Reservoir Operations Impacts on Socioeconomic Drought in Regulated Basins

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Meteorological Drought: Deficit in precipitation

Agricultural Drought: Deficit in soil moisture

Hydrologic Drought: Deficit in runoff/groundwater/storage

Snow Drought: Abnormally low snow for the time of the year

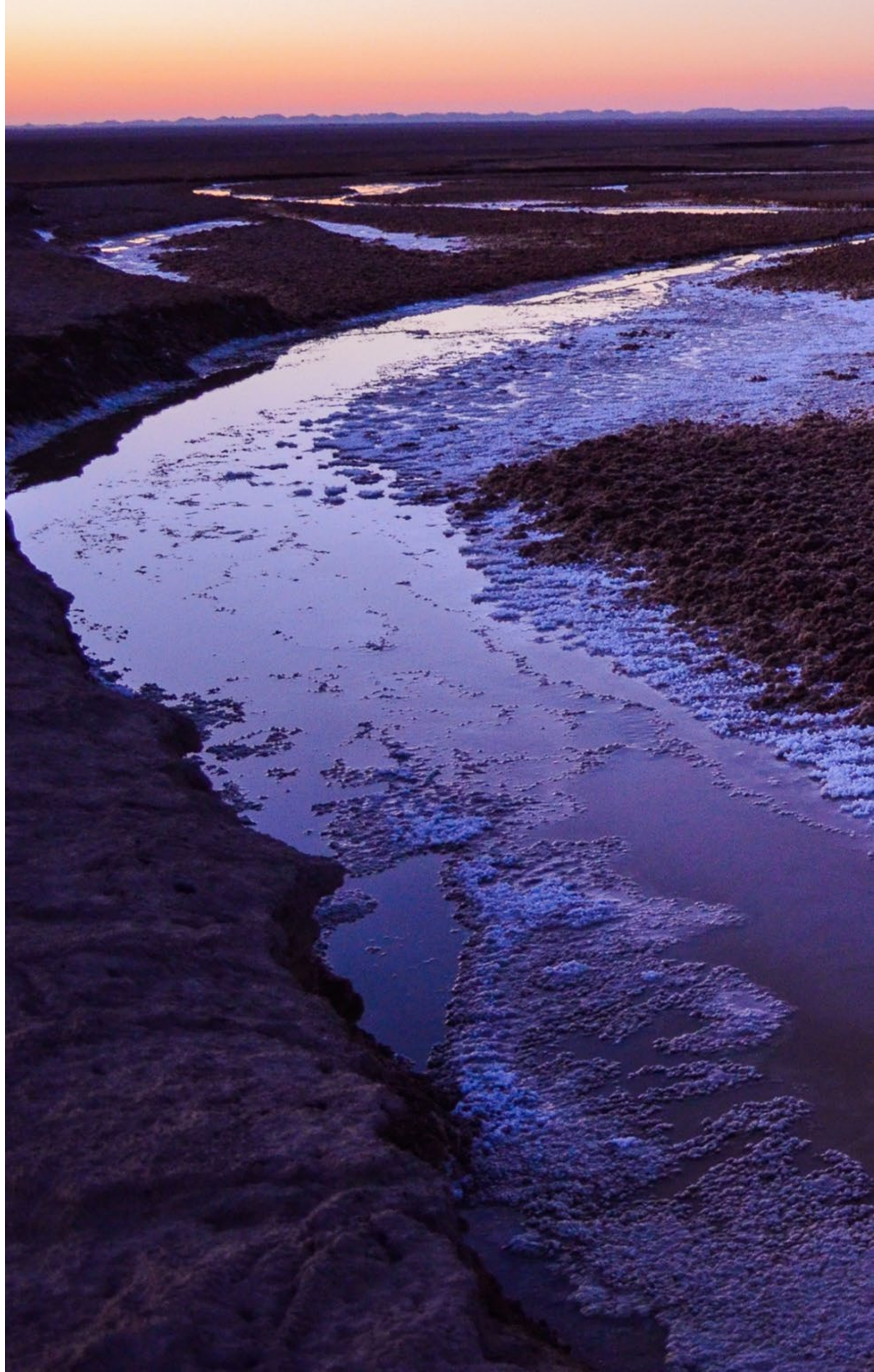
Socio-Economic Drought: Imbalance between supplies and human water demand leading to socioeconomic impacts.

Anthropogenic Drought: water stress caused or intensified by human activities, (e.g., increased demand, mismanagement, climate change from anthropogenic greenhouse gas emissions, growing energy and food production, environmental policy, and land use changed)

Mehran A., et al., 2015, *A Hybrid Framework for Assessing Socioeconomic Drought*, ***Journal of Geophysical Research***.

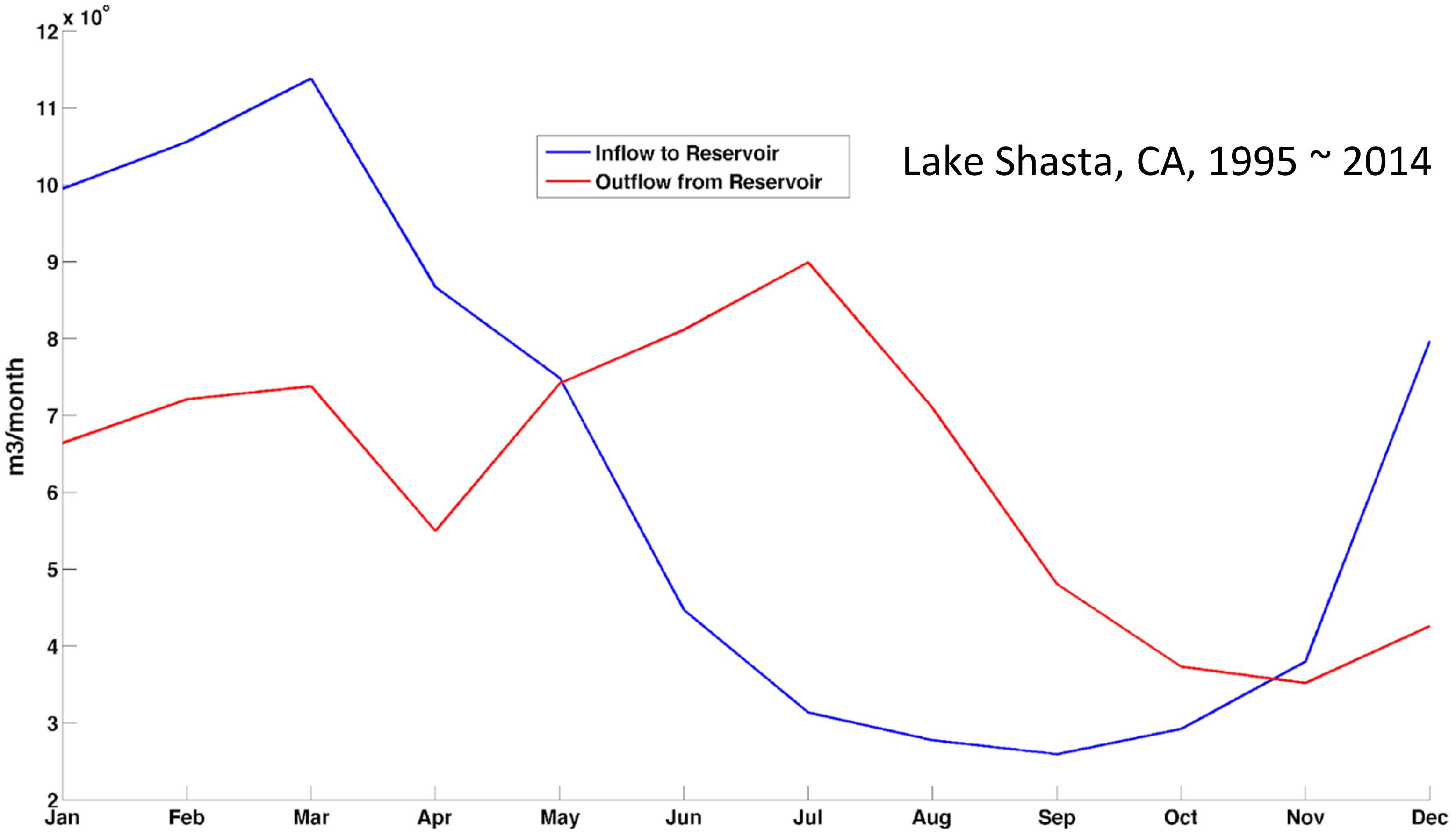
Mehran A., et al., 2017, Compounding Impacts of Human-Induced Water Stress and Climate Change on Water Availability, ***Scientific Reports***.

AghaKouchak A., et al., 2021, Anthropogenic Drought: Definition, Challenges and Opportunities, ***Reviews of Geophysics***, 59, e2019RG000683.



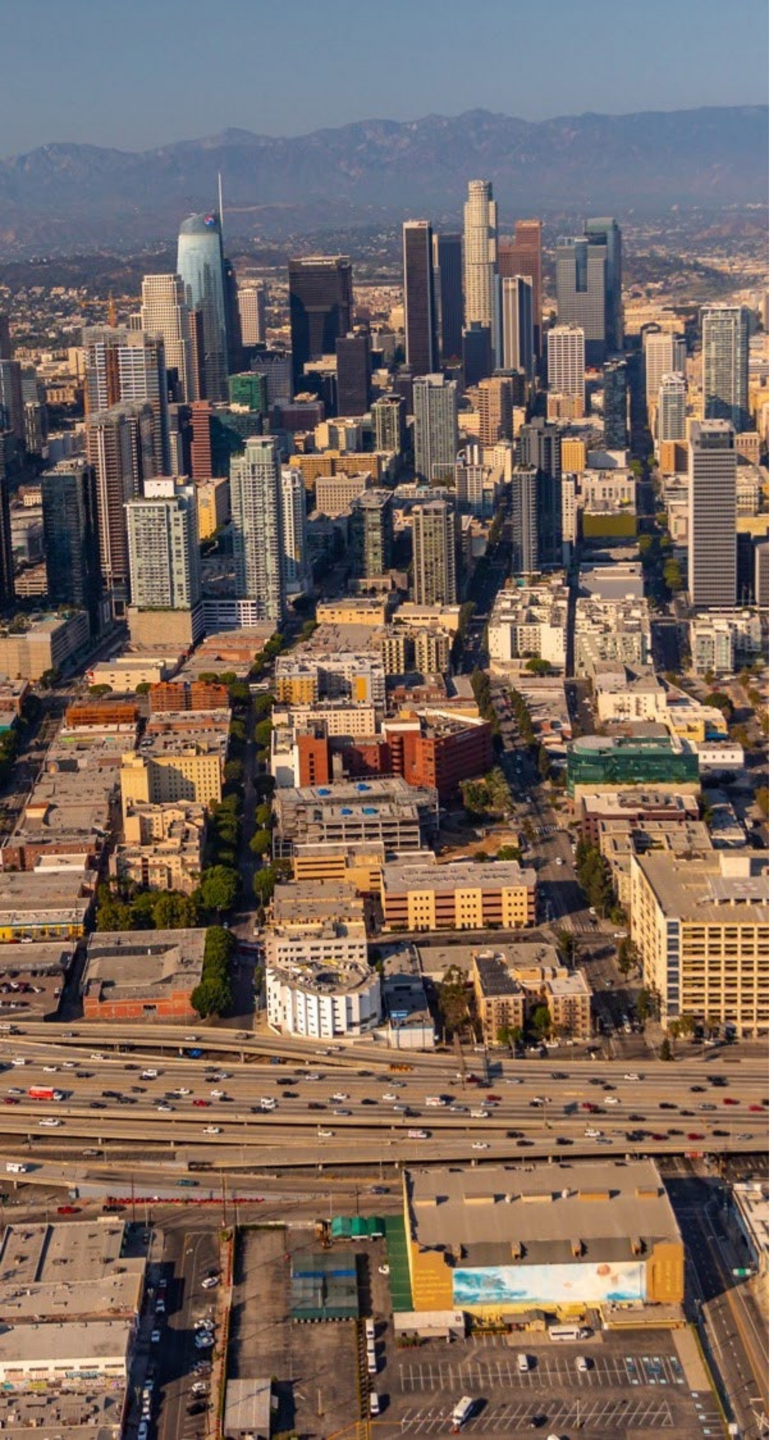
A hybrid framework for water stress assessment: linking climate variability and local resilience and human influence

(Mehran et al., 2015, JGR)




Pas


Current



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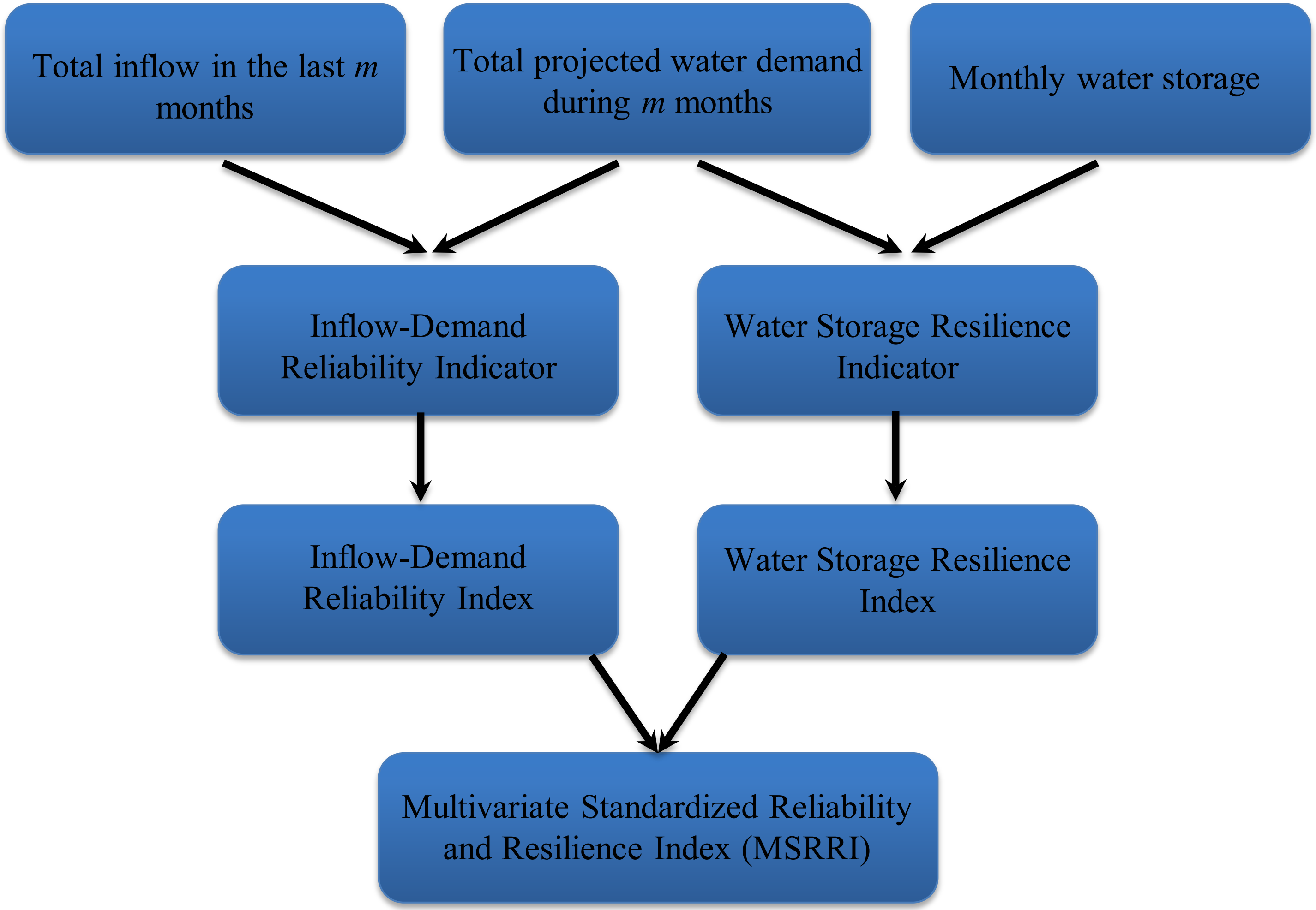


Mehran et al., JGR, 2015

Inflow-Demand Reliability Indicator

$$\alpha_t = \frac{\sum_{i=t-m+1}^{t} Q_{in_i} - Q_{\exp_t}}{Q_{\exp_t}}, \quad Q_{\exp_t} = \begin{cases} \sum_{i=t-12}^{t-13+m} Q_{out_i}, m = 6 \\ \sum_{i=t-m+1}^{t} Q_{out_i}, m = 12 \end{cases}$$

Water Storage Resilience Indicator

$$\beta_t = \frac{St_t + Q_{in_t} - Q_{out_t} - O_{\min} - Q_{\exp_t}}{Q_{\exp_t}}$$

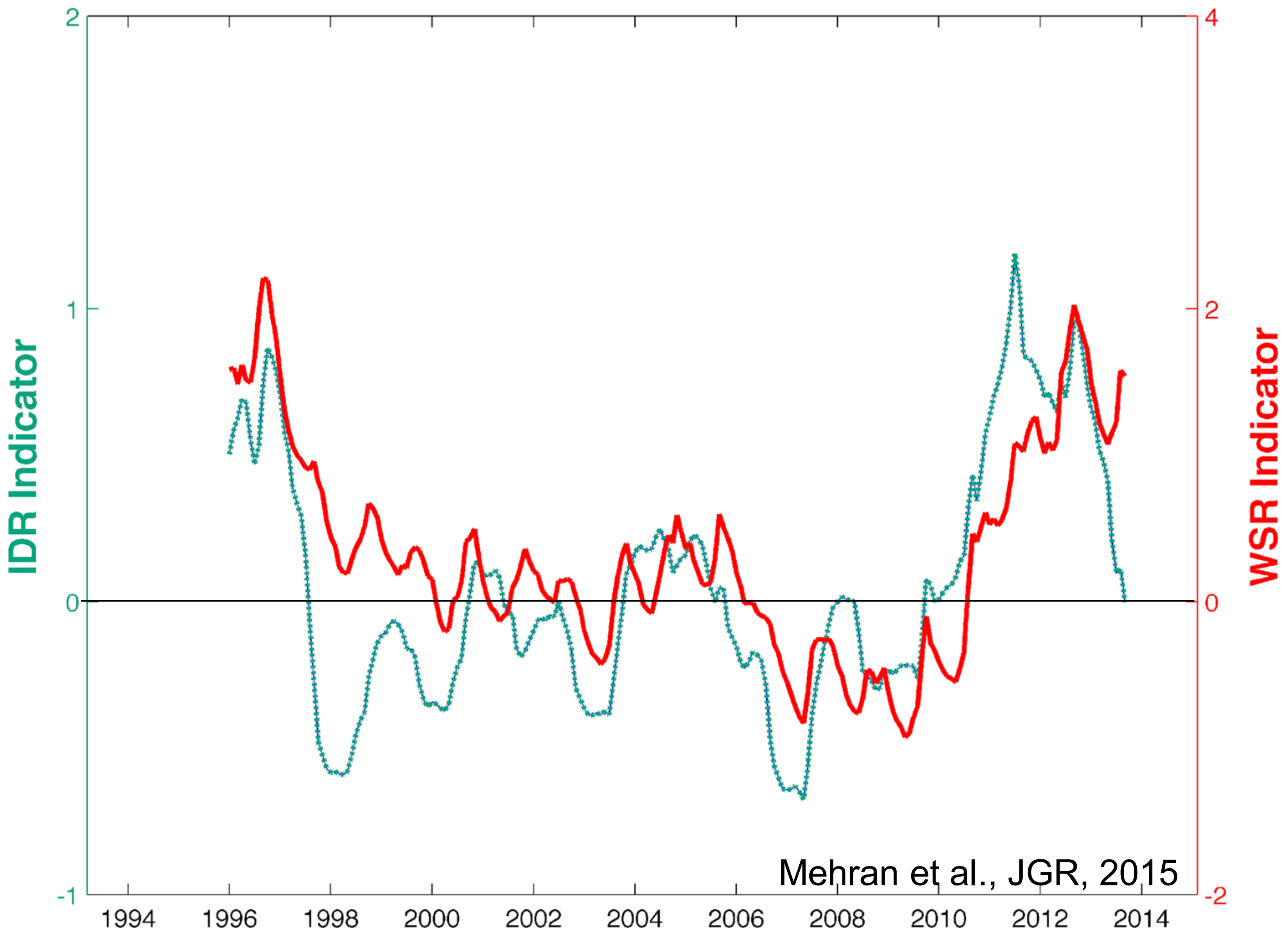
where;

Q_{in} ; monthly inflow in month *i*
$Q_{\exp_t}$; total expected water demand during the projected time frame
St_i ; reservoir storage at month *i*

i is ranging from 1 to *N* (sample size)
t is ranging from 13 to *N*

Anthropogenic Drought Assessment:

A hybrid framework for water stress assessment: linking climate variability and local resilience and human influence



- Within-year and over-year reservoir-demand analysis:
- IDR

$$\alpha_t = \frac{\sum_{i=t-m+1}^{t} Q_{in_i} - Q_{est_t}}{Q_{est_t}} \quad , Q_{est_t} = \begin{cases} \sum_{i=t-12}^{t-13+m} (Q_{out})_i, & if \;\; m = 6 \\ \sum_{i=t-m+1}^{t} (Q_{out})_i, & if \;\; m = 12 \end{cases}$$

- WSR

$$\beta_t = \frac{St_t + Q_{in_t} - Q_{out_t} - O_{min} - Q_{est_t}}{Q_{est_t}}$$

- Empirical probability

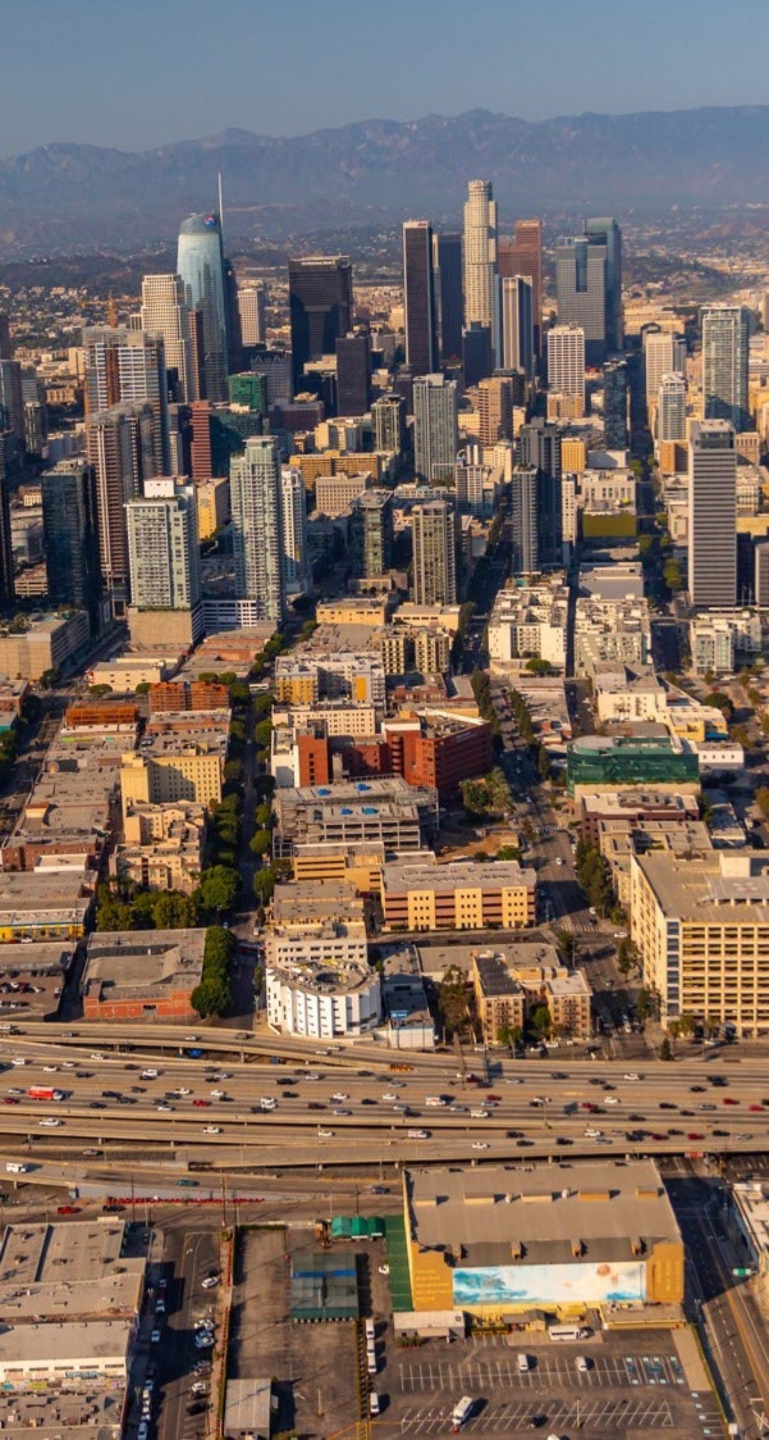
$$P(x_t) = \frac{l - 0.44}{N + 0.12}$$

- Standardized index

$$SI(\mathrm{P(x)}) = \begin{cases} if \; 0 < \mathrm{P(x)} \le 0.5, \; + \left(k - \frac{C_0 + C_1 k + C_2 k^2}{1 + d_1 k + d_2 k^2 + d_3 k^3}\right) \; and \;\; k = \sqrt{\ln({}^{1}/_{\mathrm{P(x)}^2})} \\ if \; 0.5 < \mathrm{P(x)} \le 1, \; - \left(k - \frac{C_0 + C_1 k + C_2 k^2}{1 + d_1 k + d_2 k^2 + d_3 k^3}\right) \; and \; k \; = \sqrt{\ln\left[{}^{1}/_{(1 - \mathrm{P(x)})^2}\right]} \end{cases}$$

- Combine univariate indicators

$$P_{j_t} = \Pr\left(\mathrm{SI}(\alpha) \le \mathrm{SI}(\alpha_t), \mathrm{SI}(\beta) \le \mathrm{SI}(\beta_t)\right) \longrightarrow P_{j_t}(SI(\alpha_t), SI(\beta_t)) = \frac{l - 0.44}{N + 0.12}$$



Anthropogenic Drought Assessment:

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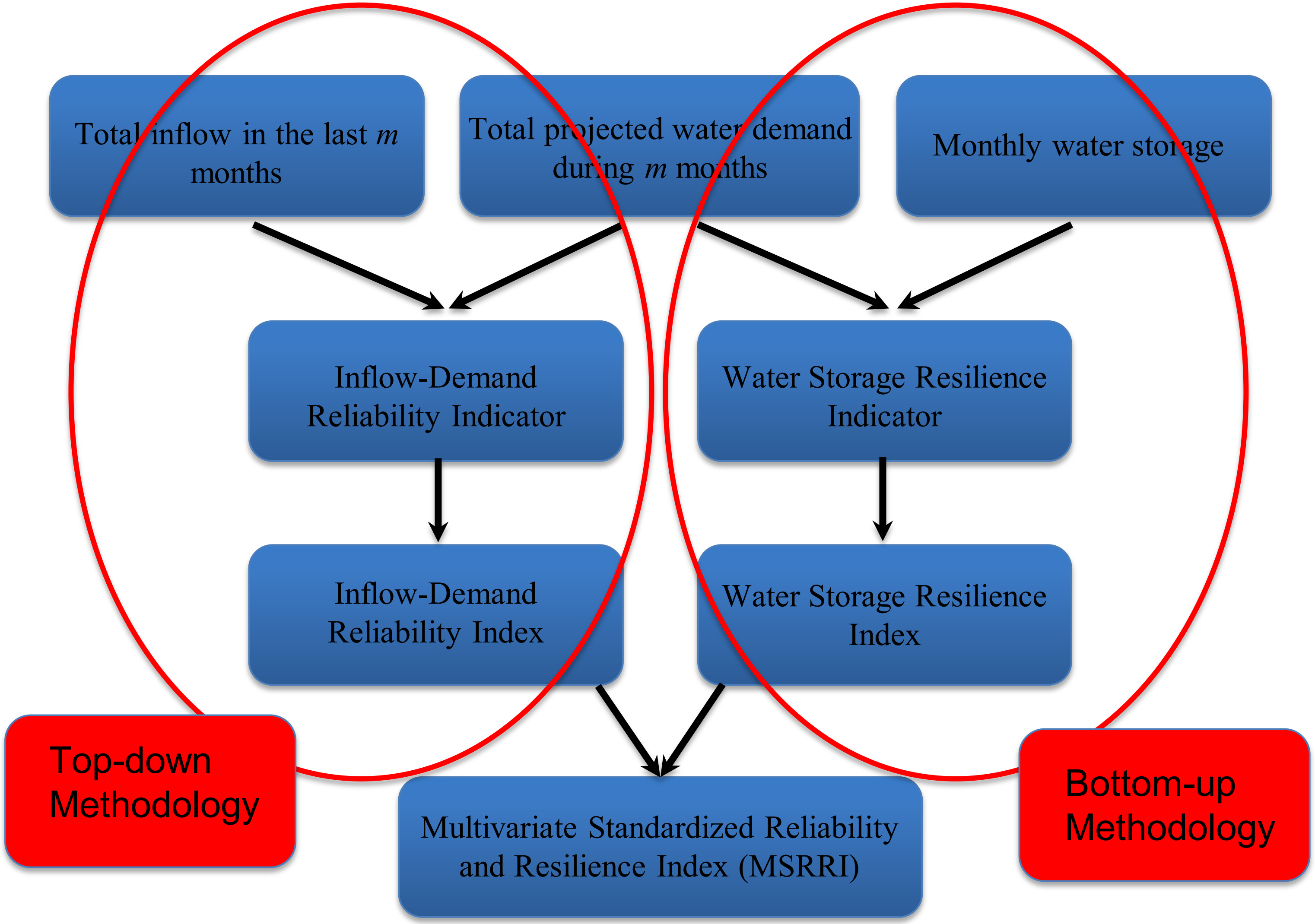
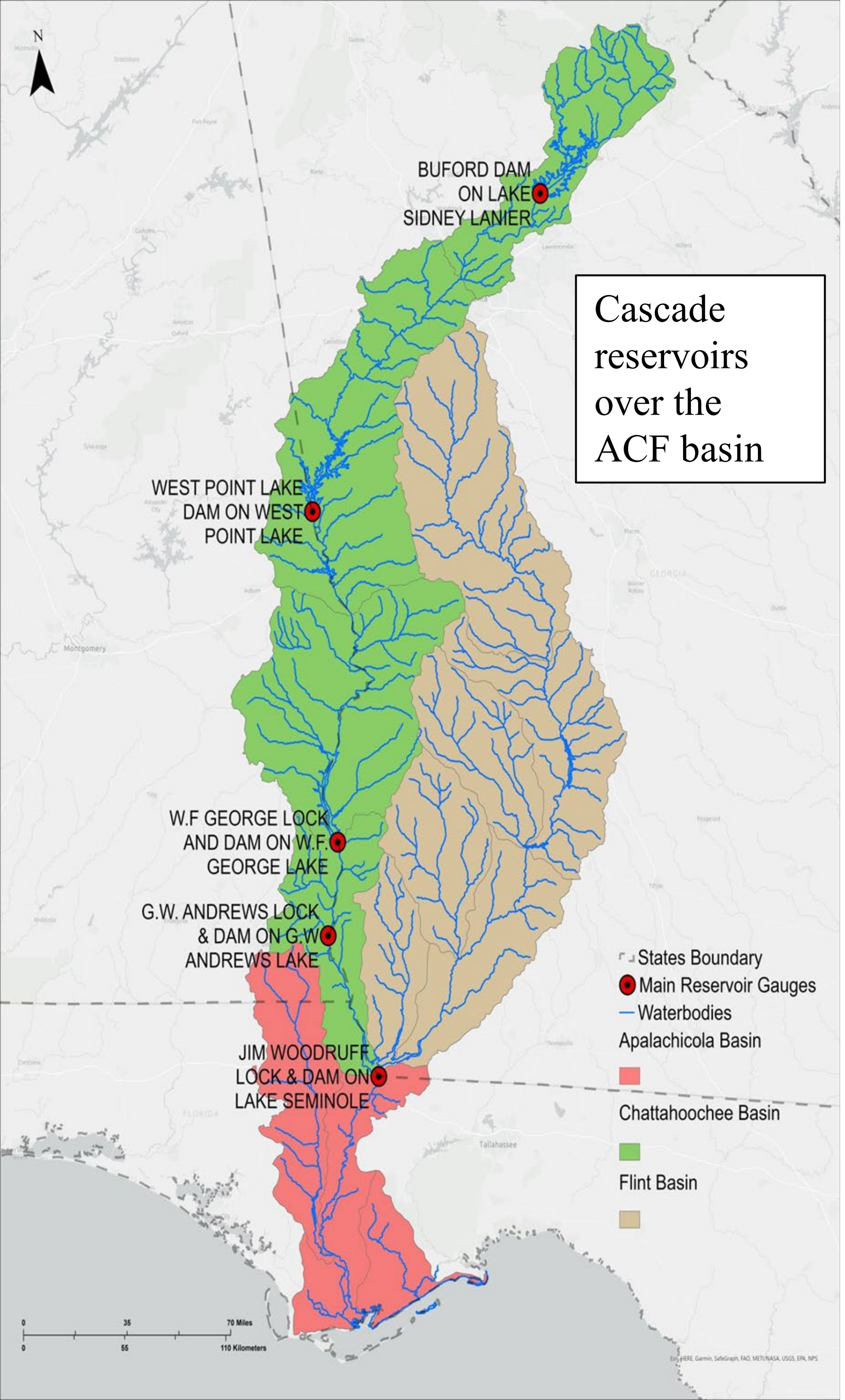
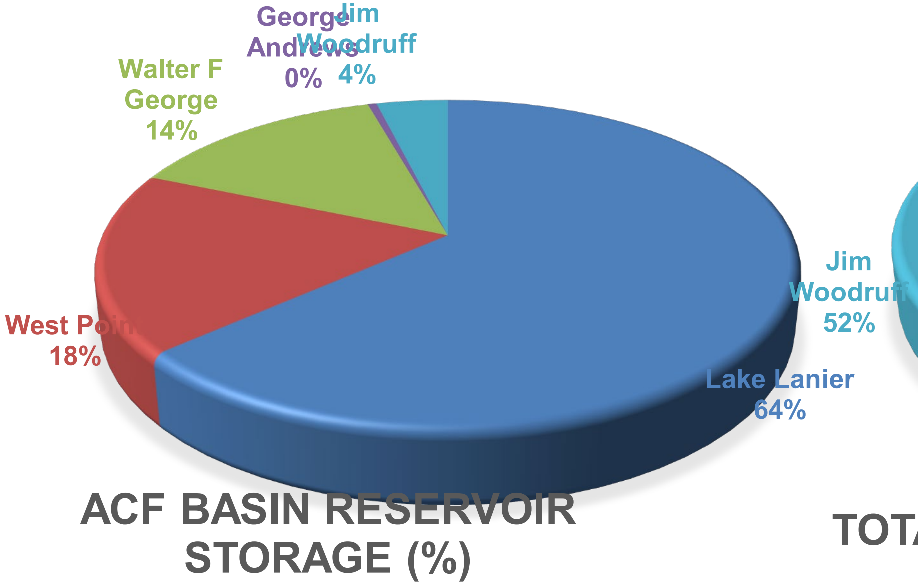


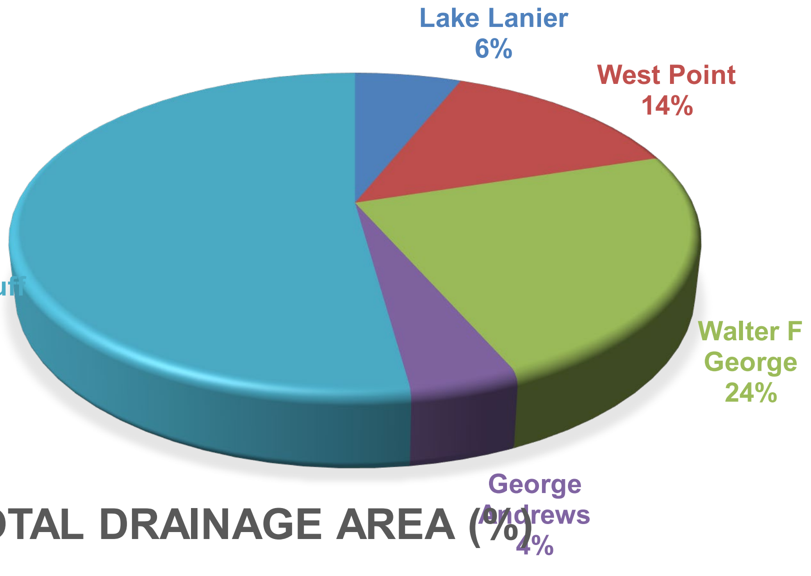
Mehran et al., JGR, 2015

- The ACF is a huge basin draining an area of 19,573 square miles across the states of Alabama, Georgia, and Florida.

- The ACF Basin is also home to nearly 6.8 million people. Water stress becomes much more prevalent in the ACF during times of drought; therefore, water management in this basin is important.



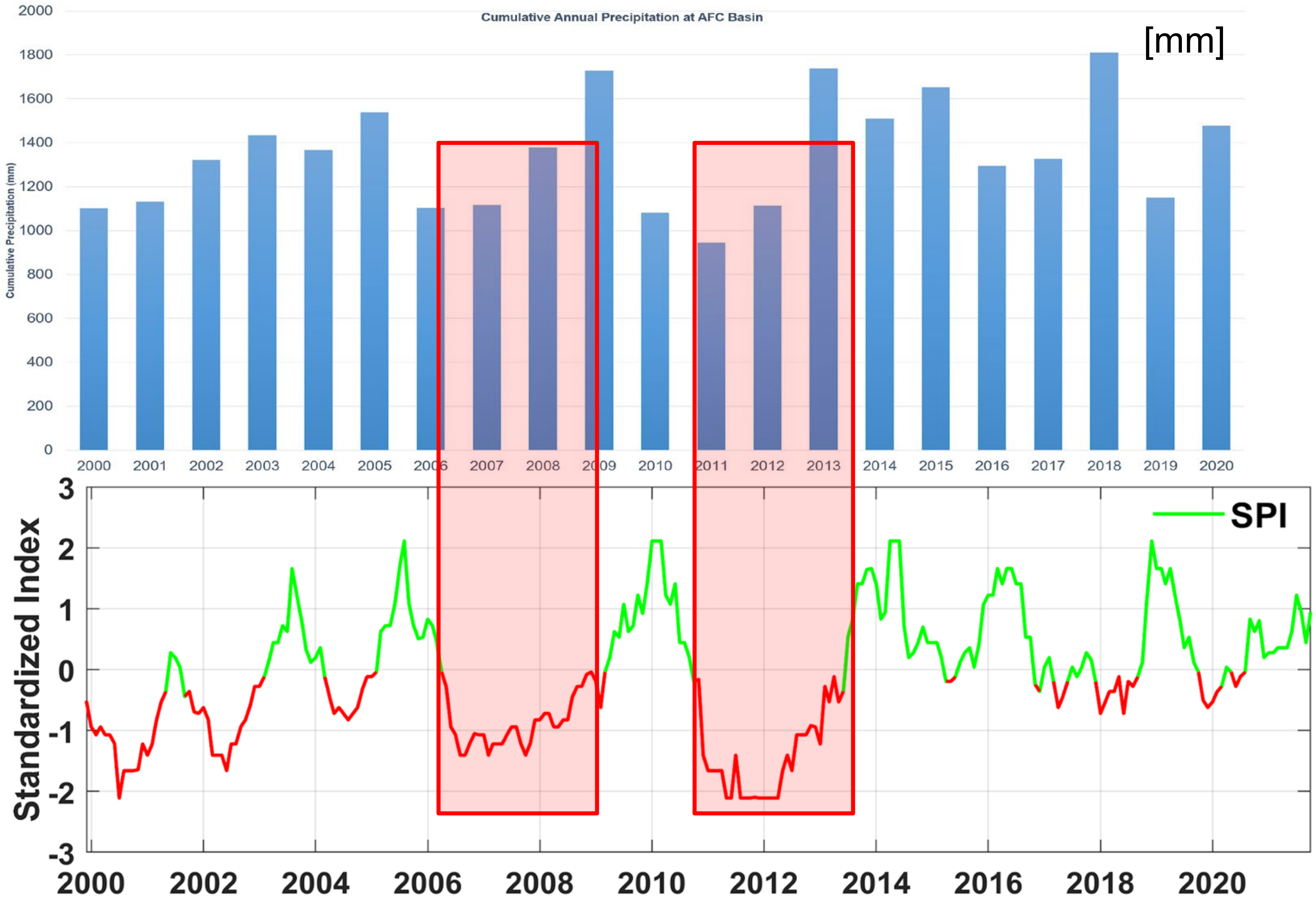




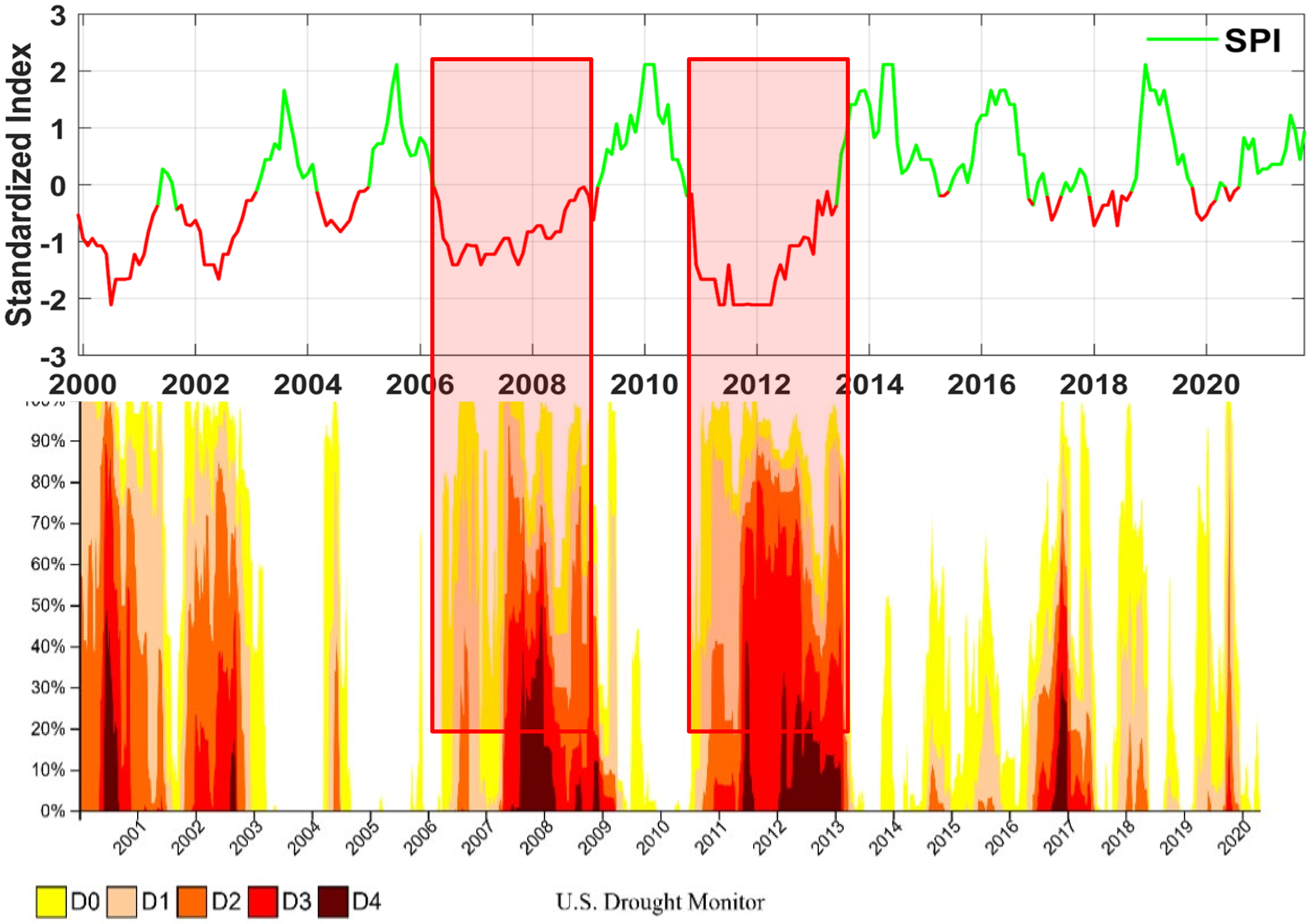
Reservoirs	Storage Capacity (ac-ft)	Max Depth (m)	Surface Area (acres)	Drainage Area (mi^2)	FRM	WS	HPG	NAV	FW	REC	WQ
Lake Lanier	1,087,600	48	37,000	1034	💧	💧	💧	💧	💧	💧	💧
West Point	306,127	26	25,864	2406	💧	💧	💧	💧	💧	💧	💧
Walter F. George	244,400	30	45,181	4020			💧	💧	💧	💧	💧
George Andrews	8,200	8	1,540	750				💧	💧	💧	💧
Lake Seminole	66,847	9.1	37,500	8954			💧	💧	💧	💧	💧

FRM = Flood Risk Management; WS = Water Supply; HPG = Hydroelectric Power Generation; NAV = Navigation; FW = Fish And Wildlife Conservation; REC = Recreation; WQ = Water Quality

Cumulative Annual Precipitation (CHIRPS) vs. SPI

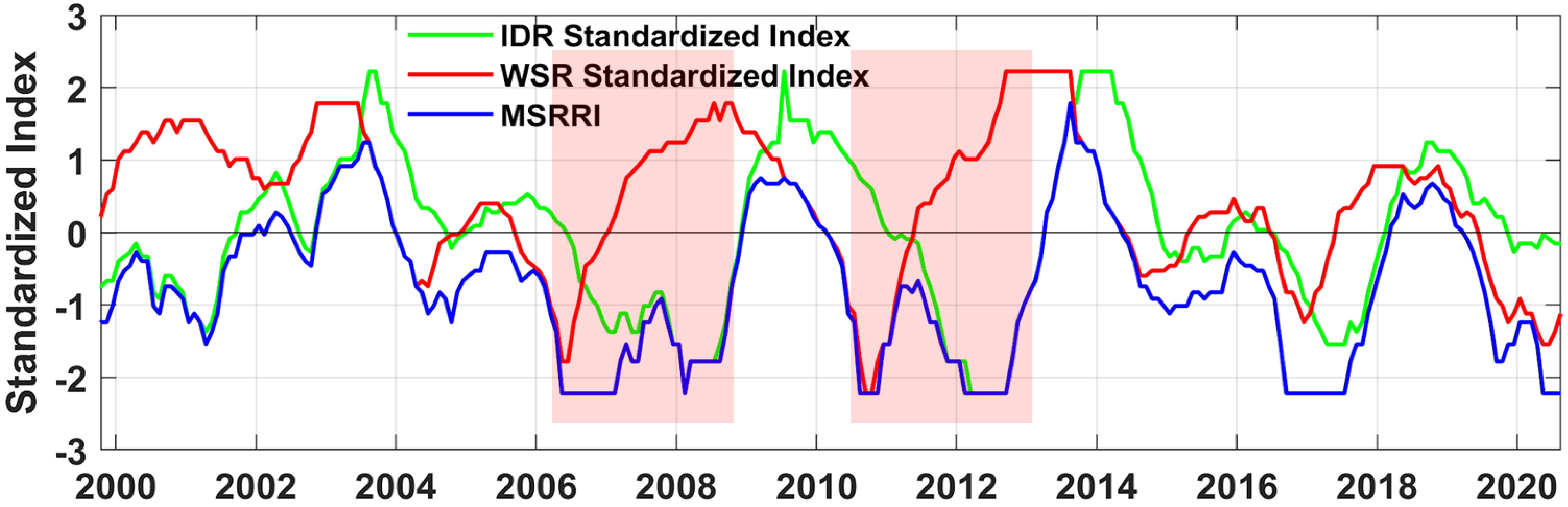


SPI vs. PDSI



SPI
Standardized Index
3
2
1
0
-1
-2
-3
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
D0
D1
D2
D3
D4
U.S. Drought Monitor

Multivariate Standardized Reliability and Resilience Index (MSRRI)



Federal, State Regulations vs. MSRRI

USACE Reservoir Management Planning

"Revised" IOP "RIOP" replaced IOP/EDO 2008

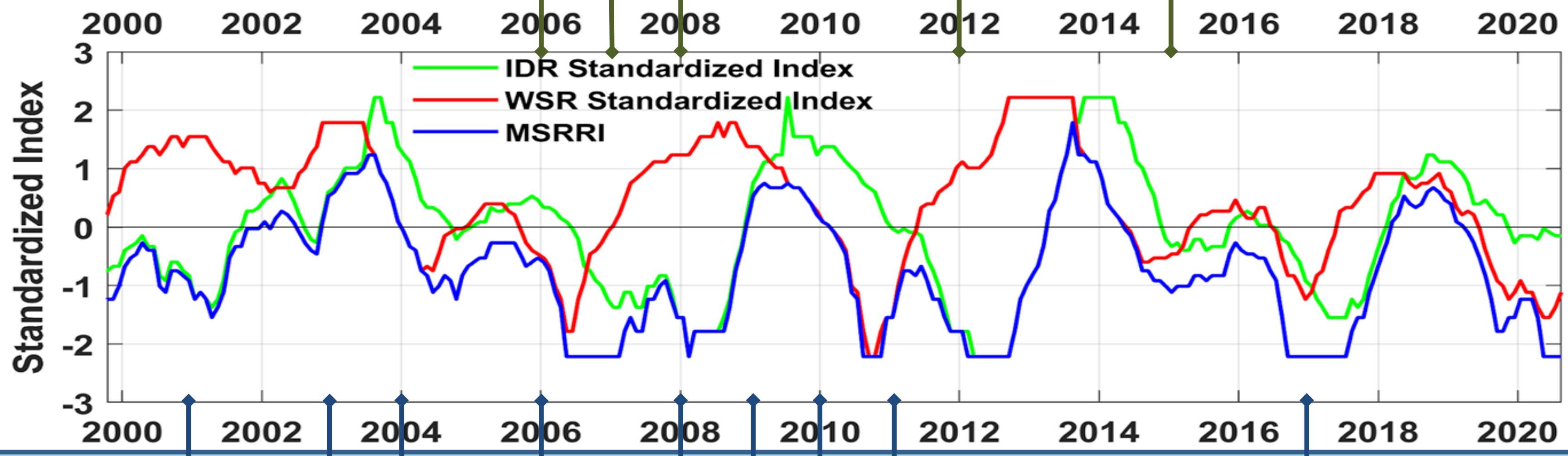
Exceptional Drought Operations ("EDO") 2007

Interim Operating Plan ("IOP") 2006

IOP "Concept 5"

New Revisions to the RIOP 2012

2015 Draft Environmental Impact Statement (DEIS)



Flint River Drought Protection Act 2001

Metro Water District 2003

Metropolitan North Georgia Water Planning Act

House Bill 579 - Agricultural Water Use (Metering) Program 2004

Georgia's Comprehensive State-wide Water Planning Act

Flint Basin Plan 2006

Georgia State Water Plan 2008

2009 All permitted irrigation withdrawals require metering

10 Regional Water Planning councils formed

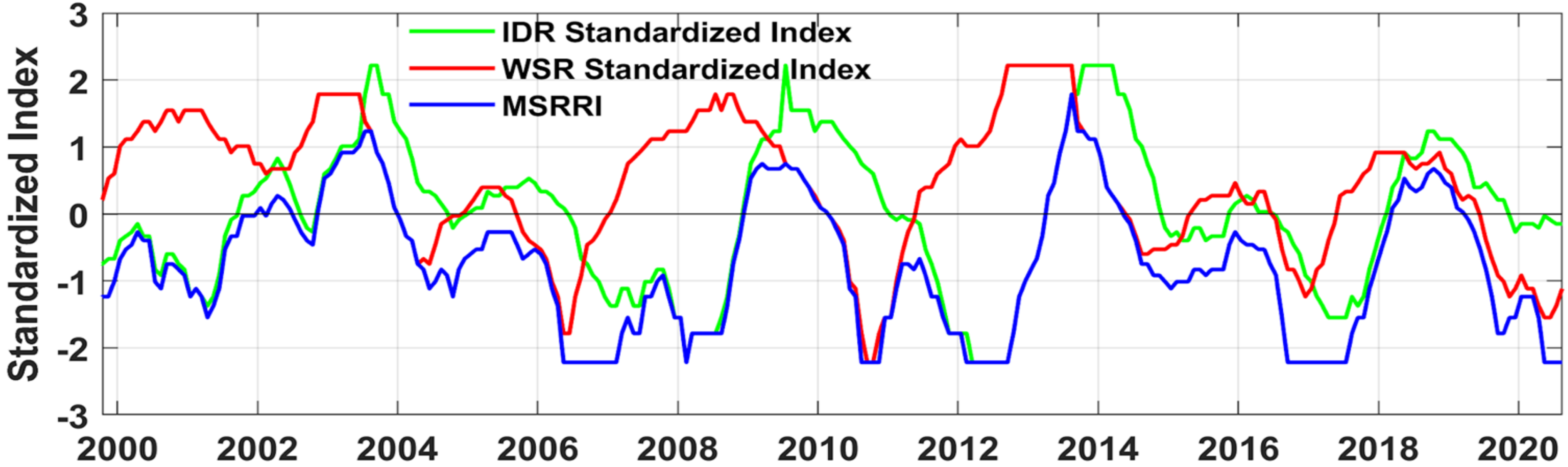
2010 Water Stewardship Act Passed

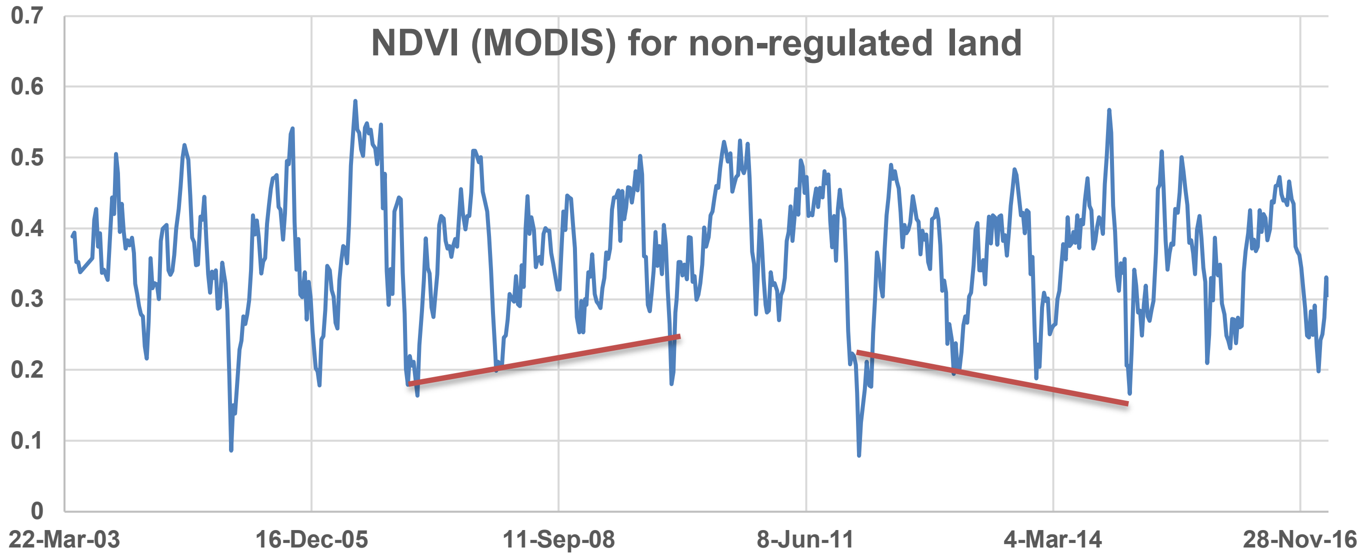
2011 Regional Water Management Plans Adopted

2017 Water Management Plans Revised for Georgia's State Water Plan and Metro Water District Plan

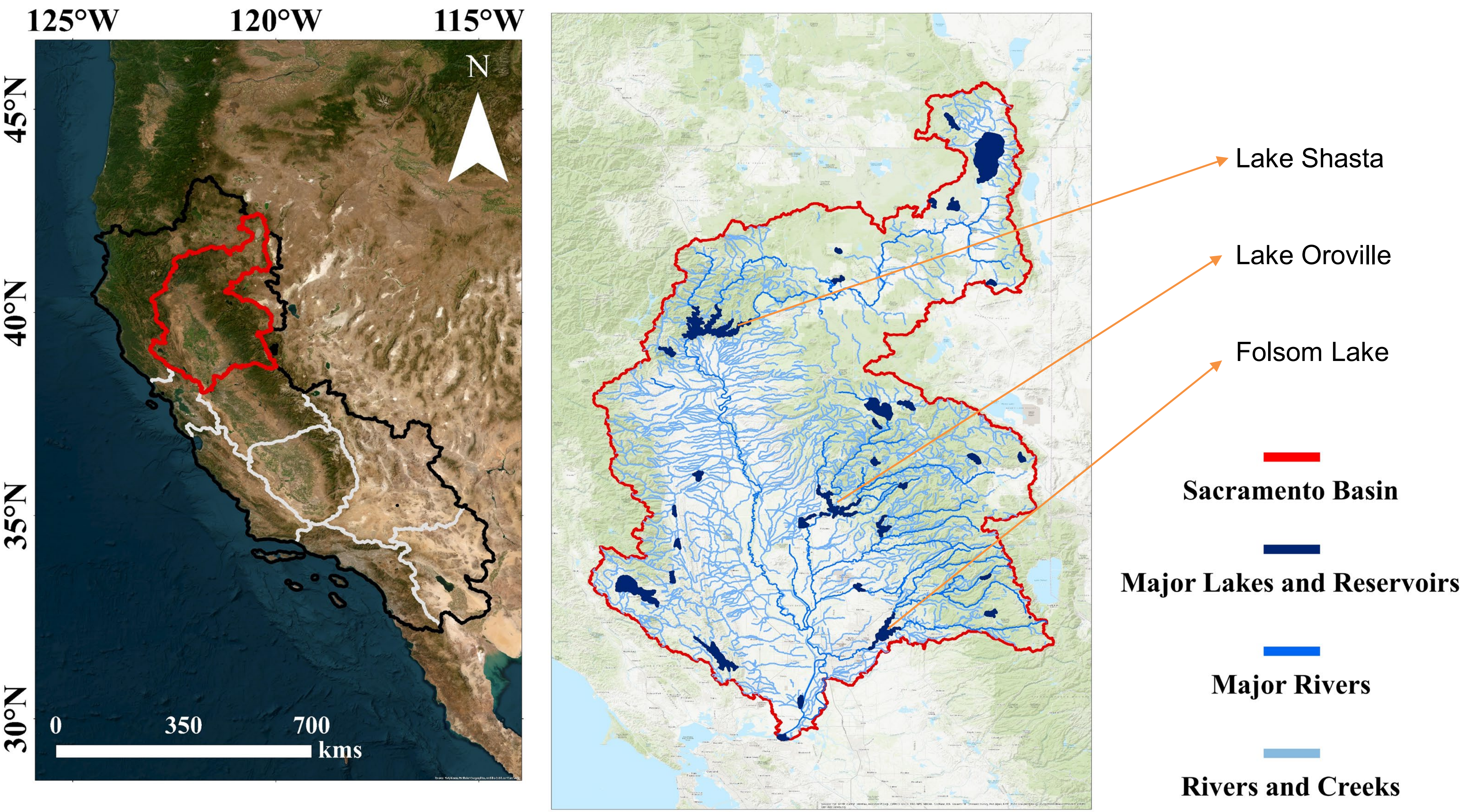
Georgia Water Management Planning Timeline

MSRRI Vs. NDVI

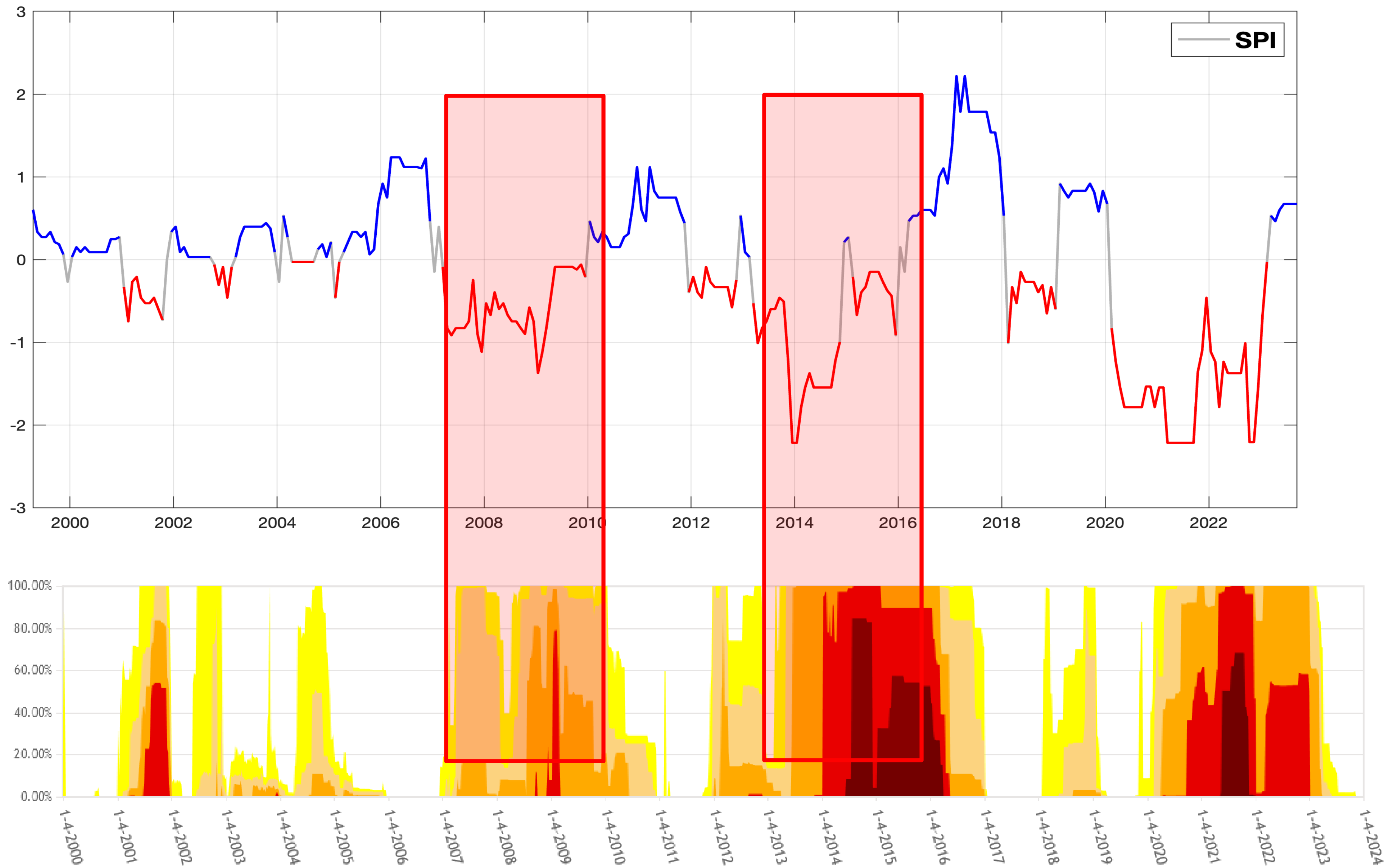




Sacramento basin



SPI vs. PDSI



SPI
3
2
1
0
-1
-2
-3
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
1-4-2000
1-4-2001
1-4-2002
1-4-2003
1-4-2004
1-4-2005
1-4-2006
1-4-2007
1-4-2008
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1-4-2011
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1-4-2013
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1-4-2016
1-4-2017
1-4-2018
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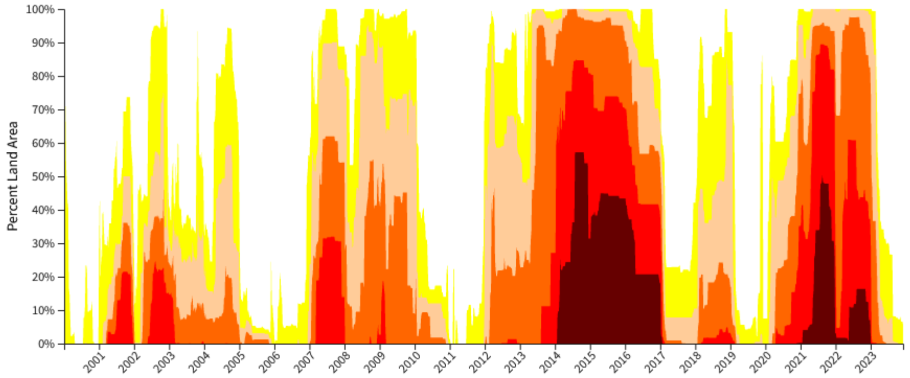
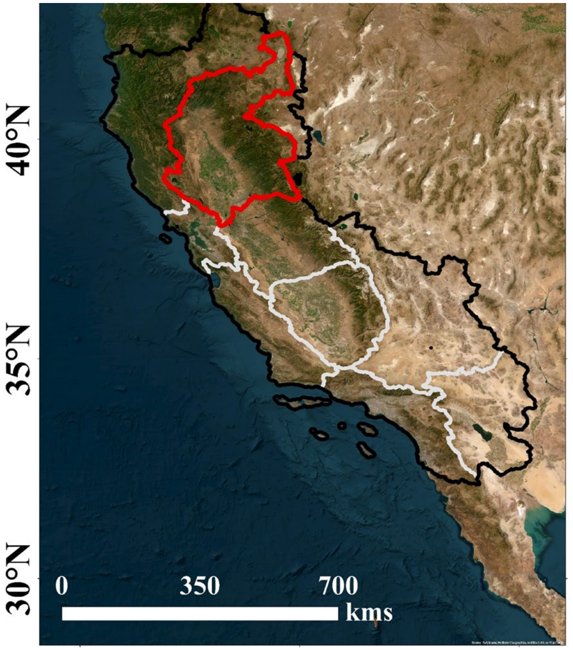
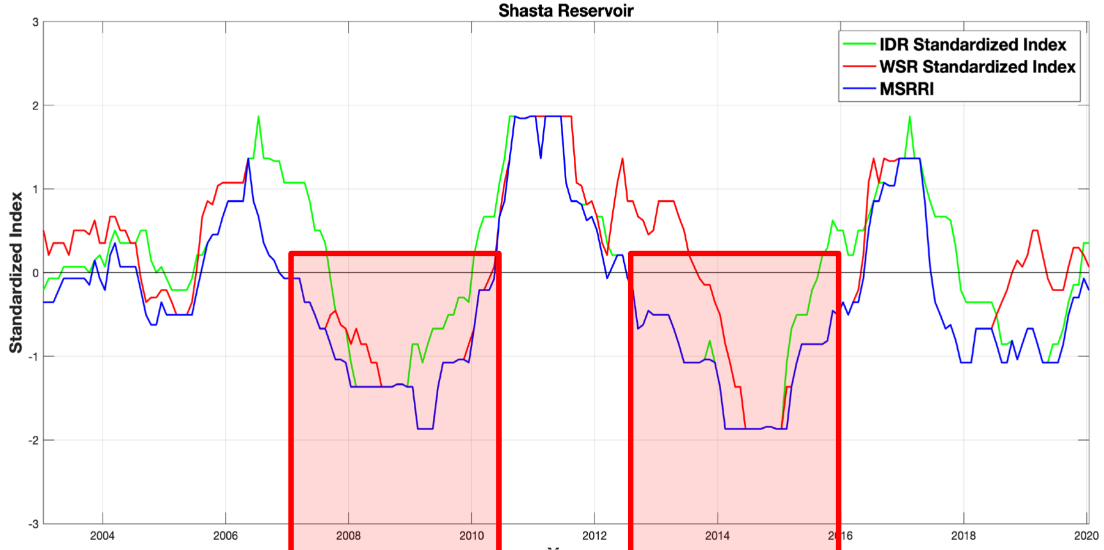
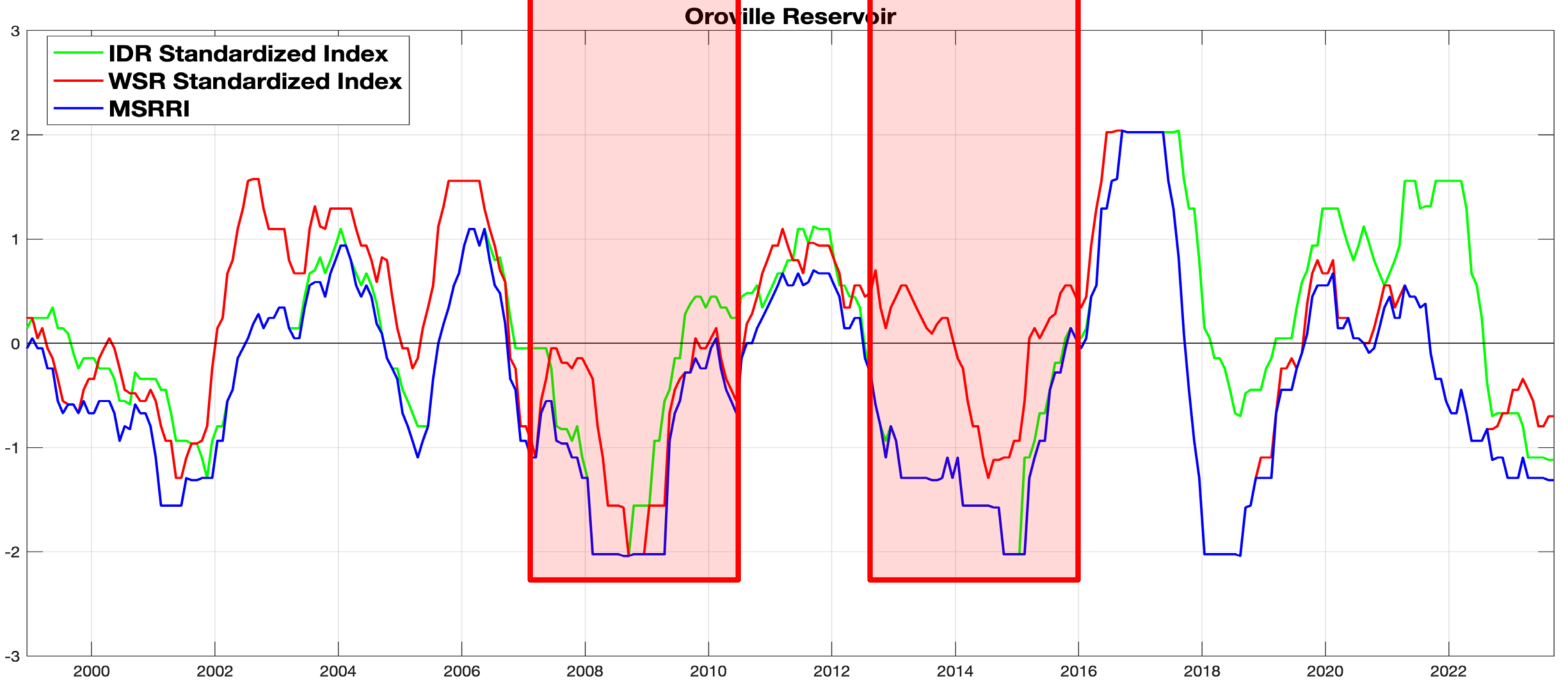
1-4-2022
1-4-2023
1-4-2024

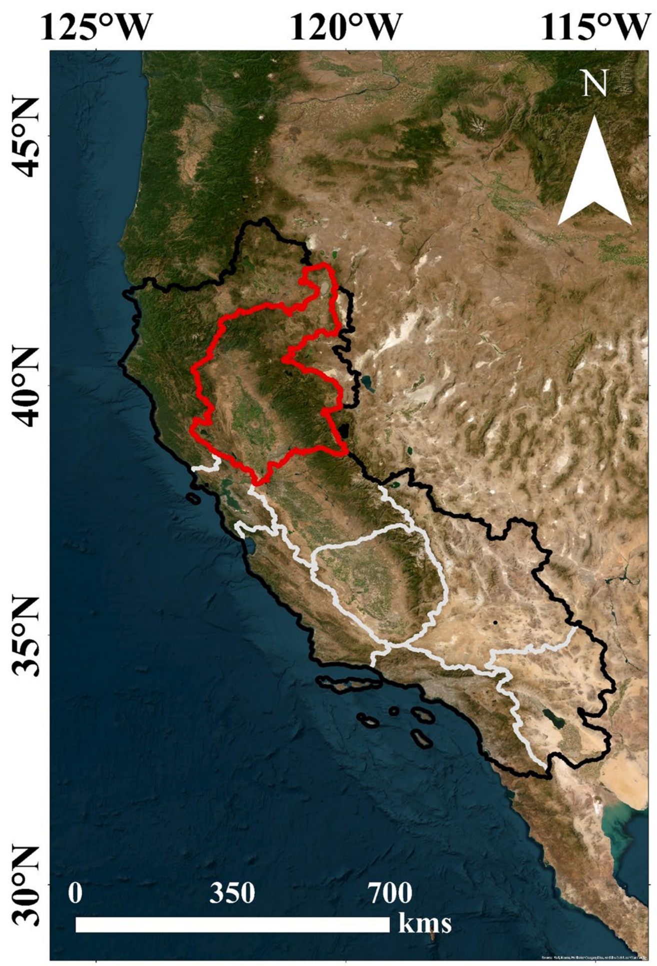
MSRRI on Major Reservoirs



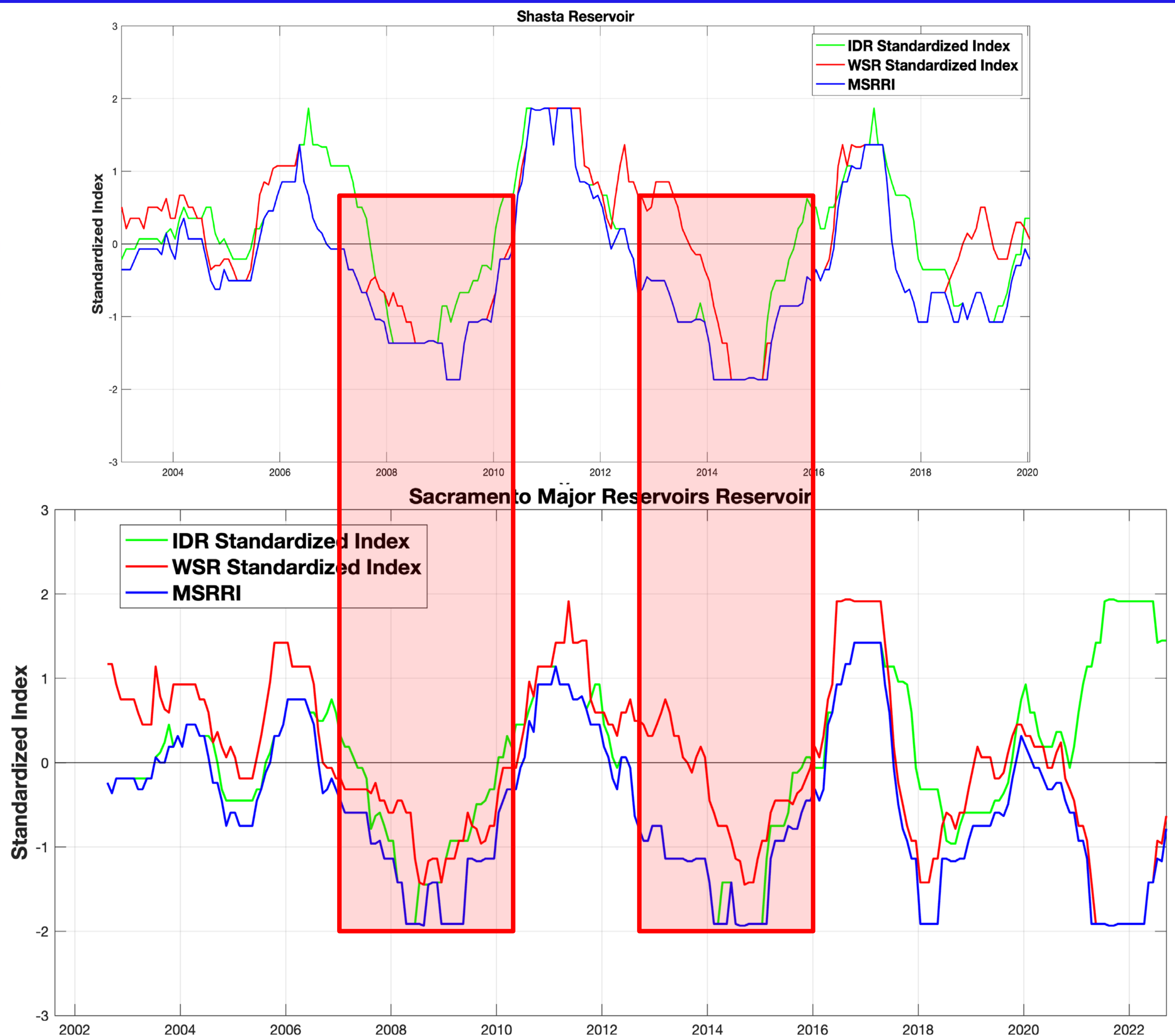








125°W
120°W
115°W
45°N
40°N
35°N
30°N
N
0
350
700
kms



Shasta Reservoir
IDR Standardized Index
WSR Standardized Index
MSRRI
Standardized Index
Sacramento Major Reservoirs Reservoir
IDR Standardized Index
WSR Standardized Index
MSRRI
Standardized Index

Questions?