Screening-Level Analysis: Causes of Historical Changes in Seasonal Low Flows in the Spokane River

Prepared for

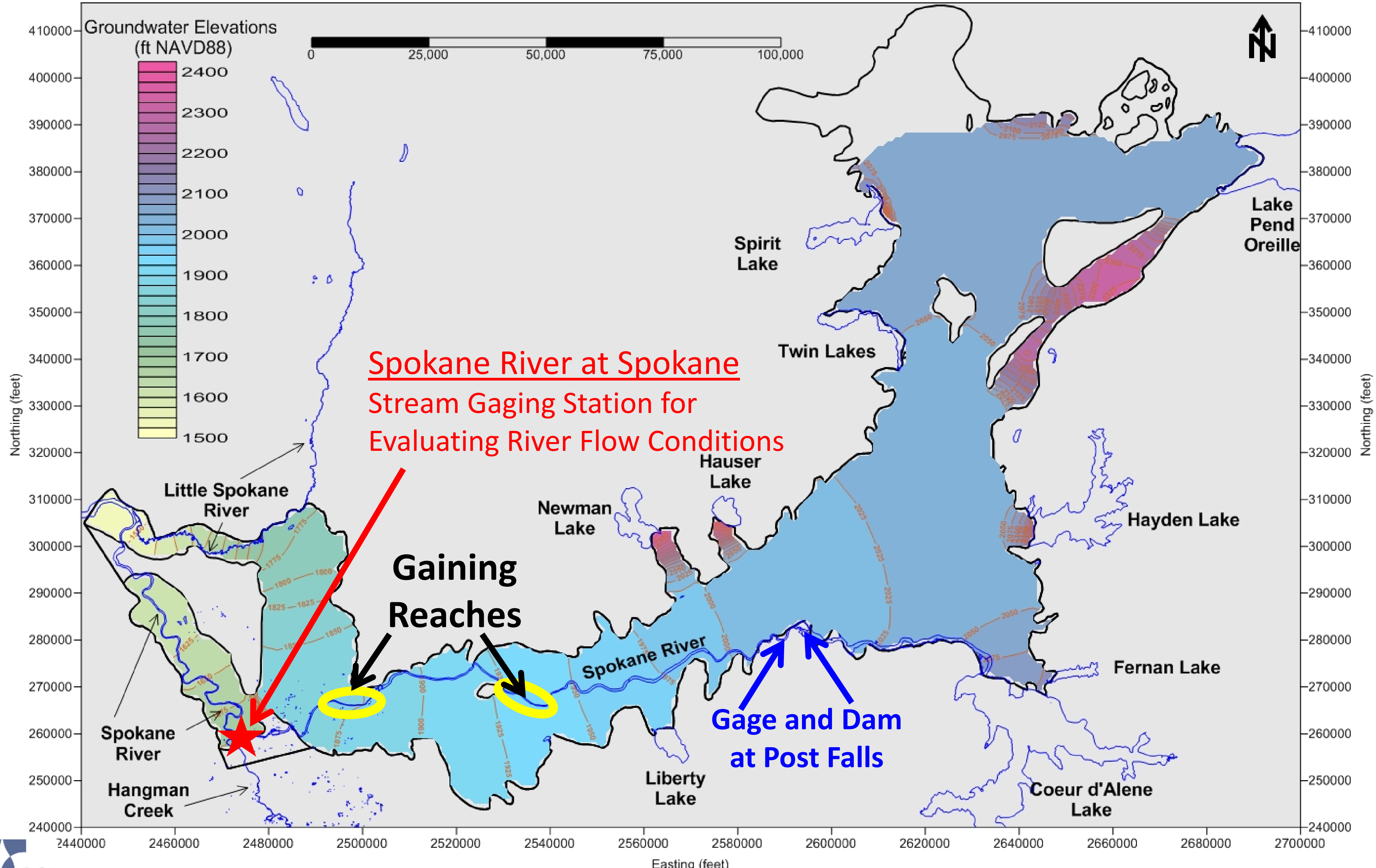
Spokane Aquifer Joint Board

Prepared by

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

December 3, 2015

Groundwater Elevations and Gaining Reaches of the Spokane River



Topics

1. Why evaluate historical changes
2. Define processes that theoretically could have been the cause of decreasing river low flows
3. Evaluate each process in depth (many slides)
4. Conclusions regarding dominant processes and what it all means

Why Evaluate Historical Changes?

1. Current ongoing concern about declining low flows, and what can be done about them

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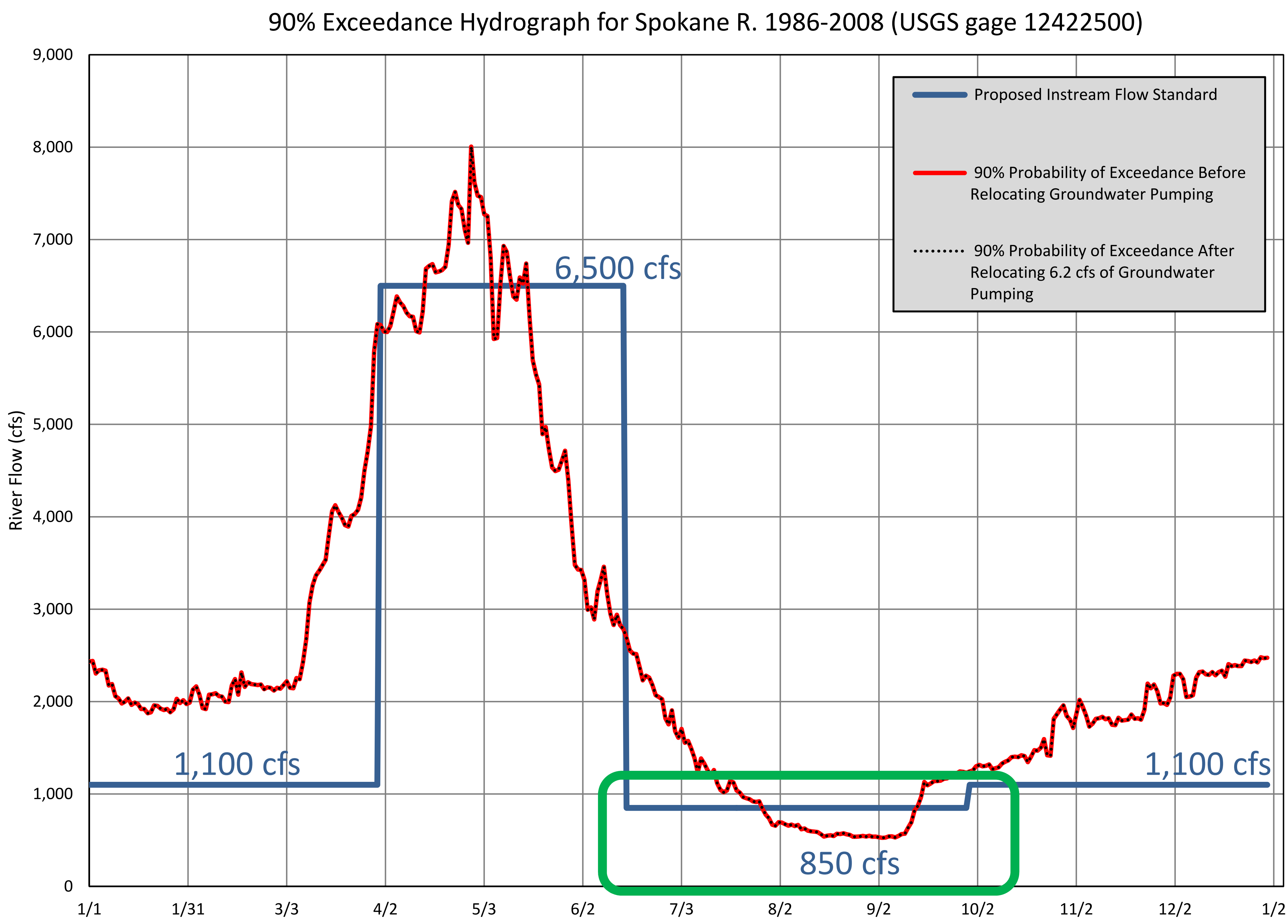
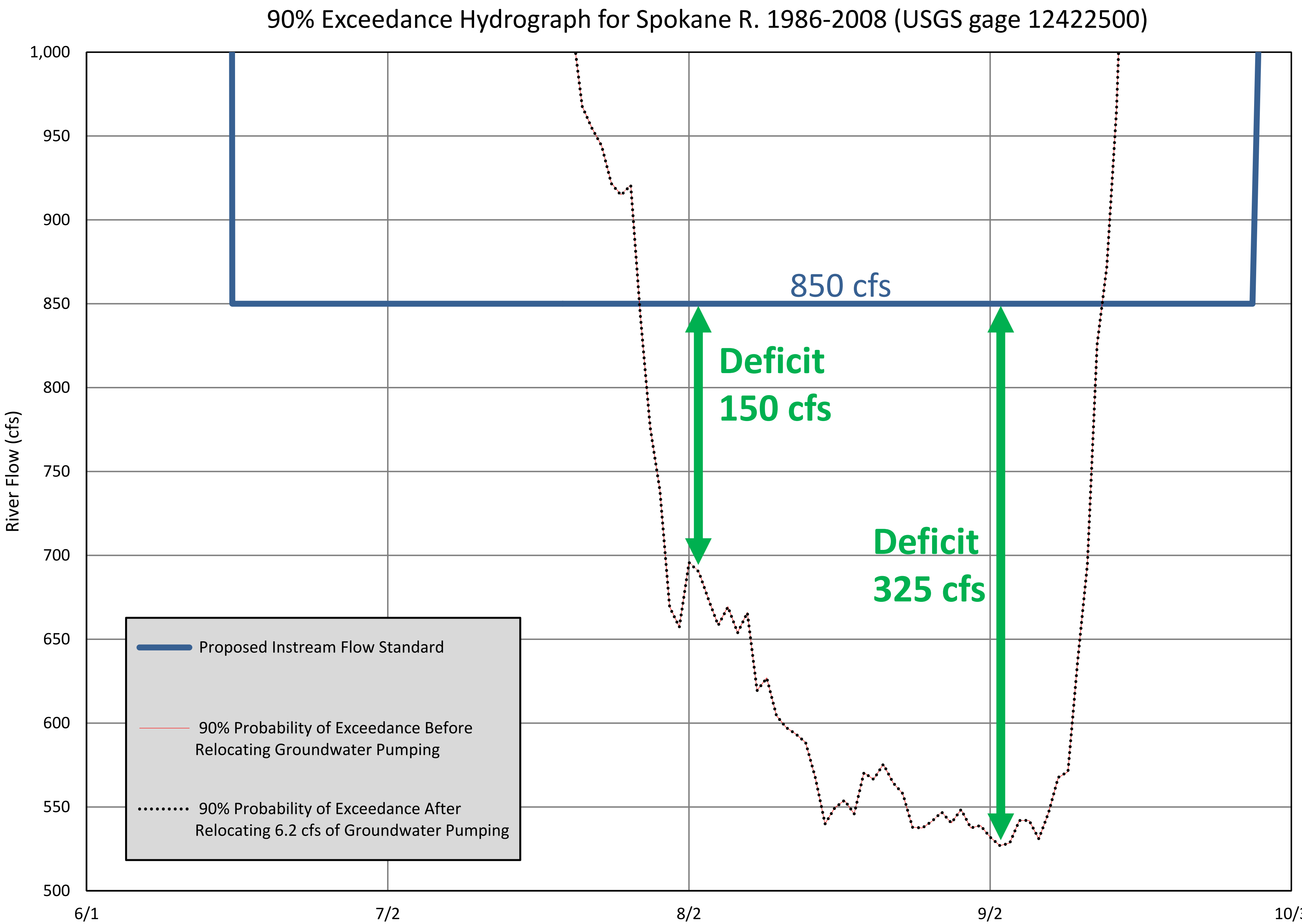


90% Exceedance Hydrograph for Spokane R. 1986-2008 (USGS gage 12422500)
River Flow (cfs)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1/1
1/31
3/3
4/2
5/3
6/2
7/3
8/2
9/2
10/2
11/2
12/2
1/2
Proposed Instream Flow Standard
90% Probability of Exceedance Before Relocating Groundwater Pumping
90% Probability of Exceedance After Relocating 6.2 cfs of Groundwater Pumping
6,500 cfs
1,100 cfs
1,100 cfs
850 cfs



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Why Evaluate Historical Changes?

2. Peak-season groundwater pumping is not the sole cause of the declines (two prior studies)
   - GSI, 2014 (using City/SAJB model)
   - Ralston Hydrologic Services, 2014 (using USGS model)

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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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Why Evaluate Historical Changes?

3. Low river flows are a concern not only at the Spokane Gage, but upstream too

Losing Reach at Greenacres
August 2003

River Not Connected to Aquifer,
Cannot Be Impacted by Changes in Groundwater Pumping

First Gaining Reach (at Sullivan Road)
August 2003

Connection to Aquifer Just Beginning,
More Gaining Reaches Downstream

Source: *Spokane Valley – Rathdrum Prairie Aquifer Atlas 2015 Edition*

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1. Why evaluate historical changes
2. Define the processes that theoretically could change river low flows
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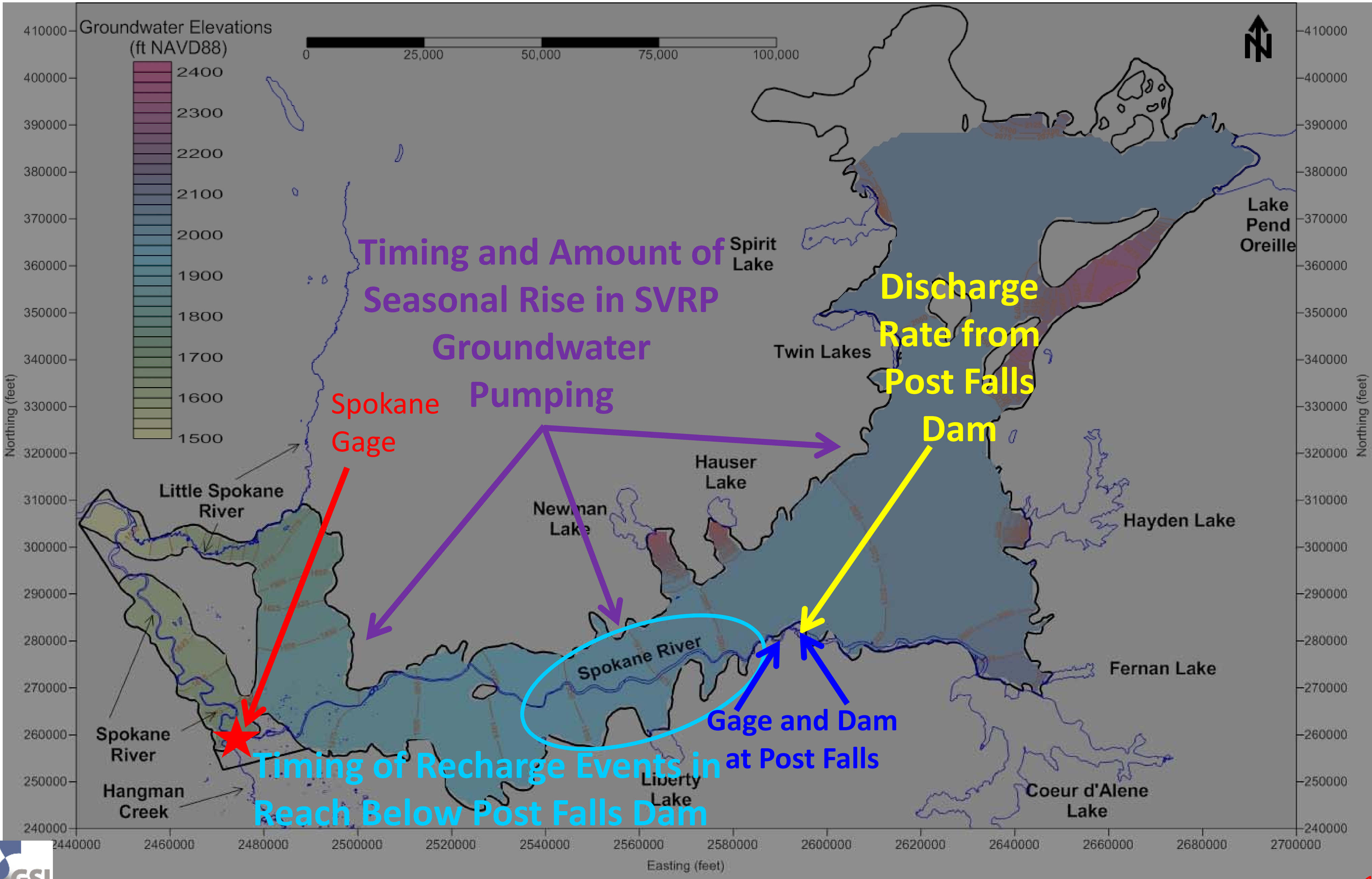
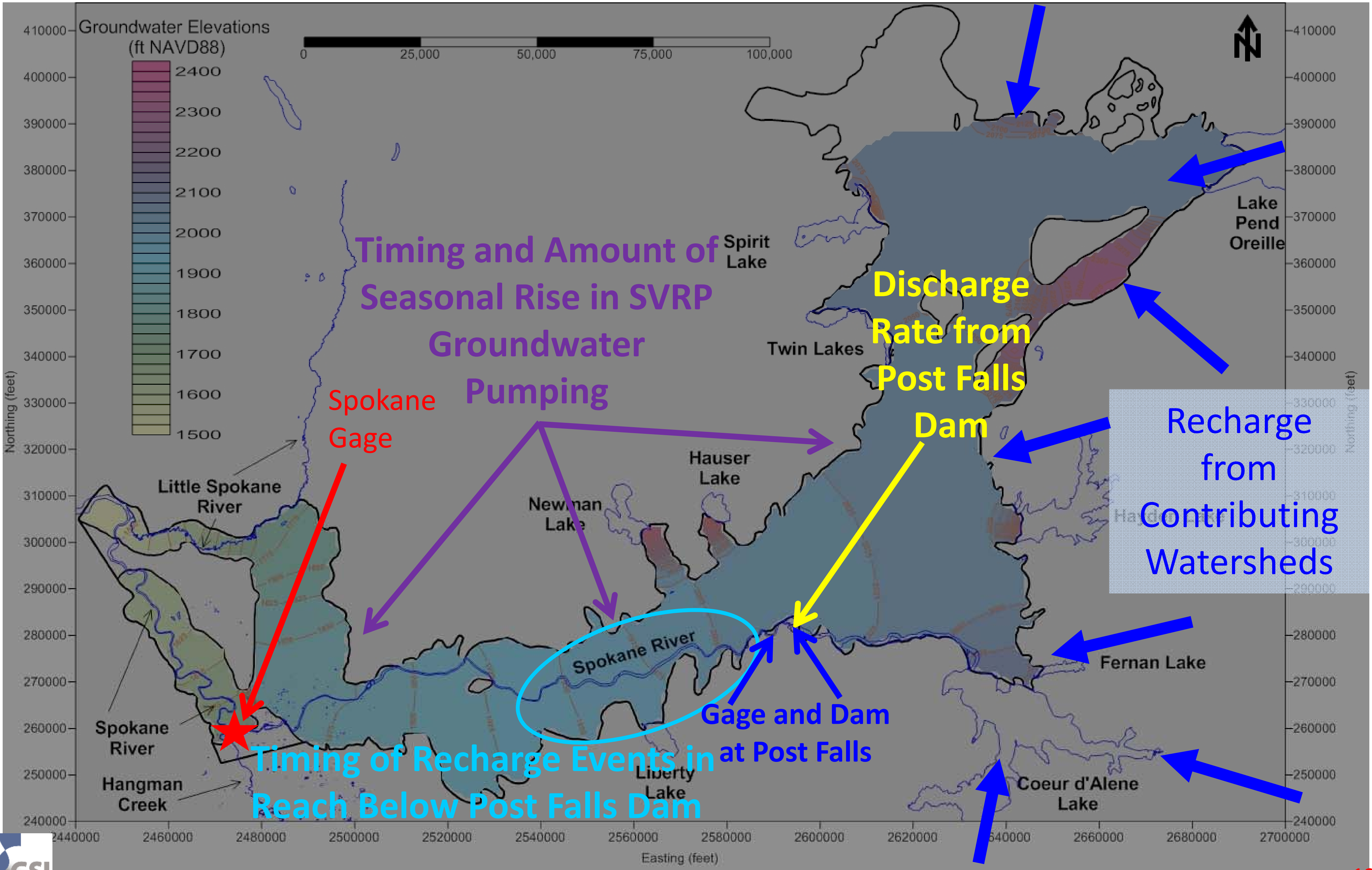
Prior Studies Found Three Factors Controlling August Low Flows at the Spokane Gage

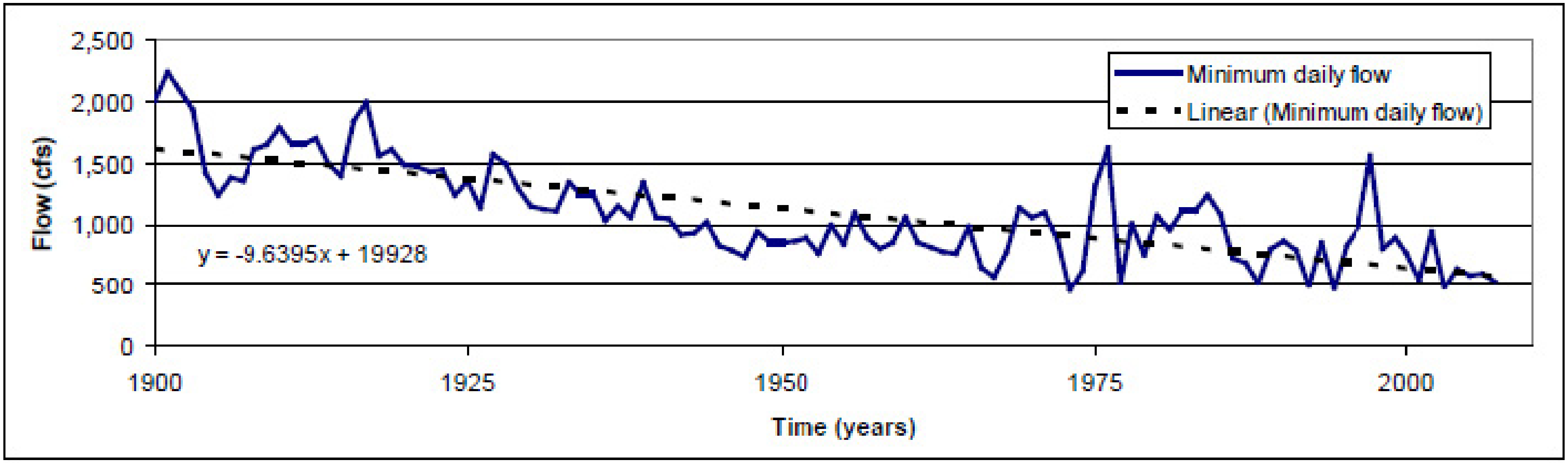


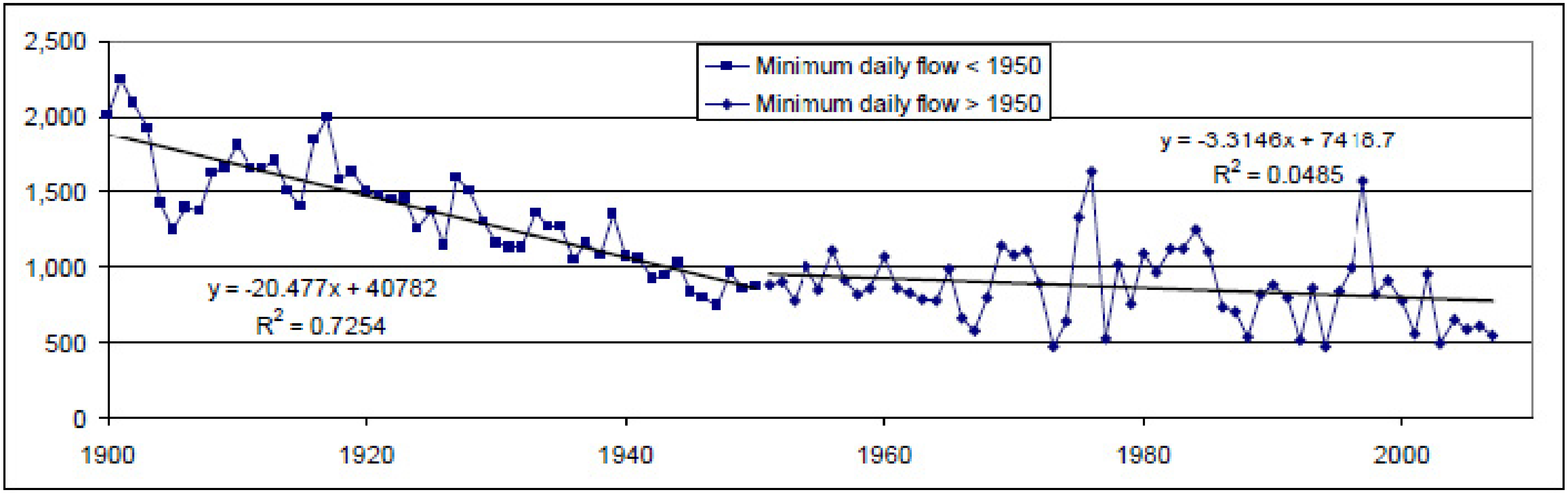
There are Actually **Four** Factors Now Controlling August Low Flows at the Spokane Gage



Trends in Seasonal Low Flows at the Spokane Gage Through 2007

(From Barber and others, 2011)





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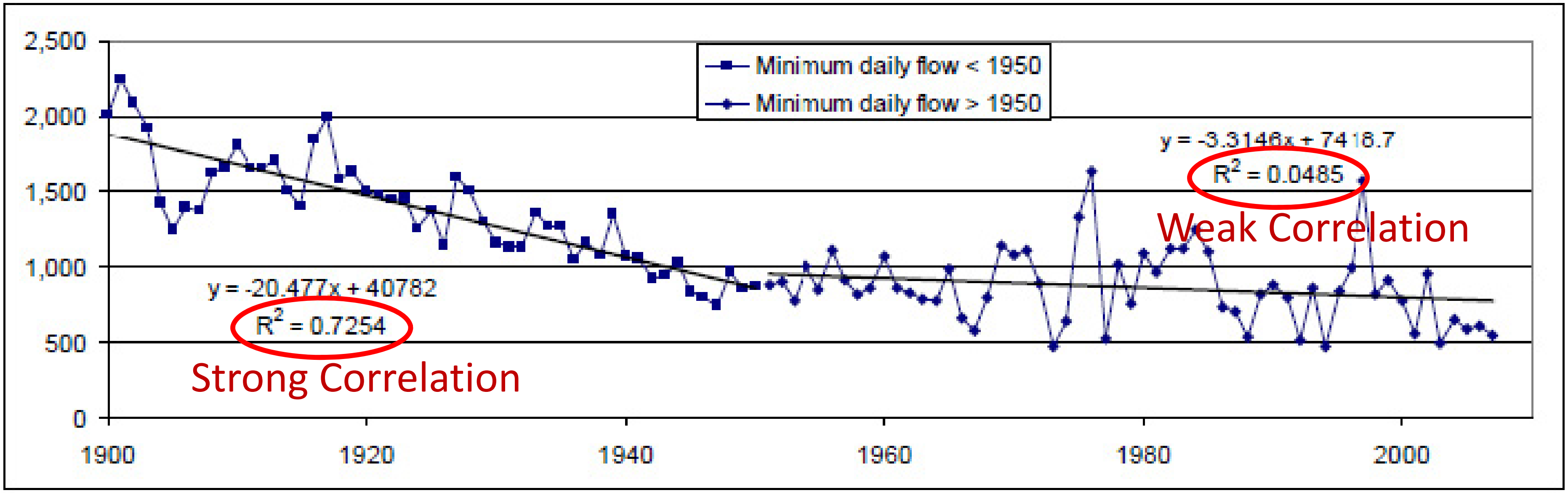

<u>This Plot Raises Several Questions</u>

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?

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Processes That Theoretically Could Change River Low Flows at the Spokane Gage

1. Snowmelt/rainfall changes upstream of the SVRP
2. Direct diversions of water from the river
   - Historical agriculture
3. Changed riverbed seepage below Post Falls Dam
   - Water temperature, flow rates/timing/wetted perimeter
4. Groundwater pumping
   - Year round indoor demands (generally no effect on baseflow)
   - Seasonal outdoor demands (30% to 65% effect on baseflow)
5. Diversion of municipal return flows
   - City of Spokane water reclamation plant is downstream of Spokane Gage
6. Urbanization effects on stormwater routing and fate
   - Conversion of undeveloped land and irrigated farmland

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Which Hydrologic Processes Might Have Changed and Where?

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
Groundwater use *(municipal and industrial)*	Watershed climate and runoff *(volumes and timing of flows into CDA Lake)*
Diversion of water around Spokane Gage *(pumping upstream)* *(wastewater return flows downstream)*	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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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.

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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

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Effect of increased urbanization on fate of stormwater *(less recharge, more evapotranspiration)*	

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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

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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

Ag Diversions

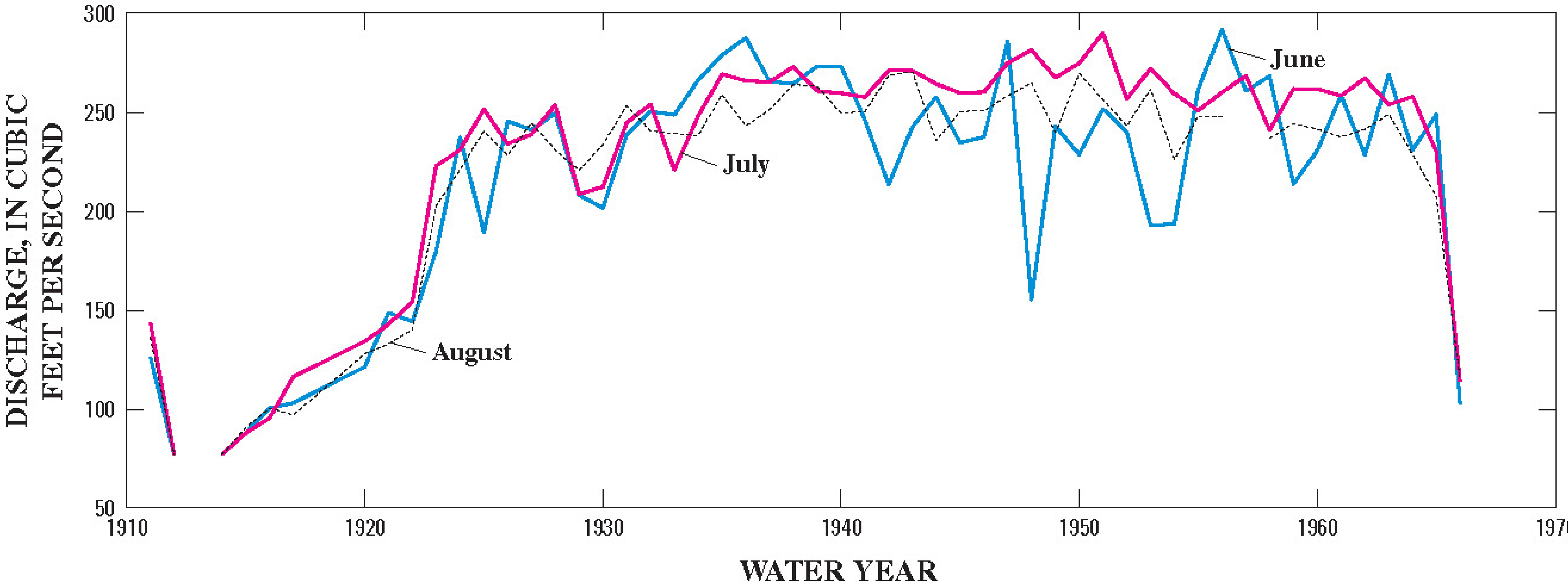

Figure 7. Monthly mean streamflows for the Spokane Valley Farms Canal at Post Falls, Idaho, June, July, and August, 1911–1966.

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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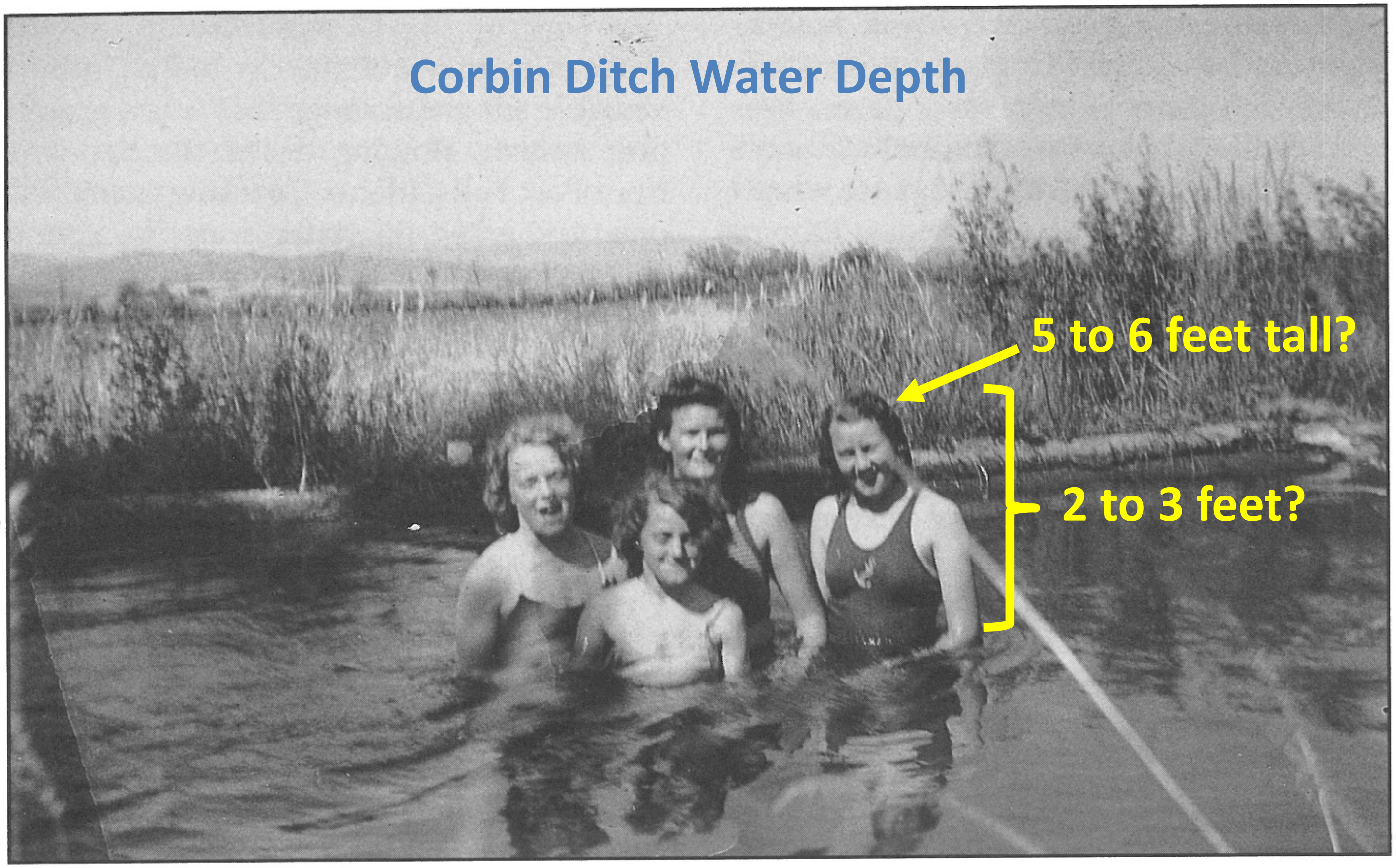
Ag Diversions

(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)

<u>Manning's Formula (Open Channel Flow)</u>

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

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

<u>Variables</u>

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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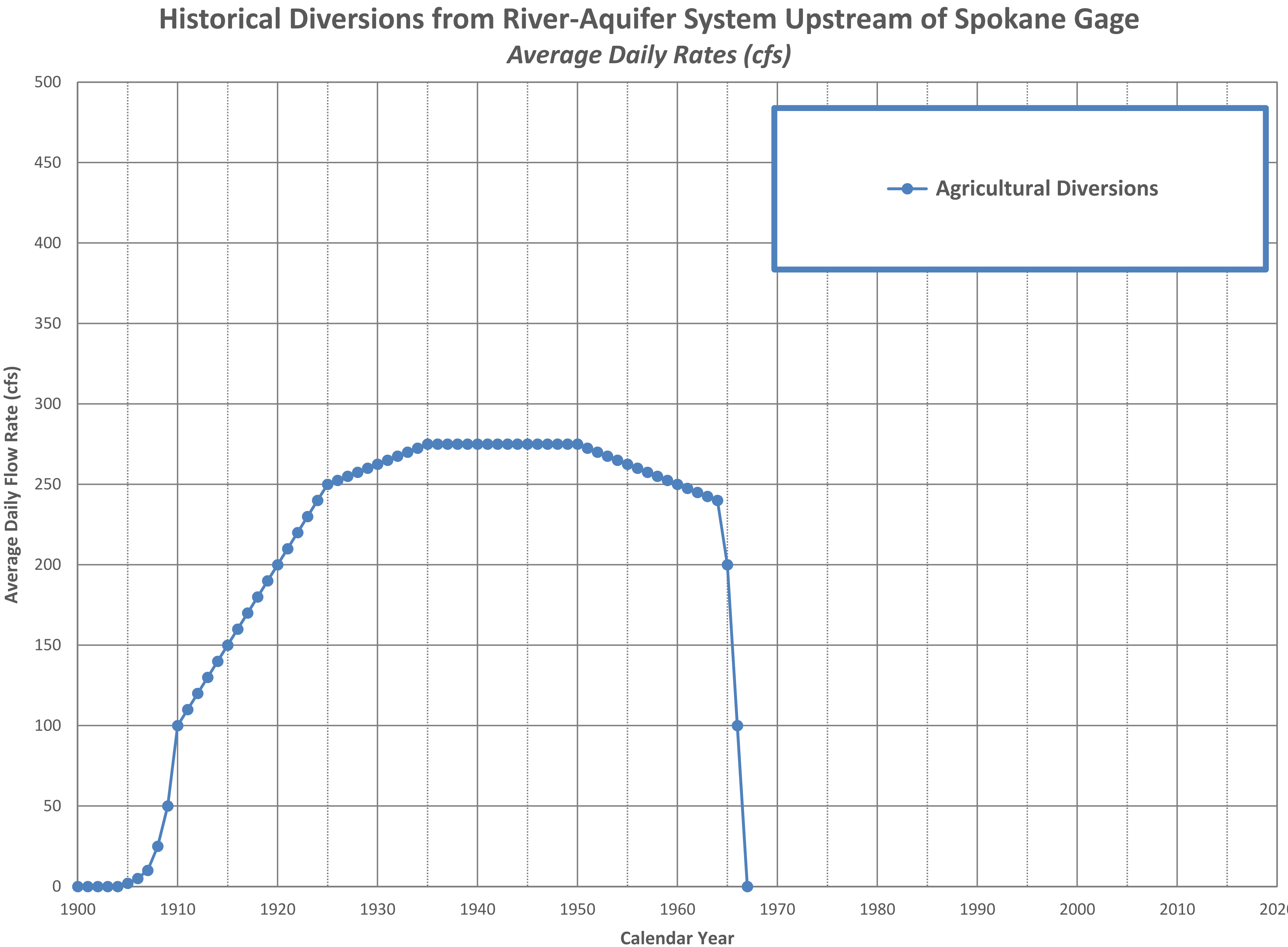

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Groundwater Pumping
(Municipal and Industrial)

- Annual Use of SVRP for M&I Purposes
  - Define trends from City of Spokane records since 1900
  - Use population data to scale this up across the SVRP
    - 10-year census since 1890
    - City of Spokane, Spokane County
    - City of Coeur d'Alene, Kootenai County
  - Assume per capita M&I use of publically provided water at any time is same inside and outside the City of Spokane
  - Use results from Spokane Co. Water Demand Model 2013
    - Self-supplied industrial groundwater volume in 2010
    - Publically provided groundwater volume in 2010 in Spokane County
    - Percentage of Spokane County population relying on SVRP (91%)

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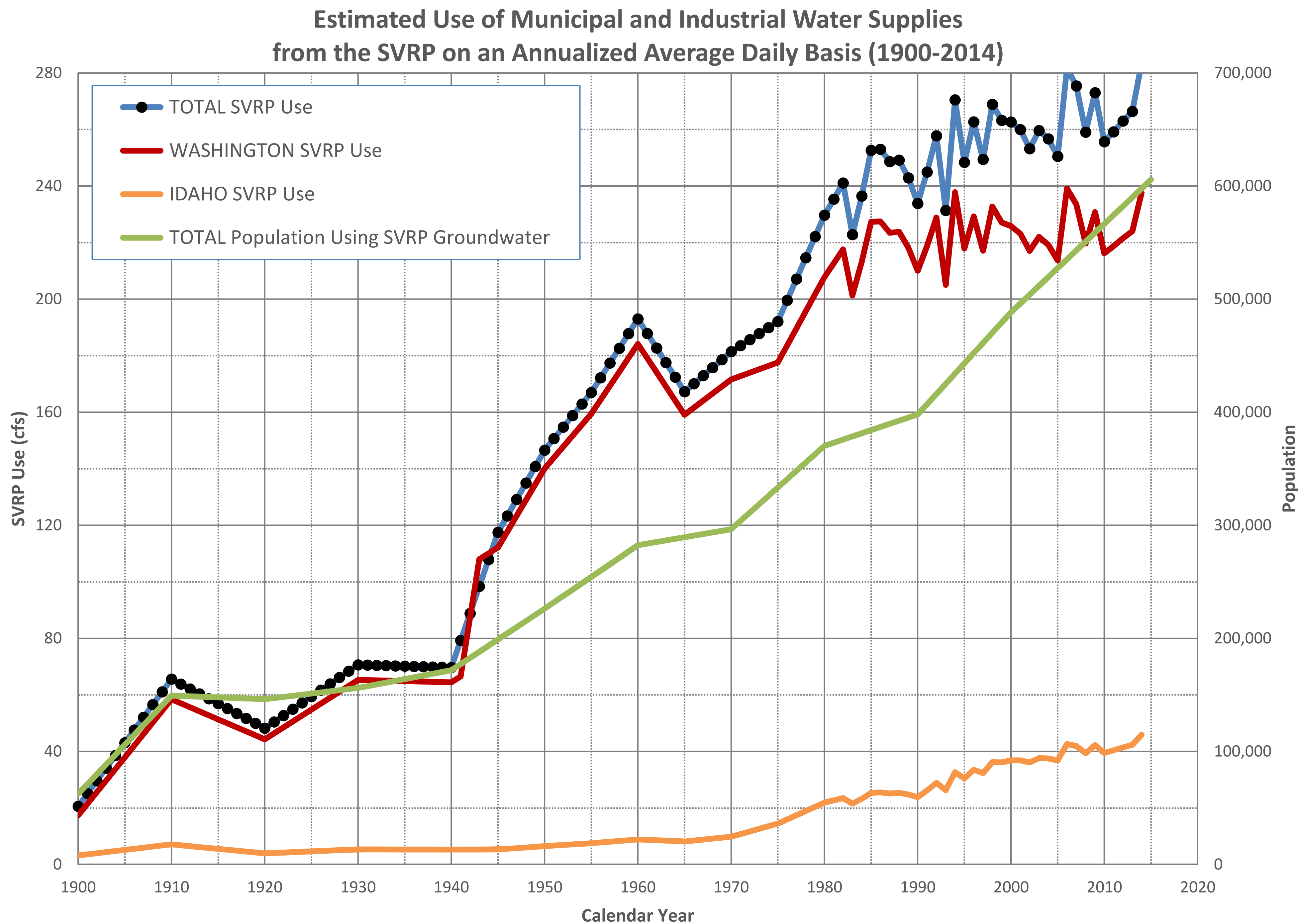

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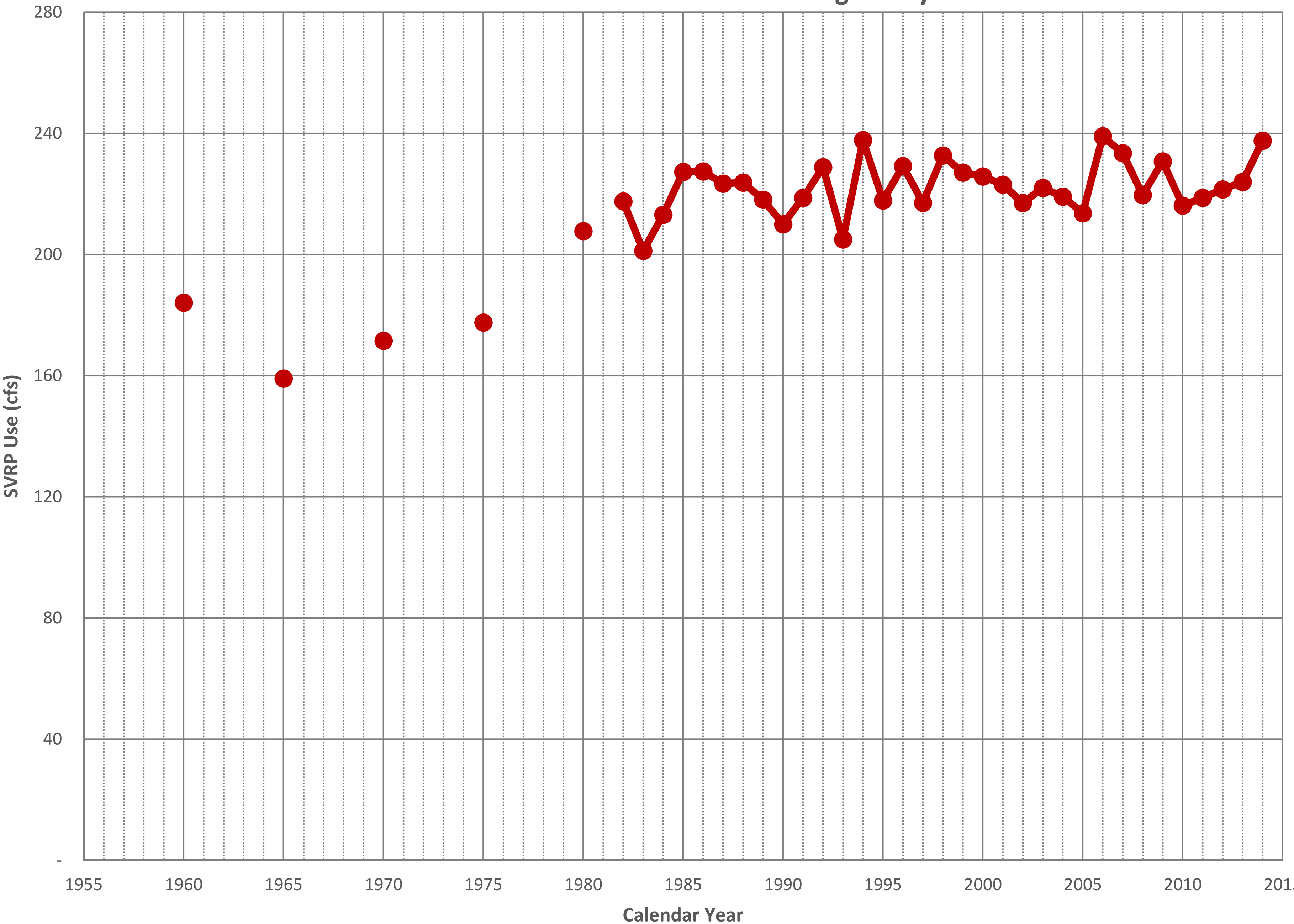
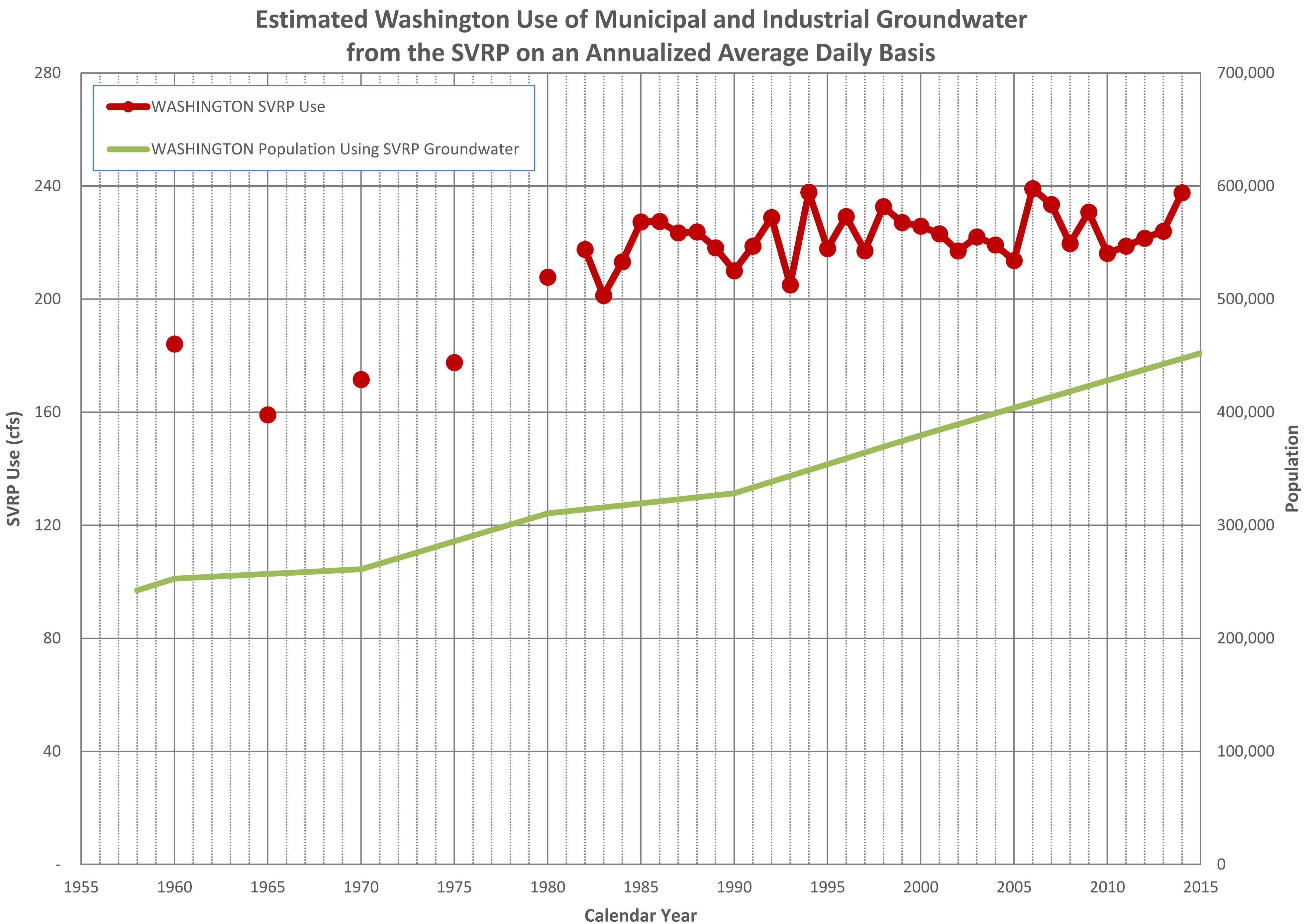
Estimated Washington Use of Municipal and Industrial Groundwater from the SVRP on an Annualized Average Daily Basis





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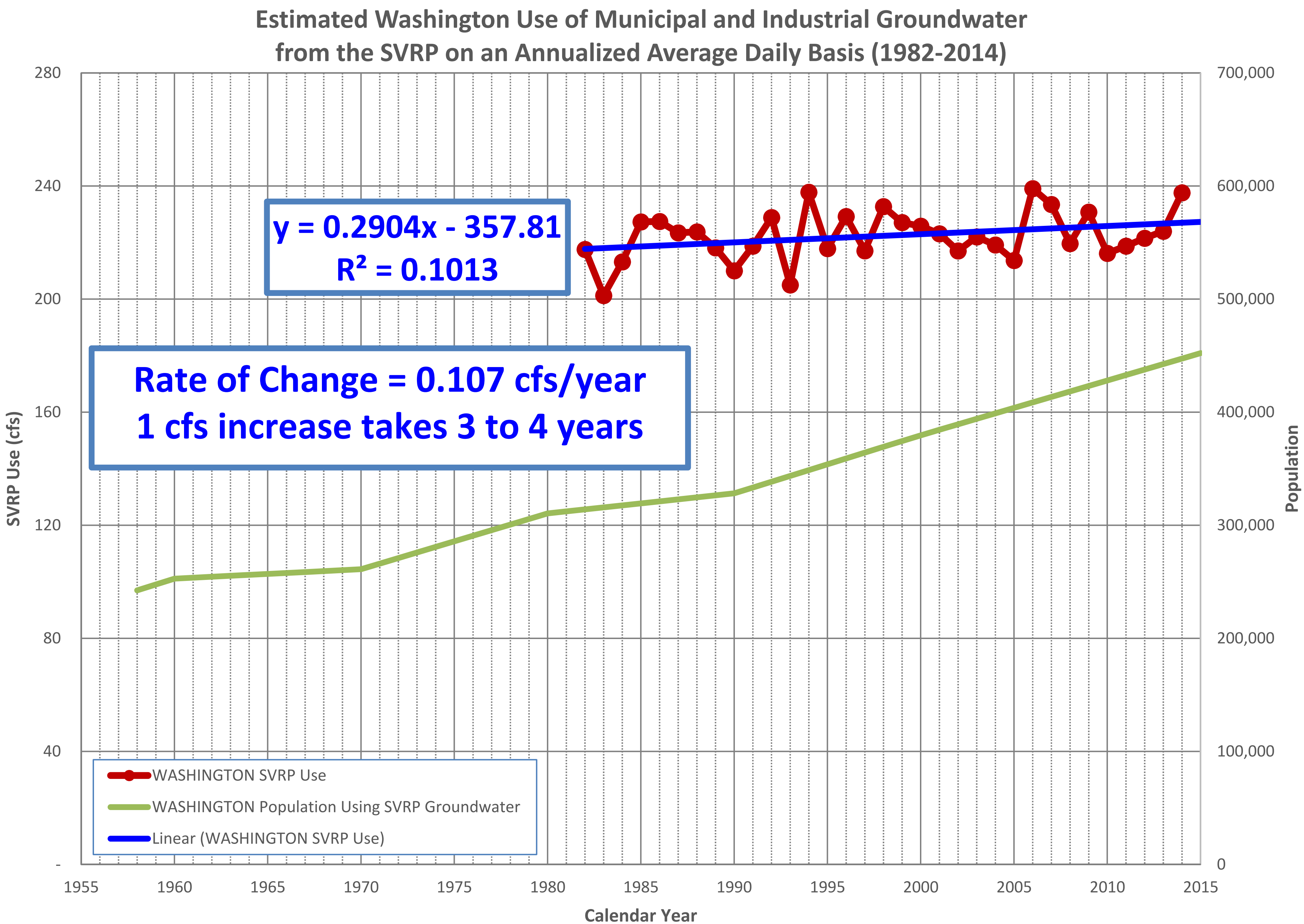

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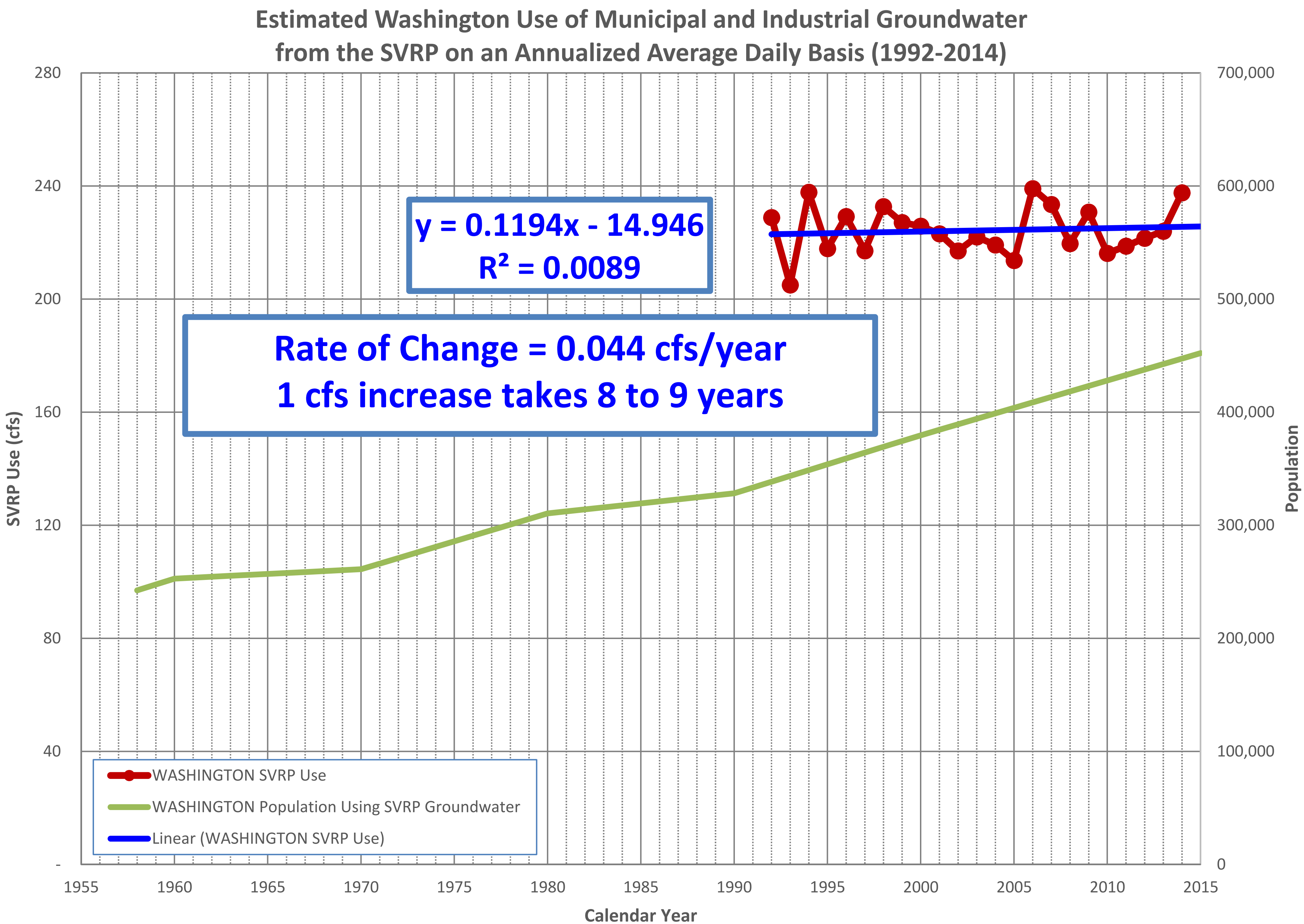

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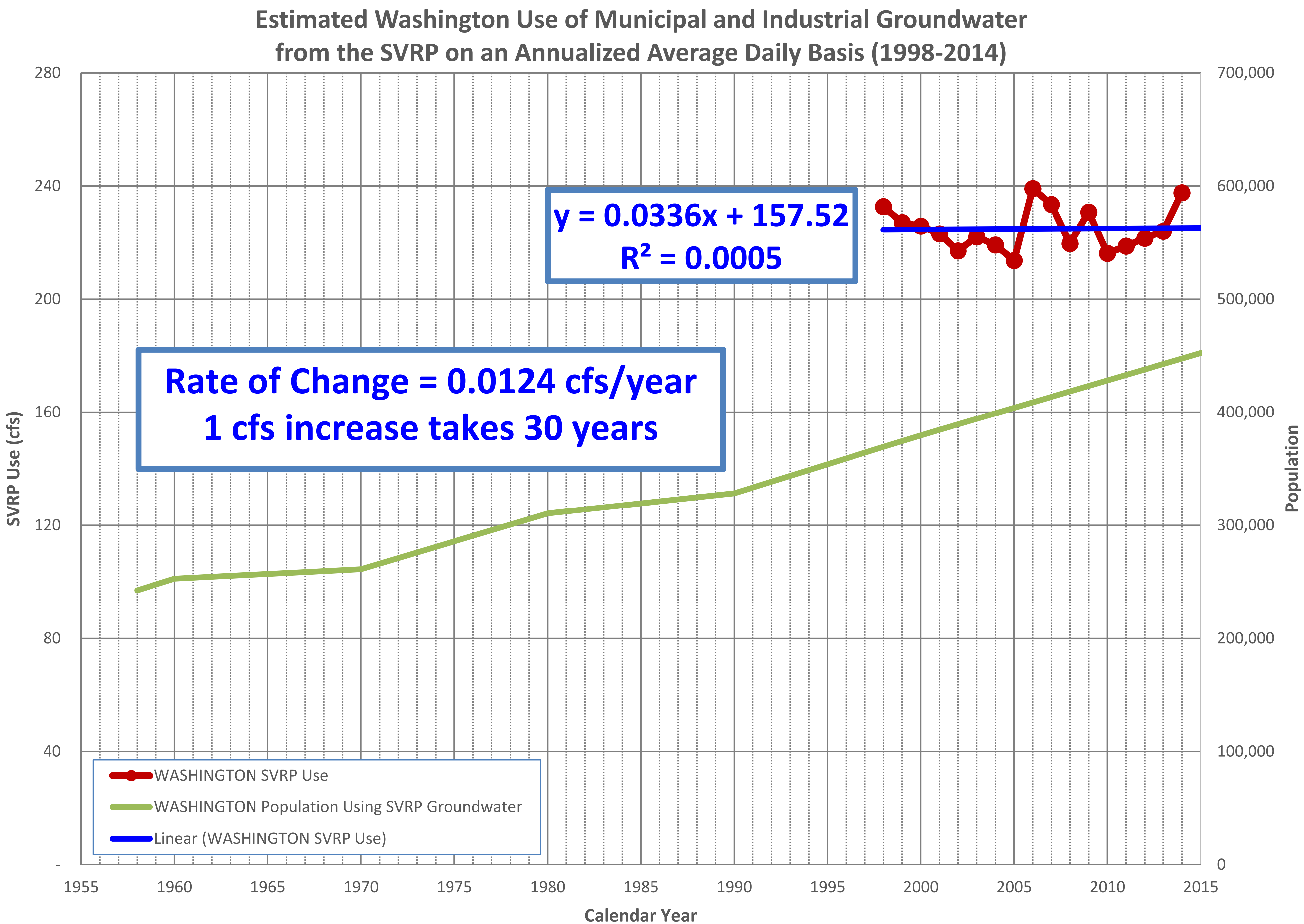

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Groundwater Pumping

(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

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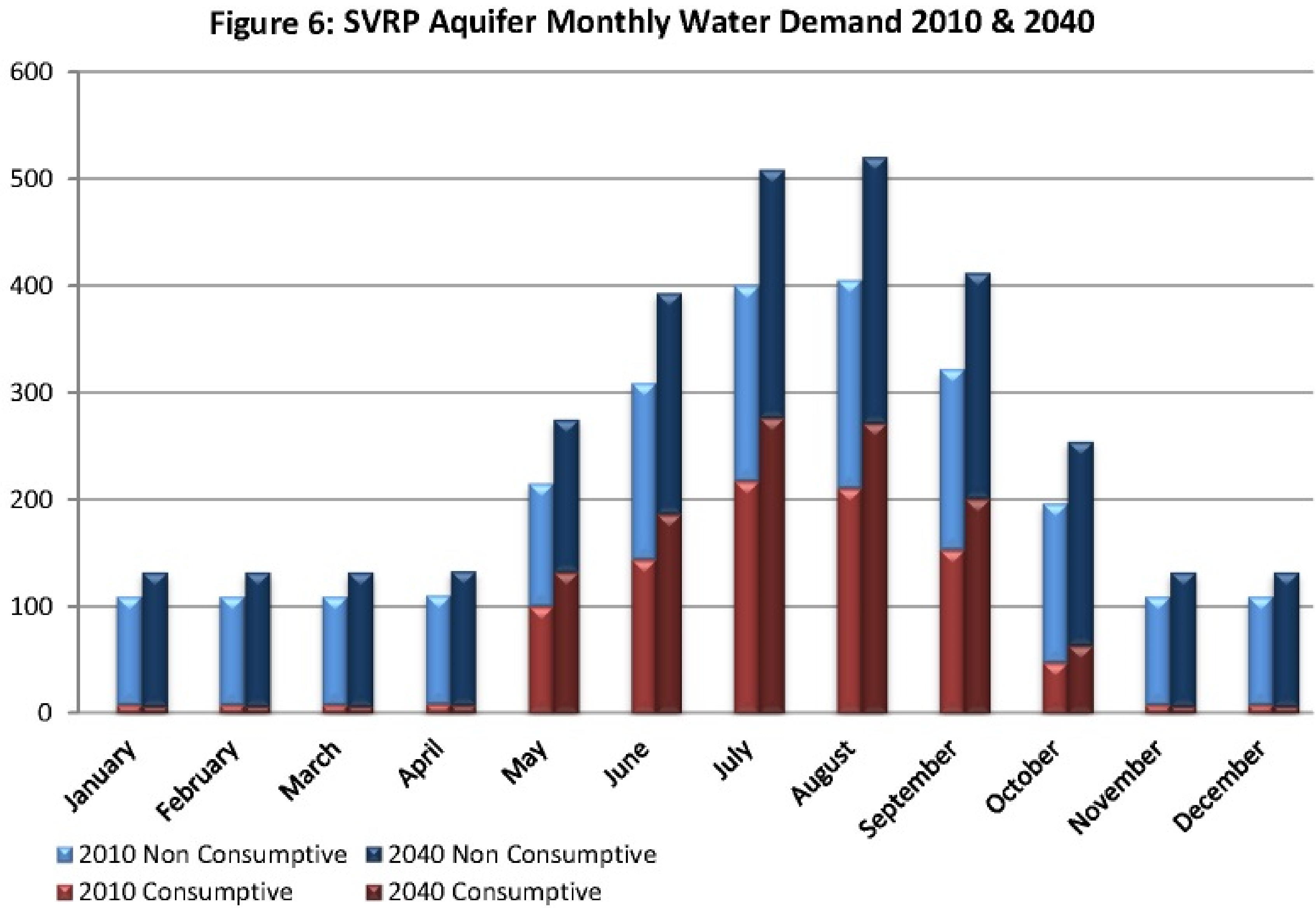
Current Seasonality of Groundwater Demands



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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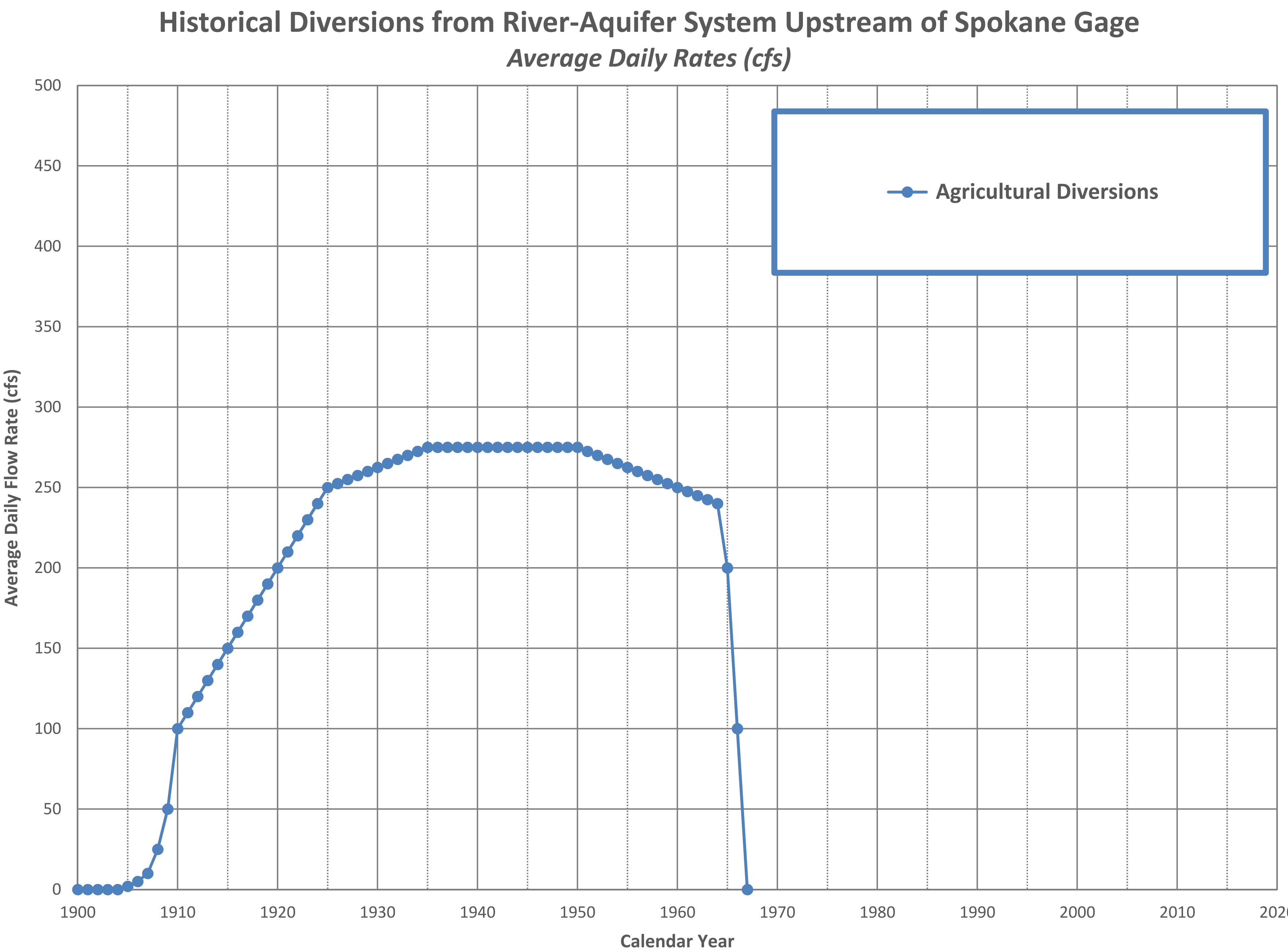
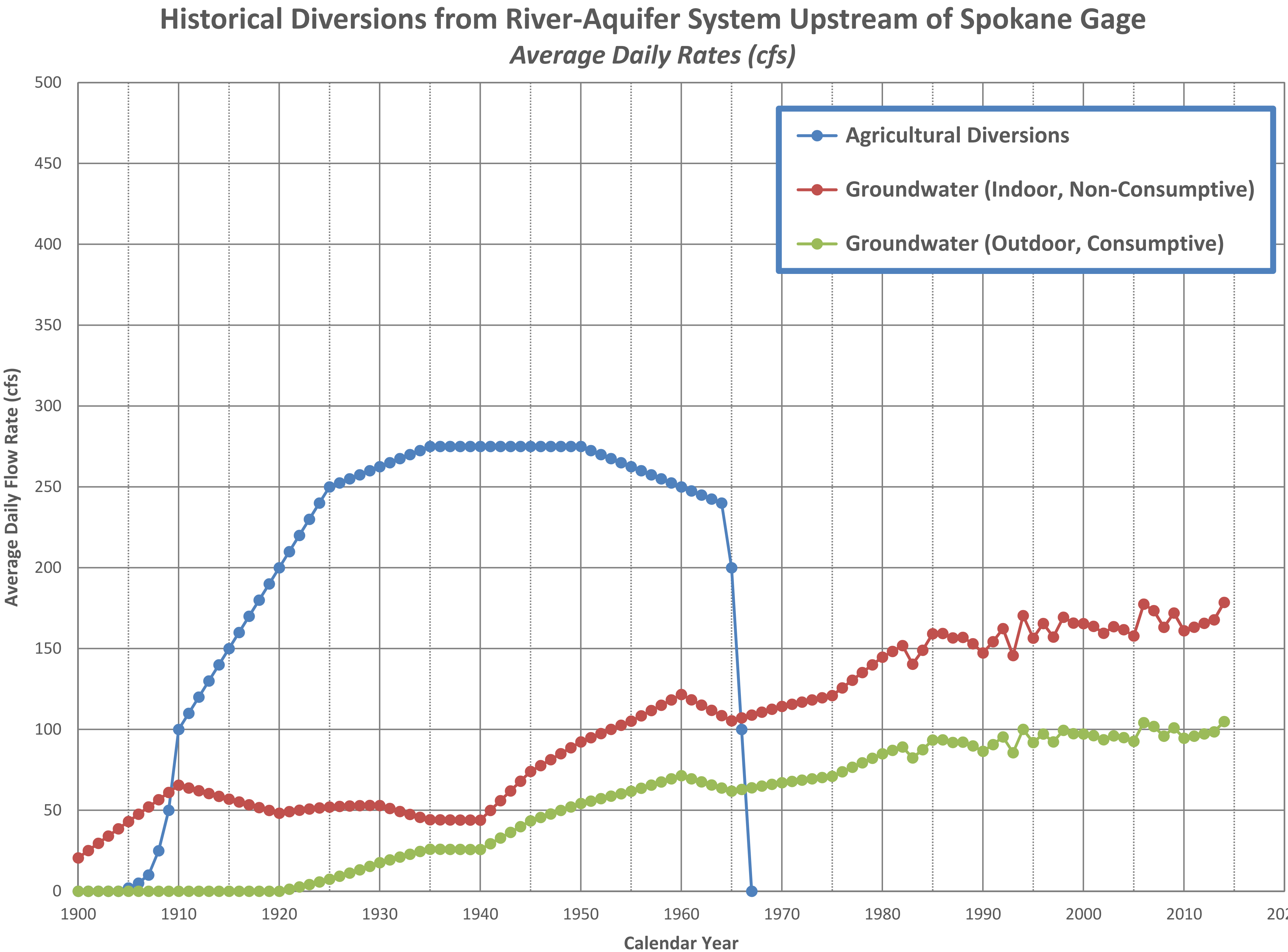
Groundwater Pumping
(Municipal and Industrial)

- 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



Historical Diversions from River-Aquifer System Upstream of Spokane Gage
Average Daily Rates (cfs)
Agricultural Diversions
Average Daily Flow Rate (cfs)
Calendar Year
0
50
100
150
200
250
300
350
400
450
500
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020



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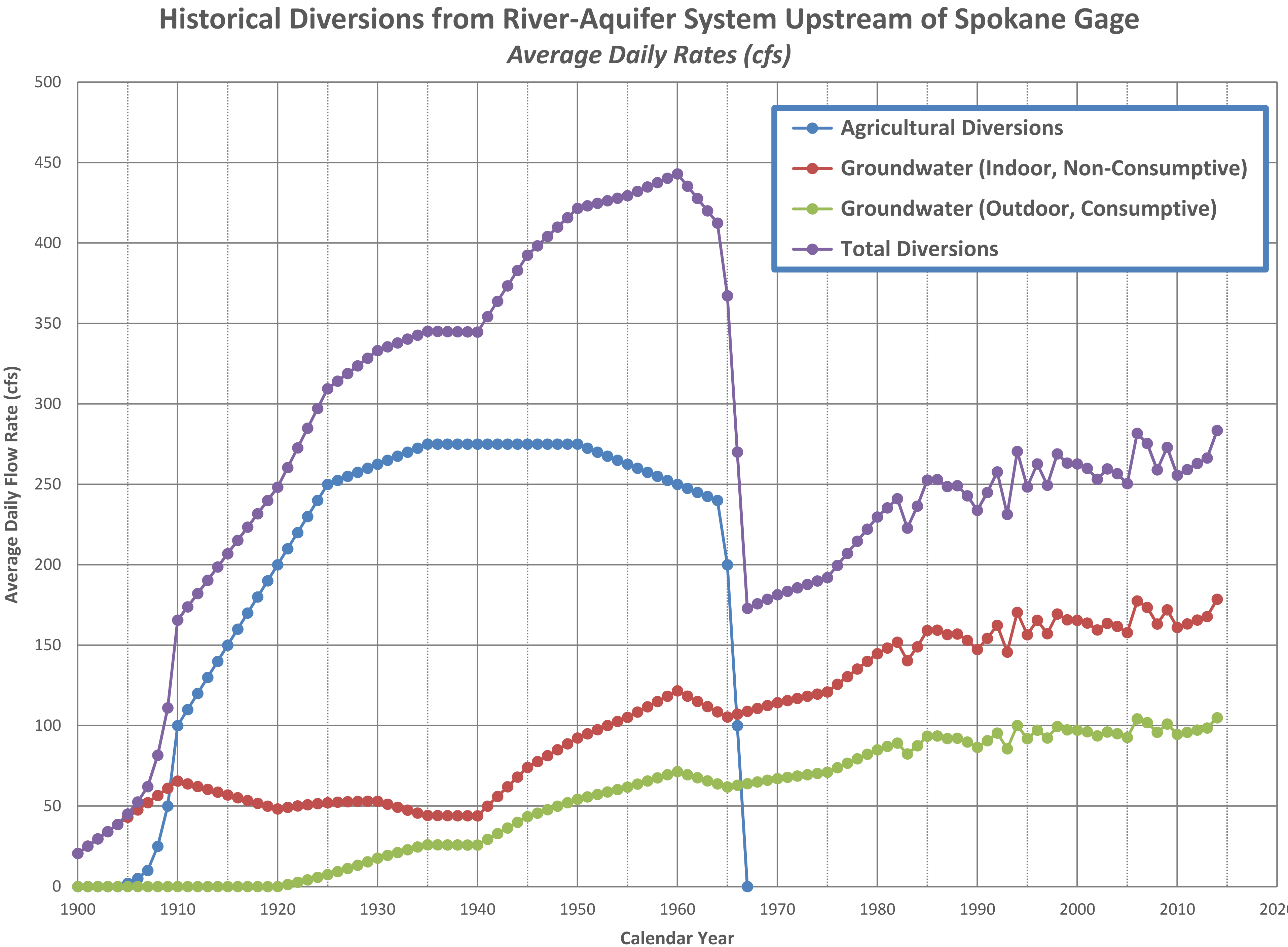

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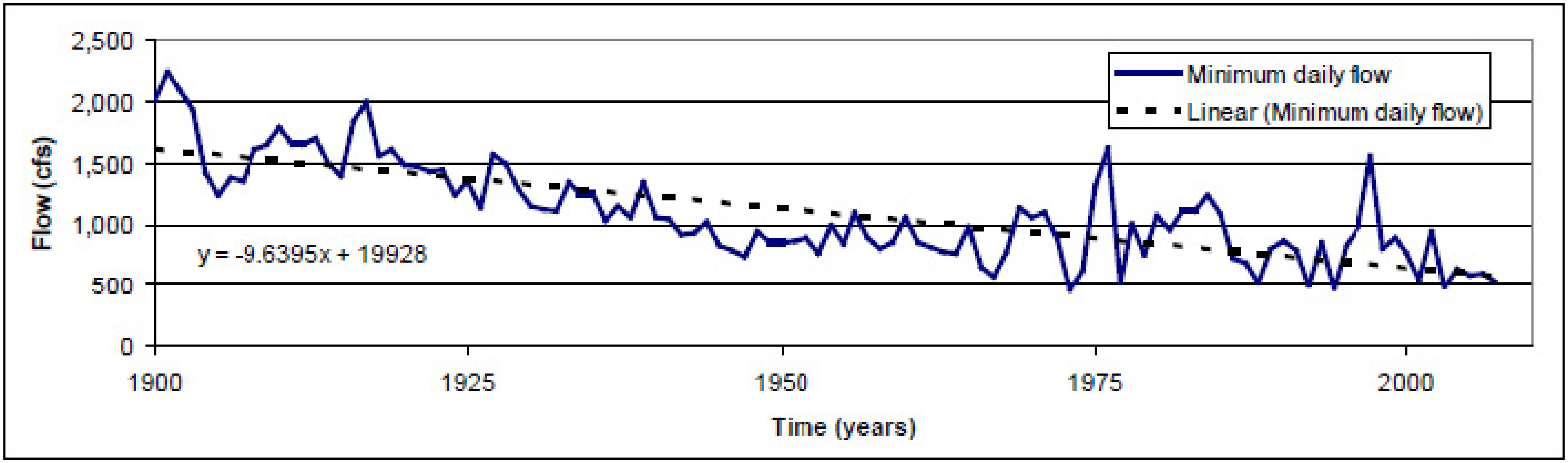
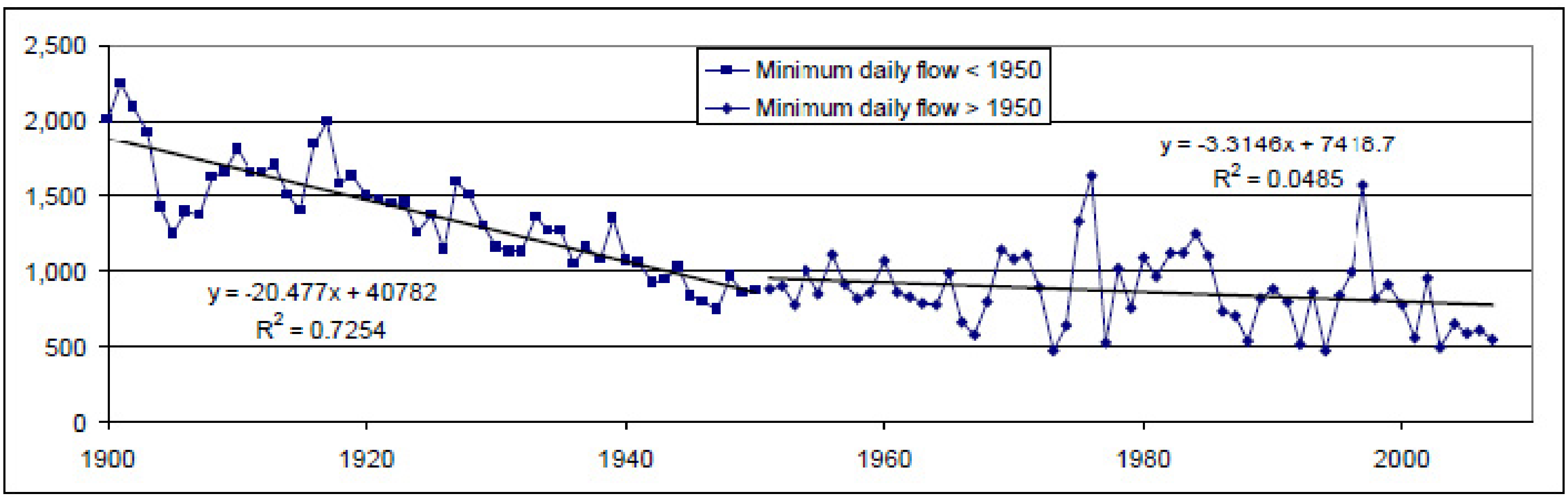
So Why a Continued Decline After the 1960s?

(→ No Ag Diversions)

(→ M&I Consumptive Use Barely Changing)





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Which Hydrologic Processes Might Have Changed and Where?

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
Groundwater use *(municipal and industrial)*	Watershed climate and runoff *(volumes and timing of flows into CDA Lake)*
Diversion of water around Spokane Gage *(pumping upstream)* *(wastewater return flows downstream)*	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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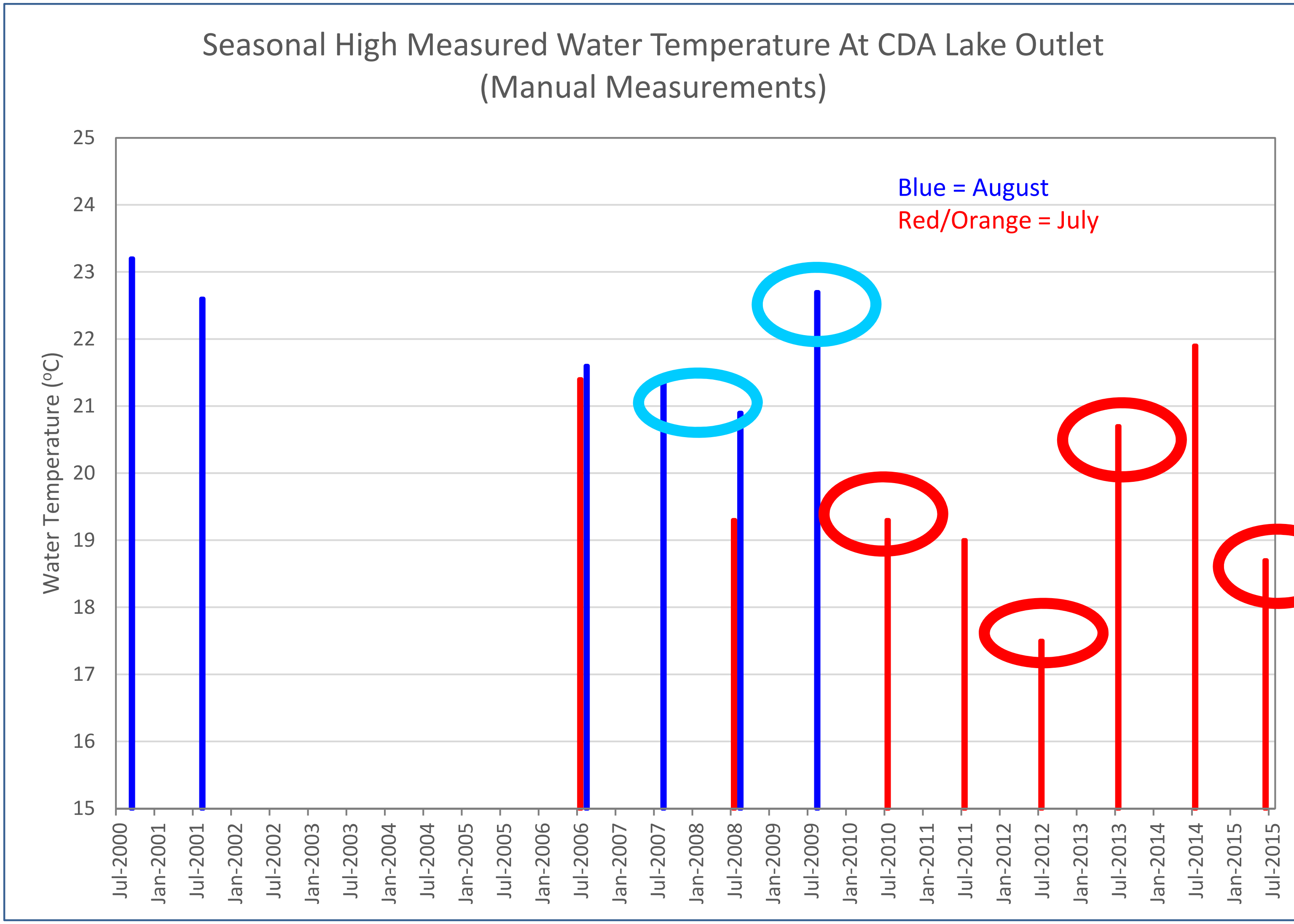
River Water Temperature
(Riverbed Seepage Rates in Losing Reach Below Post Falls)

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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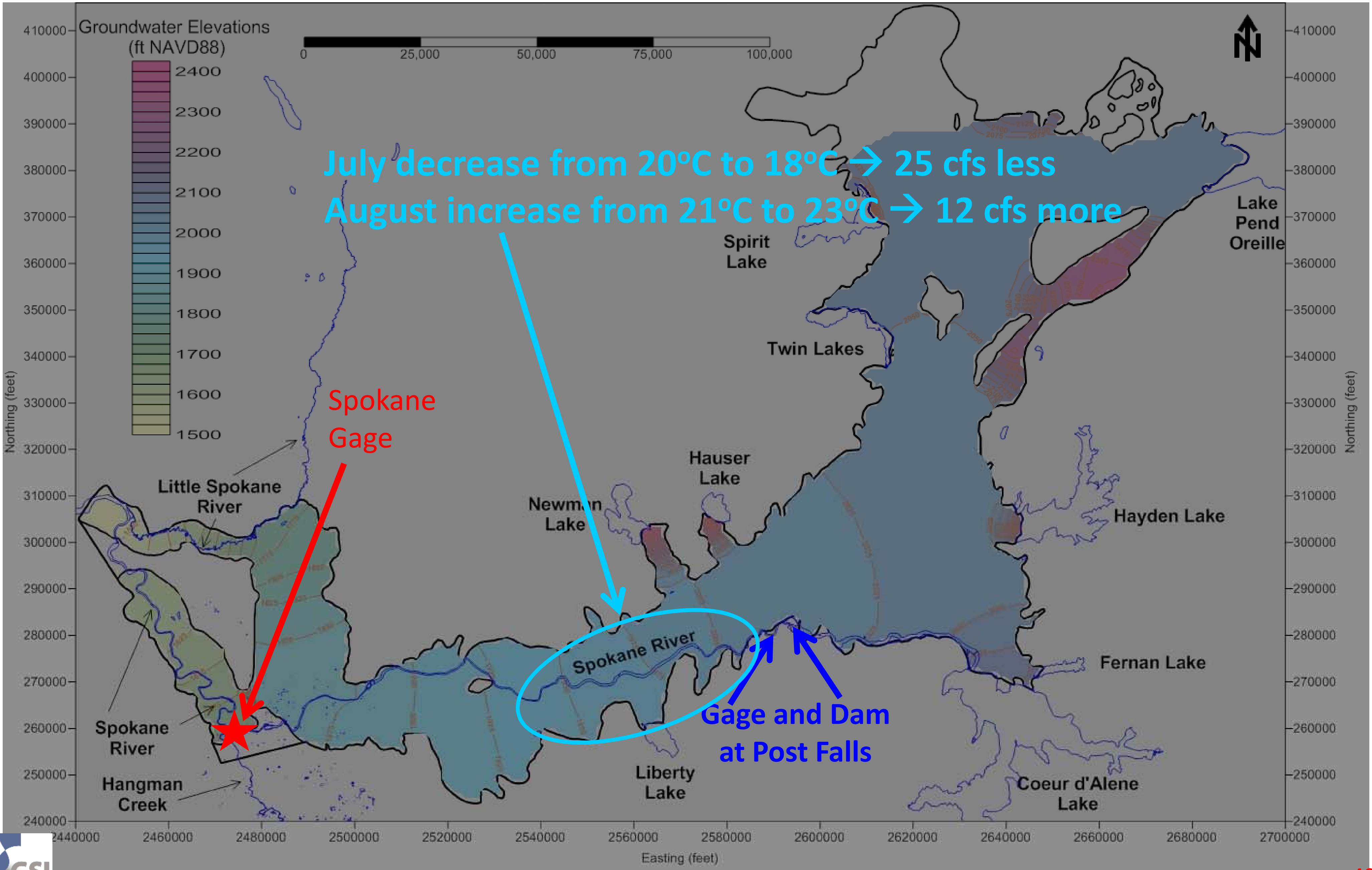
River Water Temperature

(Riverbed Seepage Rates in Losing Reach Below Post Falls)



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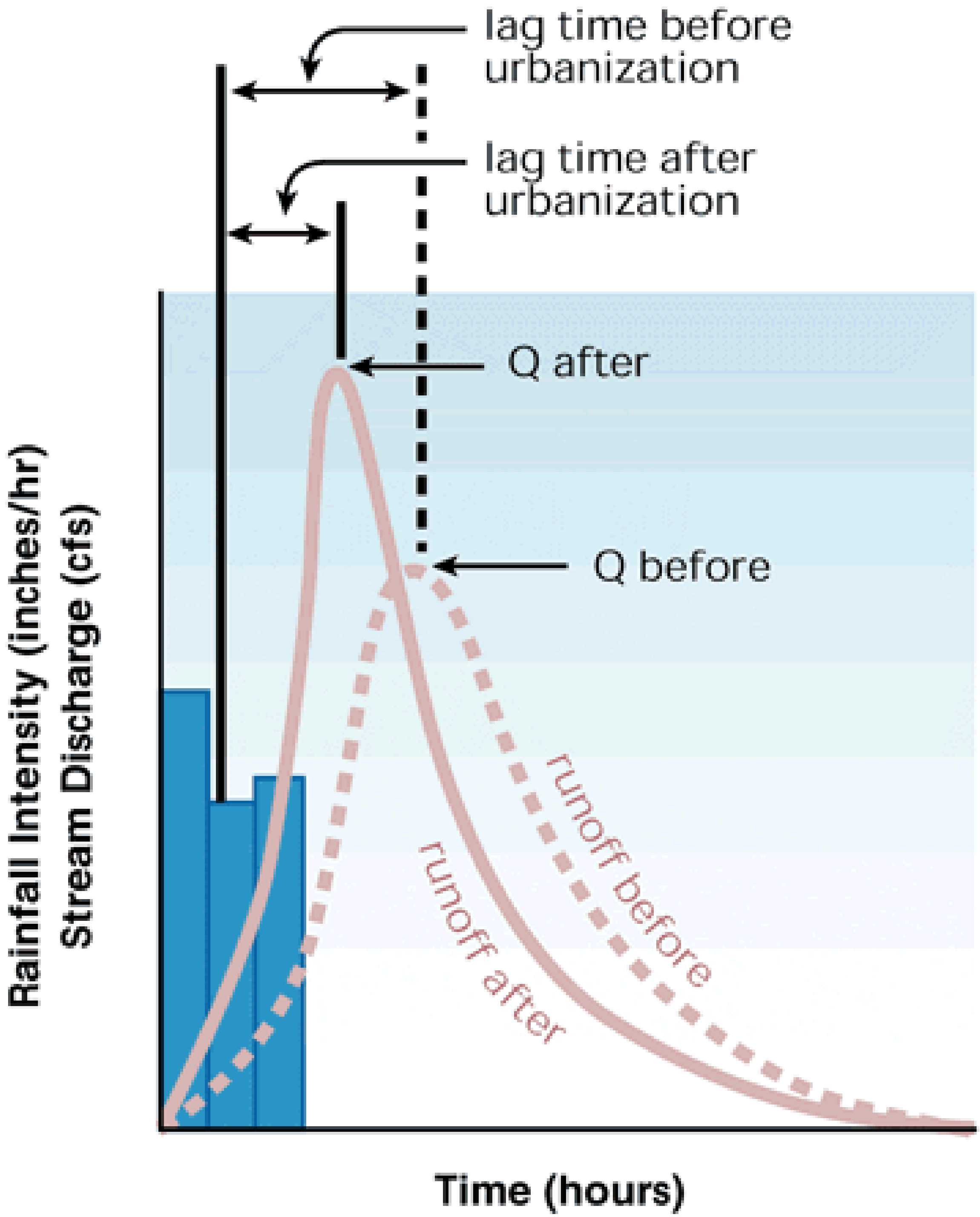
Increased Urbanization and Stormwater



Source: Watershed Academy Web, United States Environmental Protection Agency

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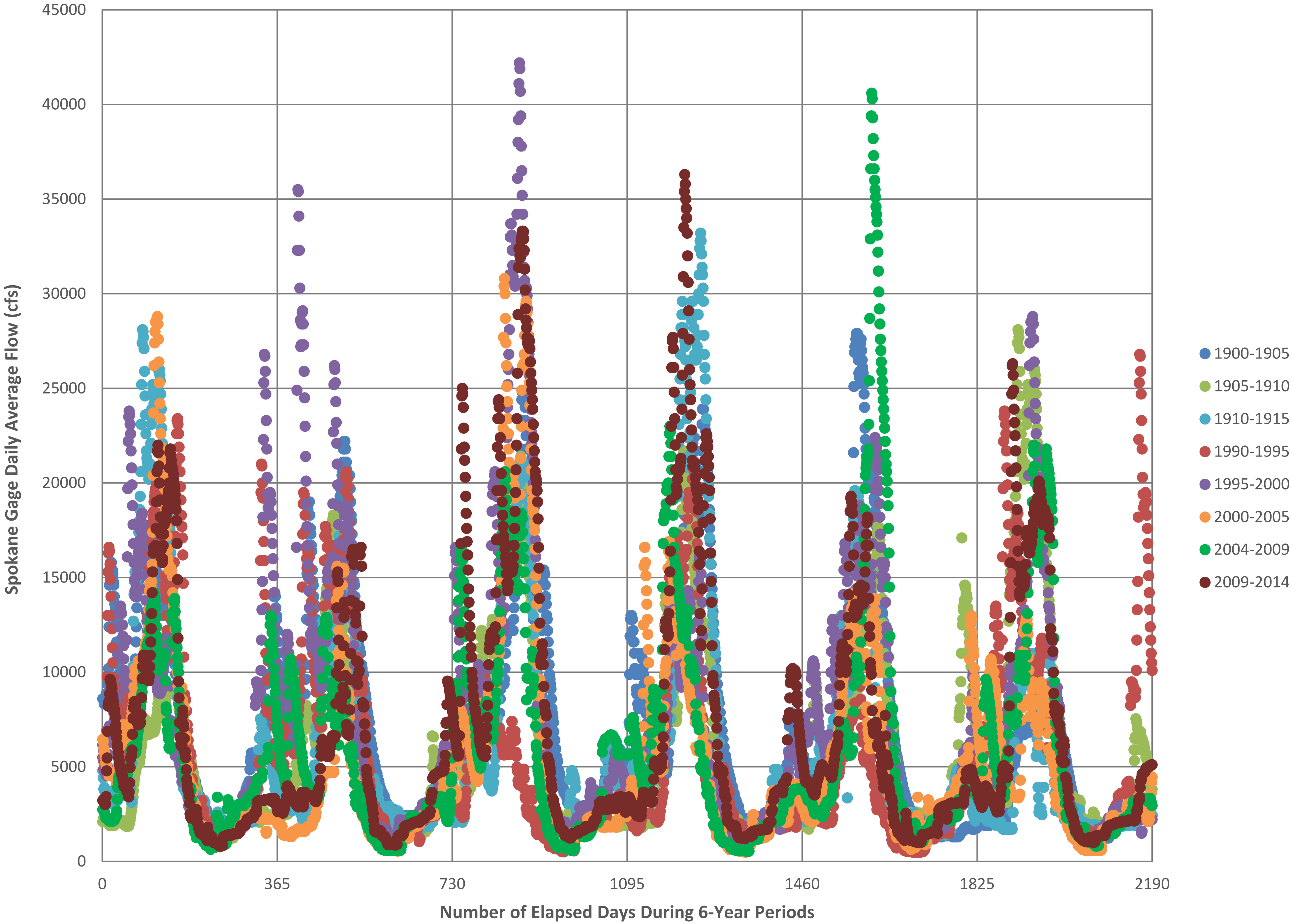
Increased Urbanization and Stormwater



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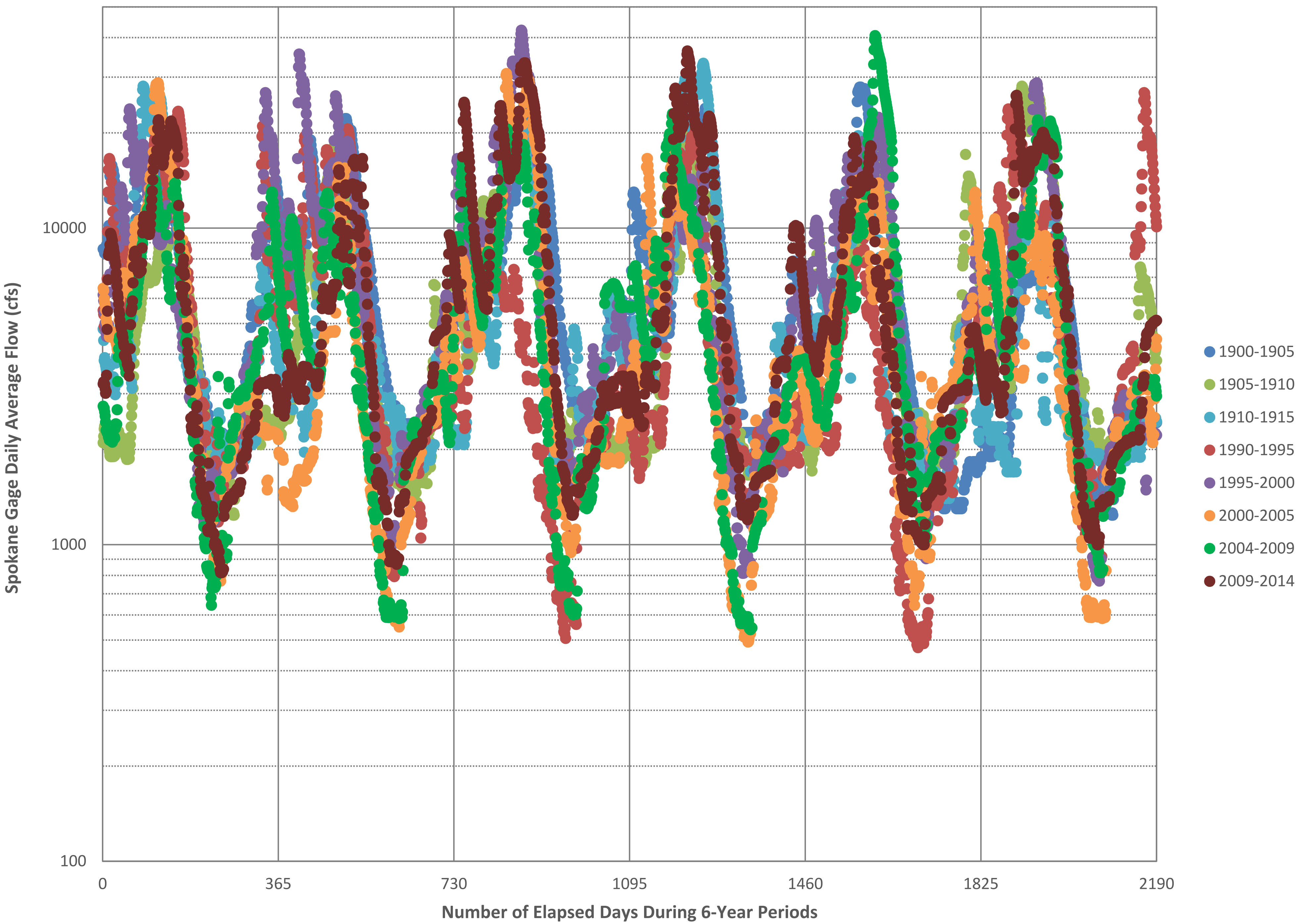
Increased Urbanization and Stormwater



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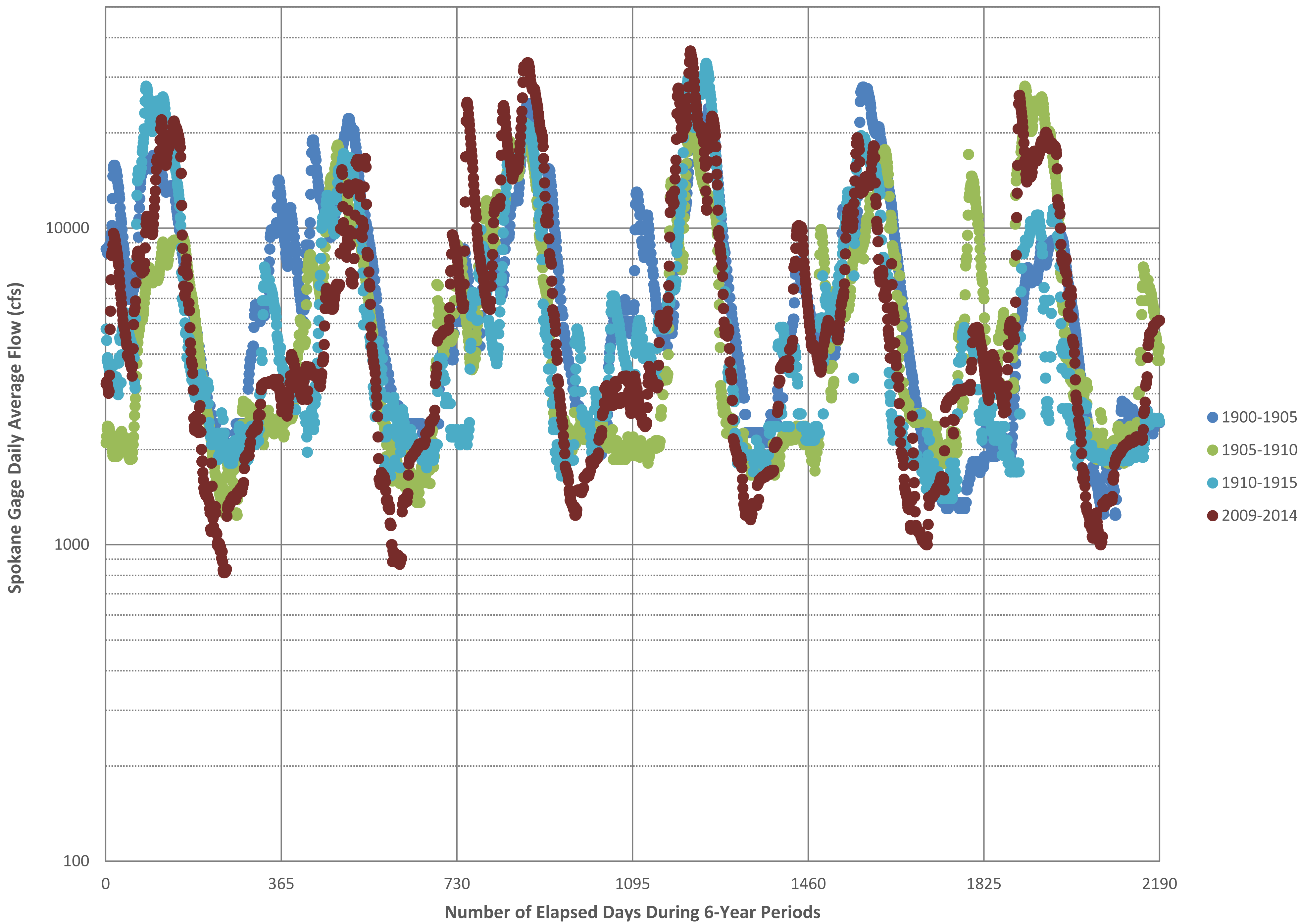
Increased Urbanization and Stormwater



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Increased Urbanization and Stormwater

Conclusion: Urbanization Effects on Stormwater are Unlikely to Affect Seasonal Low Flows

1. Not a clear change in seasonal hydrograph slope
2. In urban areas situated upgradient of the river's gaining reaches, stormwater is managed primarily using drywells
   - Infiltration rather than routing to the river
   - Lower ET than open land, thereby promoting infiltration
3. One separated stormwater system (Union Basin) in the City of Spokane straddles the river and is small (82 acres)
   - 100% industrial land
   - Wet-season runoff is 6 million gallons over 243 days
   - Equivalent to 0.019 cfs (averaged over all 243 days)
   - Equivalent to 1.9 cfs if averaged over only 2.43 days

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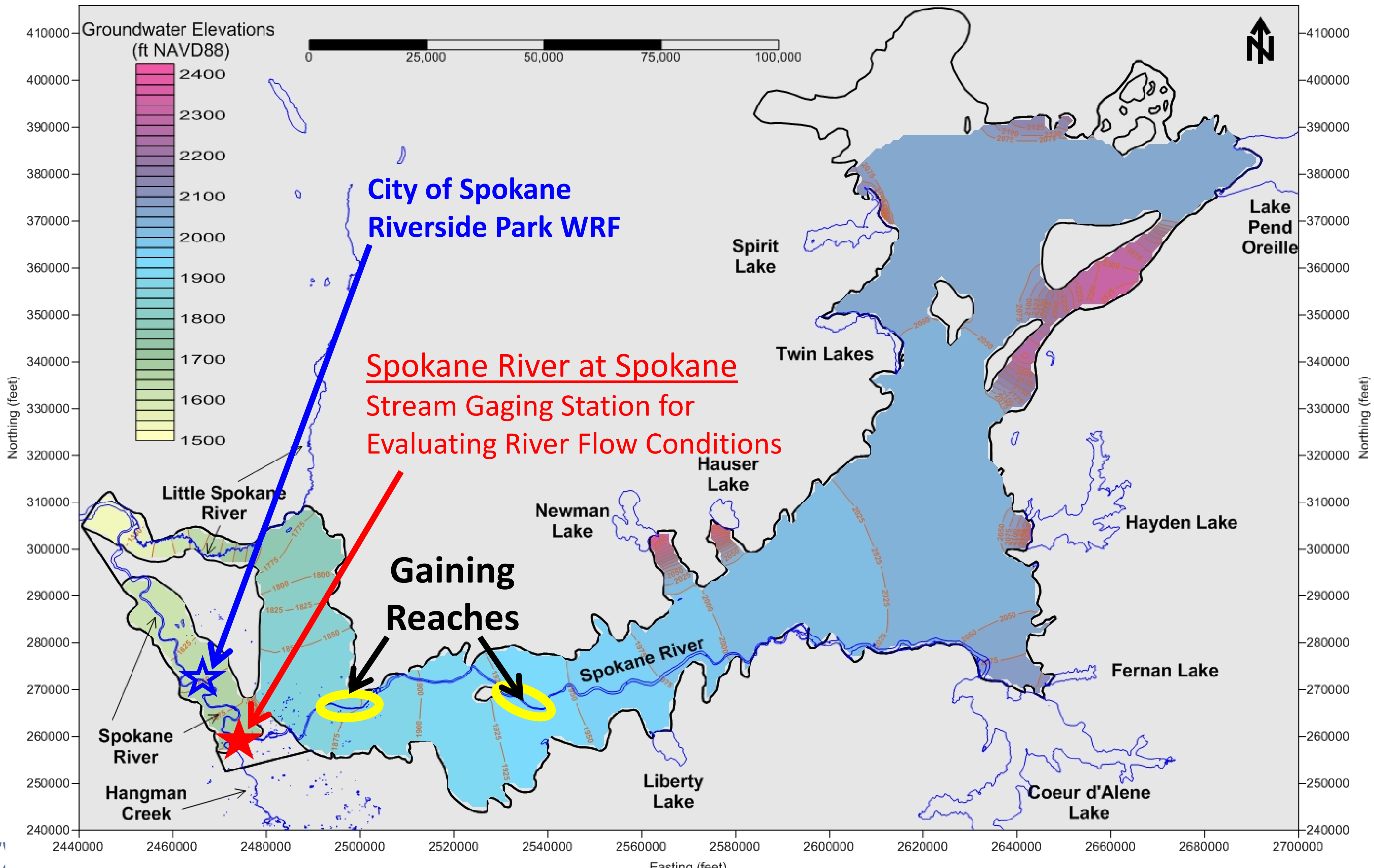
Diversion of Water Around Spokane Gage

City of Spokane Riverside Park Water Reclamation Facility (Built 1958)



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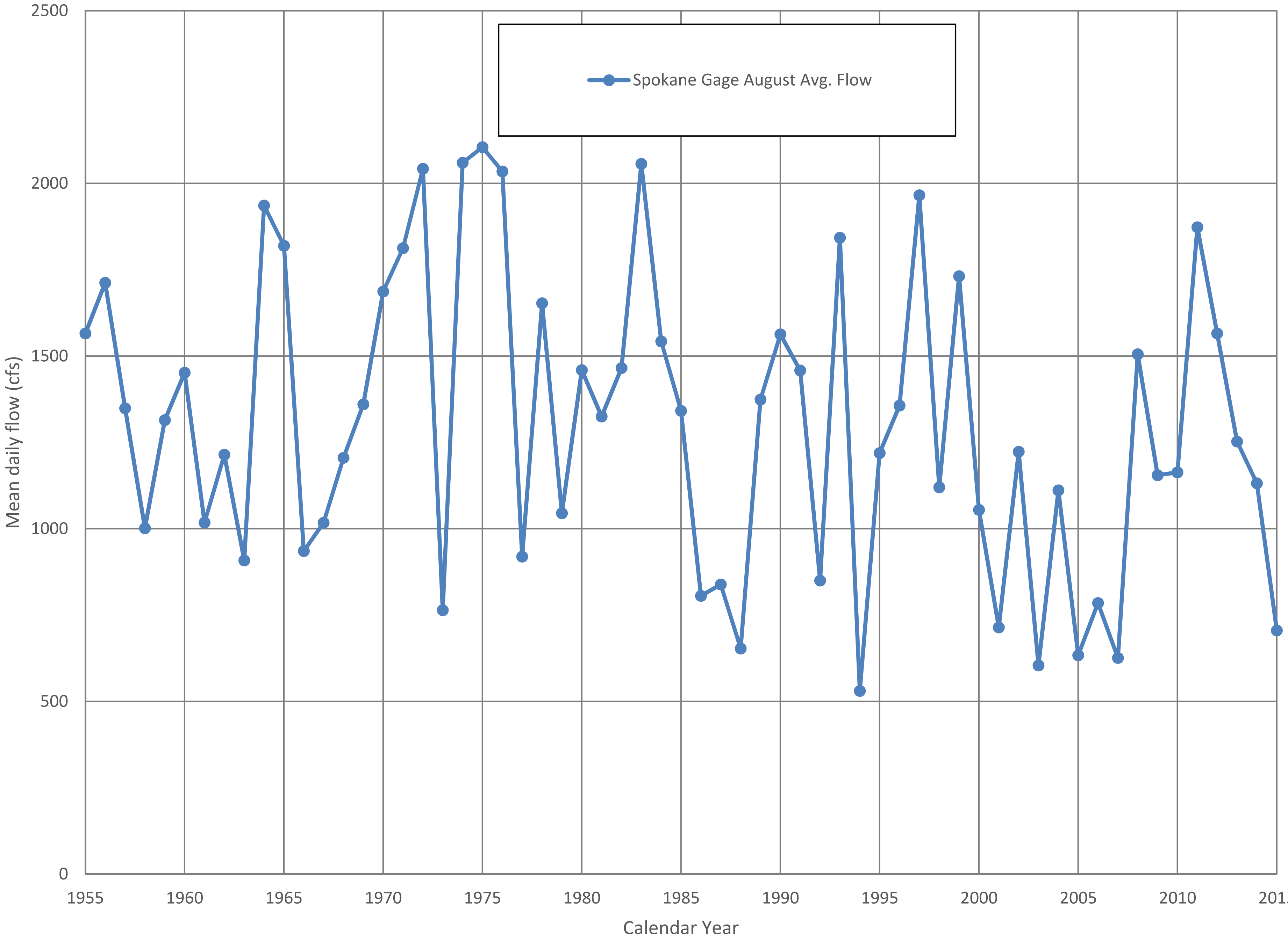

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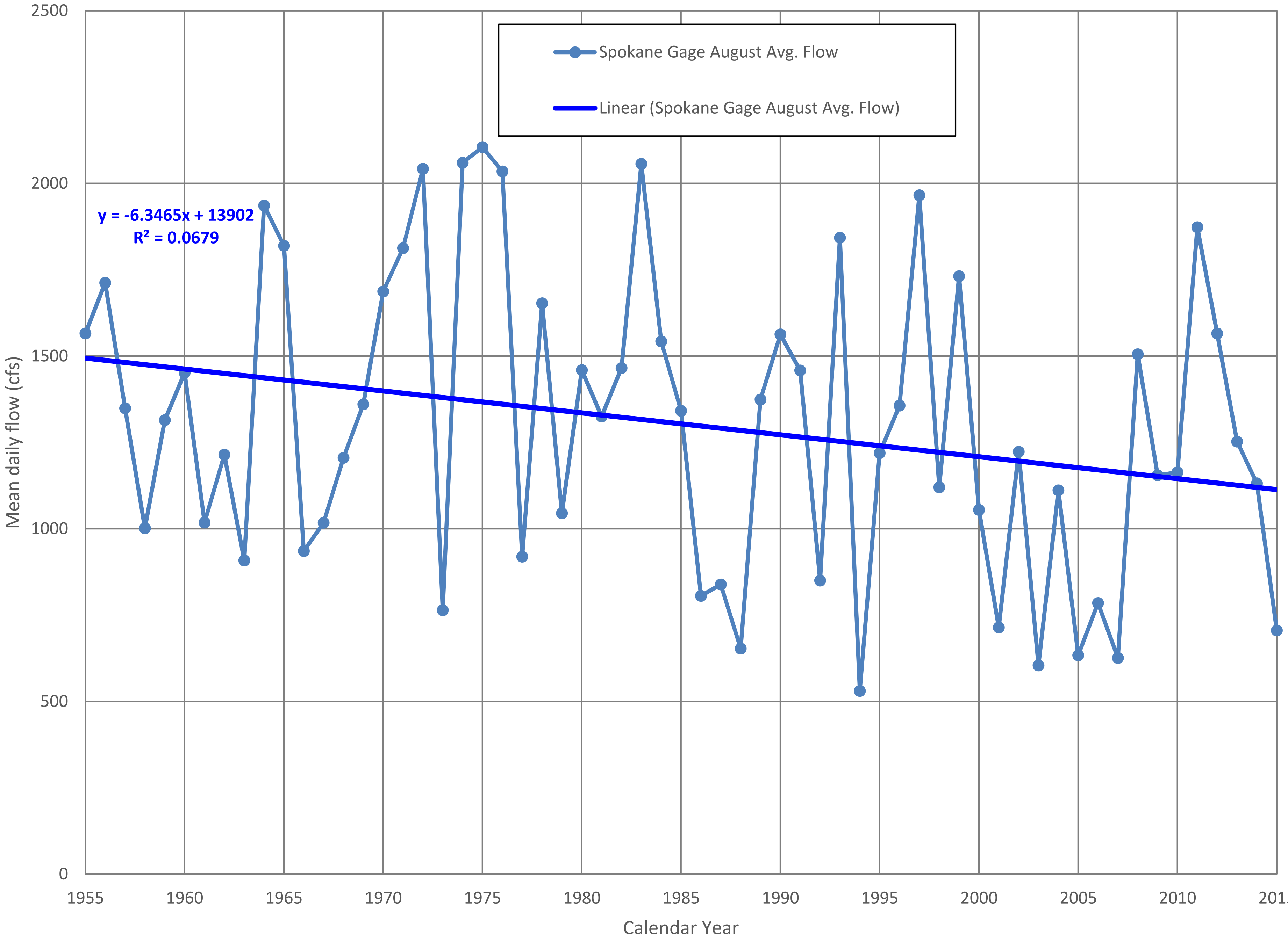

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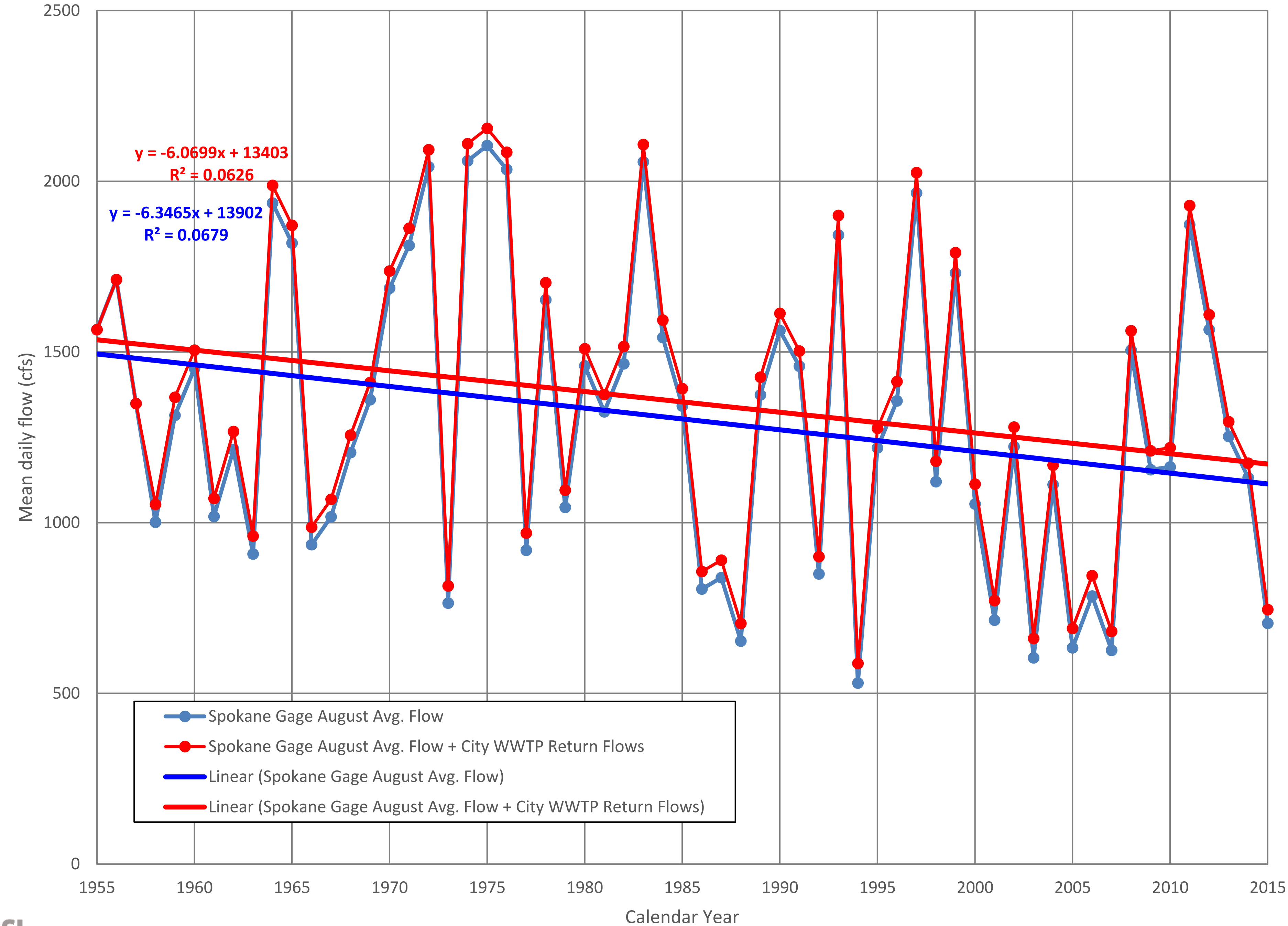

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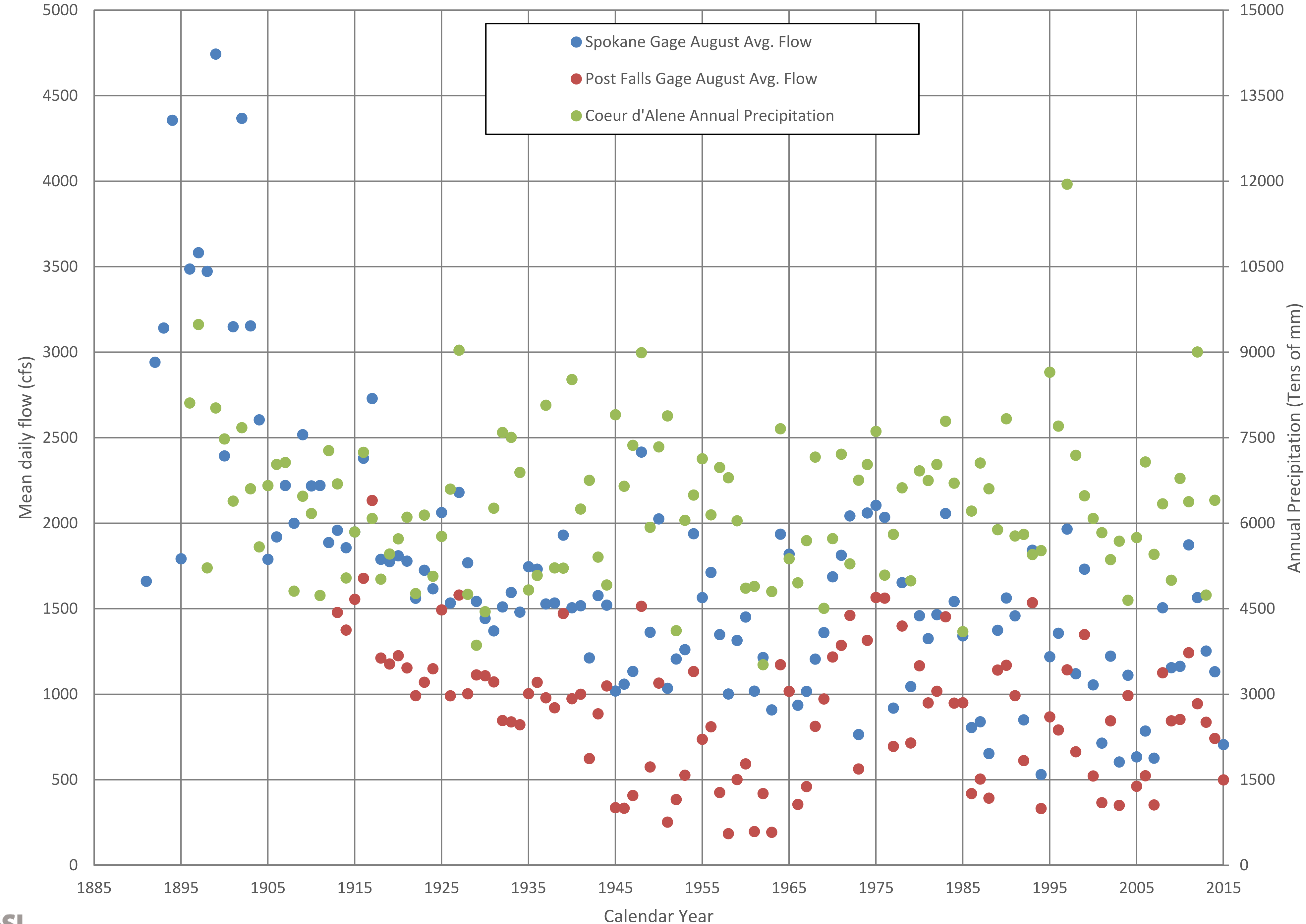
River Flow and Watershed Changes Since Late 1800s

Gaged Flows, Precipitation, Lake Stage, City Return Flows



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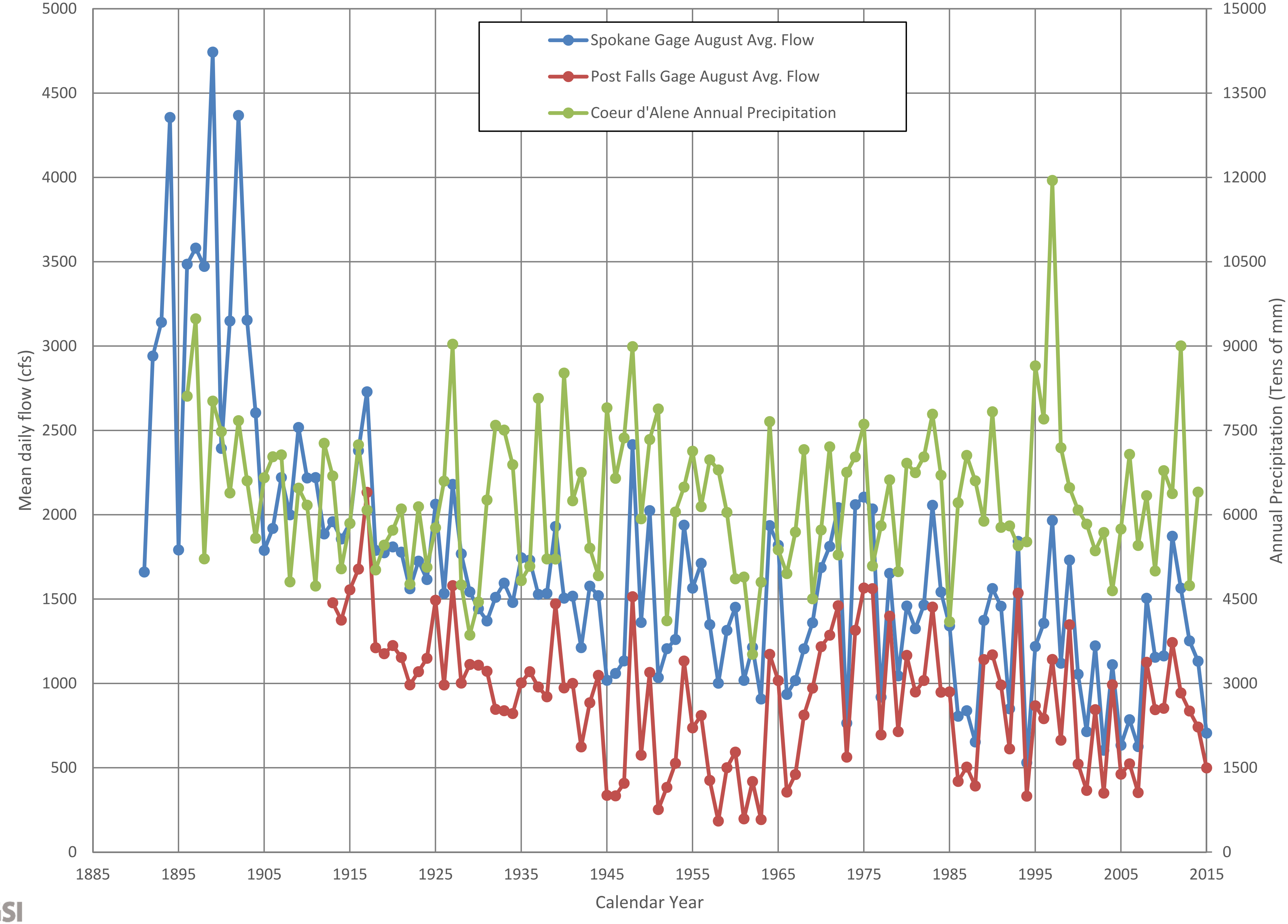

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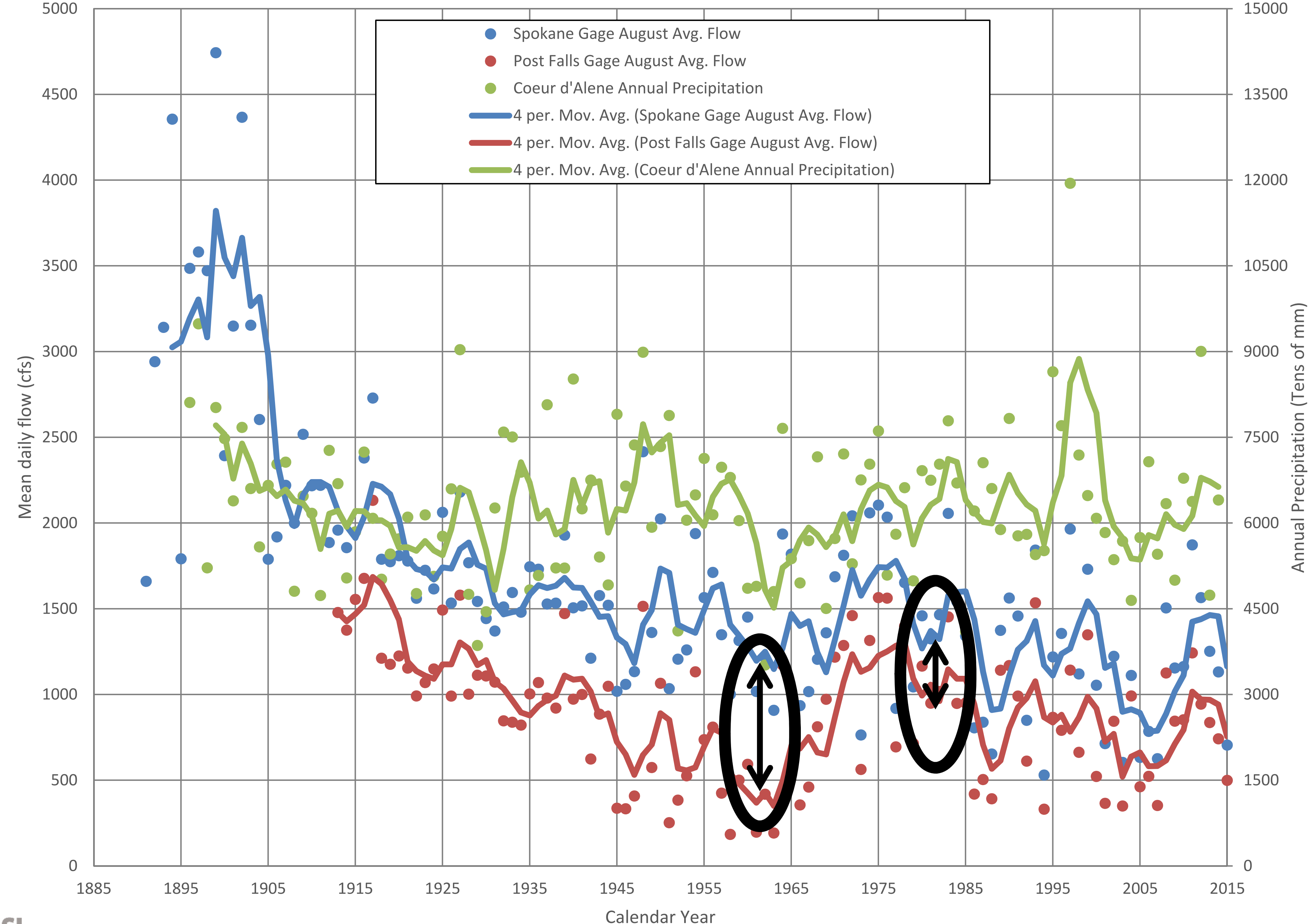

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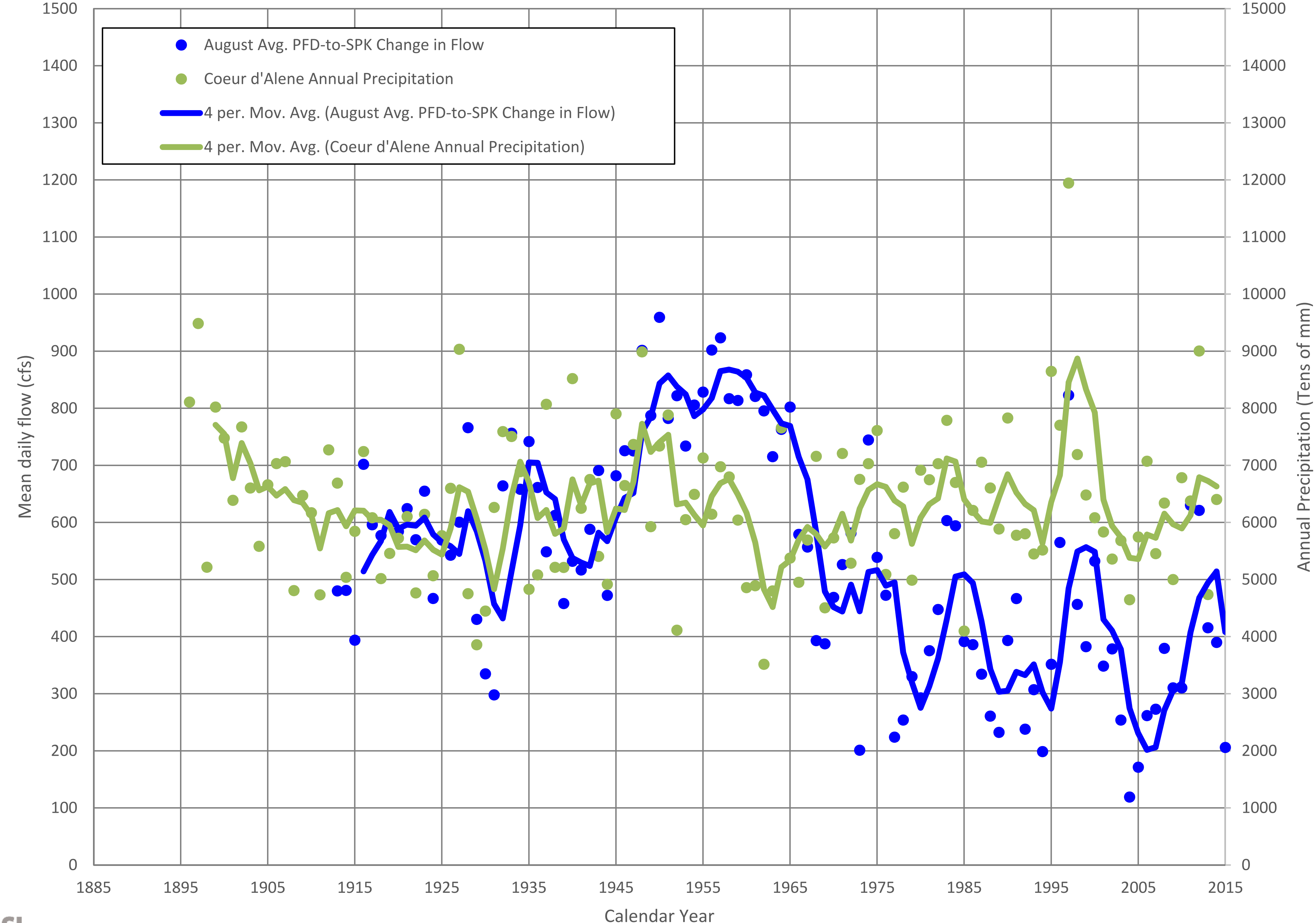

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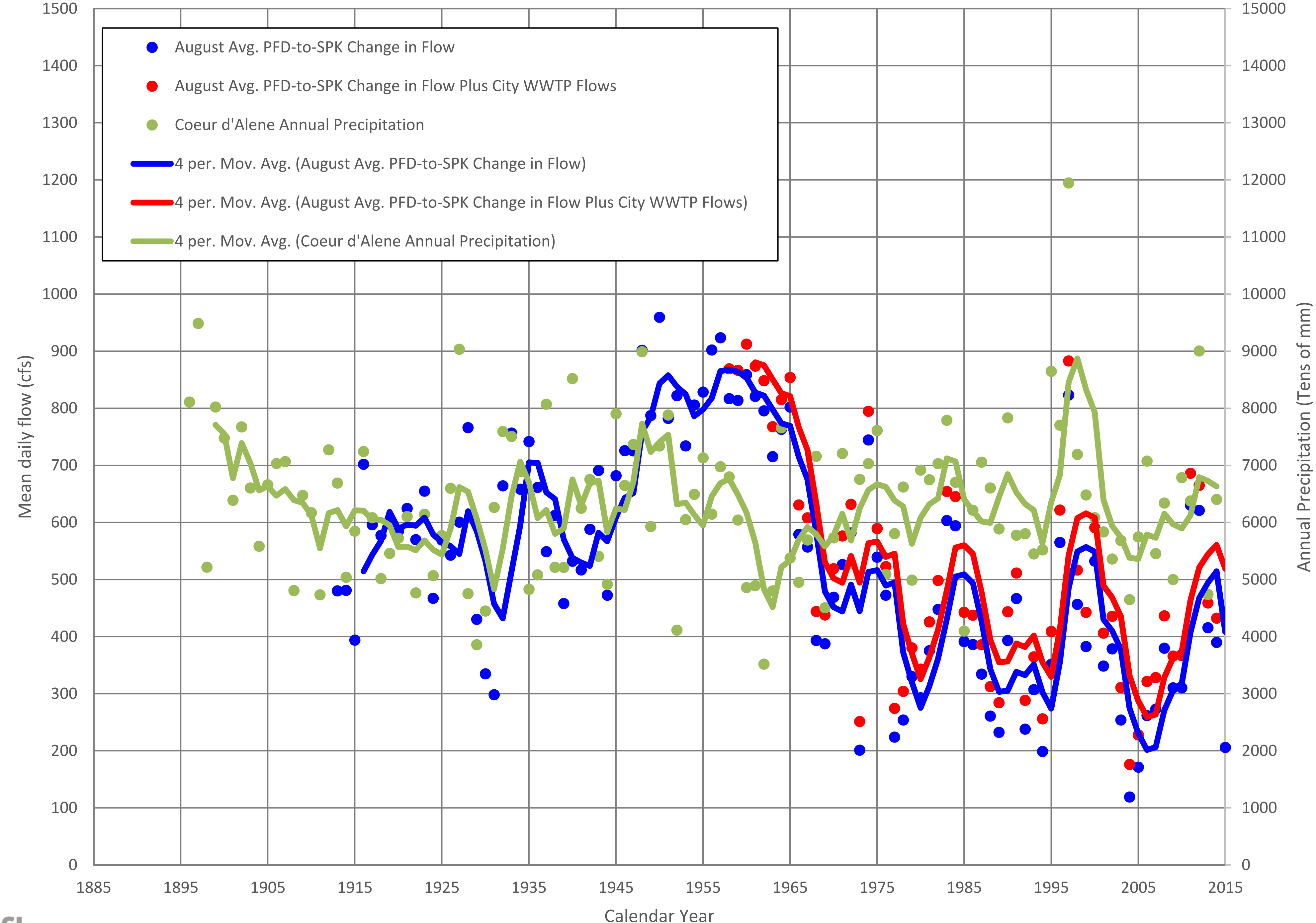

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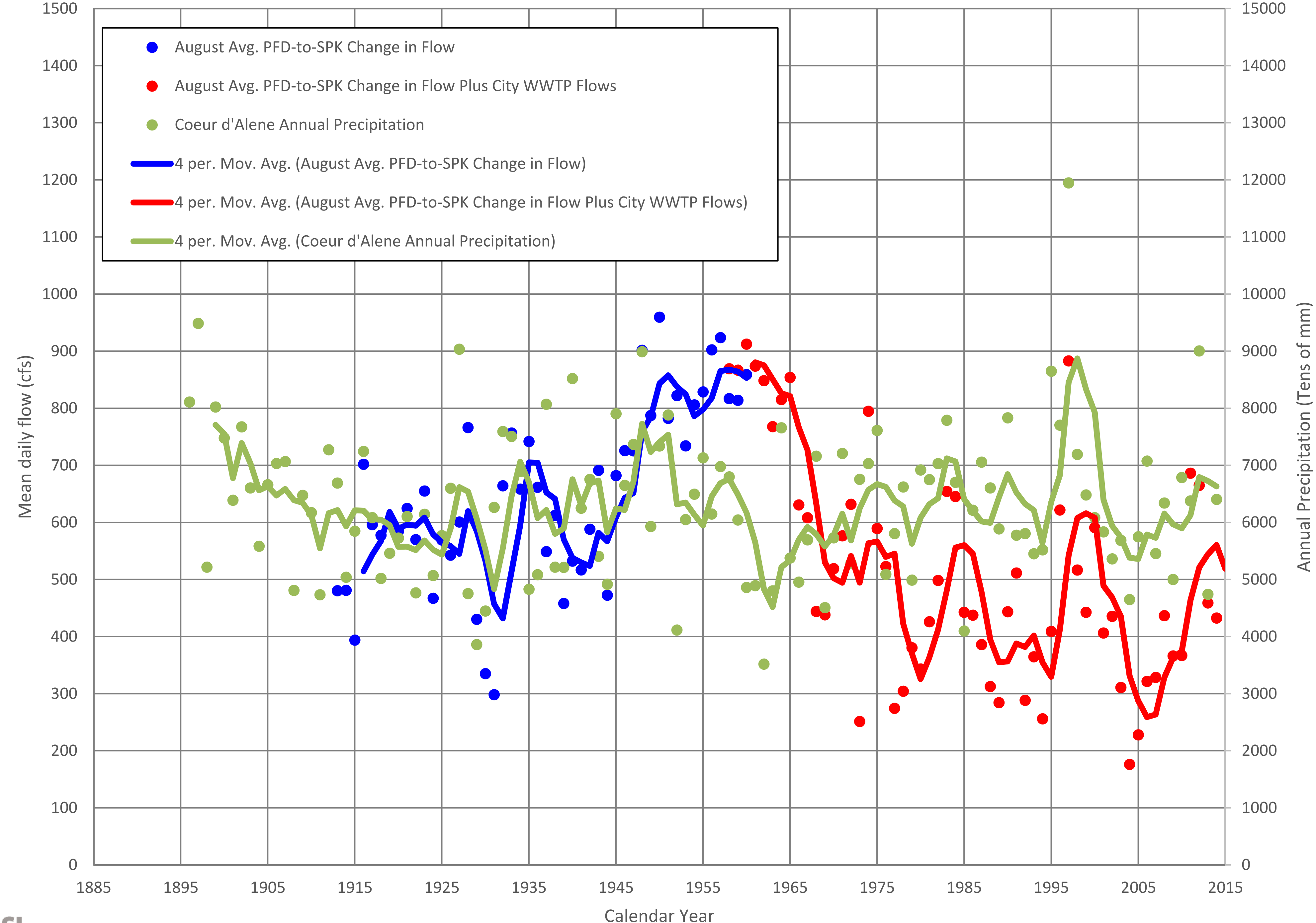

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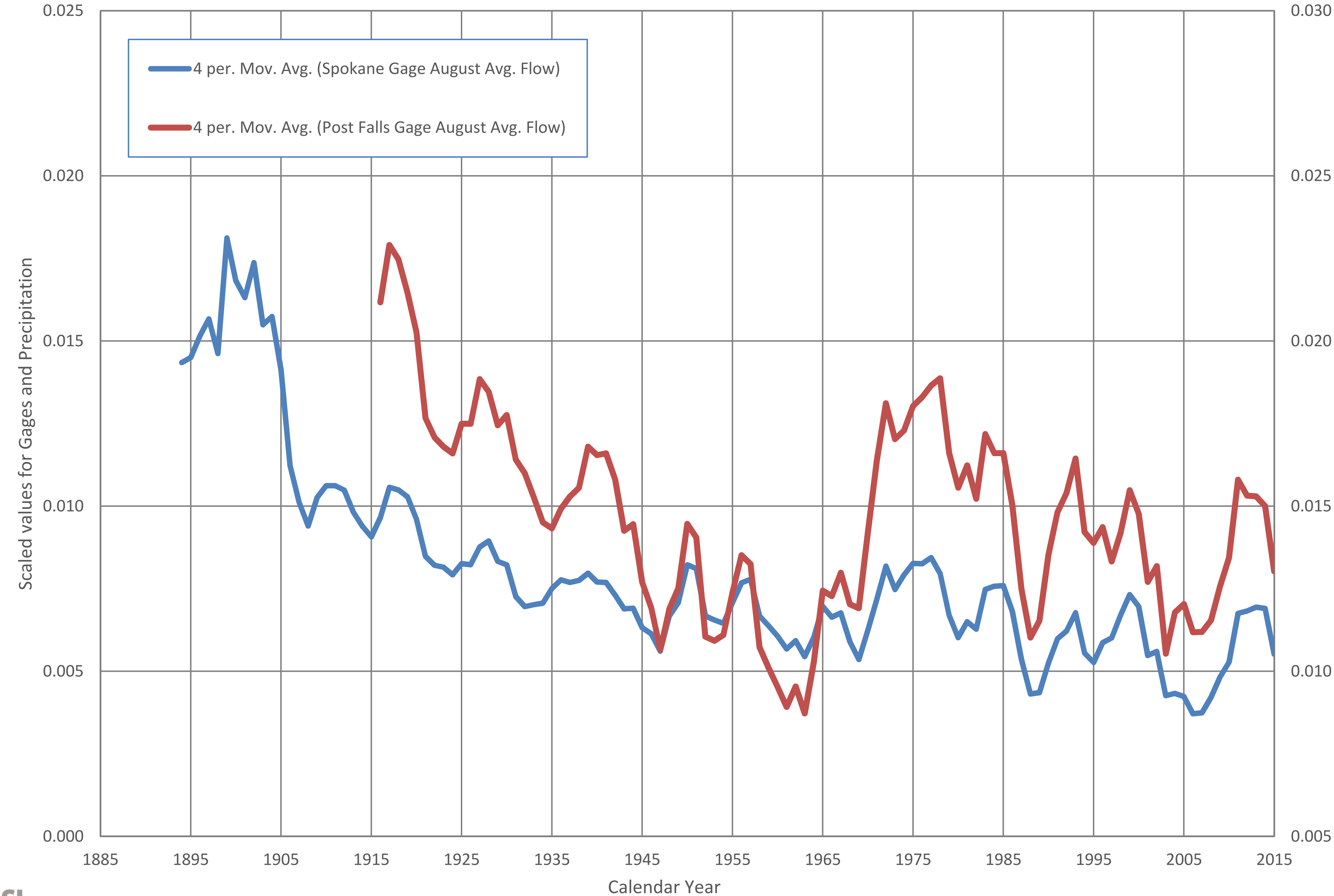

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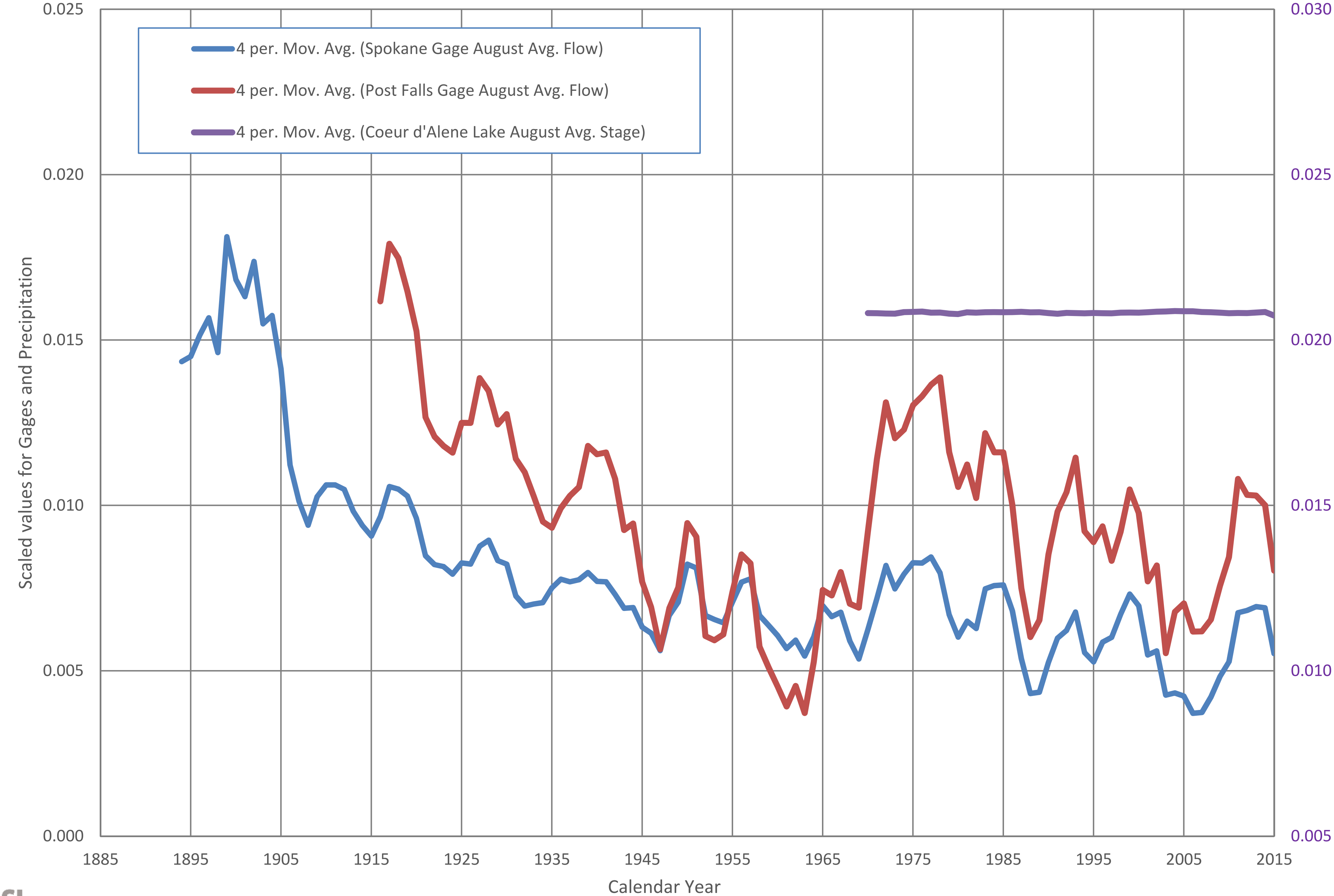

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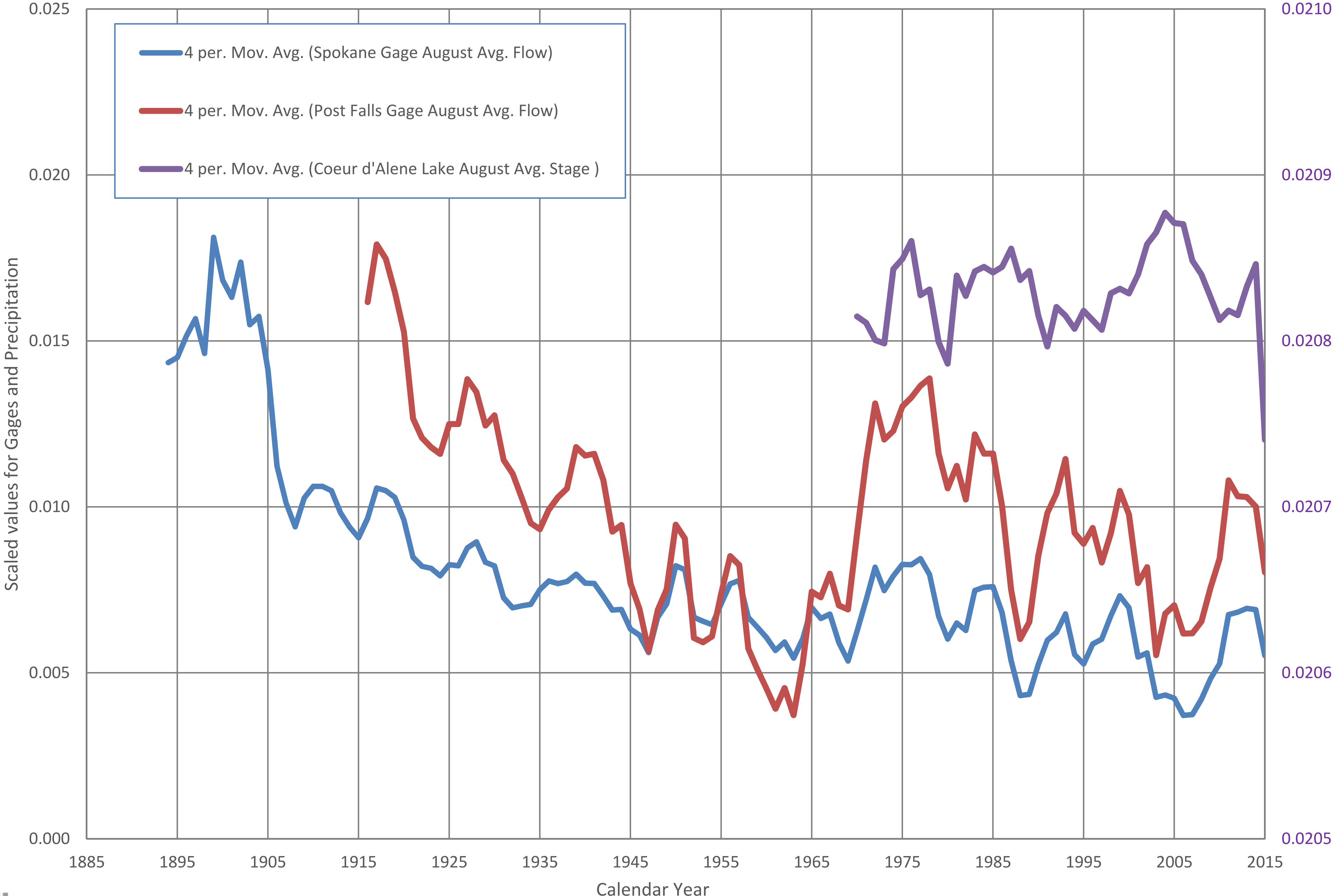

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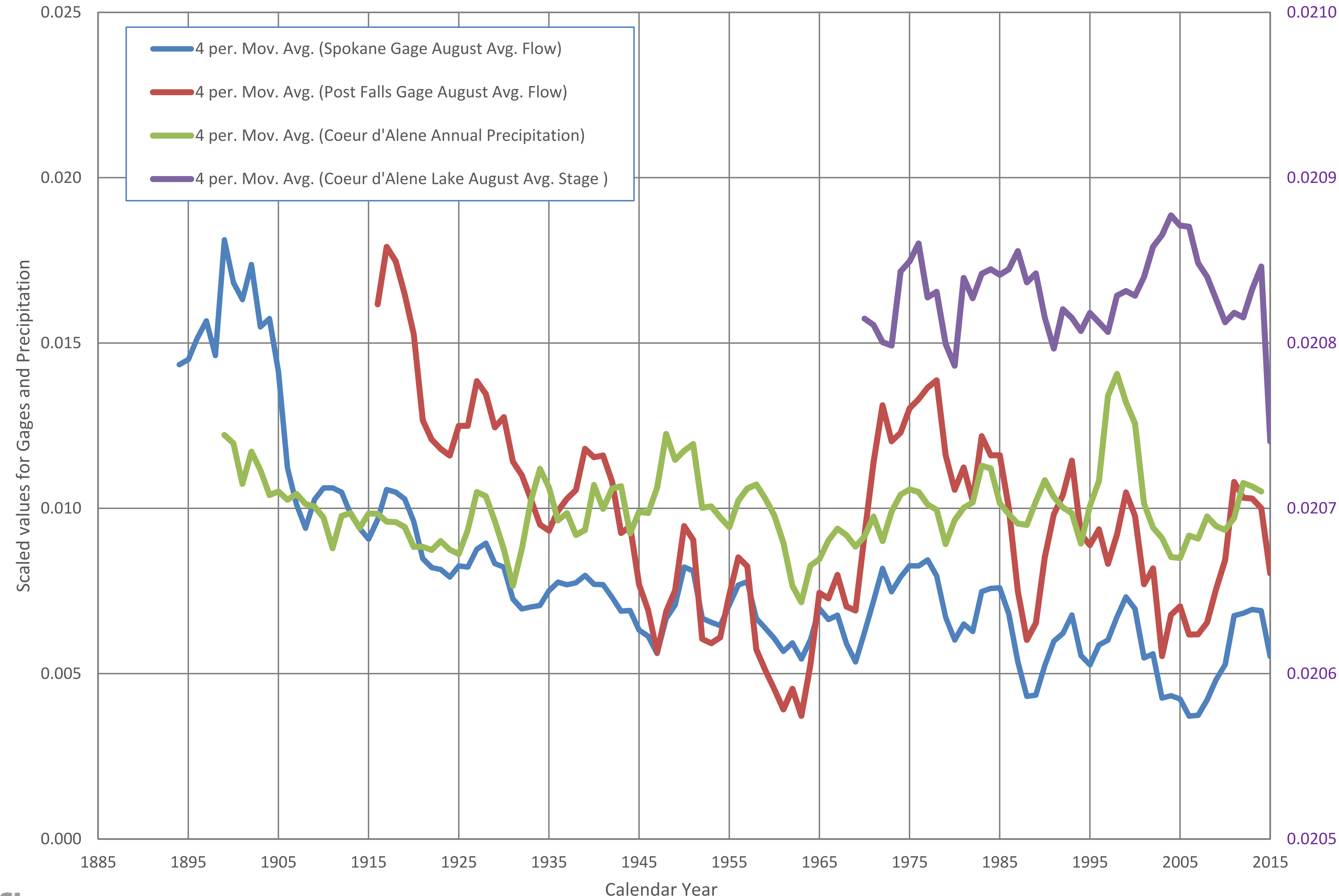

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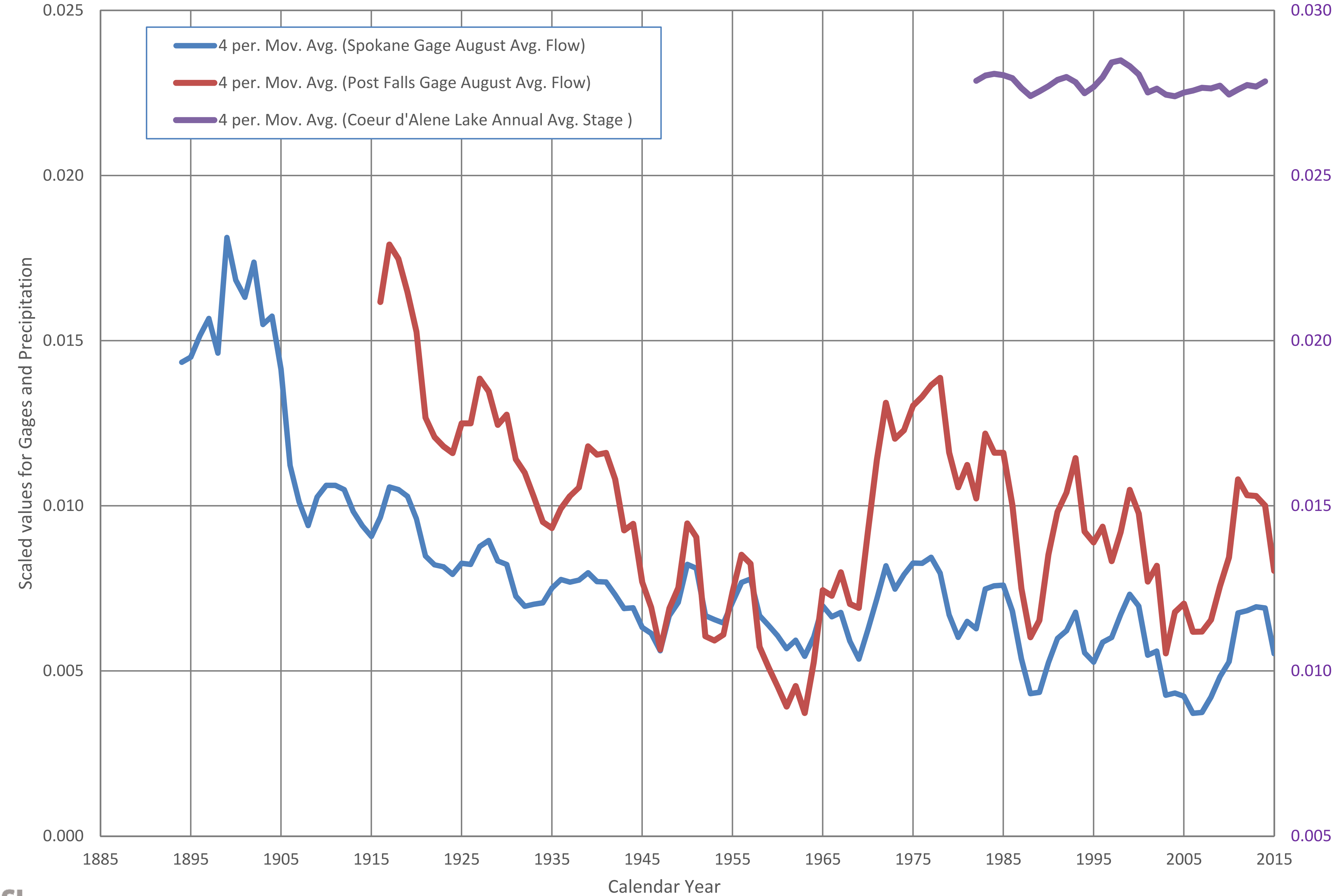

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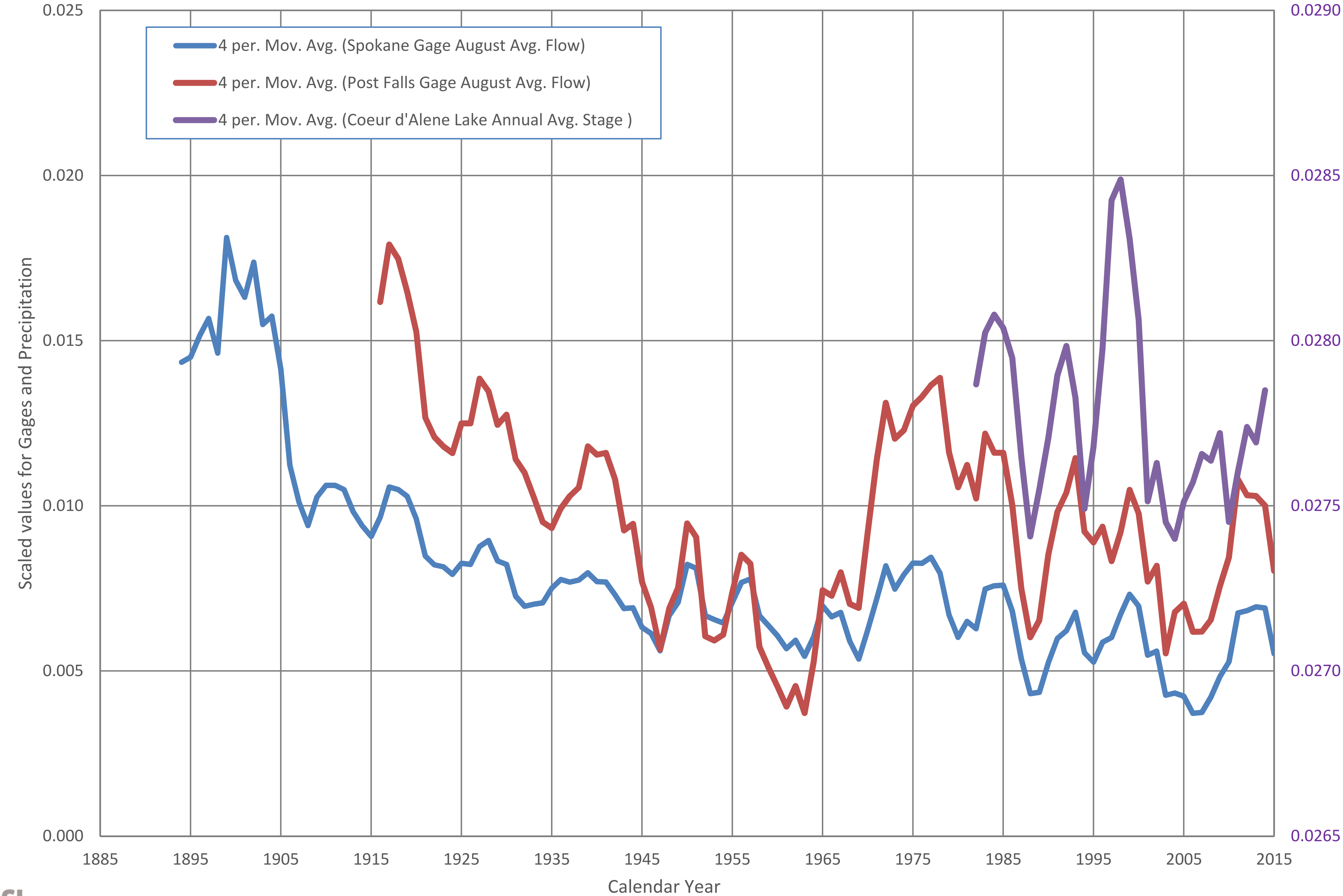

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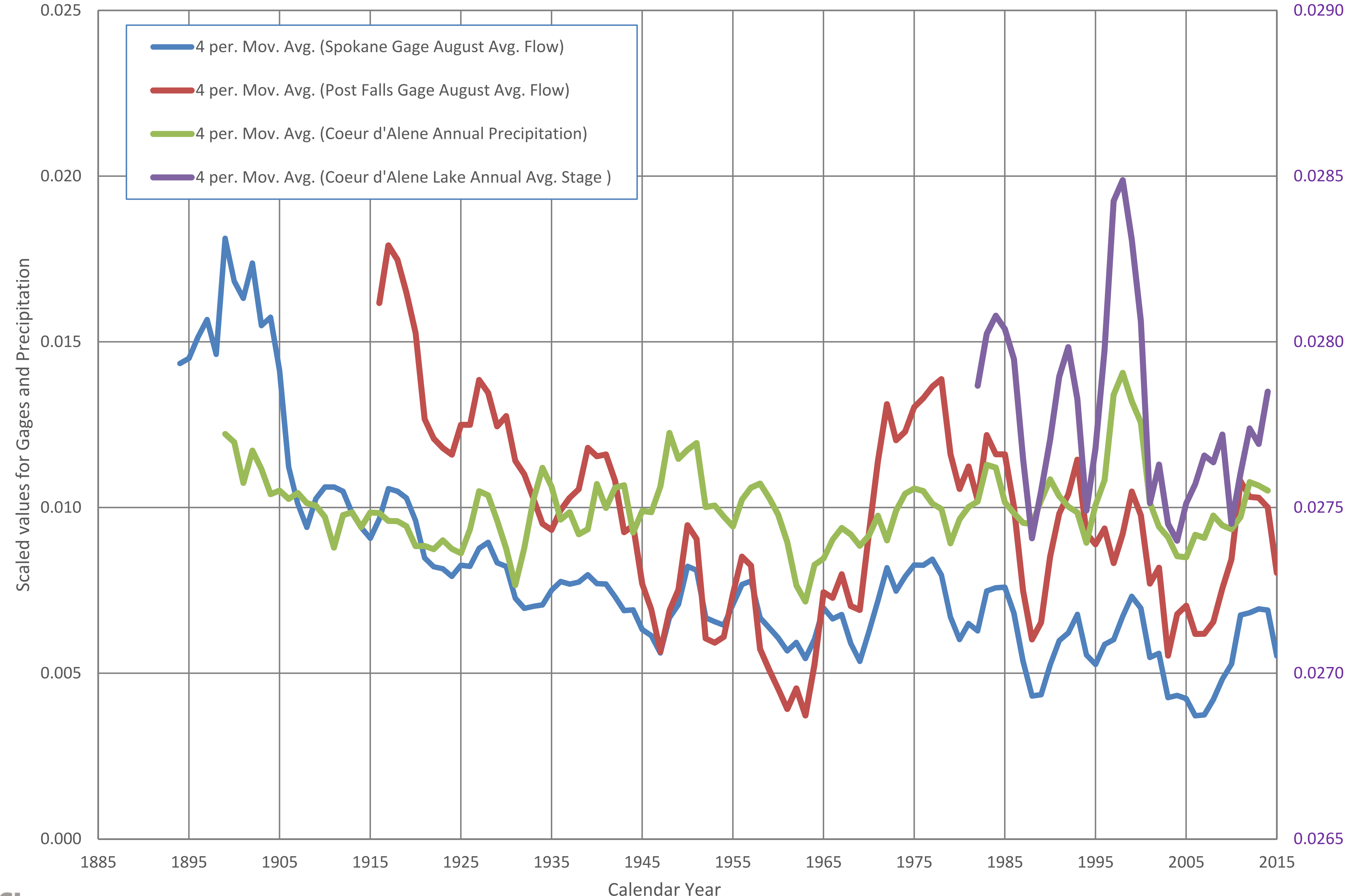

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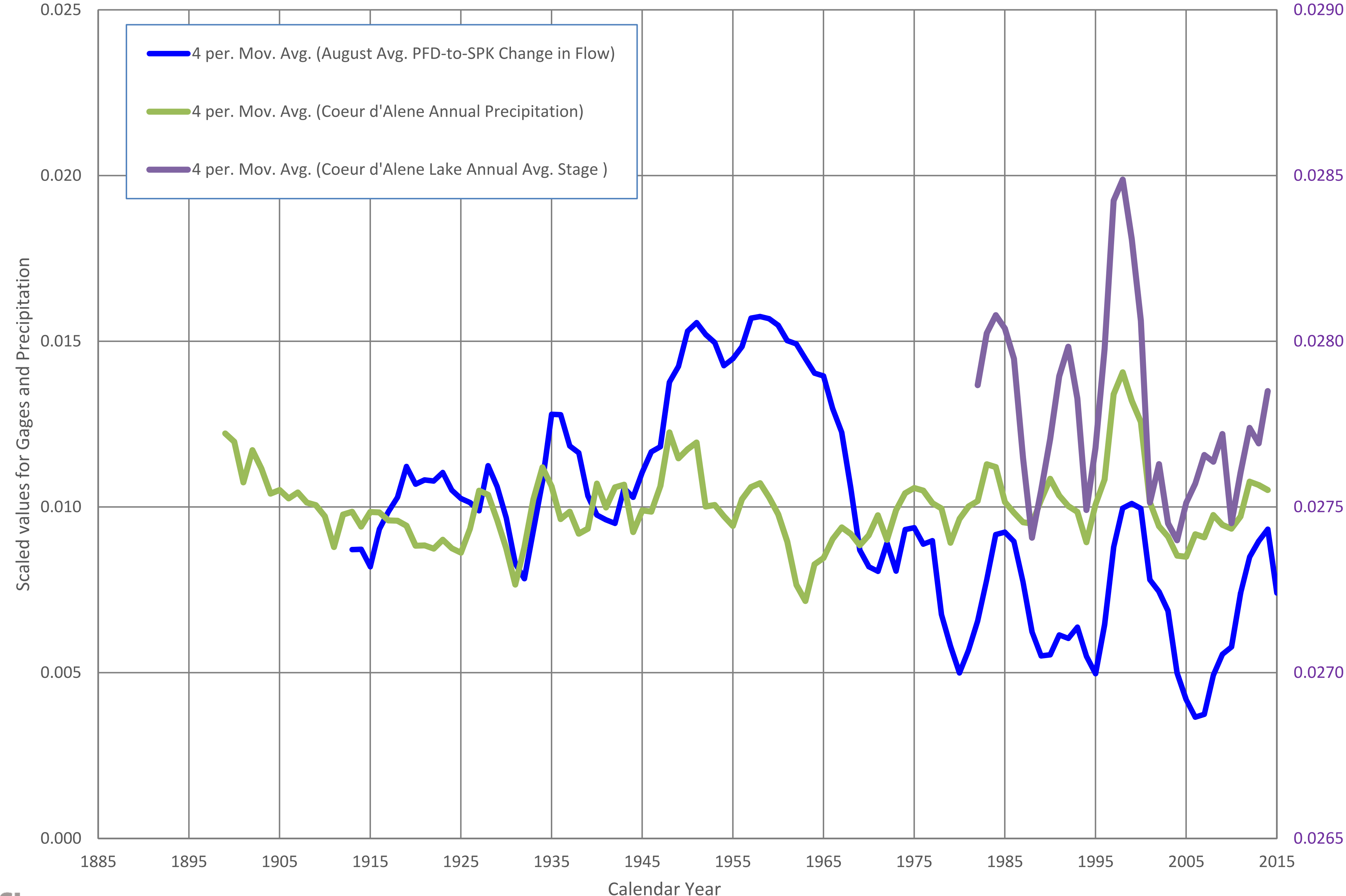

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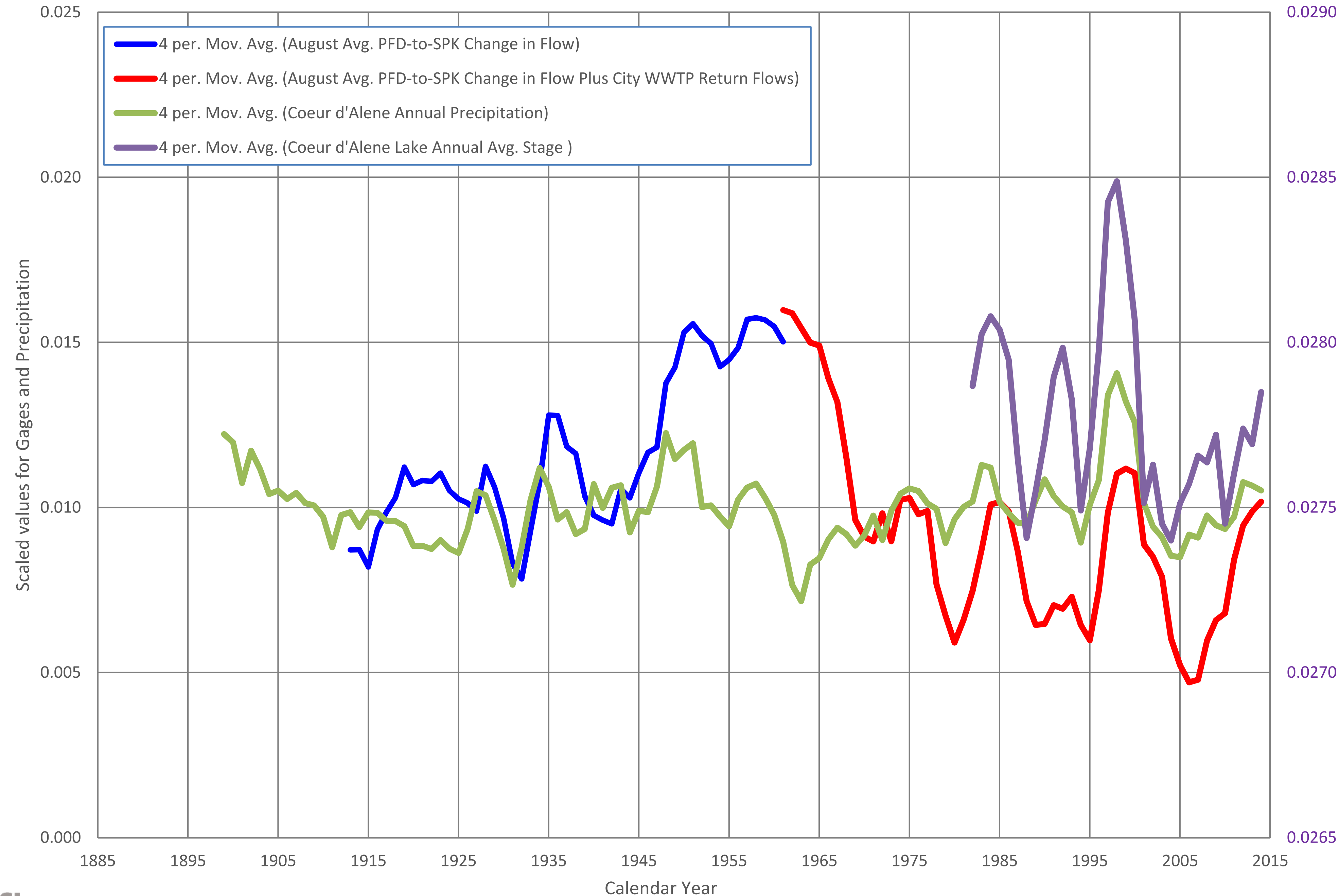

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Topics

1. Why evaluate historical changes
2. Define processes that theoretically could have been the cause of decreasing river low flows
3. Evaluate each process in depth (many slides)
4. Conclusions regarding dominant processes and what it all means

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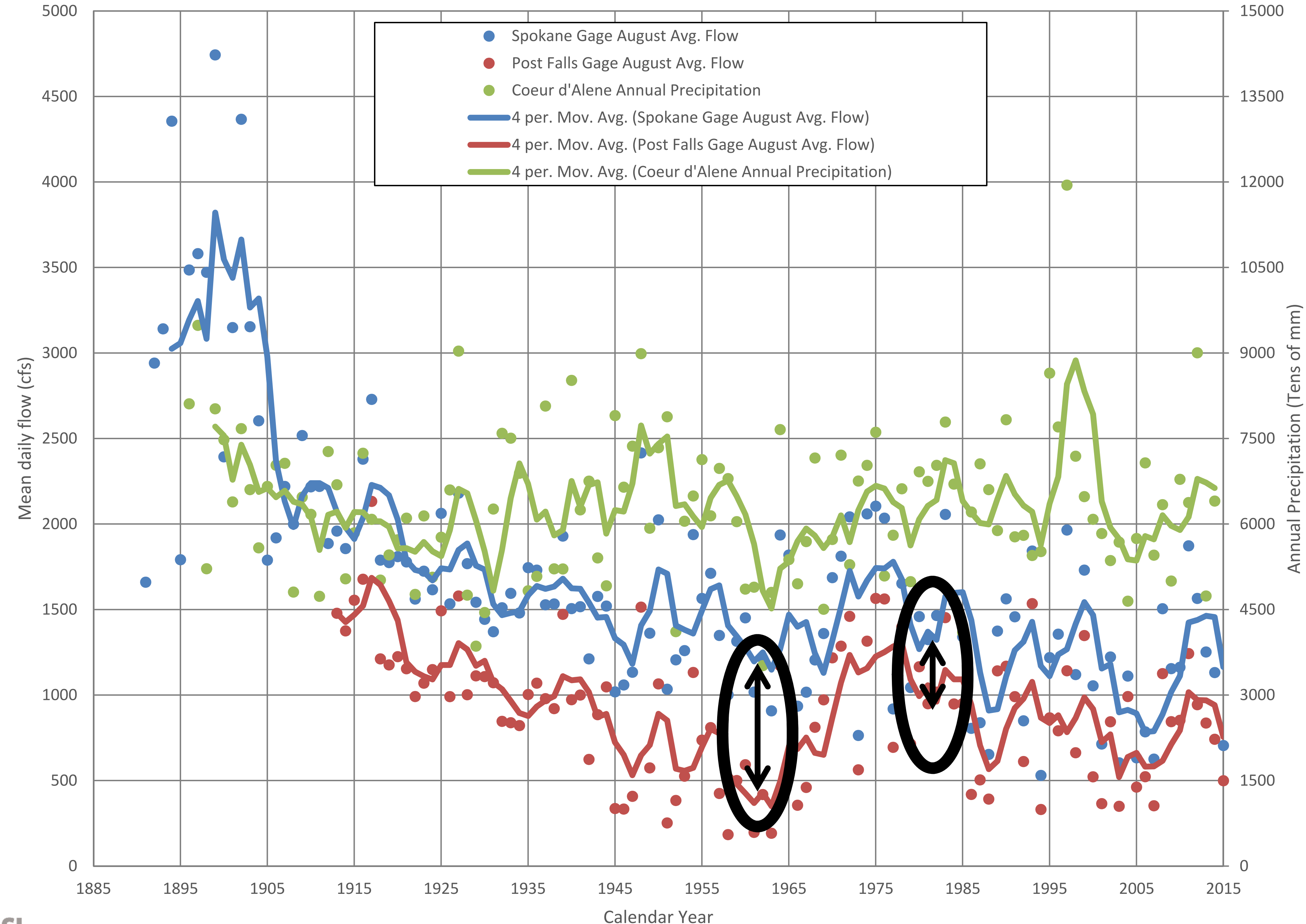
River Flow and Watershed Changes Since Late 1800s

Gaged Flows, Precipitation, Lake Stage, City Return Flows



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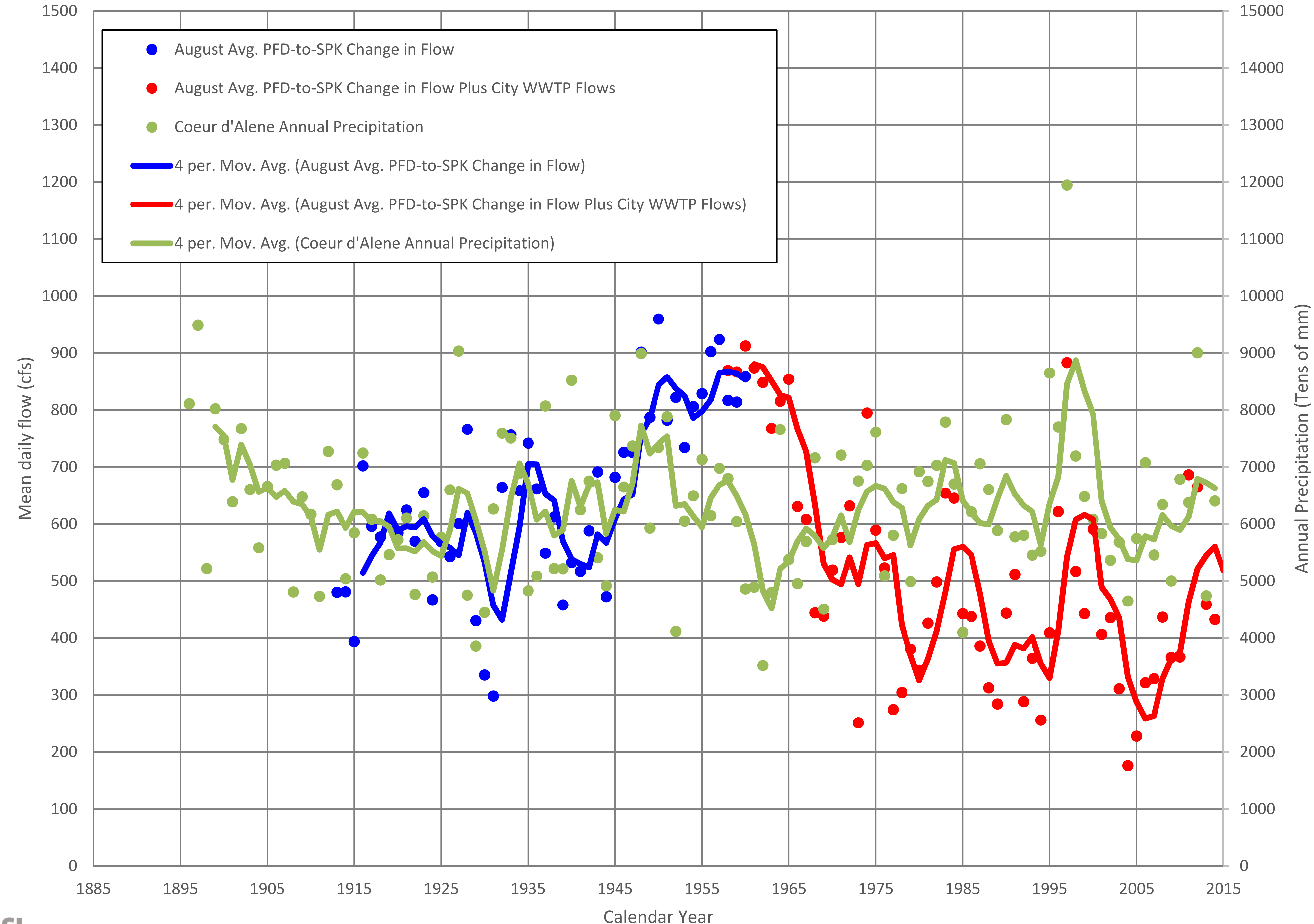

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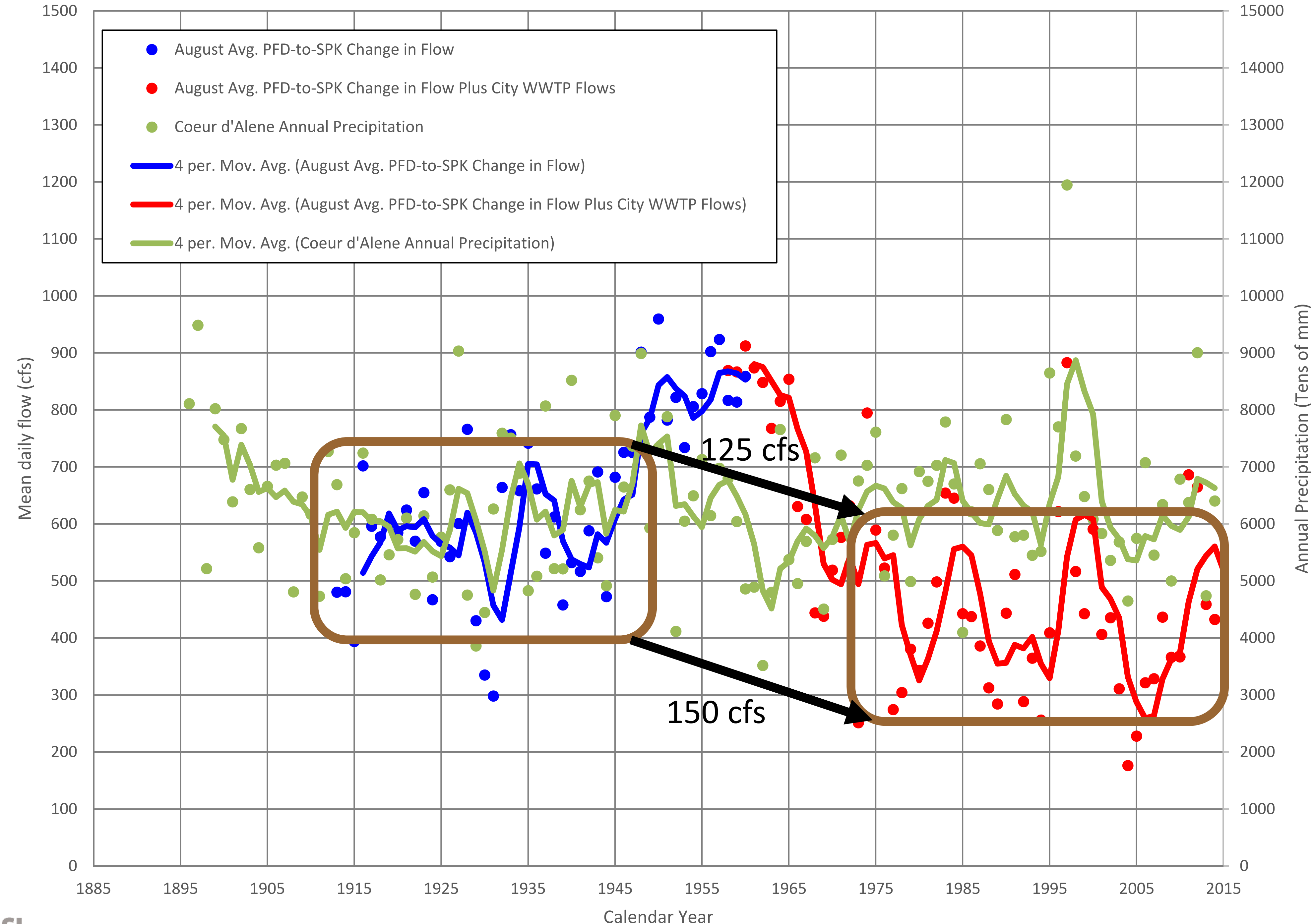

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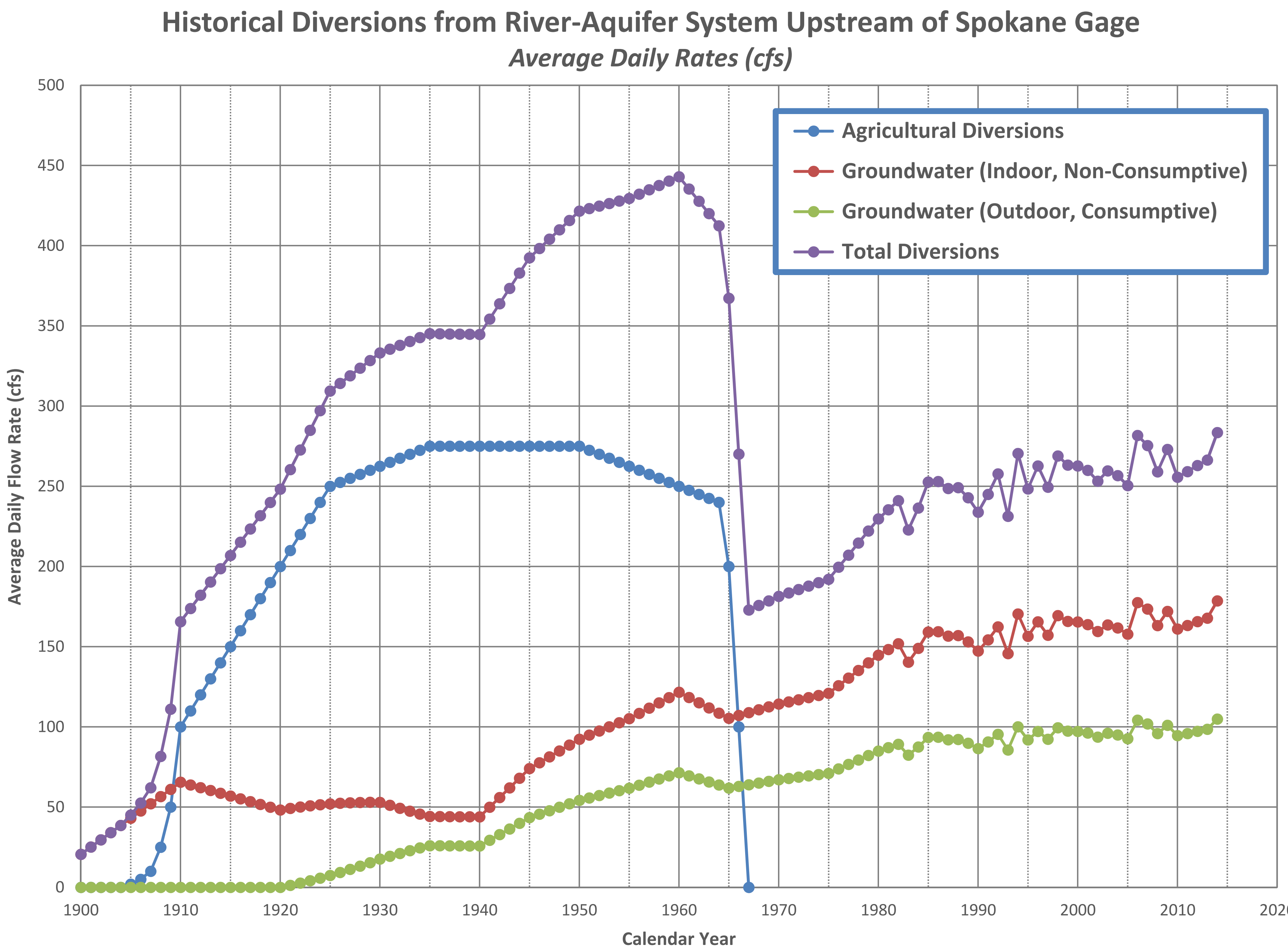

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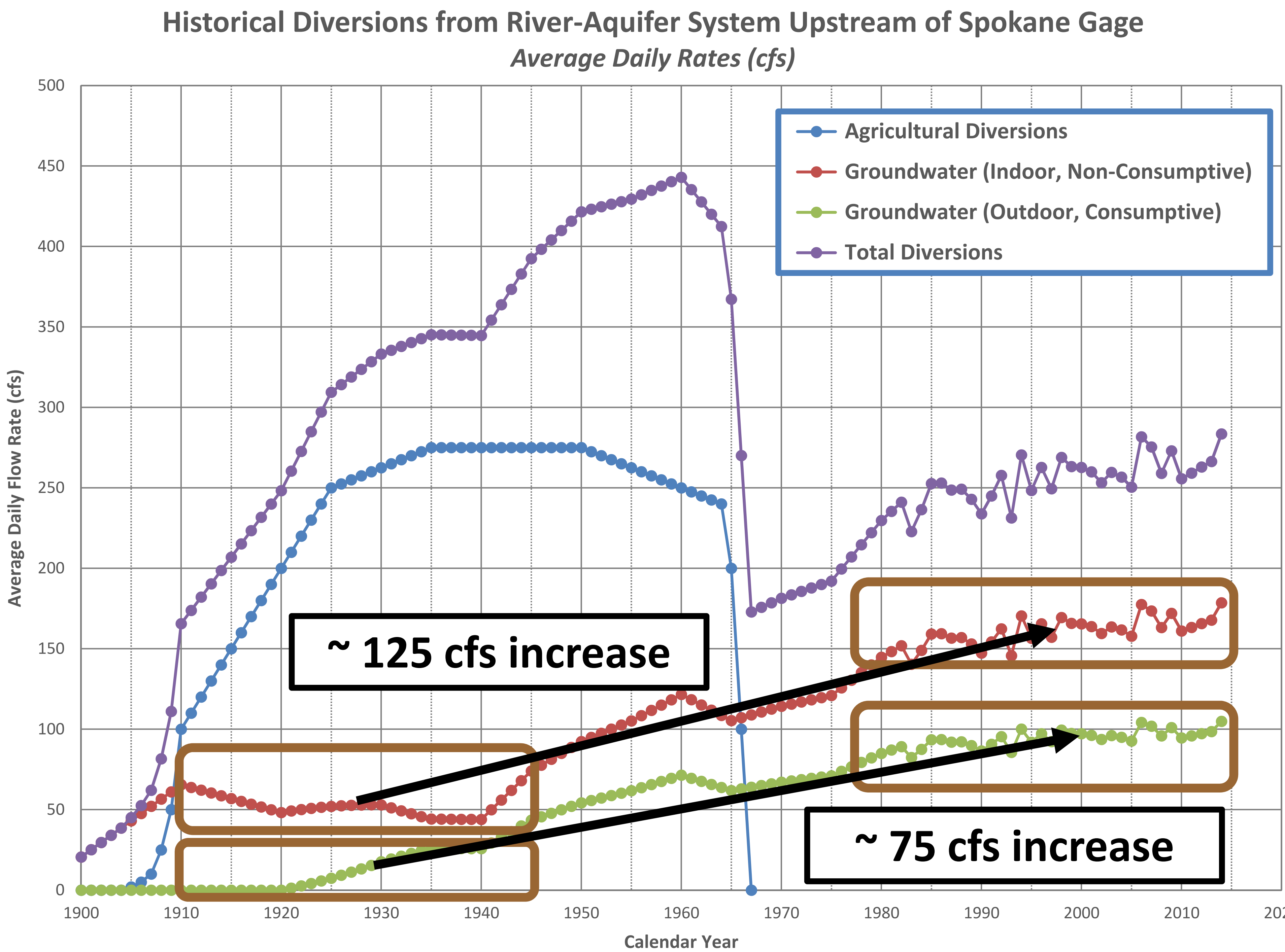
Historical Diversions from River-Aquifer System Upstream of Spokane Gage
Average Daily Rates (cfs)
Agricultural Diversions
Groundwater (Indoor, Non-Consumptive)
Groundwater (Outdoor, Consumptive)
Total Diversions
~ 125 cfs increase
~ 75 cfs increase
Average Daily Flow Rate (cfs)
Calendar Year
0
50
100
150
200
250
300
350
400
450
500
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

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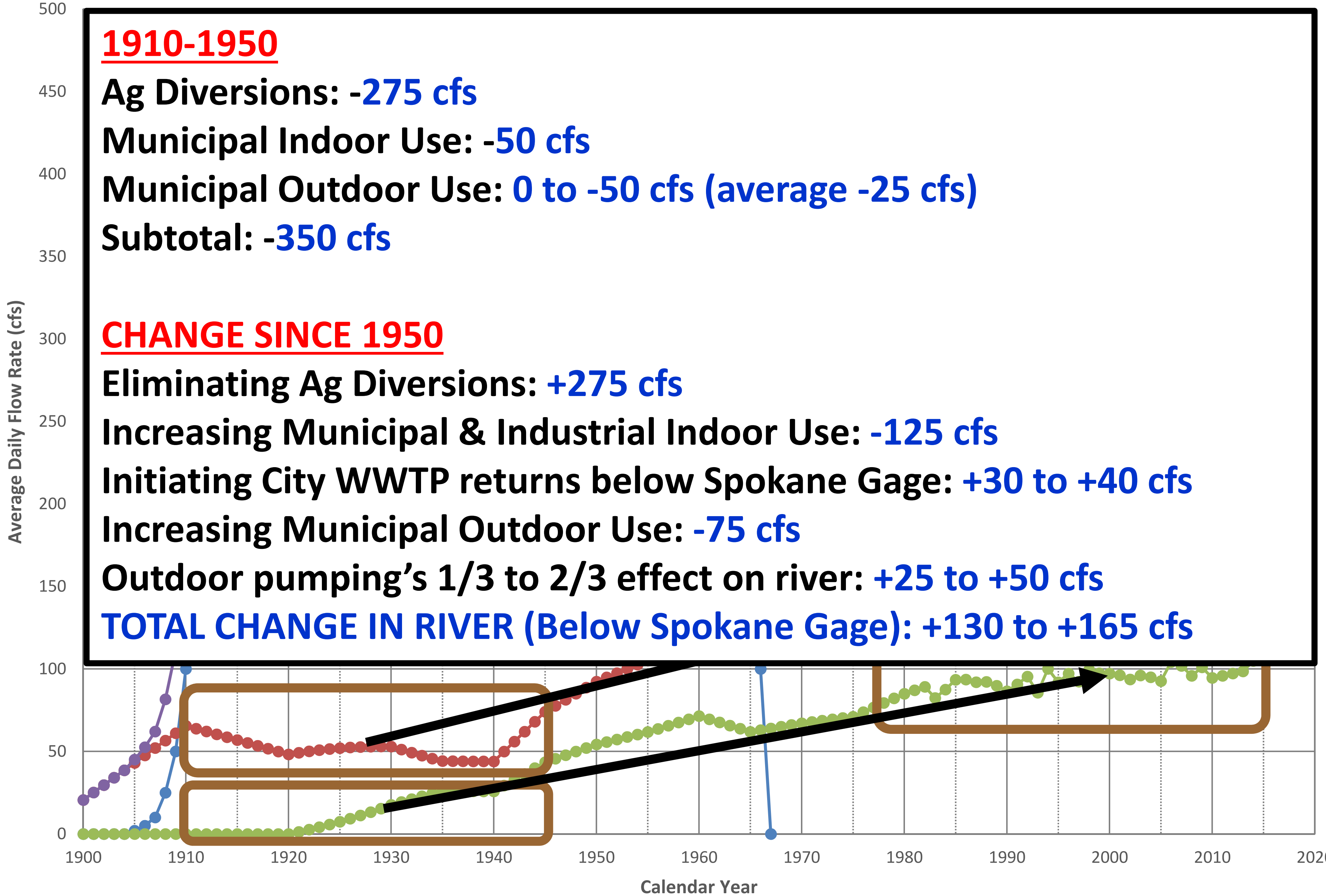
Average Daily Rates (cfs)



1910-1950

Ag Diversions: -275 cfs

Municipal Indoor Use: -50 cfs

Municipal Outdoor Use: 0 to -50 cfs (average -25 cfs)

Subtotal: -350 cfs

CHANGE SINCE 1950

Eliminating Ag Diversions: +275 cfs

Increasing Municipal & Industrial Indoor Use: -125 cfs

Initiating City WWTP returns below Spokane Gage: +30 to +40 cfs

Increasing Municipal Outdoor Use: -75 cfs

Outdoor pumping's 1/3 to 2/3 effect on river: +25 to +50 cfs

TOTAL CHANGE IN RIVER (Below Spokane Gage): +130 to +165 cfs

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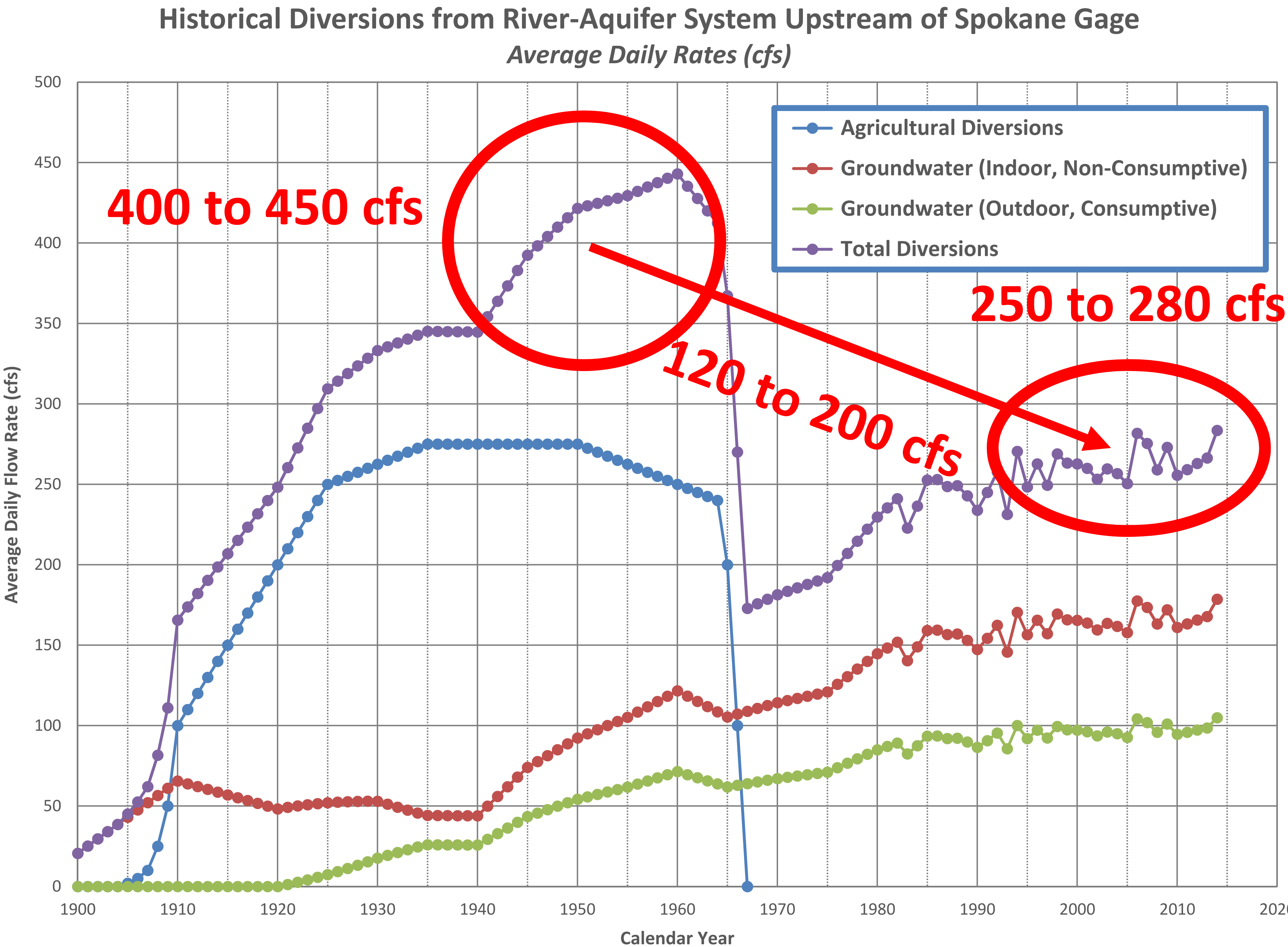

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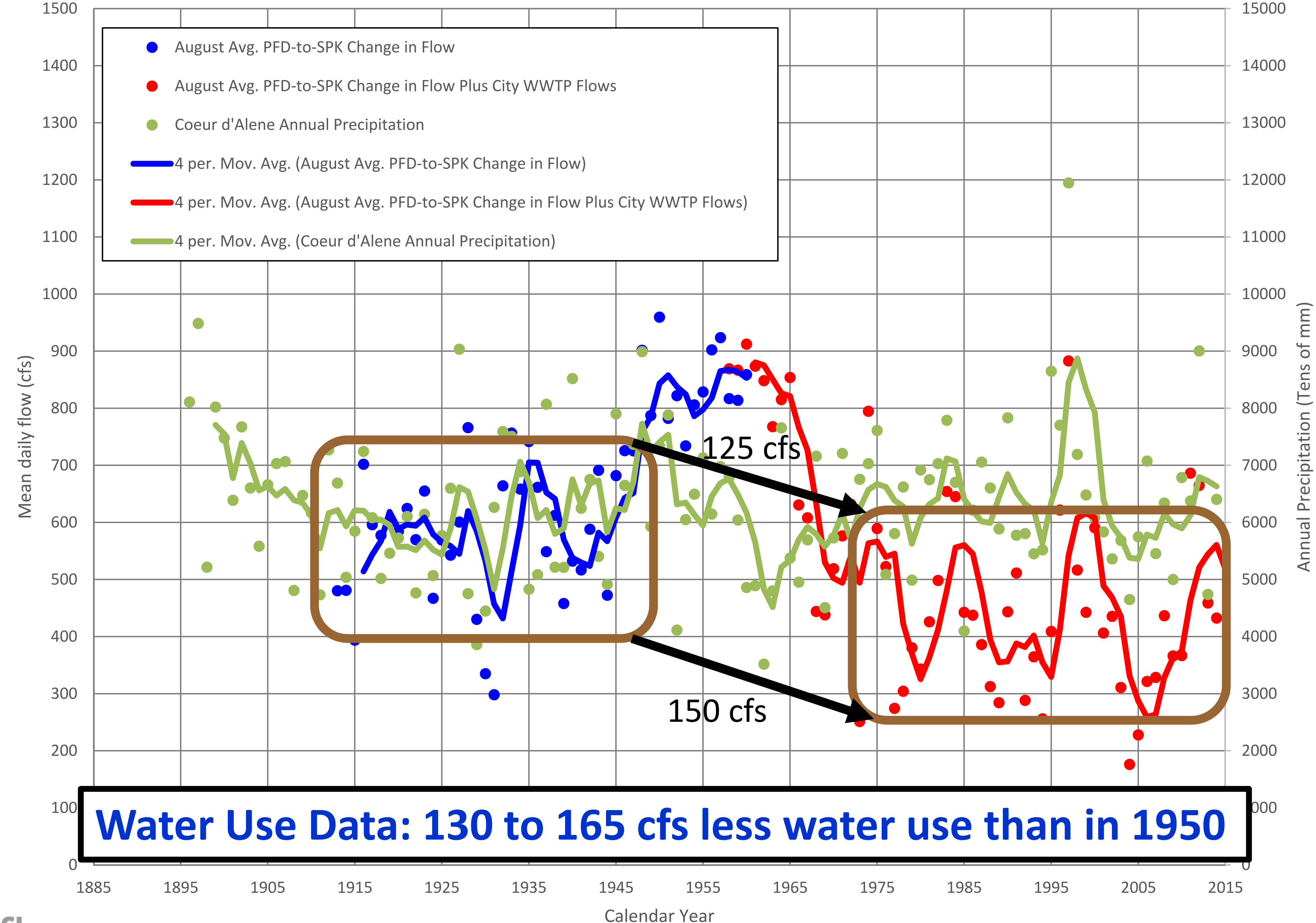
River Flow and Watershed Changes Since Late 1800s

Gaged Flows, Precipitation, Lake Stage, City Return Flows



Water Use Data: 130 to 165 cfs less water use than in 1950

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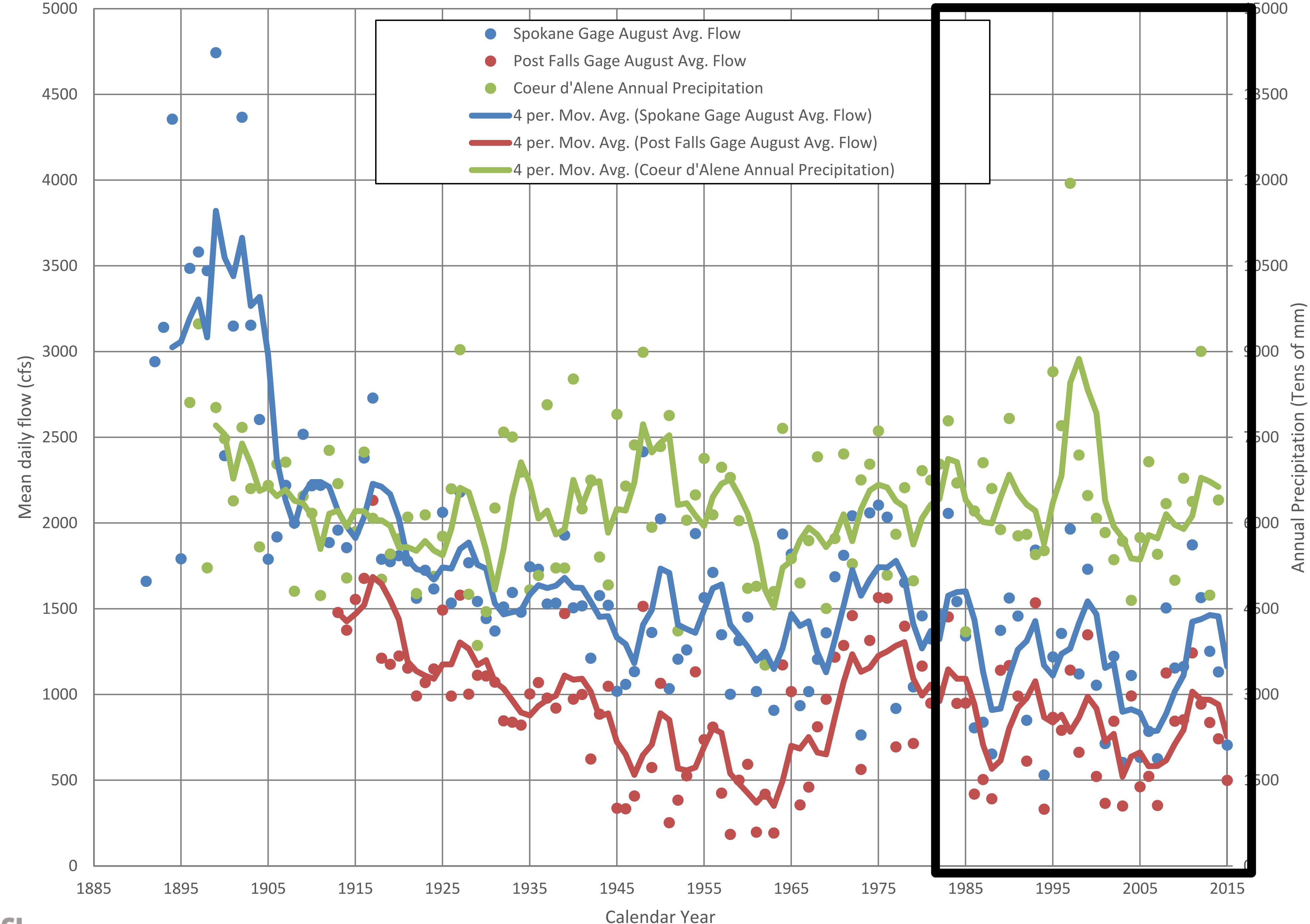

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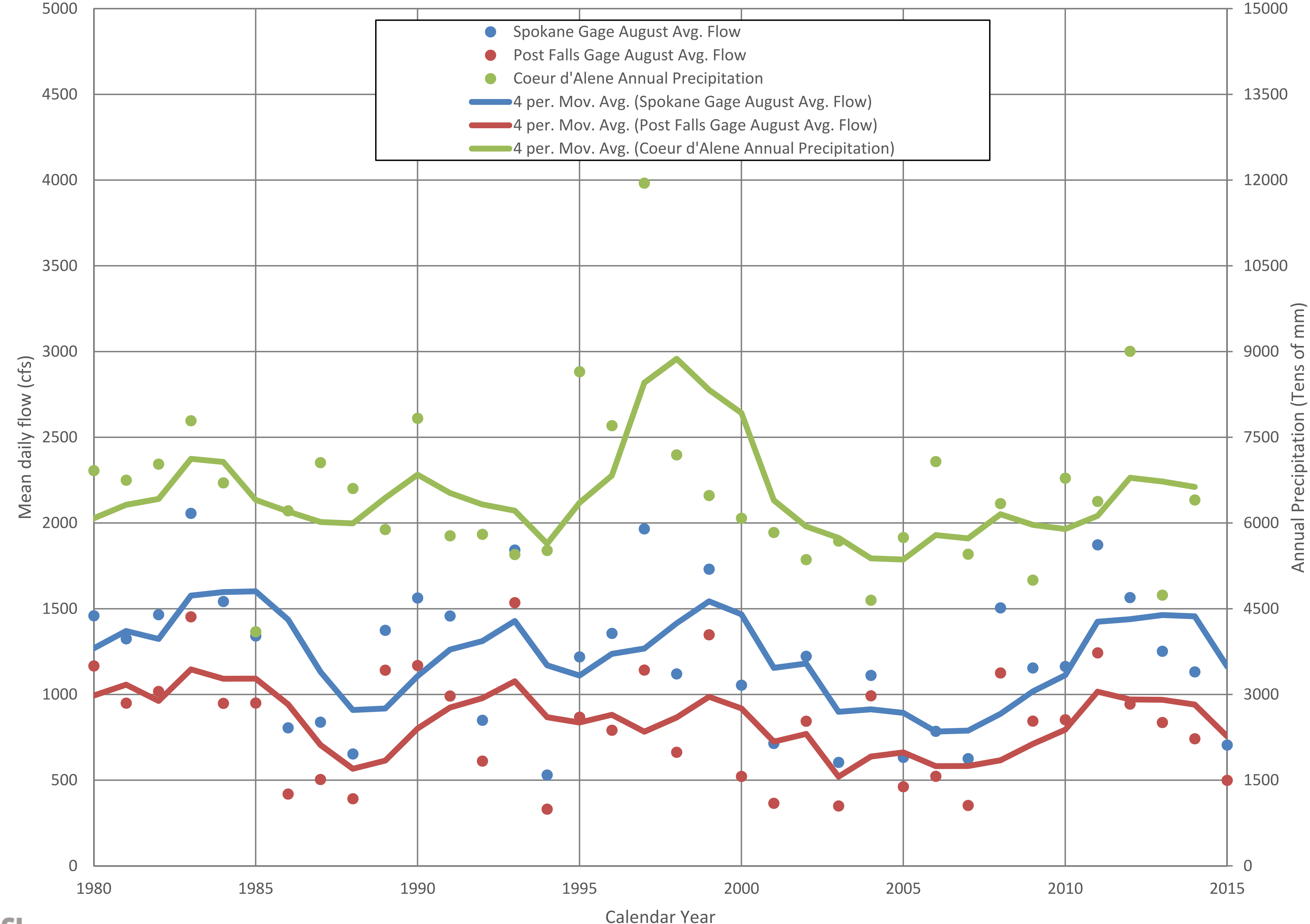

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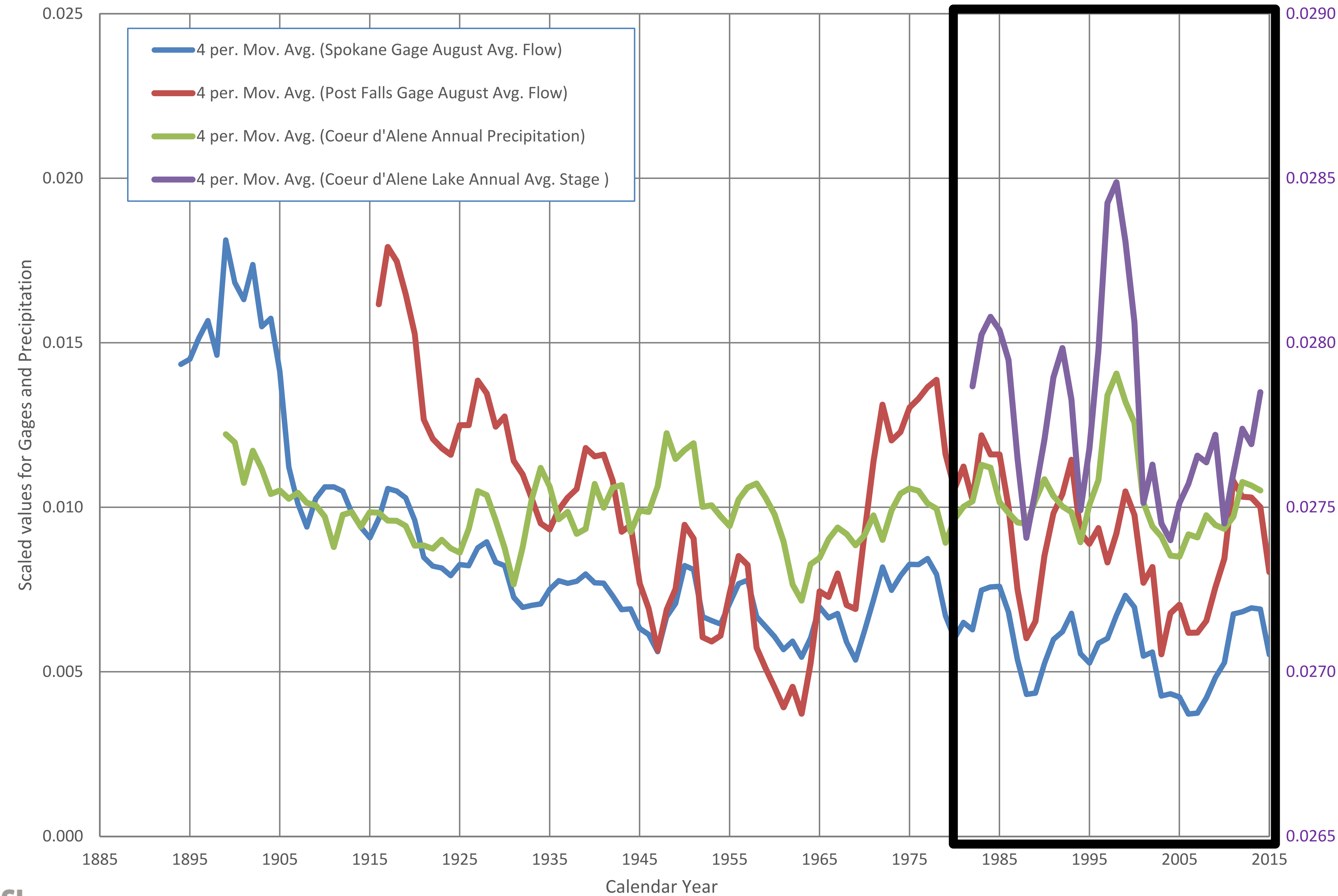

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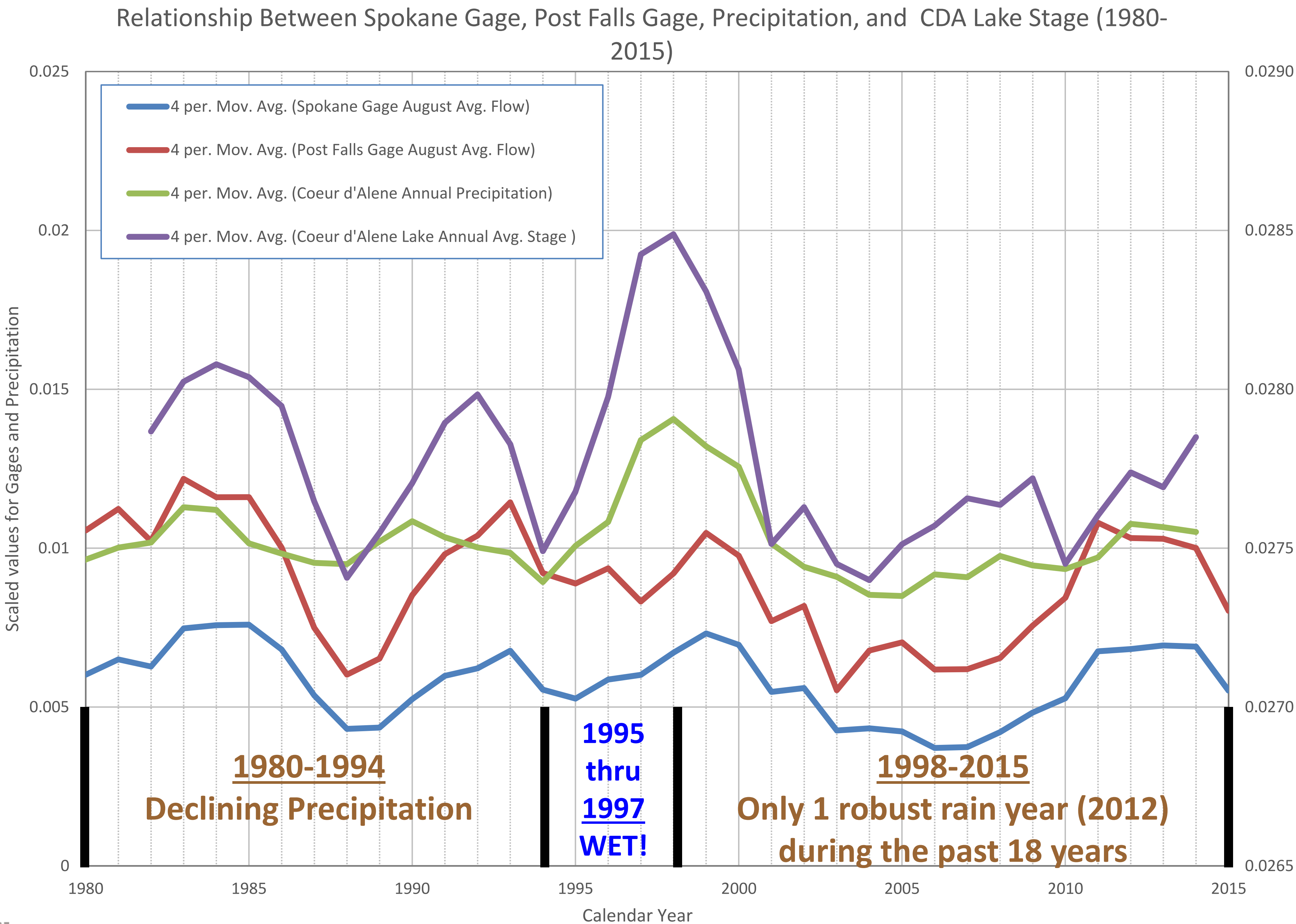

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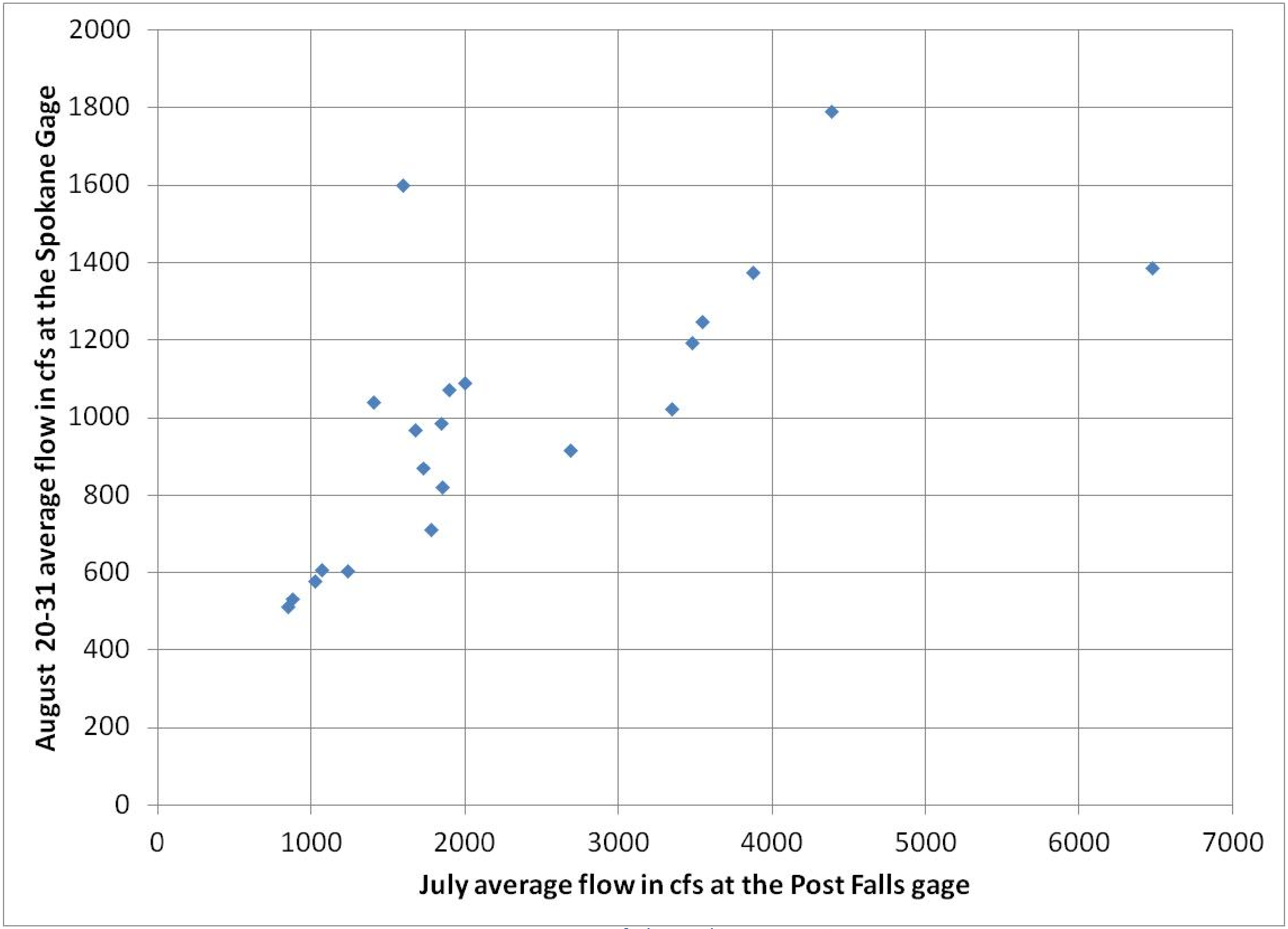
Upstream July Flow at the Post Falls Gage Affects Low Flows in August at the Spokane Gage



Source of Plot and Interpretation

Hydrogeology: Ground Water Pumping and River Flows, Part 1

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

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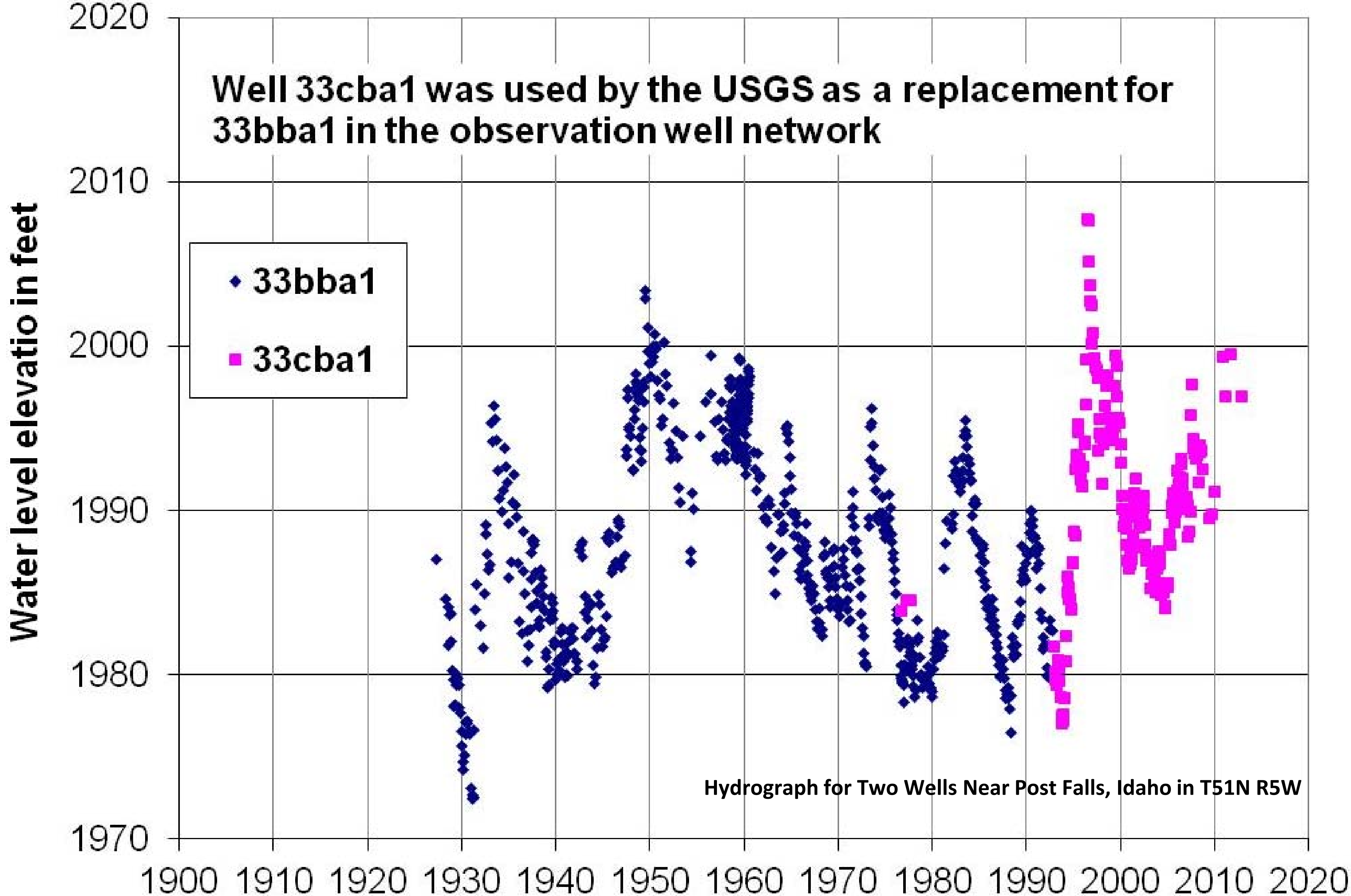
Groundwater Elevations Appear to be Rising Near Post Falls After the Early 1990s



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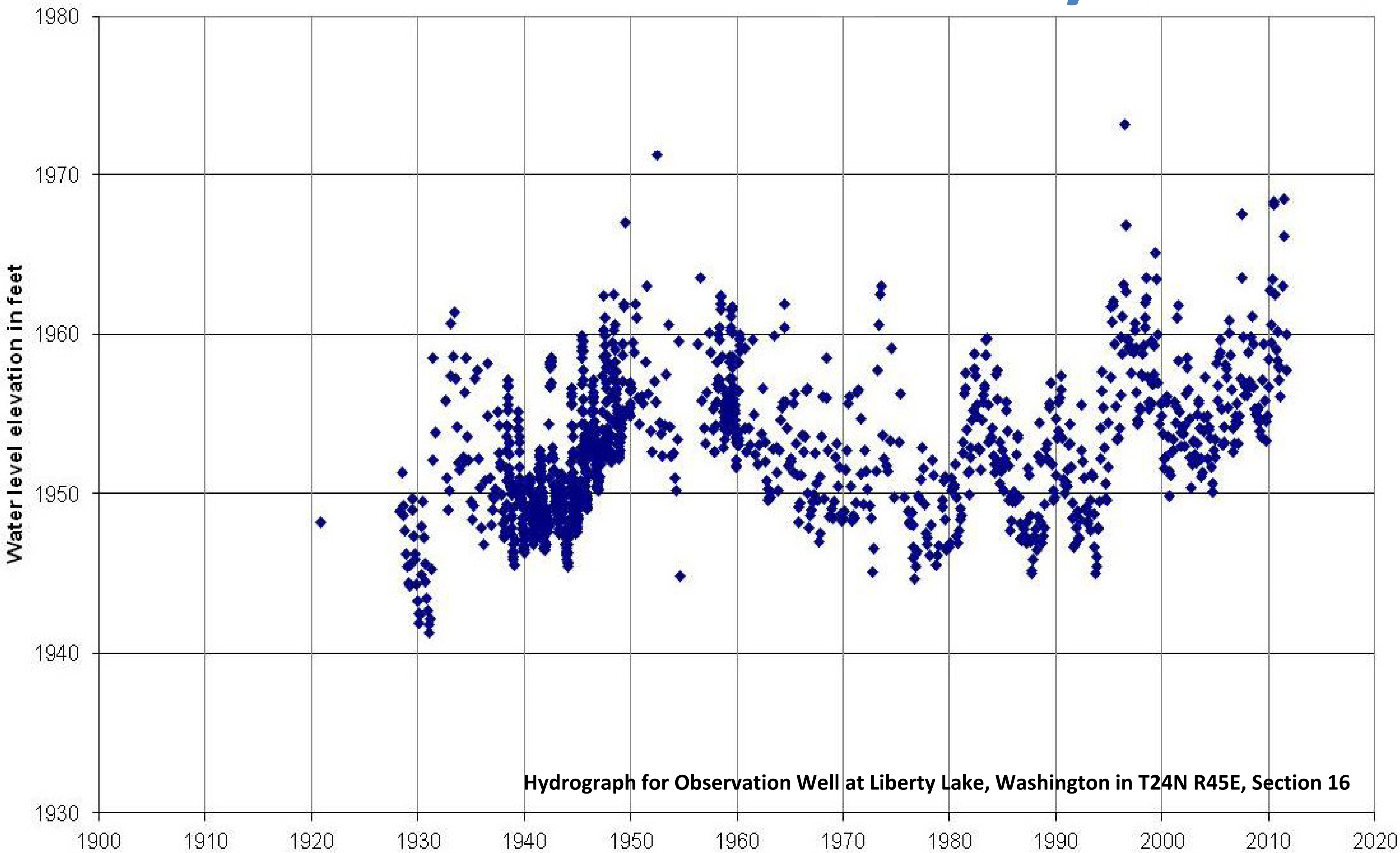

Source of Plot

Evaluation of Alternative Groundwater Pumping Schemes as an Approach to Mitigating Problems of Critical Low Flow in the Spokane River at Spokane, Washington

Proposal Prepared by Ralston Hydrologic Services, May 13, 2013

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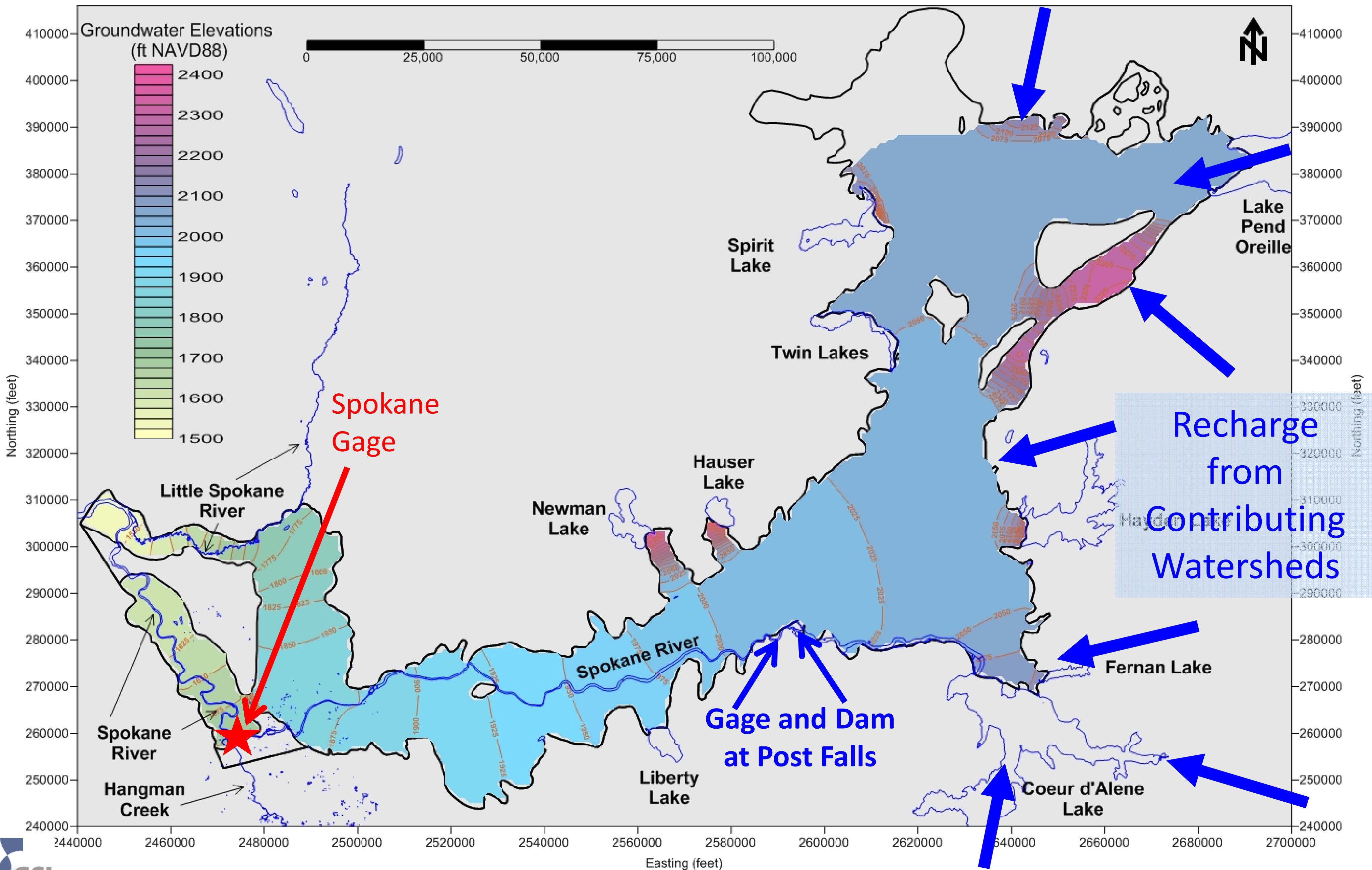
Conclusion: Ongoing Declines in Low Flows Are Likely Caused by Low Precipitation Since 1997



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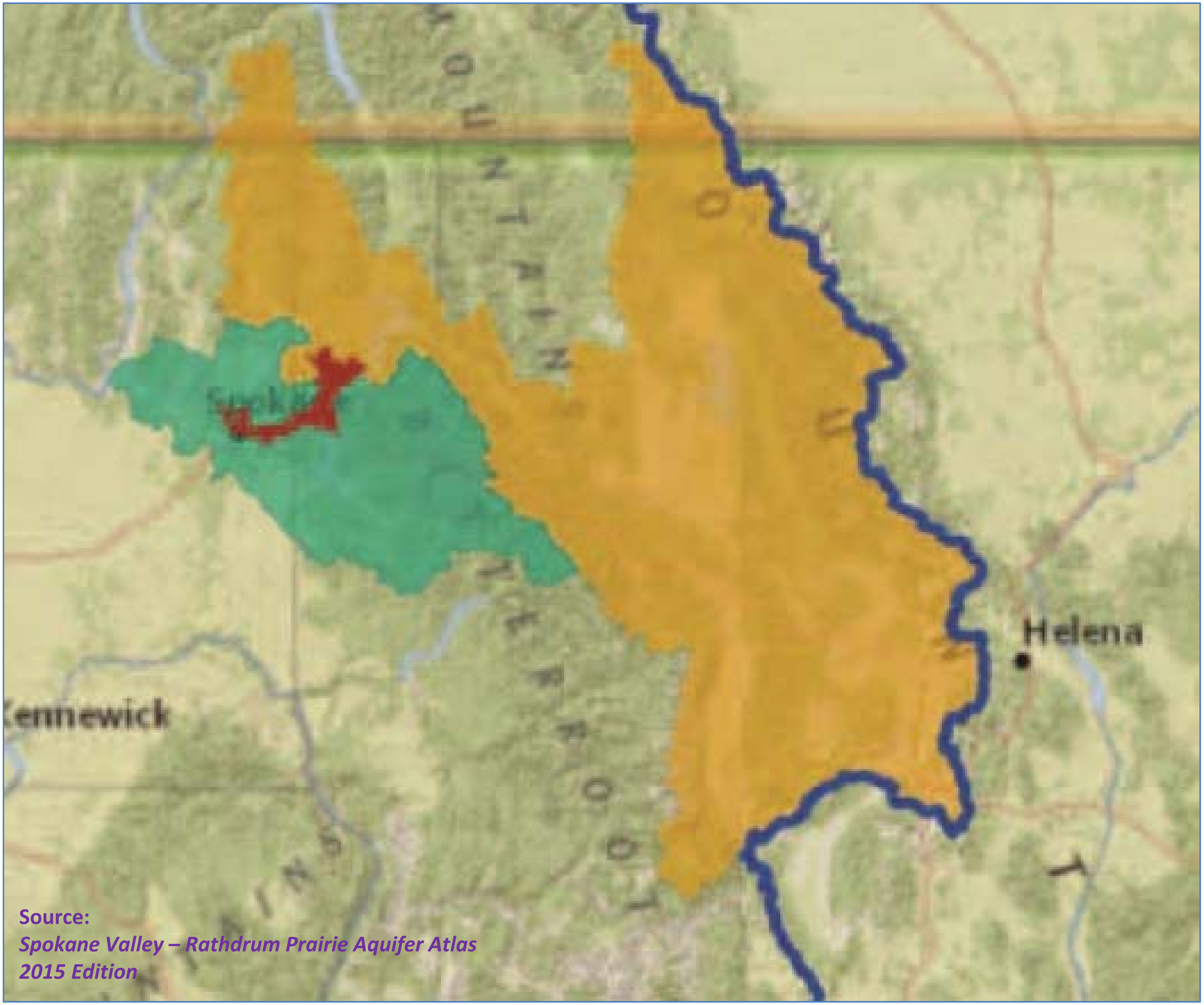

Source:
Spokane Valley – Rathdrum Prairie Aquifer Atlas
2015 Edition

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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)*~~	

GSI Water Solutions, Inc.

Discussion, Questions

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