Summary Presentation

Spokane River Low-Flow Trends

The Role of Changing Water Demands, Water Sources, and Watershed Conditions

Prepared for

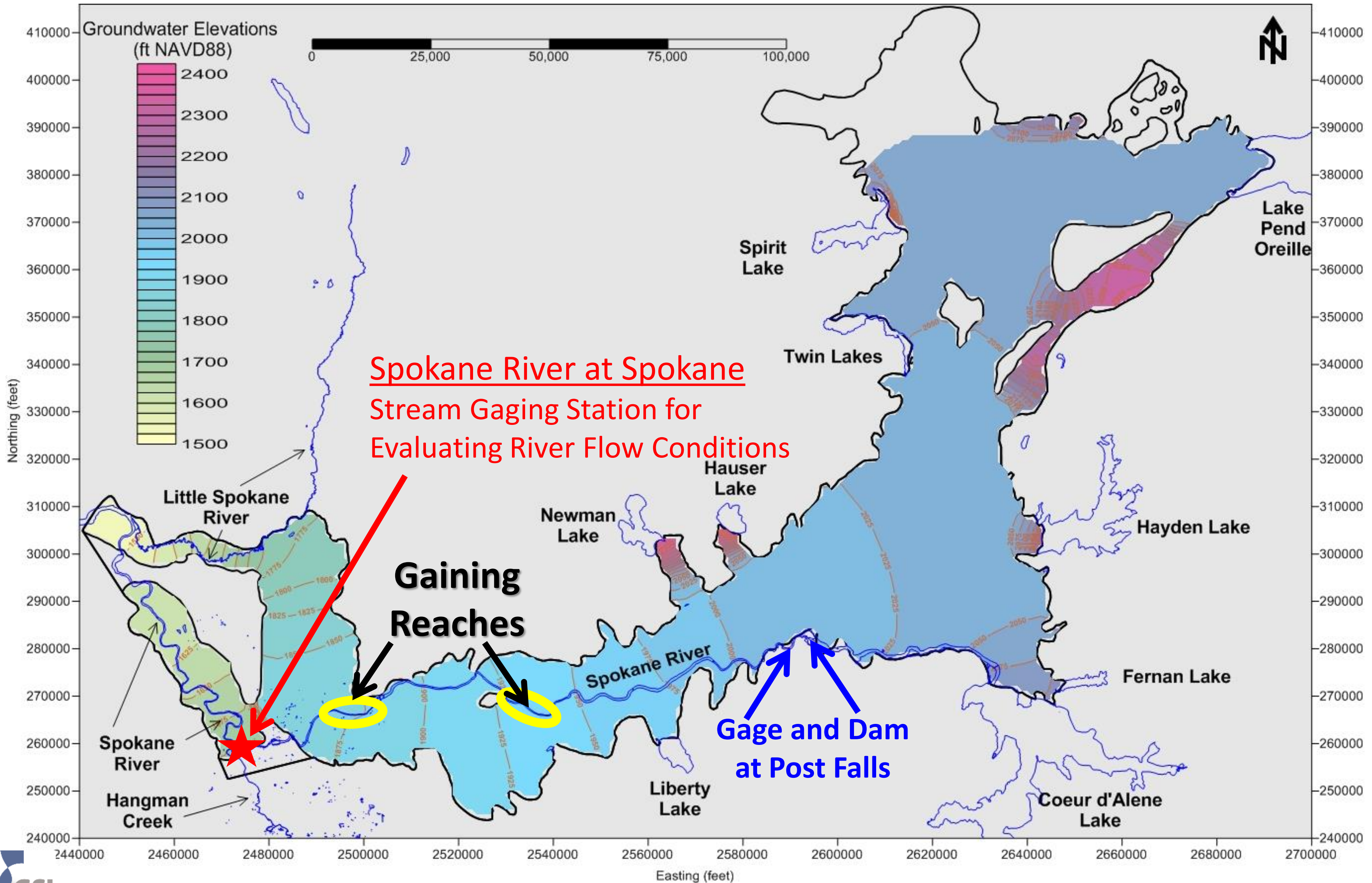
Spokane River Forum Conference

Prepared by

John Porcello, LHG and Jake Gorski, EIT
GSI Water Solutions

March 24, 2016

Groundwater Elevations and Gaining Reaches of the Spokane River



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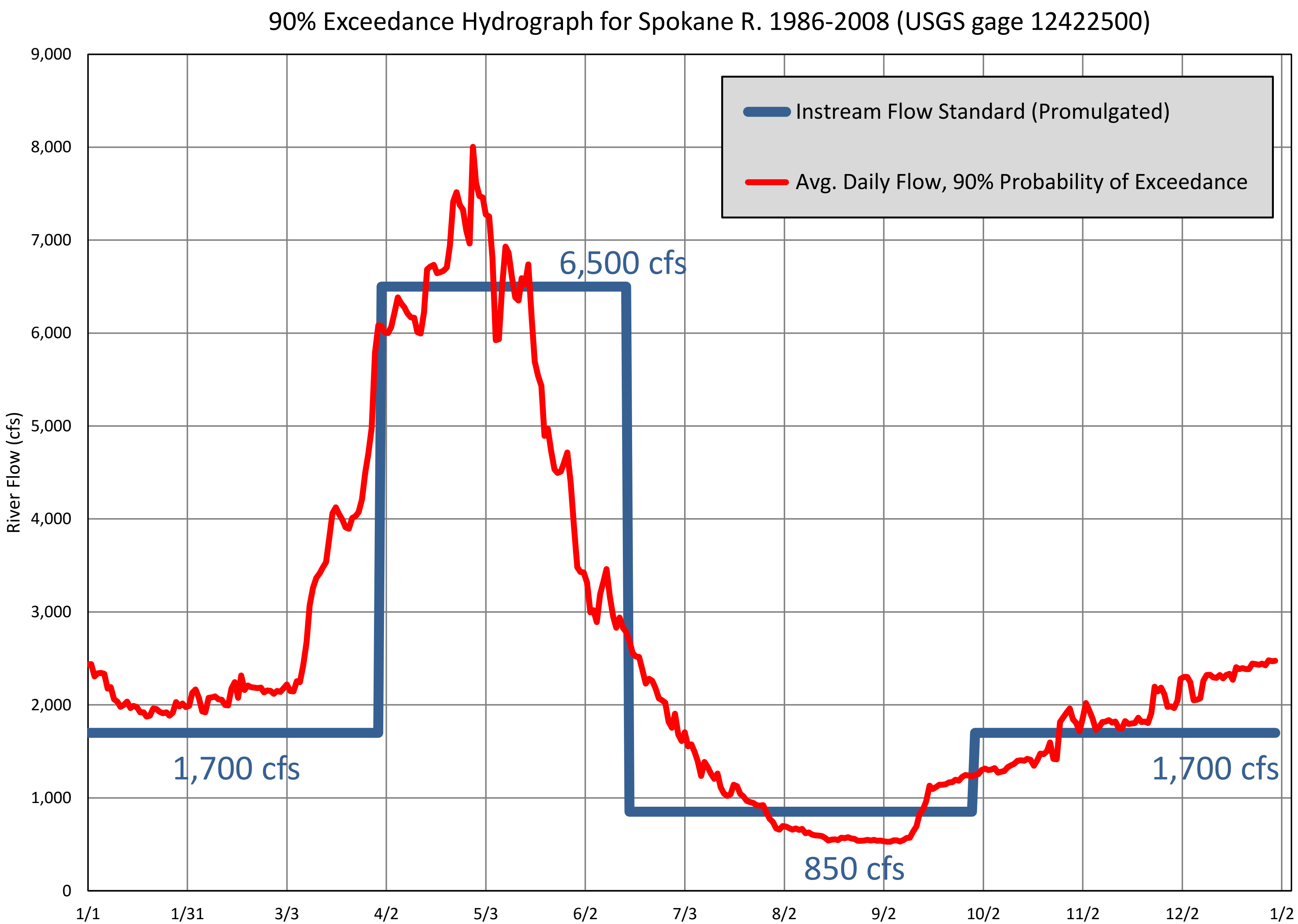

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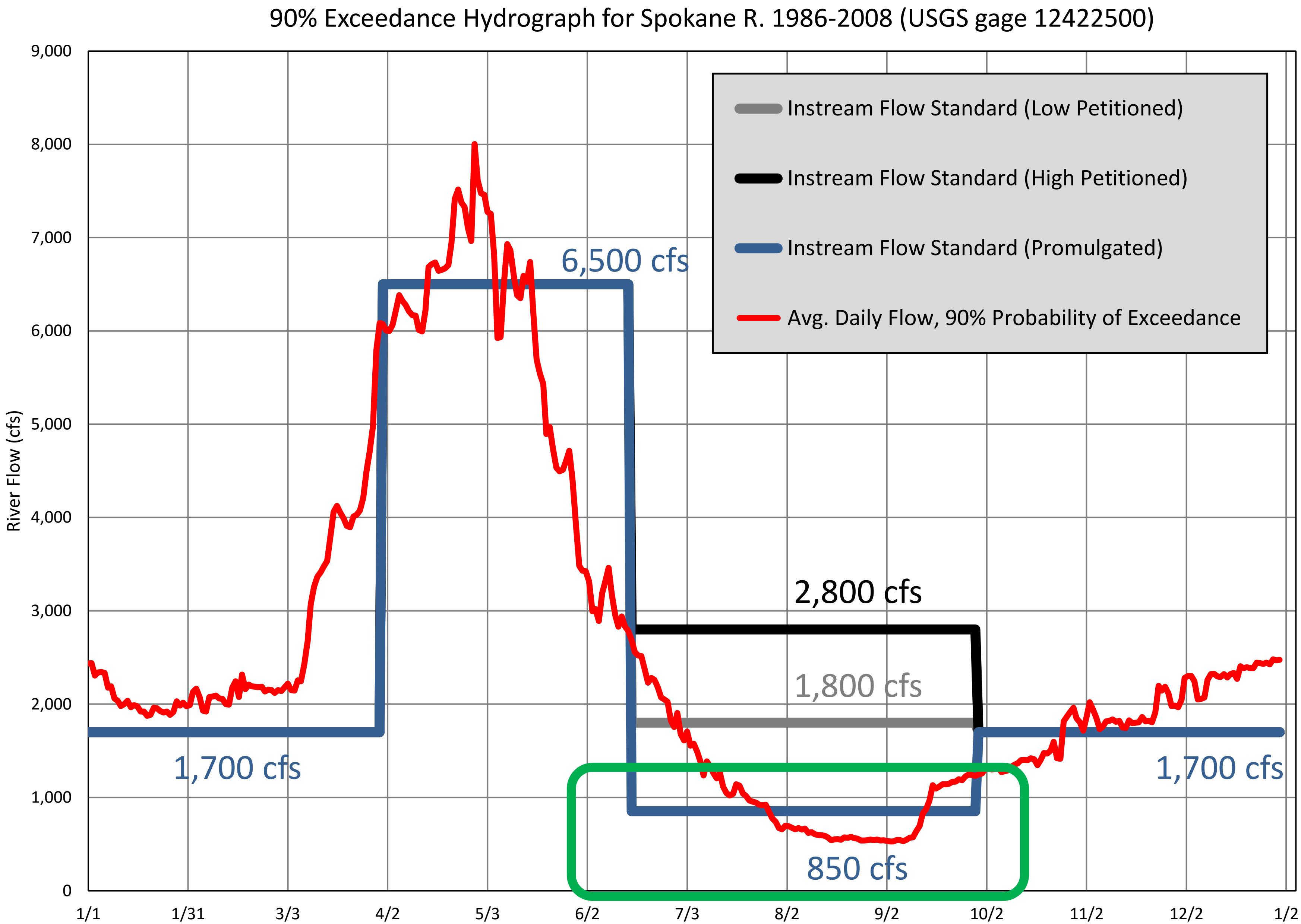

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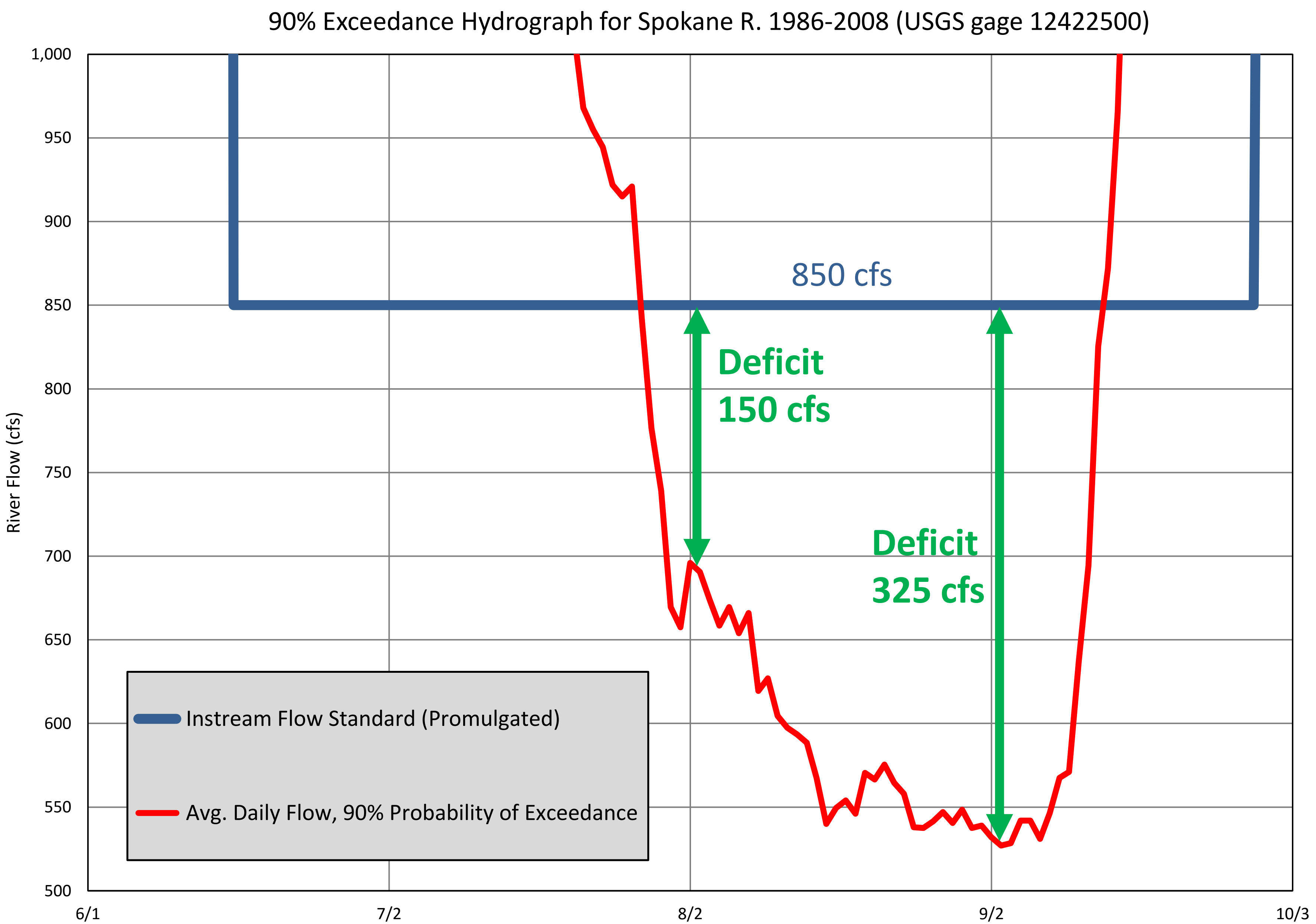

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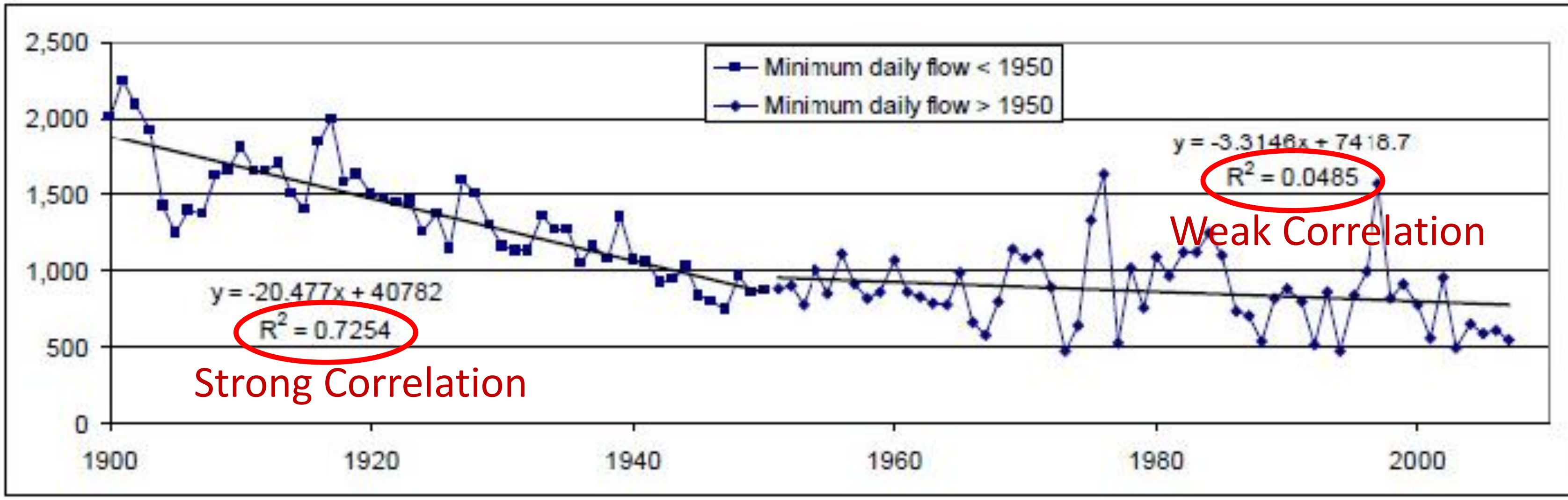
Trends in Seasonal Low Flows at the Spokane Gage Through 2007

(From Barber and others, 2011)



<u>This Plot Raises Several Questions</u>

Is the pre-1950 decline due to agricultural development, city growth, or both?

Why did the slope of the decline curve become so gentle after 1950?

Reduction in river water use?

Increased groundwater pumping?

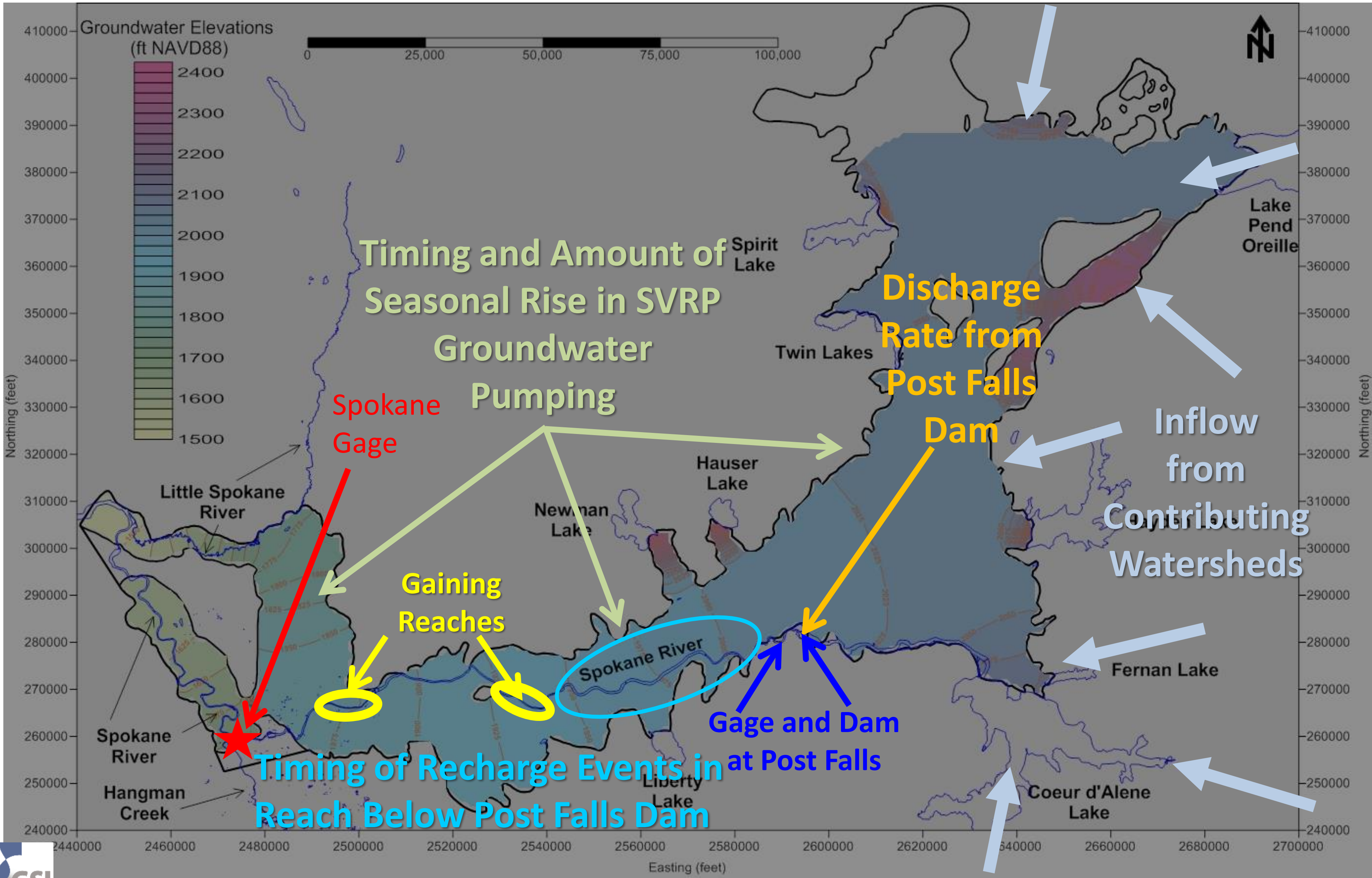
Change in type of consumptive water uses?

Other causes?

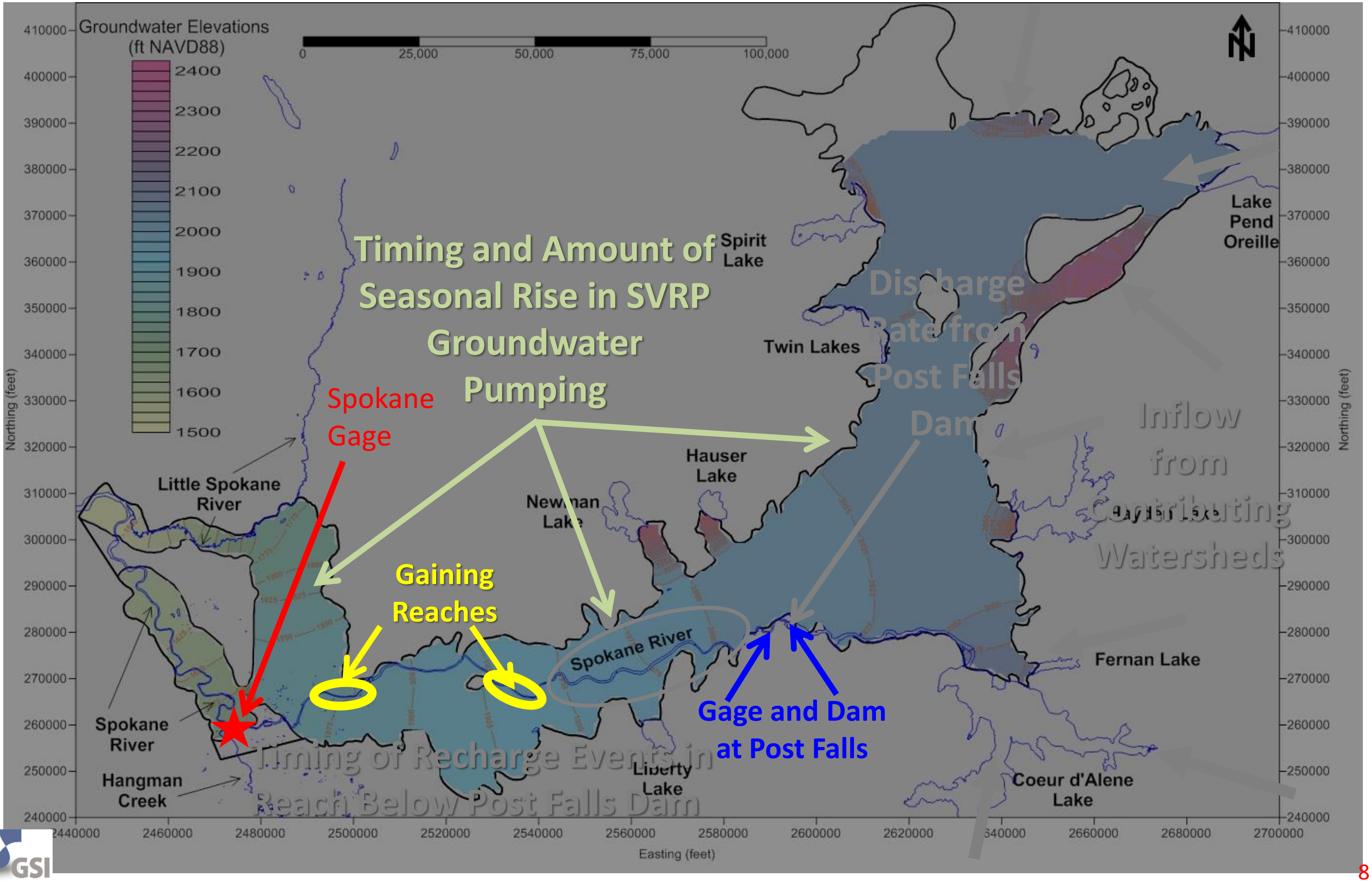
Stormwater management, wastewater return flows, releases from CDA Lake?

Something about the flow data itself?

Factors Controlling August Low Flows at the Spokane Gage



Role of Pumping on August Low Flows at the Spokane Gage



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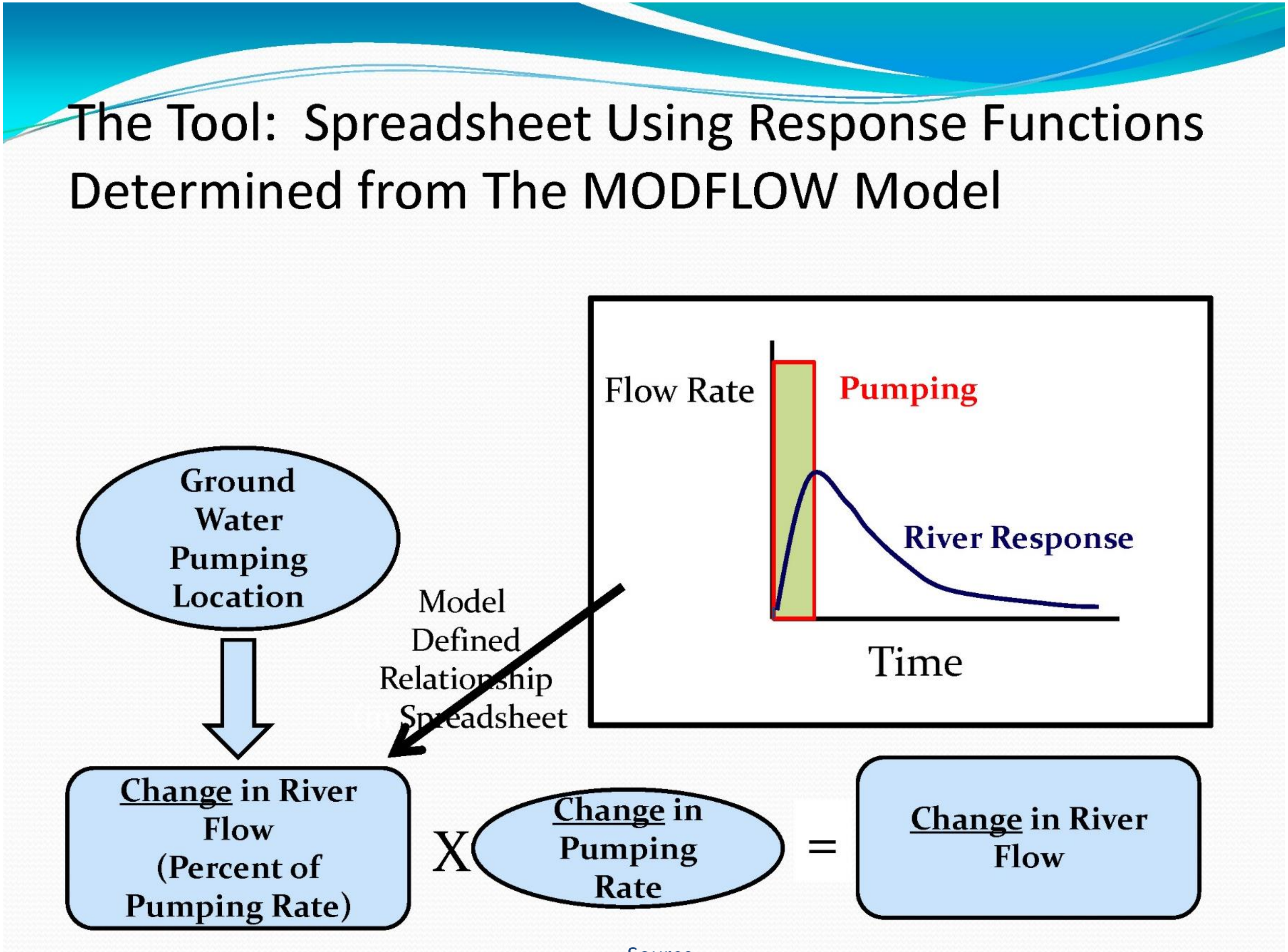
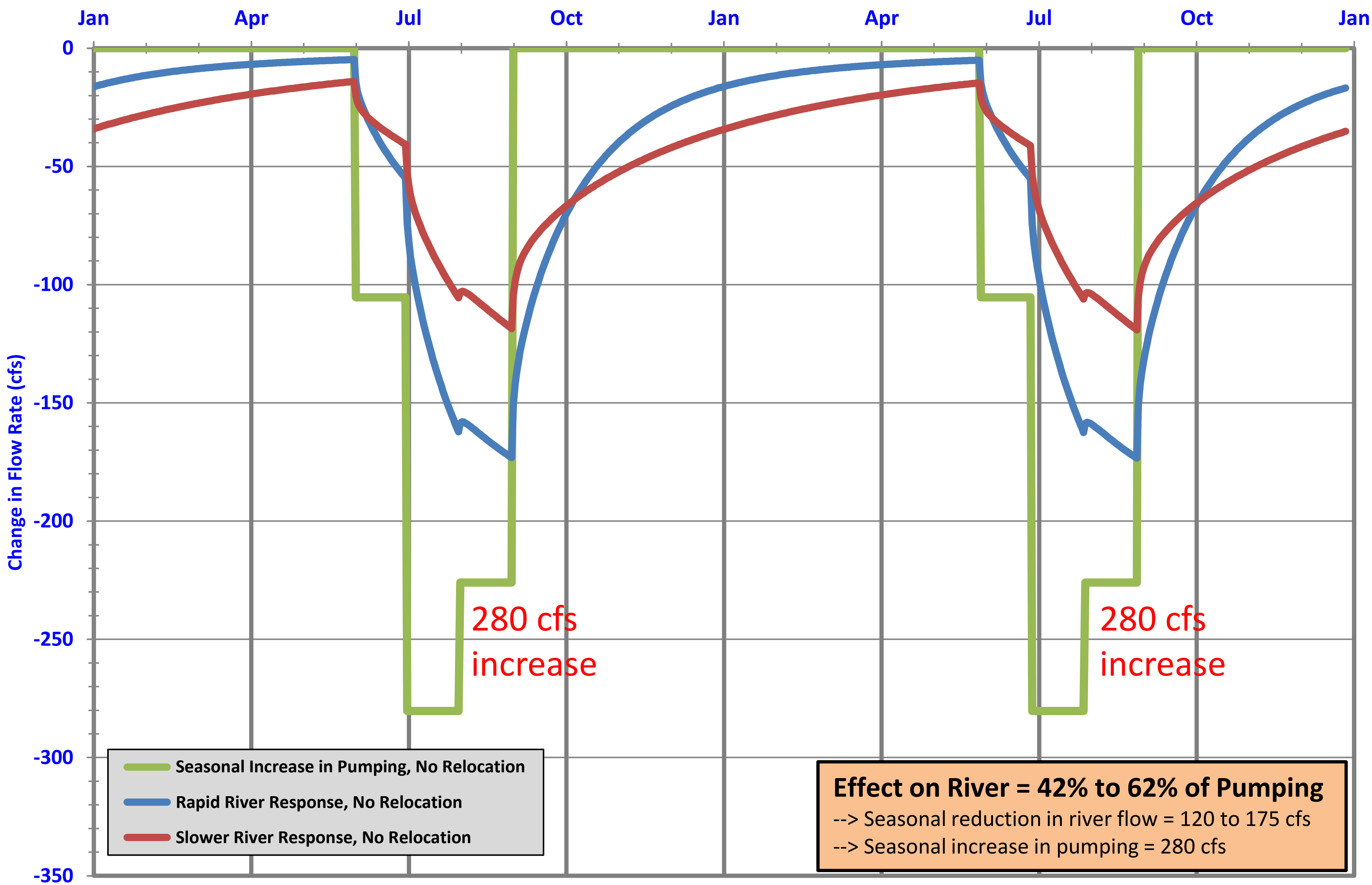
Idaho Study: Summer Pumping Effects



Source
SVRP Aquifer and the Spokane River Part 1 – How the System Works
Presentation by Ralston Hydrologic Services, April 14, 2015, Washington Hydrogeology Symposium (Tacoma, WA)

SAJB Study: Summer Pumping Effects

Modeled River Response to 2013 Seasonal Pumping (All SAJB Members)



Effects of Peak-Season Pumping

SAJB Member	SAJB Groundwater Pumping (cfs)			Effect of Peak-Season Pumping on River		
	Average	Peak Season	Peak Season minus Average	River Flow Reduction (cfs)	Reduction as % of Pumping: Min to Max	Reduction as % of Pumping: Average
MUNICIPAL PROVIDERS						
Irvin Water Dist.	1.17	3.71	2.53	2.1 to 2.4	83% to 95%	89%
Carnhope Irr. Dist.	0.76	1.76	0.99	0.5 to 0.8	50% to 81%	65%
Trentwood Irr. Dist.	3.09	7.11	4.02	2.2 to 2.9	55% to 72%	63%
City of Spokane	93.04	213.99	120.95	63 to 84	52% to 69%	61%
East Spokane Water Dist.	2.31	5.31	3.00	1.3 to 2.1	43% to 70%	57%
Orchard Irr. Dist.	4.36	10.04	5.67	2.3 to 3.9	41% to 69%	55%
Modern Electric Water Co.	4.72	17.68	12.97	5.0 to 8.8	39% to 68%	53%
Hutchinson Irr. Dist.	3.12	7.17	4.05	1.5 to 2.7	37% to 67%	52%
Pasadena Park Irr. Dist.	1.83	8.41	6.58	2.4 to 4.4	36% to 67%	52%
City of Millwood	8.20	17.18	8.98	3.2 to 6.0	36% to 67%	51%
Vera Water & Power	6.06	22.48	16.42	6.3 to 10.5	38% to 64%	51%
Model Irr. Dist.	3.37	7.76	4.38	1.4 to 2.8	32% to 64%	48%
Spokane Co. Water Dist. 3	8.47	27.67	19.20	6.0 to 10.8	31% to 56%	44%
Consolidated Irr. Dist.	15.74	47.63	31.90	8.6 to 14.1	27% to 44%	36%
North Spokane Irr. Dist.	1.16	2.67	1.51	0.3 to 0.6	20% to 40%	30%
Liberty Lake Sewer & Water Dist.	3.89	8.95	5.06	1.0 to 1.8	20% to 36%	28%
Whitworth Water Dist.	7.31	16.81	9.50	1.4 to 2.1	15% to 22%	18%
Moab Irr. Dist.	1.43	3.30	1.86	0.2 to 0.4	11% to 21%	16%
Total (municipal providers)	170.05	429.64	259.59	108.7 to 161.1	42% to 62%	52%
OTHER MEMBERS						
Total (others)	15.92	36.63	20.70	10.4 to 12.3	50% to 59%	55%
GRAND TOTAL	**185.97**	**466.26**	**280.29**	**119.1 to 173.4**	**42% to 62%**	**52%**

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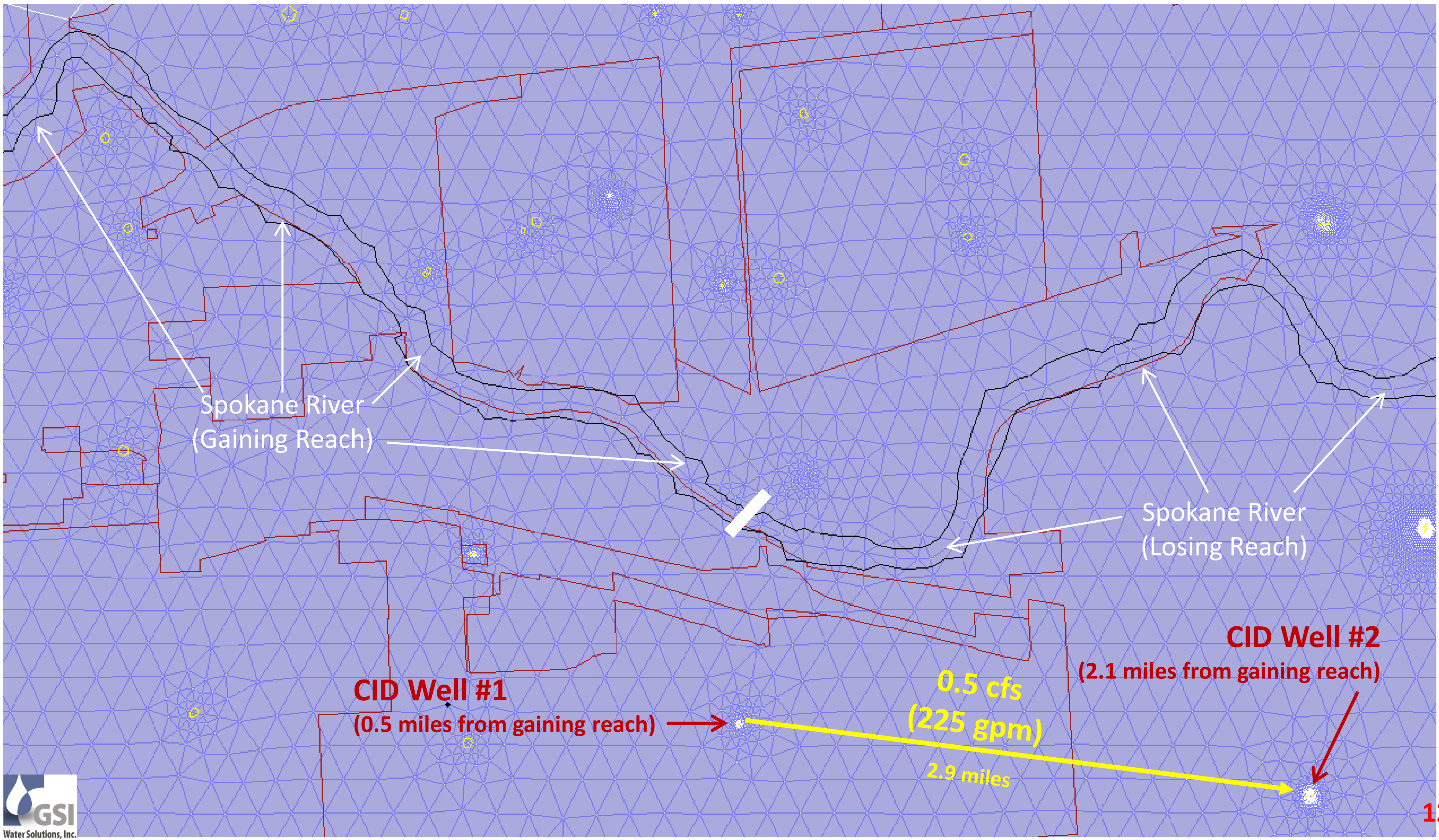
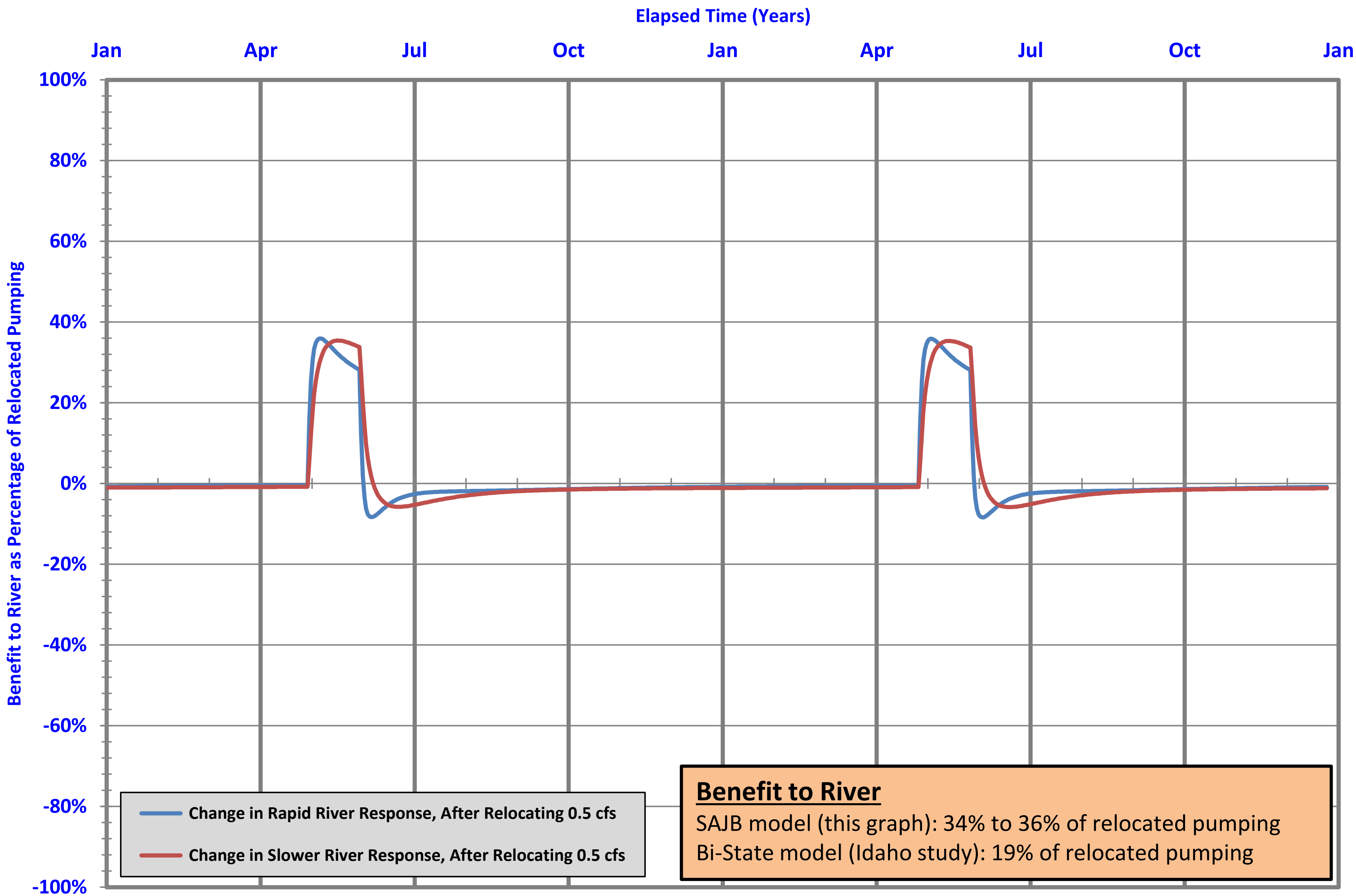
Consolidated Irrigation District

(Move From Well 1 To Well 2)

(Move 0.5 cfs = 10% Of May Pumping at Well 1)



Percent Change in Spokane River Response Relative to Seasonal Pumping Relocation - CID



Benefit to River

SAJB model (this graph): 34% to 36% of relocated pumping

Bi-State model (Idaho study): 19% of relocated pumping

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Conclusions from SAJB and Idaho Studies: Role of Groundwater Pumping

Summary

1. Groundwater pumping does influence river flows
2. But the effect on summer low flows is not 1-for-1
   - For each 1 cfs increment of 3-month summer pumping, river flows during the late summer decrease by:
     - **Washington:** generally 1/3 to 2/3 cfs in and near City of Spokane, less in Spokane Valley and near state line
     - **Idaho:** Even lower influence (far from the river's gaining reaches)

This Raises Two Important Questions

Is the aquifer showing sustained declines in groundwater levels?

What has happened to groundwater pumping and uses over time?

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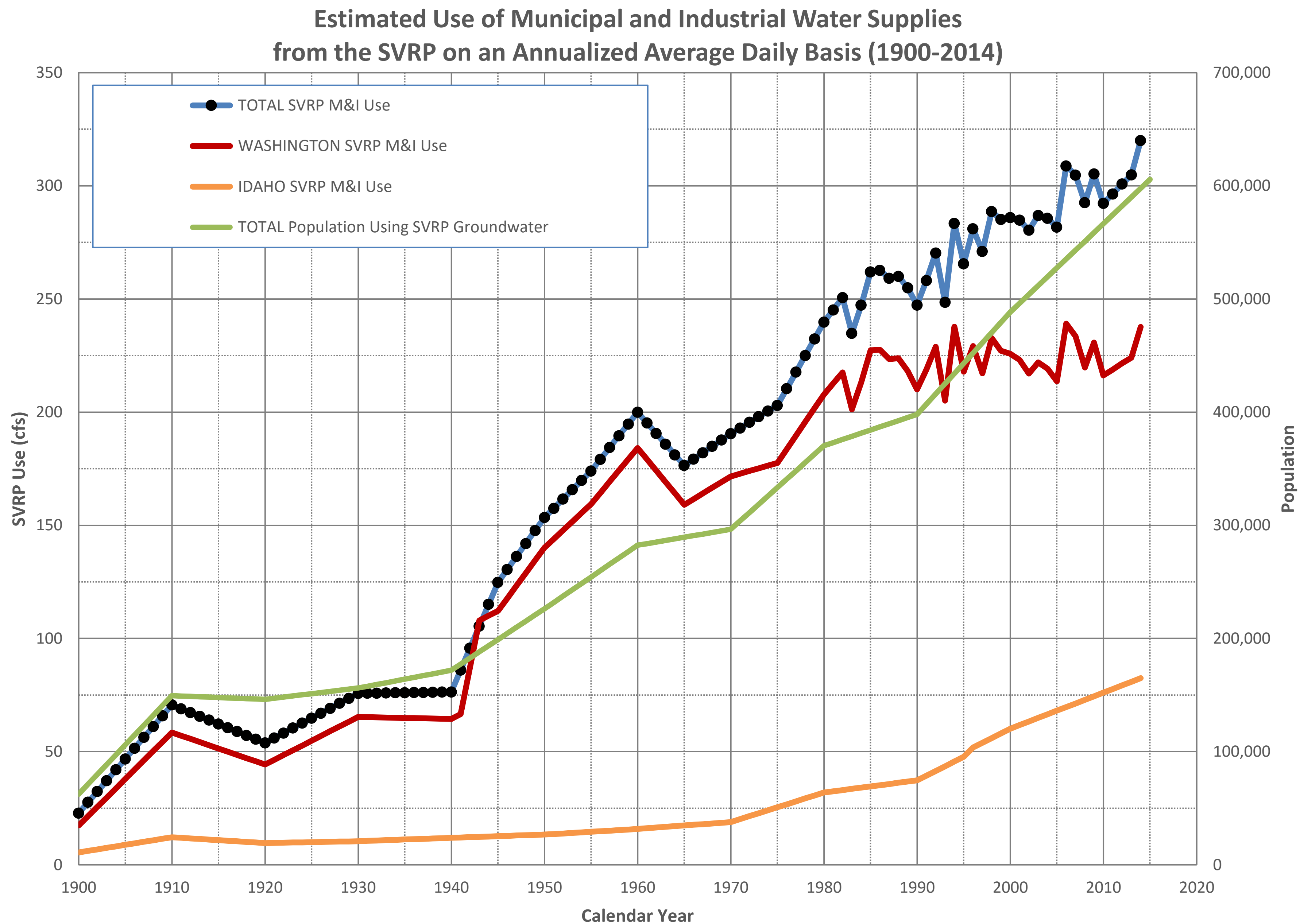

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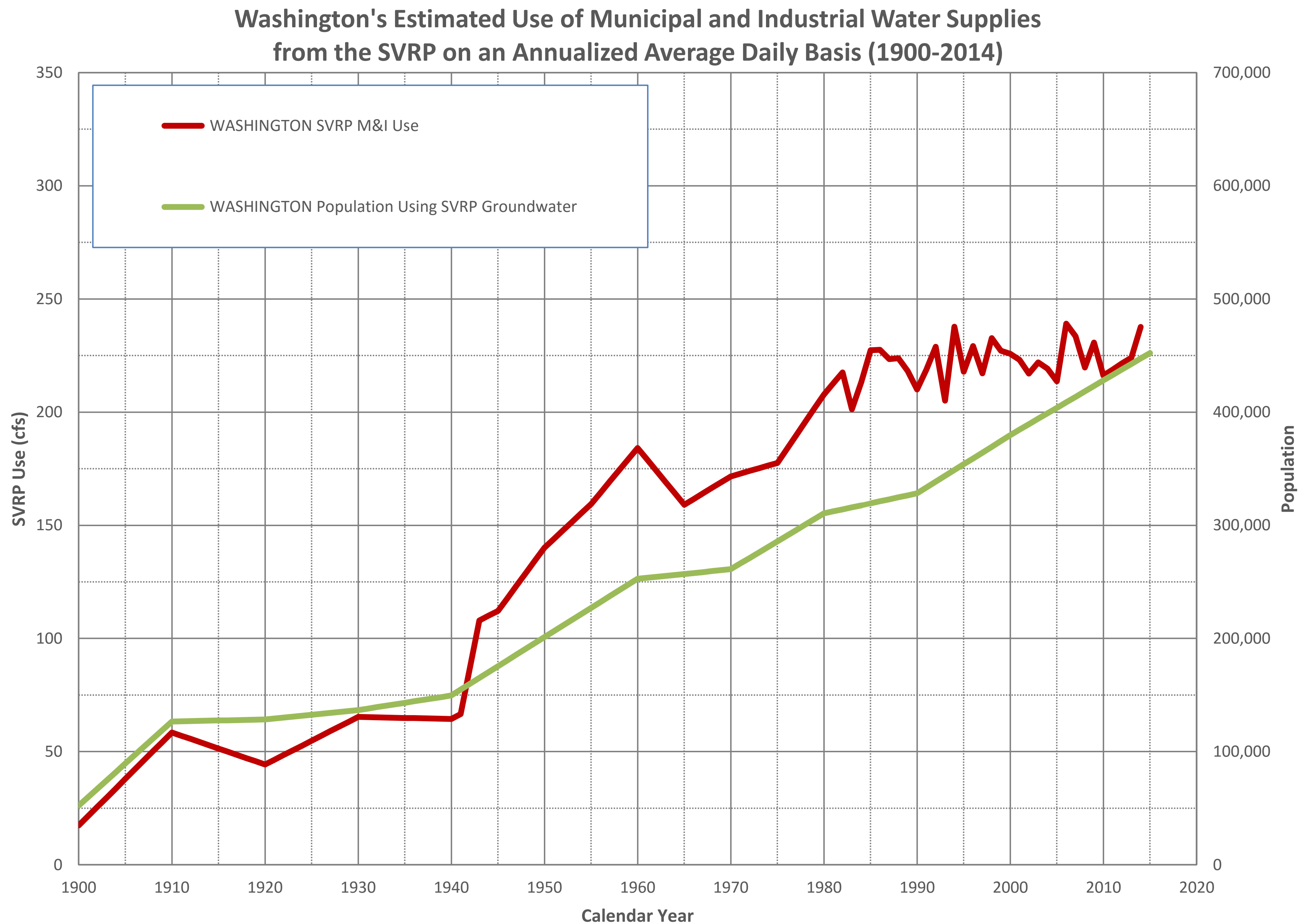

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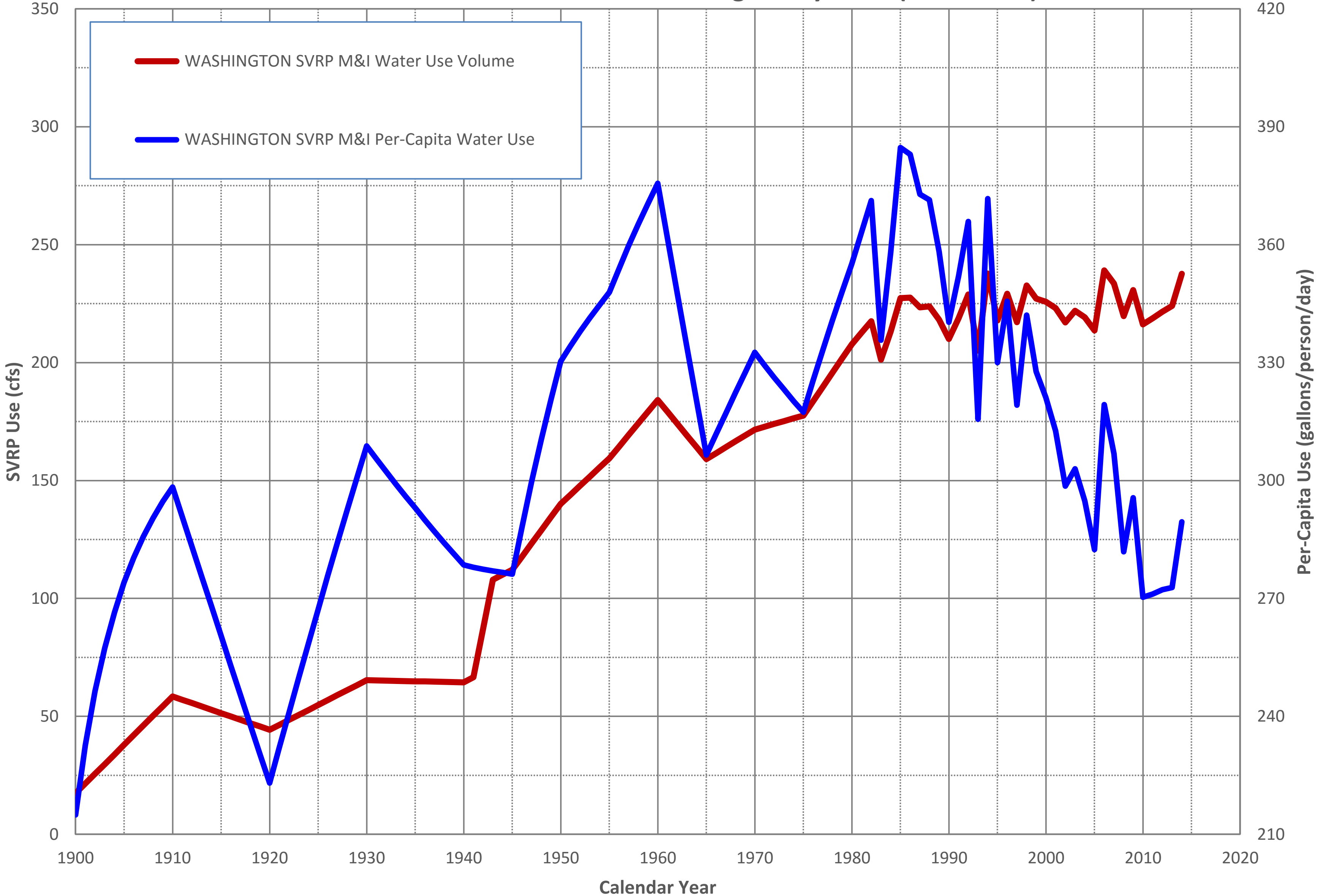
Washington's Estimated Per-Capita Use of Municipal and Industrial Water Supplies from the SVRP on an Annualized Average Daily Basis (1900-2014)



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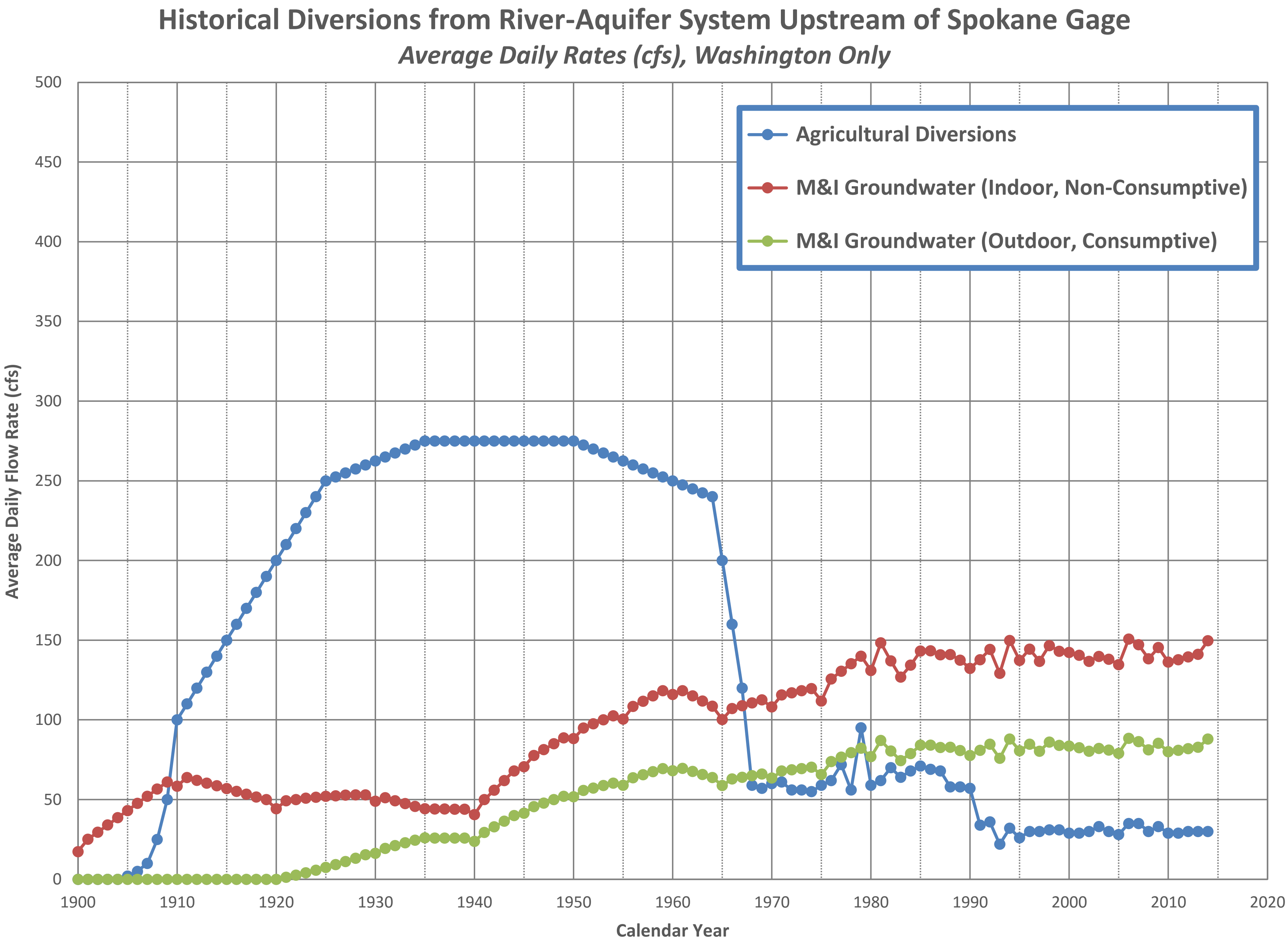

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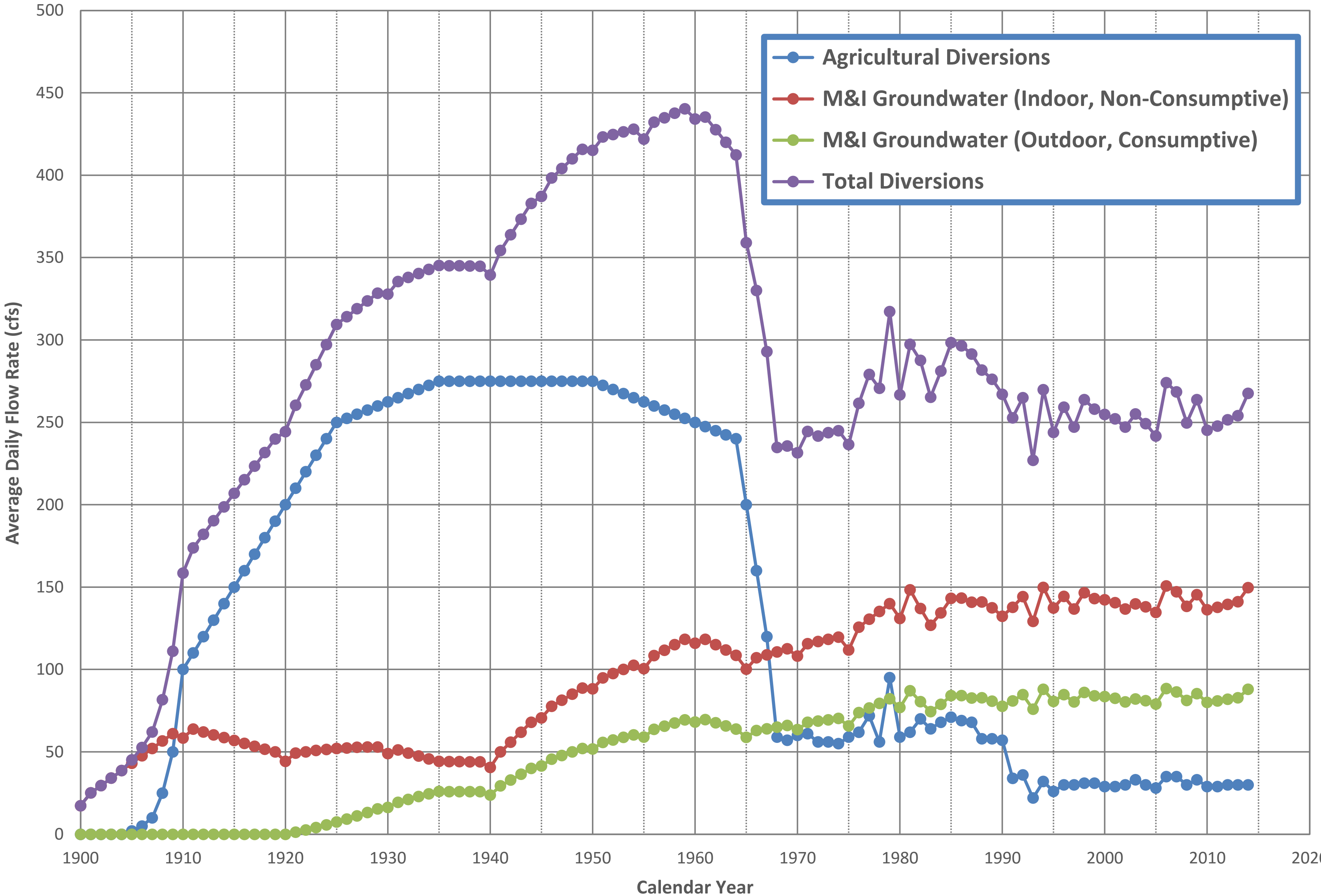
Historical Diversions from River-Aquifer System Upstream of Spokane Gage

Average Daily Rates (cfs), Washington Only



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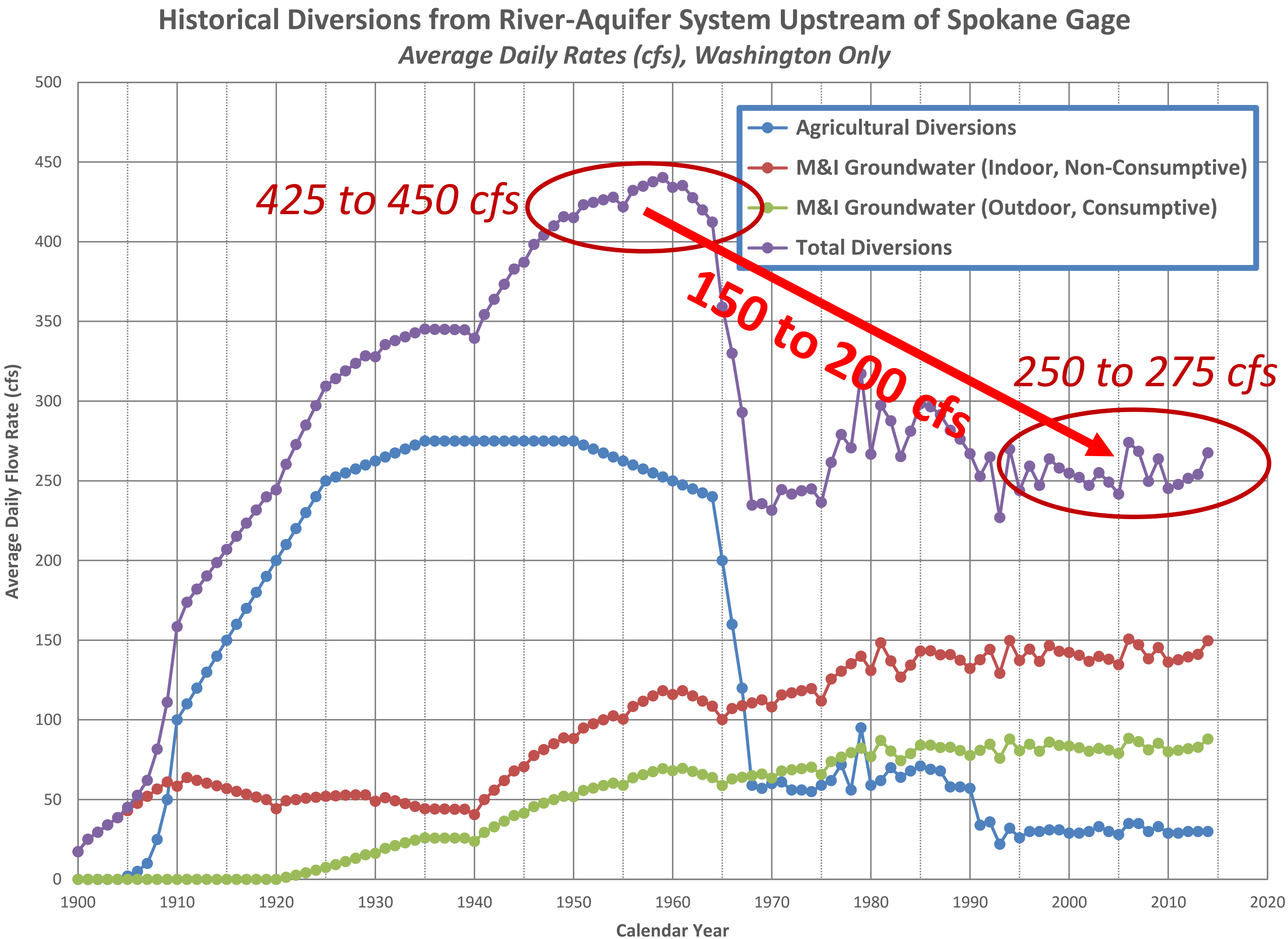

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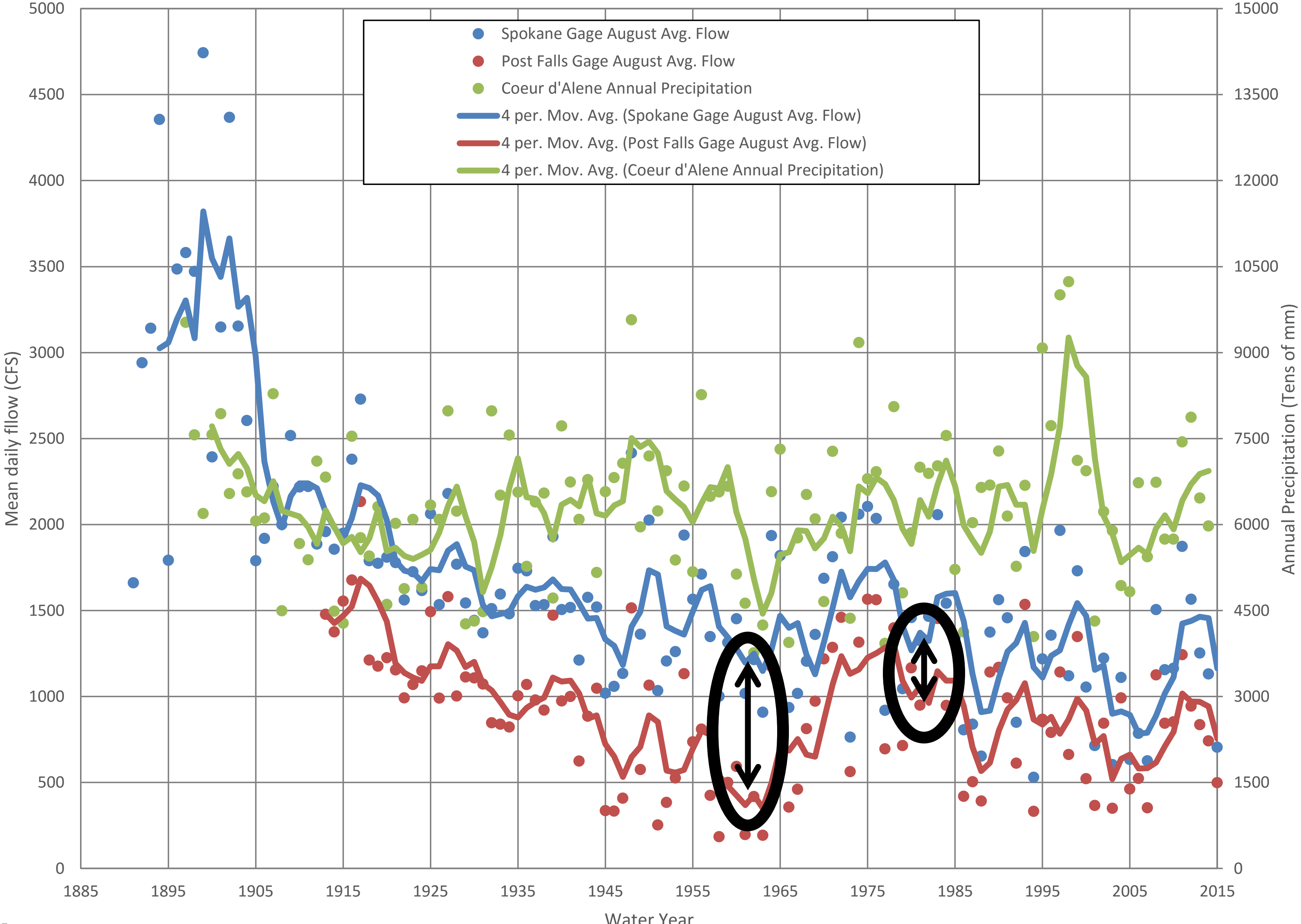
River Flow and Watershed Changes Since Late 1800s

Gaged Flows, Precipitation, Lake Stage, City Return Flows



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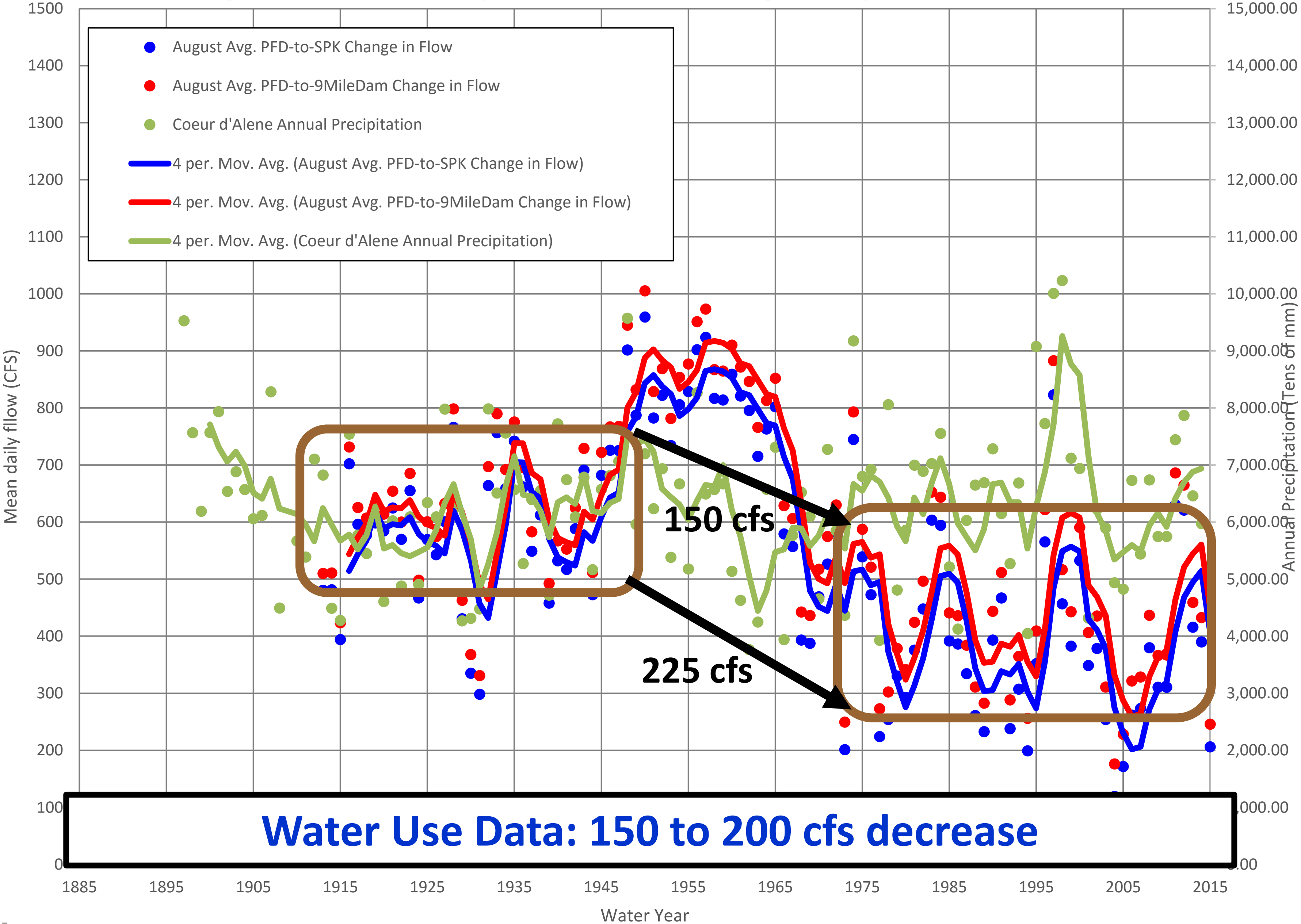
Surface Water Hydrology, 1910-1950 vs. 1980-2015

Gaged Flows, Precipitation, Lake Stage, City Return Flows



Water Use Data: 150 to 200 cfs decrease

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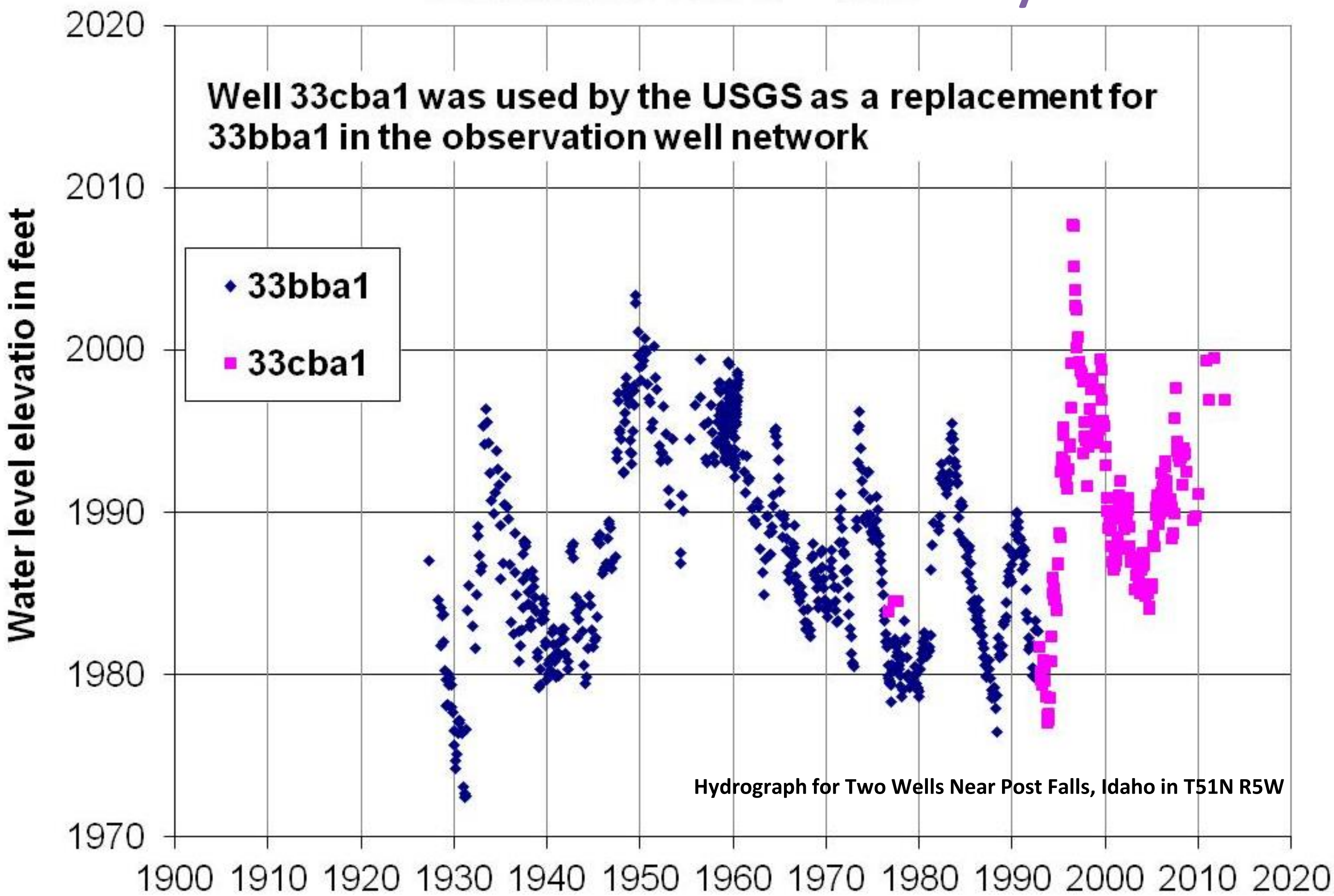
Groundwater Elevations Appear to be Rising Near Post Falls After the Early 1990s

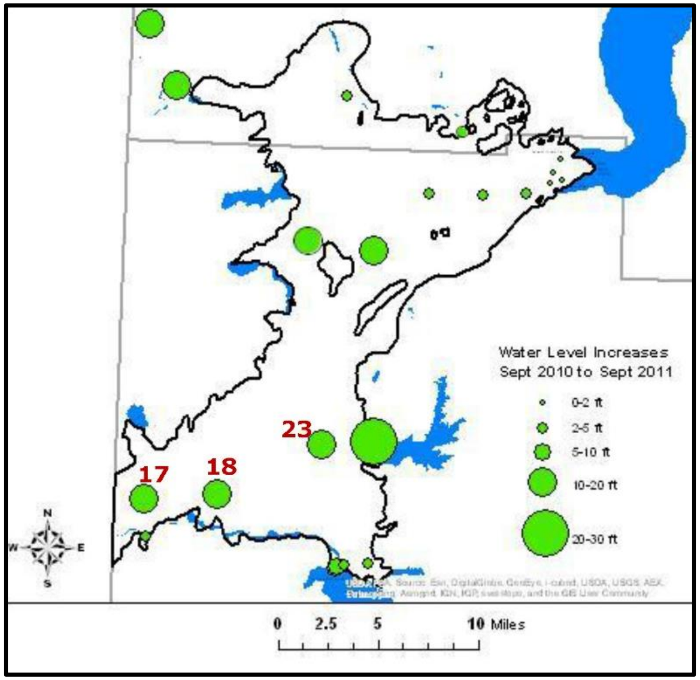


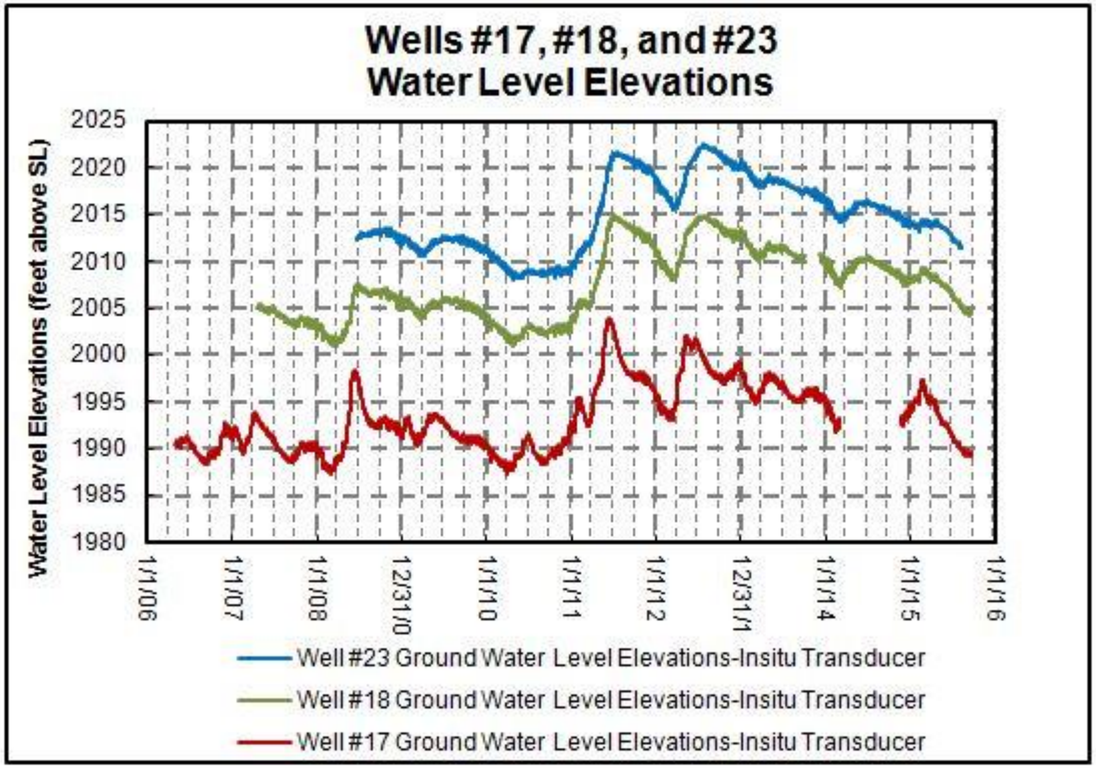
Source of Plot

Hydrogeology: Ground Water Pumping and River Flows, Part 1

Presentation by Ralston Hydrologic Services, Spokane River Forum, November 19, 2014

Groundwater Elevations in Rathdrum Prairie (2006-2015)





Source
Kenneth Neely, Idaho Department of Water Resources, February 2016

Which Hydrologic Processes Are Causing the Continued Decline in River Low Flows?

Processes Within the River-Aquifer System	Processes Upstream of the River-Aquifer System
Past agricultural diversions from river *(direct diversions, little return flow)* *(high consumptive use)*	Water level management at CDA Lake (indirectly)
Groundwater use - Washington (no) - Idaho (minor)	Watershed climate and runoff *(volumes and timing of flows into CDA Lake)*
Diversion of water around Spokane Gage (minor)	River water temperature *(riverbed seepage rates east of Spokane)*
Effect of increased urbanization on fate of stormwater *(less recharge, more evapotranspiration)*	

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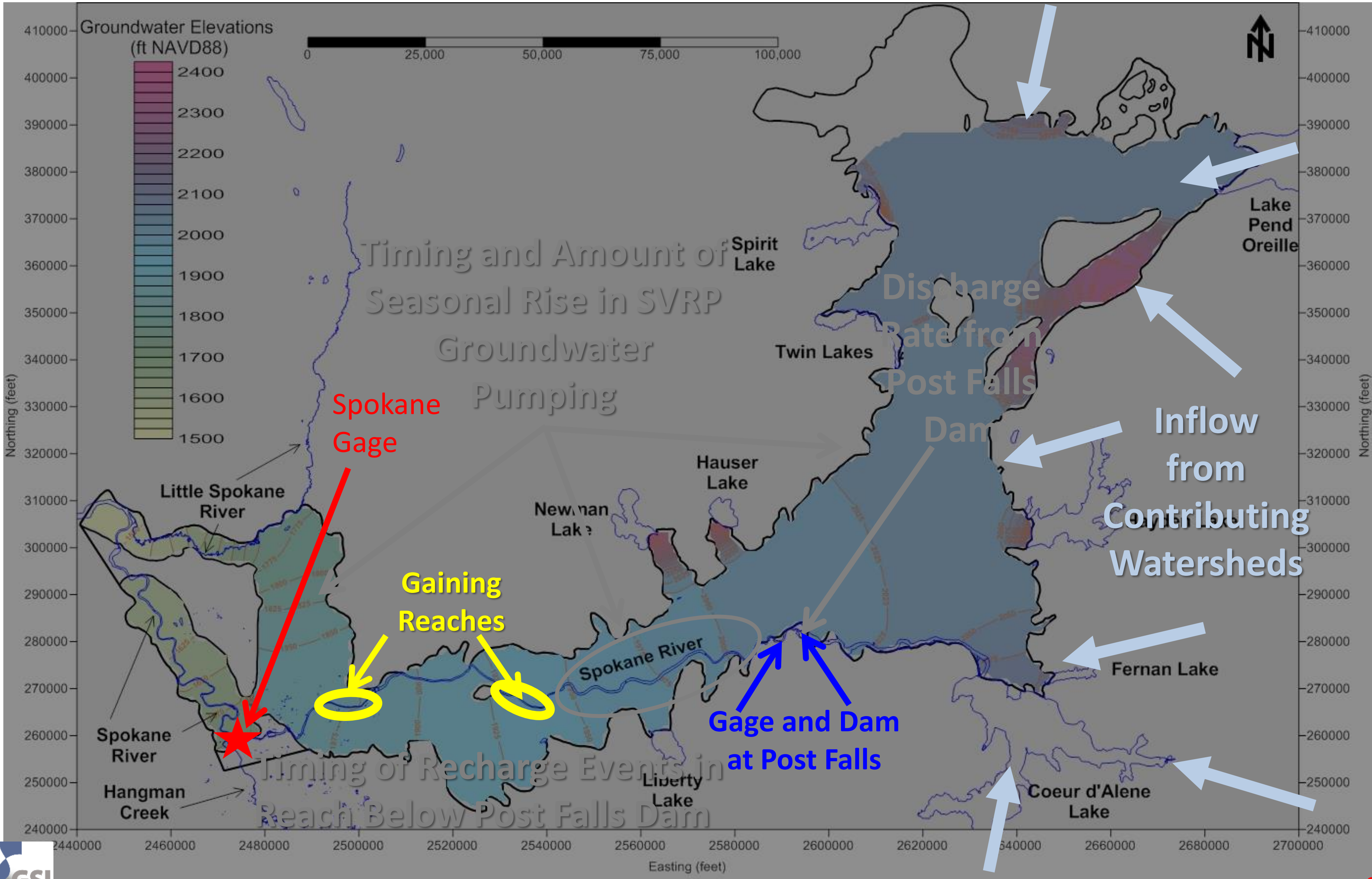
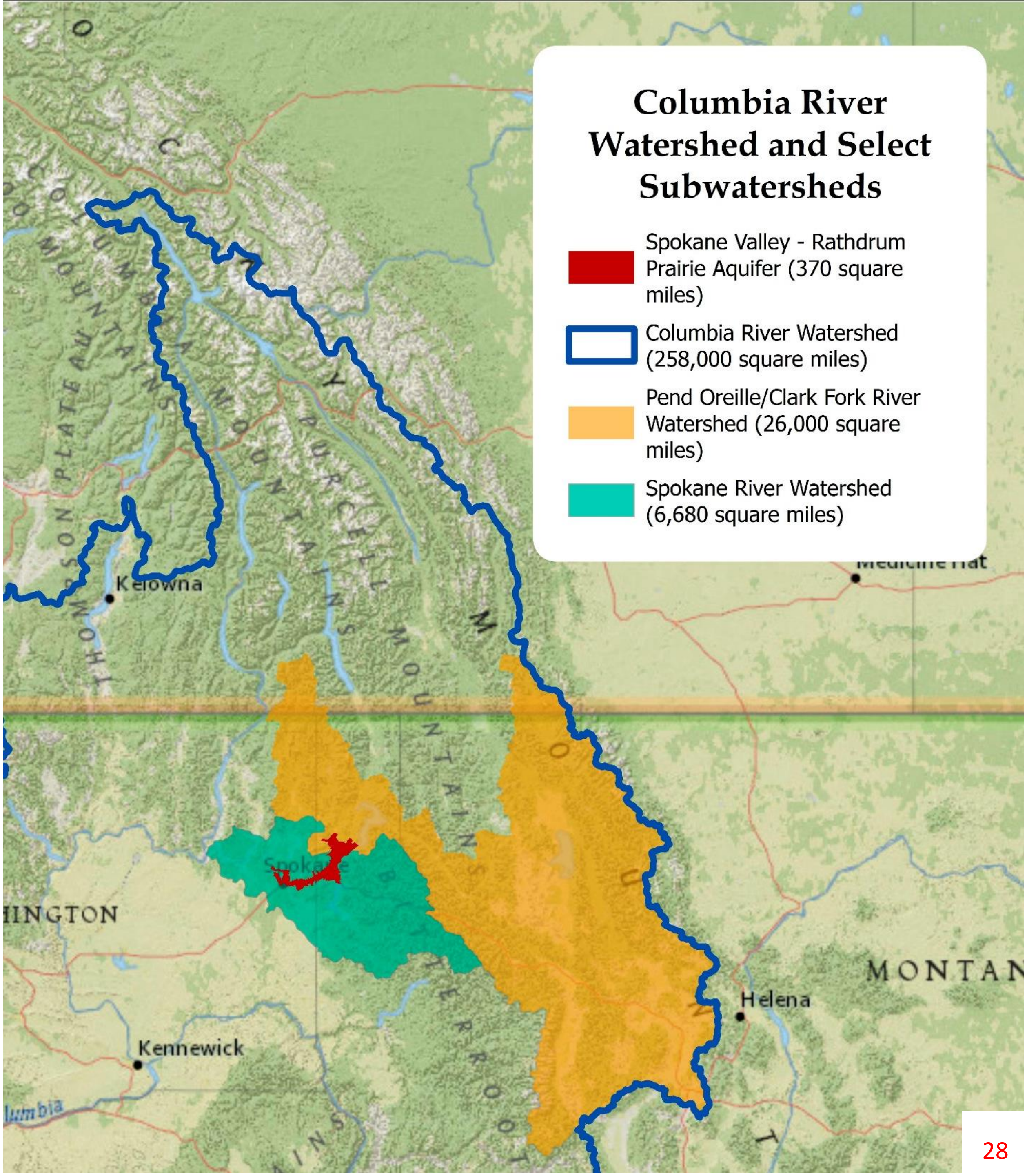
Diversion of water around Spokane Gage (minor)	~~River water temperature~~ ~~*(riverbed seepage rates east of Spokane)*~~
~~Effect of increased urbanization on fate of stormwater~~ ~~*(less recharge, more evapotranspiration)*~~	

Role of Watershed Conditions on August Low Flows at the Spokane Gage



SVRP Aquifer and Adjoining Watersheds



Source:
Spokane Valley–Rathdrum Prairie Aquifer Atlas 2015 Edition

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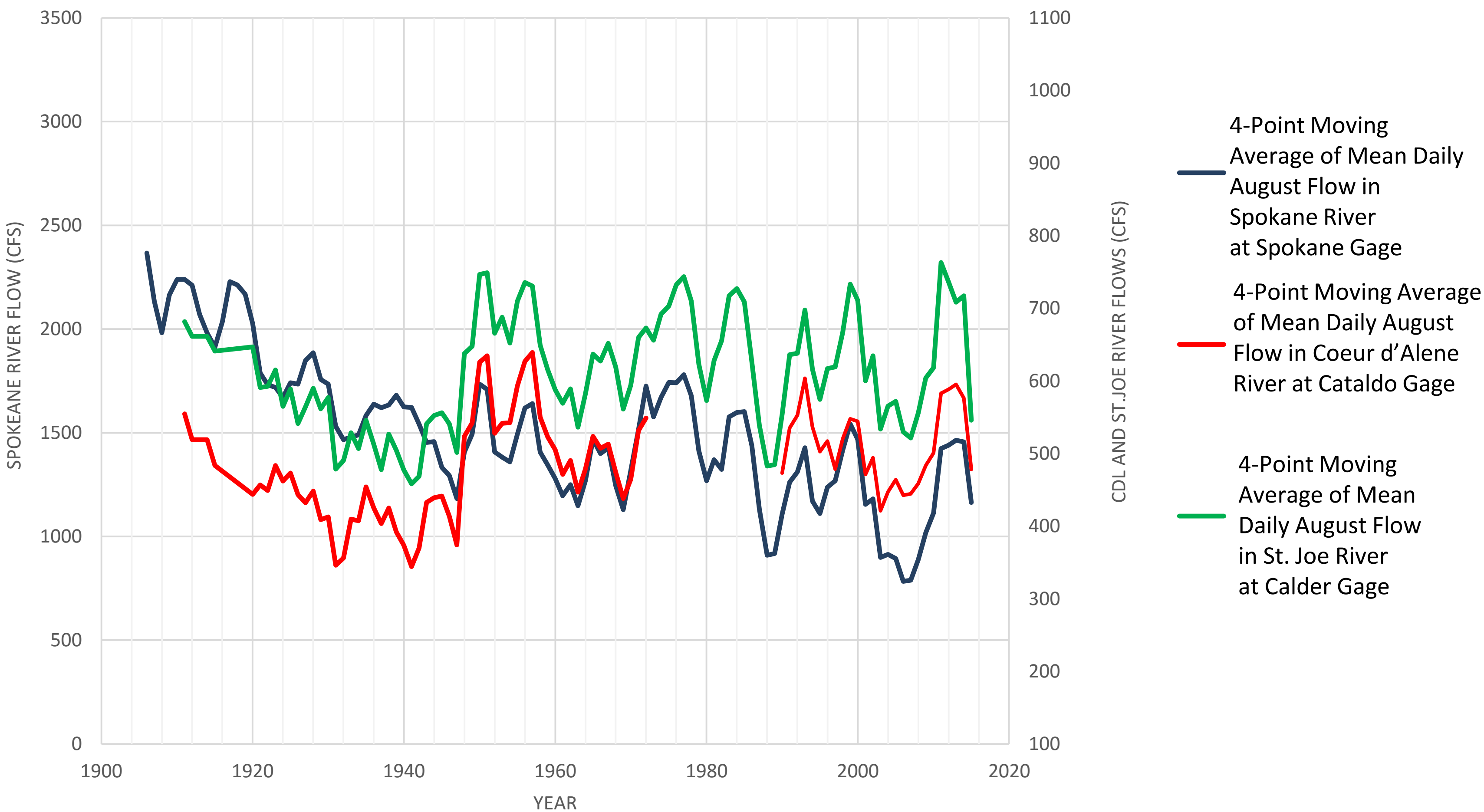
August River Flow Rates at Downtown Spokane Gage and Upstream of Coeur d'Alene Lake



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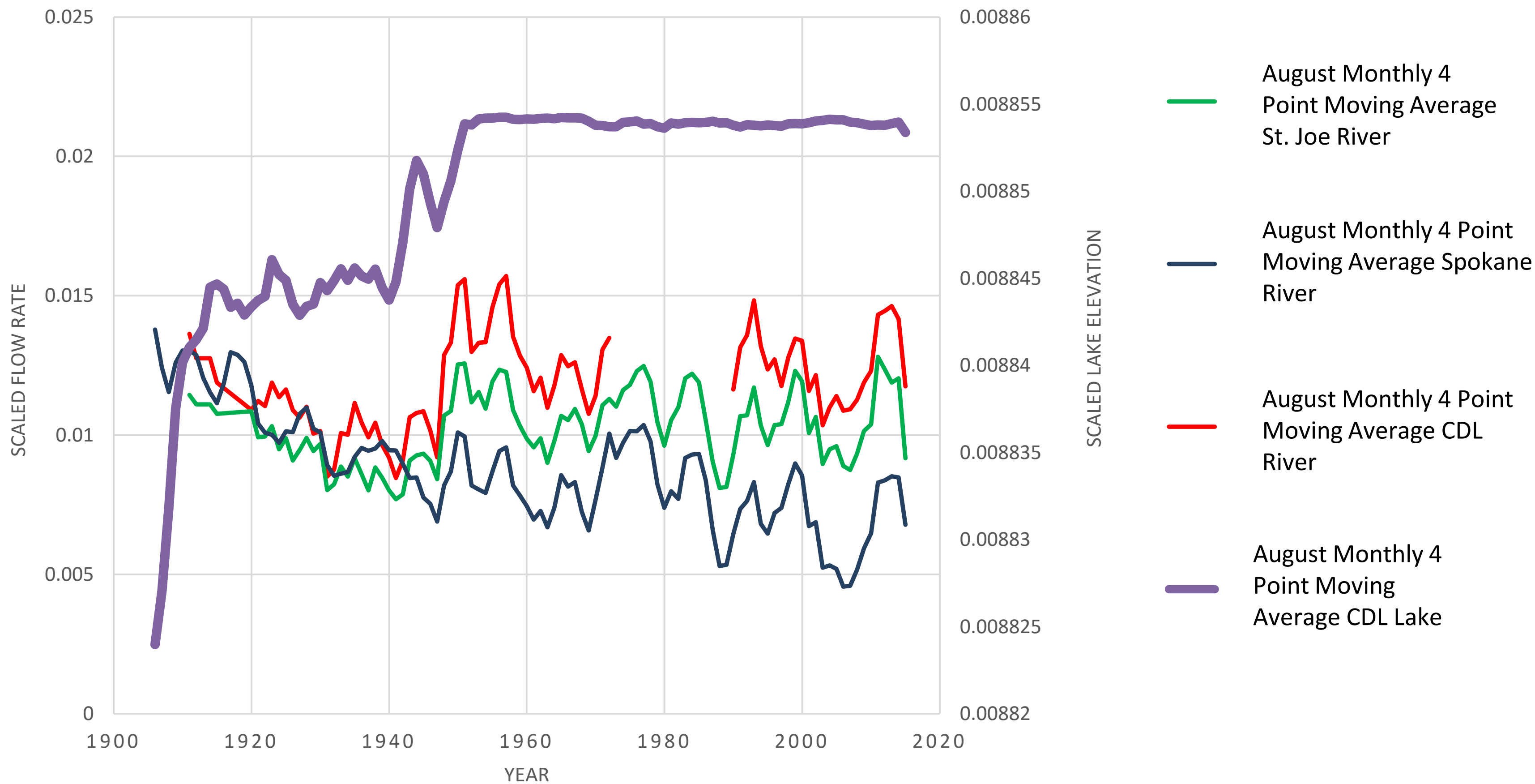
Scaled August River Flows and Scaled August Lake Levels in Coeur d'Alene Lake



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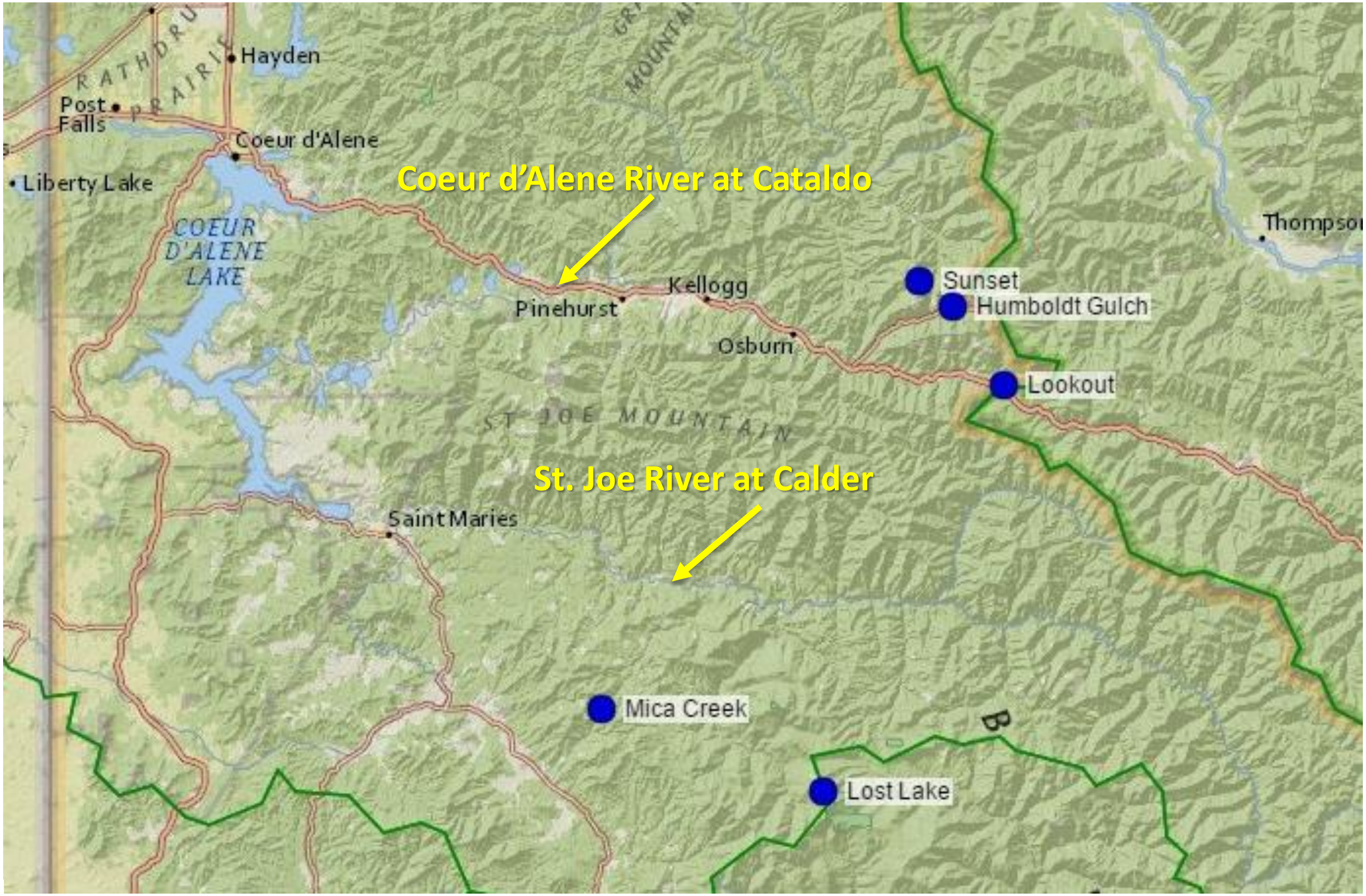
Locations of Streamflow and SNOTEL Data



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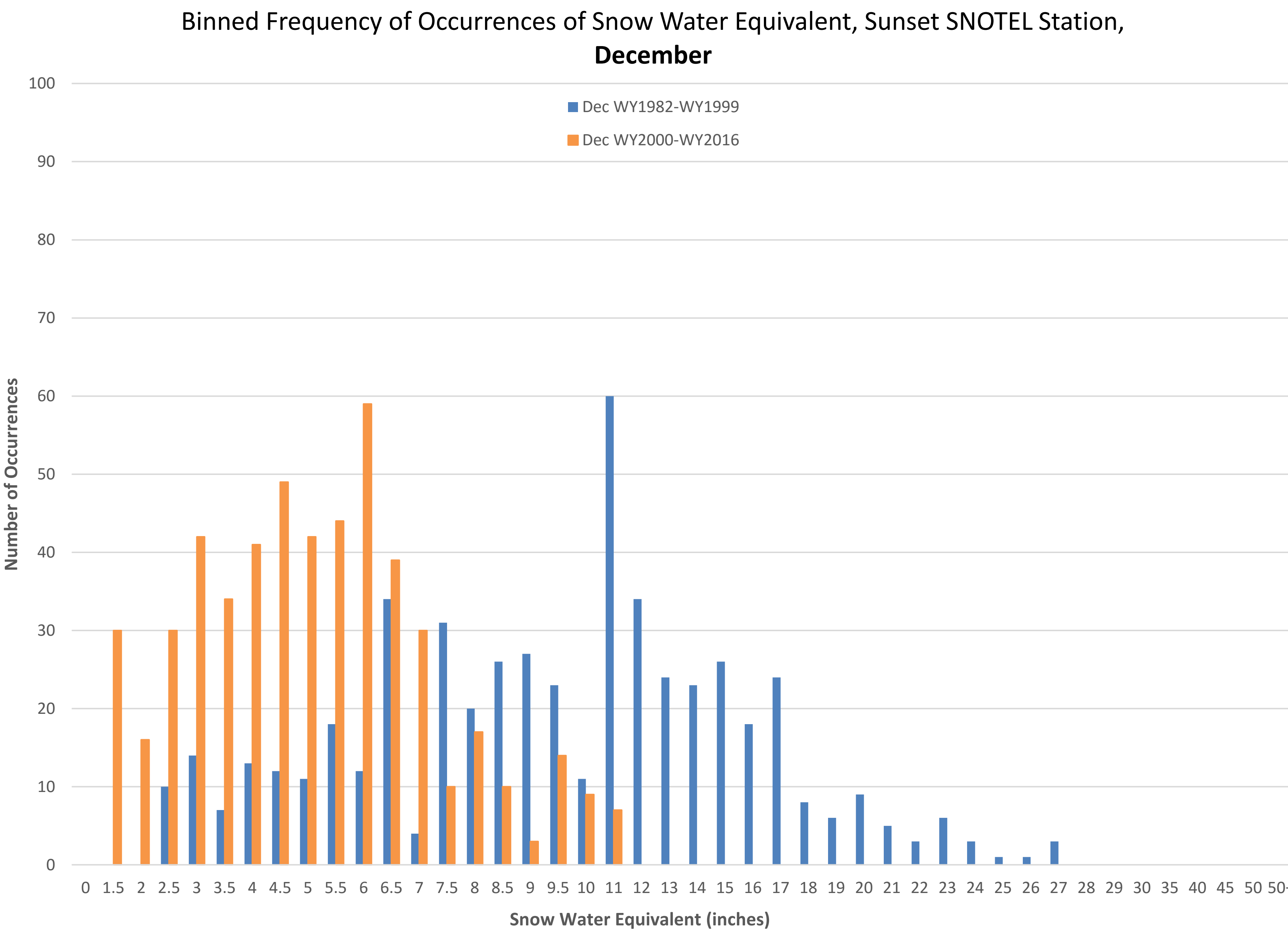
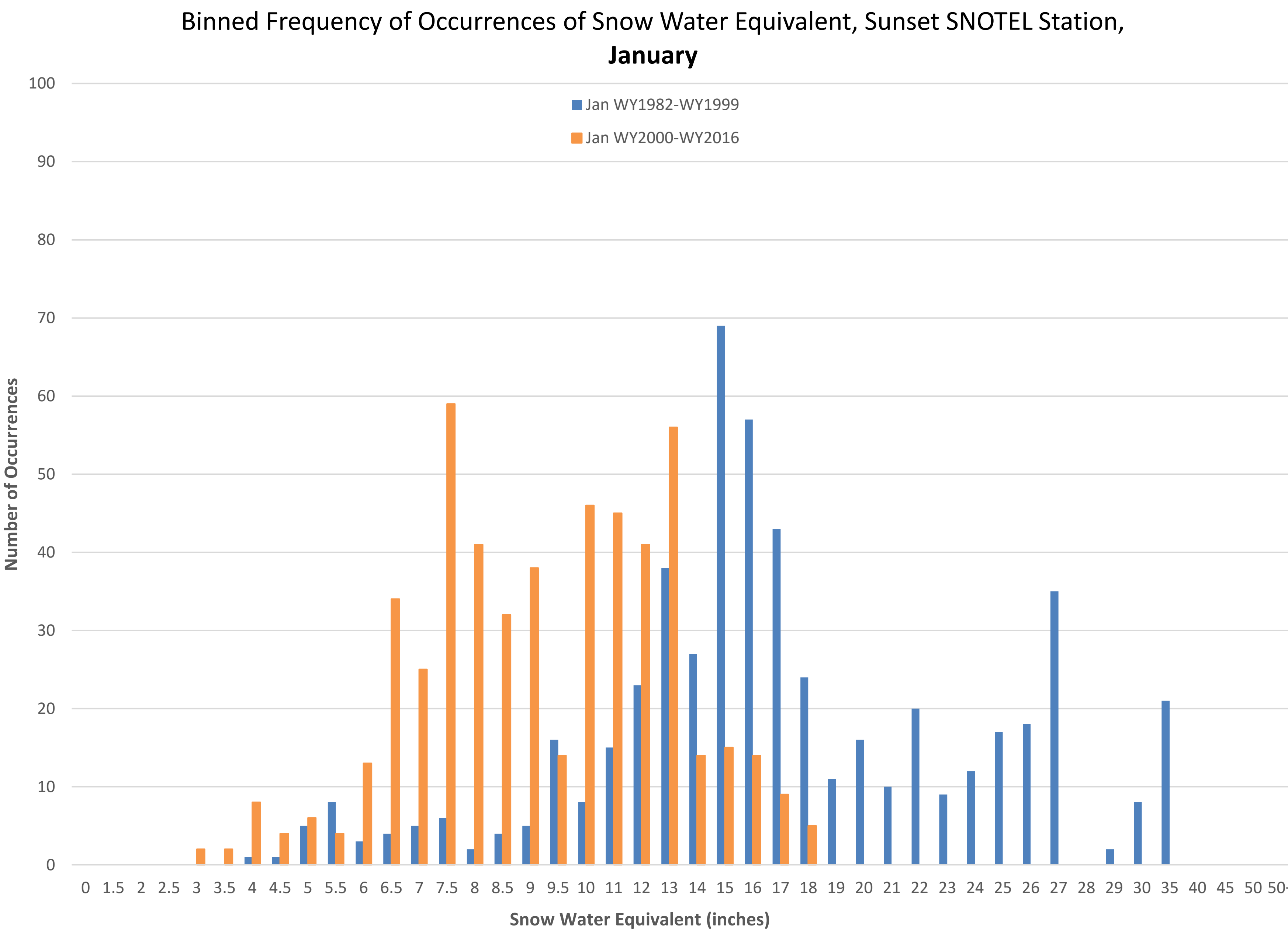


Binned Frequency of Occurrences of Snow Water Equivalent, Sunset SNOTEL Station,
December
Dec WY1982-WY1999
Dec WY2000-WY2016
Number of Occurrences
100
90
80
70
60
50
40
30
20
10
0
0 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 35 40 45 50 50+
Snow Water Equivalent (inches)


Binned Frequency of Occurrences of Snow Water Equivalent, Sunset SNOTEL Station,
January
Jan WY1982-WY1999
Jan WY2000-WY2016
Number of Occurrences
100
90
80
70
60
50
40
30
20
10
0
0 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 35 40 45 50 50+
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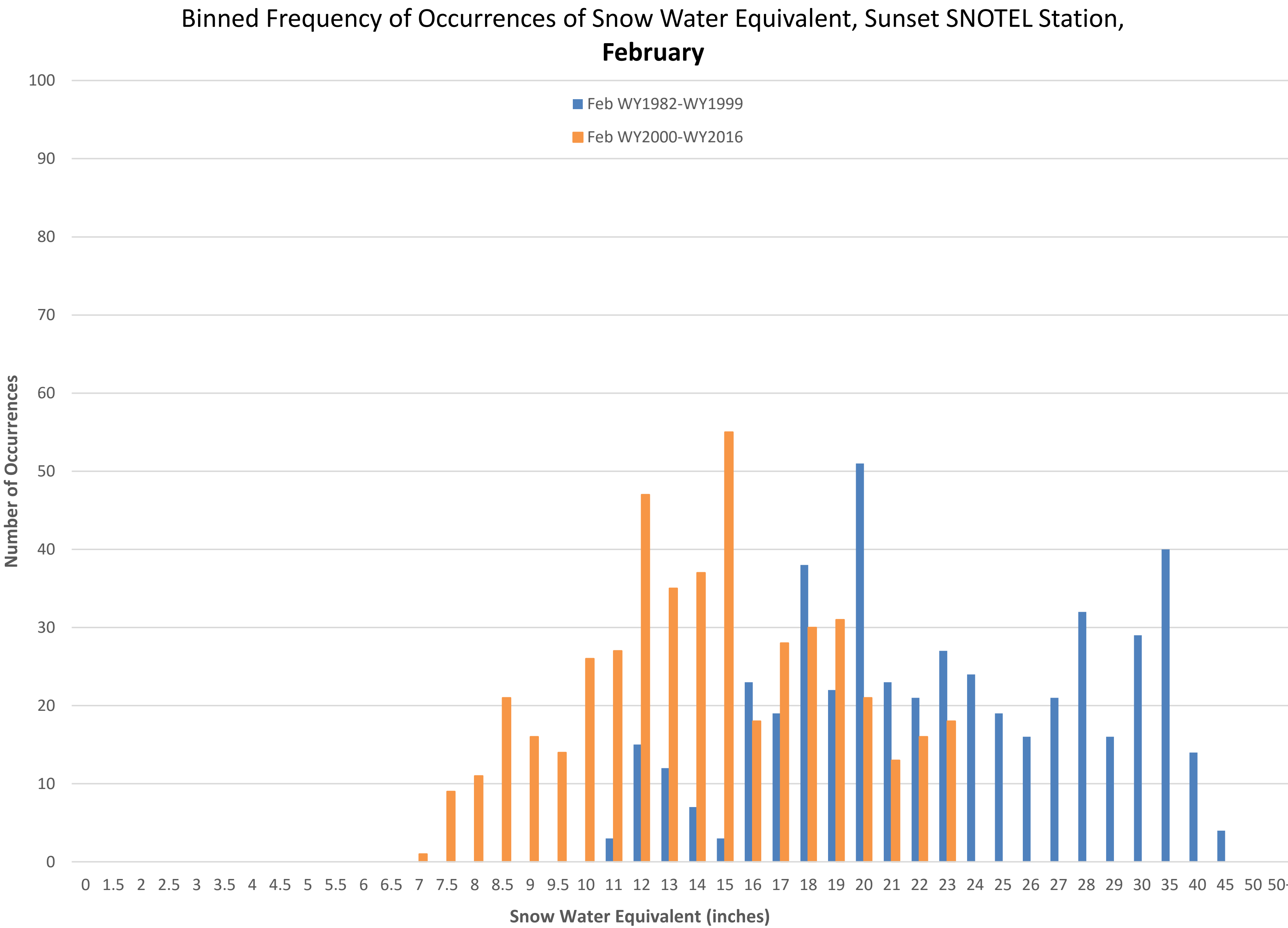

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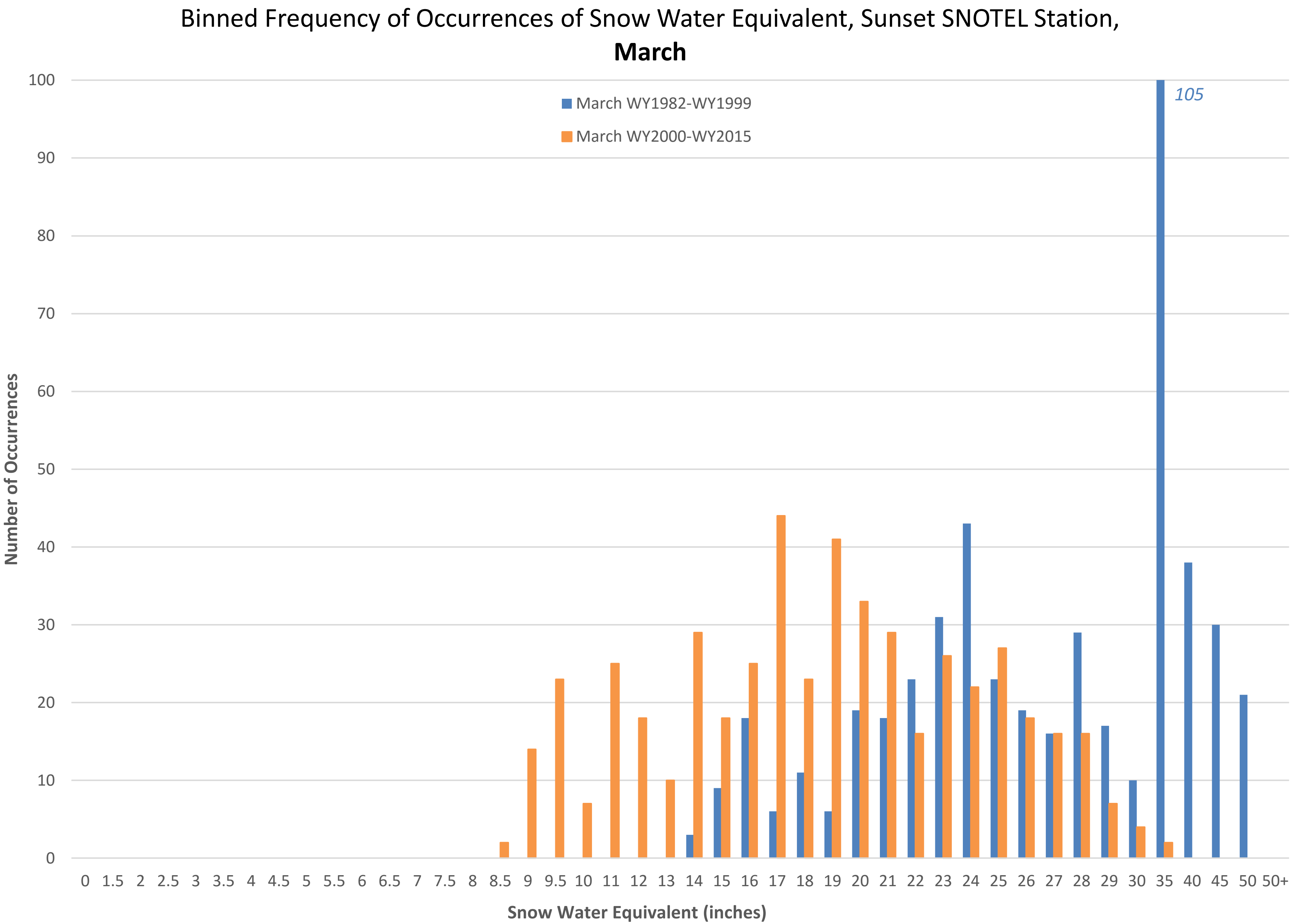
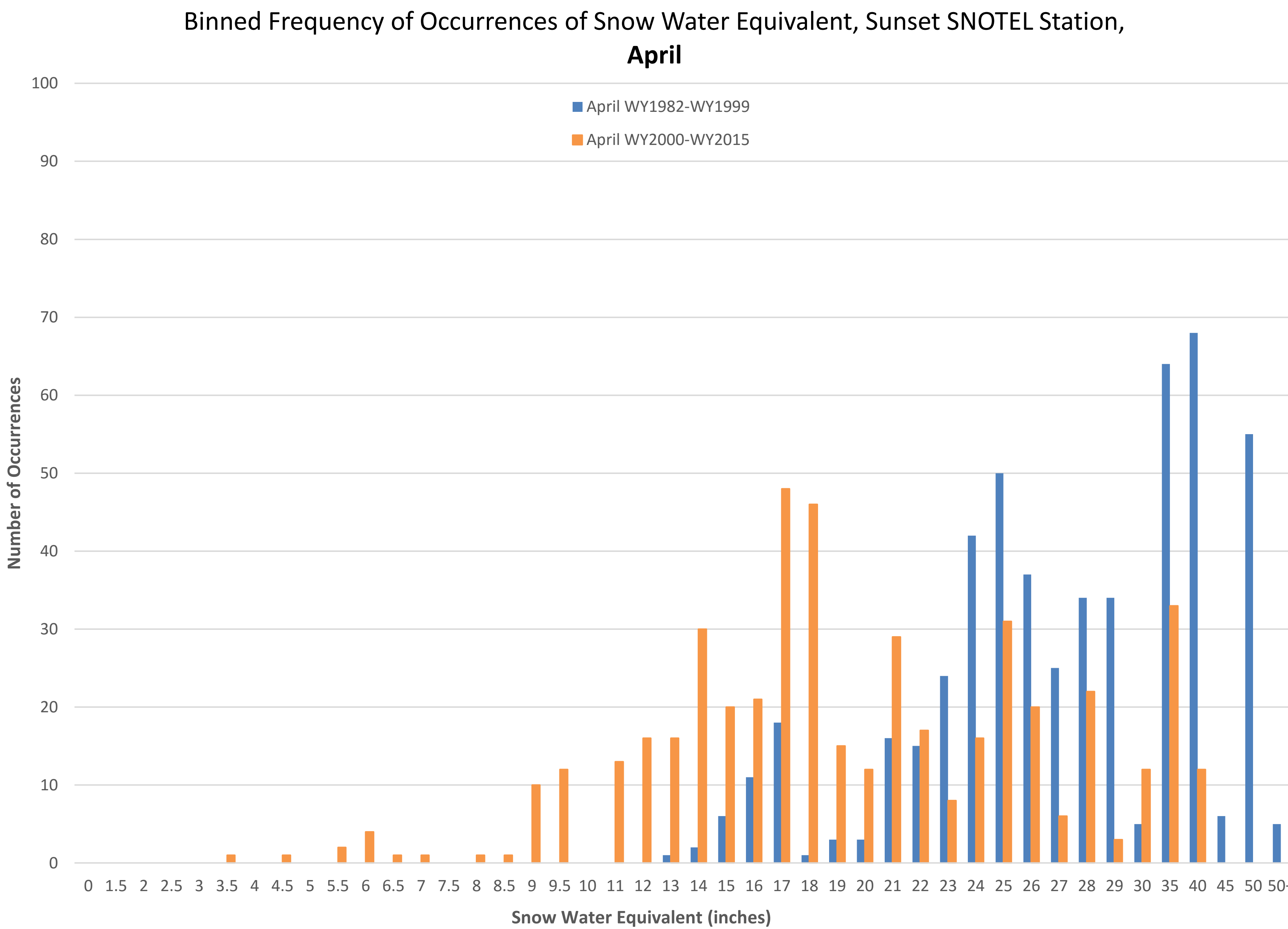
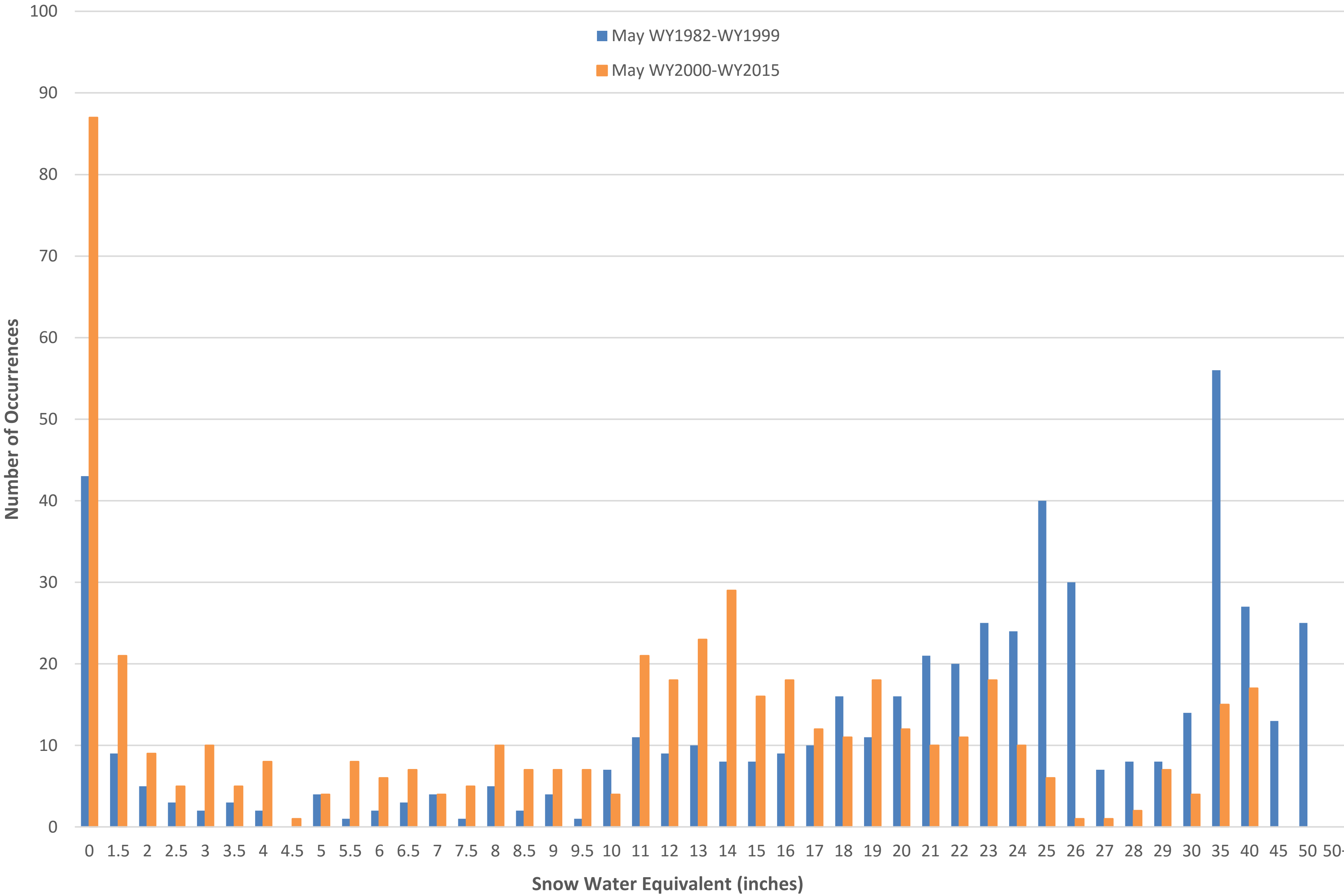

Binned Frequency of Occurrences of Snow Water Equivalent, Sunset SNOTEL Station,
March
March WY1982-WY1999
March WY2000-WY2015
105
Number of Occurrences
0
10
20
30
40
50
60
70
80
90
100
0 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 35 40 45 50 50+
Snow Water Equivalent (inches)



Binned Frequency of Occurrences of Snow Water Equivalent, Sunset SNOTEL Station,
April
April WY1982-WY1999
April WY2000-WY2015
Number of Occurrences
0
10
20
30
40
50
60
70
80
90
100
0 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 35 40 45 50 50+
Snow Water Equivalent (inches)

Binned Frequency of Occurrences of Snow Water Equivalent, Sunset SNOTEL Station, **May**



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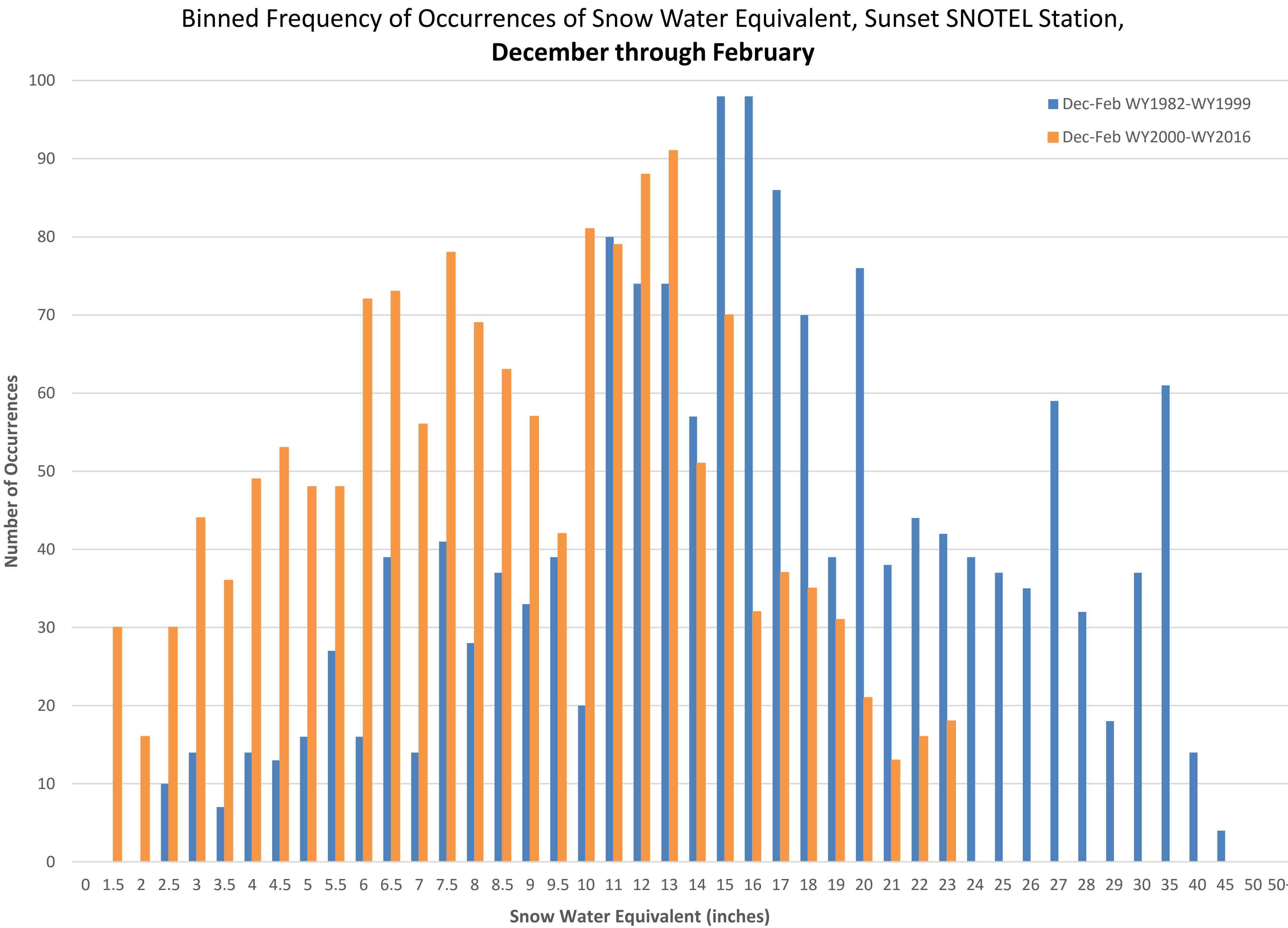
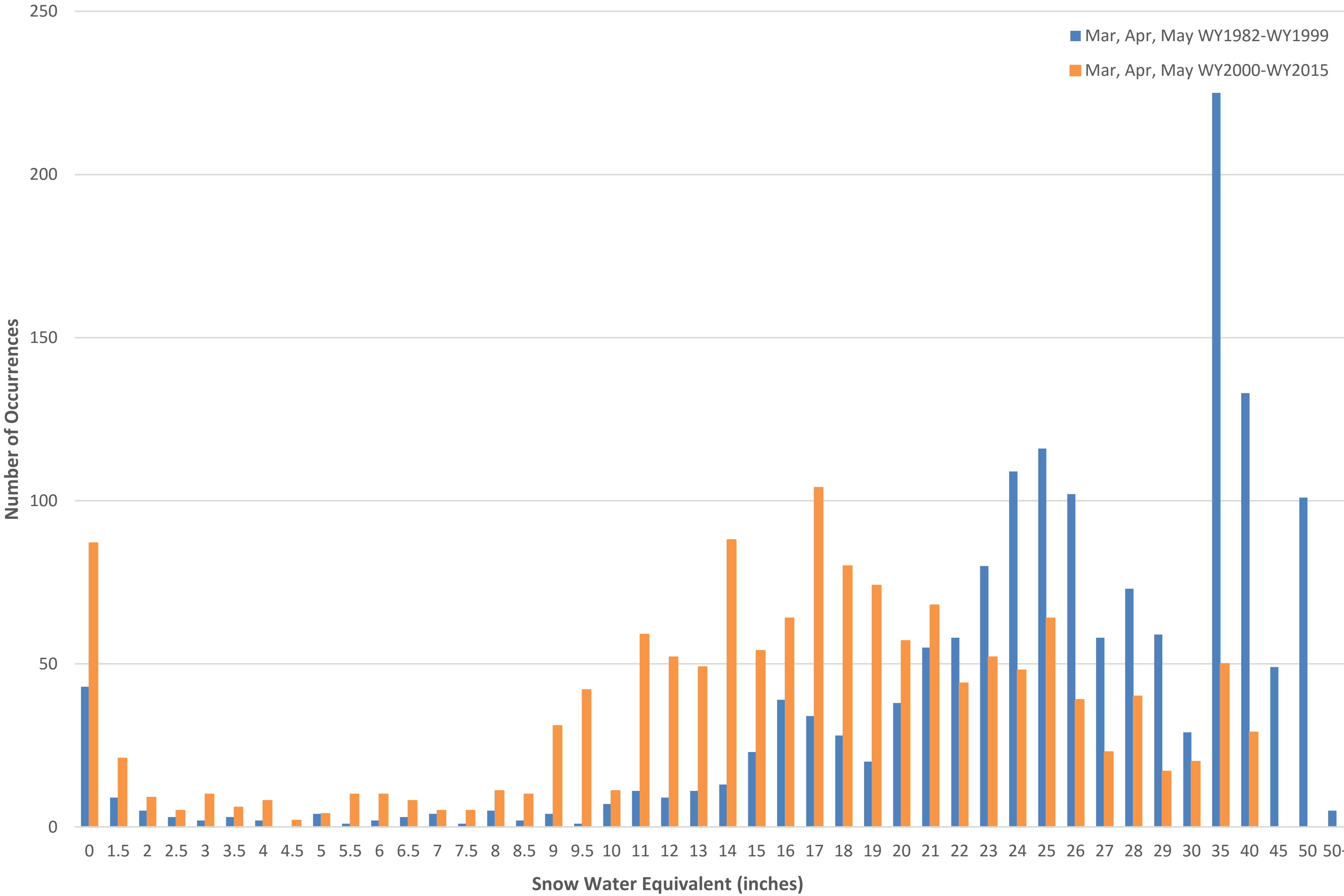


Binned Frequency of Occurrences of Snow Water Equivalent, Sunset SNOTEL Station,
December through February
Dec-Feb WY1982-WY1999
Dec-Feb WY2000-WY2016
Number of Occurrences
0
10
20
30
40
50
60
70
80
90
100
0 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 35 40 45 50 50+
Snow Water Equivalent (inches)

Binned Frequency of Occurrences of Snow Water Equivalent, Sunset SNOTEL Station, **March through May**



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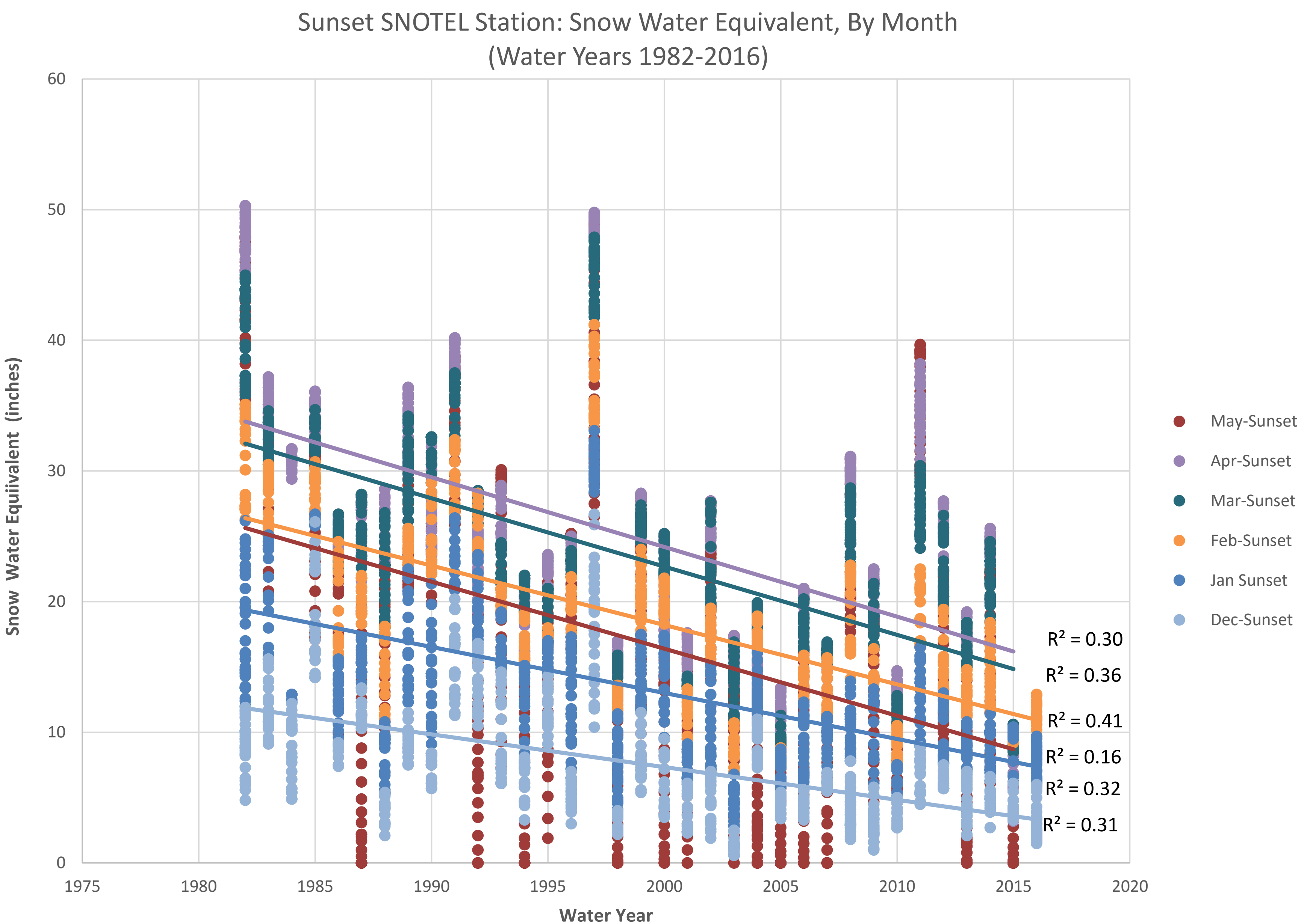

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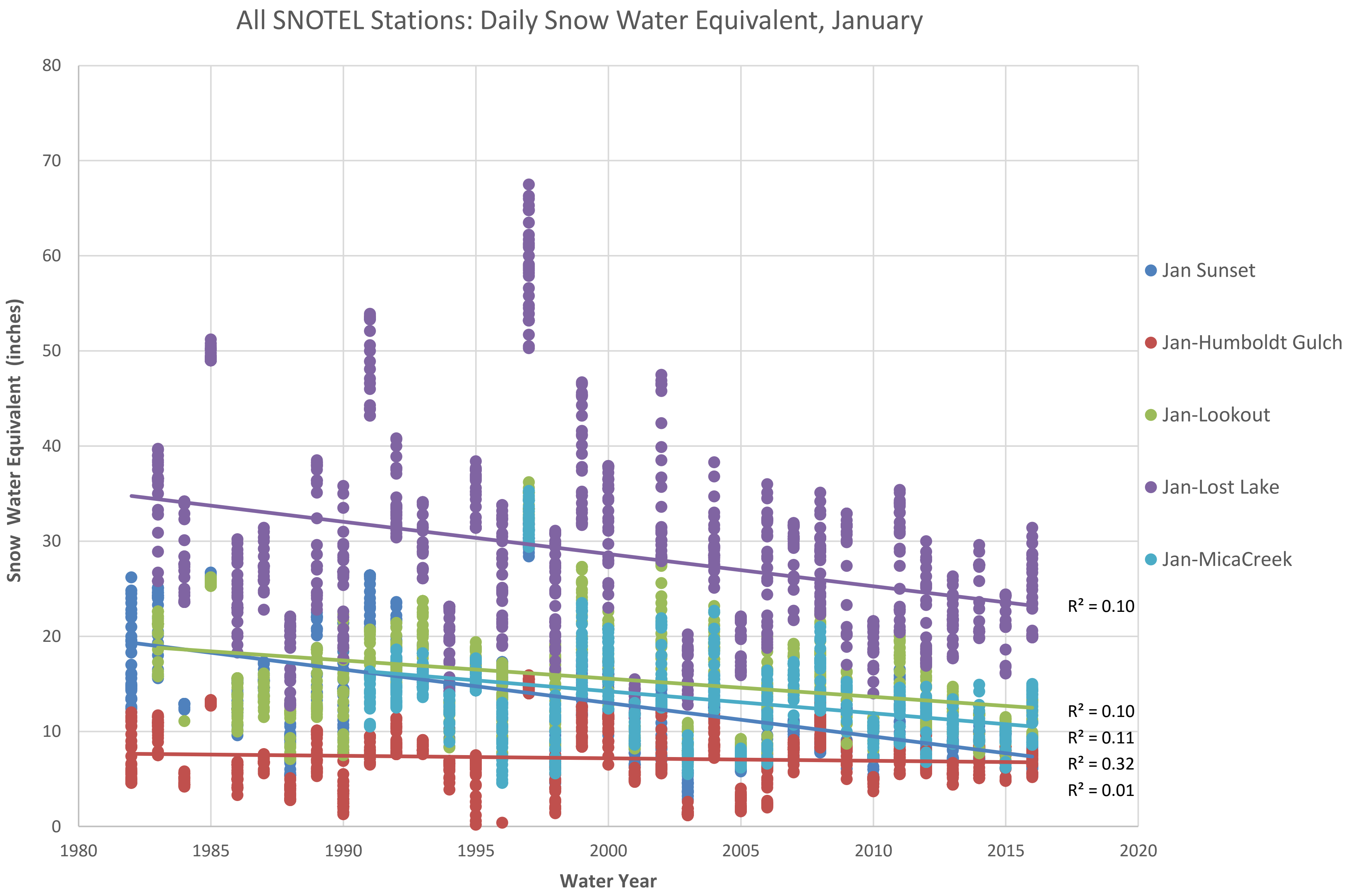
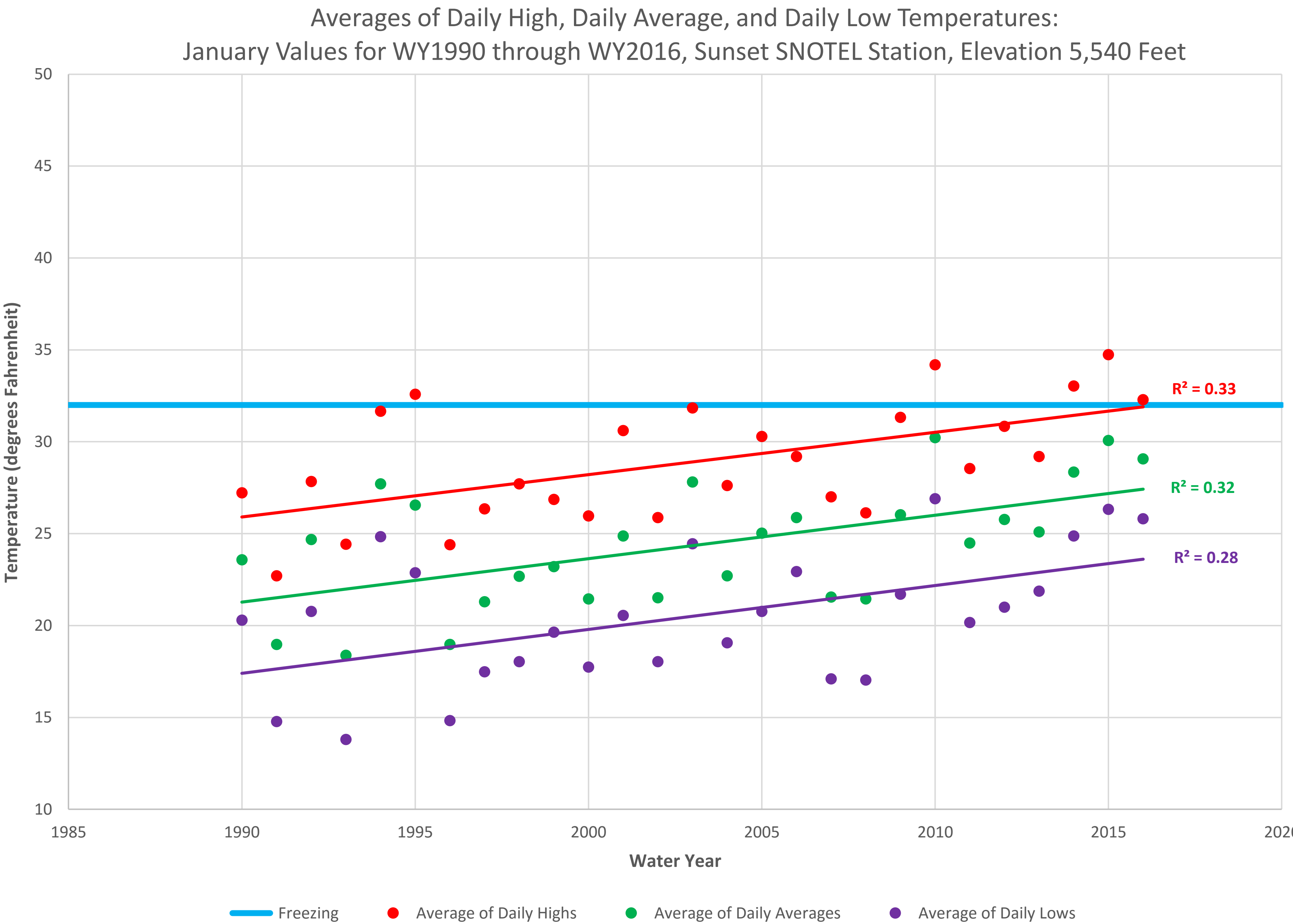

All SNOTEL Stations: Daily Snow Water Equivalent, January
80
70
60
50
40
30
20
10
0
Snow Water Equivalent (inches)
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year
Jan Sunset
Jan-Humboldt Gulch
Jan-Lookout
Jan-Lost Lake
Jan-MicaCreek
R² = 0.10
R² = 0.10
R² = 0.11
R² = 0.32
R² = 0.01



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Averages of Daily High, Daily Average, and Daily Low Temperatures: February Values for WY1993 through WY2016, Sunset SNOTEL Station, Elevation 5,540 Feet

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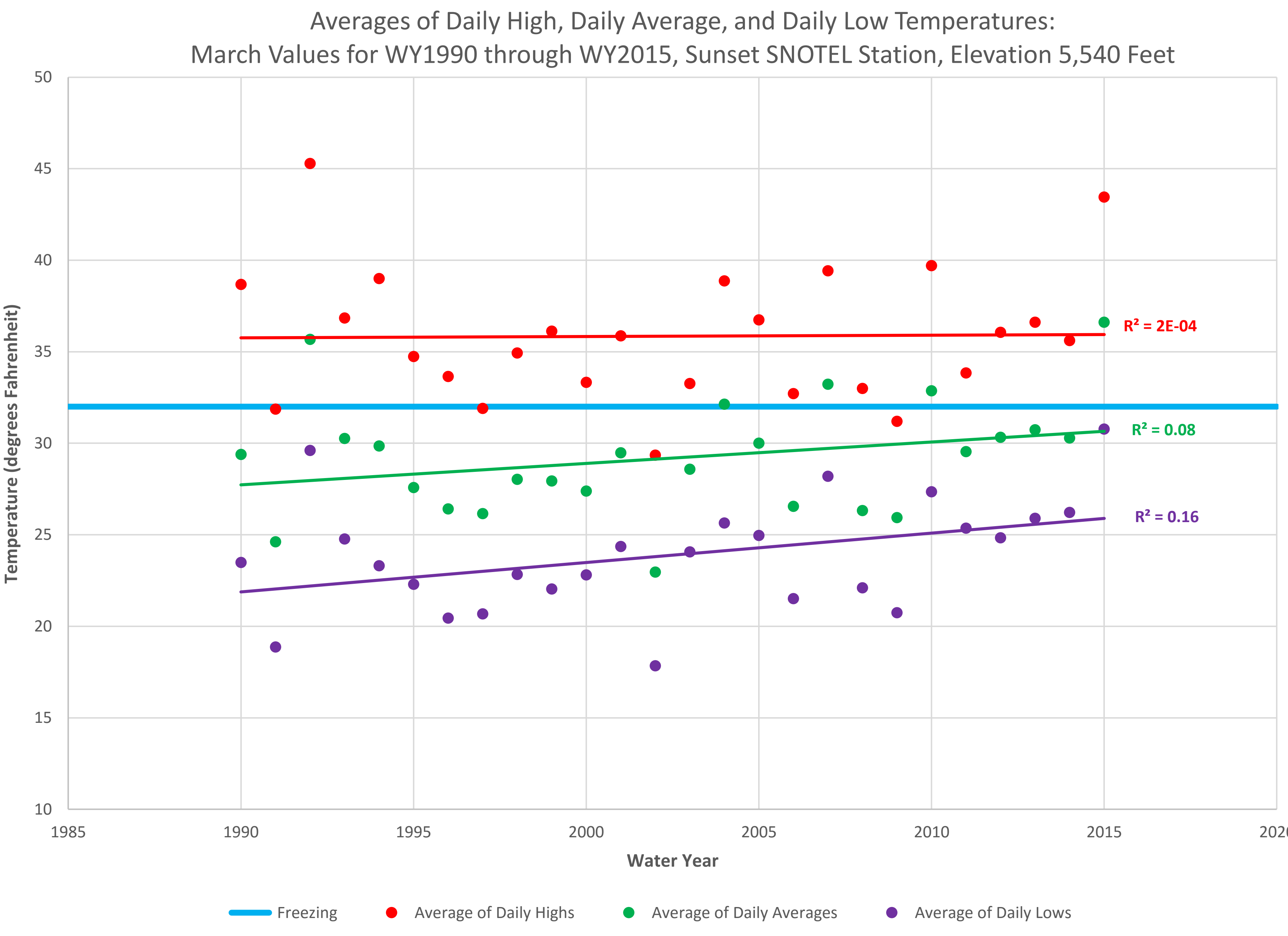
Averages of Daily High, Daily Average, and Daily Low Temperatures:
March Values for WY1990 through WY2015, Sunset SNOTEL Station, Elevation 5,540 Feet
Temperature (degrees Fahrenheit)
50
45
40
35
30
25
20
15
10
1985
1990
1995
2000
2005
2010
2015
2020
Water Year
R² = 2E-04
R² = 0.08
R² = 0.16
Freezing
Average of Daily Highs
Average of Daily Averages
Average of Daily Lows
GSI
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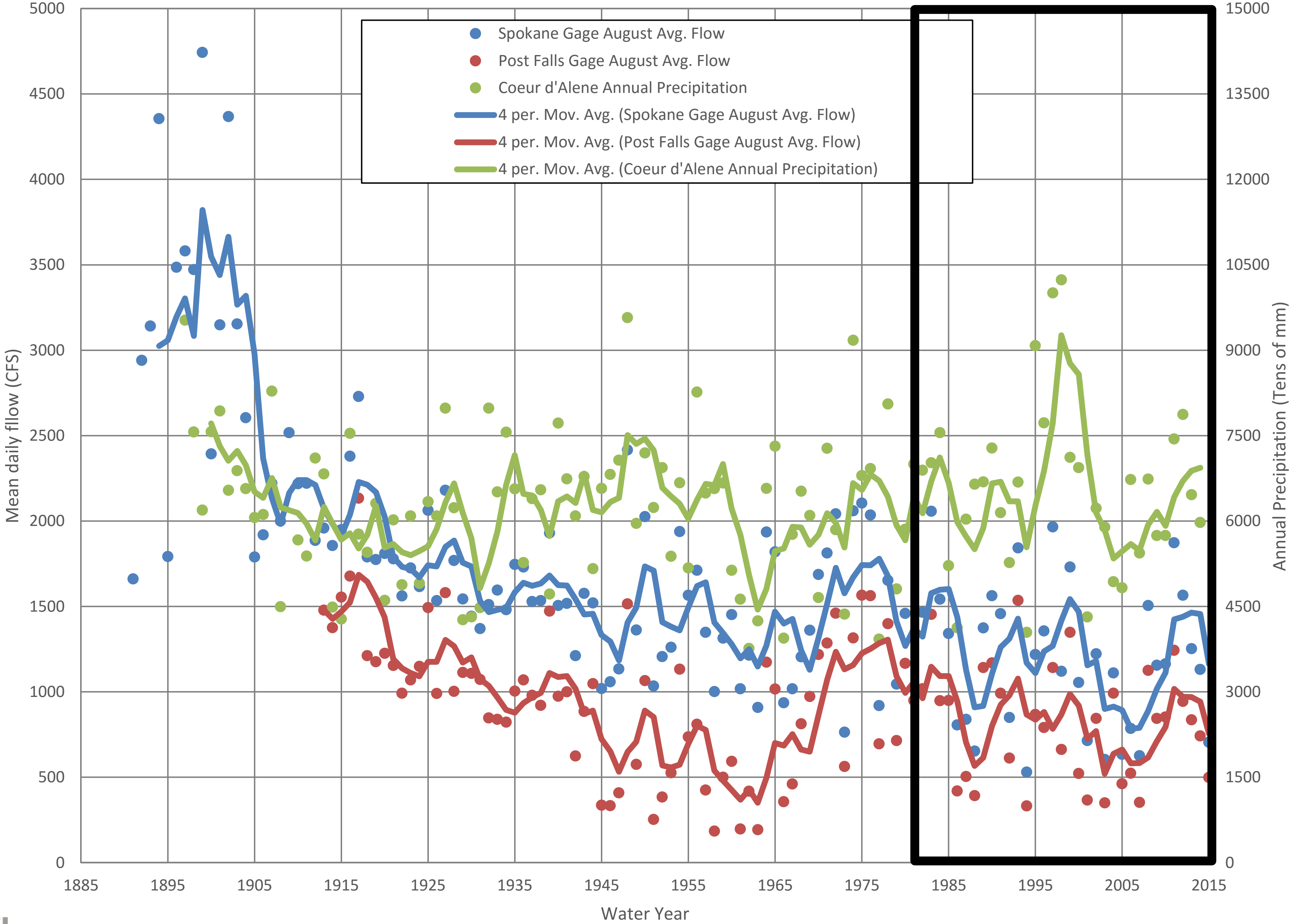
River Flow and Watershed Changes Since Late 1800s

Gaged Flows, Precipitation, Lake Stage, City Return Flows



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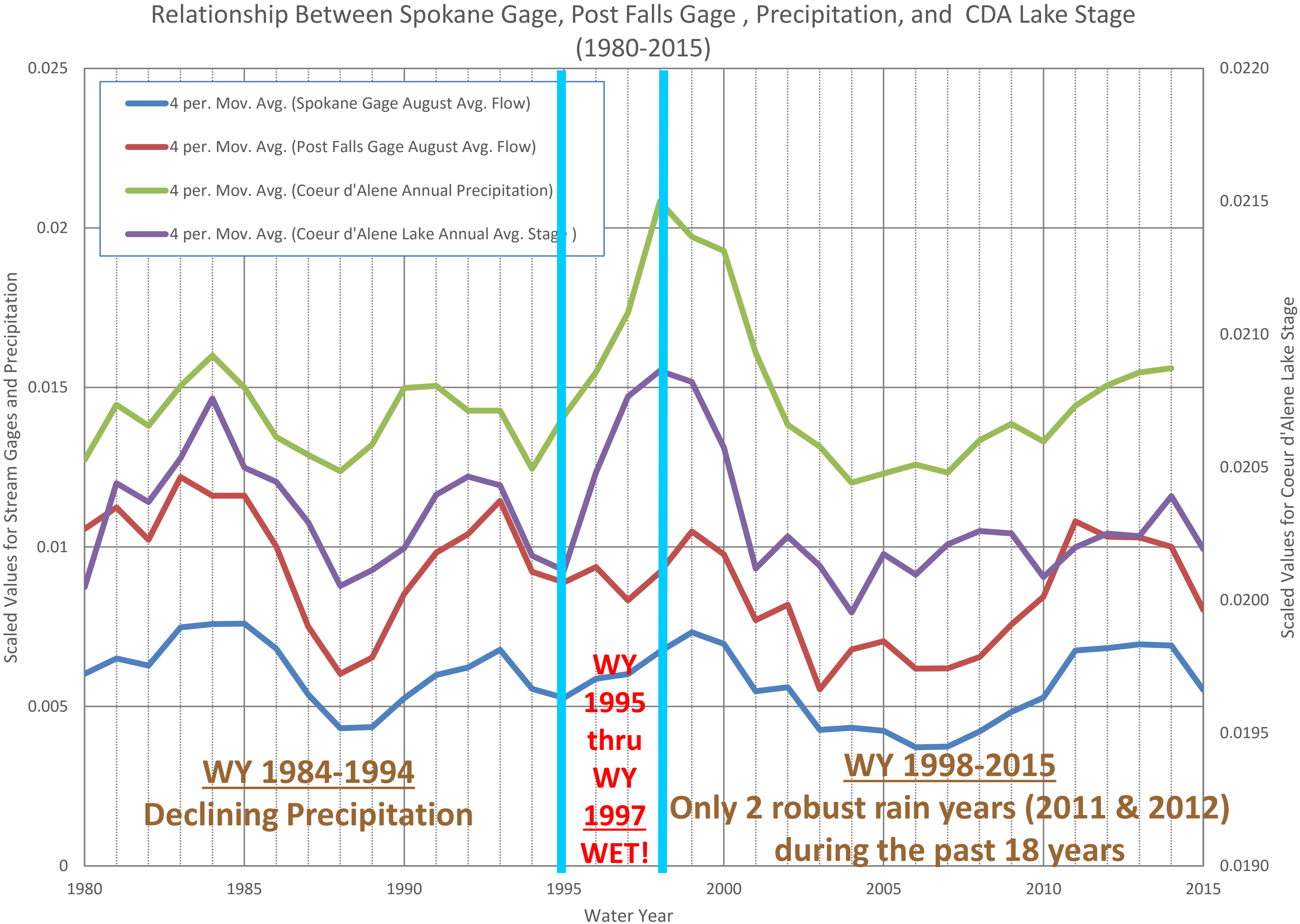
1980-2015

Gaged Flows, Precipitation, Lake Stage, City Return Flows



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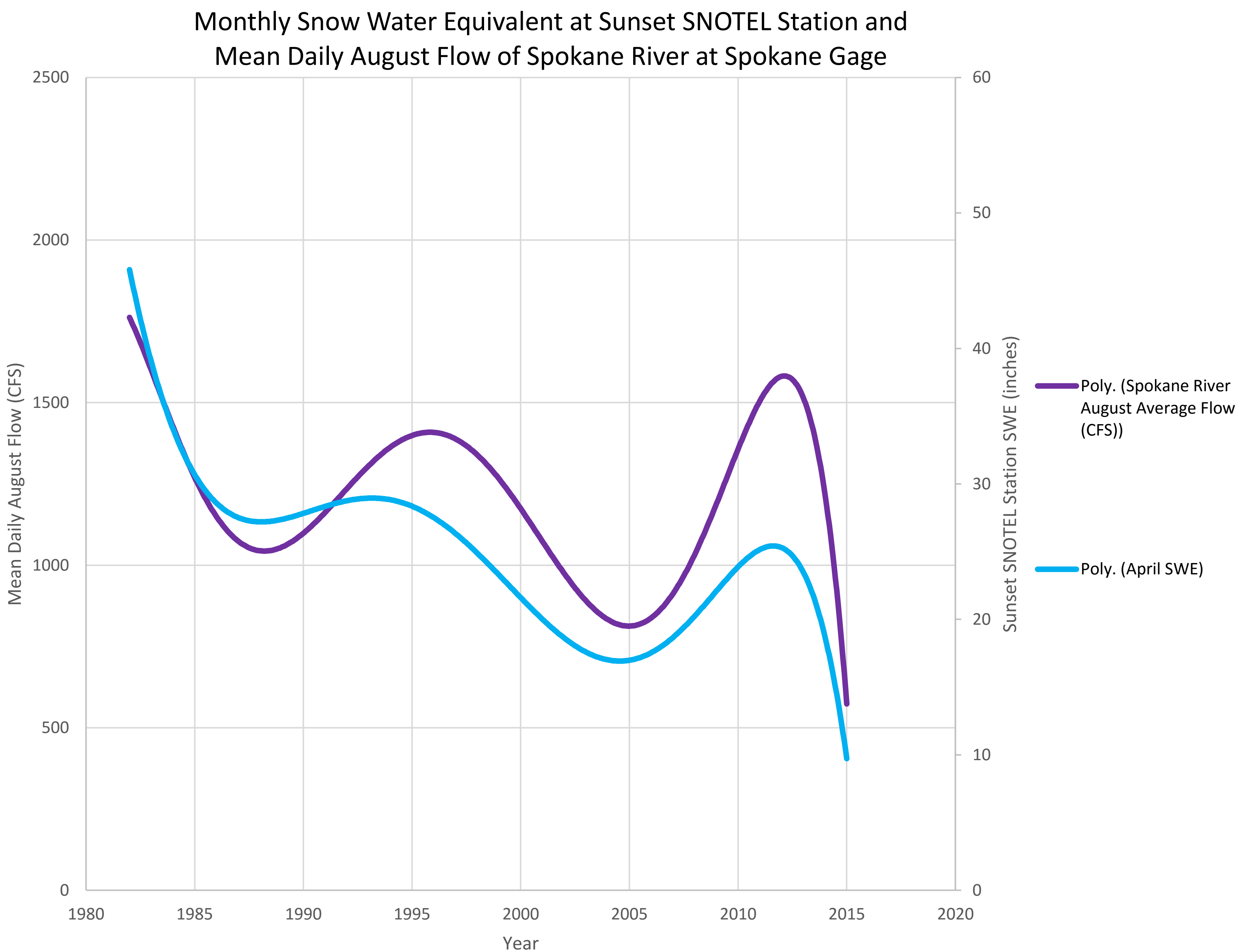
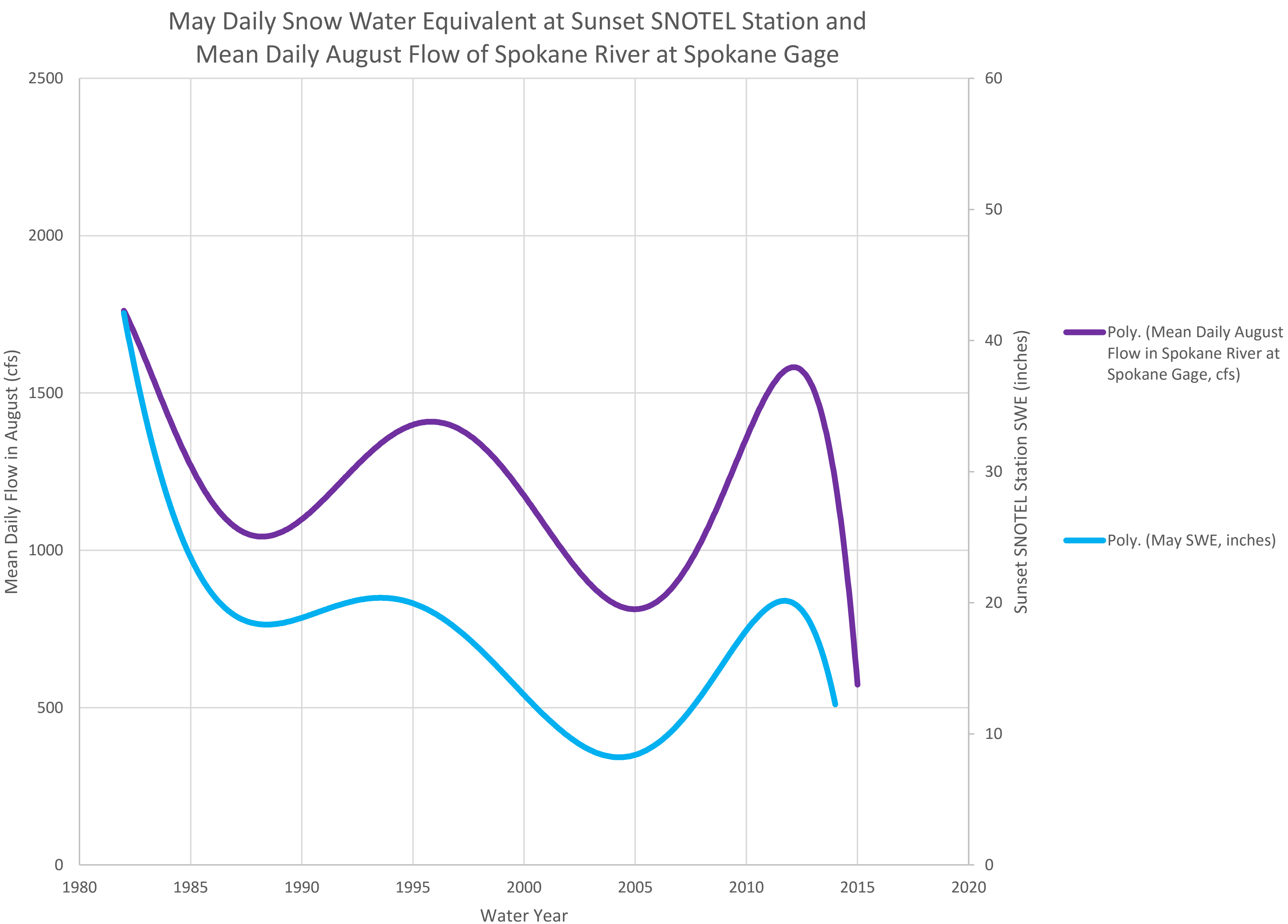

Monthly Snow Water Equivalent at Sunset SNOTEL Station and
Mean Daily August Flow of Spokane River at Spokane Gage
Mean Daily August Flow (CFS)
Sunset SNOTEL Station SWE (inches)
Year
2500
2000
1500
1000
500
0
60
50
40
30
20
10
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
Poly. (Spokane River August Average Flow (CFS))
Poly. (April SWE)



May Daily Snow Water Equivalent at Sunset SNOTEL Station and
Mean Daily August Flow of Spokane River at Spokane Gage
Mean Daily Flow in August (cfs)
2500
2000
1500
1000
500
0
Sunset SNOTEL Station SWE (inches)
60
50
40
30
20
10
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year
Poly. (Mean Daily August Flow in Spokane River at Spokane Gage, cfs)
Poly. (May SWE, inches)

Conclusions

SAJB 2014-2016 Studies

1. Urbanization of former irrigated agricultural lands has been beneficial to the river-aquifer system
   - Less consumptive use (loss) during summer irrigation season
   - Indoor uses return most water to river/aquifer system
   - Groundwater levels have been stable, if not higher
2. Summer pumping for municipal uses does not cause an equal depletion in river flows
   - Washington purveyors: 15% to 65% effect on the river
   - Idaho purveyors: Even less (far from gaining reaches)

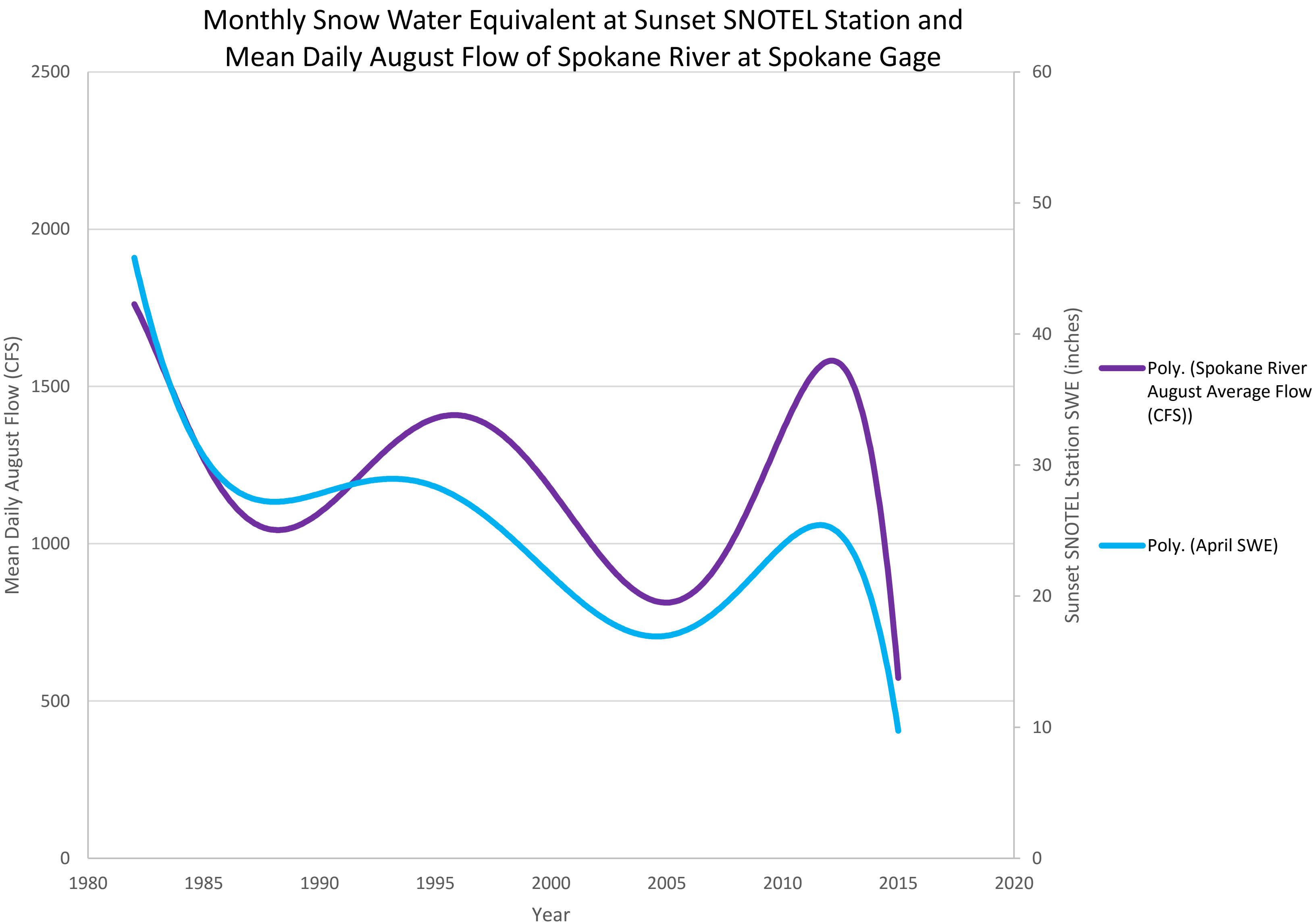
Conclusions

SAJB 2014-2016 Studies

3. The continued decline in seasonal low flows in the Spokane River is occurring despite two positives:
   - Declining per-capita usage over past 3 decades
   - Reduced summer demands in both states arising from the agricultural-to-urban conversion of land and water use
4. Changing hydrology in the contributing watershed to Coeur d’Alene Lake is the dominant cause of continued declines in Spokane River seasonal low flows
   - Earlier snowmelt
   - Smaller runoff volumes in late winter and spring
   - Lower summer stream inflows

Discussion, Questions

John Porcello, LHG and Jake Gorski, EIT: GSI Water Solutions, (503) 239-8799



Other Slides for Q&A Session

SAJB 2014-2016 Studies

Ag Diversions

- Groundwater as early as 1900
  - Albert Kelly near Sprague/Havana (1900)
  - Modern Irrigation & Land Co. near Sprague/Pines (1905)
  - Vera Water Co. (five wells drilled around 1907-1910)
  - Trentwood Irrigation Co. (one or more wells drilled in 1910)
- Lake water imported from surrounding areas
  - Hayden and Newman Lakes (1895)
  - Liberty Lake Canal (1900)
    - 20-ft wide ditch 6.5 miles long, servicing 1,400 acres at Greenacres
    - 16 miles of main and branch ditches by 1901

Ag Diversions

- River water diversions by the Corbin Ditch
  - Also known as the Spokane Valley Farms Canal
  - Diverted water just above Post Falls Dam
  - Began deliveries in 1907
    - Initially a 2-ft ditch and wooden box flume that was 5 miles long
  - By 1918 was 34 miles long with 54 miles of lateral canals
  - First lined in 1922-1924, and later

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Ag Diversions

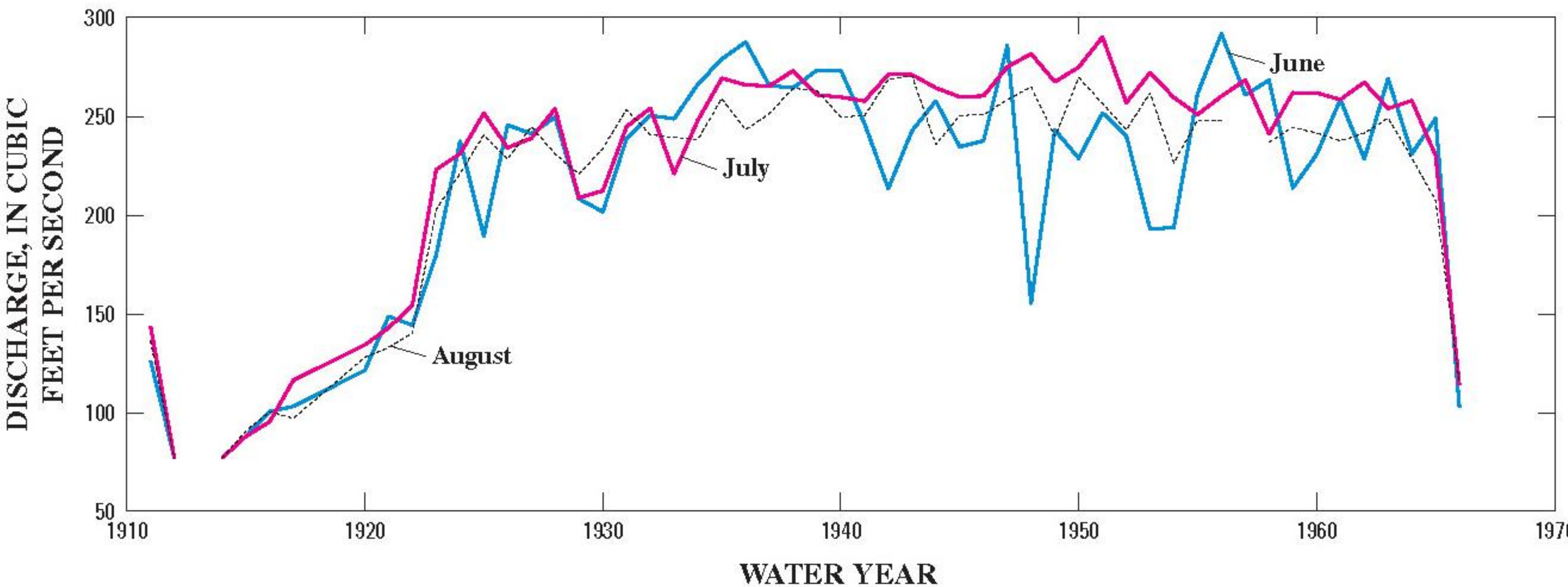

Figure 7. Monthly mean streamflows for the Spokane Valley Farms Canal at Post Falls, Idaho, June, July, and August, 1911–1966.

Source: Hortness, J.E. and J.J. Covert. 2005.
Streamflow Trends in the Spokane River and Tributaries, Spokane Valley/Rathdrum Prairie, Idaho and Washington.
U.S. Geological Survey Investigations Report 2005-5005, 17 p.

Ag Diversions

(Estimates of Corbin Ditch Flow by GSI for this Study)

Corbin Ditch Today (West of Post Falls, Looking East)

Source: Renk, N.F. 2002. *National Register of Historic Places Registration Form and Continuation Sheet: Spokane Valley Land and Water Company Canal.* Prepared by Flume Creek Historical Services. Photo #5 taken by Nancy F. Renk on June 12, 2002.

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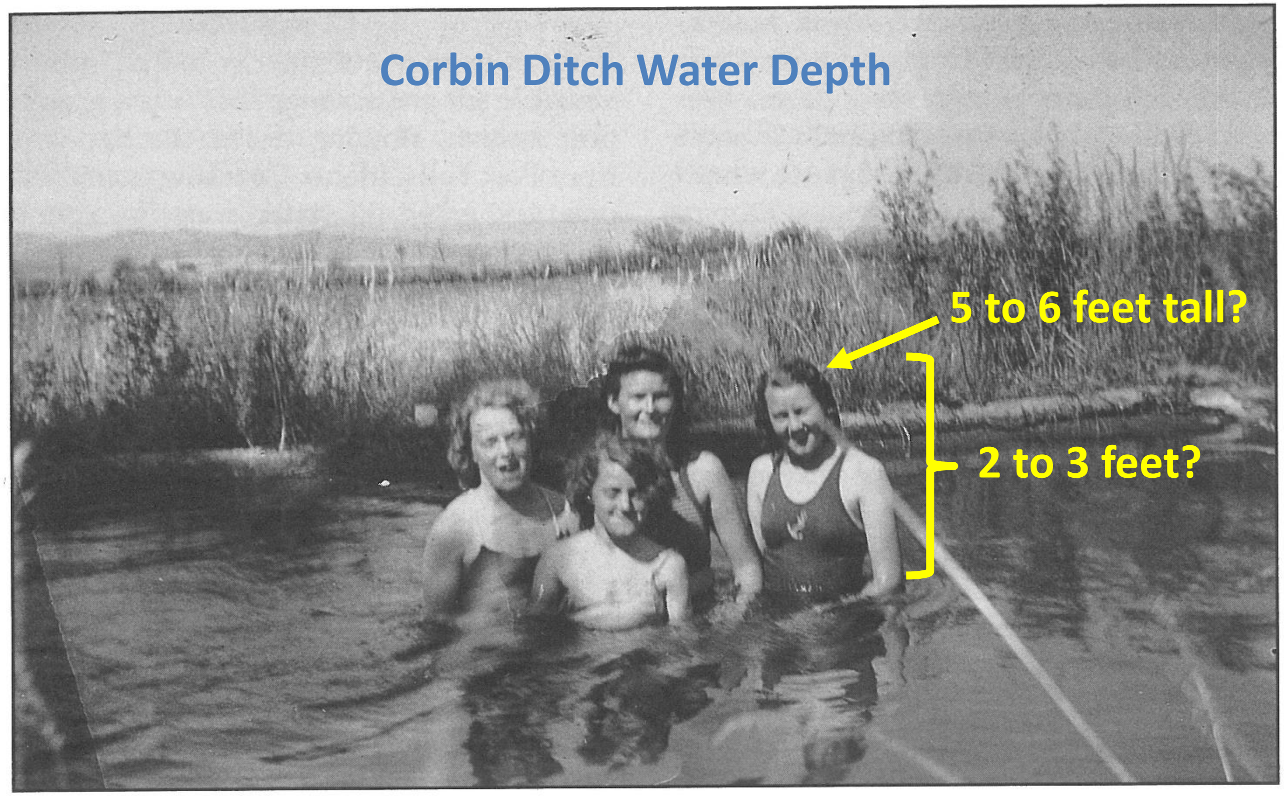
Ag Diversions

(Estimates of Corbin Ditch Flow by GSI for this Study)



SWIMMING IN THE CORBIN DITCH, 1940
The "ditch" brought water from the Spokane River to irrigate the area north of the river. Much of the "ditch" was a three-by-five foot wooden aquaduct that crossed the Valley on frame trusses, dipping beneath roads in square concrete ducts. (Left to right) Sally (Sampson) Fox, Mary Lou Sampson (Rice), Mavis Smith (Baum), Betty (Sampson) Strong. *Courtesy of Sarah Fox.*

Source: Boutwell, F. 1995. *The Spokane Valley: Volume 2, A History of the Growing Years, 1921-1945.* The Arthur H. Clark Company, Spokane, Washington, 224 pp.

Ag Diversions

(Estimates of Corbin Ditch Flow by GSI for this Study)

Manning's Formula (Open Channel Flow)

$$Q = VA = \left(\frac{1.49}{n}\right) AR^{\frac{2}{3}}\sqrt{S} \quad [U.S.]$$

$$Q = VA = \left(\frac{1.00}{n}\right) AR^{\frac{2}{3}}\sqrt{S} \quad [SI]$$

Variables

S = channel slope = 200 feet / 34 miles
= 200 ft / 179,500 ft
= 0.0011

A = cross section area = 48 ft^2
(based on 3-ft to 4-ft water depth)

R = hydraulic radius
= A / wetted perimeter

n = Manning's roughness coefficient
= 0.03 for weedy earth channel

Q = 125 to 225 cfs

If lined (n~0.02): Q = 185 to 330 cfs for a 3-ft to 4-ft range of water depths

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Ag Diversions

(Using Orchard Statistics to Estimate Demands)

Spacing	Small Apple Trees	Cherries	Pears	Prunes & Plums	Peaches
Arrangement (ft x ft)	35x35	20x25	20x20	20x20	20x20
Orchard Width (ft)	29	20	20	20	20
Orchard Length (ft)	209	209	209	209	209
No. Trees Per Row	7	10	10	10	10
No. Trees Per Acre	**49**	100	100	100	100
Water Need (inches/year)	34.5	33	27	27	31
Reference Location	George, WA	Hood River, OR	Omak, WA	Assume Same as Pears	Harrah, WA

Water Needs: AgriMet Data downloaded on November 17, 2015 from http://www.usbr.gov/pn/agrimet/ETtotals.html

NO. of TREES (Source: Washington State Dept. of Agriculture Bulletin, 1956)						
Year	**Apples**	**Cherries**	**Pears**	**Prunes & Plums**	**Peaches**	**Total**
1890	18,379	1,120	61	2,624	157	22,341
1900	431,701	18,691	26,221	103,587	5,319	585,519
1910	418,556	25,140	17,736	37,018	13,770	512,220
1920	1,118,814	32,267	26,533	33,608	16,200	1,227,422
1930	209,575	11,928	14,883	12,121	3,397	251,904
1940	94,609	4,500	10,542	6,387	585	116,623
1950	58,455	4,681	5,071	8,054	1,192	77,453
1954	14,247	5,743	1,857	3,575	493	25,915

ACRE-FEET WATER DEMAND BY ORCHARDS						
% Acres Watered	75%	75%	75%	75%	75%	
Year	**Apples**	**Cherries**	**Pears**	**Prunes & Plums**	**Peaches**	**Total**
1890	809	23	0	44	2	878
1900	18,997	384	443	1,747	103	21,674
1910	18,417	518	299	625	266	20,125
1920	49,232	665	448	567	314	51,226
1930	9,223	246	250	205	64	9,988
1940	4,162	93	178	107	10	4,550
1950	2,571	95	85	135	22	2,908
1954	626	118	31	60	8	843

Ag Diversions

(Using Orchard Statistics to Estimate Demands)

AVERAGE DAILY WATER DEMAND (cfs) BY ORCHARDS DURING 4-MONTH GROWING SEASON

Year	Apples	Cherries	Pears	Prunes & Plums	Peaches	Total	Water Supply Needed @ 50% Irrigation Efficiency
1890	3.32	0.09	0.00	0.18	0.01	3.60	7.20
1900	77.87	1.57	1.82	7.16	0.42	88.84	177.68
1910	75.49	2.12	1.23	2.56	1.09	82.49	164.98
1920	201.80	2.73	1.84	2.32	1.29	**209.97**	**419.94**
1930	37.80	1.01	1.02	0.84	0.26	40.94	81.88
1940	17.06	0.38	0.73	0.44	0.04	18.65	37.30
1950	10.54	0.39	0.35	0.55	0.09	11.92	23.84
1954	2.57	0.48	0.13	0.25	0.03	3.46	6.91

Conclusion:

The unlined Corbin Ditch likely moved 150 to 200 cfs of water by 1920 based on:

1) Manning calculations (125 to 225 cfs for an unlined canal)
2) Valley-wide ag water demand (210 cfs) needed from Corbin Ditch and other canals
3) Potential irrigation efficiency of 50% for all canals in early years (420 cfs)
4) USGS plot showing Corbin Ditch flow of about 150 cfs in 1920 (before 1922 lining event)

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Information Sources

Key Historical Documents

Fahey, J. 1965. *Inland Empire: D.C. Corbin and Spokane.* University of Washington Press (Seattle, WA). 270 p.

Boutwell, F. 1994. *The Spokane Valley: A History of the Early Years.* The Arthur H. Clark Company, Spokane, Washington, 194 pp.

Boutwell, F. 1995. *The Spokane Valley: Volume 2, A History of the Growing Years, 1921-1945.* The Arthur H. Clark Company, Spokane, Washington, 224 pp.

Renk, N.F. 2002. *National Register of Historic Places Registration Form and Continuation Sheet: Spokane Valley Land and Water Company Canal.* Prepared by Flume Creek Historical Services. August 12, 2002.

Washington State Department of Agriculture. 1956. *Spokane County Agriculture, Washington.* County Agricultural Data Series 1956. Prepared with assistance from U.S. Department of Agriculture and Washington Crop and Livestock Reporting Service.

Information Sources

Key Hydrologic Reports

Hortness, J.E. and J.J. Covert. 2005. *Streamflow Trends in the Spokane River and Tributaries, Spokane Valley/Rathdrum Prairie, Idaho and Washington.* U.S. Geological Survey Scientific Investigations Report 2005-5005, 17 p.

Caldwell, R.R. and C.L. Bowers. 2003. *Surface-Water/Ground-Water Interaction of the Spokane River and the Spokane Valley-Rathdrum Prairie Aquifer, Idaho and Washington.* U.S. Geological Survey Water Resources Investigations Report 03-4239, 60 p.

Kahle, S.C., Caldwell, R.R., and J. R. Bartolino. 2005. *Compilation of Geologic, Hydrologic, and Ground-Water Flow Modeling Information for the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho.* U.S. Geological Survey Scientific Investigations Report 2005-5227, 64 p.

Spokane County Water Resources. 2013. *Spokane County Water Demand Forecast Model: Model 3.0 and 2013 Forecast Update.* June 2013.

Information Sources

Key Data Sets

Streamflow data: Spokane Gage and Post Falls Gage

Coeur d'Alene Lake stage data and temperature data

Precipitation, temperature, and snow data: Spokane Airport and Coeur d'Alene

Census data: City of Spokane, Spokane County, City of Coeur d'Alene, Kootenai County

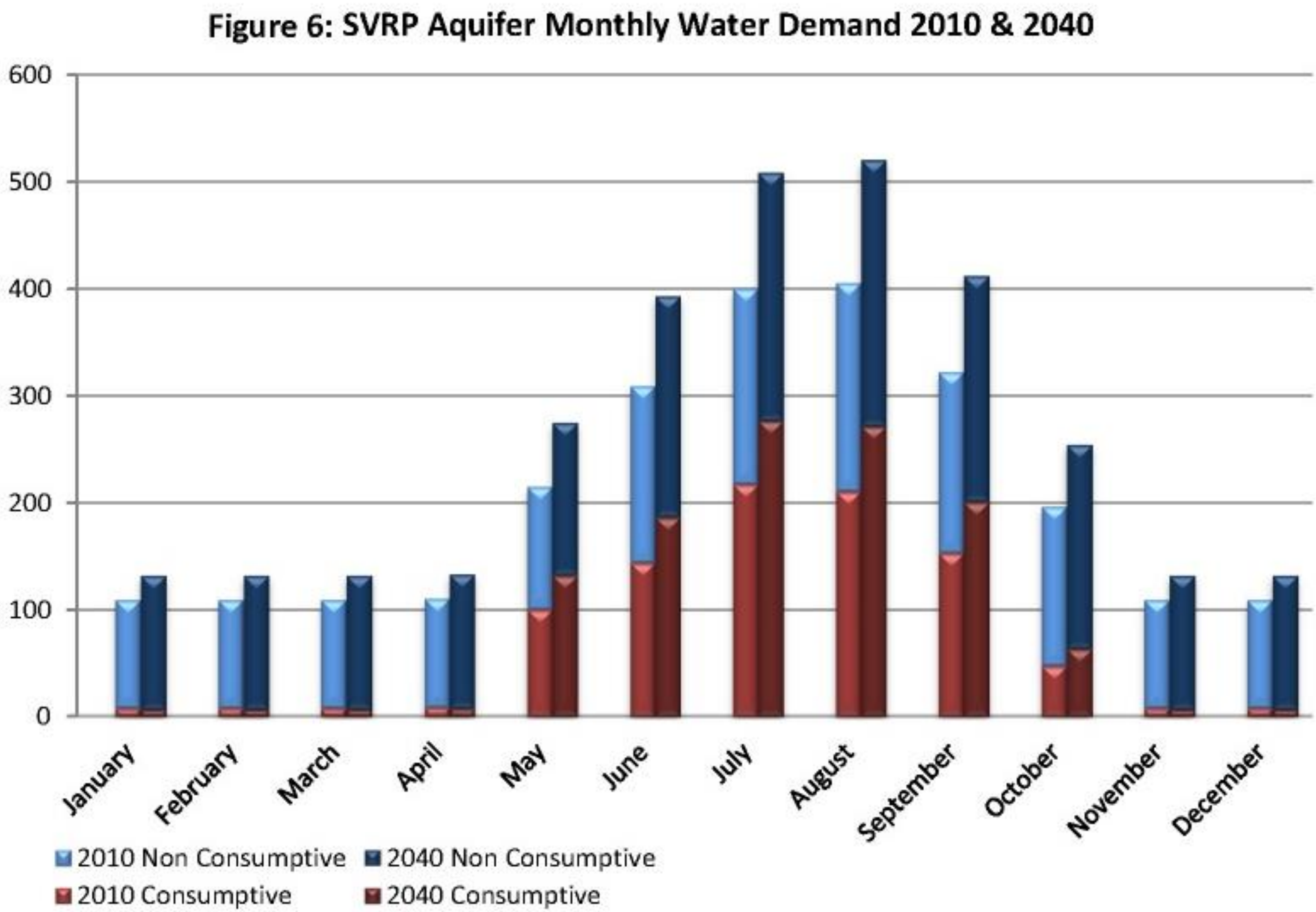
Water use data: City of Spokane, Spokane County water demand model

Water reclamation plant discharge data: City of Spokane

Groundwater Pumping
(Municipal and Industrial)

- Indoor (non-consumptive) uses
  - Industrial use (96% non-consumptive per SPK Co. model)
  - Indoor municipal use (return flows to river/aquifer system)
  - Currently 63% of water use (SPK Co. water demand model)
  - Assume 100% of M&I water use was indoors before 1921
    - Electricity and indoor plumbing rare in SPK Valley before 1921
    - Washing machines and other conveniences were reported to exist in those homes by about 1921, with presumed discharges
    - Assume this was accompanied by slow increase in outdoor use
  - Assume a gradual decrease in the indoor use %
    - From 100% of total water use in 1920 to the current ratio of 63% by the mid-1930s (as the Great Depression came to a close)
  - Less monthly variation than outdoor (consumptive) use

Current Seasonality of Groundwater Demands



Source: *Spokane County Water Demand Forecast Model: Model 3.0 and 2013 Forecast Update.*
Prepared by Spokane County Water Resources, June 2013.

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Groundwater Pumping
(Municipal and Industrial)

- Outdoor (consumptive) uses
  - Strongly seasonal
    - Strong peak July and August
    - Modest May-June and September-October
    - Minimal November-April
  - Currently 37% of annual SVRP use
    - From the 2013 Spokane County water demand model

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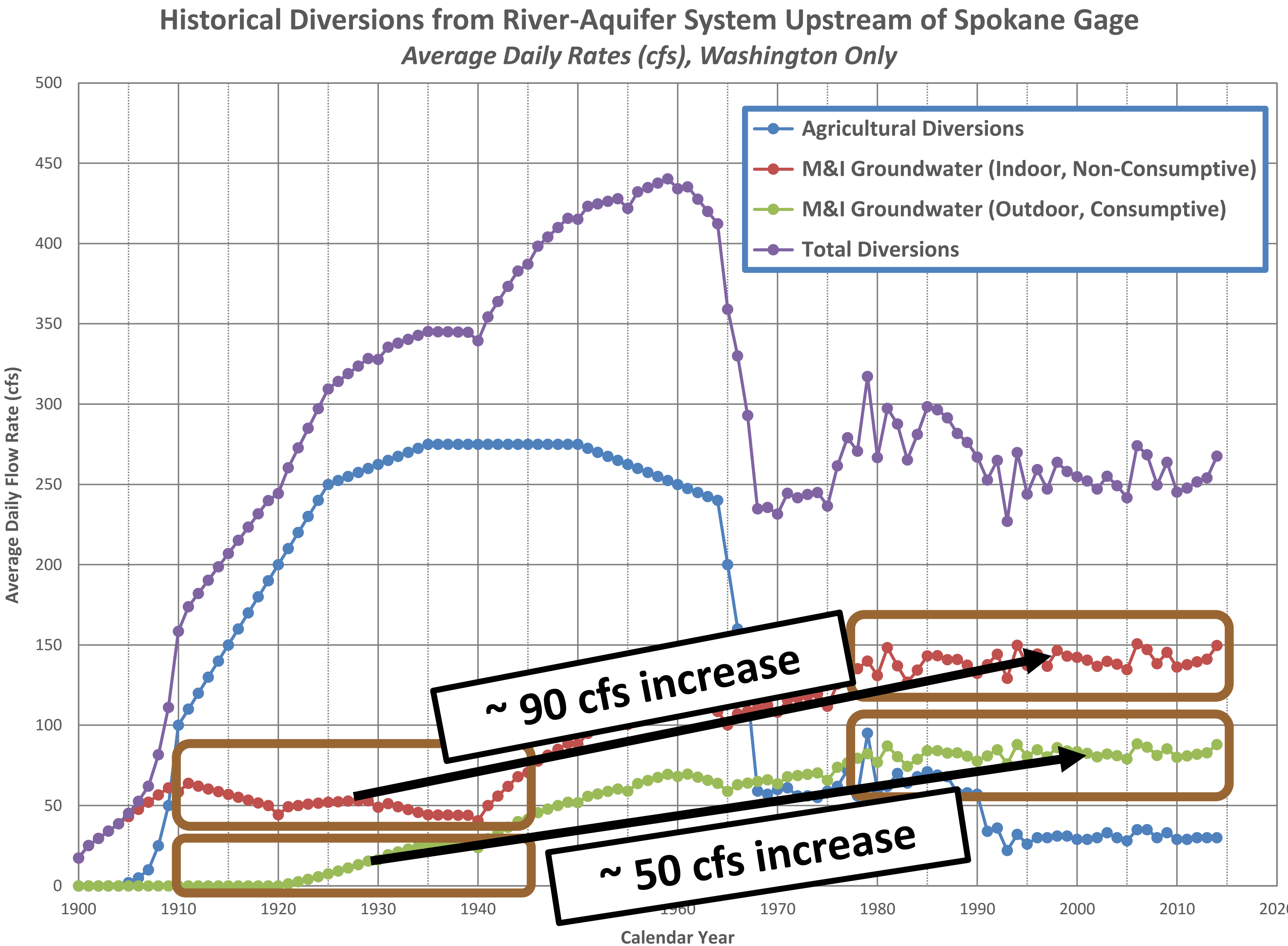

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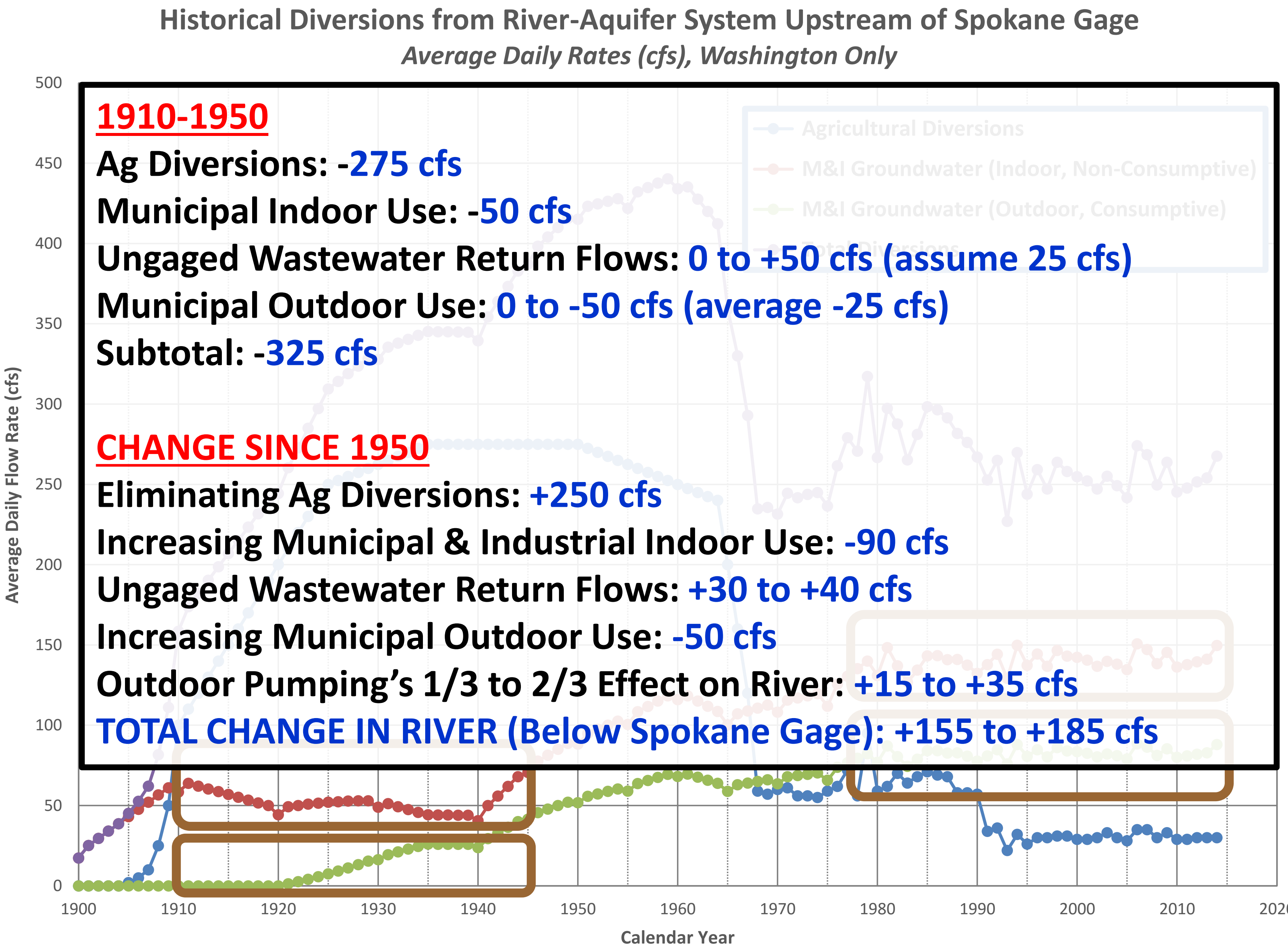

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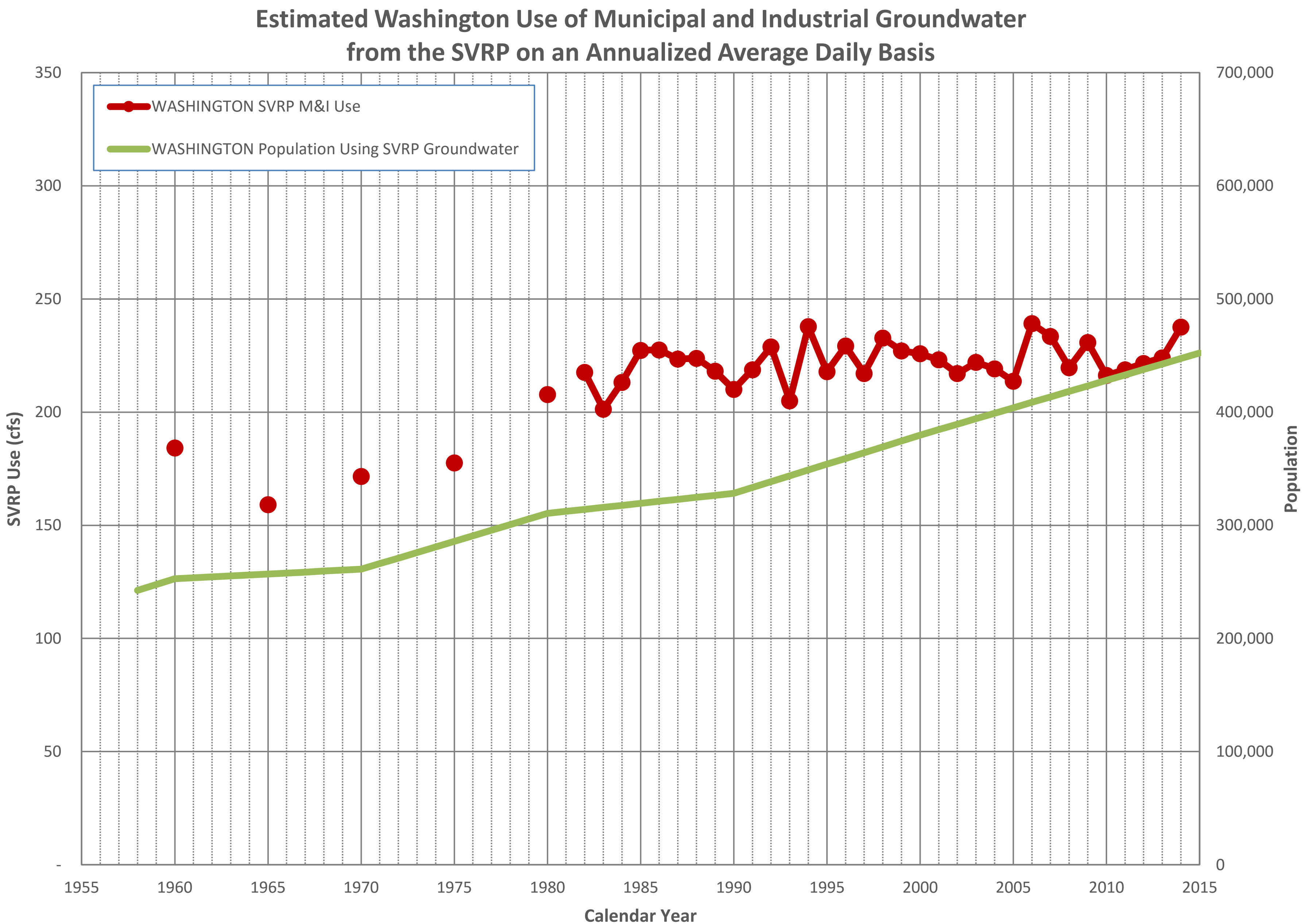

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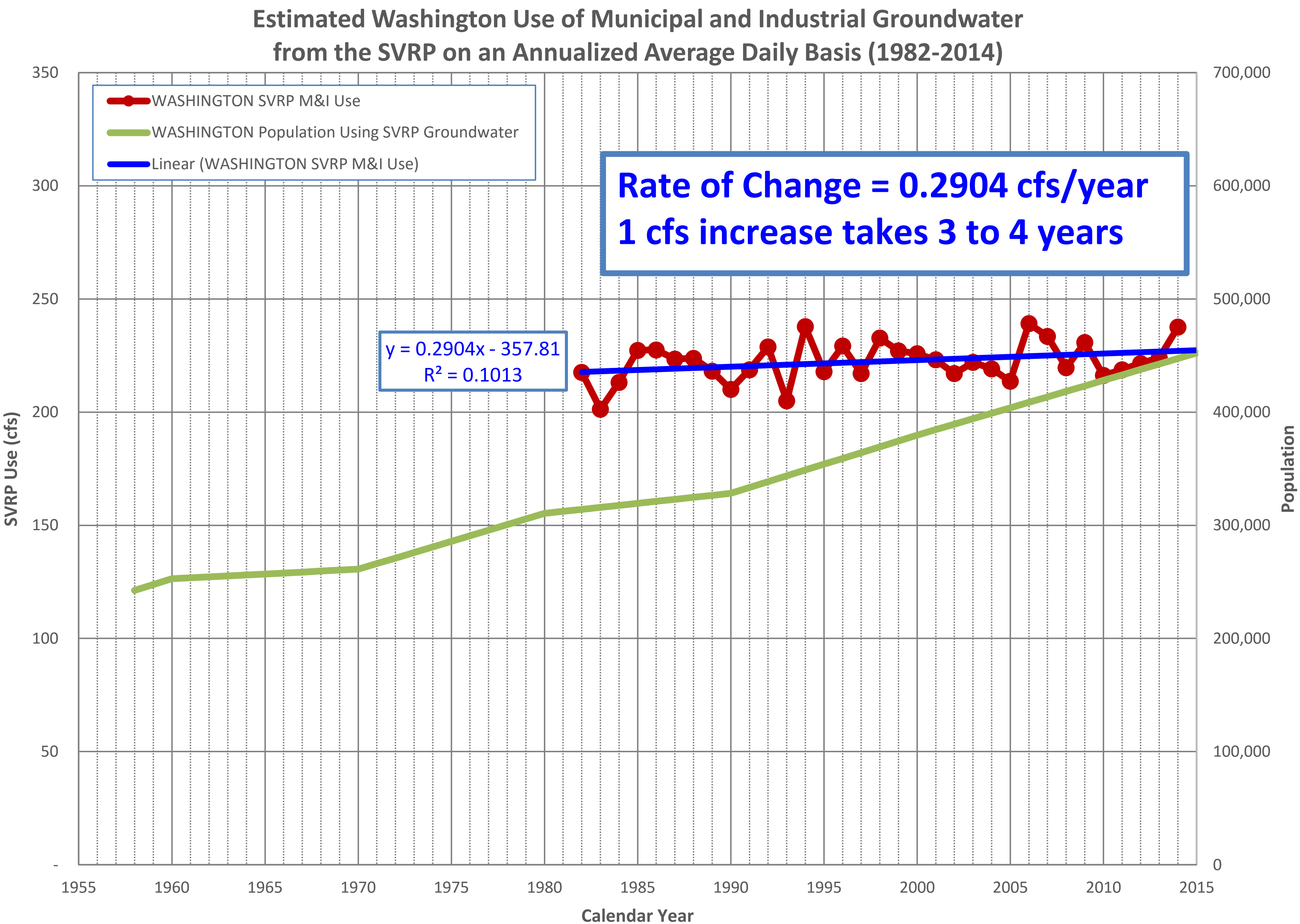

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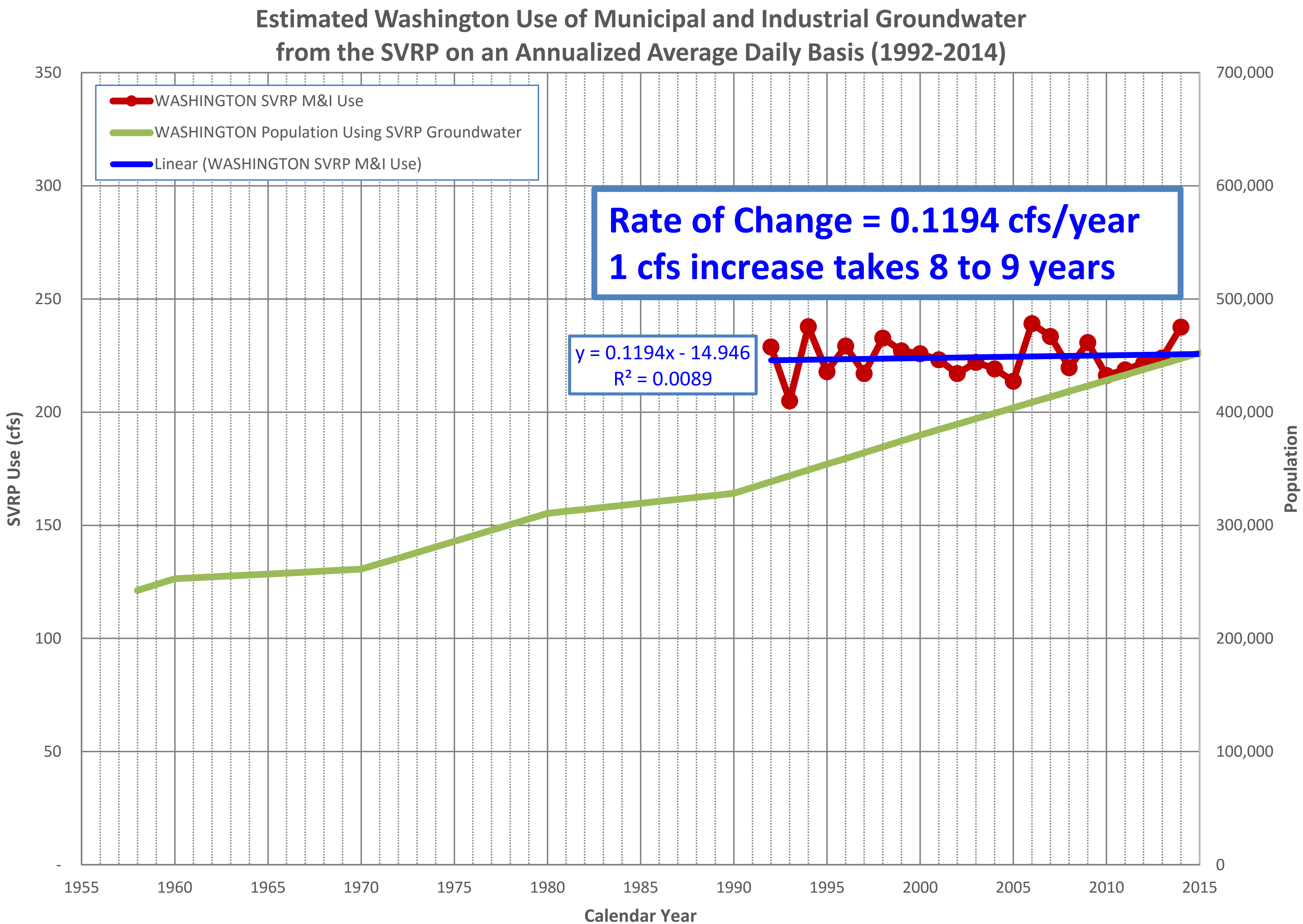

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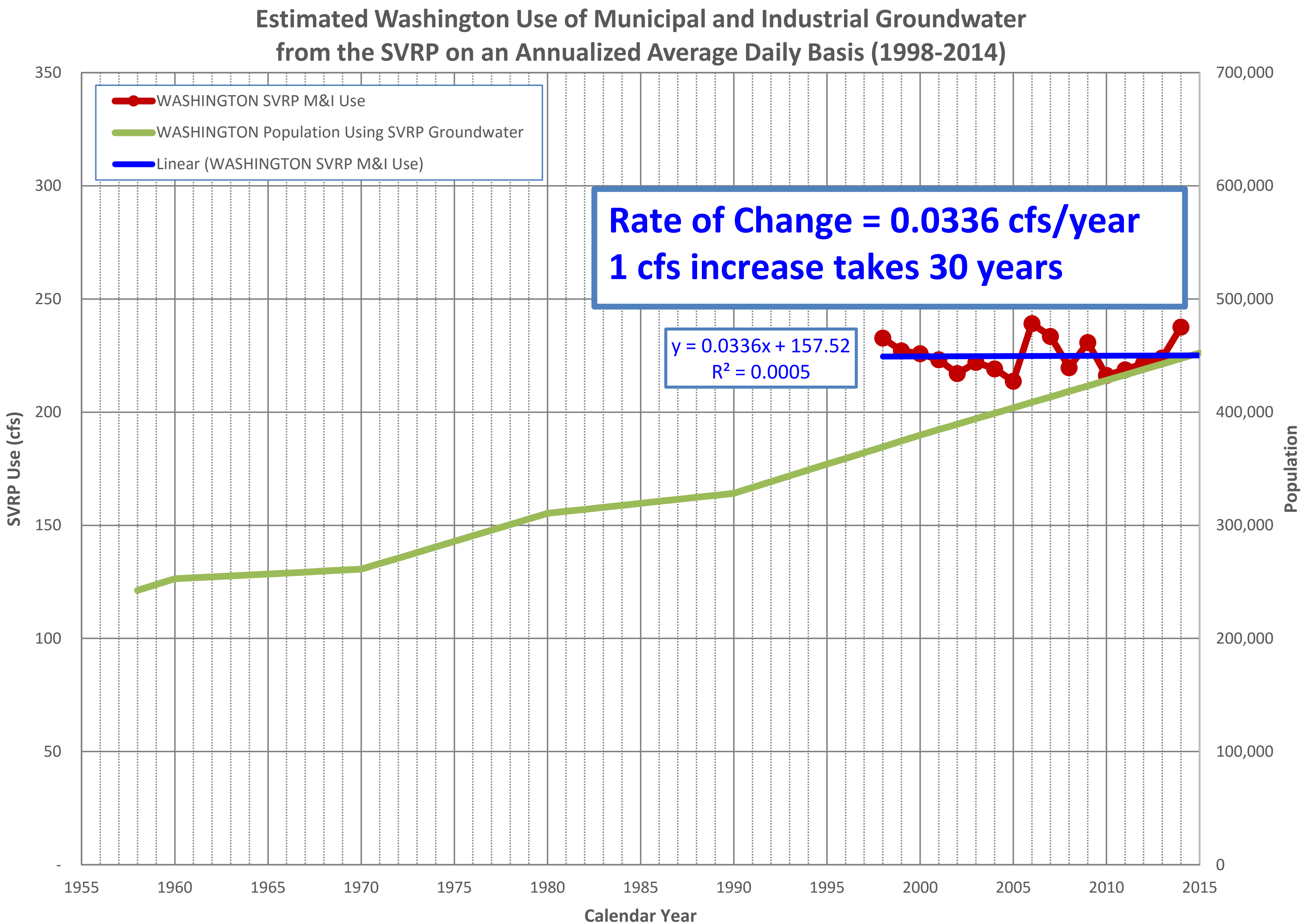

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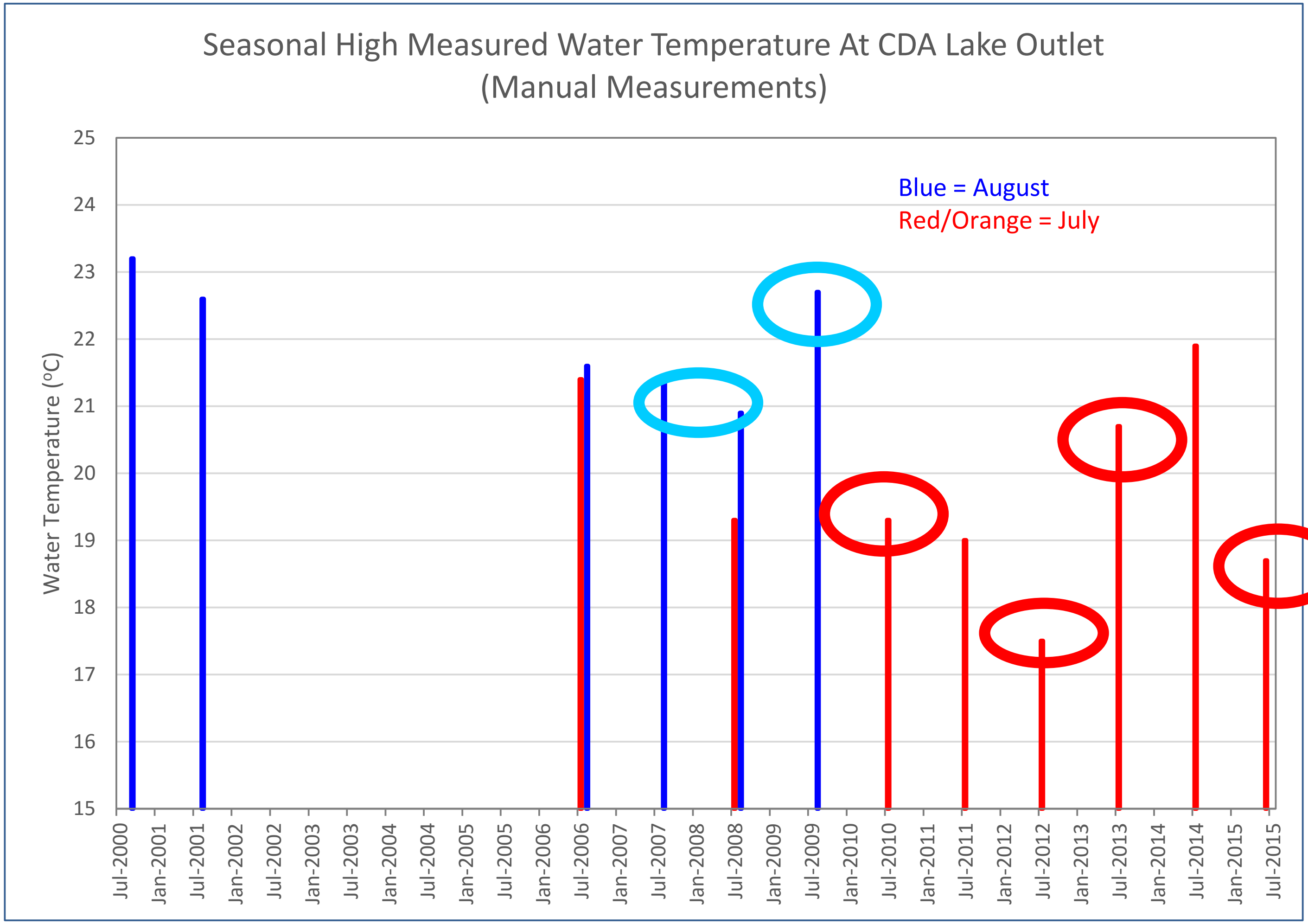
River Water Temperature
(Riverbed Seepage Rates in Losing Reach Below Post Falls)

Effect of Increasing Water Temperature

1. Lower density
2. Lower dynamic viscosity
3. Higher riverbed hydraulic conductivity
4. Higher seepage rates and streamflow loss

River Water Temperature

(Riverbed Seepage Rates in Losing Reach Below Post Falls)



An August Increase from 21°C to 23°C → Multiply Seepage Rate by 1.048

A July Decrease from 20°C to 18°C → Multiply Seepage Rate by 0.904

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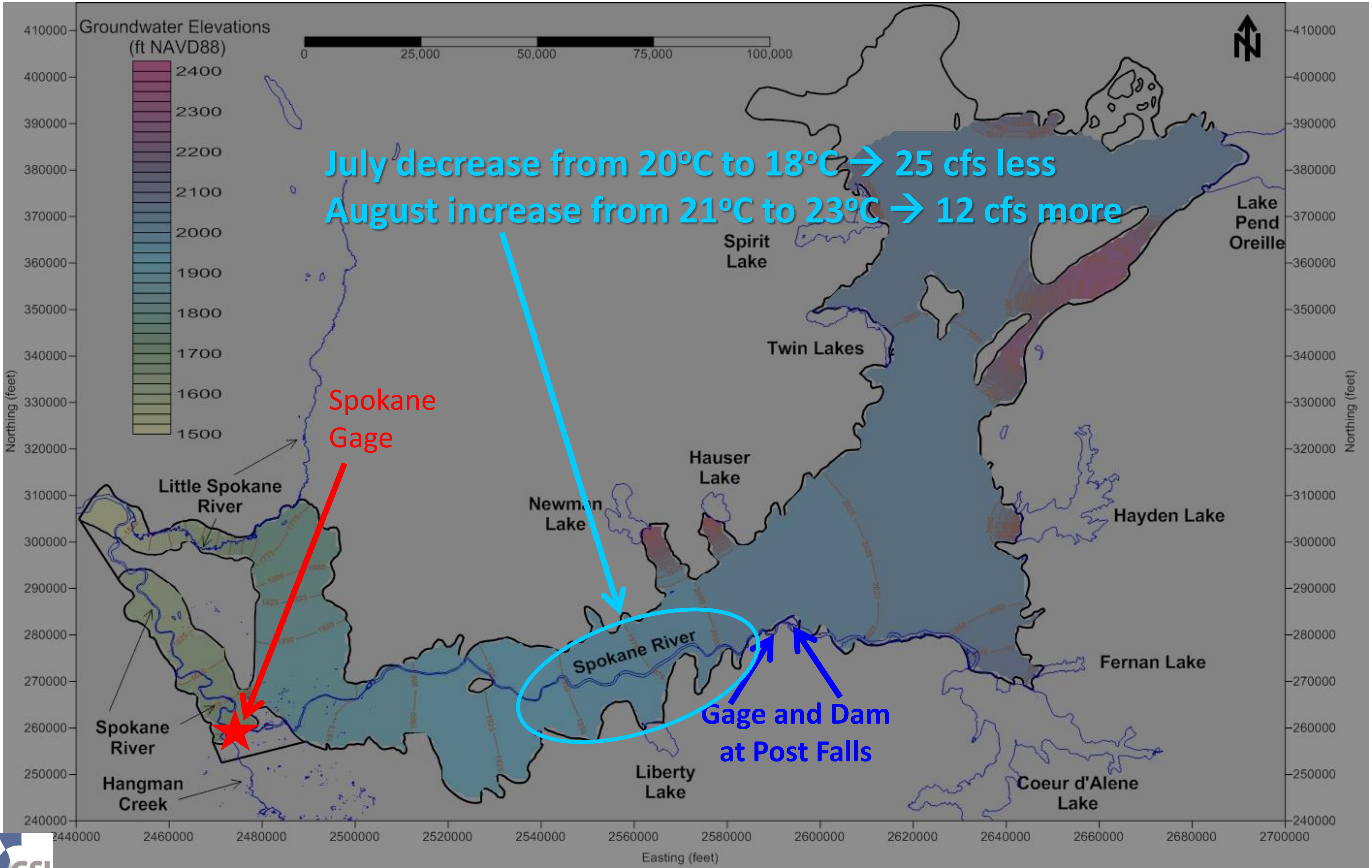
River Water Temperature

(Riverbed Seepage Rates in Losing Reach Below Post Falls)



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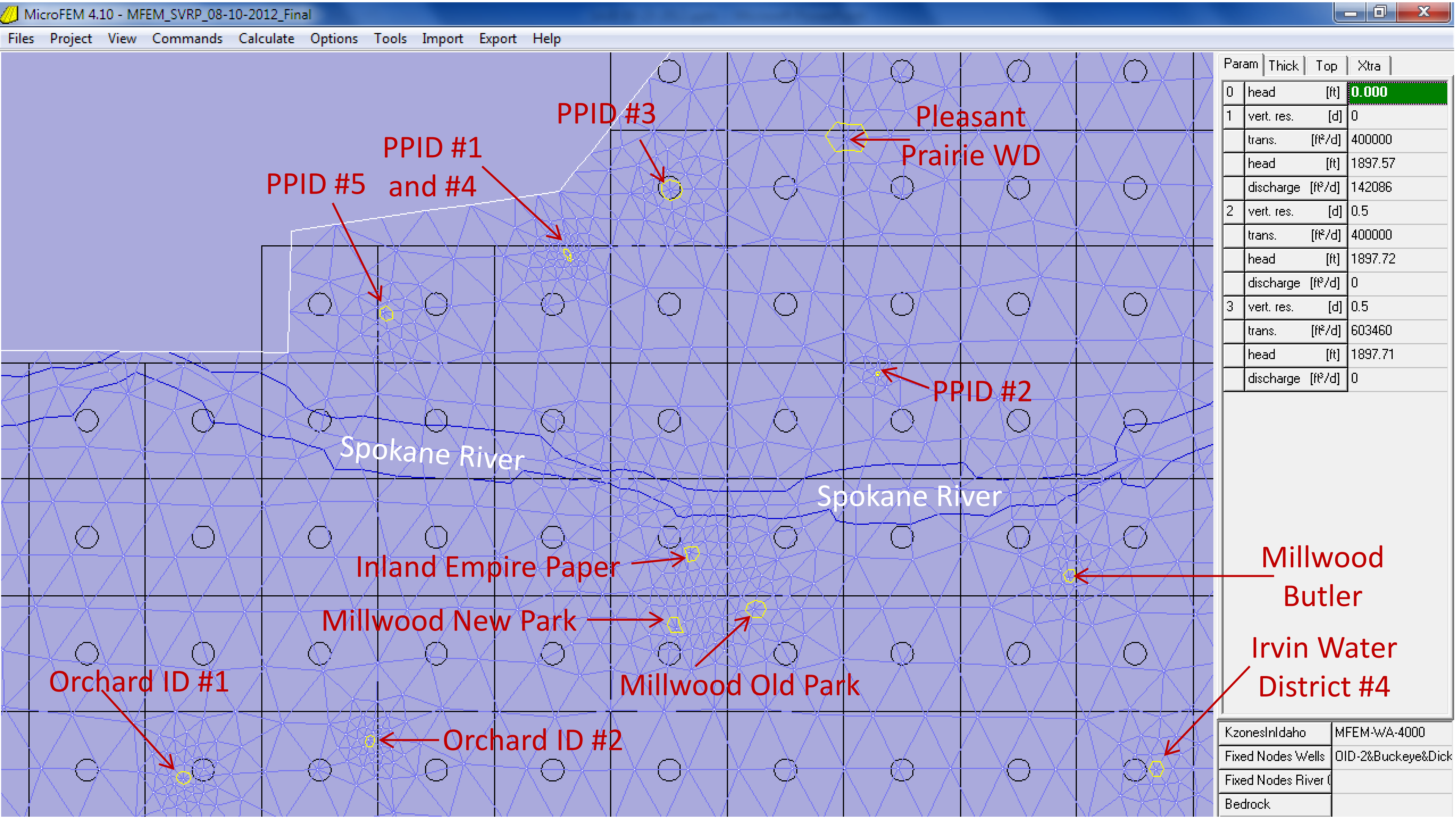
SAJB and Bi-State Model Grids at Wells Owned by PPID, OID, and Millwood



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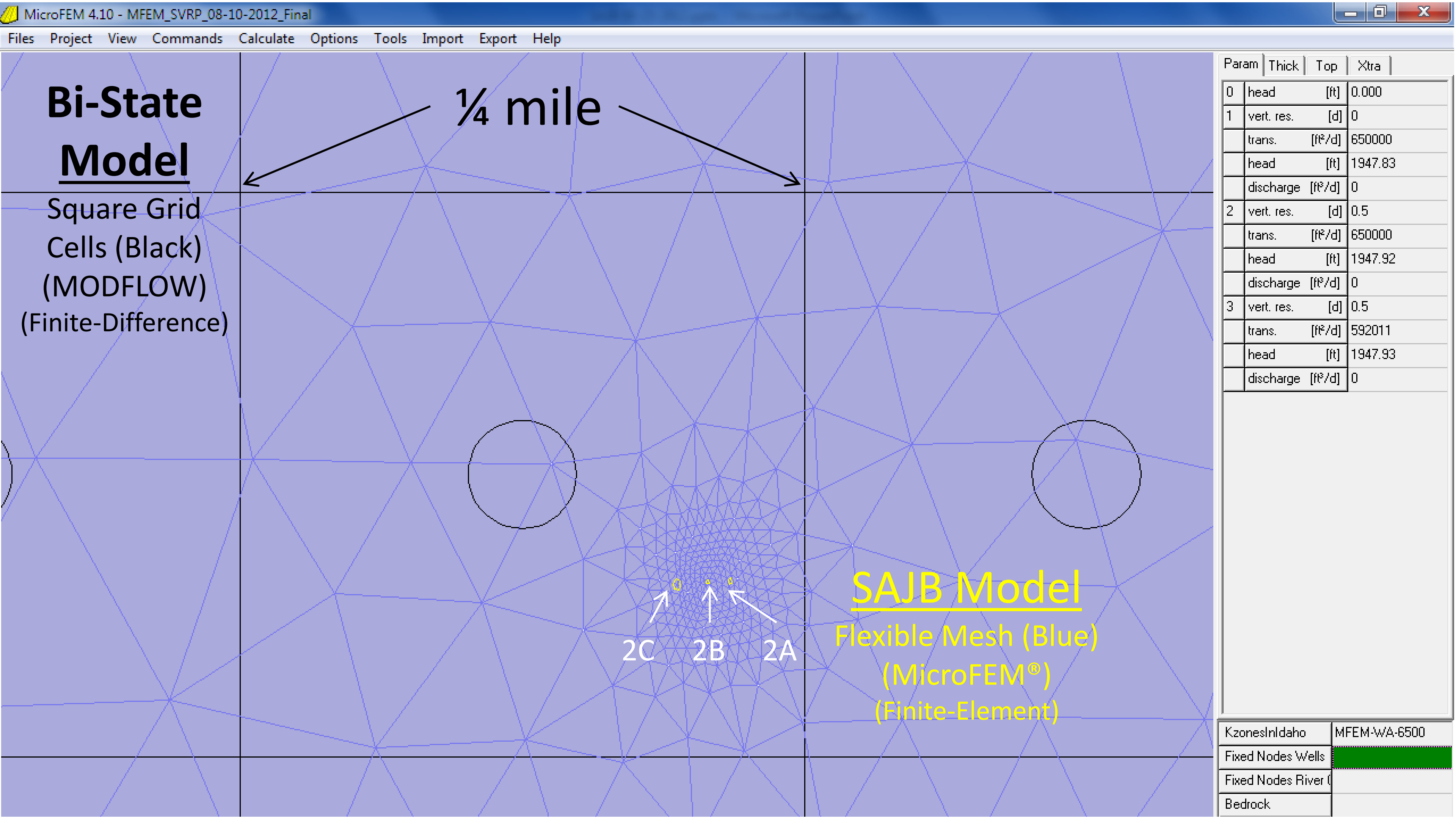
SAJB and Bi-State Model Grids at CID-2 Wellfield



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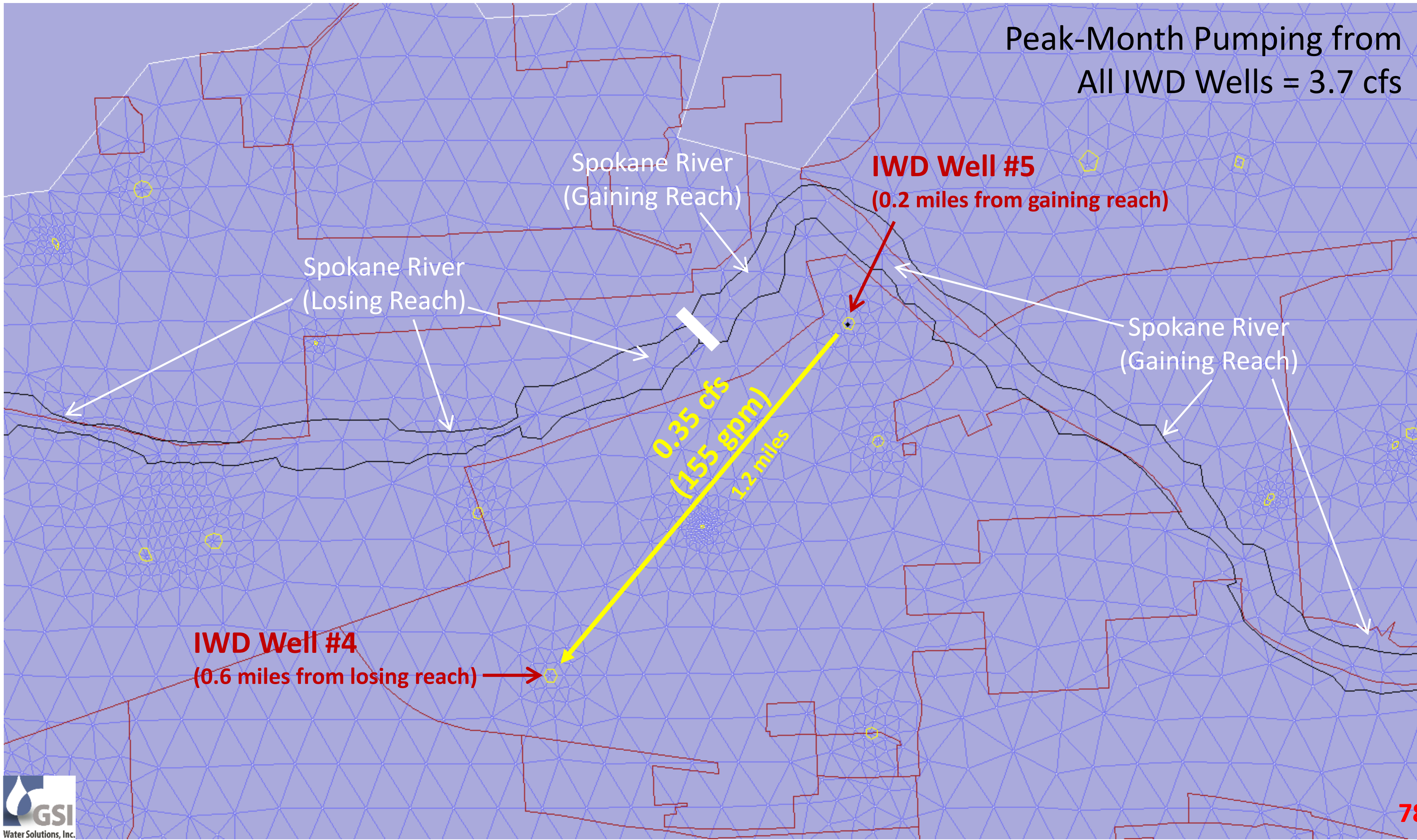
Irvin Water District

(Move From Cement Well 5 To Montgomery Well 4)
(Move Up To 0.35 cfs = 10% Of Peak Pumping)



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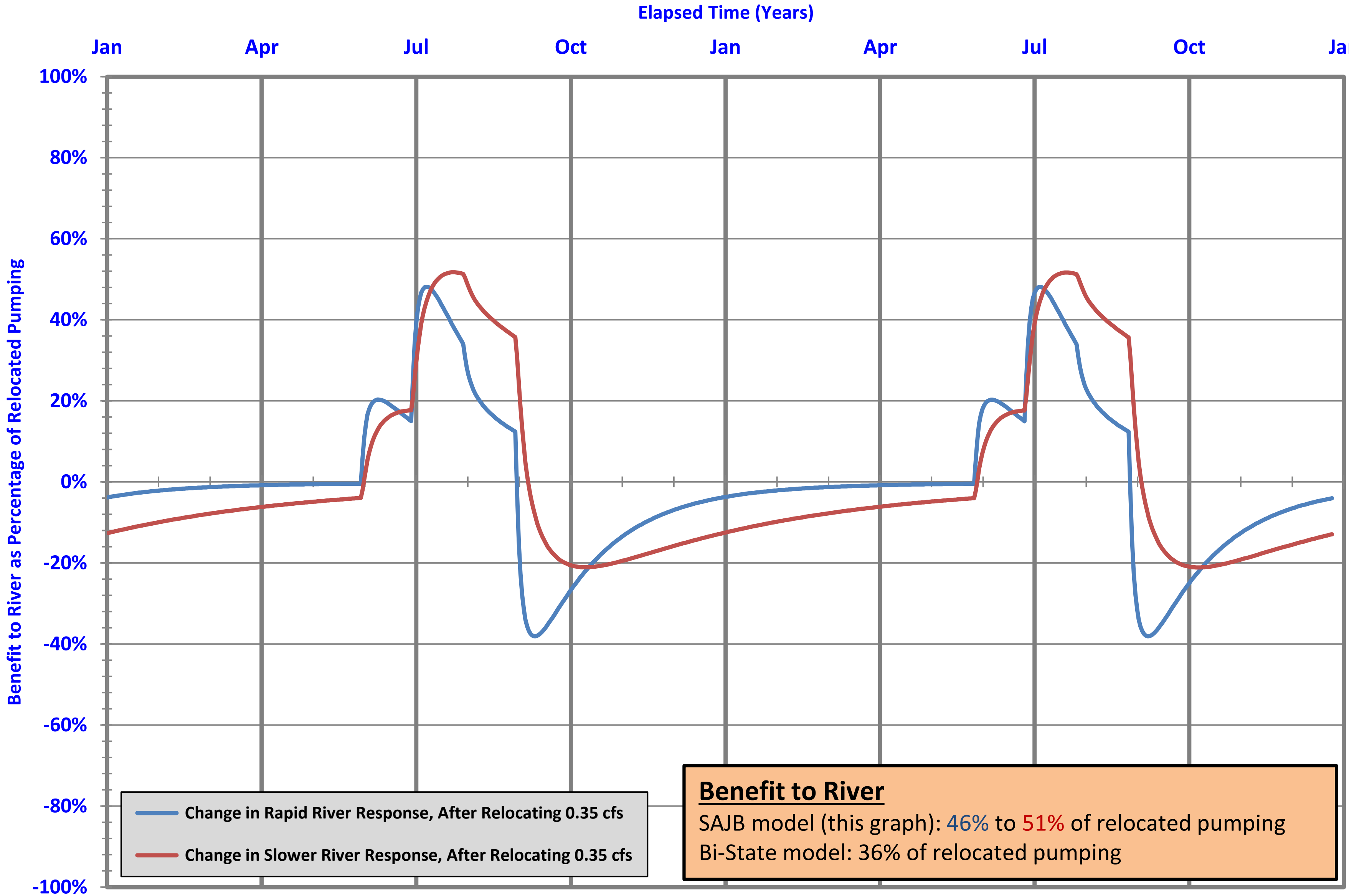
Percent Change in Spokane River Response Relative to Seasonal Pumping Relocation - IWD



Benefit to River

SAJB model (this graph): 46% to 51% of relocated pumping

Bi-State model: 36% of relocated pumping

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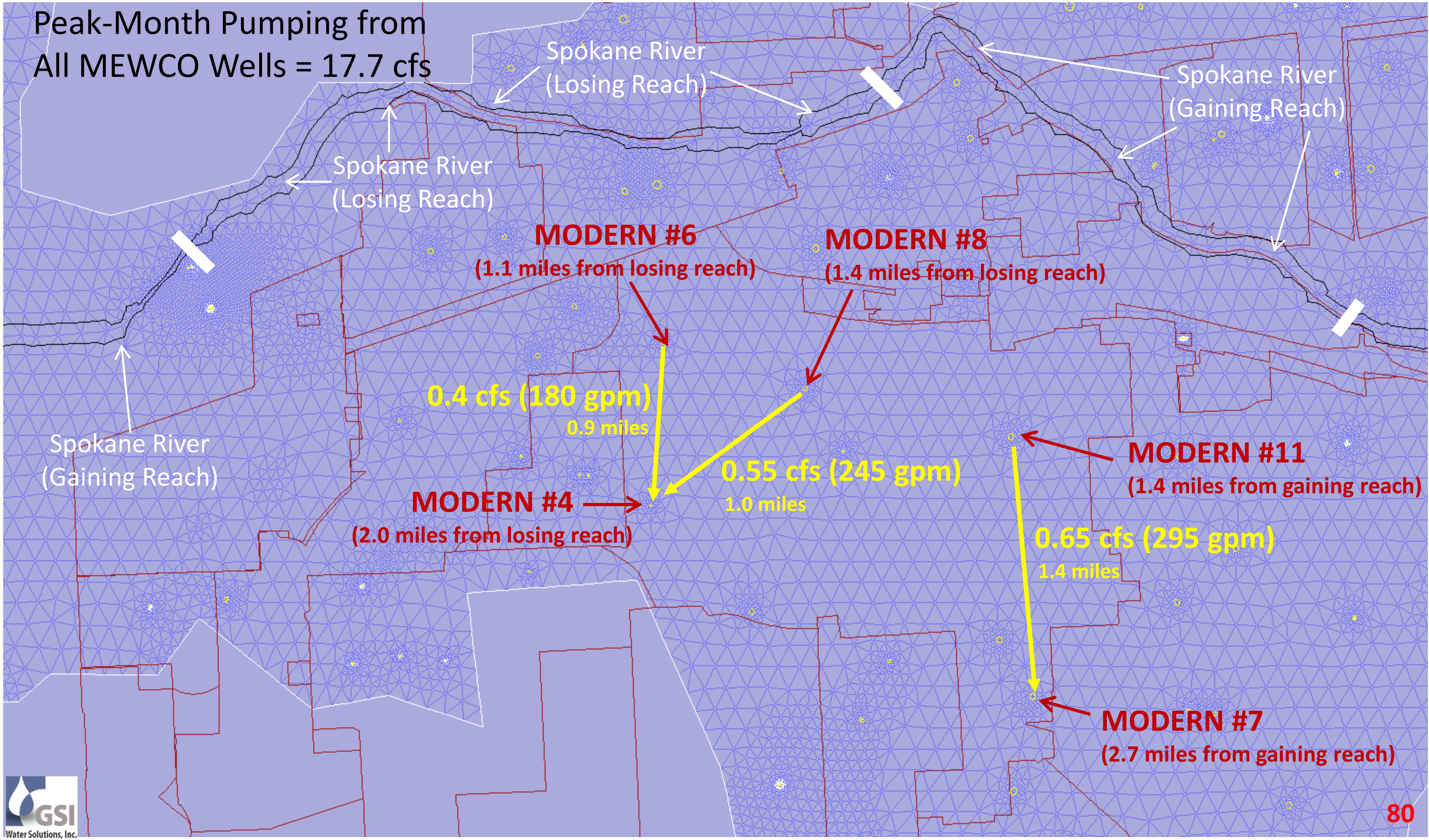
Modern Electric Water Company

(Move From Wells 6, 8, & 11 To Wells 4 & 7)

(Move Up To 1.6 cfs = 9% Of Peak Pumping)



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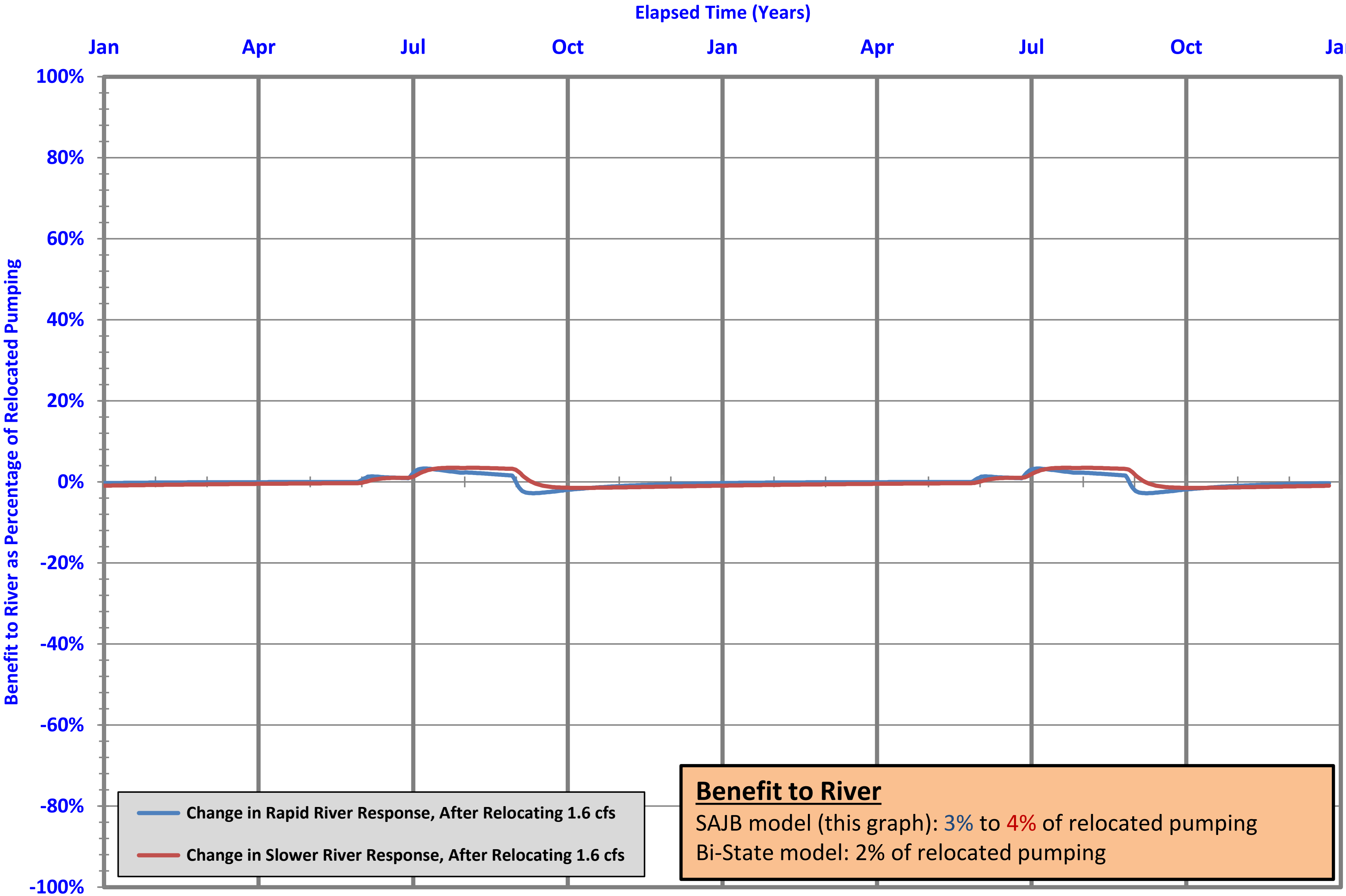
Percent Change in Spokane River Response Relative to Seasonal Pumping Relocation - MEWCO



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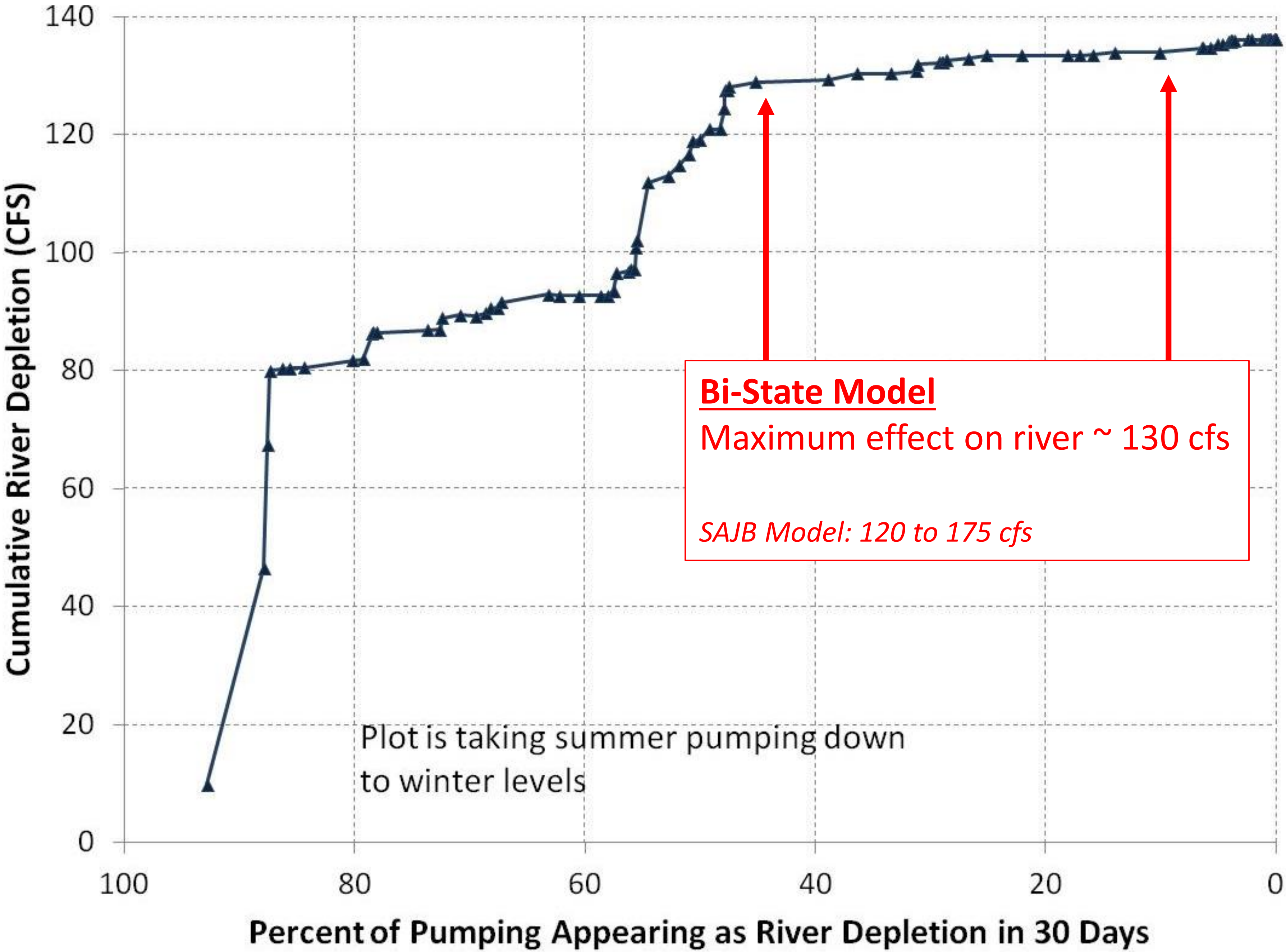

Analysis by Ralston Hydrologic Services, Inc.