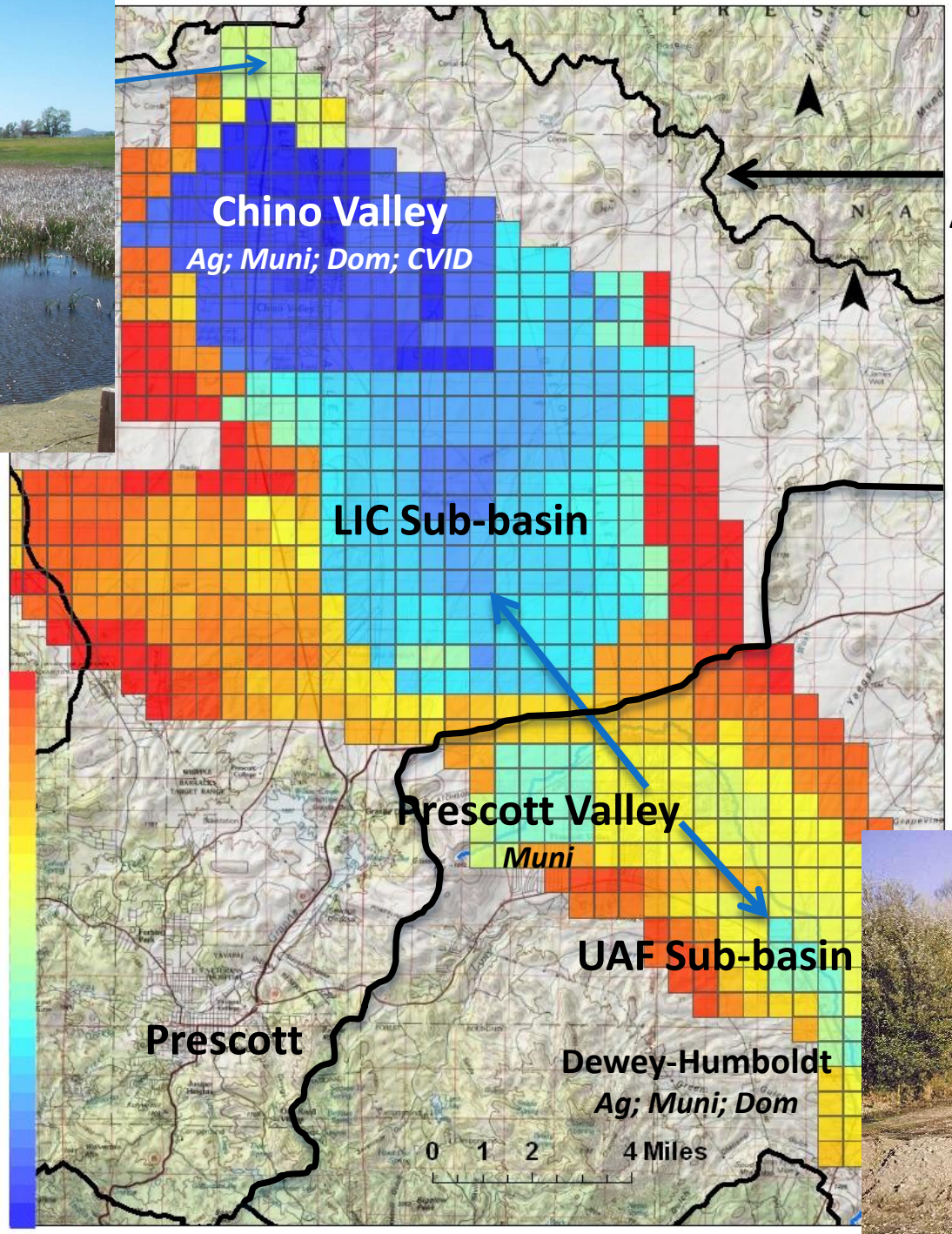
*Head-dependent boundaries. **Specified flux – uniform long-term underflow rates. [1]This predominately losing reach has a small rate of groundwater discharge out contained in the streamflow out term. [2]This predominately gaining reach has a small rate of stream inflow contained within the Natural Recharge (stream cells)[2].

| Hypothetical Water Budget Based on 1995-2011 Demand Average and a Very Wet Year (i.e., 2004/05) | | |
|---|---|---|
| **Inflow Component** | **AF/yr** | **In Af/yr** |
| Agricultural-related Recharge | | 2860 |
| Artificial Recharge | | 3900 |
| Natural Recharge (stream + MFR/MFR) | | **34,527** |
| **Total Inflow** | | **41,287** |
| **Outflow Component** | | **Out Af/yr** |
| Pumping | | 21650 |
| Evapotranspiration* (saturated zone) | | 800 |
| Underflow LIC* Sub-basin | | 1530 |
| Underflow UAF** Sub-basin | | 1130 |
| Groundwater Discharge*[2] at Del Rio Springs and Baseflow, Agua Fria River | | 2520 |
| **Total Outflow** | | 27,630 |
| **Net Change-in-Storage: Annualized (1995-2011) Rate of Water Lost from Storage** | **13,657 AF/yr** | |
| Natural recharge based on "Base" Model, simulation year 2004/05. A "wet" year such as 2005 was relatively rare period with the exception of the mid-19709's to mid-1990's period. | | |

| Hypothetical Water Budget Based on 1995-2011 Demand Average & and Very Dry {for example year (2012)}<br>Results in a NET Negative Imbalance ≈ 18,000 AF/yr | | |
|---|---|---|
| **Inflow Component** | | **IN AF/yr** |
| Agricultural-related Recharge | | 2860 |
| Artificial Recharge | | 3900 |
| Natural Recharge (recharge – Long-term constant MFR and/or MBR; no variable stream recharge) | | **2,930** |
| **Total Inflow** | | 9,690 |
| **Outflow Component** | | **Out AF/yr** |
| Pumping | | 21650 |
| Evapotranspiration* (saturated zone) | | 800 |
| Underflow LIC* Sub-basin | | 1530 |
| Underflow UAF** Sub-basin | | 1130 |
| Groundwater Discharge*[2] at Del Rio Springs and Baseflow, Agua Fria River | | 2520 |
| **Total Outflow** | | 27,630 |
| **Net Change-in-Storage: Annualized (1965-1995) Rate of Water Lost from Storage** | **17,940 AF/yr** | |
| Natural recharge based on "Base" Model, for a nominally-dry year: 53 out of 72 of the simulated years between 1939 and 2011 imposed nominal natural recharge – in this case, 2,930 AF/yr. | | |

# Cumulative Net Change-in-Storage

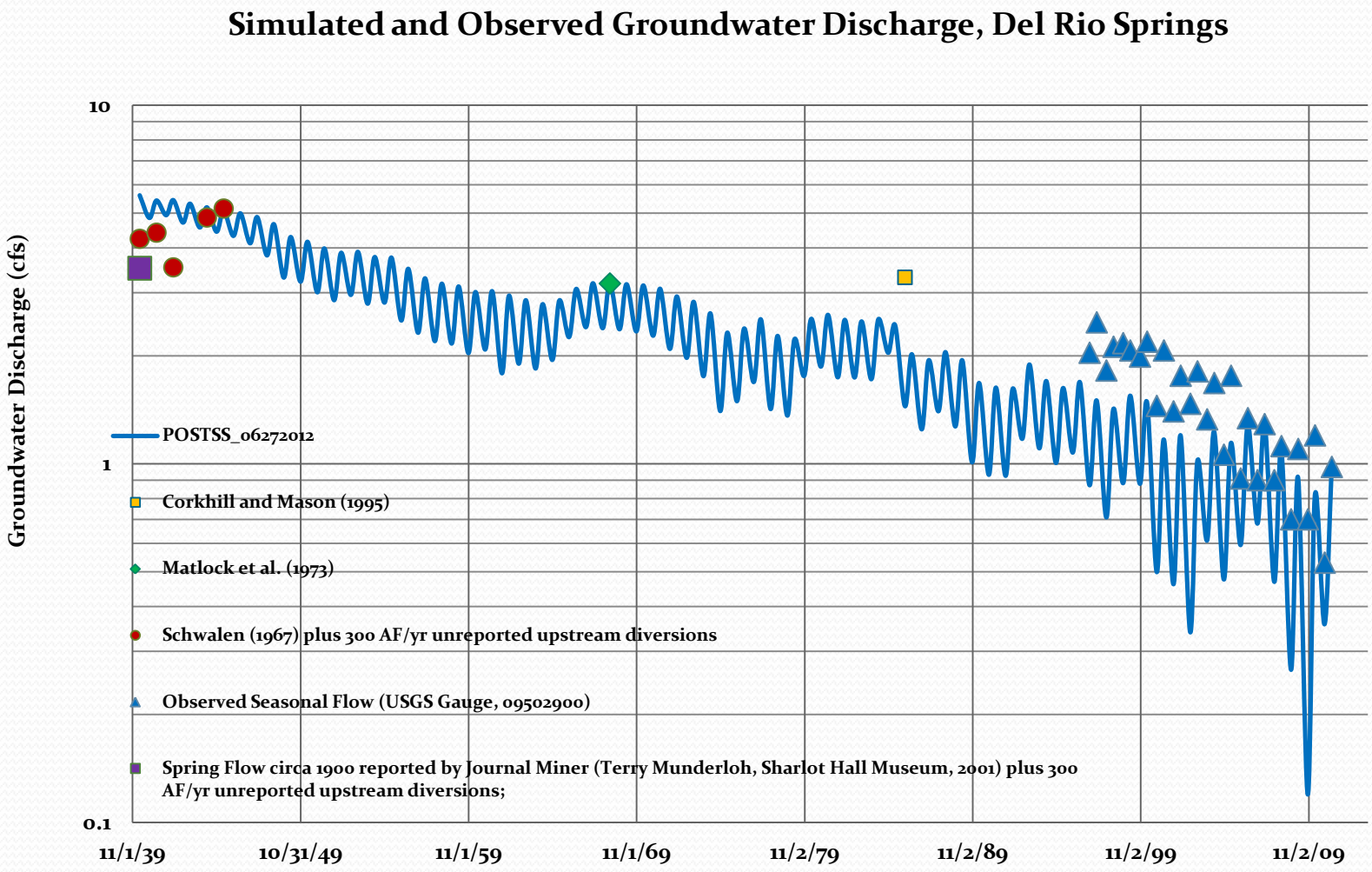





Prescott
AMA Boundary

# Simulated & Observed Groundwater Discharge Del Rio Springs

## Base Solution – calibrated Natural Recharge ≈ 9,920 AF/yr

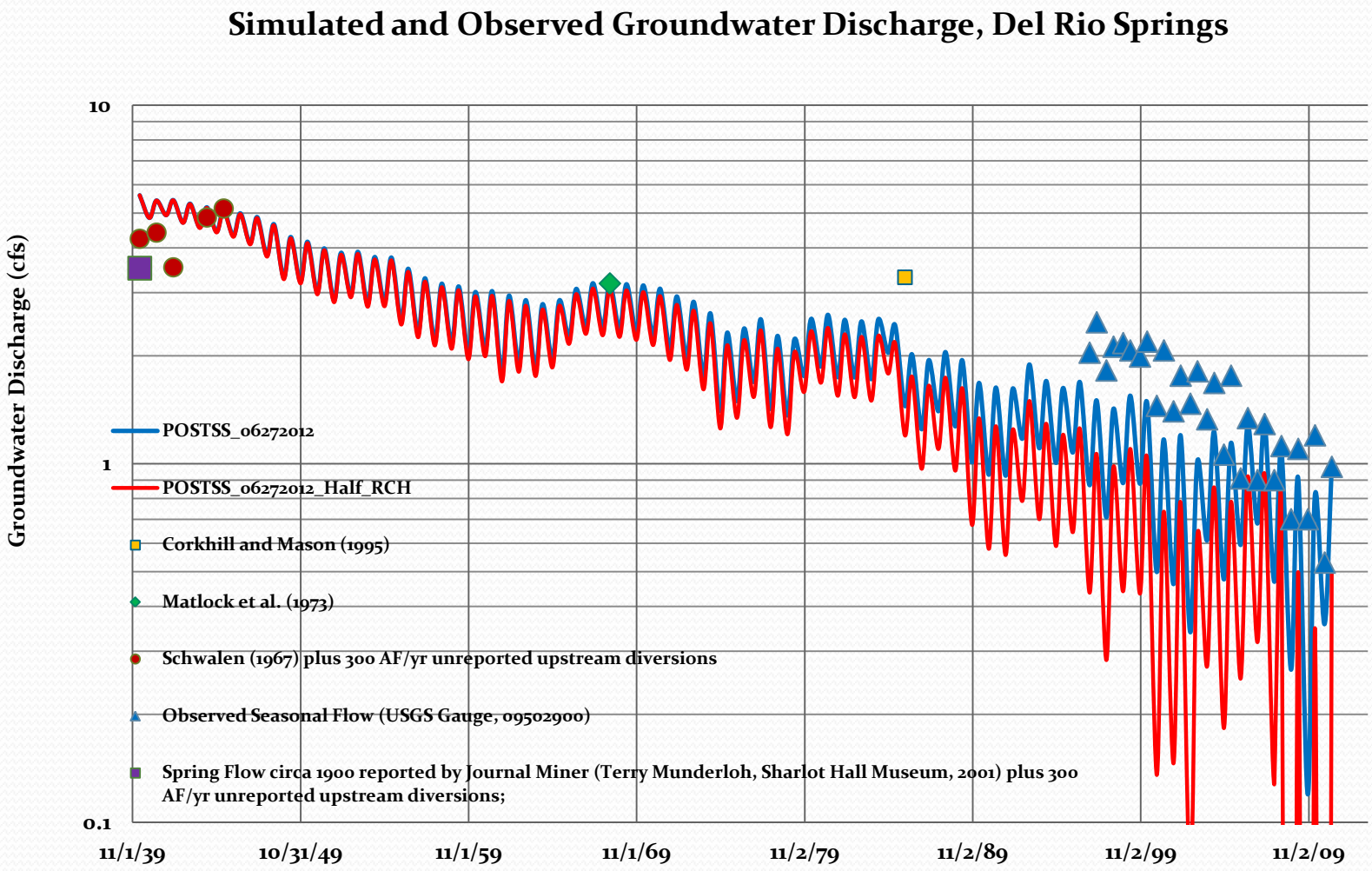



## Del Rio Springs

# Simulated & Observed Groundwater Discharge Del Rio Springs

## Base Model Solution – calibrated Natural Recharge ≈ 9,920 AF/yr

## Base Model -- with reduced Natural Recharge ≈ 5,100 AF/yr



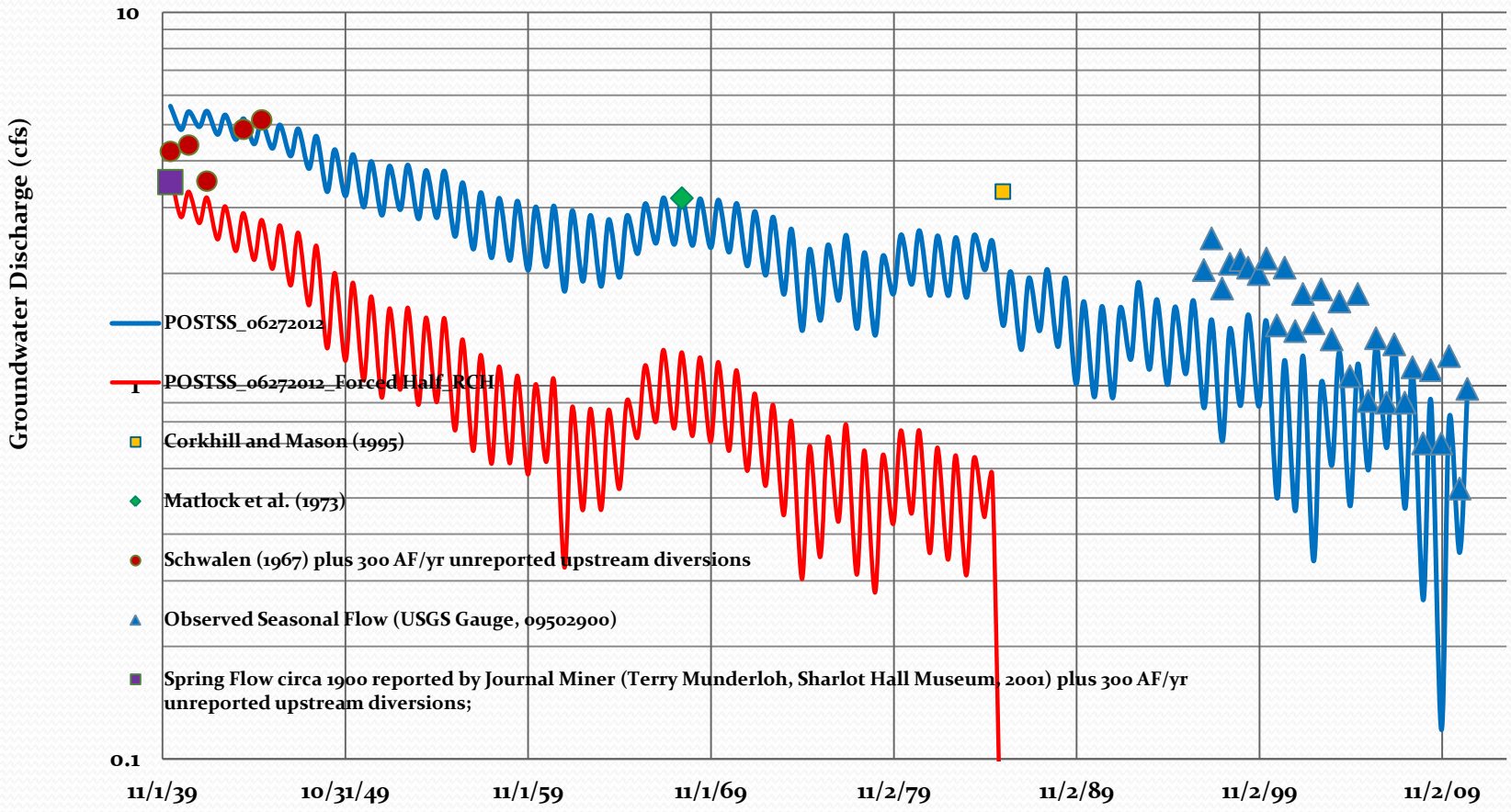

## Del Rio Springs

# Simulated & Observed Groundwater Discharge Del Rio Springs

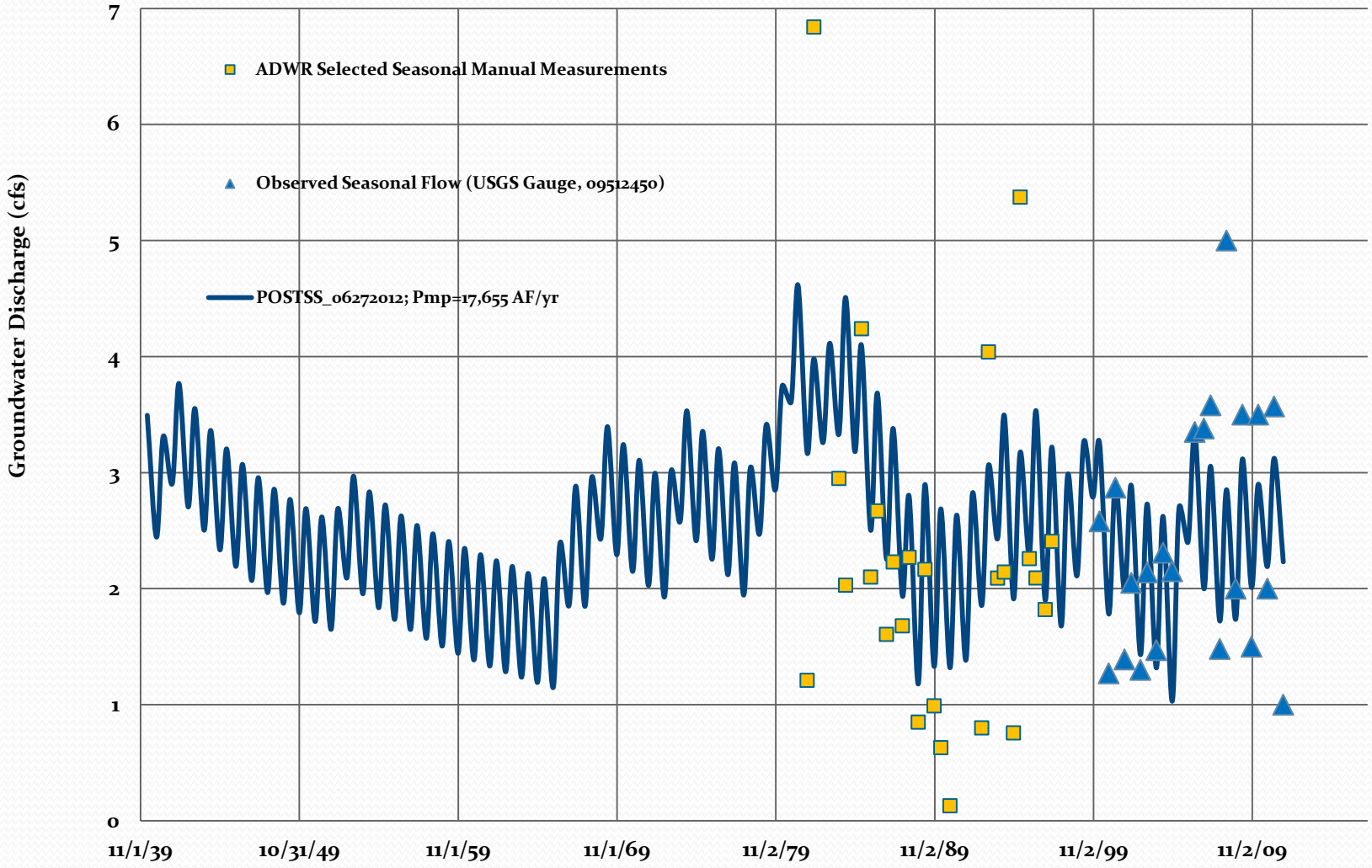
## Base Solution Natural Recharge ≈ 9,920 AF/yr

## ACM: PEST -> Constrained Natural Recharge to 5,000 AF/yr

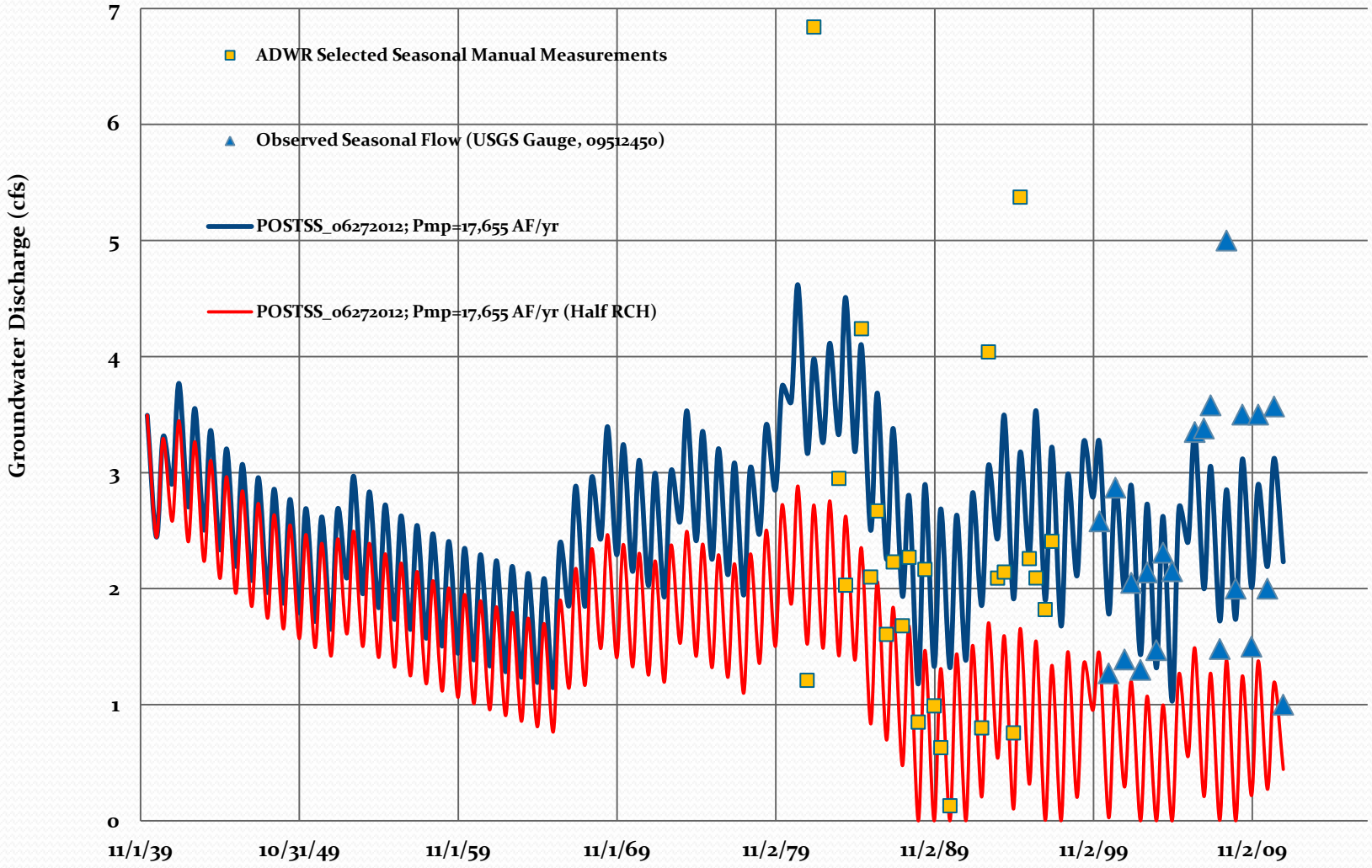
## Conditioned Solution Sustains L1 – L2 head separation and lower LIC & UAF Sub-basin Underflow, but Under-simulates Groundwater Discharge

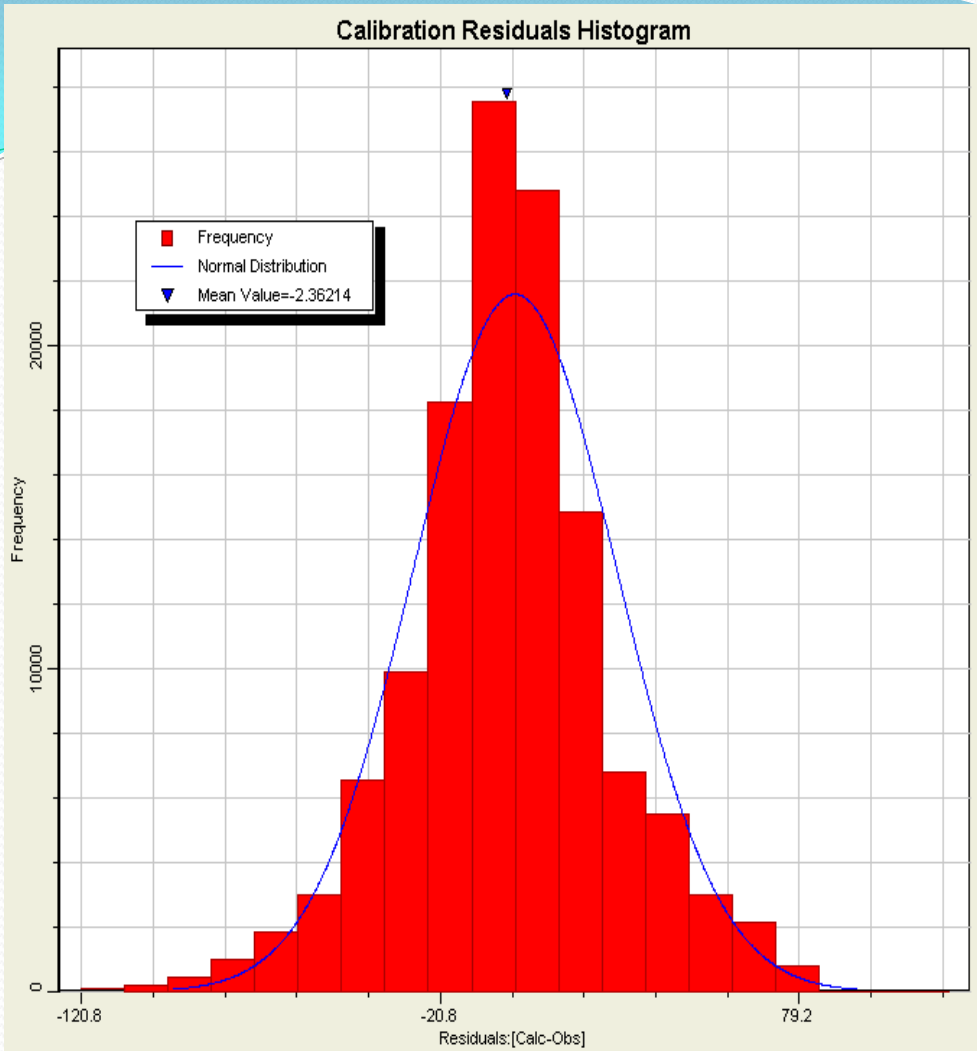


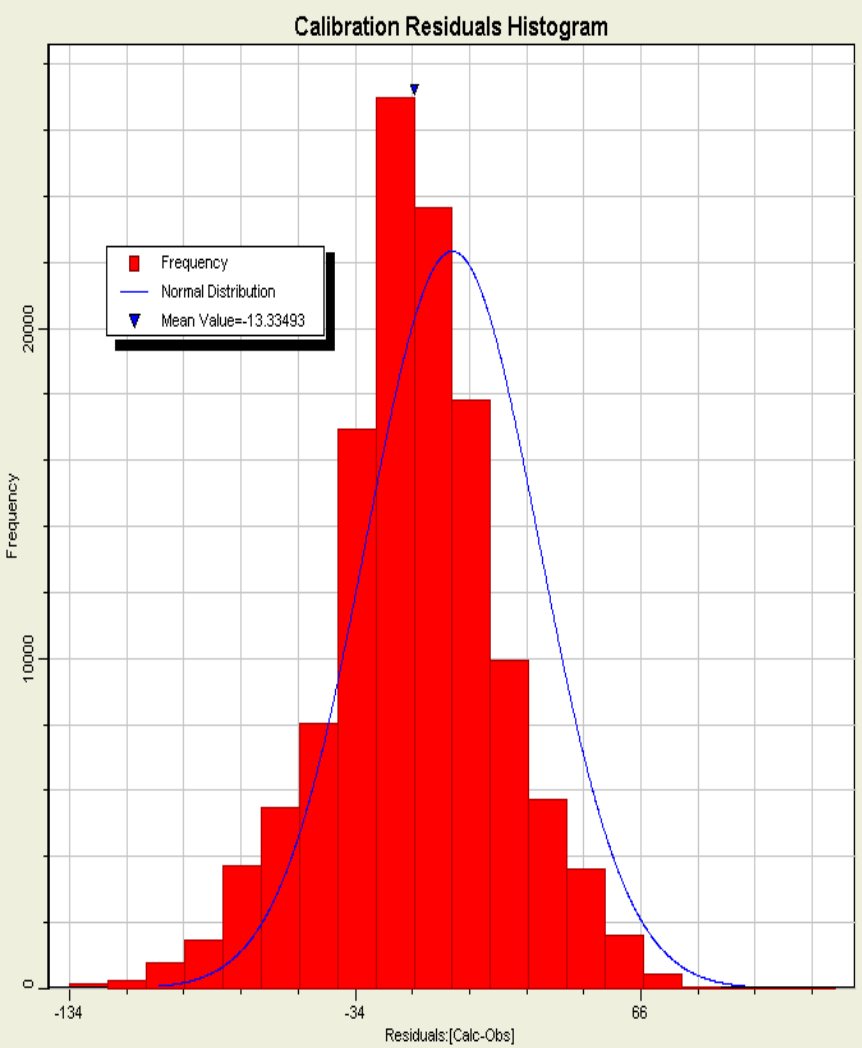
## Simulated and Observed Groundwater Discharge, Agua Fria River



## Simulated and Observed Groundwater Discharge, Agua Fria River

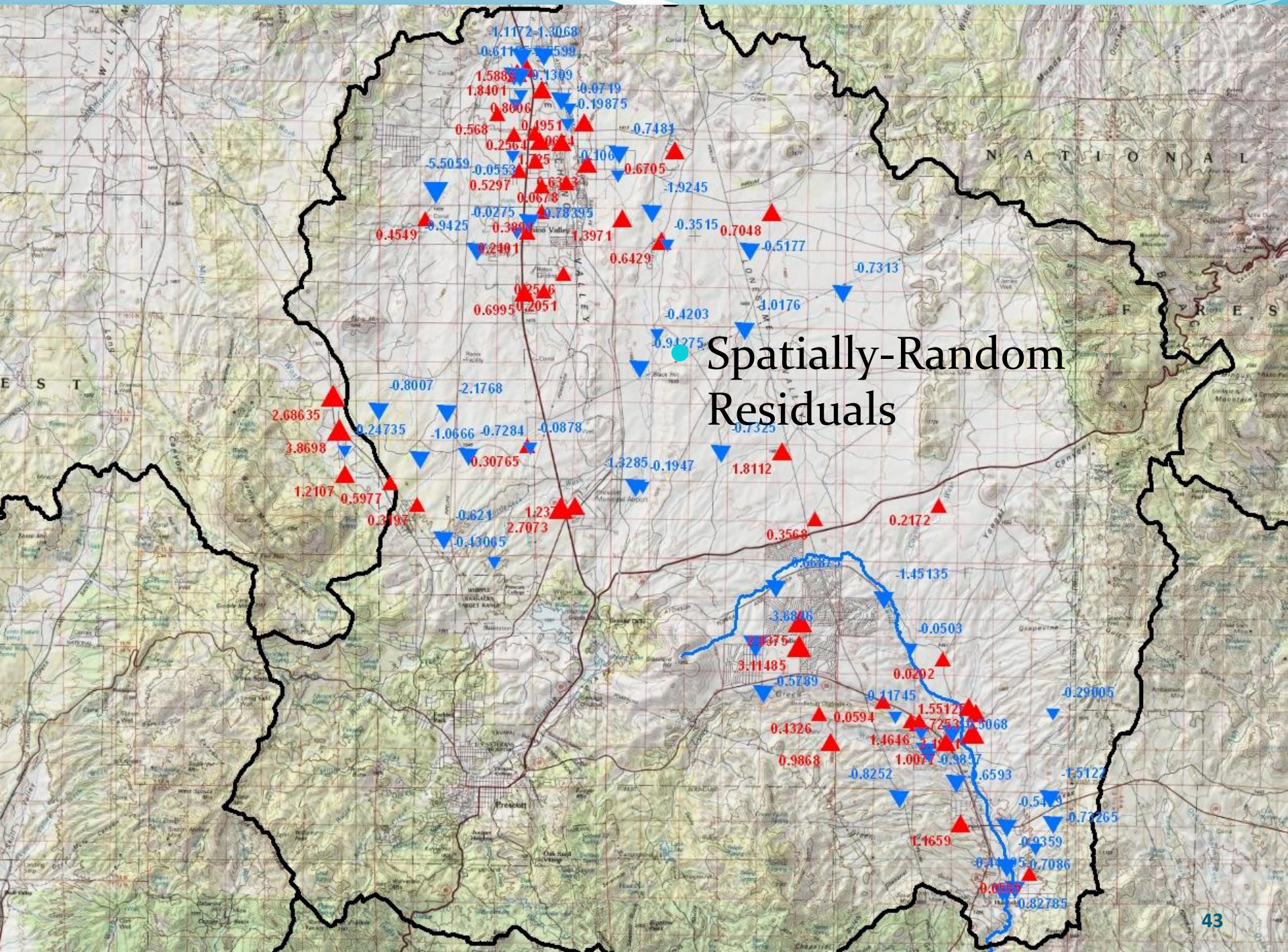


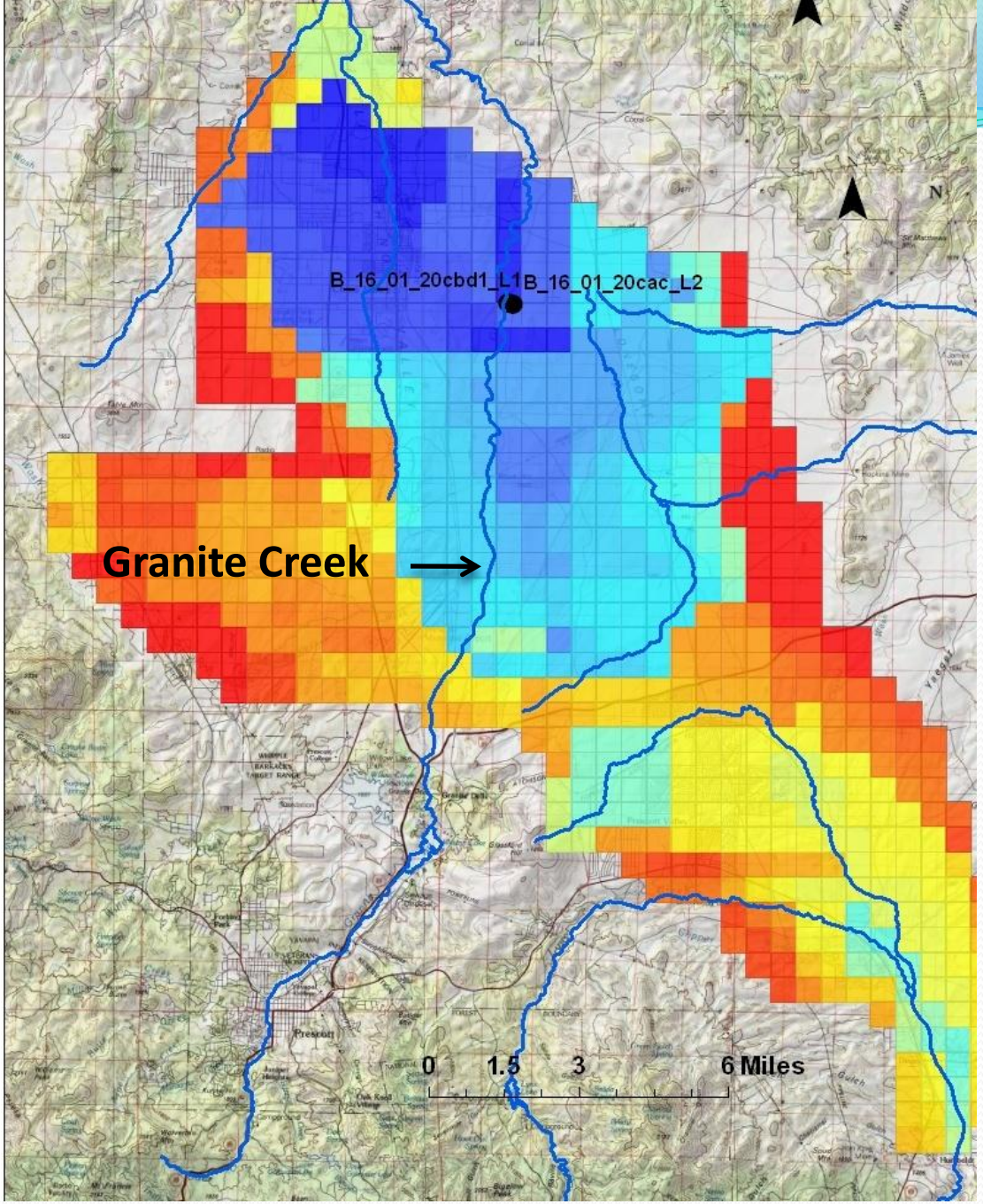


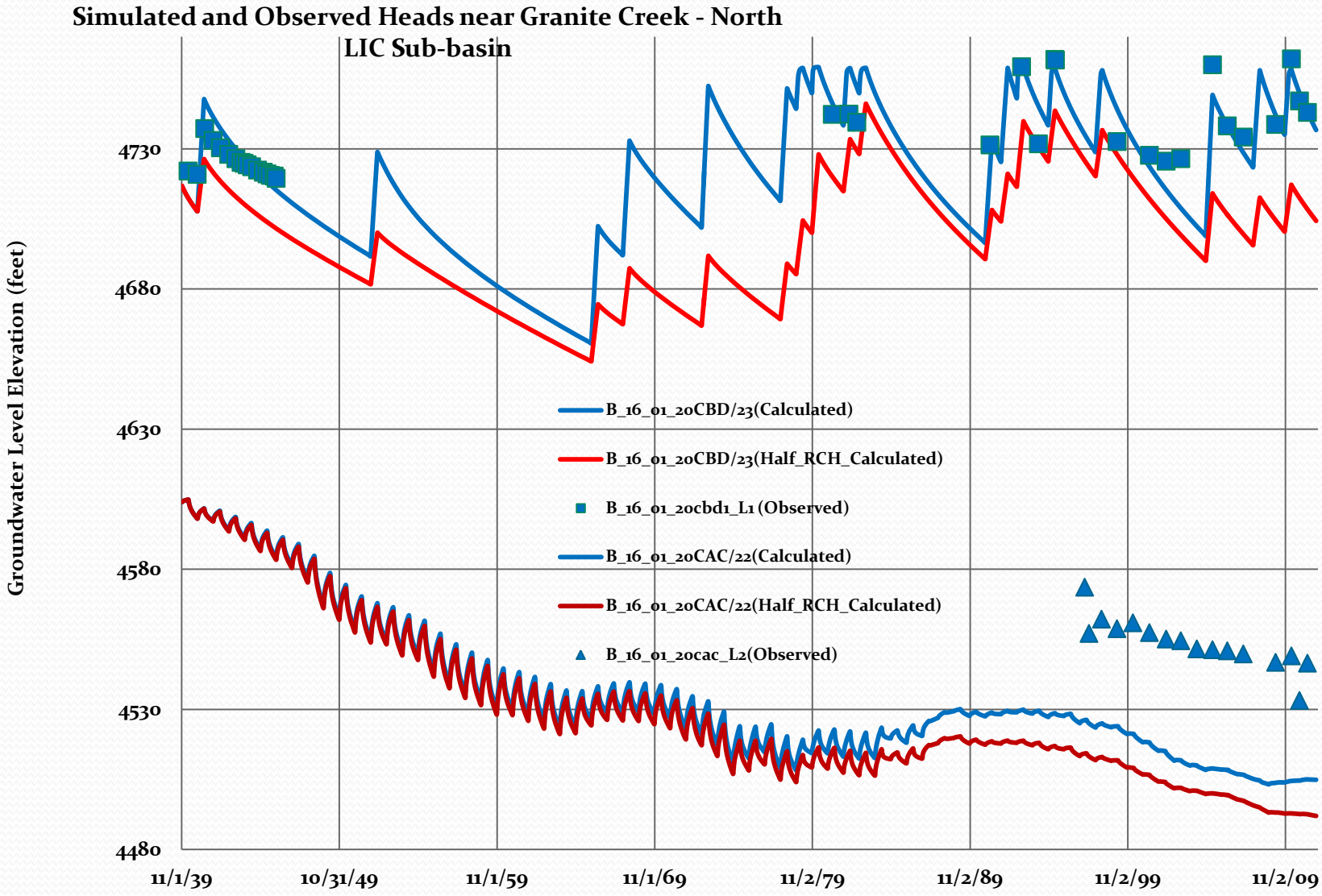




**Calibrated Model long-term transient natural recharge rate = 9,920 AF/yr**
**= sim-obs = - 2.4 feet**
**slightly under-simulated Base Model**

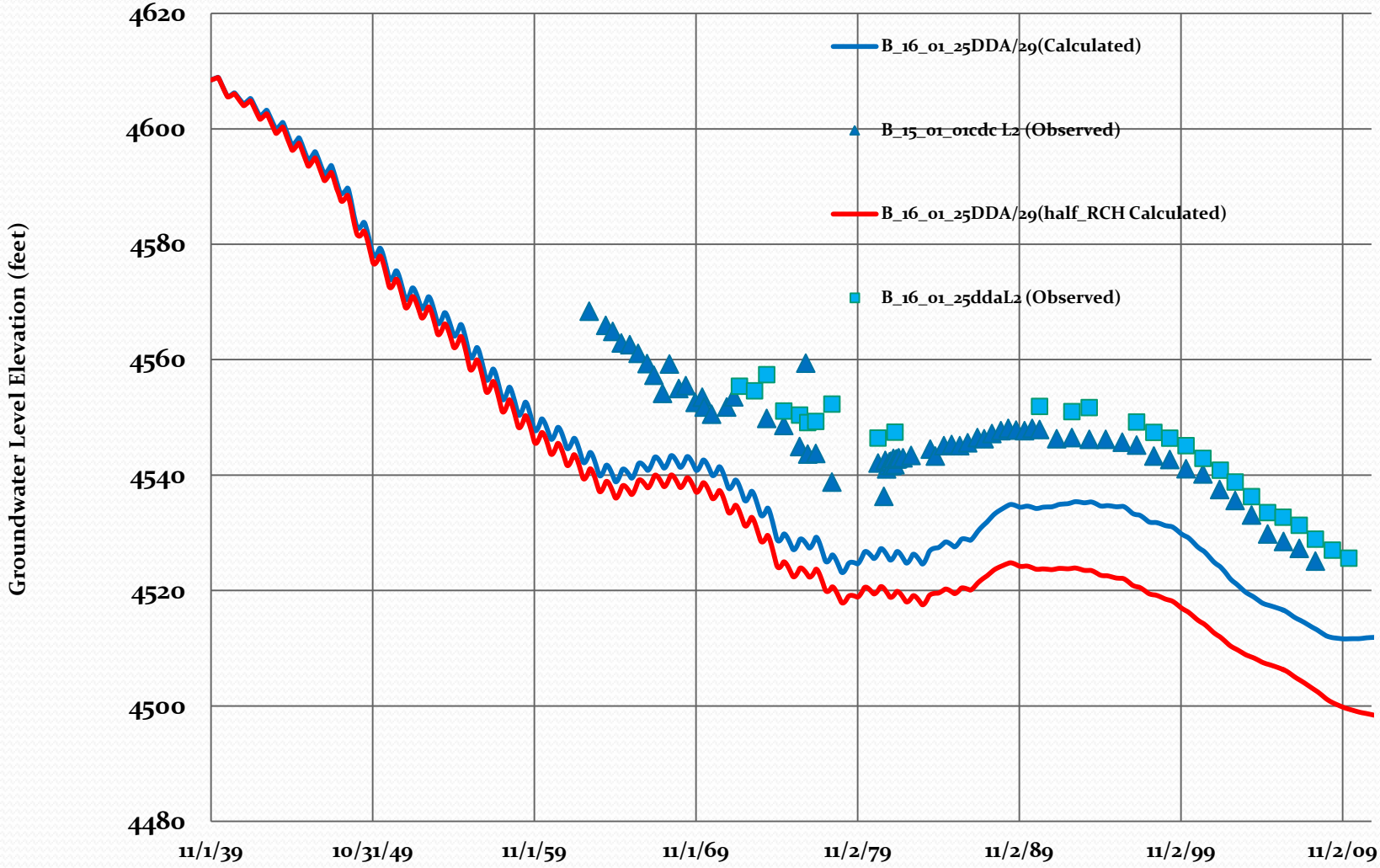
**ACM Model long-term transient nat recharge rate = 5,100 AF/yr**
**= sim – obs = -13.3 feet**
**fairly significant under-simulated bias**

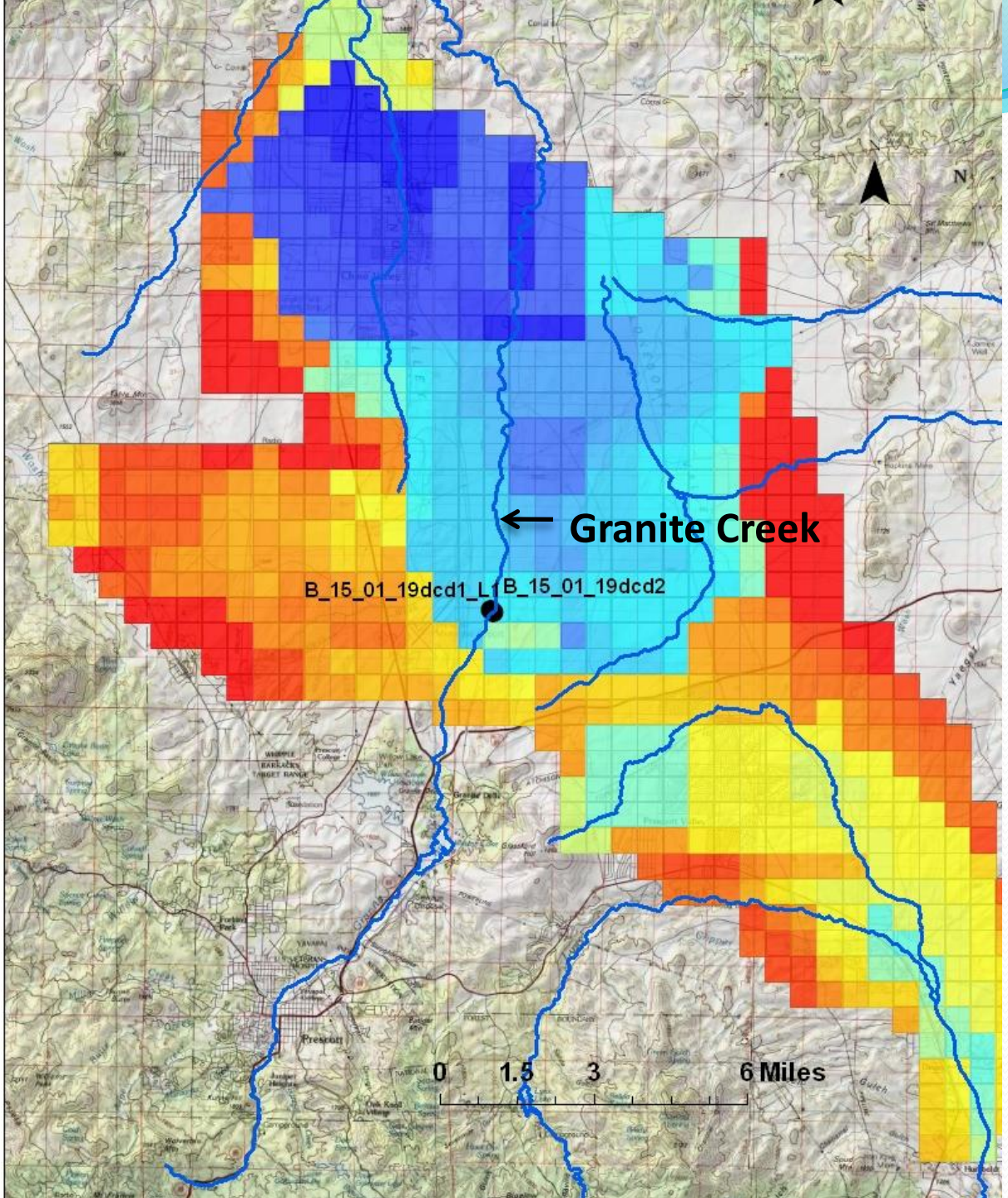

Spatially-Random Residuals


B_16_01_20cbd1_L1
B_16_01_20cac_L2
Granite Creek
N
Prescott
0
1.5
3
6 Miles

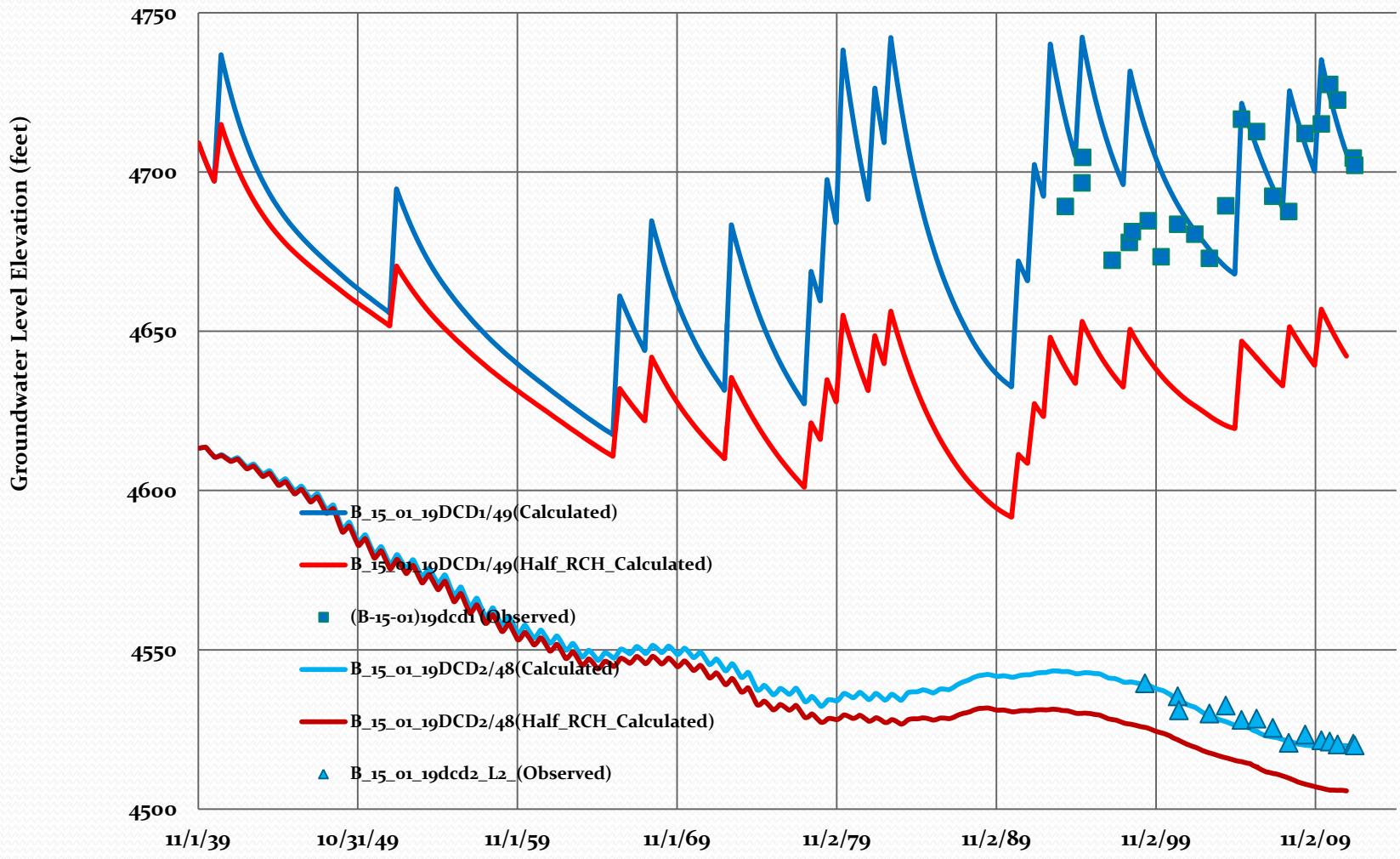

Simulated and Observed Heads near Granite Creek - North LIC Sub-basin
Groundwater Level Elevation (feet)
4730
4680
4630
4580
4530
4480
11/1/39
10/31/49
11/1/59
11/1/69
11/2/79
11/2/89
11/2/99
11/2/09
B_16_01_20CBD/23(Calculated)
B_16_01_20CBD/23(Half_RCH_Calculated)
B_16_01_20cbd1_L1 (Observed)
B_16_01_20CAC/22(Calculated)
B_16_01_20CAC/22(Half_RCH_Calculated)
B_16_01_20cac_L2(Observed)

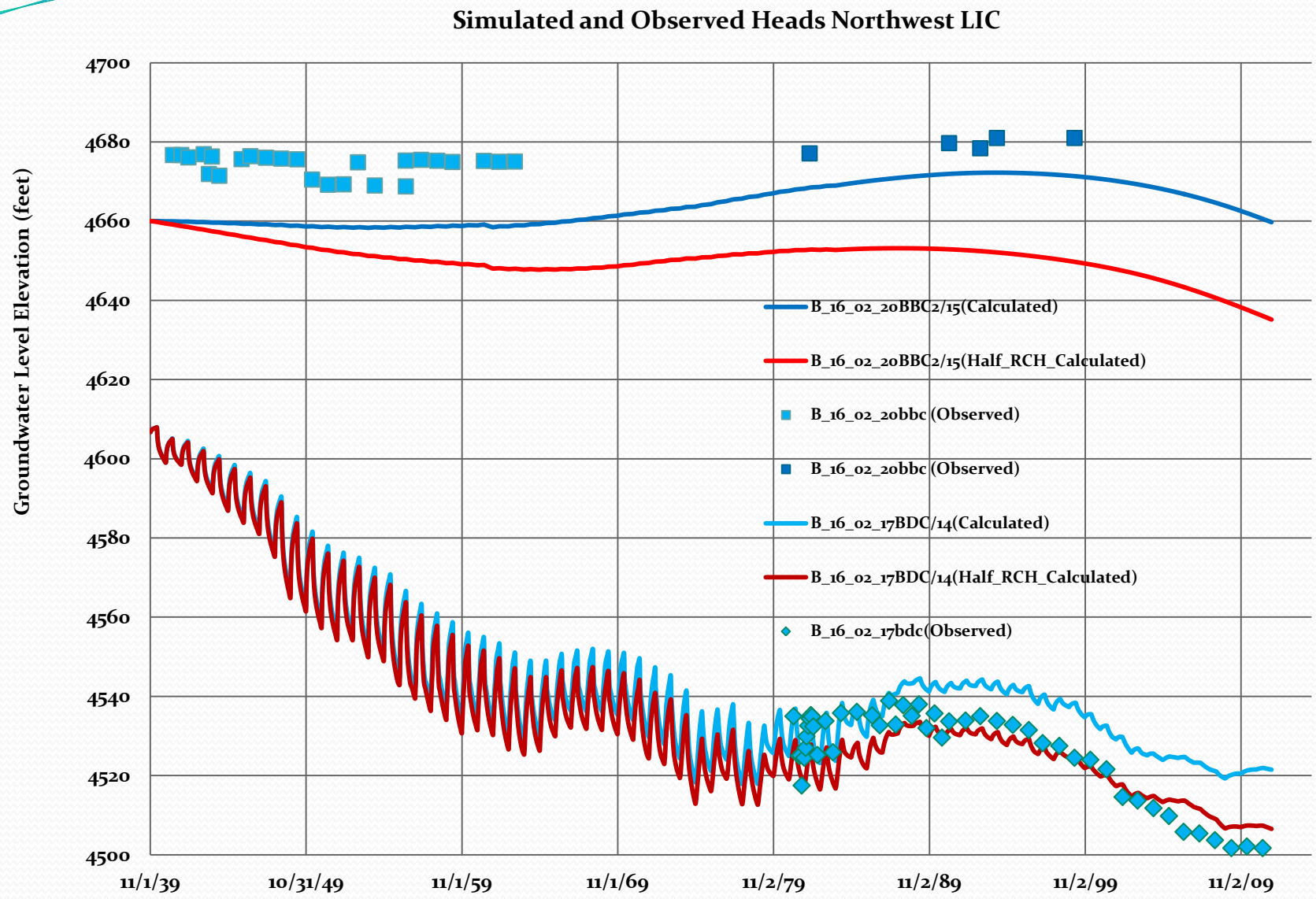
## Simulated and Observed Heads Far Eastern LIC Sub-basin

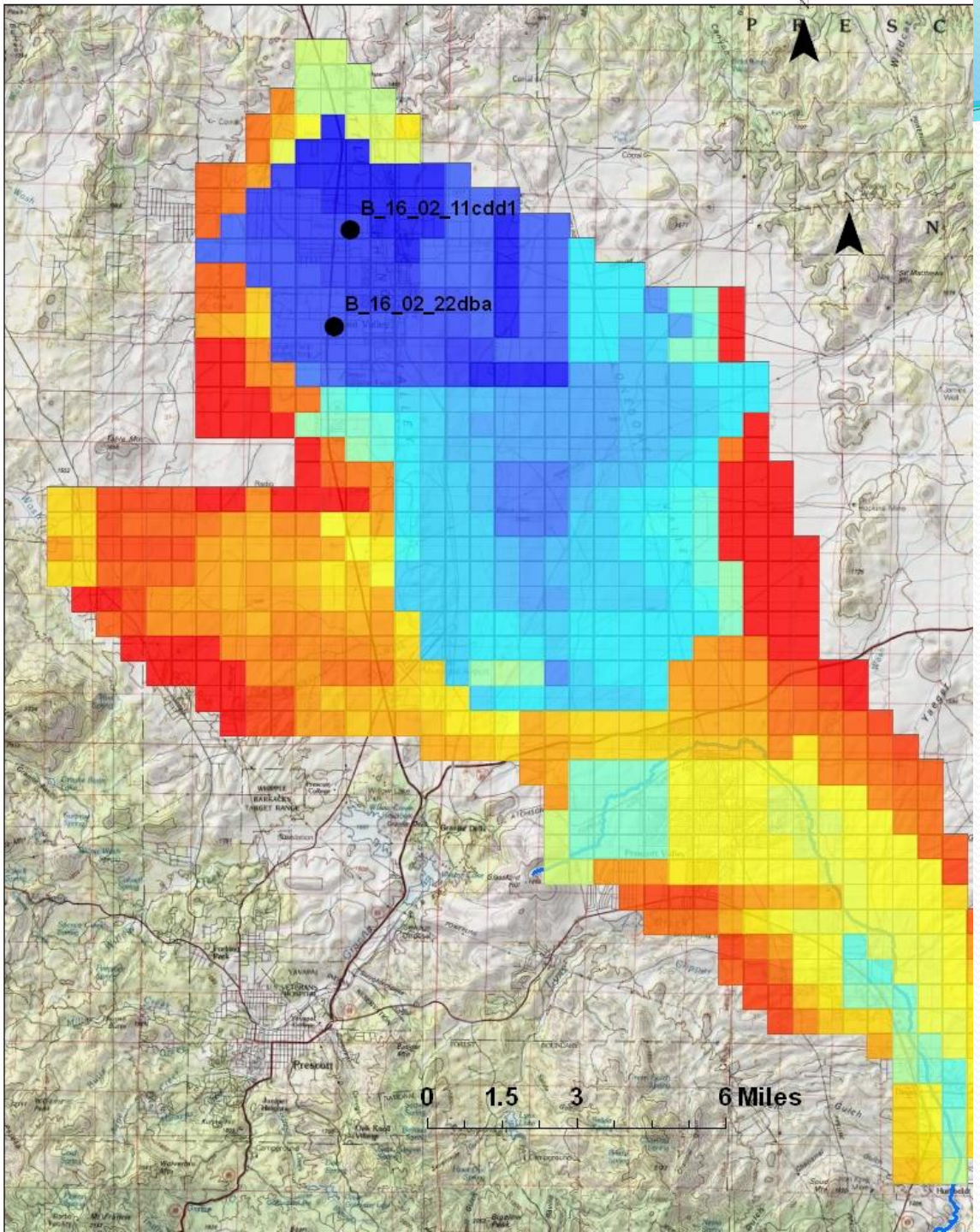



Granite Creek
B_15_01_19dcd1_L1
B_15_01_19dcd2
N
Prescott
0
1.5
3
6 Miles

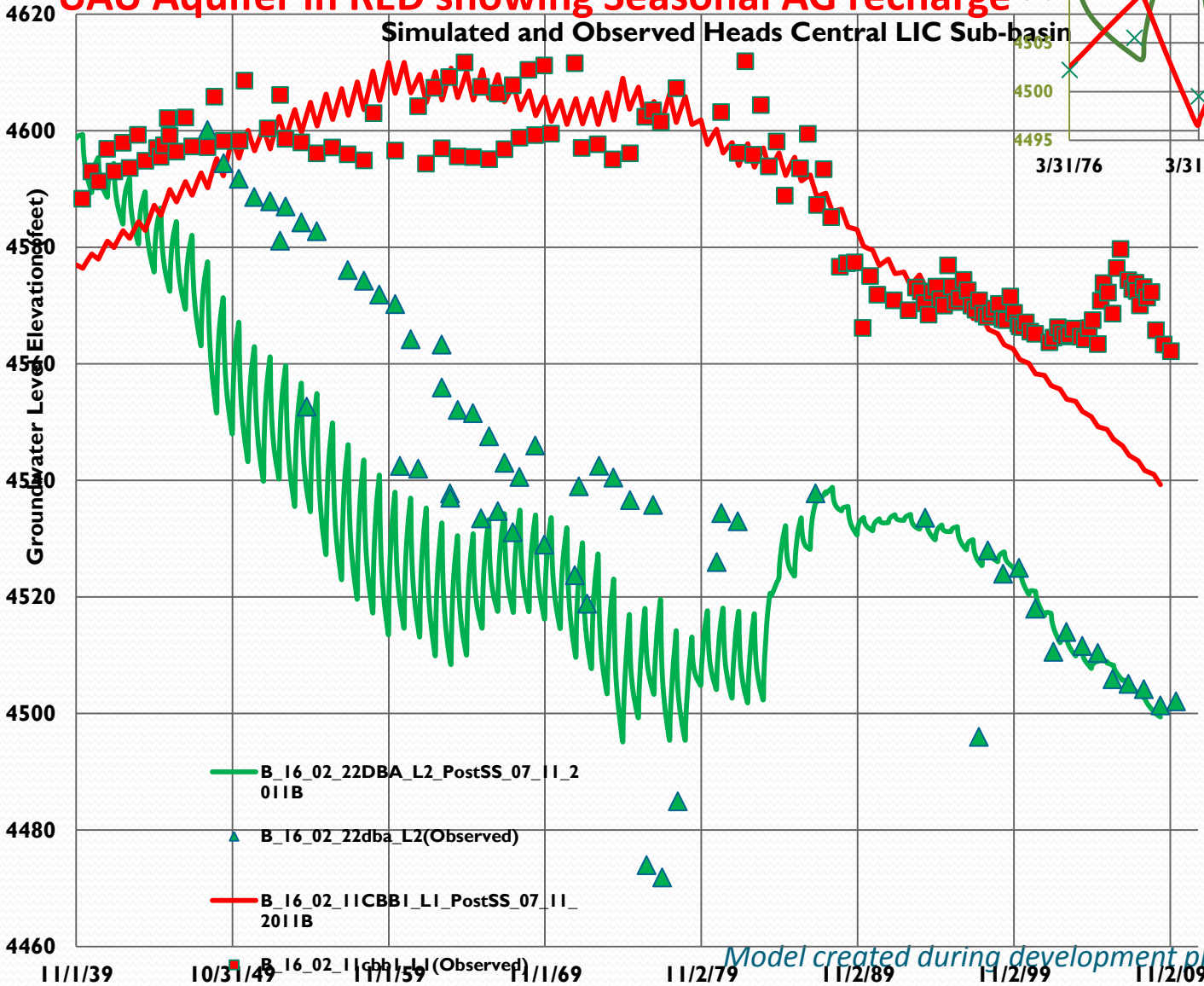
## Simulated and Observed Heads near Granite Creek - South LIC Sub-basin

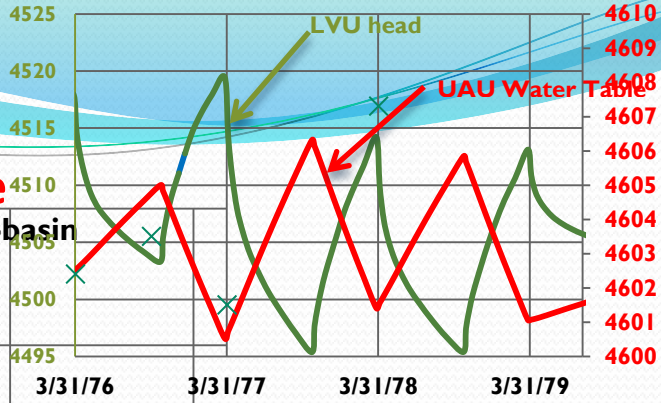



Simulated and Observed Heads Northwest LIC
Groundwater Level Elevation (feet)
4700
4680
4660
4640
4620
4600
4580
4560
4540
4520
4500
11/1/39
10/31/49
11/1/59
11/1/69
11/2/79
11/2/89
11/2/99
11/2/09
B_16_02_20BBC2/15(Calculated)
B_16_02_20BBC2/15(Half_RCH_Calculated)
B_16_02_20bbc (Observed)
B_16_02_20bbc (Observed)
B_16_02_17BDC/14(Calculated)
B_16_02_17BDC/14(Half_RCH_Calculated)
B_16_02_17bdc(Observed)

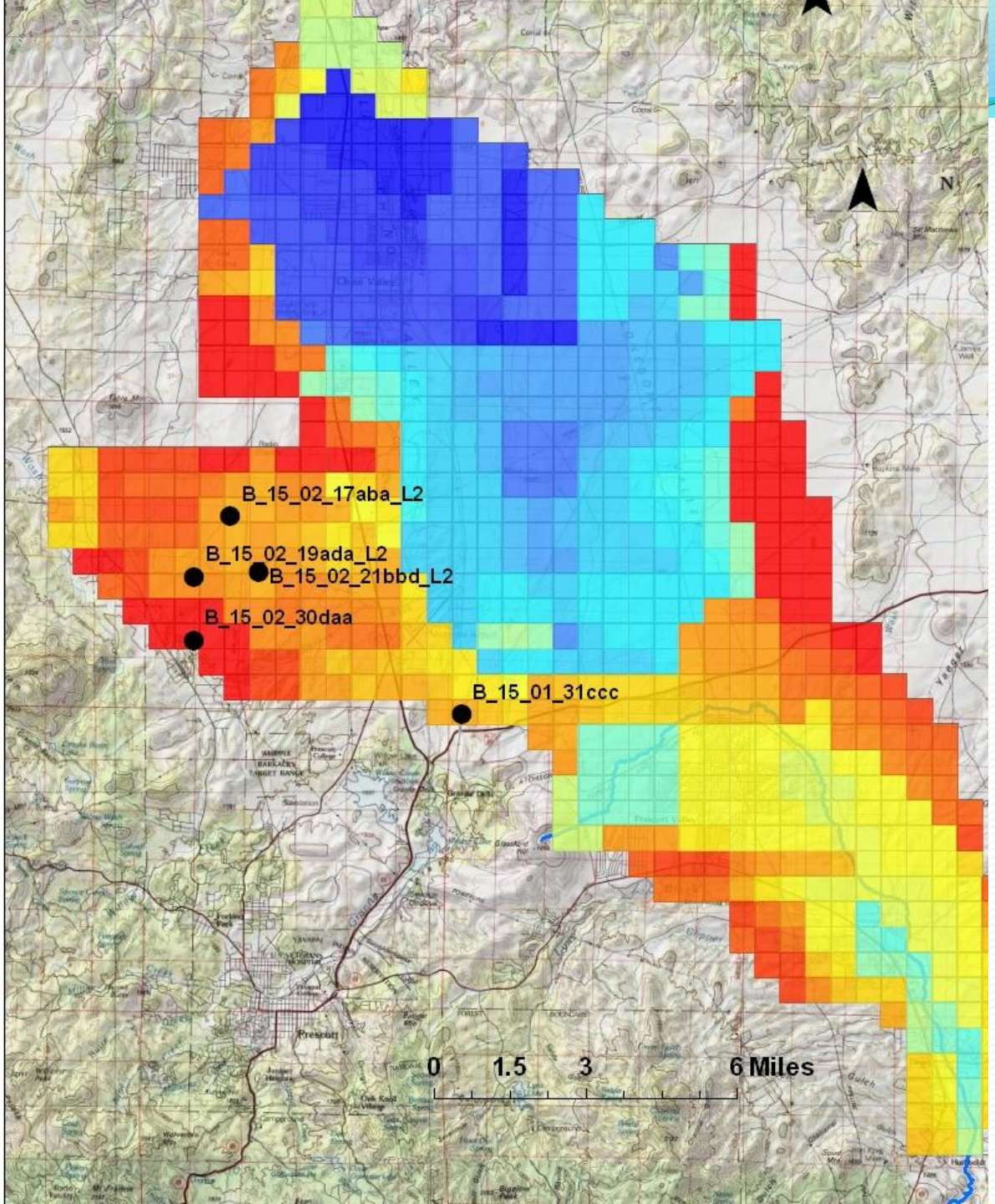

P E S C
N
B_16_02_11cdd1
B_16_02_22dba
0 1.5 3 6 Miles
Prescott

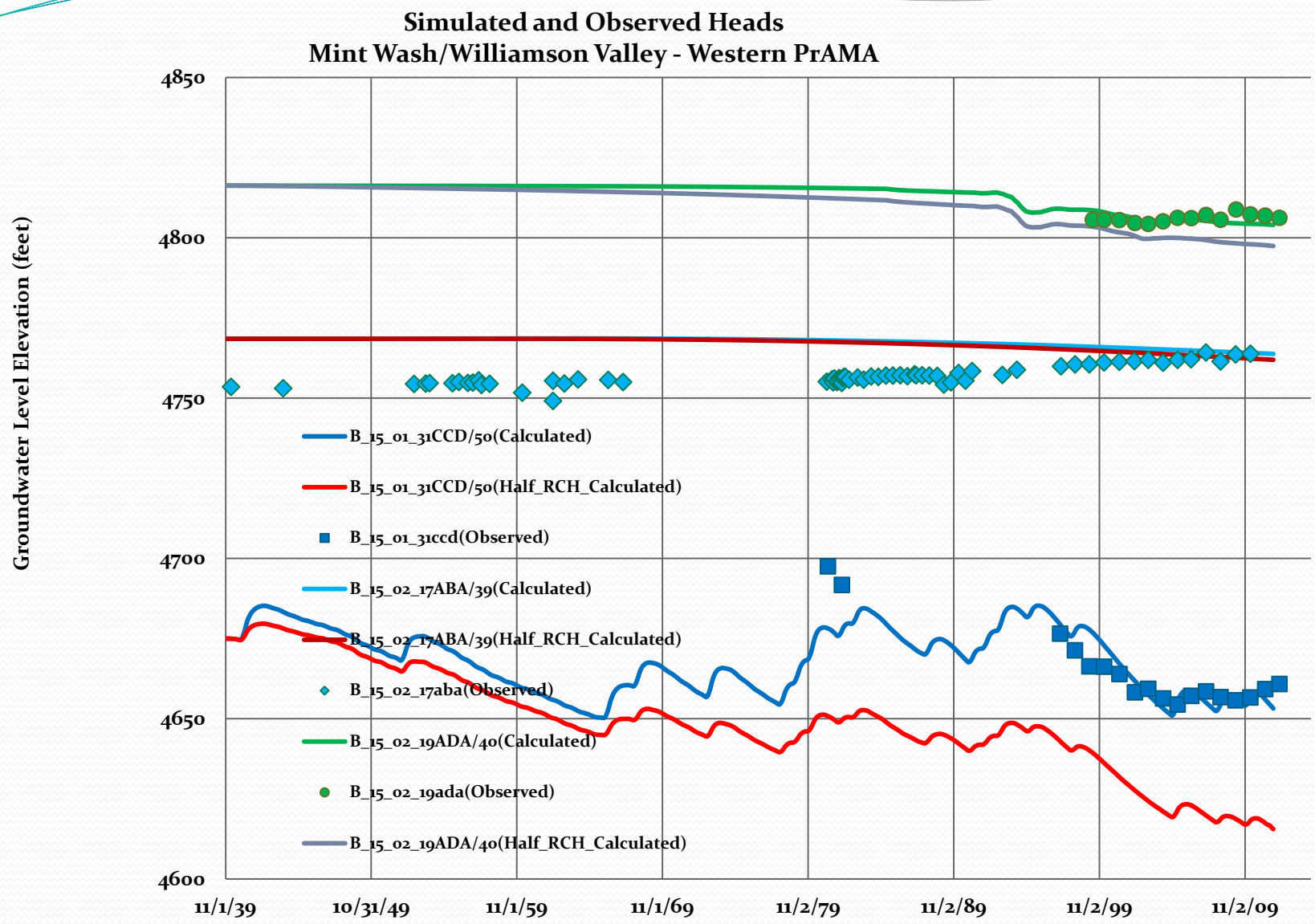
# UAU Aquifer in RED showing Seasonal AG recharge

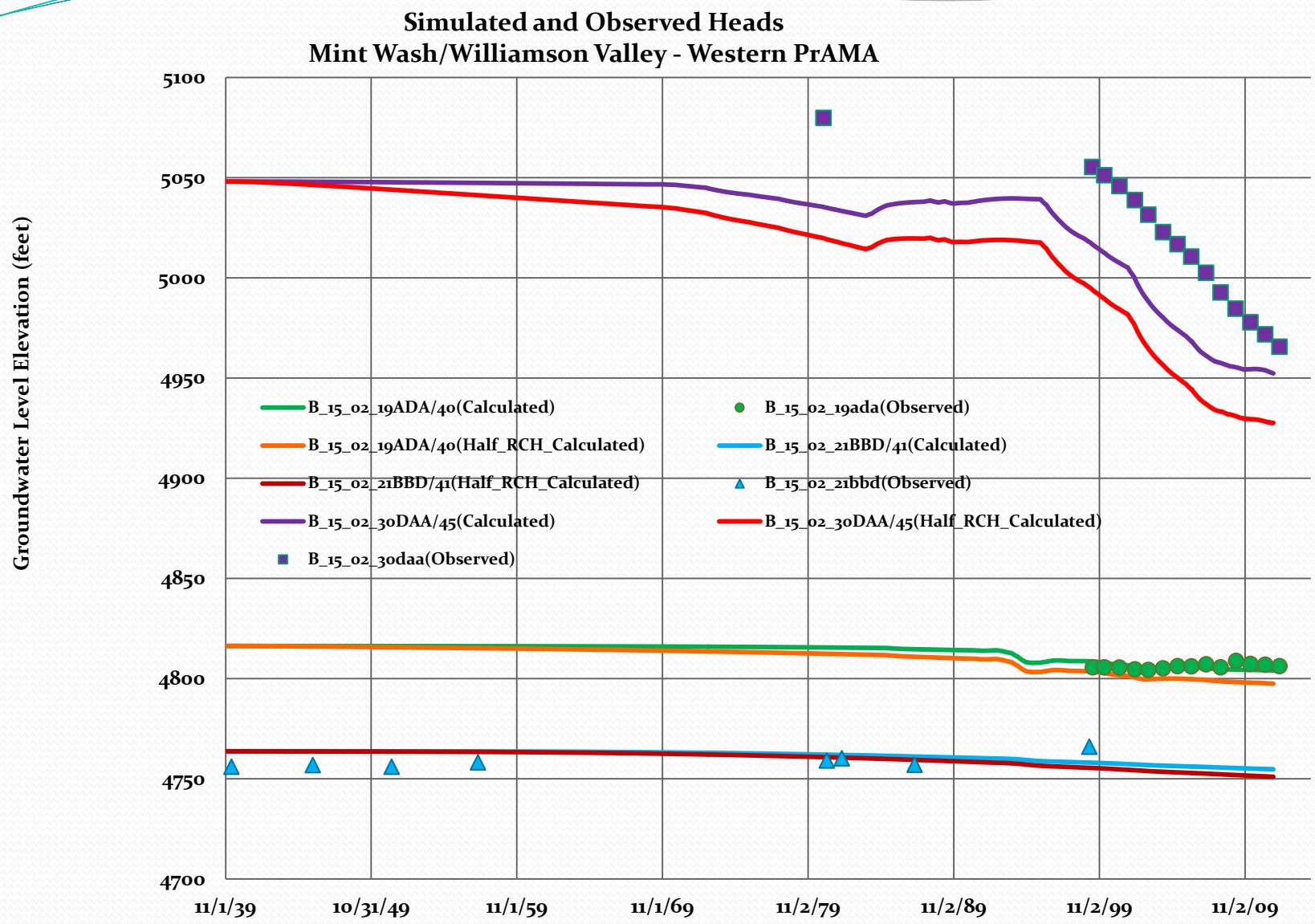


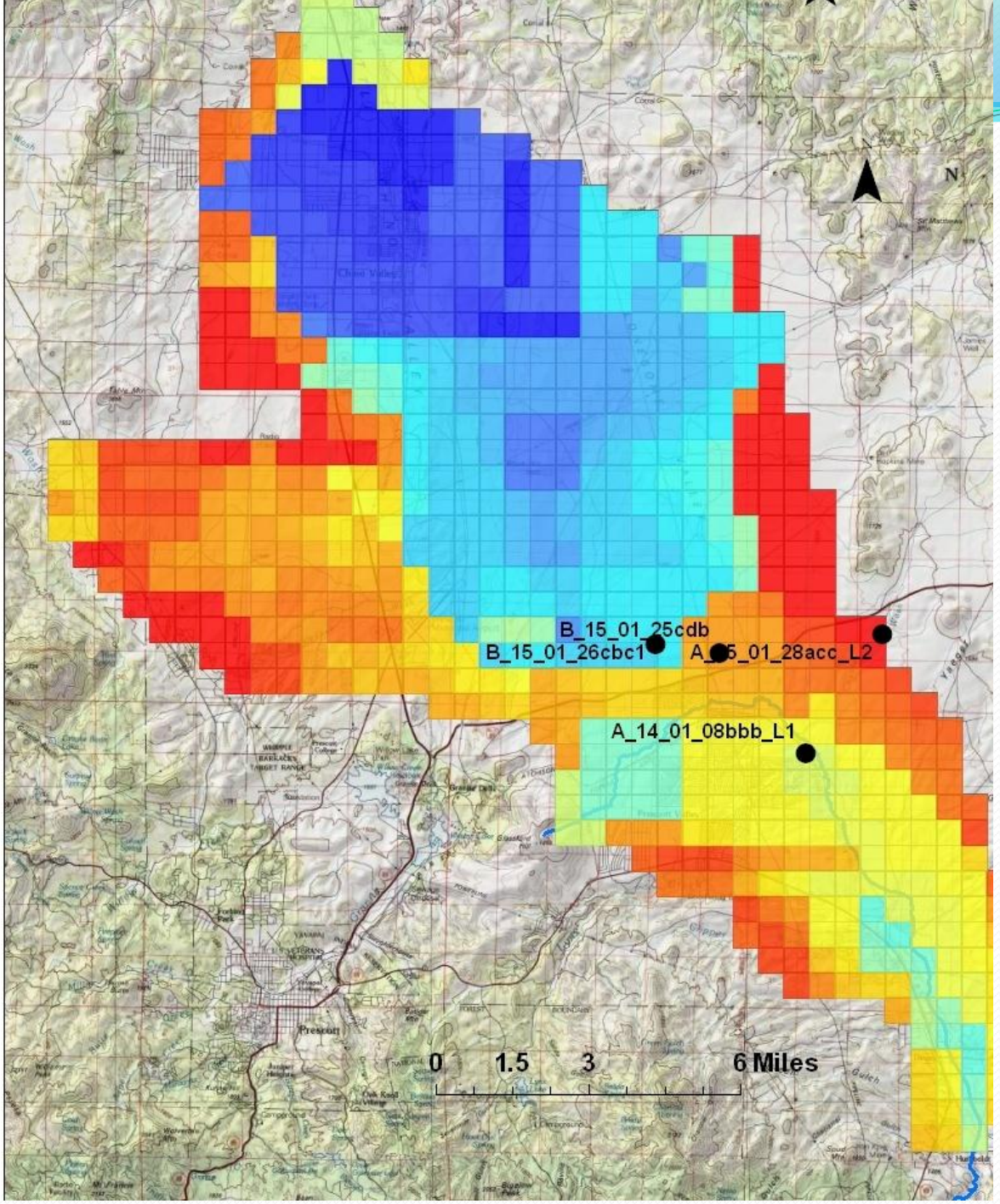




*Model created during development phase*

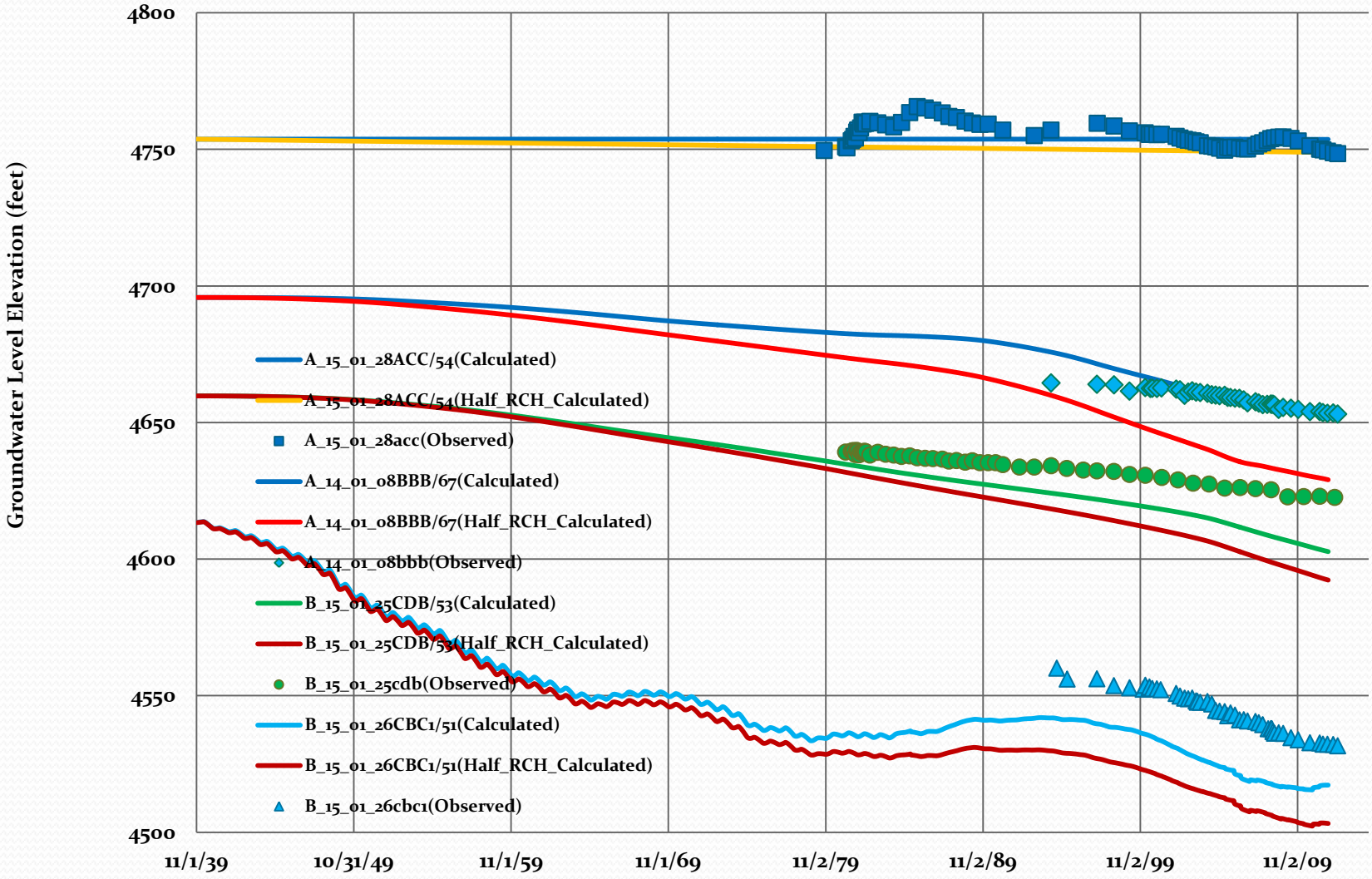

B_15_02_17aba_L2
B_15_02_19ada_L2
B_15_02_21bbd_L2
B_15_02_30daa
B_15_01_31ccc
N
0 1.5 3 6 Miles

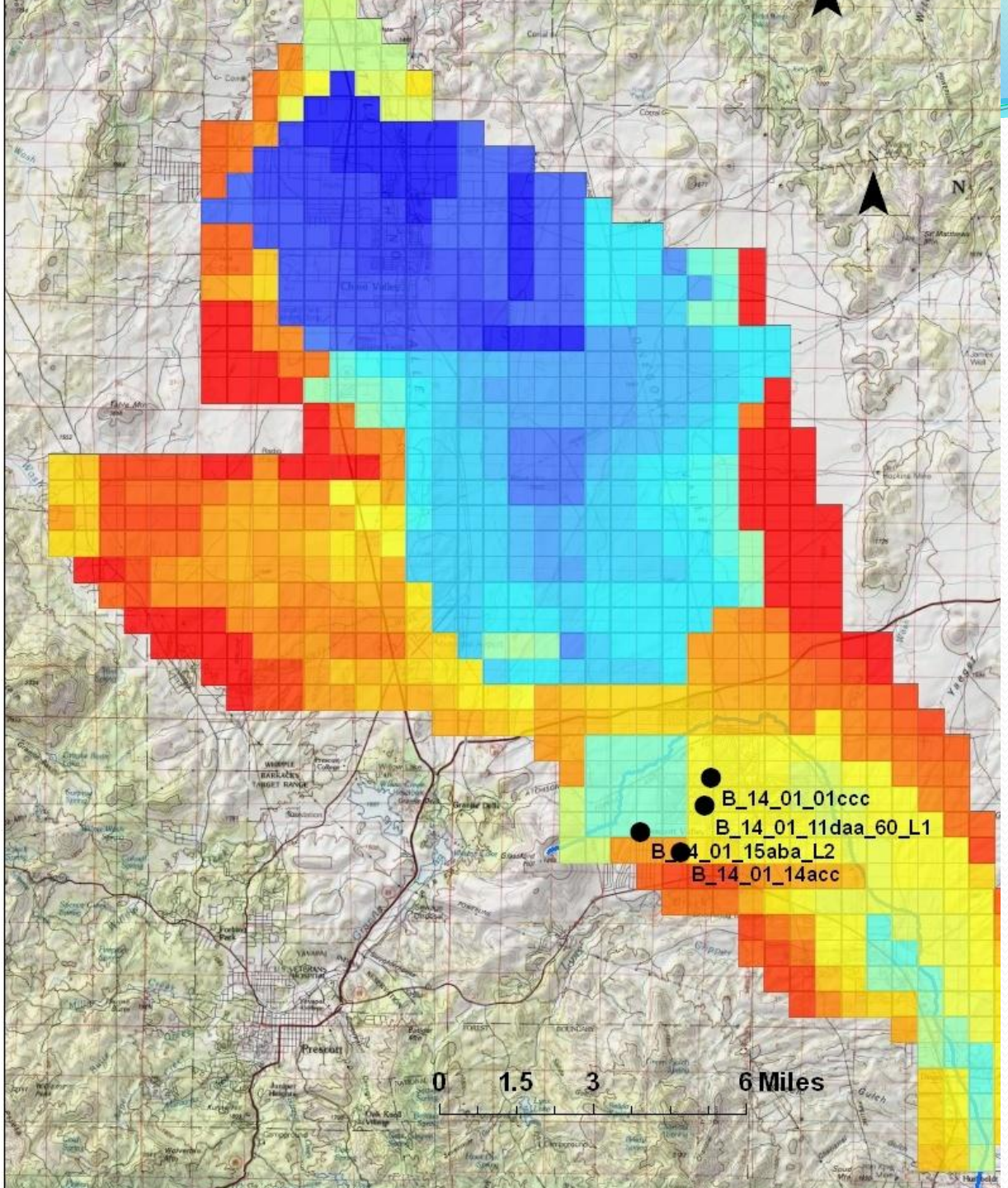

Simulated and Observed Heads
Mint Wash/Williamson Valley - Western PrAMA
Groundwater Level Elevation (feet)
4850
4800
4750
4700
4650
4600
11/1/39
10/31/49
11/1/59
11/1/69
11/2/79
11/2/89
11/2/99
11/2/09
B_15_01_31CCD/50(Calculated)
B_15_01_31CCD/50(Half_RCH_Calculated)
B_15_01_31ccd(Observed)
B_15_02_17ABA/39(Calculated)
B_15_02_17ABA/39(Half_RCH_Calculated)
B_15_02_17aba(Observed)
B_15_02_19ADA/40(Calculated)
B_15_02_19ada(Observed)
B_15_02_19ADA/40(Half_RCH_Calculated)


Simulated and Observed Heads
Mint Wash/Williamson Valley - Western PrAMA
Groundwater Level Elevation (feet)
5100
5050
5000
4950
4900
4850
4800
4750
4700
11/1/39
10/31/49
11/1/59
11/1/69
11/2/79
11/2/89
11/2/99
11/2/09
B_15_02_19ADA/40(Calculated)
B_15_02_19ADA/40(Half_RCH_Calculated)
B_15_02_21BBD/41(Half_RCH_Calculated)
B_15_02_30DAA/45(Calculated)
B_15_02_30daa(Observed)
B_15_02_19ada(Observed)
B_15_02_21BBD/41(Calculated)
B_15_02_21bbd(Observed)
B_15_02_30DAA/45(Half_RCH_Calculated)

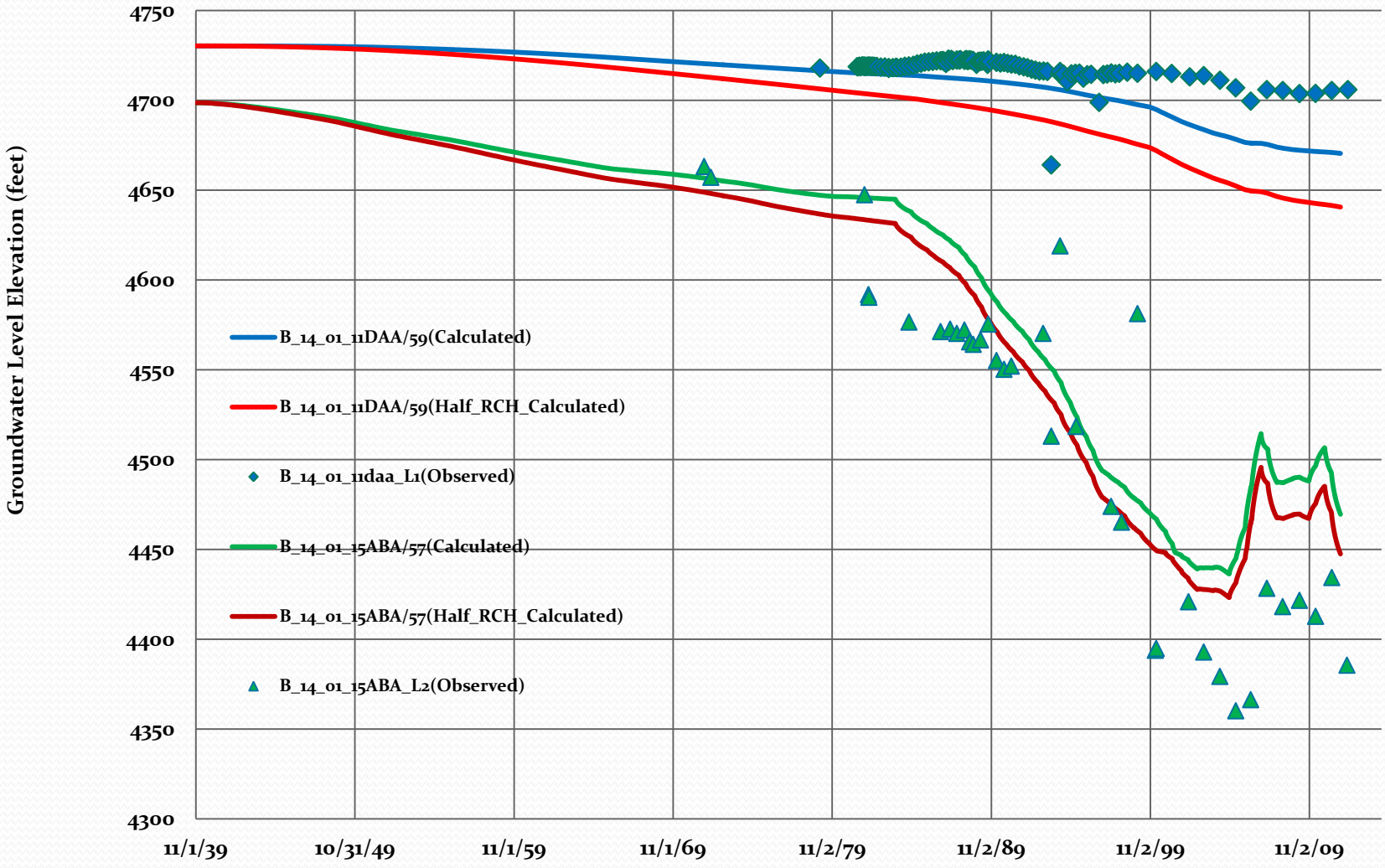

B_15_01_25cdb
B_15_01_26cbc1
A_15_01_28acc_L2
A_14_01_08bbb_L1
N
0
1.5
3
6 Miles

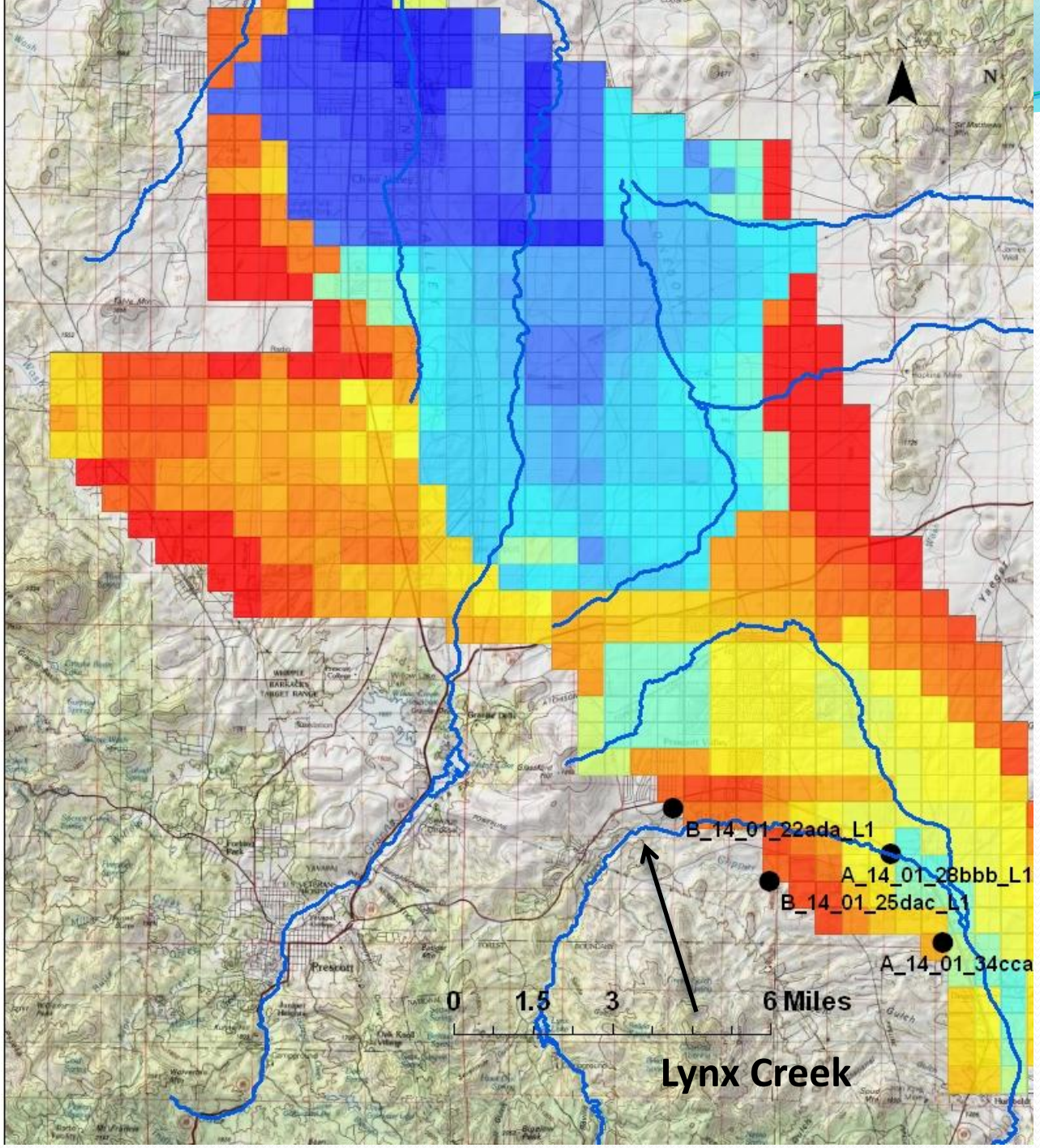
## Simulated and Observed Heads Near UAF / LIC Sub-basin Divide



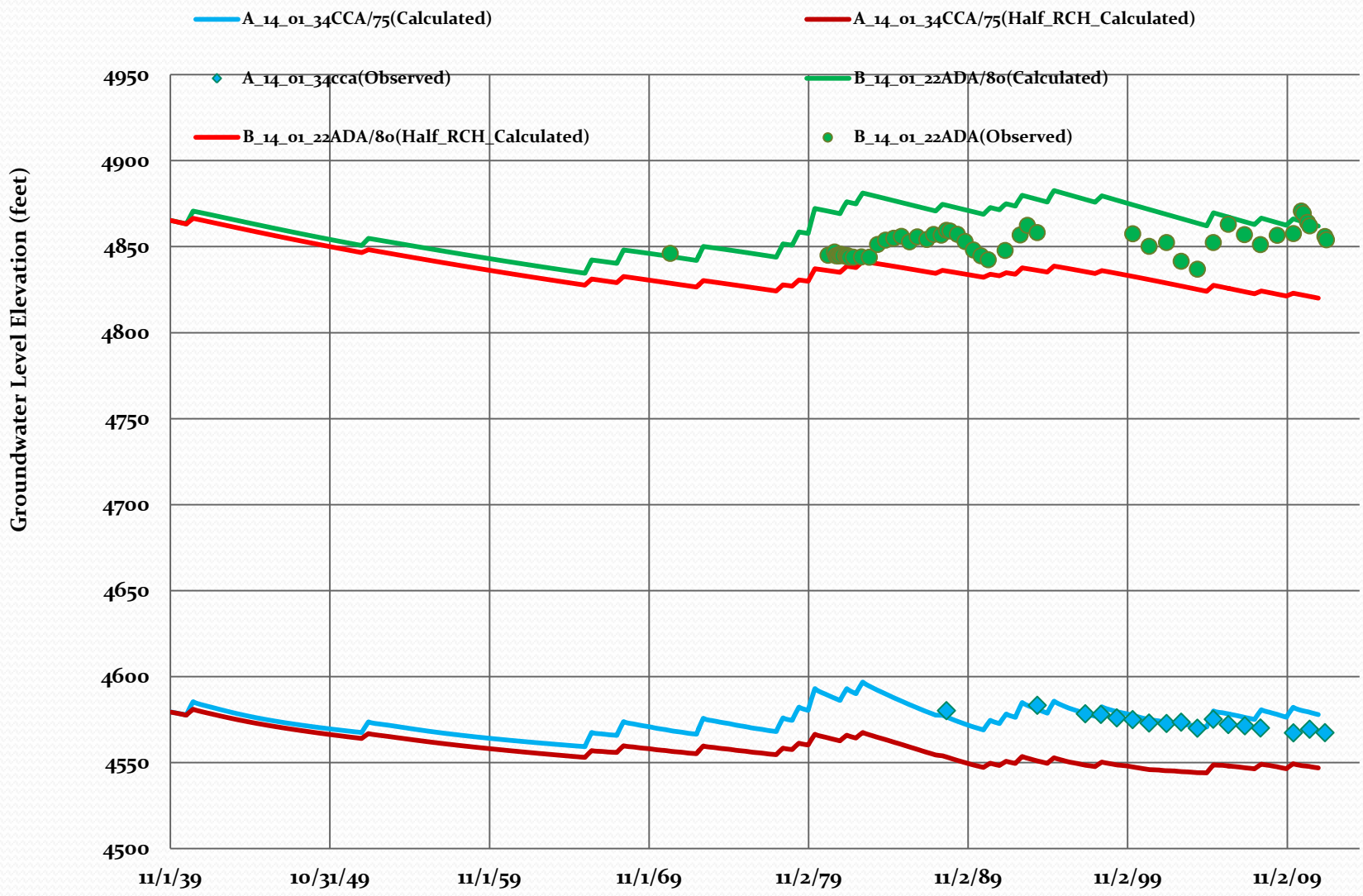

N
B_14_01_01ccc
B_14_01_11daa_60_L1
B_14_01_15aba_L2
B_14_01_14acc
Prescott
0
1.5
3
6 Miles

## Simulated and Observed Heads PV's Upper Well Field, UAF Sub-basin

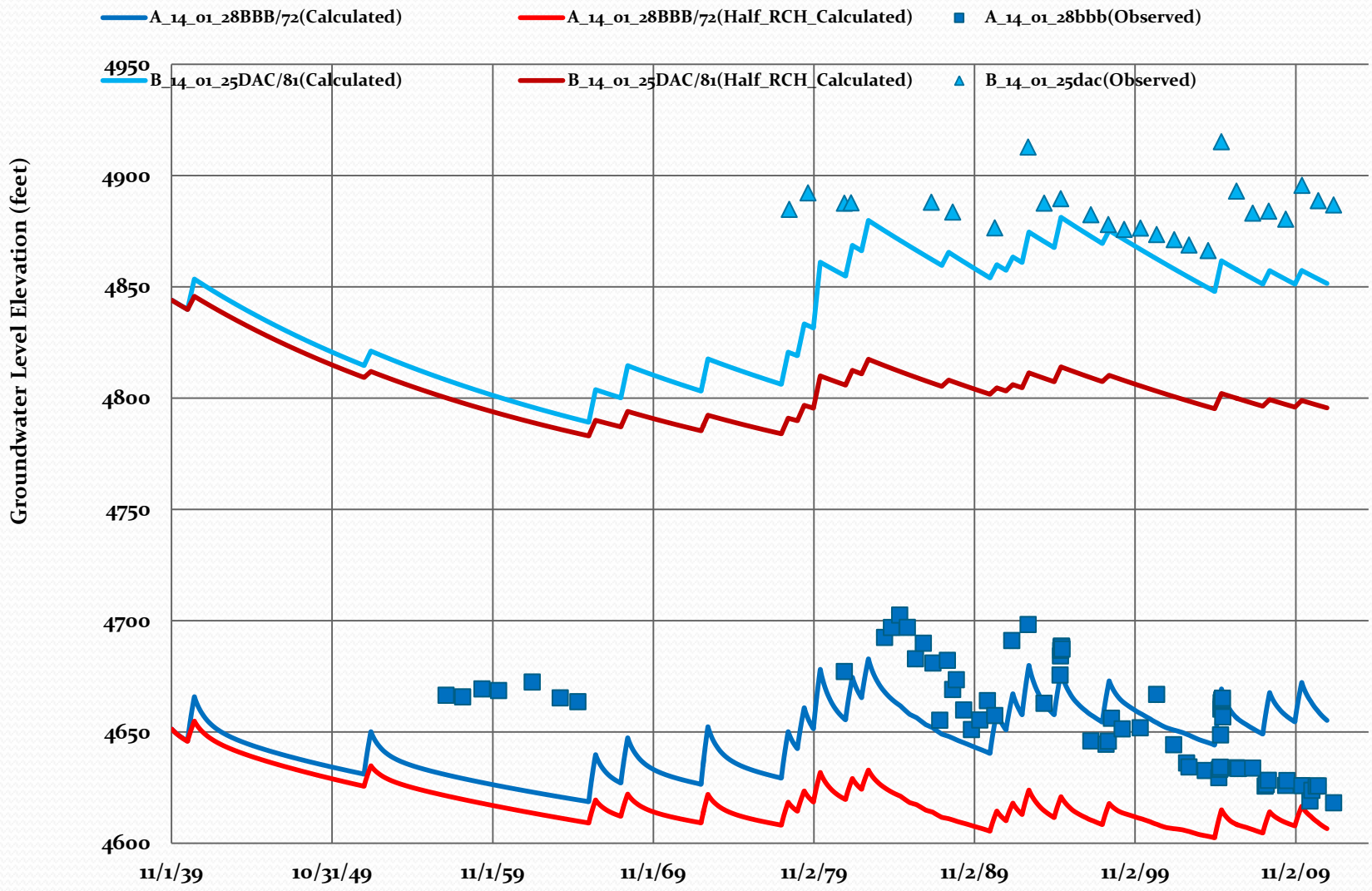



N
B_14_01_22ada_L1
A_14_01_28bbb_L1
B_14_01_25dac_L1
A_14_01_34cca
0
1.5
3
6 Miles
Lynx Creek
Prescott

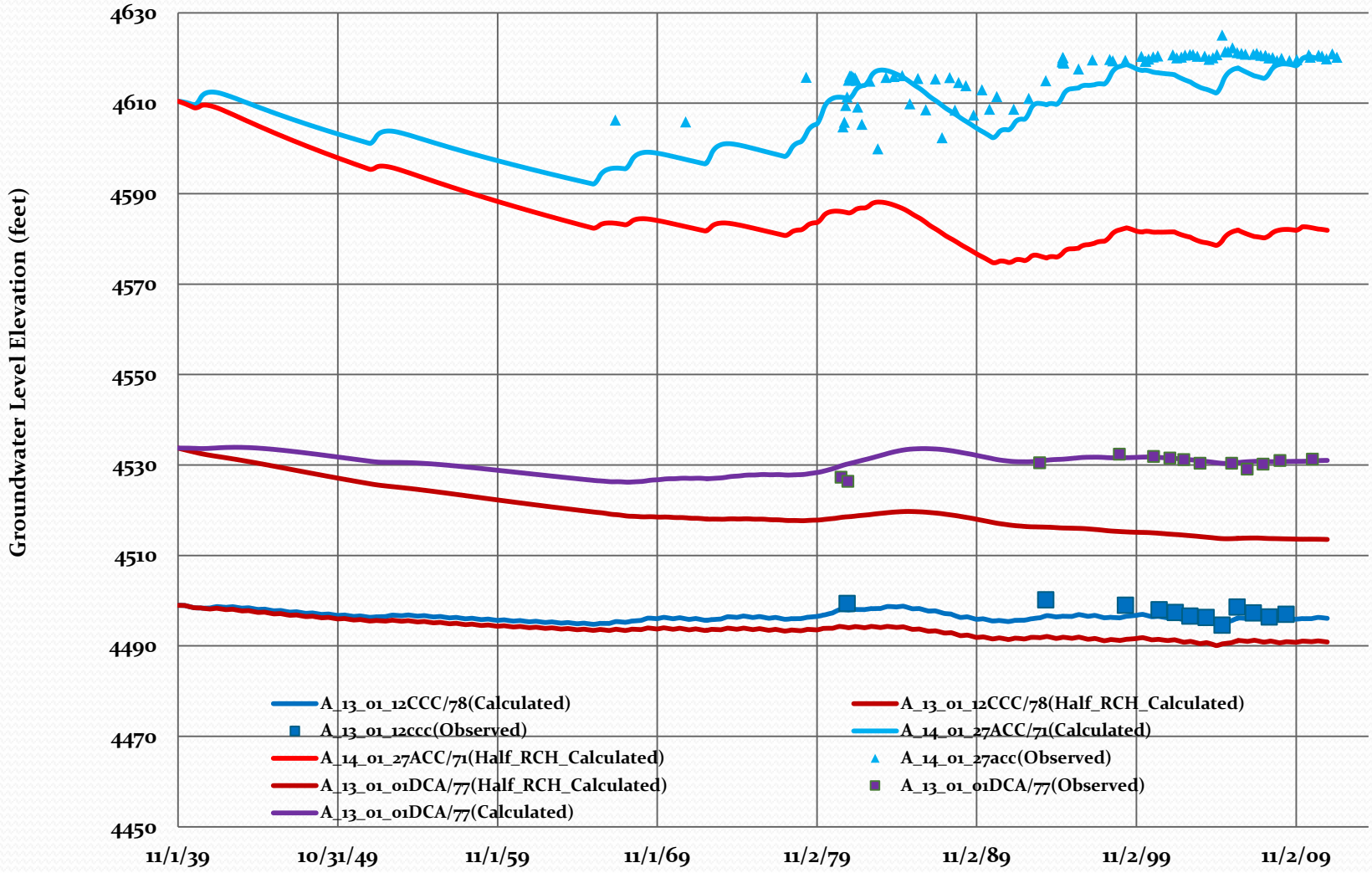
## Simulated and Observed Heads Near Lynx Creek, UAF Sub-basin



## Simulated and Observed Heads Near Lynx Creek, UAF Sub-basin



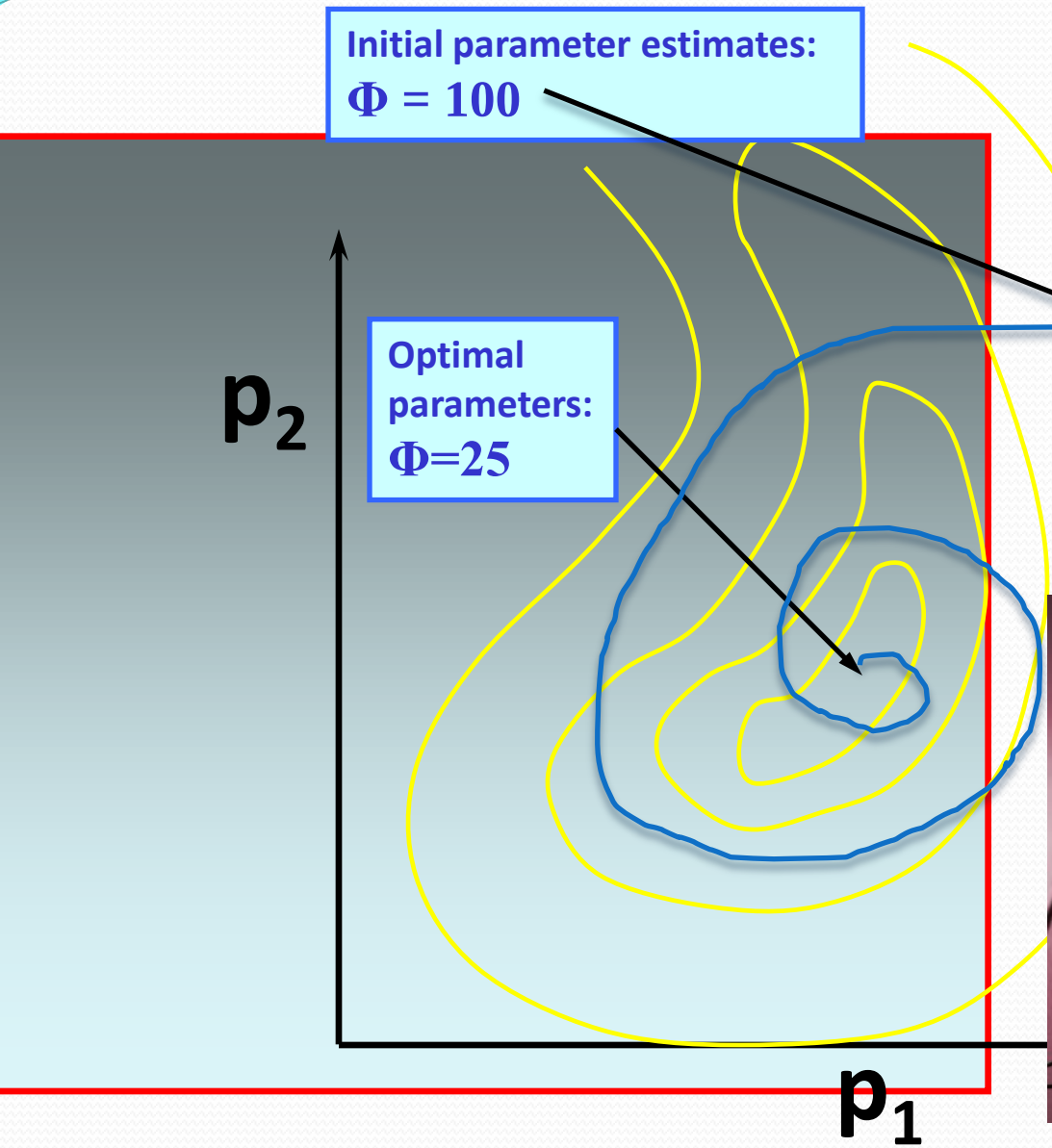
## Simulated and Observed Heads Lower UAF Sub-basin



## *Model Calibration: Objective, Φ, Minimize Error*

*Steady State: K, Recharge and Underflow Distribution*

*Transient: Time-dependent Stresses and S*




## *Calibration Targets*

$$\Phi = \Sigma\ (residual * weight)^2$$

### Head Targets

UAU SS & Tran σ=20 feet; $\sigma^{-1}$=0.05 $ft^{-1}$

LVU SS σ =10 feet; Tran= 20 feet; $\sigma^{-1}$= 0.1 $ft^{-1}$

### Baseflow Targets (Groundwater Discharge)

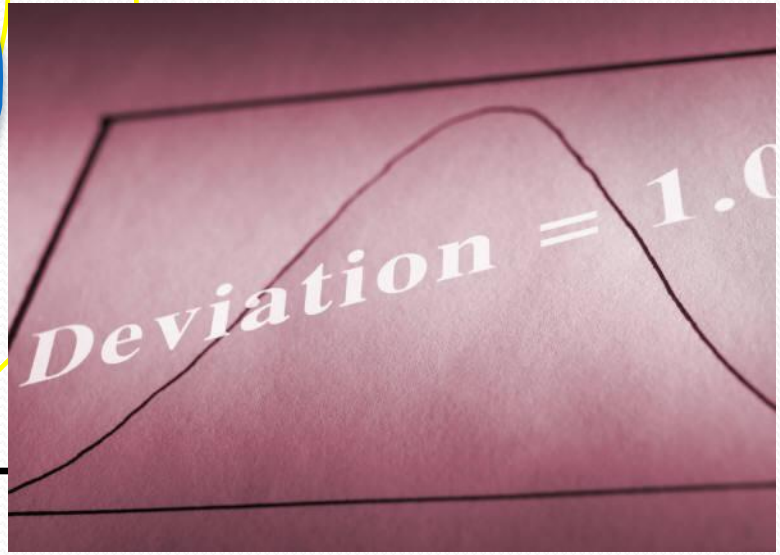
SS Del Rio Springs μ = 6cfs; σ = 0.5 cfs

Transient σ = 1.0 cfs

Agua Fria River μ = 4cfs; σ = 1.0 cfs

Transient σ = 1.0 cfs

SS Prior Information: 3 LVU Zones

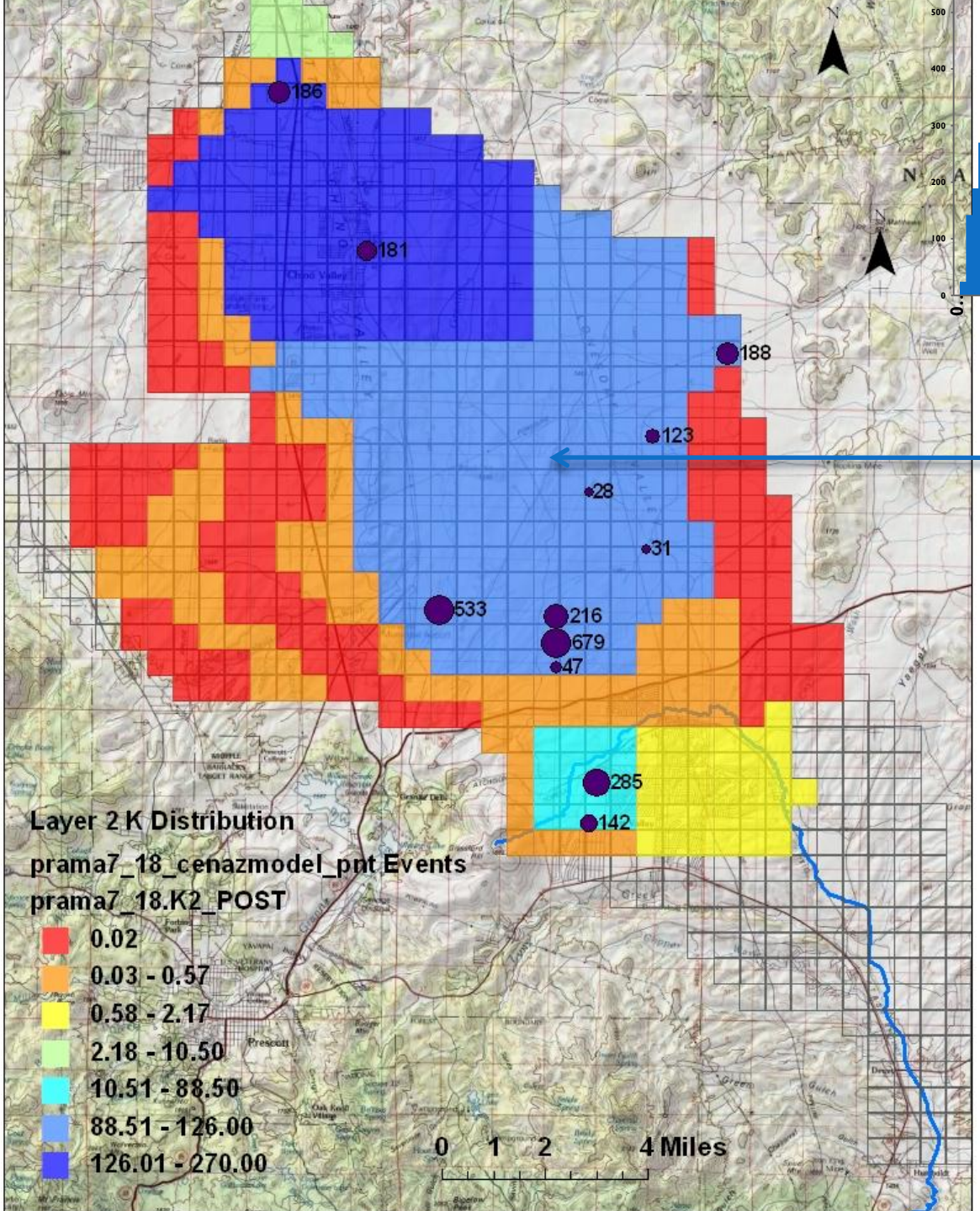


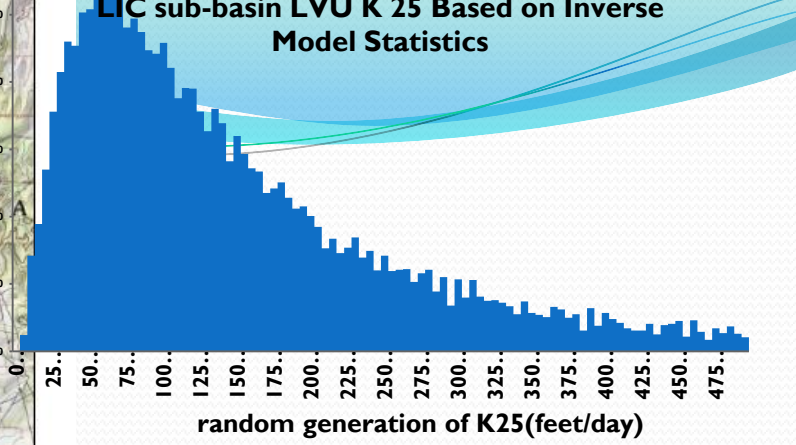
- Alternative Initialization Assumptions
  - True Pre-development: Higher natural recharge rate (PEST)
  - USGS AG RCH Assumptions: Natural recharge rate similar to base
  - Different Layer 2:Layer 1 pumping ratios – largely insensitive
- Alternative Natural Recharge Assumptions
  - Constrained Natural recharge 5K AF/yr - Higher model error & bias
  - Lowest possible rate without losing target wells $\approx$ 4,300 AF/yr
  - Forced MFR:Stream RCH =1:1
    - Resulted in Nat RCGH ~ 5K AF/yr – higher model errror and bias
    - Similar to USGS NARGFM Concept (BCM) – i.e., MFR locations
  - Alternate Natural Recharge Locations (valley locations – low RCH rates
  - Started PEST with natural recharge 5K ended at 9K AF/yr (600 iterations)
- No UAF Sub-basin Underflow – higher model error & bias; less plausible
  - Data shows low seasonal flow; tried higher exempt pumpage in UAF – didn't fix
- Alternative Weighting schemes
  - Heads and flows – insensitive about assigned weights;
  - Weighting consistent with standard error
- No prior information – higher LVU K's, recharge, lower model error

Table D.1.

| ACM / Nat RCH Model<br>All models applied recharge (RCH cells) along portions of Granite & Lynx Creek and Agua Fria River<br>Blue = Solution plausible; Green = Plausible solution, but less likely; Red = Solution much less unlikely | Steady State Annualized Natural recharge using both stream cells and recharge cell | |
|---|---|---|
| | Total rate of simulated natural recharge AF/yr<br>Steady State | PEST Φ<br>Steady State All models applied same weighting and target number |
| Base Model | 9,167 | 175.7 |
| ACM 5: Lower prior info weighting on 3 LVU K zones[b] | 9,910 | 173 |
| ACM: No prior information | 10,770 | 171.2 |
| ACM 6: Underflow into model assigned near Watson Lake | 9,474 | `174.3 |
| ACM 4: Initialization assumes true pre-development[a] | 10,613 | 185 |
| ACM 9: Same initial stresses applied in USGS NARGFM | 8,340 | 175.5 |
| ACM: Same as Base except Layer 2 thickness=250 feet | 8,600 | 182.4 |
| ACM: "Base except Layer 2 thickness=250 feet; lower prior[b] | 10,000 | 175.8 |
| ACM: Same as Base except Layer 2 thickness=400 feet | 9,050 | 177.3 |
| ACM: "Base except Layer 2 thickness=400; lower prior[b] | 11,160 | 172.6 |
| ACM: Same as Base except Layer 1 1owered by 15 feet | 8,840 | 182.1 |
| ACM: " Base except Layer 1 1owered by 15 feet; lower prior[b] | 10,460 | 178.3 |
| ACM: "Same as Base except Layer 1 increased by 15 feet | 9,890 | 170.7 |
| ACM: "Base except Layer 1 increased by 15 feet; lower prior[b] | 10,090 | 169.3 |
| ACM 3b: Assumed steady state baseflow mean = 3cfs | 9,336 | 170.5 |
| ACM 3: No underflow in UAF Sub-basin* 12 parameter | 7,780 | 178 |
| ACM 3a: No underflow in UAF Sub-basin 13 parameter | 8,080 | 177 |
| ACM 2: Natural recharge PEST constrained to ~5,000 AF/yr | 5,000 | 201 |
| ACM 8: MFR-to-stream recharge constrained to 1:1 | 5,200 | 241 |
| ACM 10: Constrained PEST to Lowest Possible Nat RCH | 4,310 | 224 |
| ACM 11: Limit LIC Sub-Basin Underflow to 100 AF/yr | 5710 | 189 |

| ACM / Nat RCH Model<br>All models applied variable recharge (RCH cells) along portions of Granite & Lynx Creek and Agua Fria River unless otherwise noted<br>Blue = Solution plausible;<br>Green=Plausible solution, but less likely<br>Red = Solution not likely | Transient State Annualized Natural recharge RCH cells only | |
|---|---|---|
| | Annualized Rate of Simulated long-term natural recharge AF/yr | PEST Φ Transient<br>All models applied same weighting and target number |
| Base Model variation–variable natural recharge using only recharge cells | 9,352 | 4,080 |
| Base Model variation–variable natural recharge rate fixed at higher rate | 10,287 | 4,045 |
| ACM 6: Underflow into model assigned near Watson Lake | 9,659 | 3,876 |
| ACM 1 Base with all constant natural recharge | 9,352 | 4,518 |
| ACM 3: No underflow UAF Sub-basin–variable natural recharge rate | 7,950 | 5,235 |
| ACM 7 Base Model variation with lower natural recharge set to 7,482 | 7,482 | 4,903 |
| ACM 2: PEST Constrained natural recharge ~5,000 AF/yr | 5,100 | 7,300 |
| ACM 8: MFR-to-stream recharge constrained to 1:1 | 5,200 | 7,948 |
| ACM 10: Constrained PEST to Lowest Possible Nat RCH | 4,310 | 16,969 |
| ACM 11: Limit LIC Sub-Basin Underflow to 100 AF/yr | 5710 | 7,370 |



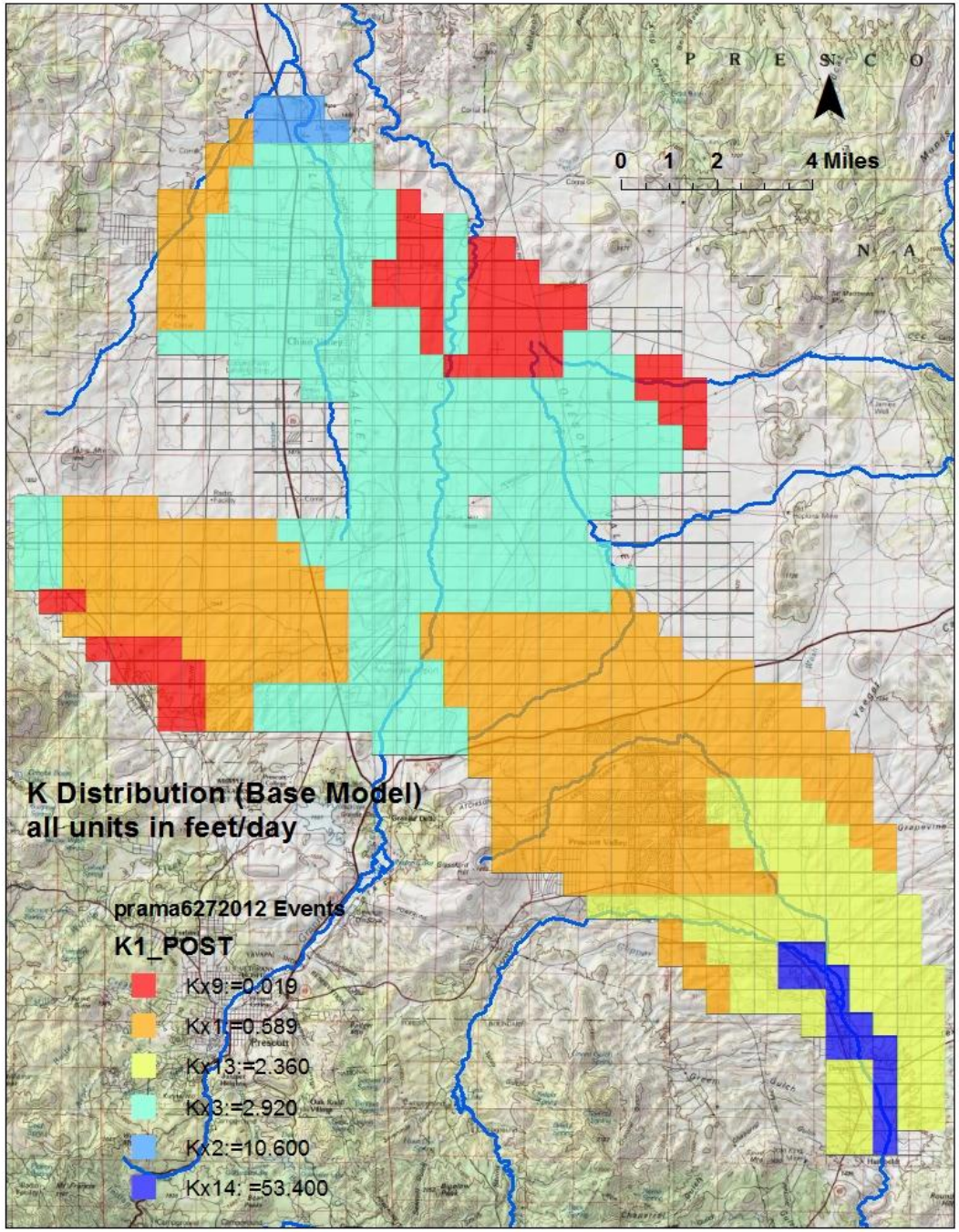




LIC LVU -> prior Information

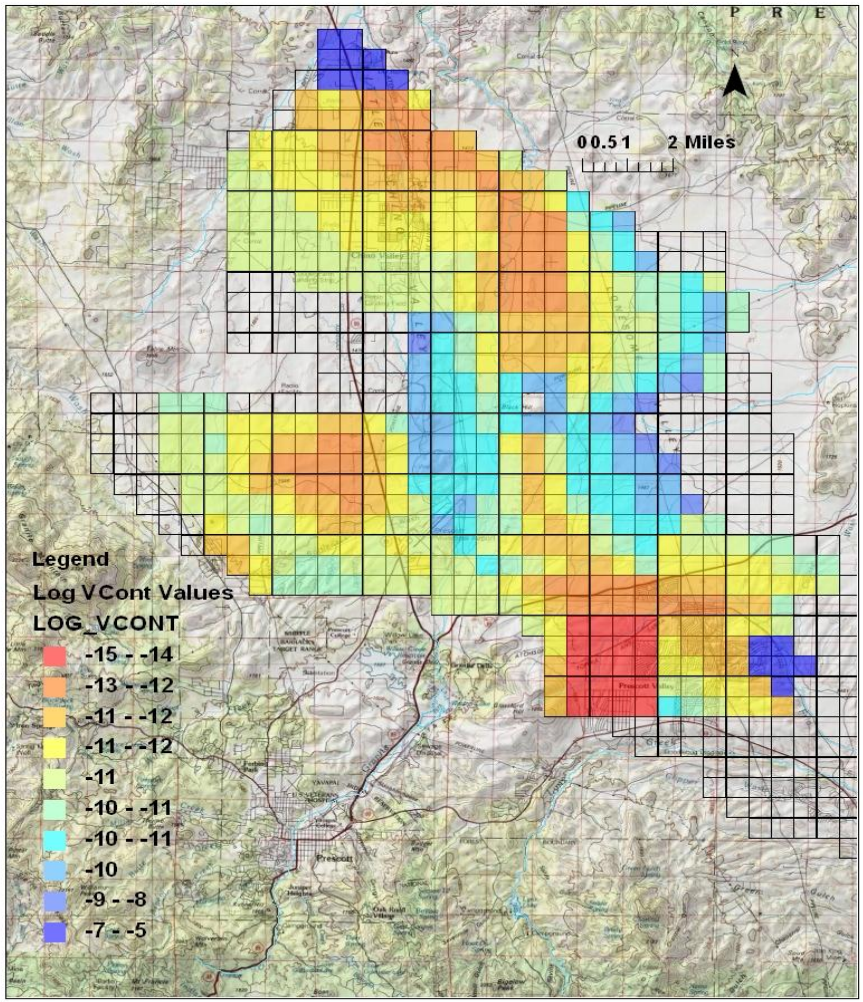
Base Model

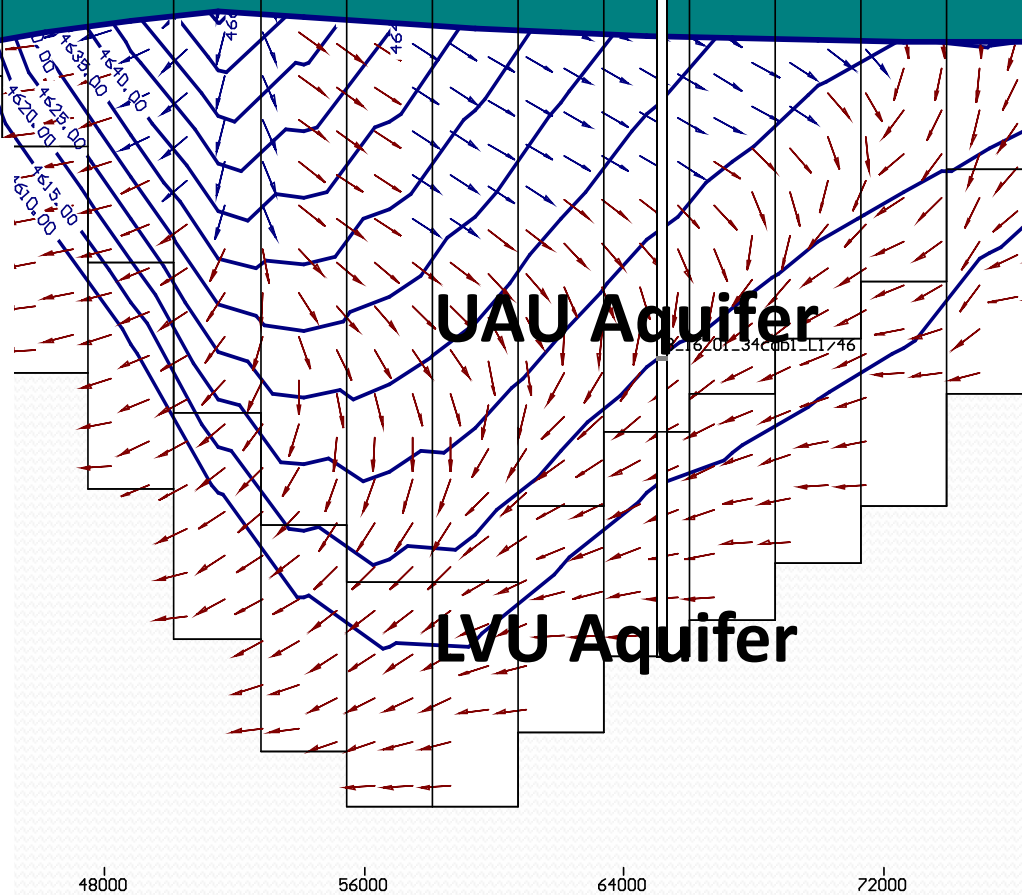
| Est. Parameter | 95% CI |
|---|---|
| K13= 2.4 | 0.89 --- 6.3 |
| K14= 53 | 24 -------121 |
| K1 = 0.6 | 0.2 ---- 1.2 |
| K23= 272 | 116 ---- 639 |
| K25 = 138 | 37 ---- 513 |
| K26 = 102 | 36 ----- 290 |
| K2 = 10.6 | 6 ----- 19 |
| K3 = 2.9 | 1.3 --- 6.6 |
| Kz3 = 0.00151 | 0.0008 – 0.003 |
| K9 = 0.019 | 0.009 – 0.037 |
| RCH=9200 | 4,100 - 14,300 |
| UF_LIC=2320 | 0 - 4,640 |
| UF_UAF=1140 | -1,480---3,760 |

# Layer 1 K-Distribution



# **Complex Recharge Path to LVU**




**Aquitard – very sensitive!**

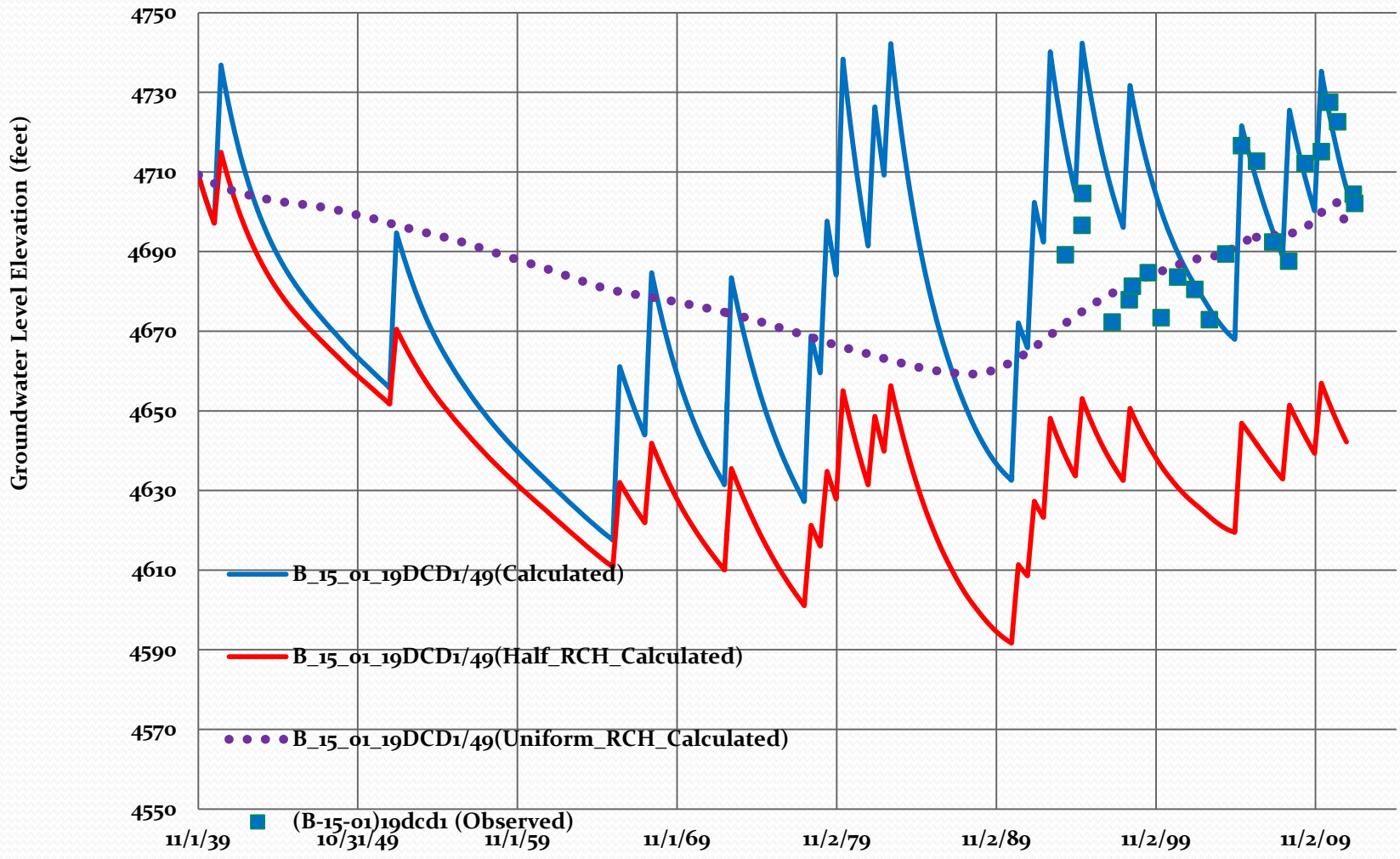
**Kz= 0.0015 ft/d**

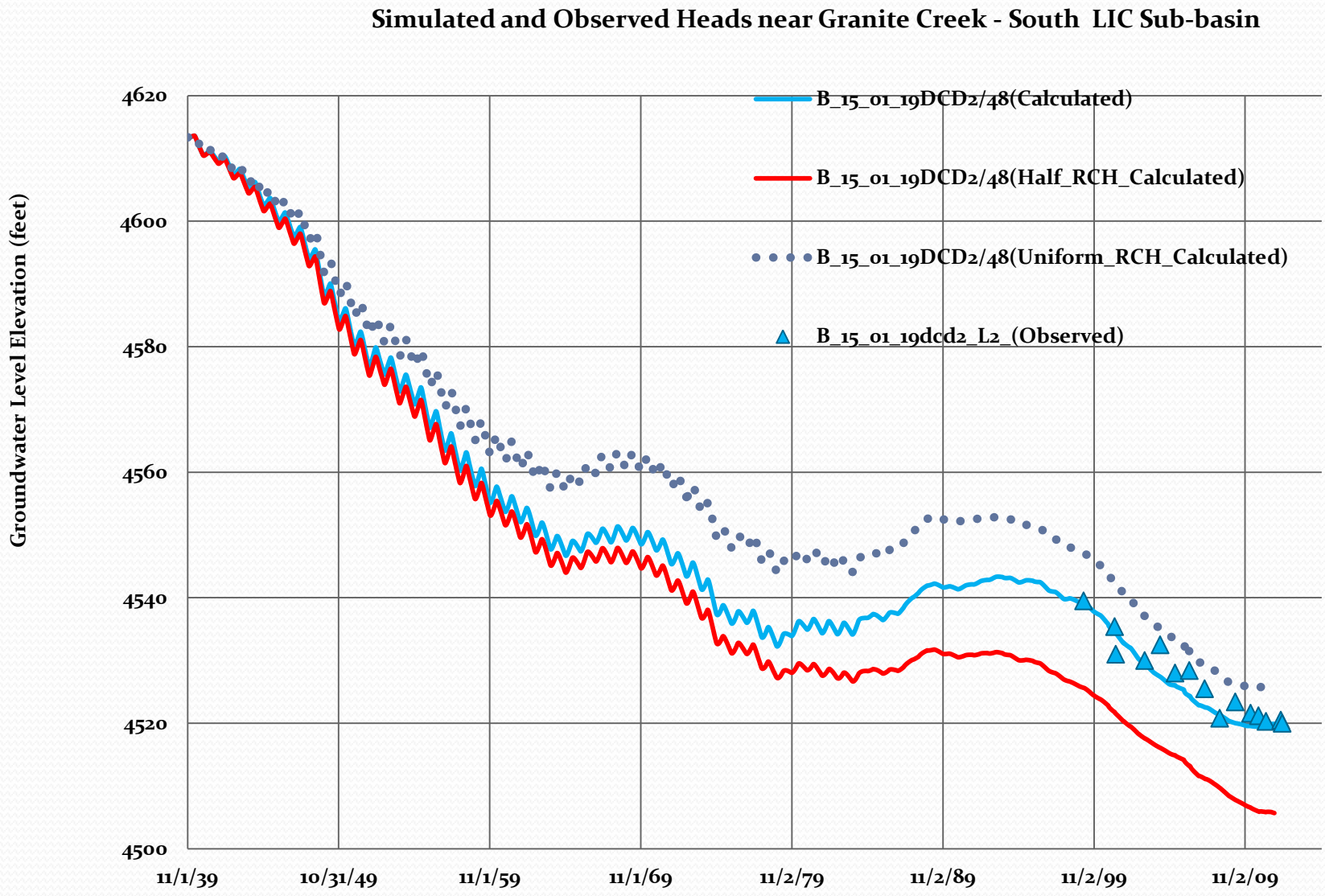
**95% CI:= 0.0007 – 0.003 ft/d**

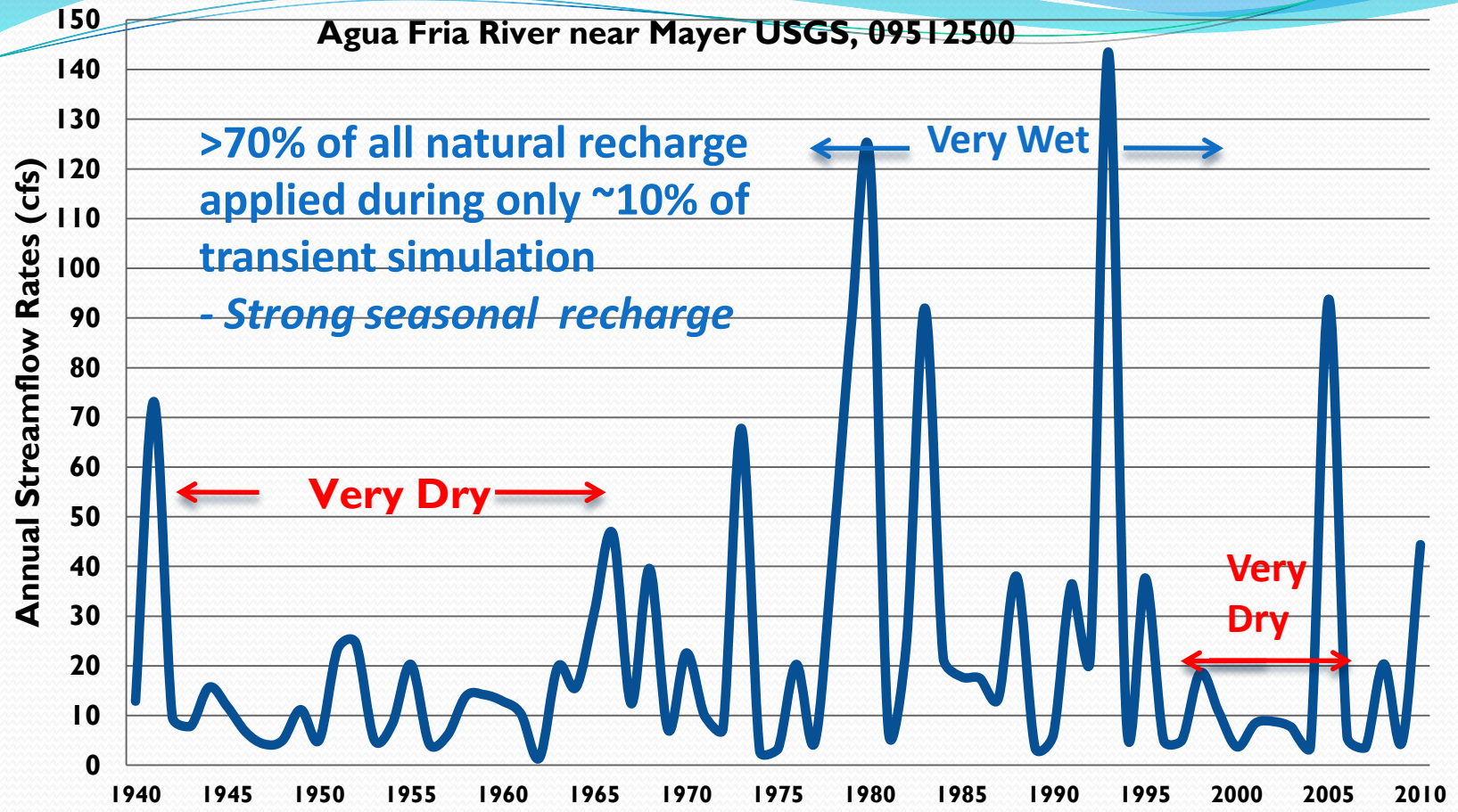
| Model Parameter Composite Sensitivity<br>Steady State > 3 72-Year Transient State (common parameters) | | |
|---|---|---|
| Parameter (15-P) | Steady scaled | 72-Year Transient State scaled |
| Kx13 | 0.320 | 0.022 |
| Kx14 | 0.292 | 0.031 |
| Kx1 | 0.526 | 0.171 |
| Kx23 | 0.186* | 0.159 |
| Kx25 | 0.0589* | 0.157 |
| Kx26 | 0.055* | 0.0071 |
| Kx2 | 0.685 | 0.150 |
| Kx3 | 0.237 | 0.158 |
| Kz3* | 0.247 | 0.156 |
| Kx9 | 0.324 | 0.149 |
| Underflow UAF | 0.153 | 0.0027 |
| Underflow LIC | 0.0134 | 0.069 |
| MFR | 0.276<br>0.535<br>0.493 | 0.069 |
| Gran Crk RCH | | 0.025 |
| Lynx AF RCH | | 0.064 |
| S (all Sy and Ss) | N/A | 3.74 |

| Calibration Target Composite Sensitivity | | |
|---|---|---|
| | **Steady State (Targets)** | **72-Year Transient State (targets)** |
| Del Rio Springs | **2.44 (1)** | **0.54 (38)** |
| Agua Fria Baseflow | **0.694 (1)** | **0.19 (30)** |
| Layer 1 heads | **0.31 (61)** | **0.21 (1,413)** |
| Layer 2 heads | **0.54 (43)** | **0.026 (1,775)** |
| Prior info | **0.39 (3)** | N/A |

## Simulated and Observed Heads near Granite Creek - South LIC Sub-basin




Simulated and Observed Heads near Granite Creek - South LIC Sub-basin
Groundwater Level Elevation (feet)
4620
4600
4580
4560
4540
4520
4500
11/1/39
10/31/49
11/1/59
11/1/69
11/2/79
11/2/89
11/2/99
11/2/09
B_15_01_19DCD2/48(Calculated)
B_15_01_19DCD2/48(Half_RCH_Calculated)
B_15_01_19DCD2/48(Uniform_RCH_Calculated)
B_15_01_19dcd2_L2_(Observed)




- **Annual Stream Recharge Variability for other areas**
- Tucson AMA: Max 469,900; Min 15,750; Mean: 63,000 AF/yr
- **Santa Cruz AMA: Max≈ 100,000 AF/yr; Min ≈10,000 AF/yr**
- **Gila River ~ Pinal AMA 1993 alone ≈ 800,000 AF/yr**

# Questions?

Thanks to…

- ADWR Basic Data
- ADWR Modeling
- USGS (SW gauges)

Some of the photos
Provided courtesy of:
-Prescott Courier;
-Chino Valley Review;
-CWAG