Drought Analysis Using Reconstructed Snowpack and Streamflow in the Upper Colorado basin

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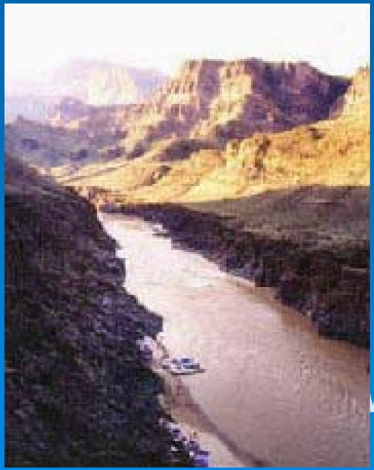

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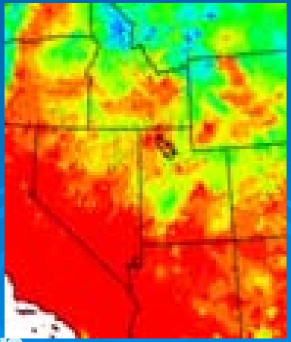


Other Researchers

STUDENTS

- Glenn Tootle (PhD, 2005)
- Janak Timilsena (PhD, 2007)
- William Paul Miller (current PhD student)
- Tom Watson (MS, 2008)
- Anthony Barnett (MS, 2008)
- John Bellamy (MS, 2008)

FACULTY

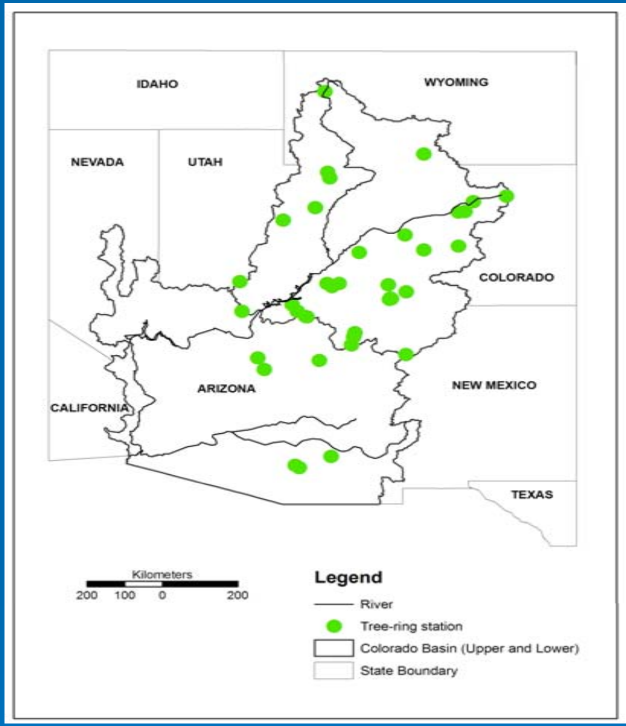
- Steve Gray (University of Wyoming)
- Ashok Singh (University of Nevada, Las Vegas)

Presentation Outline

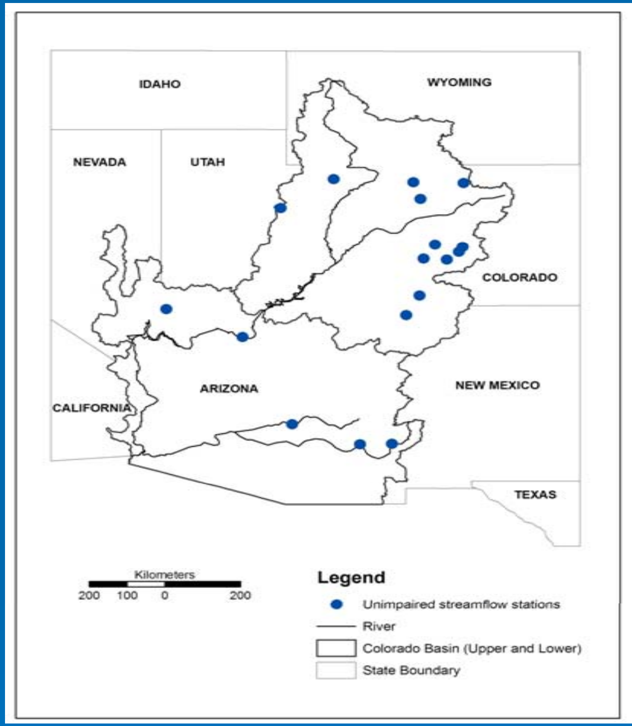
- Regional Drought Analysis (Tom)
  - Streamflow
  - Snow
- Headwater Reconstruction (Glenn)
- Drought Frequency Analysis (Glenn)

Drought Studies for Colorado River Basin

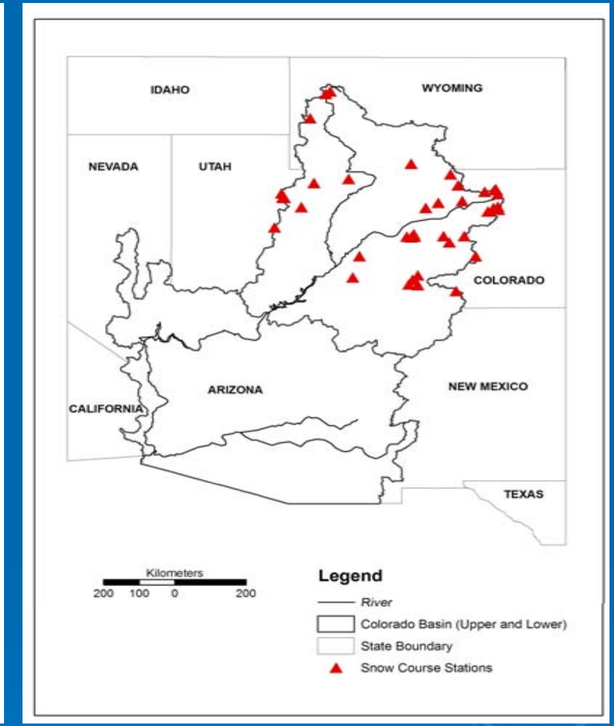
Tree Ring Sites
International Tree Ring Databank



Streamflow Sites
(Bureau of Reclamation and HCDN)



Snow Sites
(SNOTEL and NRCS)



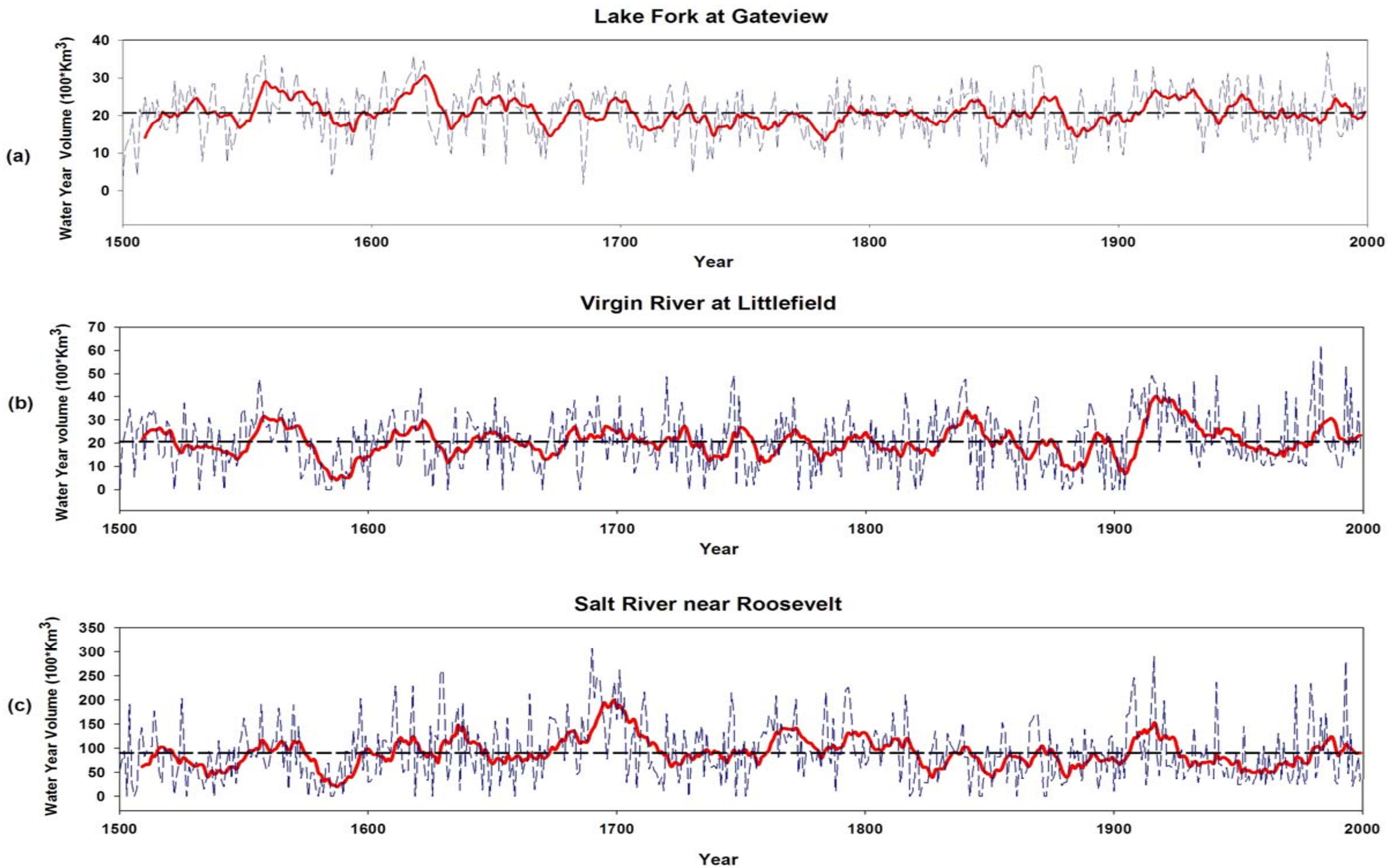
Piechota, T.C., Hidalgo, H., Timilsena, J., and G. Tootle, 2004. Western U.S. drought: How bad is it? *EOS Transactions,* 85(32), 301-308.

Timilsena, J., **T.C. Piechota,** H. Hidalgo, G. Tootle, 2007. Five Hundred Years of Hydrological Drought in the Upper Colorado River Basin. *Journal of American Water Resources Association, 43(3), 798-812.*

Timilsena, J., and **T.C. Piechota**, 2008. Regionalization and Reconstruction of Snow Water Equivalent in the Upper Colorado River Basin. *Journal of Hydrology,* DOI 10.1016/j.jhydrol.2007.12.024.

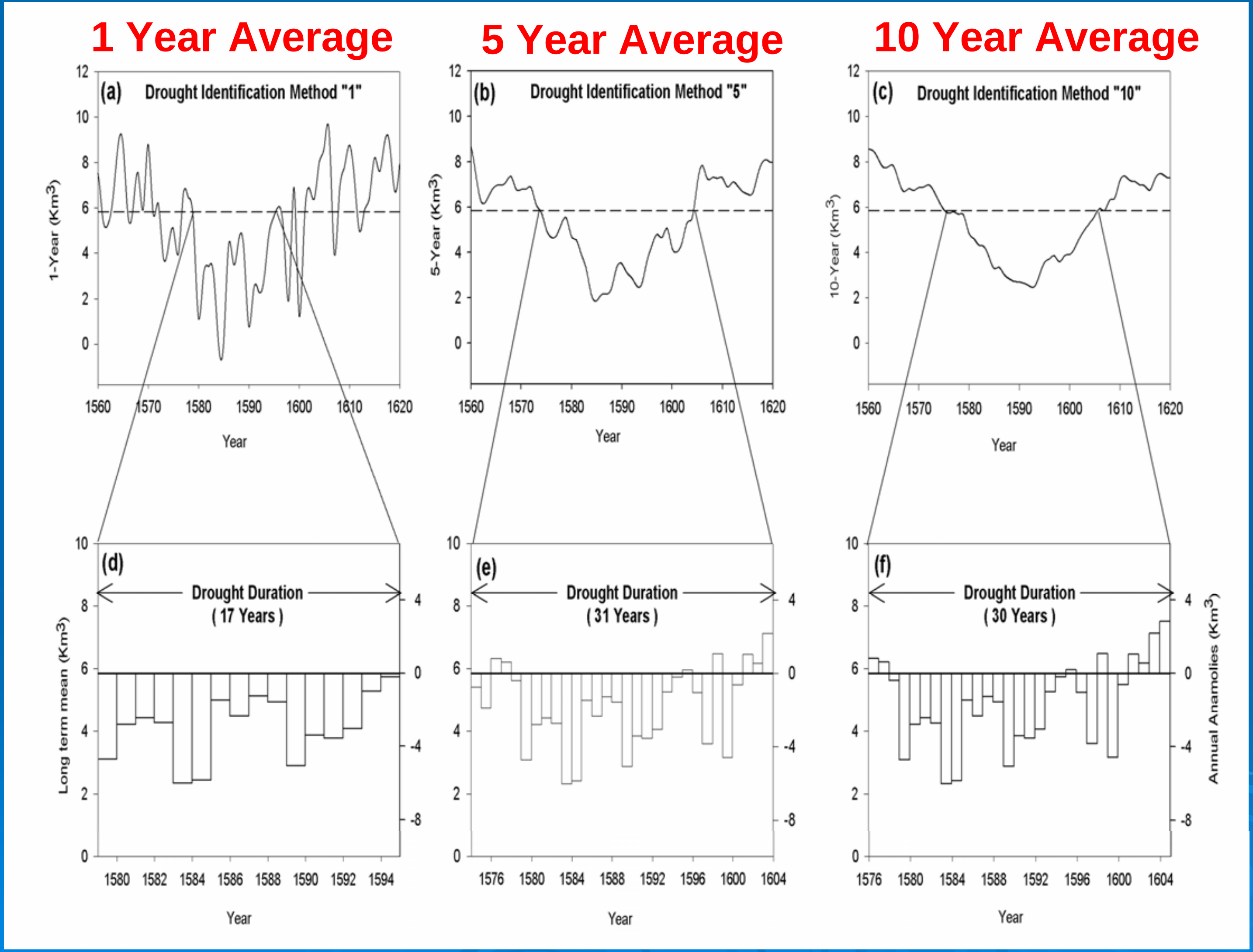
Timilsena, J., **T.C. Piechota**, G. Tootle, and A. Singh, 2008. Associations of Interdecadal/Interannual Climate Variability and Long-Term Colorado River Basin Streamflow. *Journal of Hydrology, in press.*

Example Reconstructions
(using regression-based methods)



(from Timilsena et al., 2008)

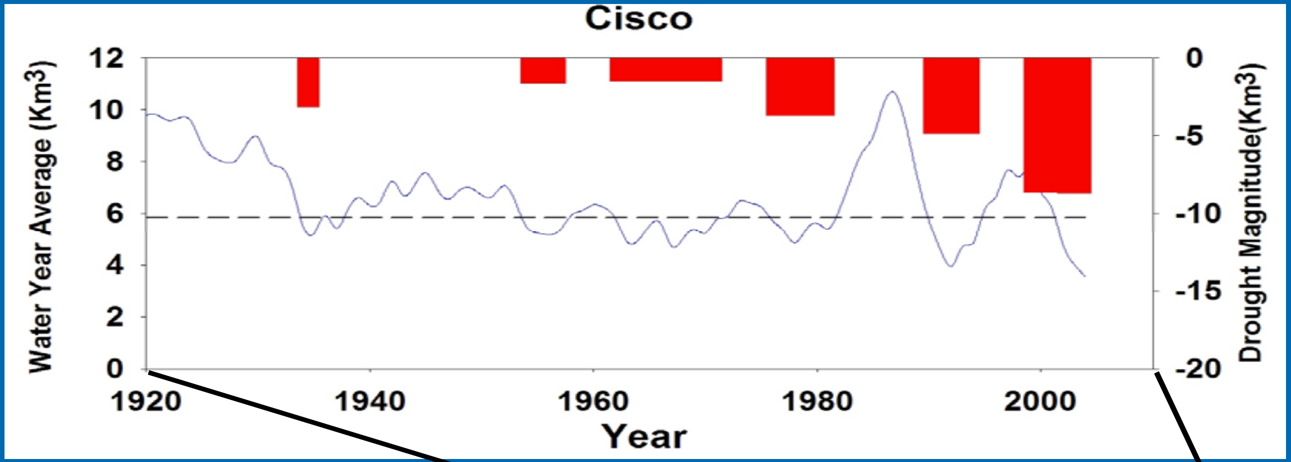
Drought Identification Methods



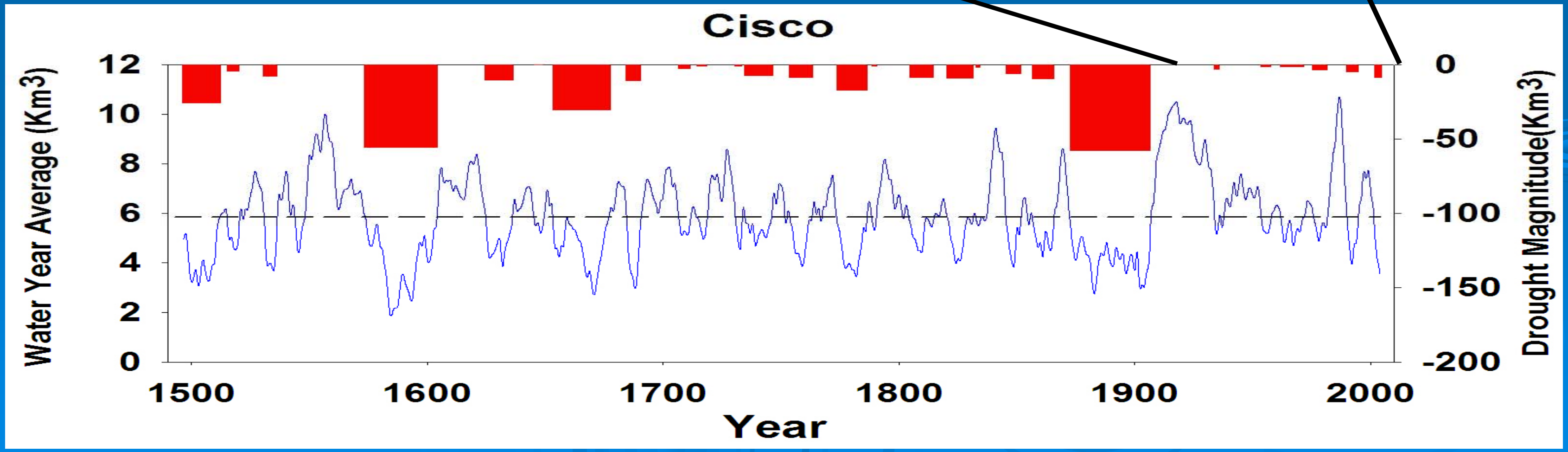
(from Timilsena et al., 2007)

Recent Drought and Streamflow
(from Timilsena et al., 2007)

INSTRUMENTAL



RECONSTRUCTED



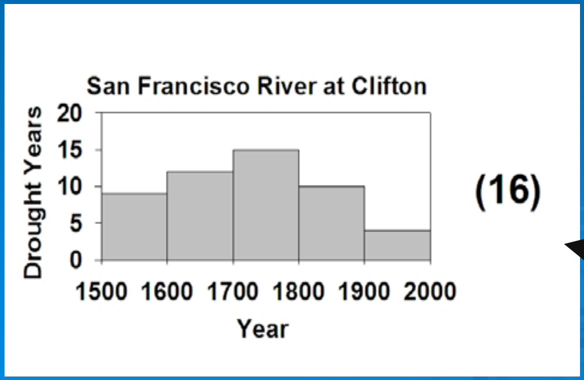
Severe Drought Indentification
(from Timilsena et al., 2008)

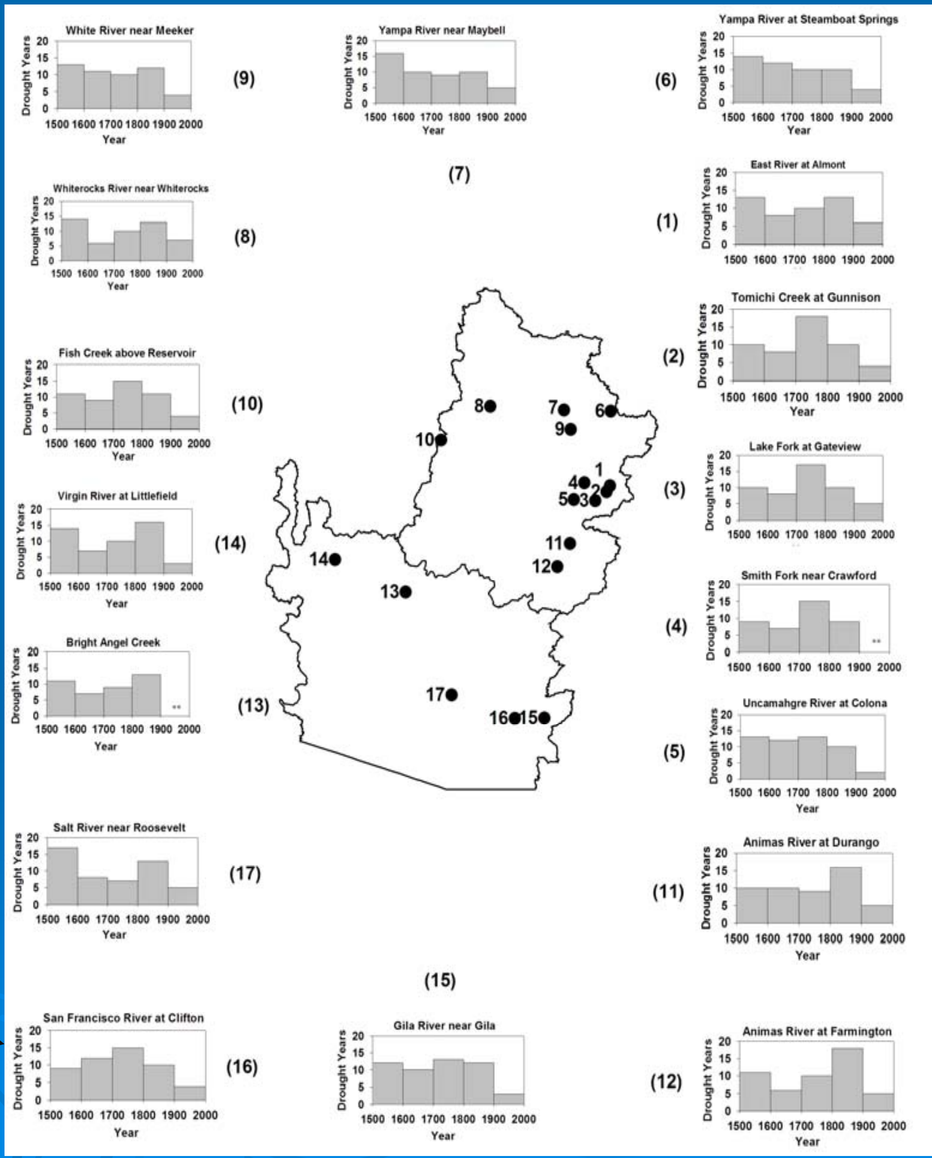
Nos.	Station Name	3- Year Moving Average	5-Year Moving Average	10-Year Moving Average
1	EAST RIVER AT ALMONT	1585	1883	1671
2	TOMICHI CREEK AT GUNNISON	1847	1883	1782
3	LAKE FORK AT GATEVIEW	1847	1883	1782
4	SMITH FORK NEAR CRAWFORD	1847	1883	1782
5	UNCOMPAHGRE RIVER AT COLONA	1847	1883	1782
6	YAMPA RIVER AT STEAMBOAT SPRINGS	1847	1594	1593
7	YAMPA RIVER NEAR MAYBELL	1847	1585	1592
8	WHITEROCKS RIVER NEAR WHITEROCKS	1585	1587	1588
9	WHITE RIVER NEAR MEEKER	1847	1587	1592
10	FISH CREEK ABOVE RESERVOIR NEAR SCOFIELD	1847	1587	1593
11	ANIMAS RIVER AT DURANGO	1585	1585	1587
12	ANIMAS RIVER AT FARMINGTON	1585	1585	1587
13	BRIGHT ANGEL CREEK NEAR GRAND CANYON	1585	1585	1585
14	VIRGIN RIVER AT LITTLEFIELD	1585	1585	1587
15	GILA RIVER NEAR GILA	1585	1670	1585
16	SAN FRANCISCO RIVER AT CLIFTON	1544	1670	1782
17	SALT RIVER NEAR ROOSEVELT	1587	1588	1587

Spatial Drought Variability

(from Timilsena et al., 2008)

- Drought < 10 percentile
- Least Nos. Drought in 1900's
- Maximum Nos. of Drought 1500's and 1800's





Snow Regionalization

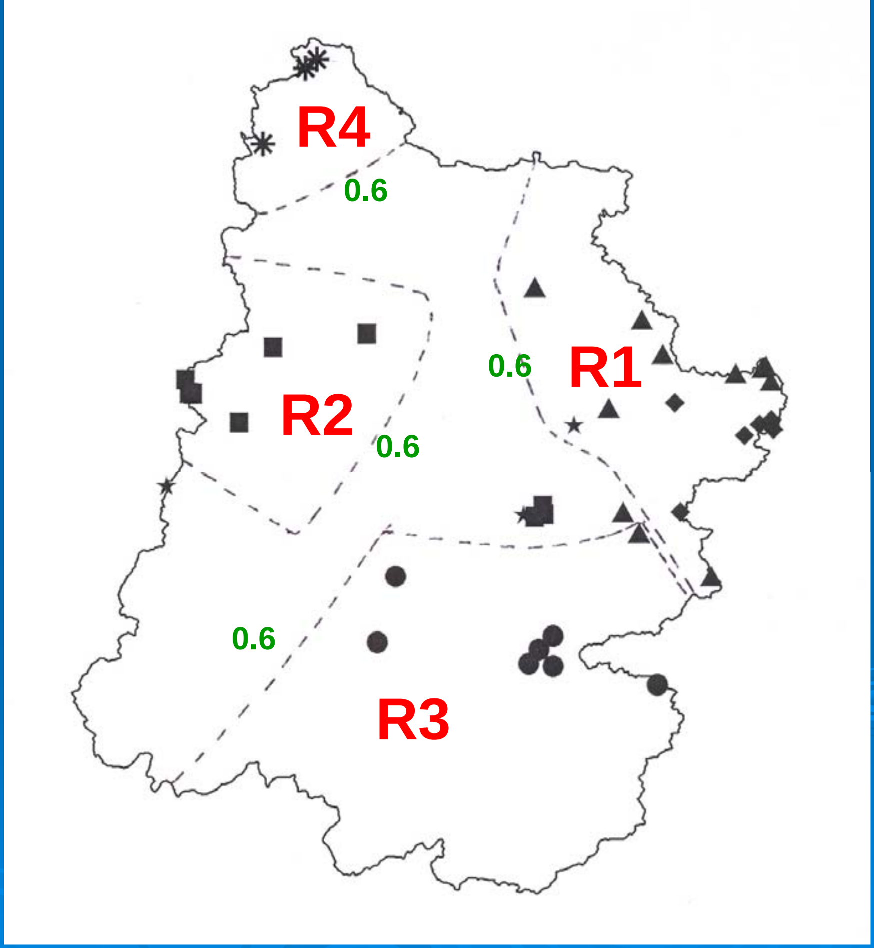
(from Timilsena et al., 2008)

PCA

- 4 Rotated Principal Component by Varimax Rotation

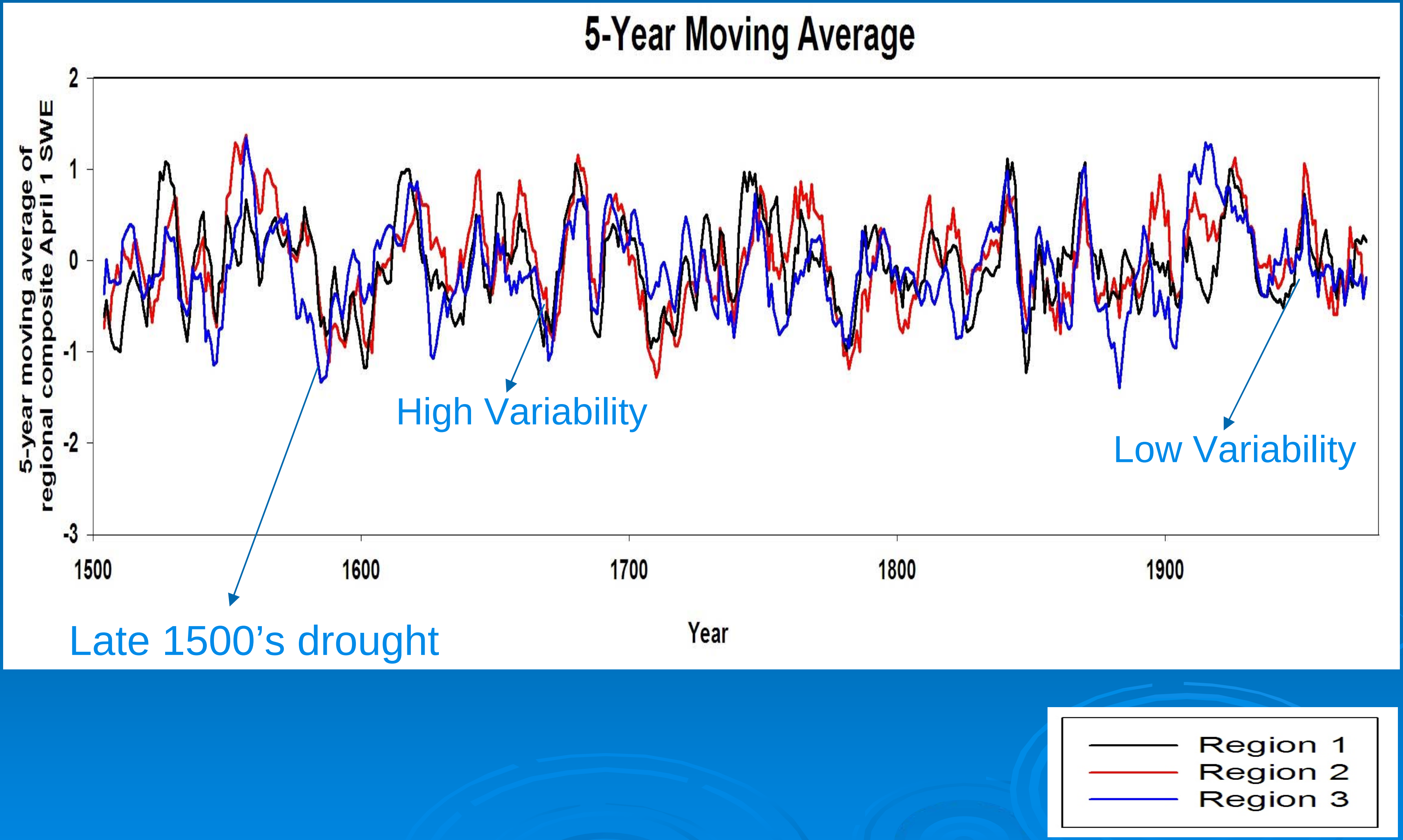
Cluster Analysis

- 6 cluster solution
- Cubic cluster criterion
- Pseudo-t^2 statistics



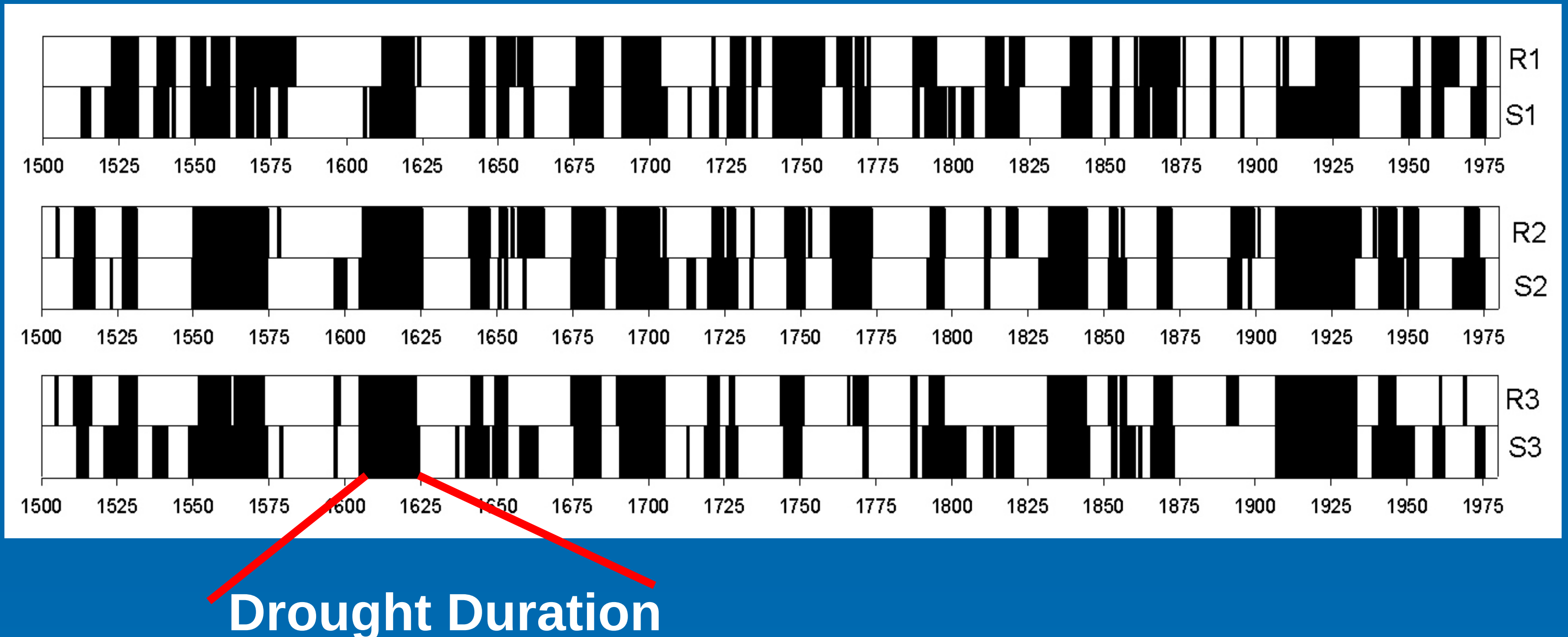
Upper Basin

5-year Moving Average of April 1 Snow Water Equivalent (SWE)



(from Timilsena et al., 2008)

Comparison of Reconstructed Streamflow (R) and Snow (S)



- Depending on region and averaging period, about 60-80% of the years had common streamflow and snow deficits.

(from Timilsena et al., 2008)

Comparison of Snow Regional vs Individual Reconstruction

	Snow Station Name	% Variance	CVSE	Calibration Period
REGIONS	Region 1, Eastern Region	41.28	0.67	1940-1975
	Region 2, Western Region	45.27	0.73	1940-1975
	Region 3, Southern Region	54.48	0.59	1940-1975
STATIONS	Region 1, Station 05K03	30.12	0.83	1940-1975
	Region 2, Station 09J01	32.55	0.86	1940-1975
	Region 3, Station 07M05	53.07	0.67	1940-1975

Presentation Outline

- Regional Drought Analysis (Tom)
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  - Snow
- **Headwater Reconstruction (Glenn)**
- **Drought Frequency Analysis (Glenn)**

Acknowledgments

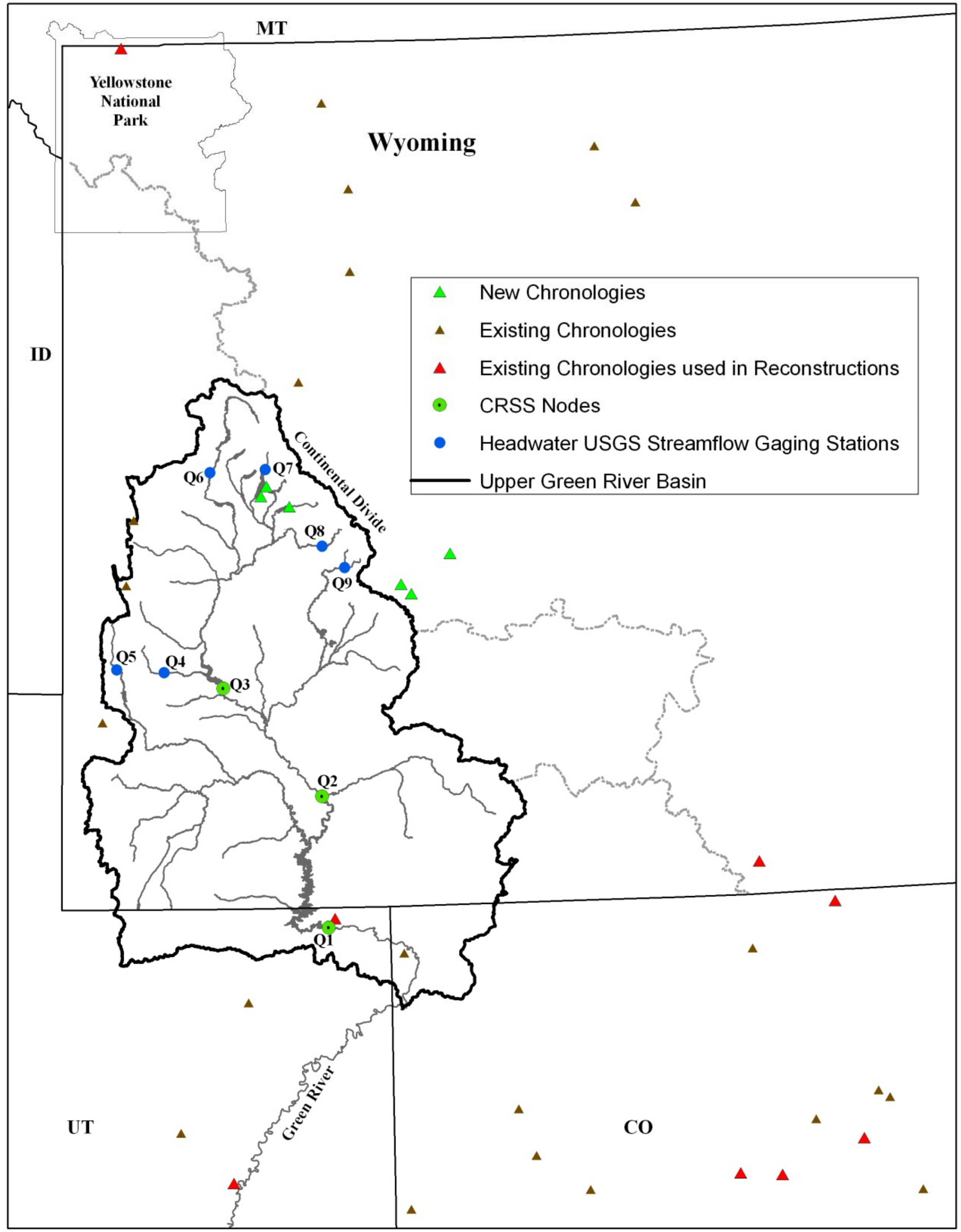
- Wyoming Water Development Commission & USGS Water Research Program
- Bellamy, J., G. Tootle, G. Kerr and L. Pochop, 2008. Frequency and Duration of Drought in the Green River Basin, WY, USA. Proceedings of the *ASCE World Water & Environmental Resources Congress 2008*, May 11-17, 2008, Honolulu, HI.
- Watson, T., F.A. Barnett, S. Gray and G. Tootle, 2009. Reconstructed Streamflow for the Headwaters of the Wind River, Wyoming USA. J*ournal American Water Resources Association* (In press).

From Barnett (2008)

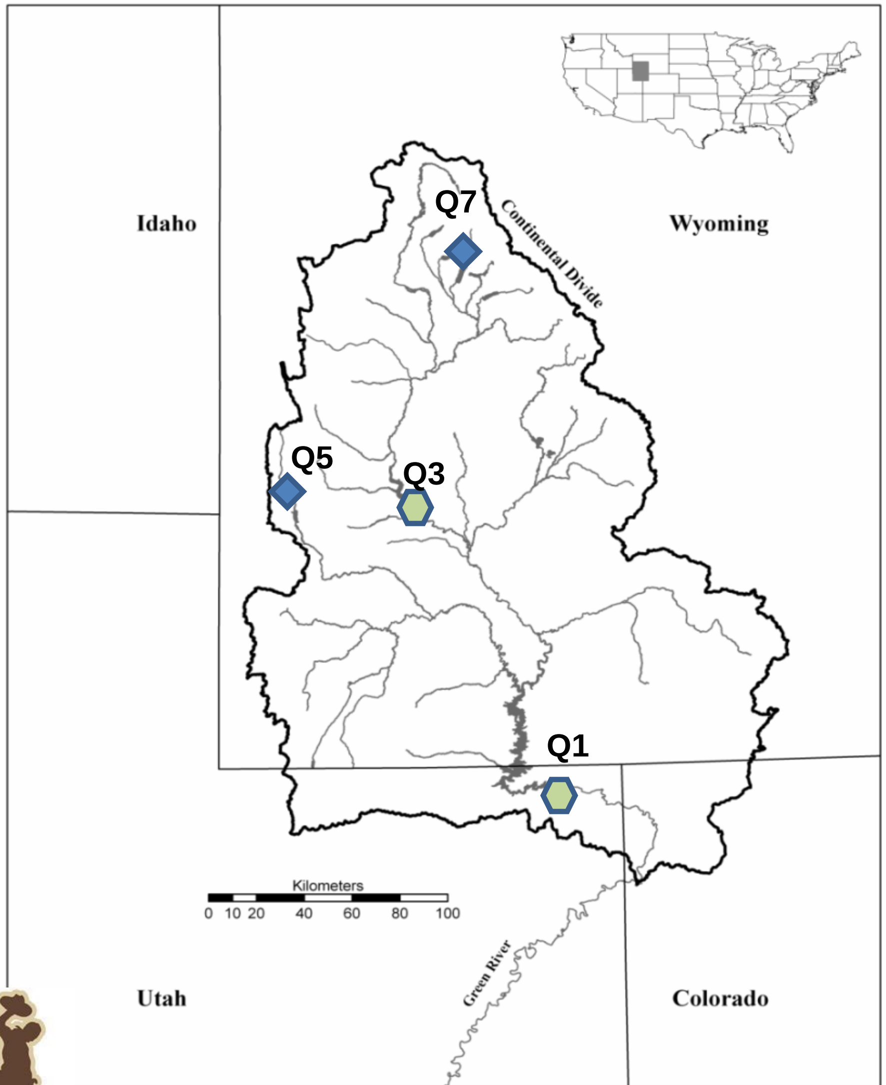
Regional tree ring network

- Thirty five current tree ring chronologies were available in the region

17 – Wyoming
4 – Utah
14 – Colorado



Upper Green River Basin



Headwater USGS Streamflow Gage Station

CRSS Node (Colorado River Simulation System)

Upper Green River Basin

Q1: Green River near Greendale, UT (R^2 = 0.65)

Q3: Green River Below Fontenelle Reservoir, WY (R^2 = 0.59)

Q5: Hams Fork below Pole Creek, near Frontier, WY (R^2 = 0.48)

Q7: Pole Creek above Freemont Lake, WY (R^2 = 0.53)

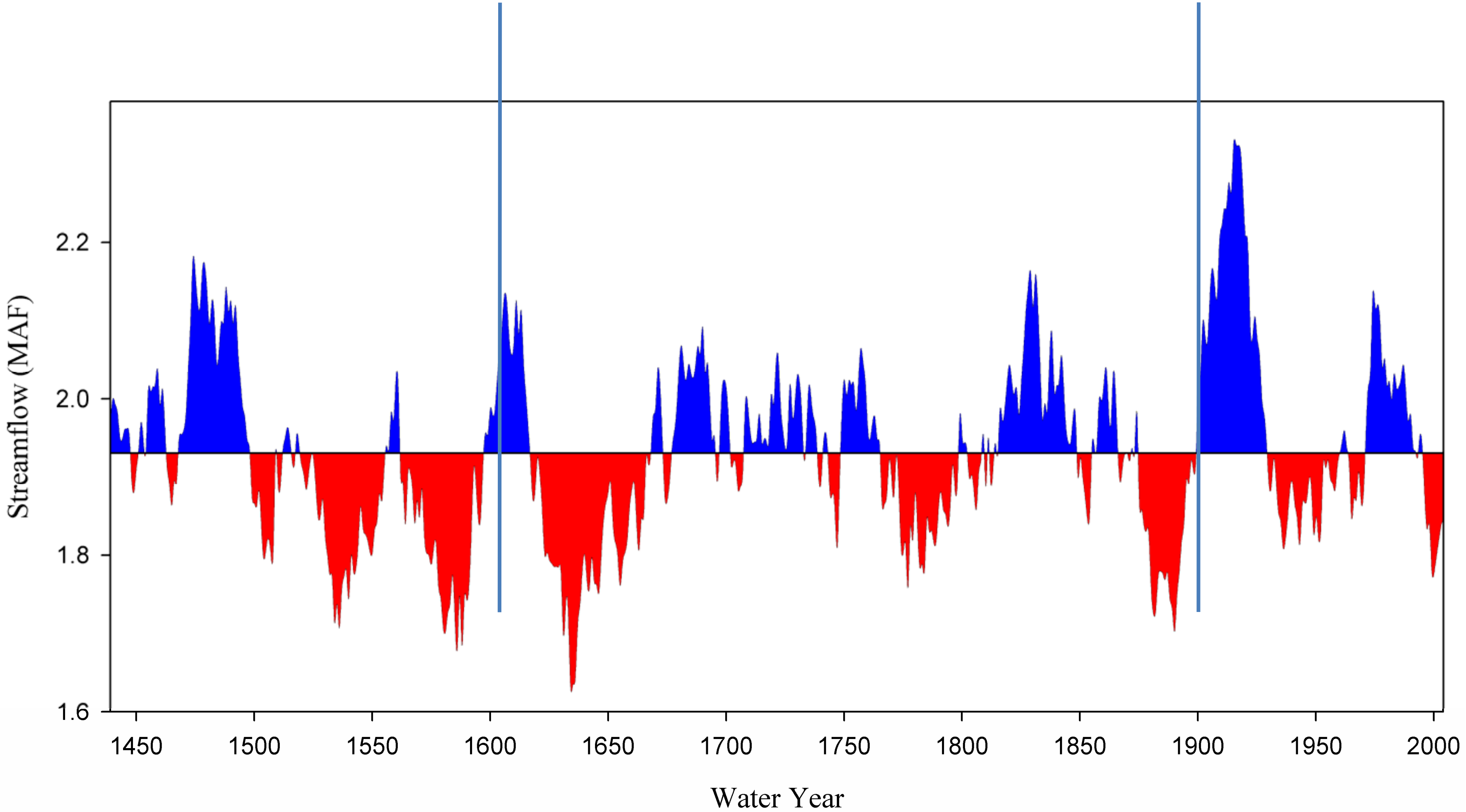
Data for Drought Analysis

from Barnett (2008)

- Unimpaired stations (Q5, Q7): Are stations with man made influences such as storage, diversion, and consumption that minimally impact the natural flow of a stream.

- Naturalized stations (Q1, Q3): Are stations with an impaired streamflow record that are "naturalized" to approximate natural flow conditions by removing man made influences.

Extended Q1 Reconstruction: 25 year moving average



Drought Definitions

- Deficit / Anomaly: Identified when an individual water year value is below a defined threshold.
- Threshold: For this analysis the threshold is defined as the long term mean of the reconstructed record. The threshold can also be defined as annual consumptive use.
- Duration: Sum of consecutive years that have been identified as a deficit year.
- Magnitude: Sum of a deficits included in the duration.
- Severity: Average deficit over an event's duration (magnitude / duration).

3 Methods for Identifying and Quantifying Droughts

- Method 1: Drought Magnitude and Severity

  Timilsena, J., T. C. Piechota, H. Hidalgo, G. Tootle (2007), Five hundred years of hydrological drought in the Upper Colorado River Basin, *Journal of the American Water Resources Association* (JAWRA), 43(3): 798-812.

- Method 2: Compound Renewal

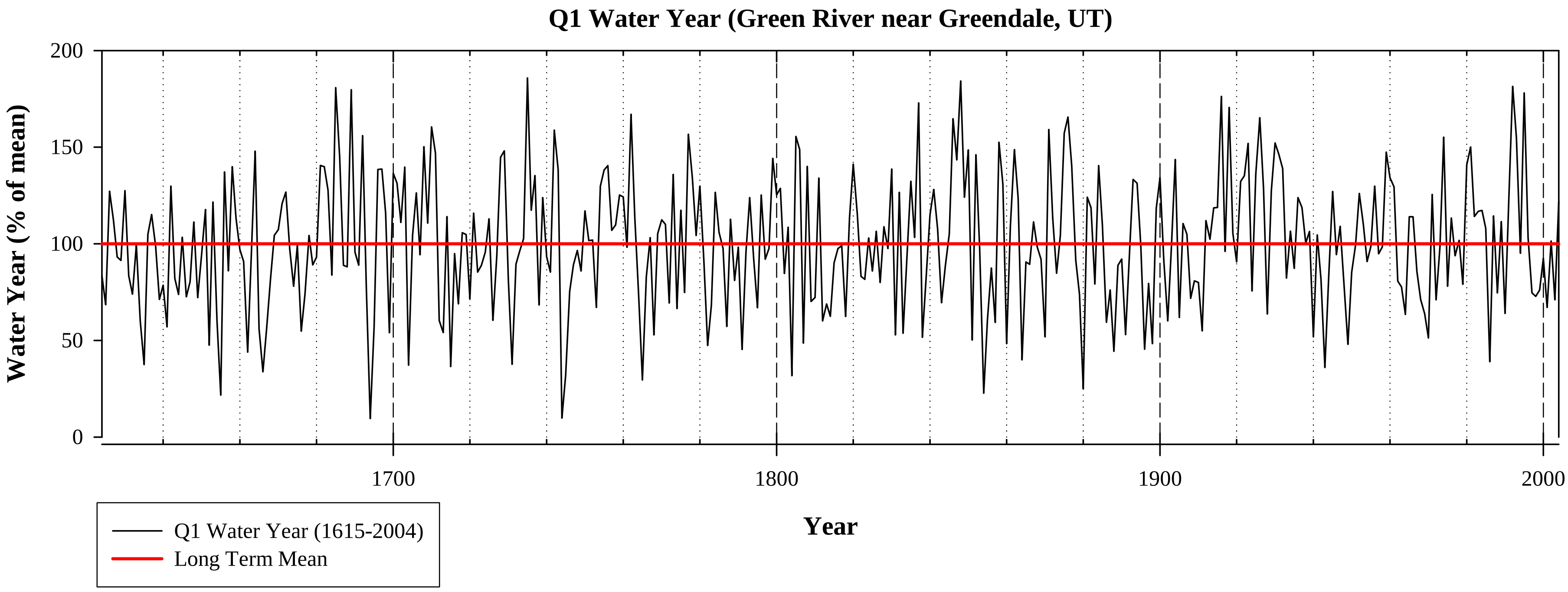
  Loáiciga, H. A. (2005), On the probability of droughts: The compound renewal model, *Water Resources Research (WRR)*, 41, W01009.

- Method 3: Drought Risk

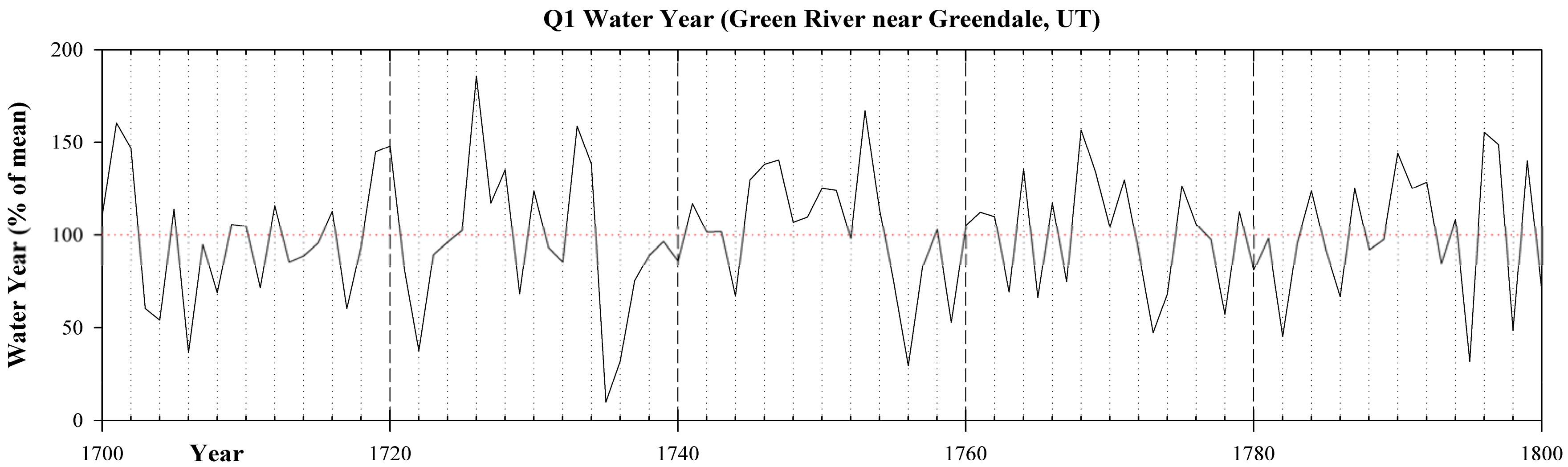
  Salas, J. D., C. Fu, A. Cancelliere, D. Dustin, D. Bode, A. Pineda, E. Vincent (2005), Characterizing the severity and risk of drought in the Poudre River, Colorado, *Journal of Water Resources Planning and Management*, doi:10.1061/(ASCE)0733-9496(2005)131:5(383).

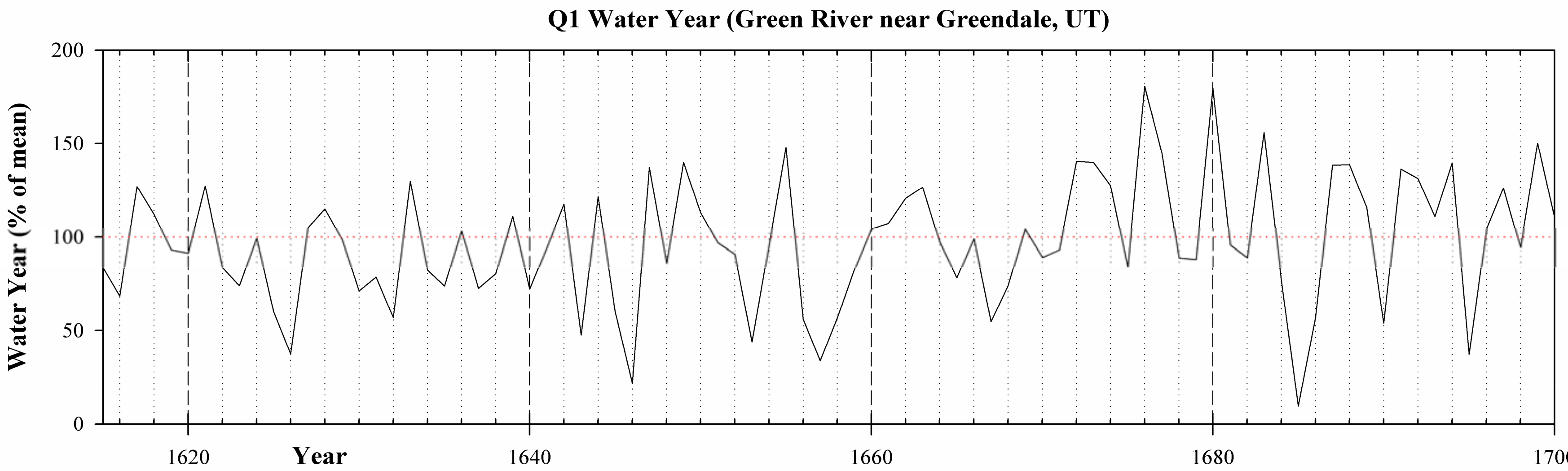
Method 1 : Drought events sorted for magnitude and severity

- a: Considers droughts with a minimum duration of two years
- b: 3 year (end year) moving average
- c: 5 year (end year) moving average
- d: 7 year (end year) moving average
- e: 10 year (end year) moving average



Q1 Water Year (Green River near Greendale, UT)
Water Year (% of mean)
0
50
100
150
200
1700
1800
1900
2000
Year
Q1 Water Year (1615-2004)
Long Term Mean


Q1 Water Year (Green River near Greendale, UT)
Water Year (% of mean)
200
150
100
50
0
1700
1720
1740
1760
1780
1800
Year


Q1 Water Year (Green River near Greendale, UT)
Water Year (% of mean)
200
150
100
50
0
1620
1640
1660
1680
1700
Year

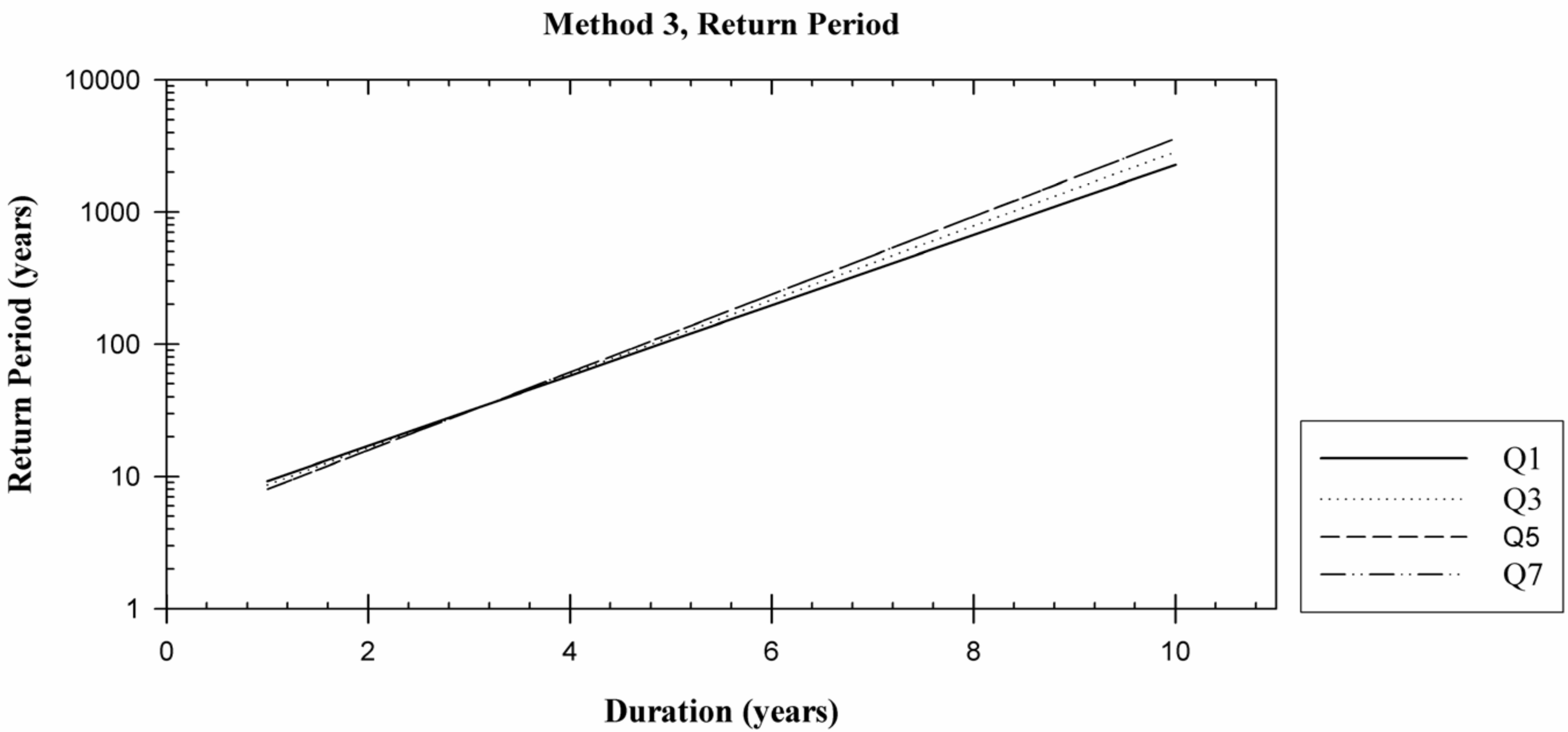
Sorted for Magnitude

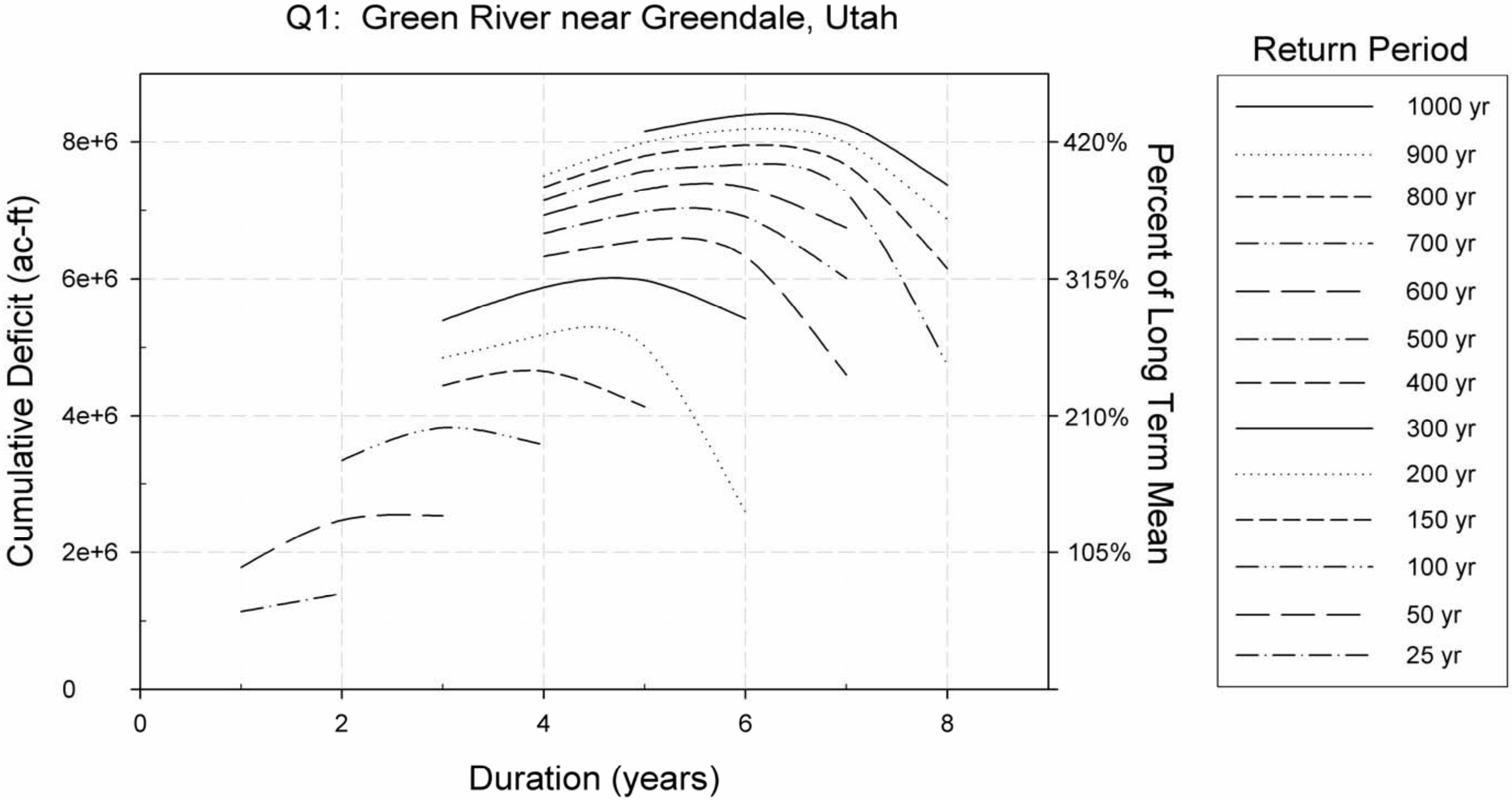
Gage Station	Drought Identification Method 1	Ranked 1st	Ranked 2nd	Ranked 3rd	Ranked 4th	Ranked 5th	Average Duration (years)	Rank of Recent Drought	Method 1 Return Time (years)	Method 2 Return Time (years)
Q1	a	1735-1740	1877-1883	2000-2004	1844-1848	1656-1659	3	# 3 (2000-2004)	130	132
	b	1630-1648	1704-1719	1653-1661	1878-1884	1736-1742	4	# 8 (2001-2004)	49	52
	c	1623-1650	1932-1944	1653-1662	1706-1718	1735-1742	6	# 17 (2002-2004)	23	23
	d	1624-1652	1879-1895	1931-1946	1656-1664	1706-1719	7	# 19 (2003-2004)	21	21
	e	1624-1655	1877-1906	1657-1673	1933-1949	1801-1818	9	# 18 (2003-2004)	22	22
Q3	a	1877-1883	1844-1848	1803-1809	2000-2004	1735-1740	3	# 4 (2000-2004)	98	65
	b	1800-1810	1878-1884	1704-1715	1844-1849	1653-1660	4	# 8 (2001-2004)	49	49
	c	1878-1894	1622-1641	1931-1944	1801-1811	1845-1852	6	# 16 (2002-2004)	24	25
	d	1879-1906	1624-1651	1931-1946	1803-1813	1706-1719	7	# 16 (2003-2004)	24	25
	e	1624-1673	1877-1908	1933-1949	1801-1816	1708-1719	10	# 15 (2003-2004)	23	23
Q5	a	1703-1711	1803-1809	2000-2004	1844-1848	1931-1936	3	# 3 (2000-2004)	130	148
	b	1704-1713	1630-1639	1802-1810	1989-1996	1896-1906	4	# 8 (2001-2004)	49	52
	c	1619-1640	1704-1715	1804-1811	1896-1906	1933-1941	5	# 12 (2001-2004)	33	34
	d	1879-1907	1621-1641	1704-1718	1803-1813	1934-1942	6	# 14 (2002-2004)	28	29
	e	1624-1655	1878-1908	1706-1718	1804-1815	1993-2004	8	# 5 (1993-2004)	78	90
Q7	a	1703-1711	1803-1809	1629-1632	1931-1936	1844-1848	3	# 20 (2000-2004)	20	52
	b	1630-1639	1704-1713	1802-1810	1932-1938	1897-1904	4	# 19 (2001-2004)	21	23
	c	1619-1641	1887-1906	1704-1713	1804-1811	1933-1941	6	# 19 (2002-2004)	21	21
	d	1621-1643	1880-1907	1803-1813	1706-1715	1934-1941	6	# 20 (2004)	20	20
	e	1624-1655	1878-1908	1802-1815	1706-1718	1935-1943	7	No Drought	No Drought	No Drought

Sorted for Severity

Gage Station	Drought Identification Method 1	Ranked 1st	Ranked 2nd	Ranked 3rd	Ranked 4th	Ranked 5th	Rank of Recent Drought	Number of Identified Droughts
Q1	a	1645-1646	1684-1686	1656-1659	1703-1704	2000-2004	# 5 (2000-2004)	51
	b	1685-1687	2001-2004	1736-1741	1871-1873	1887-1890	# 2 (2001-2004)	47
	c	2002-2004	1878-1884	1735-1742	1653-1662	1667-1671	# 1 (2002-2004)	35
	d	1656-1664	1803-1811	1846-1852	1624-1652	1735-1745	# 7 (2003-2004)	29
	e	1736-1745	1624-1655	1657-1673	1960-1970	1877-1906	# 19 (2003-2004)	23
Q3	a	1703-1704	1625-1626	1645-1646	1684-1686	1844-1848	# 7 (2000-2004)	50
	b	2001-2001	1878-1884	1685-1687	1844-1849	1736-1740	# 1 (2001-2004)	52
	c	2002-2004	1845-1852	1645-1661	1801-1811	1991-1996	# 1 (2002-2004)	37
	d	1846-1852	1656-1663	1803-1813	1992-1996	1879-1906	# 6 (2003-2004)	31
	e	1877-1908	1801-1816	1933-1949	1708-1719	1624-1673	# 15 (2003-2004)	21
Q5	a	1919-1920	1684-1686	1901-1902	1625-1626	1886-1887	# 8 (2000-2004)	42
	b	2001-2004	1846-1849	1685-1687	1704-1713	1802-1810	# 1 (2001-2004)	53
	c	1804-1811	2001-2004	1845-1852	1989-1996	1756-1761	# 2 (2001-2004)	40
	d	1846-1853	1803-1813	1621-1641	2002-2004	1934-1942	# 4 (2002-2004)	32
	e	1804-1815	1706-1718	1624-1655	1936-1943	1878-1908	# 6 (1993-2004)	26
Q7	a	1919-1920	1625-1626	1684-1686	1629-1632	1721-1722	# 37 (2000-2004)	45
	b	1846-1849	1685-1687	1630-1639	1704-1713	1802-1810	# 17 (2001-2004)	48
	c	1804-1811	1704-1713	1933-1941	1845-1852	1619-1641	# 12 (2002-2004)	36
	d	1706-1715	1934-1941	1803-1813	1846-1853	1621-1643	# 16 (2004)	35
	e	1624-1655	1706-1718	1802-1815	1935-1943	1878-1908	No Drought	29

Duration Only





Q1: Green River near Greendale, Utah
Cumulative Deficit (ac-ft)
8e+6
6e+6
4e+6
2e+6
0
0
2
4
6
8
Duration (years)
420%
315%
210%
105%
Percent of Long Term Mean
Return Period
1000 yr
900 yr
800 yr
700 yr
600 yr
500 yr
400 yr
300 yr
200 yr
150 yr
100 yr
50 yr
25 yr

Conclusions

- Droughts need to be quantified in terms of duration, magnitude and severity
- Current drought magnitude and duration is small in comparison to past droughts
- Combination of return period and duration can provide drought magnitude.
- Regionalization of snow improves reconstruction
- Use of reconstructed streamflow could improve understanding of interdecadal climate variability

QUESTIONS?