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

Prepared for

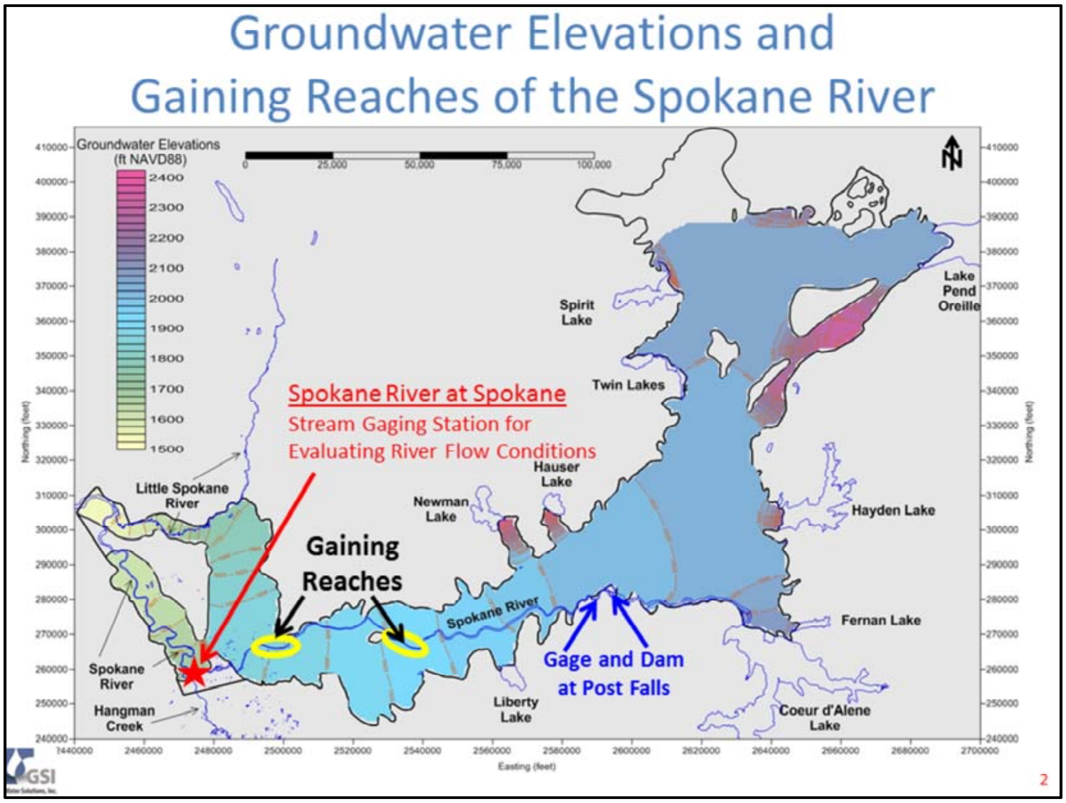
Spokane Aquifer Joint Board

Prepared by

John Porcello, LHG and Jake Gorski, EIT

GSI Water Solutions

December 3, 2015



This presentation discusses historical changes in the seasonal low flows of the Spokane River, as measured at two gages with long-term records: the Spokane Gage at Spokane (in downtown Spokane) and the Post Falls Gage (located just downstream of Post Falls Dam). The role of groundwater in the Spokane Valley – Rathdrum Prairie (SVRP) Aquifer also will be discussed, particularly in regards to groundwater inflows to the river at two gaining reaches and the recharge of groundwater by the losing reaches of the river that lie east of (upstream of) the two gaining reaches shown on this map.

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

GSI

3

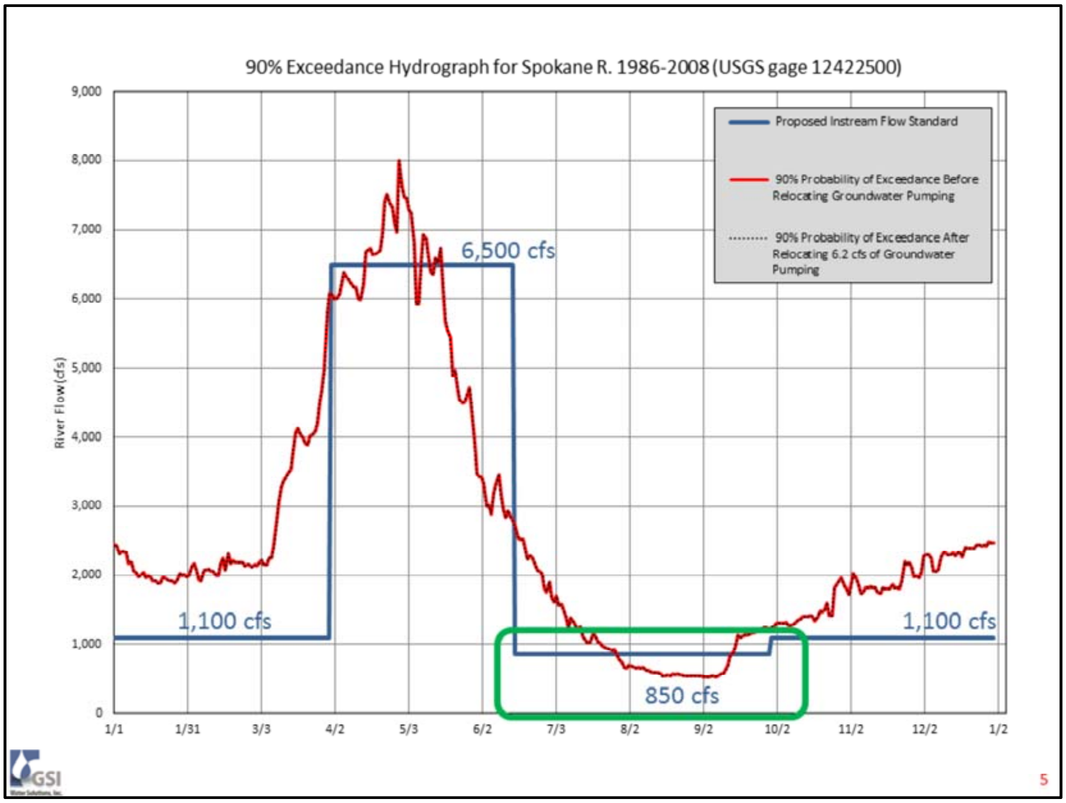
This presentation has four parts. Parts 3 and 4 in particular are each a package of concepts and/or data analyses that gradually reveal the key observations from this study.

Why Evaluate Historical Changes?

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

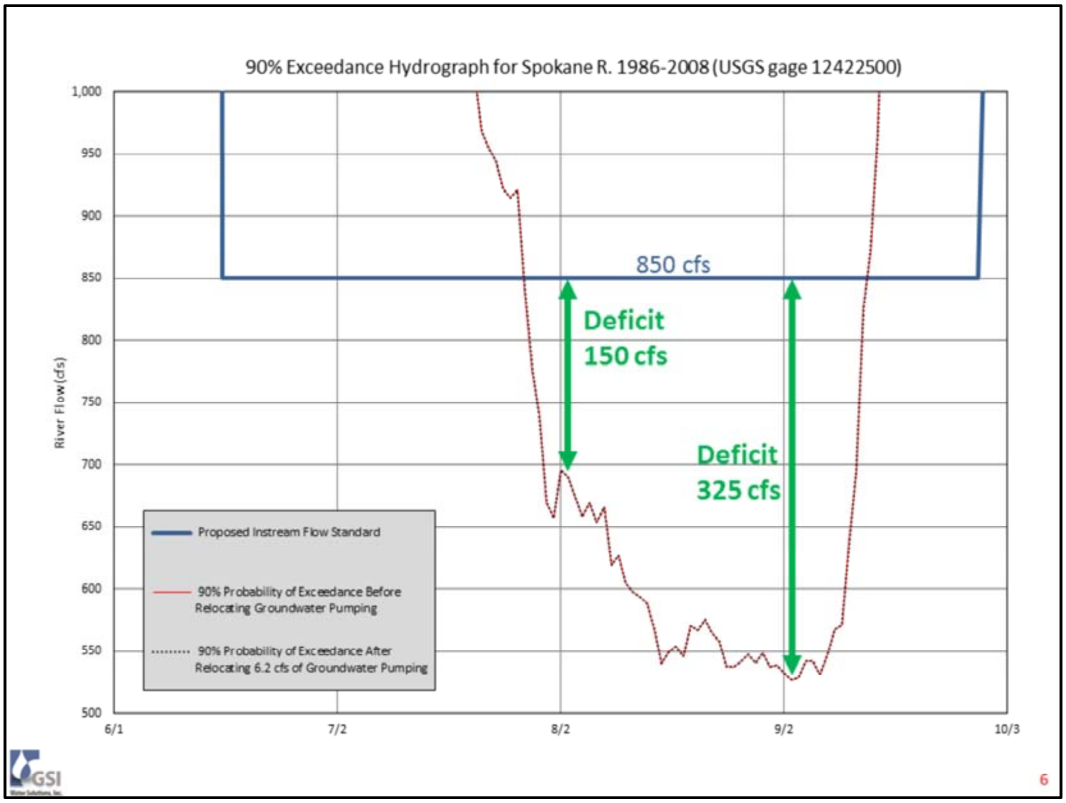
GSI Water Solutions, Inc.

4



In recent years, much attention and discussion has occurred in the water resources community regarding seasonal low flows in the Spokane River, and the Washington Department of Ecology (Ecology) recently promulgated instream flow standards for flows at the Spokane Gage throughout the year. The red line on this plot shows the daily flows at the Spokane Gage that are expected to be exceeded 90% of the time, as calculated from historical daily flow records at the Spokane Gage from 1986 through 2008. Any flows below the red line at a given point in time during the year theoretically should occur in only 10% of all years. The blue line is the instream flow standard, which varies seasonally. (Note: All flow values shown in this diagram are in units of cubic feet per second [cfs].)

Let’s zoom in on this plot to take a closer look at the seasonal low flows during the period shown in the green box.



The 90% exceedance curve (red line) has a very steep decline that continues through July and drops below the instream flow standard in late July. At the beginning of August, the 90% exceedance flows are about 150 cfs below the instream flow standard, and this deficit increases to 325 cfs by mid to late August.

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)

GSI

7

At various times in the past, there have been discussions about whether groundwater pumping is the primary cause of continued declines seen over the past few decades in seasonal low flows in the Spokane River. Two separate groundwater modeling studies conducted independently of each other in 2014 began to examine this question by simulating the effect of summer-time seasonal increases in pumping (to meet seasonal outdoor demands for water). Both studies concluded that these peak-season groundwater pumping demands do not fully explain the declining trends in the river's seasonal low flows.

Effects of Peak-Season Pumping

SAJB Member	SAJB Groundwater Pumping (cfs) Average	Peak Season	Peak Season minus Average	Effect of Peak-Season Pumping on River: River Flow Reduction (cfs)	Reduction as % of Pumping Min to Max	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%**

GSI 8

The 2014 modeling study by GSI (conducted on behalf of SAJB) found that the peak-season pumping by many of the SAJB's individual members causes about a 35% to 65% amount of corresponding change in the river's seasonal low flows at the Spokane Gage. In other words, for each additional 1 cfs of pumping during the peak season (June through August), the river loses between 0.35 and 0.65 cfs of flow in late August. This ratio is applied to the group of purveyors outlined in blue. A few members fall outside that bandwidth. One member has a higher effect on the river during the summer season (89%), while other members have a 30% or less effect. Collectively, the entire group of SAJB members have between a 42% and 62% effect on the river when their collective pumping increases from June through August (as indicated in the bottom row of the table).

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

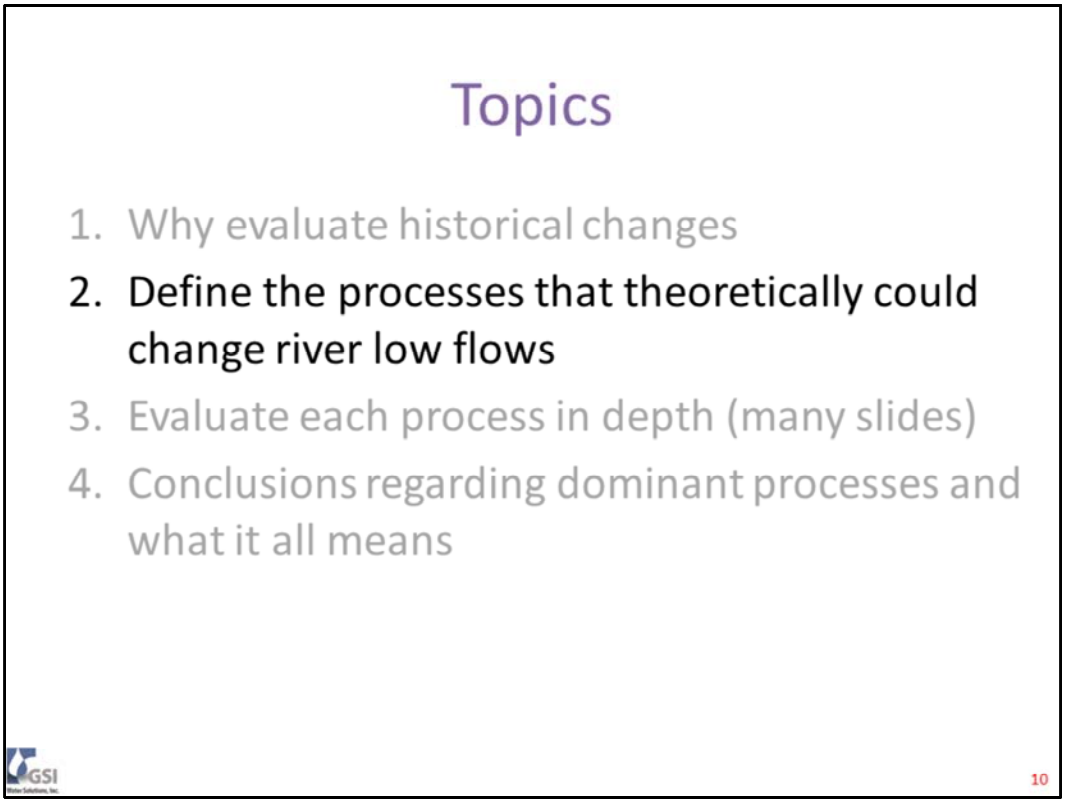
Connection to Aquifer Just Beginning,
More Gaining Reaches Downstream

GSI

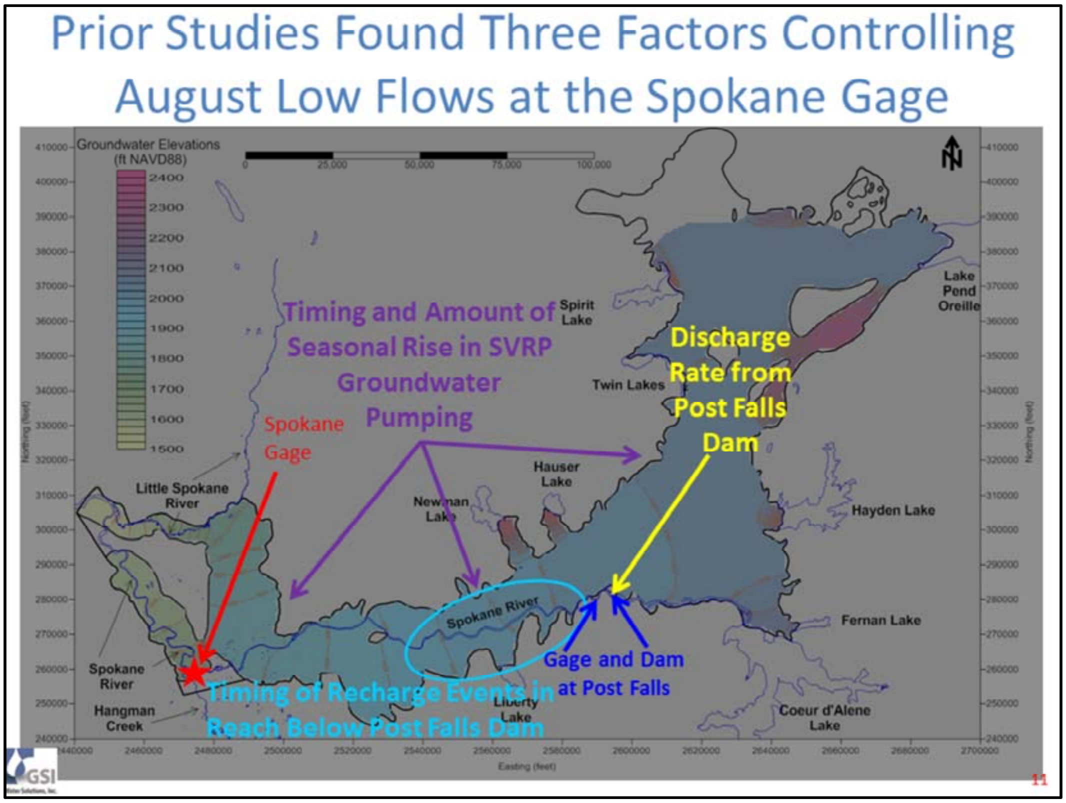
Source: *Spokane Valley – Rathdrum Prairie Aquifer Atlas 2015 Edition*

9

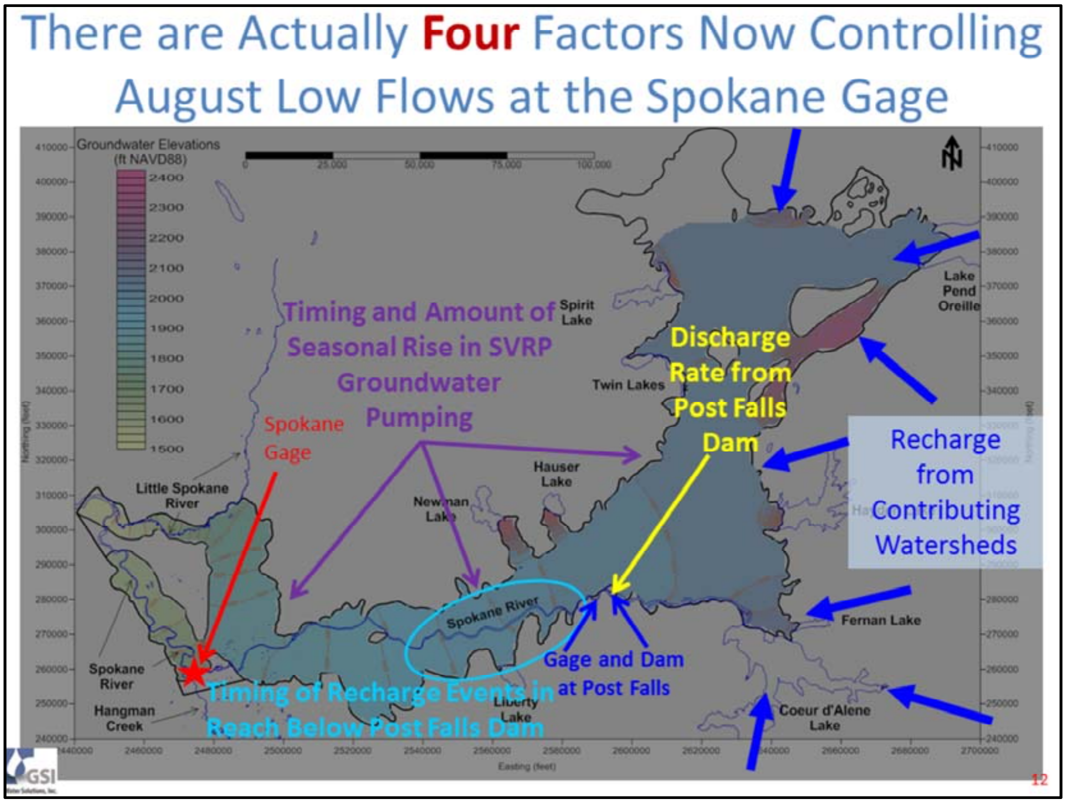
The prior slides discussed the conditions measured at the Spokane Gage, the influence of the gaining reaches just east of that gage, and the role of groundwater pumping. But declines in seasonal low flows are also a concern in losing reaches of the river that lie upstream of (east of) the gaining reaches. In these losing reaches, the groundwater system does not provide water to the river. Instead, the river seeps a portion of its water through its bed to recharge groundwater. Very low flows were observed in August of 2003 (pictured) and during August of other years (including 2015) in the middle of this losing reach (the photo at Greenacres) and also where river flows first start to increase (at Sullivan Road) due to groundwater discharges into the river. In fact, as we will discuss later in this presentation, seasonal low flows and year-round flows at the Spokane Gage have always been higher than at the upstream Post Falls Gage (in the losing reach) because of the groundwater discharges that occur at and downstream of Sullivan Road.



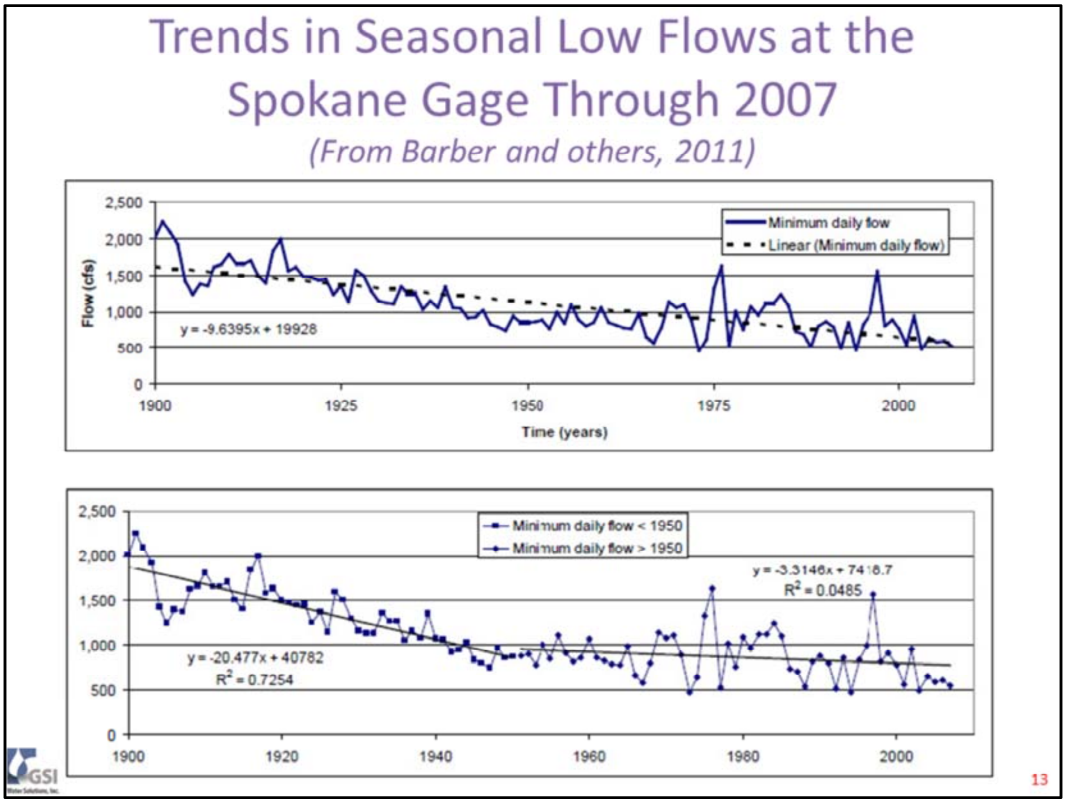
To conduct our analysis, we not only need data, but we also need to first identify all the possible processes that could affect river flows. The family of processes that theoretically can affect flow conditions in a river consist of natural hydrologic processes (rain, snow, air temperature, and water temperature); lake level and river flow management; surface water and groundwater uses; return flows of used indoor water to the river (by publically owned treatment works) and/or the aquifer (by septic systems); and changes in stormwater discharges to the river (storm sewers) and/or stormwater recharge to the underlying aquifer (via dry wells and other stormwater infiltration facilities).



The 2014 studies by GSI (for the SAJB) and by Ralston Hydrologic Services (for the Idaho Department of Water Resources) identified three processes that, to varying degrees, each influence the amount of seasonal low flow at the Spokane Gage.

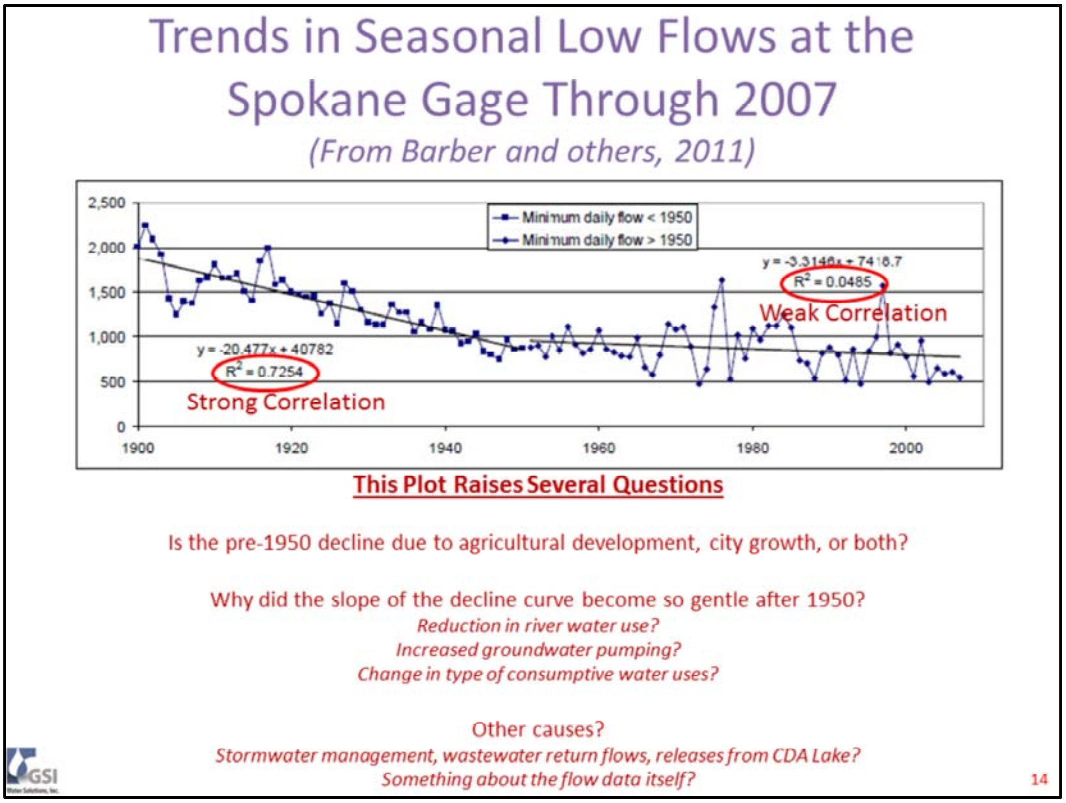


GSI's work for the current (2015) study finds that there is a fourth factor: recharge from the contributing watersheds lying adjacent to the aquifer, particularly the watershed contributing flow to Coeur d'Alene Lake and the headwaters of the Spokane River.

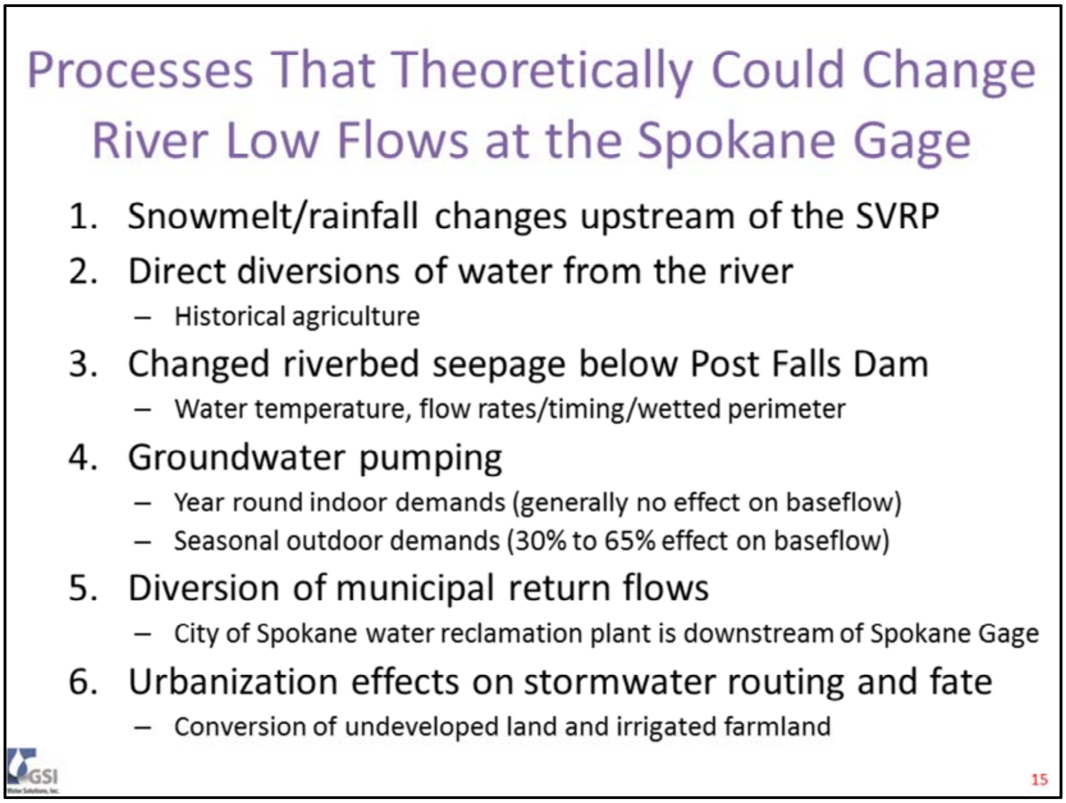


A 2011 study by Washington State University included a plot of the lowest day flow at the Spokane Gage for each year between 1900 and 2007 . The authors drew two trends lines in the lower plot: one from 1900 through 1950, and one from 1950 through 2007.

Citation: Barber, M.E., Hossain, M.A., Poor C.J., Shelton, C., Garcia, L., and M. McDonald. 2011. *Spokane Valley-Rathdrum Prairie Aquifer Optimized Recharge for Summer Flow Augmentation of the Columbia River*. Submitted to Washington State Department of Ecology Office of Columbia River, Yakima, Washington. Prepared by the State of Washington Water Research Center, Washington State University-Tricities, and Washington State University-Pullman. April 1, 2011.



The trend line for 1900-1950 shows a strong correlation between seasonal low flows and time, as shown by the high coefficient of determination (R^2=0.7254). In contrast, the period 1950-2007 has a very weak trend over time (R^2 is much less than 10 percent). This raised several questions in the minds of GSI and SAJB personnel about what happened historically and what those historical conditions might mean for the current continued decline that is being seen in seasonal low flows.



To understand what happened historically, GSI identified these 6 primary processes to examine for this study.

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)*	

GSI

16

Here is the same list of processes, but categorized in terms of whether they are processes that occur within the river-aquifer system (the local "river-aquifer bucket" that lies downstream of Coeur d'Alene Lake and the Post Falls Gage) versus those that occur upstream of the local bucket. GSI also decided to split one of the processes on the previous slide (snowmelt/rainfall changes upstream of the SVRP) into two pieces: water level management at Coeur d'Alene Lake, and watershed climate and rainfall. This differentiation was made because of the availability of three important data sets at the lake: (1) precipitation data, (2) lake stage data, and (3) lake discharge data (as measured at Post Falls).

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.

GSI reviewed several historical references that describe the population, land use, and water use in the area in the late 1800s and the first half of the 20th century. These five were particularly important to the analysis.

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.

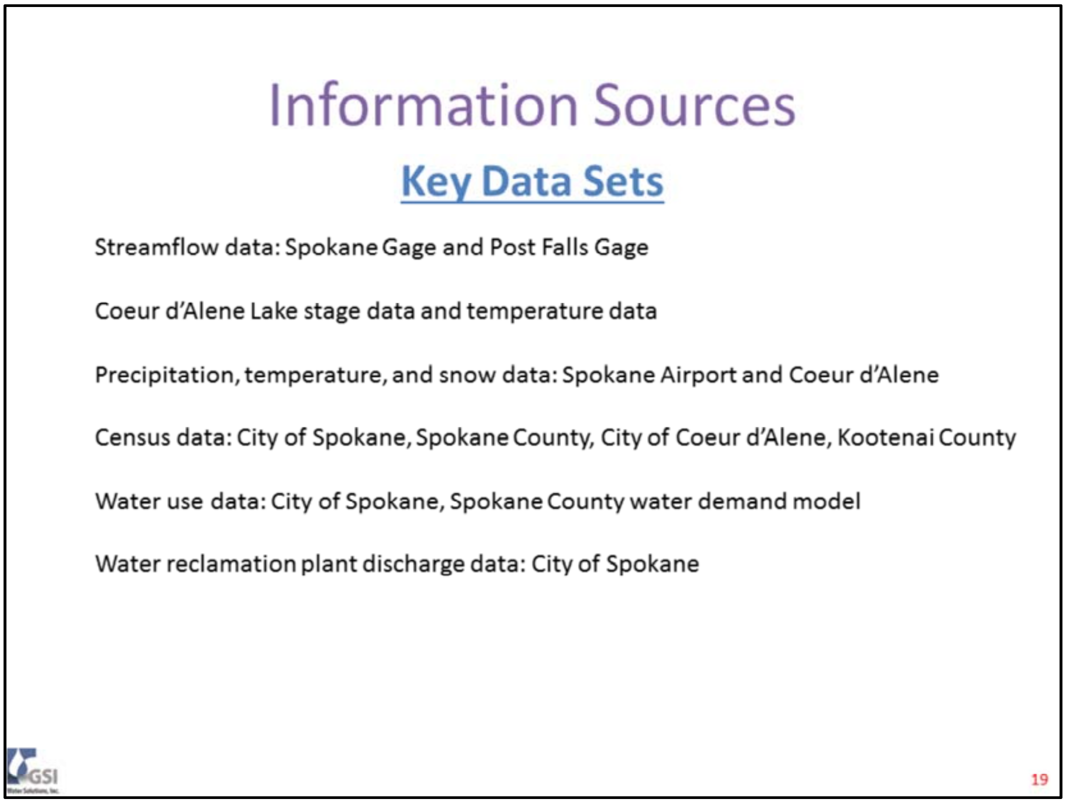
Kahle, S.C., Caldwell, R.R., and J. R. Bartolino. 2005. *Compilation of Geologic, Hydrologic, and Ground-Water Flow Modeling Information for the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho.* U.S. Geological Survey Scientific Investigations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

GSI

18

Hydrologic reports were also an important source of information. Many U.S. Geological Survey (USGS) and other publications were reviewed, but these four were the most important to the analysis.



GSI's approach to the study consisted of coupling historical information sources, hydrologic studies, and GSI's own analysis of publically available data sets. This slide shows those data sets, which were evaluated for their entire period of record, regardless of how early or late the data were first recorded or how long a record was available. The two longest data sets are Spokane Airport climatic data (dating back to 1896); Spokane Gage flows (dating back to 1891); and Post Falls Gage flows (dating back to 1913).

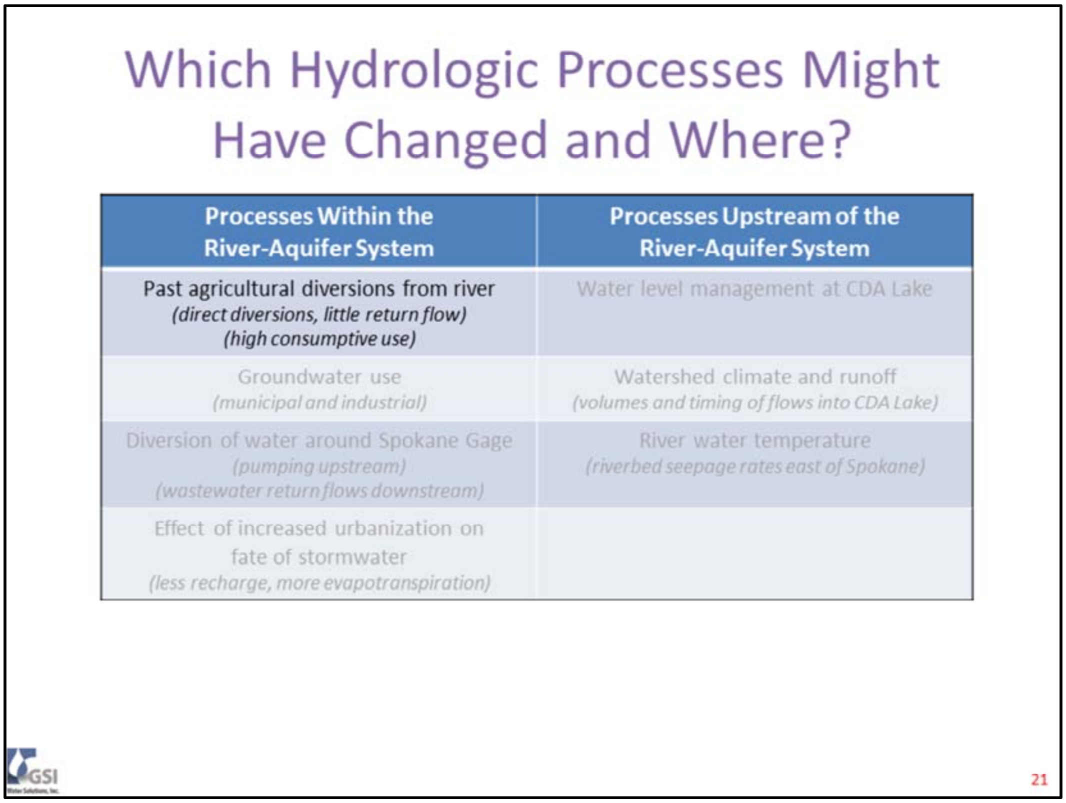
Topics

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

GSI Water Solutions, Inc.

20

Slides 21 through 77 present our analysis of the seven hydrologic processes that potentially could be affecting seasonal low flows at the Spokane Gage.



First we will present our evaluation of past agricultural diversions from the river.

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

GSI

22

In the earliest years of agricultural development in the valley (when agriculture was still in its very fledgling years), water was obtained from a small number of groundwater wells and from canals that brought in water from three lakes in the nearby upland areas on the margin of the aquifer. Consequently, through 1906, the only agricultural withdrawals from the "river-aquifer bucket" were small amounts of groundwater pumping. No data could be found on groundwater withdrawal rates; only anecdotal information was available (i.e., reports of "large wells") from old articles and recollections. Note that what was reported in those days as "large wells" might not be considered "large" wells by today's standards in the SVRP.

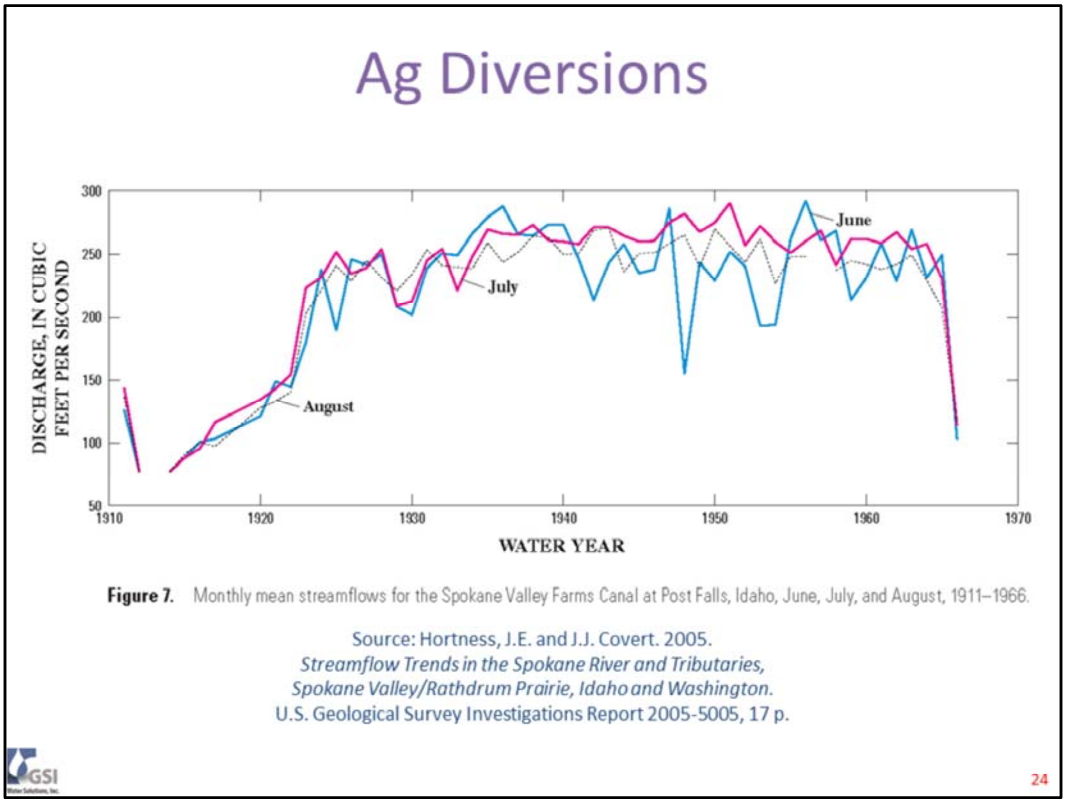
Ag Diversions

- 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

GSI Water Solutions, Inc.

23

By far the biggest hydrologic event related to agricultural development was the construction of the Corbin Ditch, which withdrew water directly from the Spokane River on the upstream side of Post Falls Dam beginning in 1907. This canal was located upstream of the Post Falls Gage and was responsible for the subsequent rapid growth in irrigated agriculture that is described in many of the written documents on the history of the Spokane Valley.



The USGS published a report in 2005 that included this time-series plot (hydrograph) of month-by-month and year-by-year flows in Corbin Ditch. However, the report did not provide any information on the measurement location or how the flows were measured. Additionally, the flow data prior to about 1922 or 1923 appear to be possibly too low when considering the pace of agricultural development that is described in several descriptions of the Spokane Valley's history, and in a detailed history of orchard tree inventories developed by the Washington State Department of Agriculture (which is discussed in slide 28).

Ag Diversions

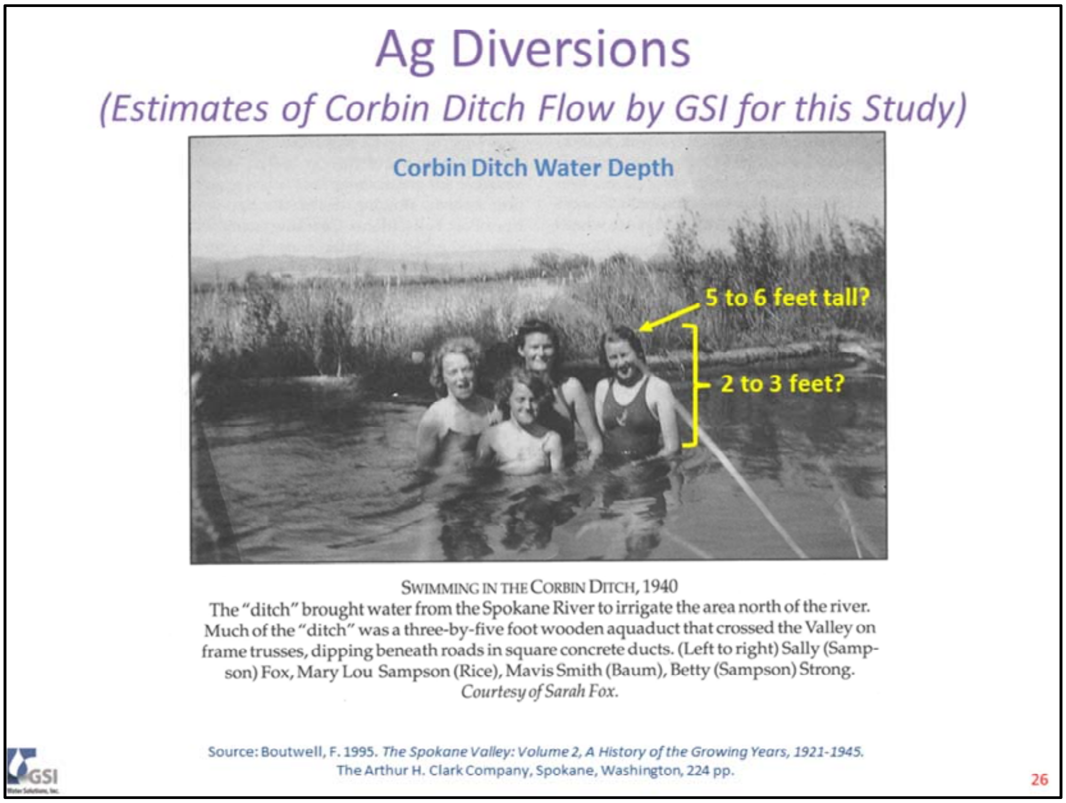
(Estimates of Corbin Ditch Flow by GSI for this Study)

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.

25

Here is a photo of the upper reaches of Corbin Ditch, taken in 2002 just downstream of its headworks. Note that it has concrete lining, which was installed in 1922 or later.



Let's use this great photo to think about how deep the water was in Corbin Ditch, and in particular to help us conduct some calculations of possible flow rates under conditions such as shown here. It looks like the ditch was flowing at a depth of about 3 feet when this picture was taken during the summer of 1940.

(Thank you, Florence Boutwell, for finding this photo and including it in your impressive books that tell the story of the Spokane Valley's rich history!)

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

GSI

27

Good ol' Manning's formula to the rescue! GSI's estimate of the flow rate in Corbin Ditch in its early years (when it was unlined) is 125 to 225 cfs, depending on the depth of water in the canal. These calculations rely on a Manning's roughness coefficient value that is descriptive of a canal consisting of nothing more than a weedy earth channel. A clean earth ditch or a ditch lined with rough concrete would have a higher flow at these same depths for the water column, as shown in red.

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

GSI

28

GSI decided to also think about the potential flow of the Corbin Ditch in terms of what it was being used for … to meet crop water demands. A 1956 publication by the Washington Department of Agriculture contained a valuable inventory of orchard trees at 10-year frequencies between 1890 and 1950. GSI used this information together with online information about tree spacing to estimate how many acres might have been developed, and to estimate the water demands for individual orchards (assuming that 75% of any given orchard was experiencing irrigation).

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:

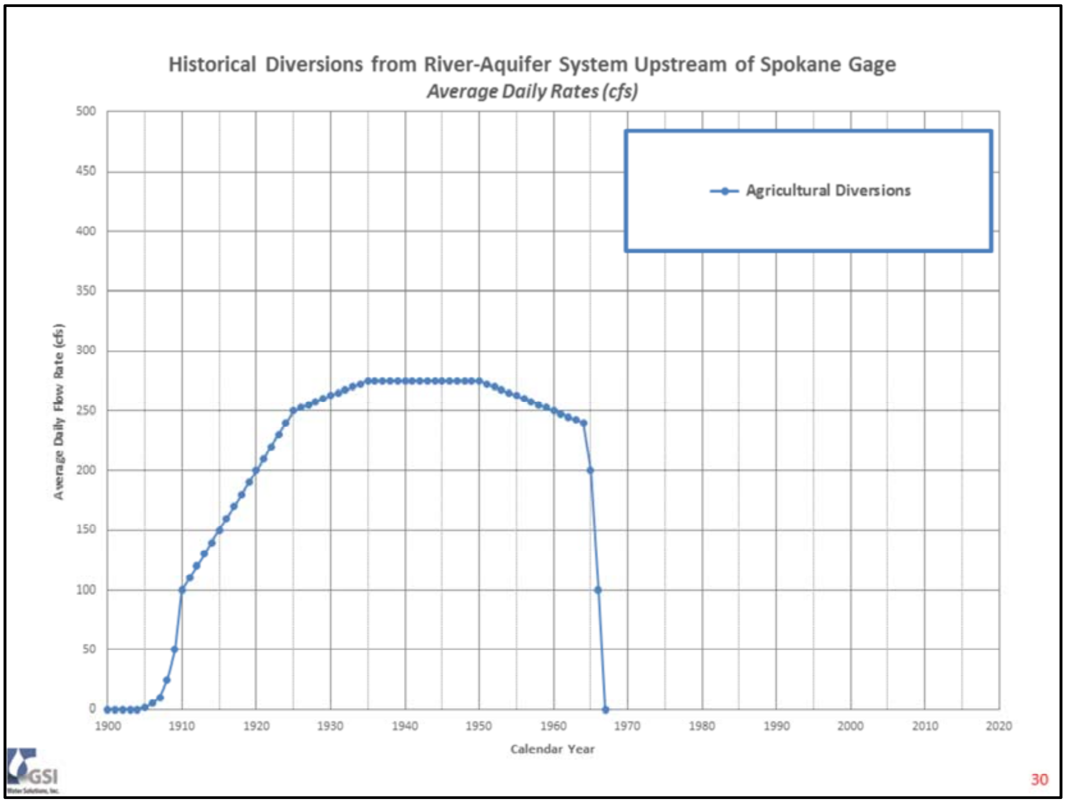
1) Manning calculations (125 to 225 cfs for an unlined canal)
2) Valley-wide ag water demand (210 cfs) needed from Corbin Ditch and other canals
3) Potential irrigation efficiency of 50% for all canals in early years (420 cfs)
4) USGS plot showing Corbin Ditch flow of about 150 cfs in 1920 (before 1922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

GSI

29

For a four-month irrigation season (May through August), here are the water demands for each year and each type of orchard. These volumes are based on the GSI-estimated acreages being irrigated, as shown on the prior slide. Notice that the apple and other orchards were at their maximum production around 1920 (or more likely 1922 through 1925, as reported by Florence Boutwell and others), and that the orchard industry began to tail off significantly by 1930. Notice that the peak value shown here (in 1920) was about 210 cfs of demand, which was being supplied by the Corbin Ditch plus the other smaller canals and some groundwater. The conveyance and distribution systems are widely described as being very leaky in those days. If they were only 50% efficient, then the water supply that was needed to meet the demands may have been double the 210 cfs demand, or about 420 cfs in total in 1920 and the next few years. This total valley-wide demand is greater than the 150 to 300 cfs of flow that the USGS reported as occurring in the Corbin Ditch starting in the early to mid 1920s. Consequently, their estimates of Corbin Ditch flow are probably reliable from the early 1920s on, even if their early-year estimates might appear to be a bit low when considering the initial pace of agricultural development.

Note that once orchard production decreased, the irrigated lands were used primarily for truck crops, including the famous Heart of Gold melon, various berries, and a large cucumber industry that supported the growth of large picking operations in the valley. It is likely that similar flow rates were needed from the canals to support the increased farming of these crops as the orchard industry declined.



From those prior calculations, here is a plot showing GSI's best estimate of the history of diversions from the Spokane River for agricultural irrigation use. This plot is solely for the Corbin Ditch. We did not include groundwater in these numbers because of the lack of quantitative information. Also, we did not include flows in other canals because their water sources were not the Spokane River or local groundwater.

Now let's consider what other diversions besides agriculture were occurring from the "river-aquifer bucket" from 1900 to the present. The other diversions consist primarily of municipal and industrial (M&I uses).

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)*	

GSI

31

This next evaluation focuses on municipal and industrial (M&I) uses of water from the local bucket. This is largely from groundwater, though some very early uses within the City of Spokane were from the Spokane River itself.

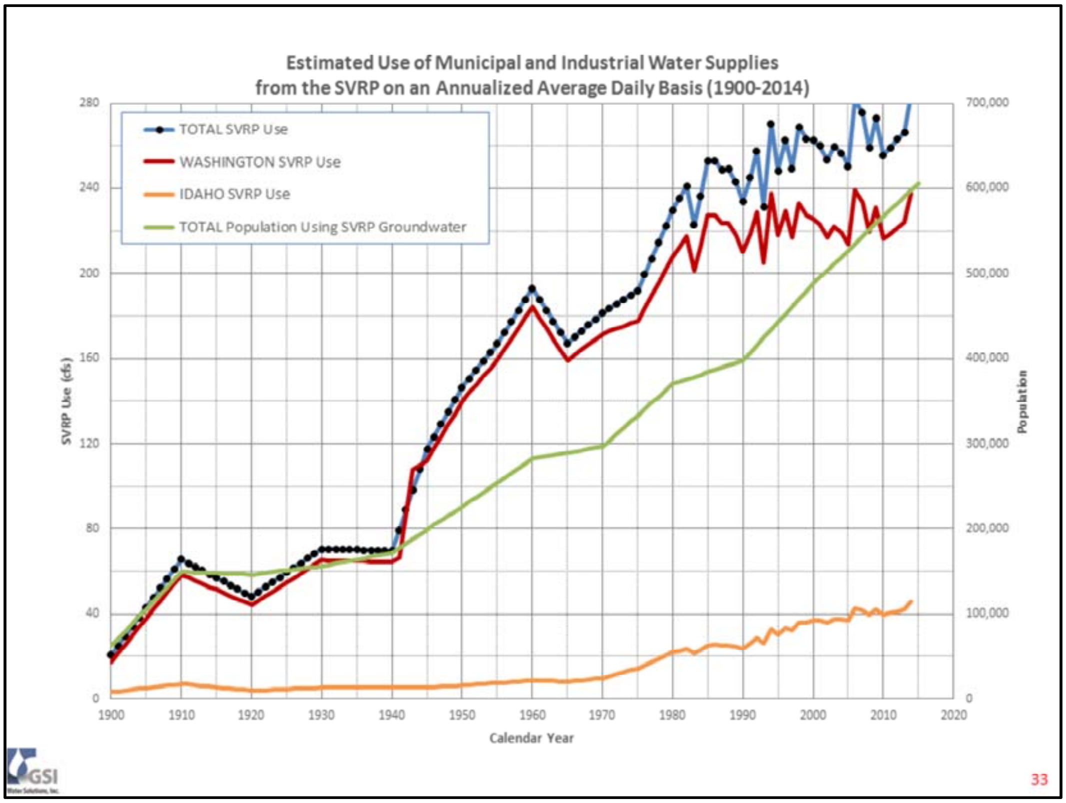
Groundwater Pumping
(Municipal and Industrial)

- 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%)

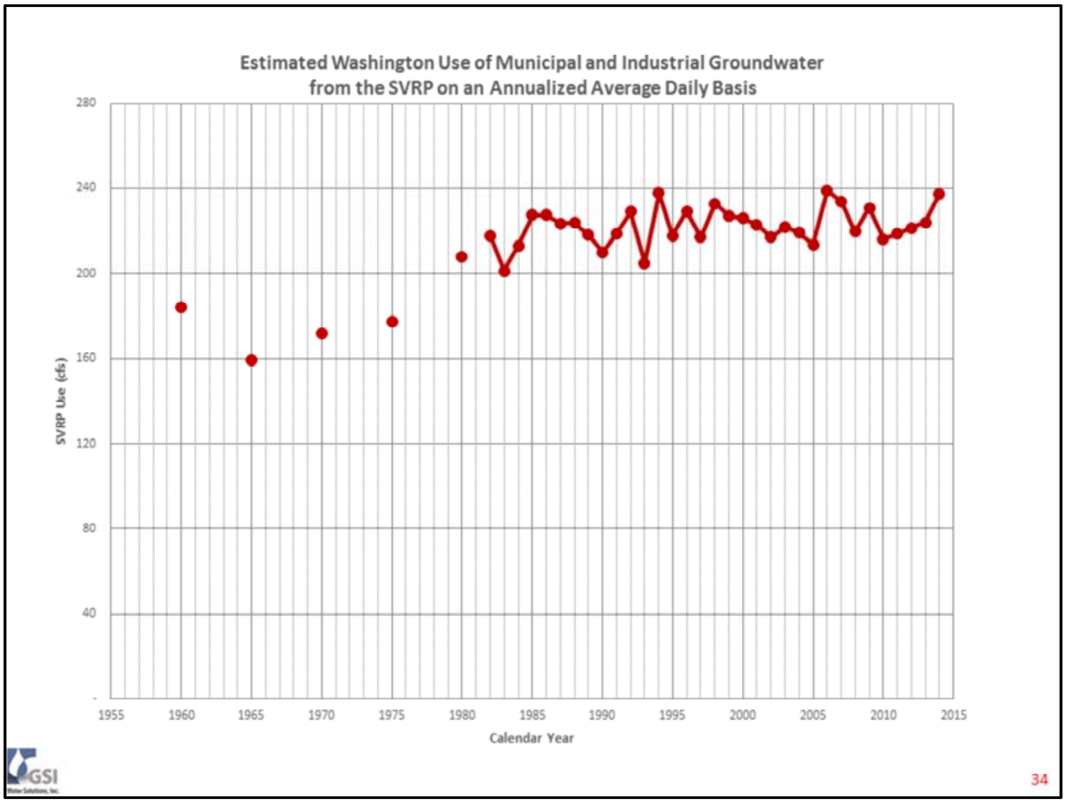
GSI

32

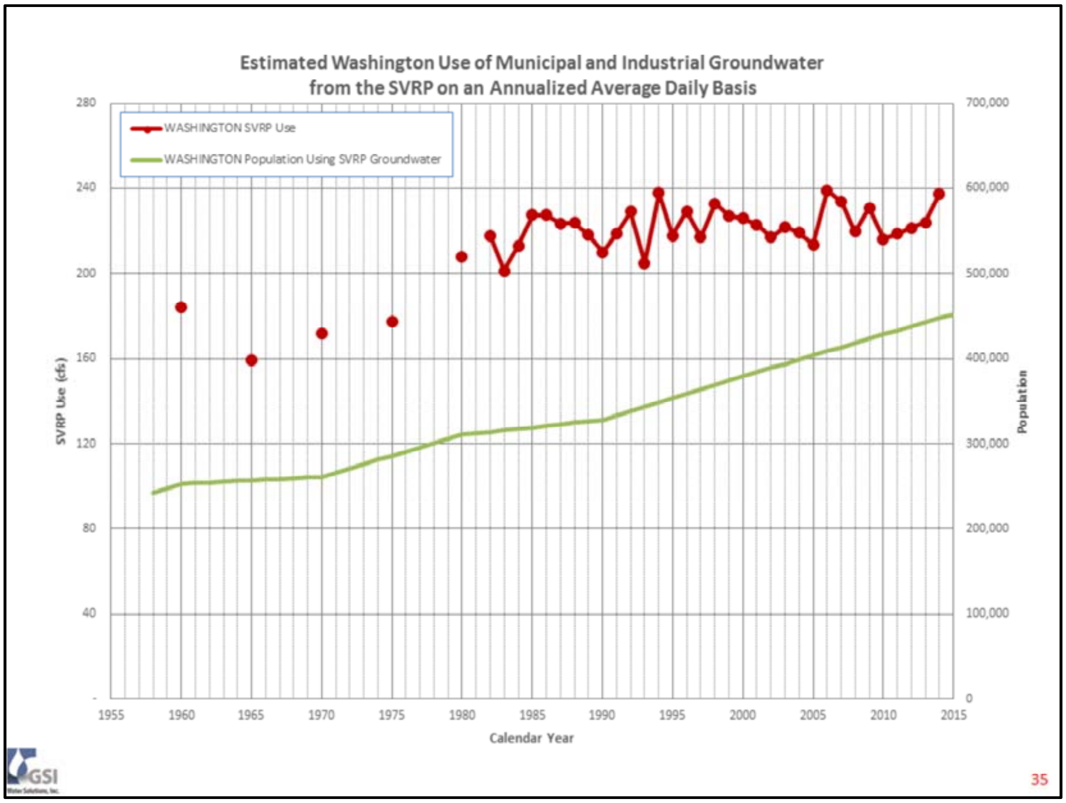
During this study, the City of Spokane provided GSI with its total water use volumes going as far back as 1900. The annual production volumes were available only every 5 years prior to 1980, but annually starting in 1982. GSI used that information together with census data inside the City and elsewhere to estimate water demands outside the City. This was further refined into year-by-year estimates of total SVRP groundwater use, based on information from Spokane County's 2013 update of its water demand model, which indicated that in 2010 about 91% of Spokane County was relying on groundwater from the SVRP for its supply. GSI assumed this was the case historically throughout Spokane County. Additionally, GSI assumed that Kootenai County's entire population was solely reliant on the SVRP for its water supply, though it is known that the City of Coeur d'Alene used lake water for its supply during its early years.



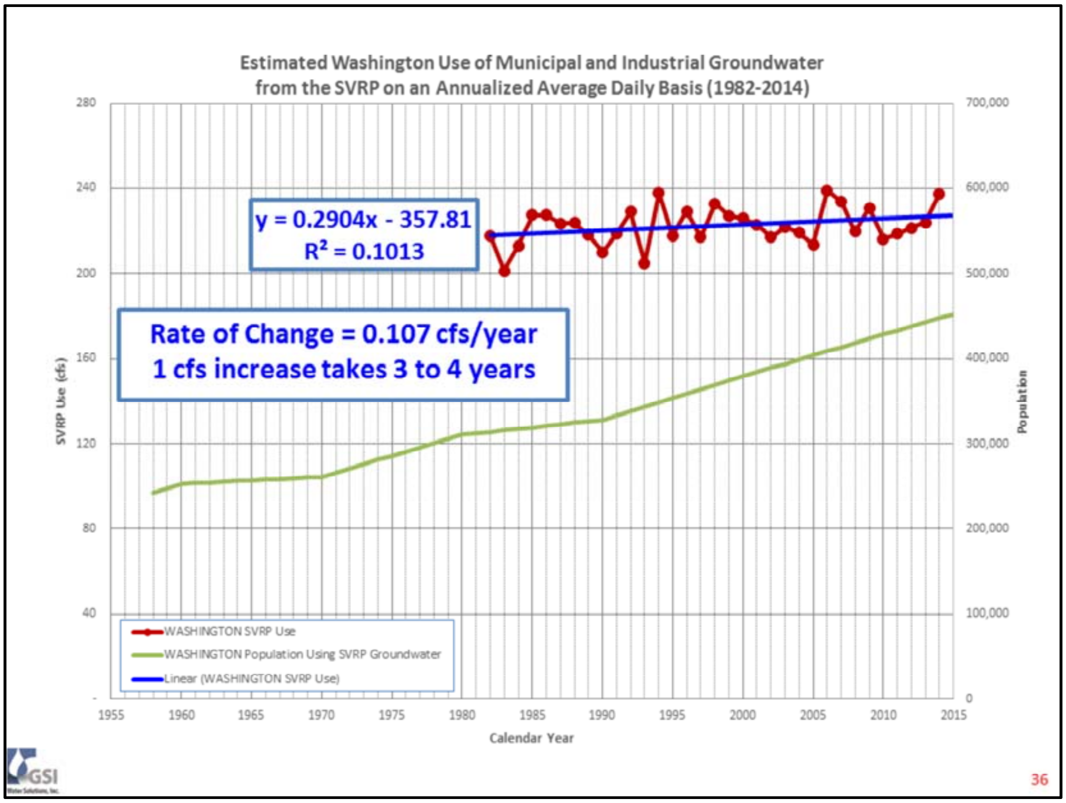
This plot shows GSI's resulting calculations of total SVRP water use, the portions of that use that occurred historically in Washington versus Idaho, and the population over time for the collective population that relied on SVRP water each year. Notice that the amount of water use from the SVRP is relatively small in Idaho but has risen fairly steadily since about 1970. In Washington, water use is much greater, but appears to have leveled off since the early to mid 1990s. Let's explore that recent trend in Washington in more detail in the next few slides.



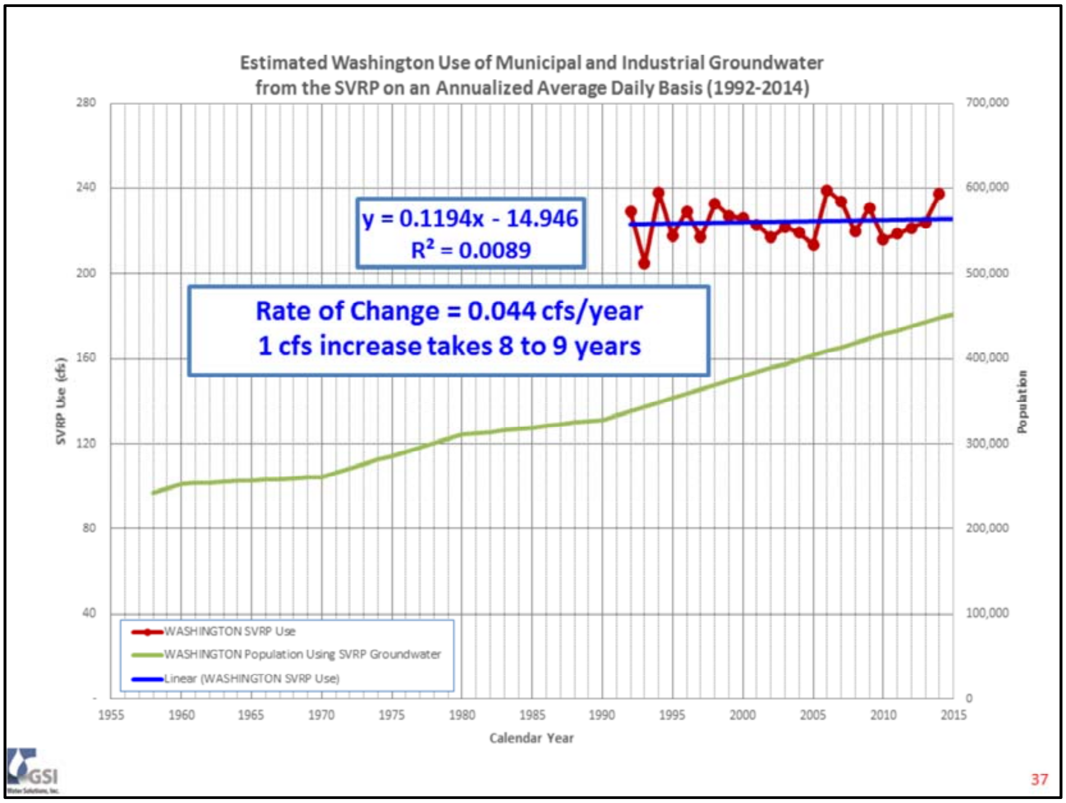
Here are the years in which we have annual water use data from the City of Spokane.



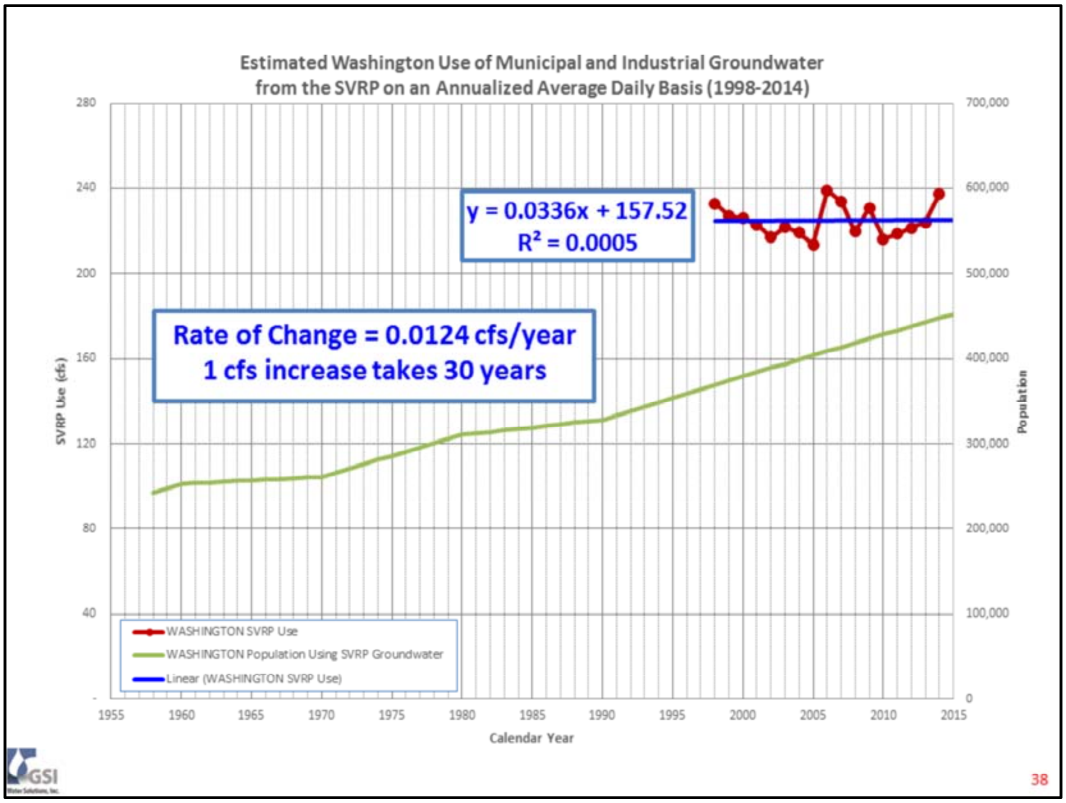
Now add population (the green line, plotted on the right-hand vertical axis).



Here is a linear regression trend line of SVRP water use in Washington. This is for the entire period for which annual pumping records are available (the 33-year period 1982 through 2014). The slope of the line is 0.2904 cfs/year, which is equivalent to 1 cfs of increase every 3 to 4 years.

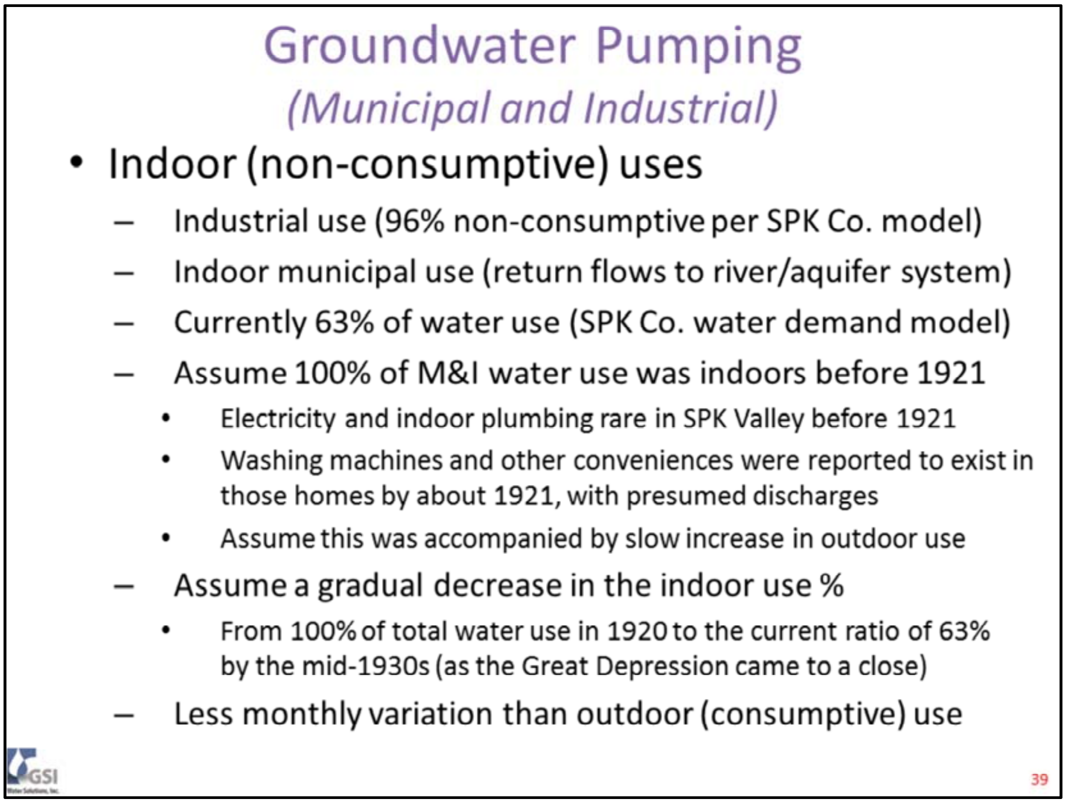


Here is a linear regression trend line for the period that starts in 1992, which is 10 years later than in the prior slide. The slope of the regression line from 1992 through 2014 is 0.1194 cfs/year, which is equivalent to 1 cfs of increase every 8 to 9 years.



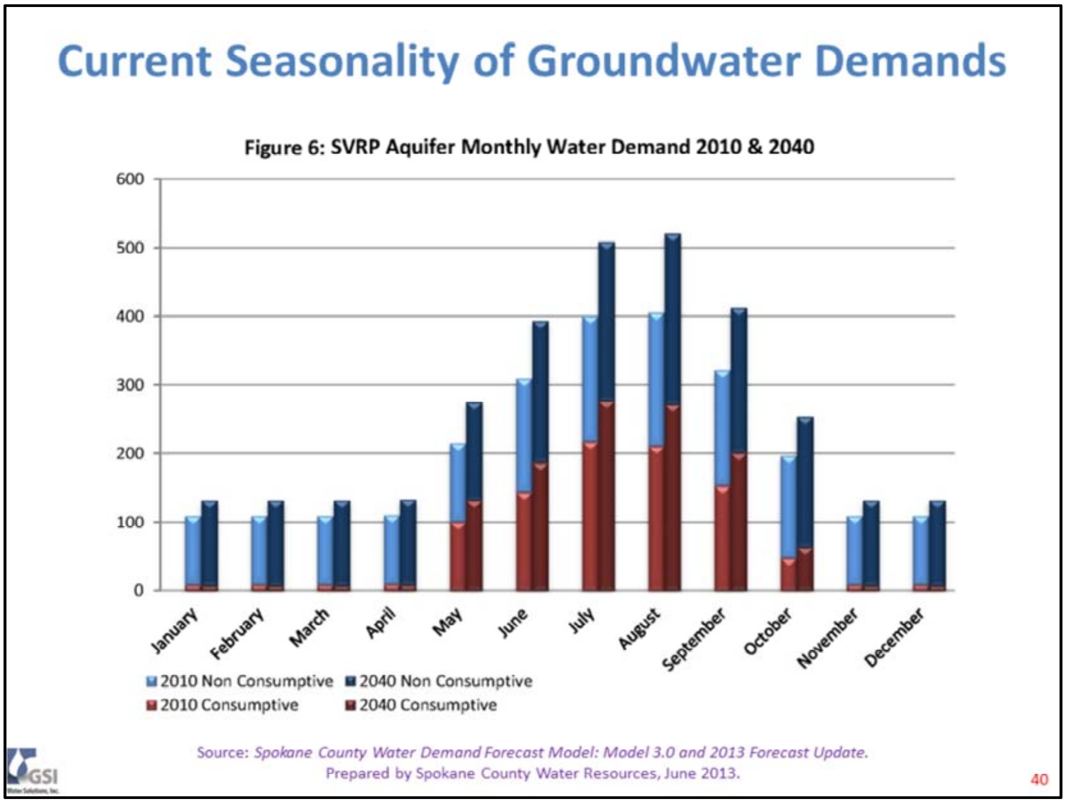
Here is a linear regression trend line for the period that starts in 1998, which examines the last 17 years of the available record. The slope of the line for the period 1998 through 2014 is 0.036 cfs/year, which is equivalent to 1 cfs of increase every 30 years.

This slide and the prior slides together indicate that despite a continued increase in population in Spokane County, the Washington use of the SVRP gradually leveled off beginning in the 1990s, which in turn means that per-capita water use has been declining for the past 2+ decades.



But let's look at more than just total water use. In order to evaluate the effects of water use on the Spokane River, we need to understand the amount of water use that is indoor use versus outdoor use. In the GSI analysis, indoor uses are considered "non-consumptive" because after the use occurs indoors, the water is returned to the "river-aquifer bucket" as a combination of (1) return flows to the river of treated water from publically-owned treatment works and (2) recharge to groundwater from septic systems.

This slide summarizes the key methods and assumptions that GSI used to estimate the year-by-year historical amounts of annual indoor water use. Notice that for years going as far back as the mid to late 1930s, GSI used calculations from the Spokane County Water Demand model as part of this process, primarily regarding the percentages of annual indoor use (63%) annual versus outdoor use (37%). Although that model is specific to Spokane County, GSI applied these same percentages in Kootenai County as well.



This plot includes indoor (non-consumptive) and outdoor (consumptive) use rates in 2010, as reported in the documentation for the Spokane County water demand model. The units are cfs.

Groundwater Pumping

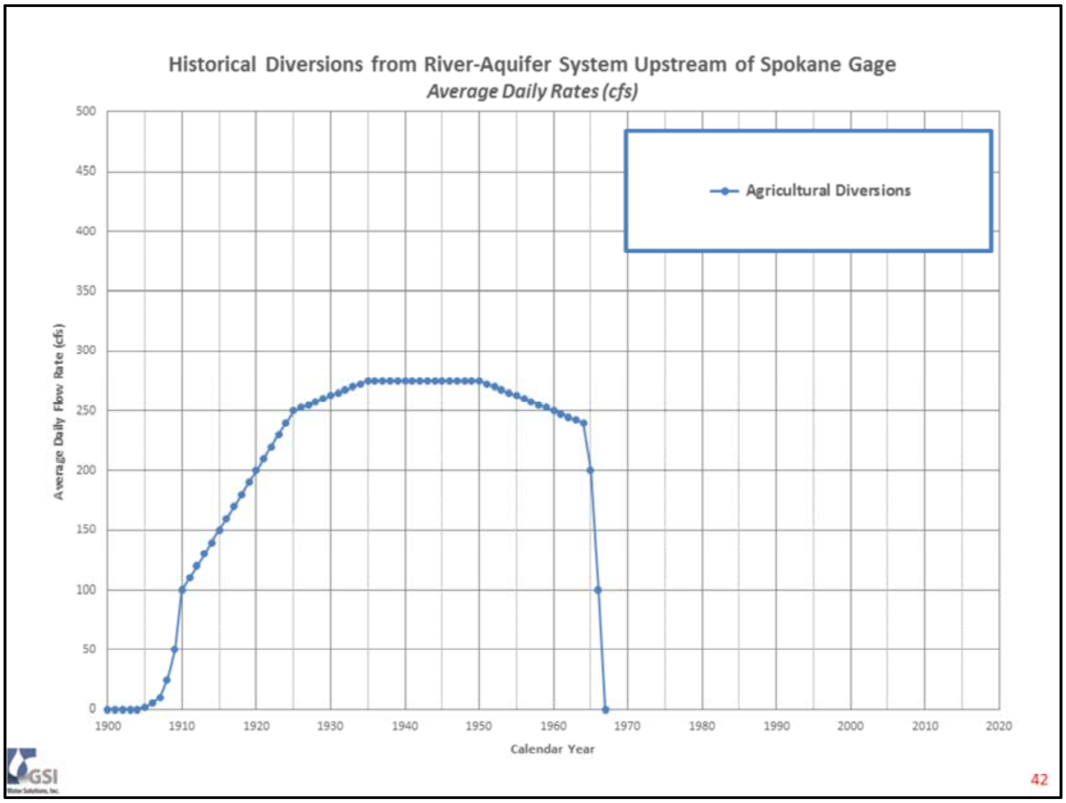
(Municipal and Industrial)

- 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

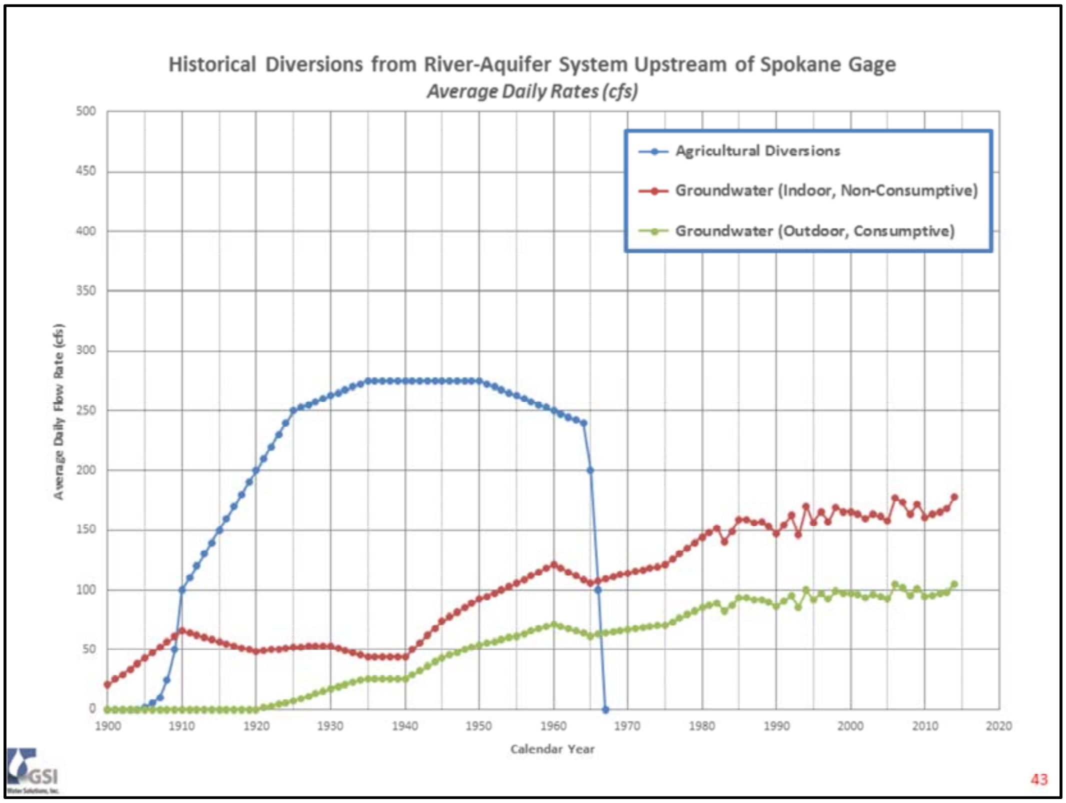
GSI

41

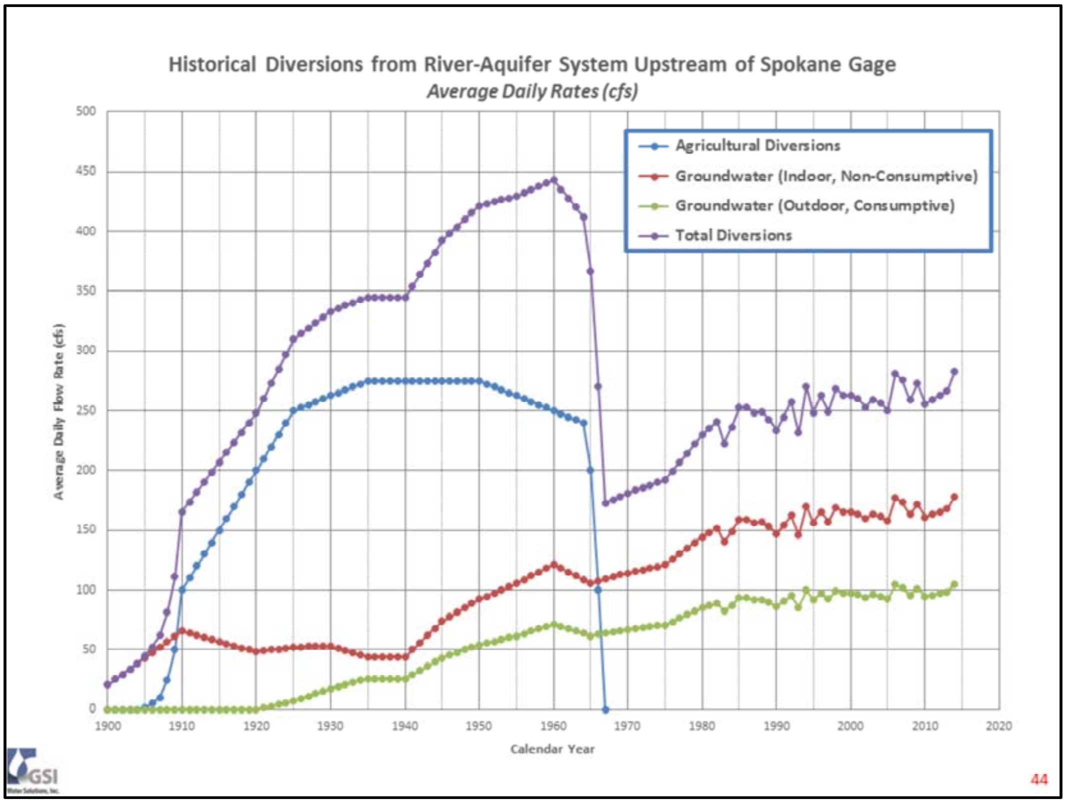
As indicated on slide 39, the amount of indoor water use is set at 37% starting in the mid-1930s, which means that outdoor consumptive use is set at 63% starting at that same time. However, prior to that time, it was probably less. Before electricity and indoor plumbing arrived, outdoor water use was likely occurring primarily in public parks and small-scale family or community gardening. GSI has assumed that outdoor water uses began growing by 1921, when written histories of the Spokane Valley discuss that indoor plumbing and other “modern” conveniences became available in peoples’ homes in urban and near-urban areas. GSI also assumed that outdoor uses grew to 37% around the time the Great Depression ended. While these assumptions may over-estimate the outdoor water uses prior to the 1950s, the 37% outdoor use assumption likely is reasonable by 1950 because of the significant population that moved to the area during and after World War II and the associated rapid urbanization that occurred during that era.



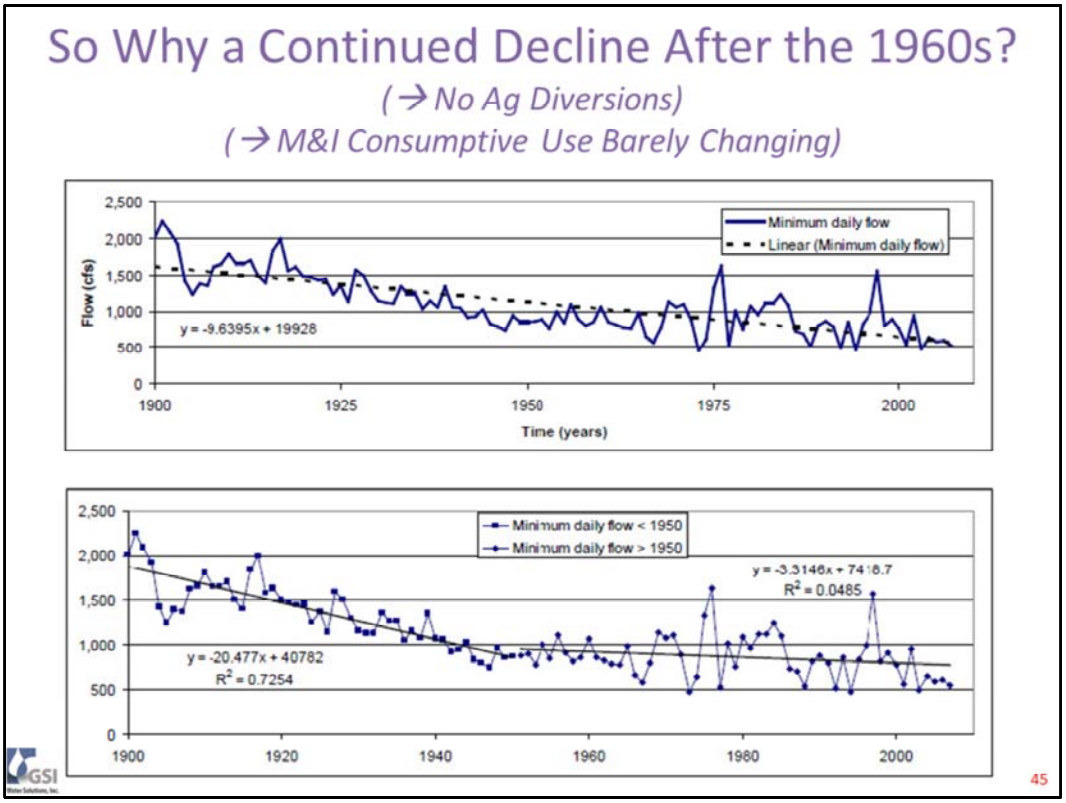
Here is the plot that was shown earlier (on slide 30) of agricultural diversions. Let's add the groundwater withdrawals, starting on the next slide.



This plot adds GSI's estimates of historical rates of SVRP groundwater use indoors and outdoors. The units are cfs (cubic feet per second) and are computed from the estimates of annual water use volumes, divided by the number of days each year (and with unit conversions).



This plot adds a fourth line (in purple) that sums up the three historical water uses of (withdrawals from) the “river-aquifer bucket” from 1900 to the present. Notice that total water use peaked in about 1960 at nearly 450 cfs, then dropped to about 175 cfs when the Corbin Ditch agricultural diversions ended in about 1965. During the next few years, total water uses were lower than at any time seen since about 1910 and were about 40% of the 1960 peak use rate. Since the mid 1990s, total water use has ranged between about 250 and 280 cfs, which is about 60% of the peak use in 1960.



Despite the very large and sudden decline in water use from the “river-aquifer bucket” after 1960, the river flows still kept declining … which is a particularly remarkable observation when we consider that the big decline in water use occurred solely in the form of eliminating direct diversions from the river (i.e., shutting down the Corbin Ditch). Furthermore, this reduction in agricultural use after the early to mid-1960s was <u>not</u> accompanied by large increases in groundwater withdrawals. So why did river flows keep declining, including in recent years that occurred after this plot was made?

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)*	

GSI

46

Let's answer the question on the prior slide by evaluating each of the remaining items on this list. We'll start with river water temperature, which GSI evaluated to consider its potential effects on changing seepage rates through the riverbed, and thus changing the amount of flow in the river between the Post Falls Gage and where the gaining reaches lie.

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

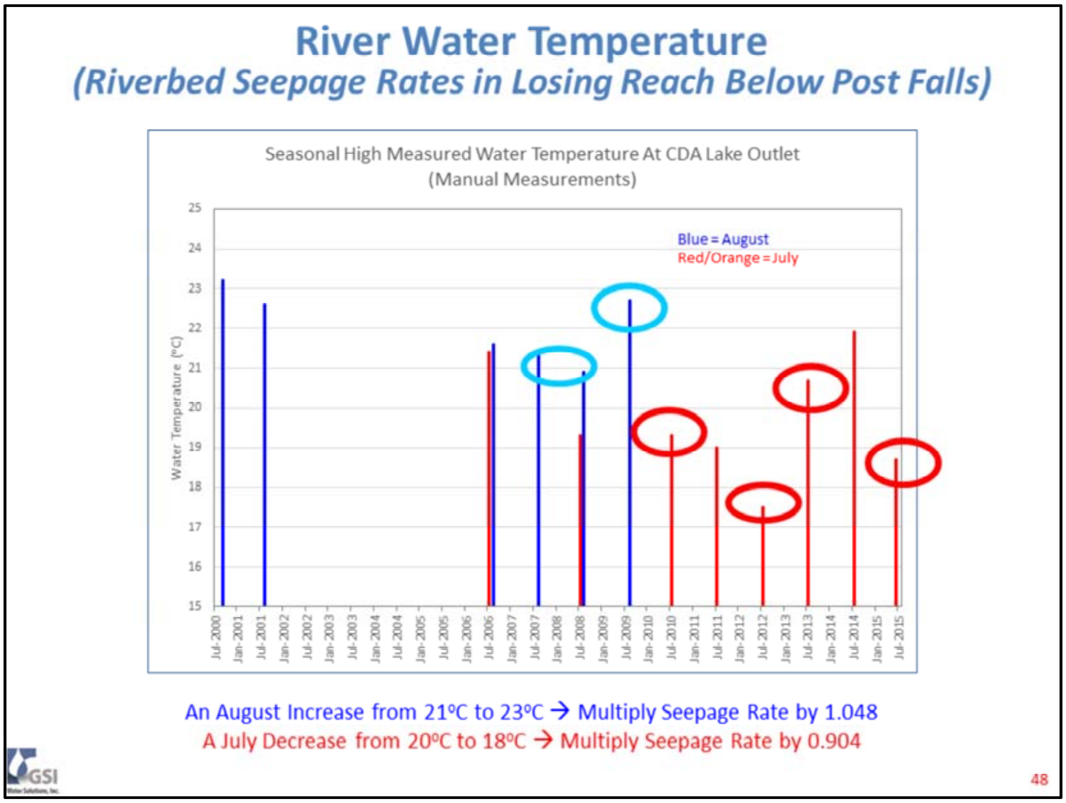
Effect of Increasing Water Temperature

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

GSI Water Solutions, Inc.

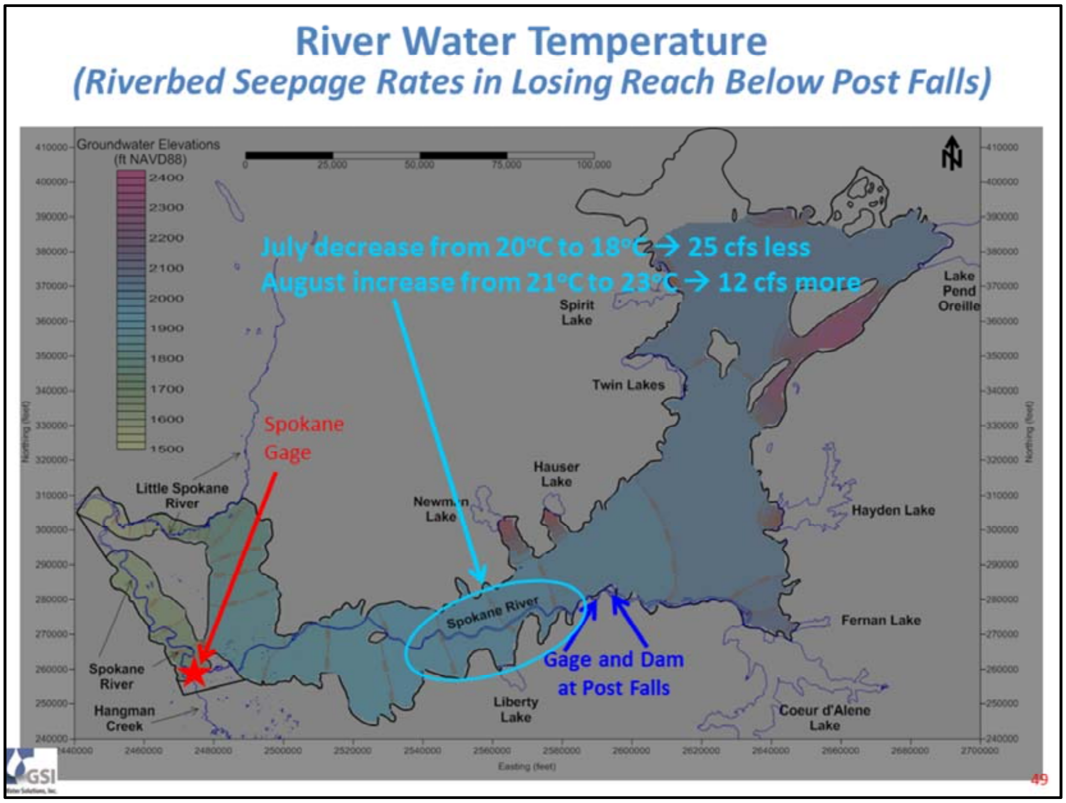
47

The hydraulic conductivity of the riverbed is a function of the ratio of density to dynamic viscosity. Warmer temperatures cause both the density and dynamic viscosity to be low in value. But the density increases at a proportionally greater rate than the dynamic viscosity for every 1 degree Celsius increase in water temperature. Hence, increasing water temperatures increase the hydraulic conductivity of the riverbed. In contrast, a decrease in temperature decreases the ratio of density to dynamic viscosity and thereby decreases the hydraulic conductivity of the riverbed.



Temperature data at the outlet for Coeur d'Alene Lake are collected a few times each year by the USGS. These data are point measurements in time that are made by personnel visiting the sampling station. Accordingly, the measurements each season occur on different days from one year to the next, and recently have occurred predominantly in July compared with in August during most years prior to 2010. Additionally, the river water temperature data go back only to 2000.

No long-term changes in river water temperature can be discerned from these data. But it appears that differences can occur from one year to the next. This plot was used simply to examine what amount of temperature increase or temperature decrease might be worth evaluating with the model. The blue circles show that readings in August 2009 were about 2 degrees C higher than in August 2008. In July, readings in 2011 were about 2 degrees C cooler than in July 2010, and readings in July 2015 were about 2 degrees C cooler than in July 2013. Hence, GSI decided to examine the effects of these specific temperature changes, using the numerical groundwater flow model.



The hydraulic conductivity (conductance) terms in the model for the riverbed over the reach between Post Falls Dam and Sullivan Road were multiplied by the appropriate factors shown on slide 48 for each river water temperature change that was evaluated. The City/SAJB groundwater flow model indicates that the particular changes in river water temperature that GSI evaluated could cause small changes in flow rates in the river, as a result of differing rates of seepage from the riverbed to the underlying aquifer. These changes are relatively small compared with the amount of change in river low flow that has occurred historically since 1900. Consequently, while this hydrologic process is worth keeping in mind, it is likely not the main driver for why river flows continue to decline (especially since the available temperature data set does not point to any distinct historical warming of river water).

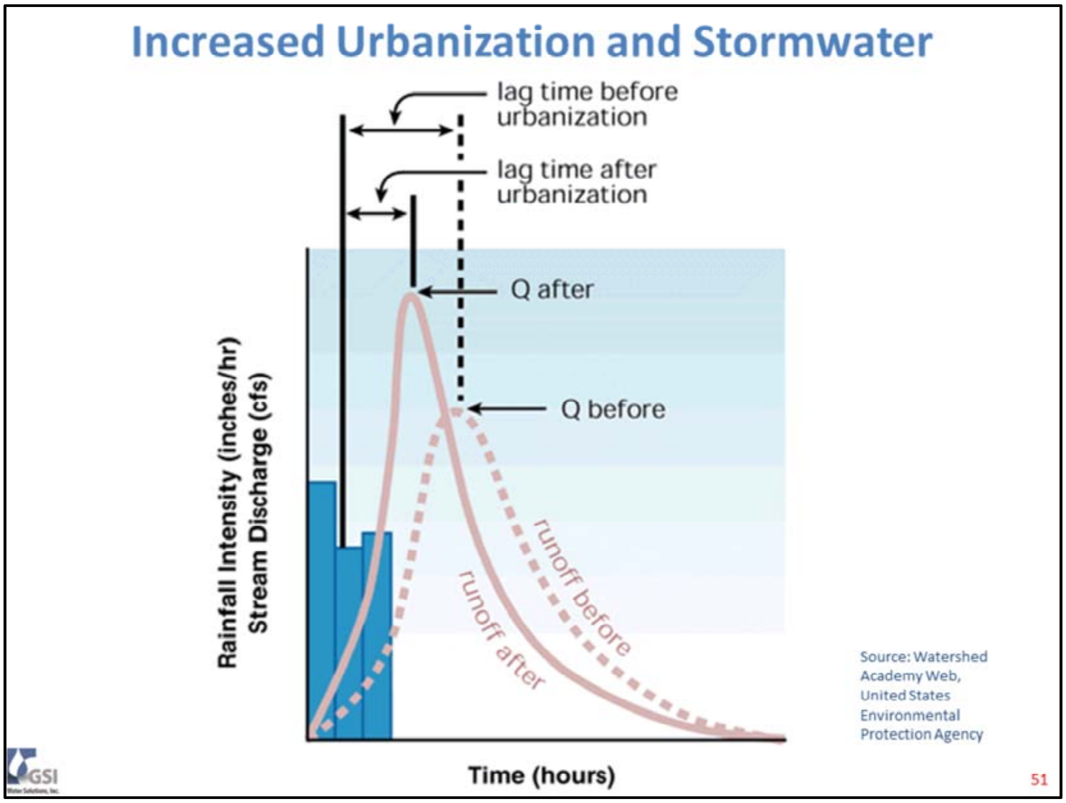
Which Hydrologic Processes Might Have Changed and Where?

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)***	

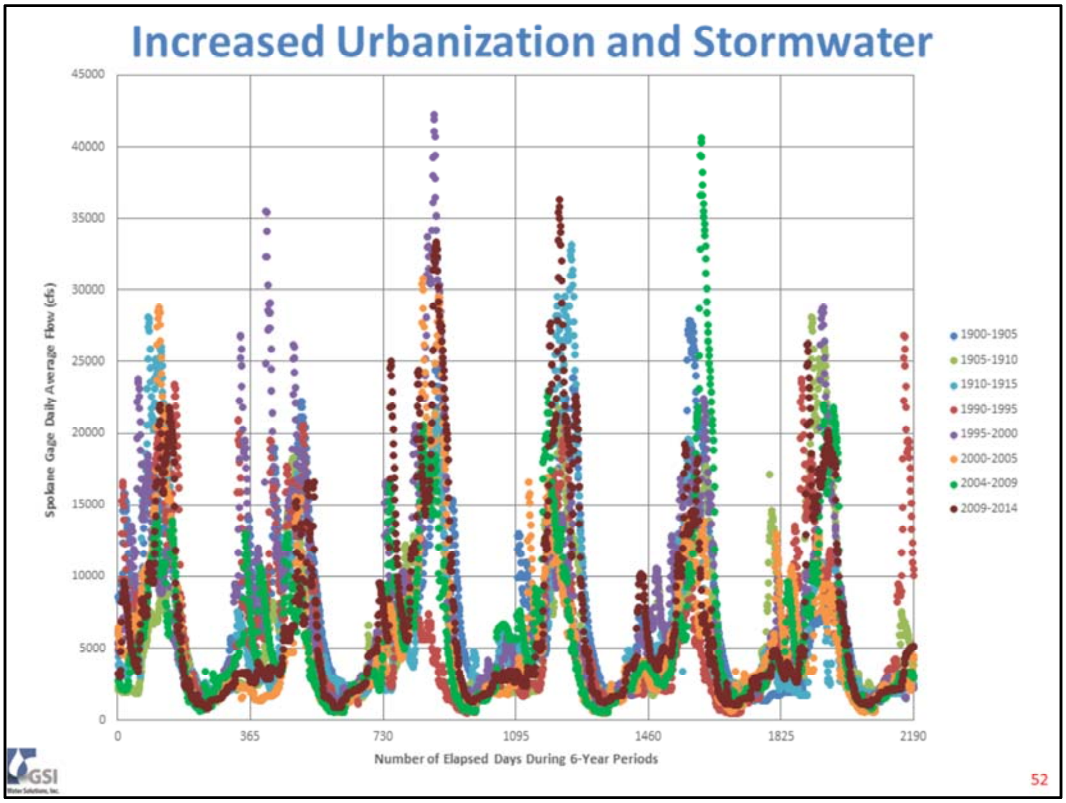
GSI

50

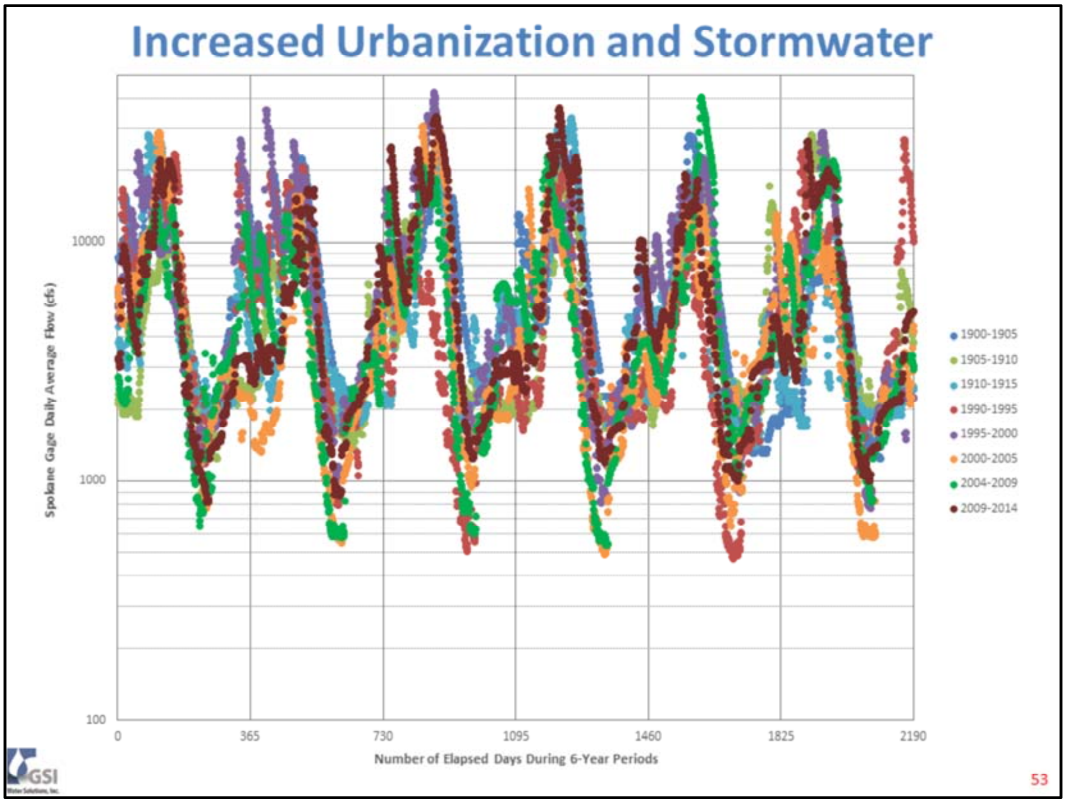
Let's scratch the river water temperature off the list. Let's now look at the potential effect of increased urbanization on the fate of stormwater and what (if any) effect stormwater management in urban areas has had on flows in the river at and above the Spokane Gage, compared with pre-urban conditions.



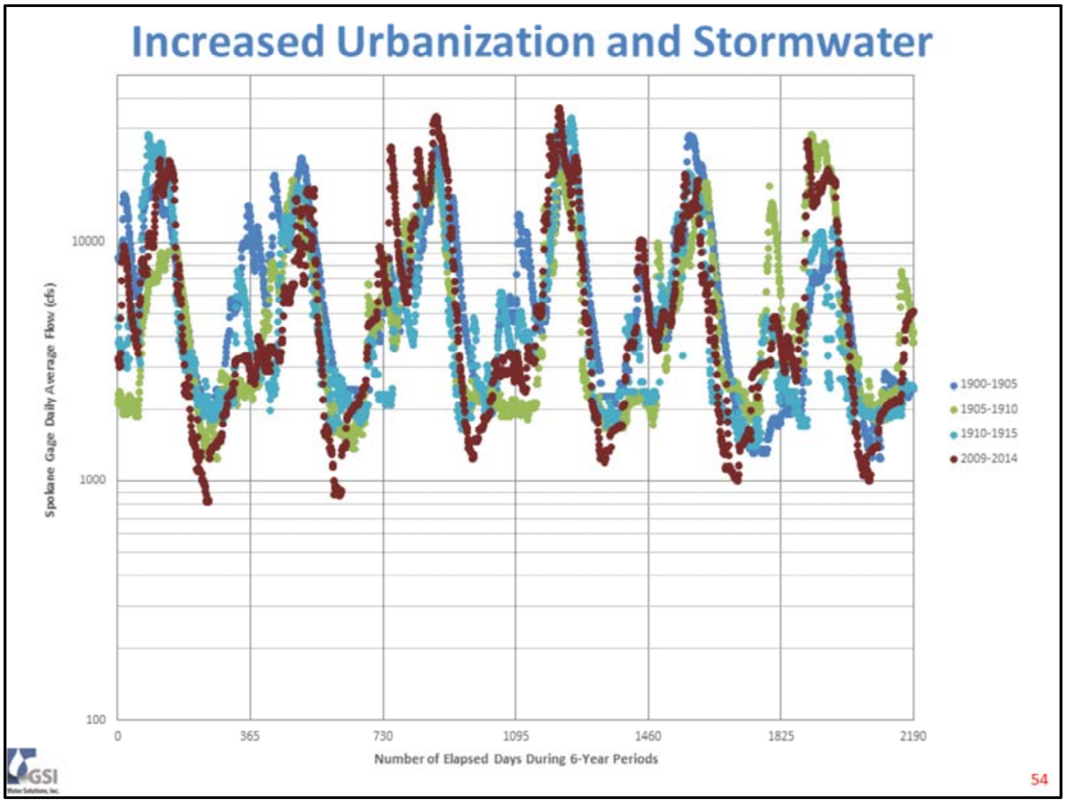
Changes in surface permeability change the way receiving waters respond to storm events. In many heavily urbanized areas in the United States, instead of infiltrating to groundwater, stormwater runs off of roads and buildings quickly and travels through a stormwater conveyance system and into a receiving water or a wastewater treatment plant. Less infiltration and recharge in these types of urbanized areas generally results in higher peak flow rates that occur sooner, followed by a quicker decline in flow rates and hence lower base flows.



To determine if urbanization and changes in pervious/impervious cover are affecting flows to and in the Spokane River, GSI superimposed hydrographs of the daily river flow data at the Spokane Gage for multiple 6-year periods in the early 1900s and multiple 6-year periods in recent years (since 1990). The data is cluttered, and the magnitude of seasonal difference makes it difficult to discern any differences between the plots for the recent years versus the early years.

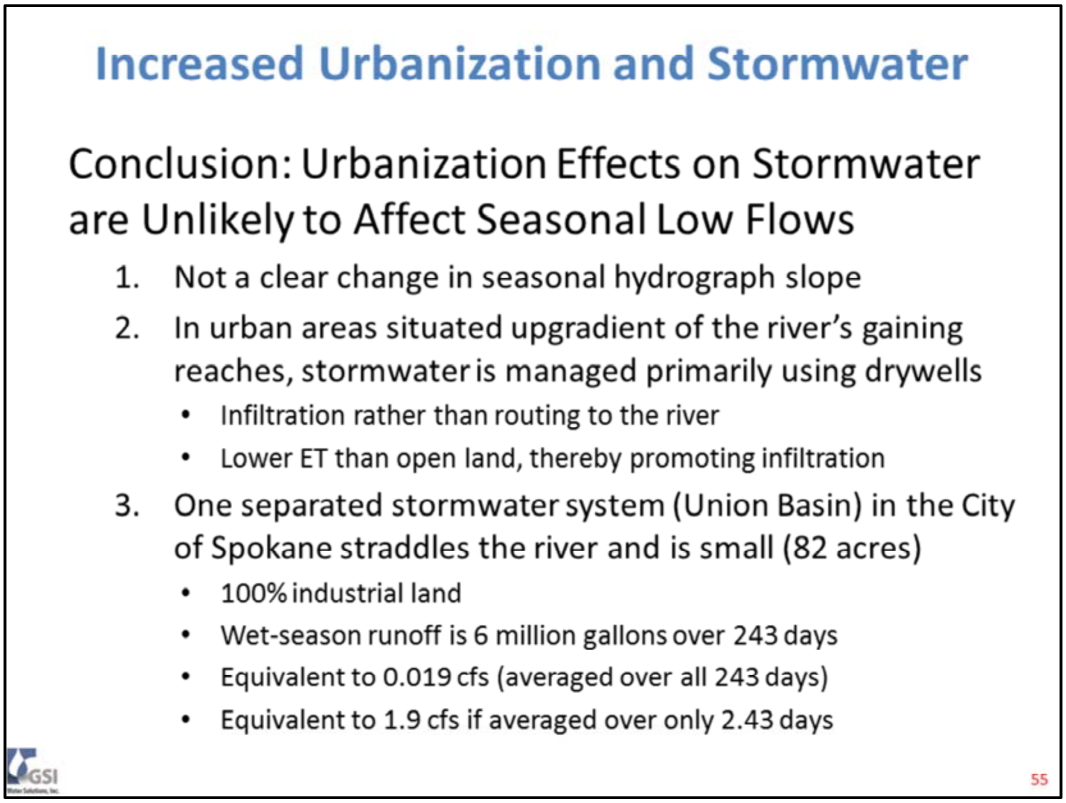


Plotting the data on a log scale shows peak and low flows better, but the data are still cluttered.



This slide shows the most recent 6-year period (2009-2014) superimposed on three periods that span the first 1-1/2 decades of the 20th century (before modern urbanization had begun). In comparing the early hydrographs to the most recent 6-year period, we see that recent peak flows are not necessarily higher than in the early 1900s; recent low flows are notably lower than in the past; and the difference in time between peak flows and minimum flows is not remarkably different. A very slight difference in the slope of the declines from peak-season to low-season values appears to have occurred in one or two cases (particularly the second years of each time period on the plot), but this might reflect nothing more than the choice of years to bundle together. (For example, if the second year [2010] was plotted further right on this plot, it might actually line up well with the later years' slopes for the three early time periods that are shown).

These plots do not show the type of difference in the hydrograph shape that is shown on slide 51 when a watershed becomes urbanized. For that reason, and because the slopes of the recent-year curves are not significantly different from those of the early years, there is no strong evidence that the onset of stormwater management in urbanizing areas is noticeably influencing flow rates in the Spokane River.



Upstream of the gaining reaches, stormwater is managed primarily through dry wells. A small amount is handled in one separated stormwater system inside the City of Spokane, but it is too small to affect flows in the Spokane River.

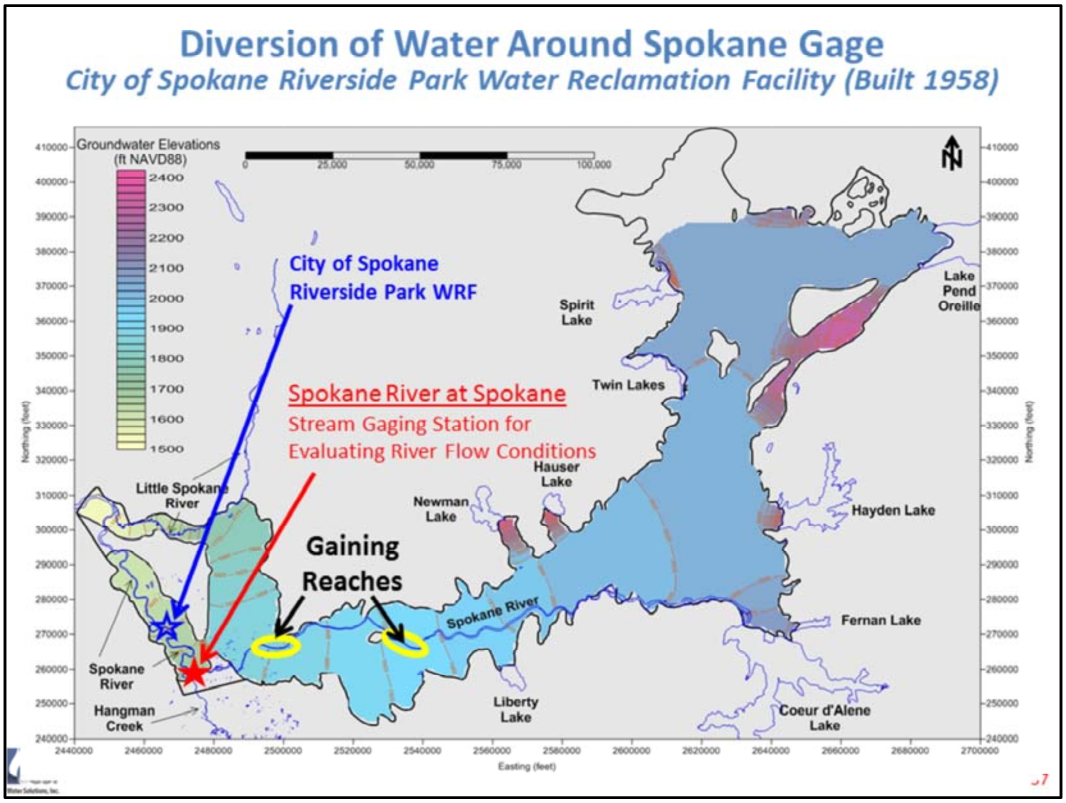
Which Hydrologic Processes Might Have Changed and Where?

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)~~*	

GSI

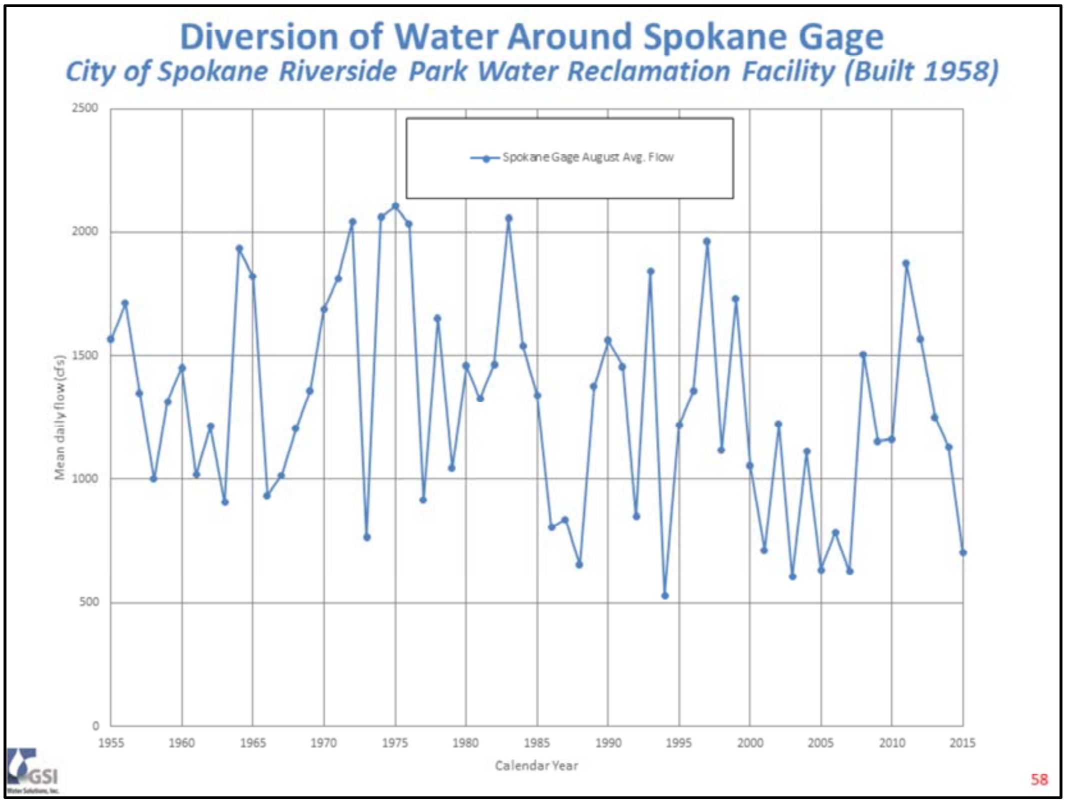
56

Let’s scratch off our list the potential effect of stormwater management. The next item on the list quantifies the amount of water being added to the river downstream of the Spokane Gage.

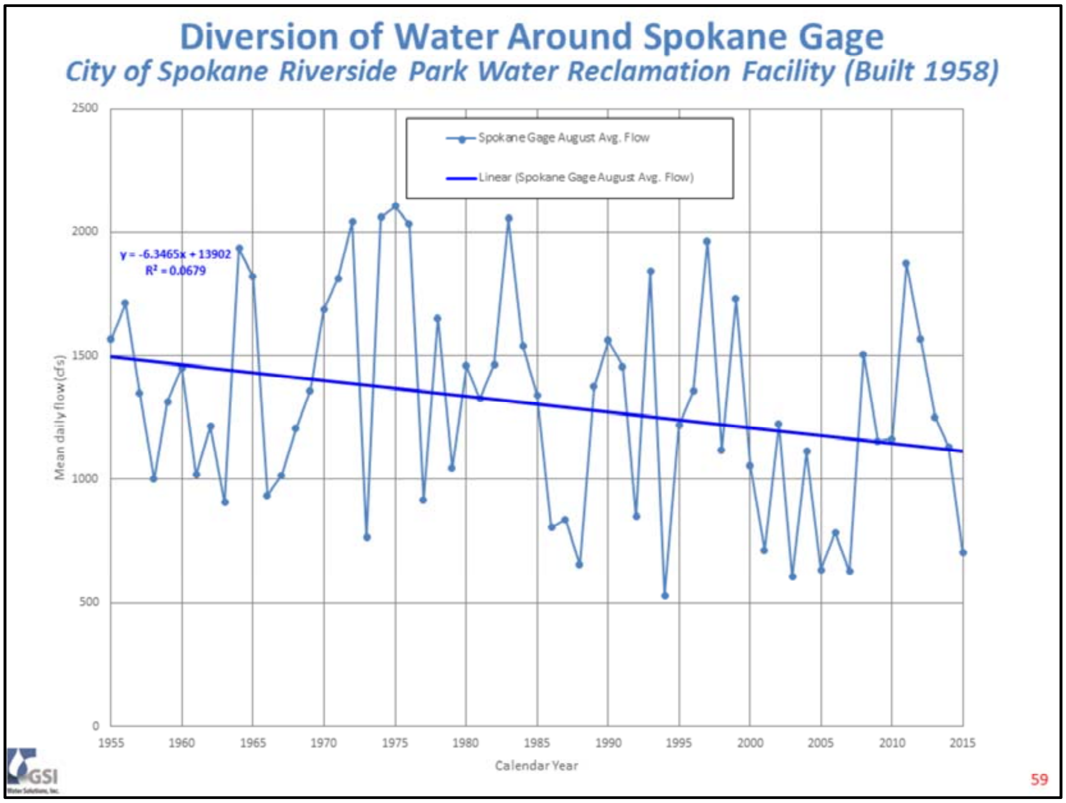


Looking at the aquifer map, it is seen that the City of Spokane's water reclamation facility is located downstream of the Spokane Gage. Water pumped from the SVRP in areas upstream of the gage for indoor use is returned to the river downstream of the Spokane Gage. GSI chose to call this process "diversion of water around the Spokane Gage" because the publically-provided water that is used indoors within the City of Spokane is pumped from the "main stem" of the SVRP (both upstream of the Spokane Gage and also just north of the river in Hillyard Trough), whereas that water is routed to the City's Riverpark Water Reclamation Facility and into the river at a location well downstream of the Spokane Gage. Hence the Spokane Gage's readings are (1) reflecting the withdrawal of water from the SVRP but (2) missing the return of much of that water to the river within the total "river-aquifer" bucket.

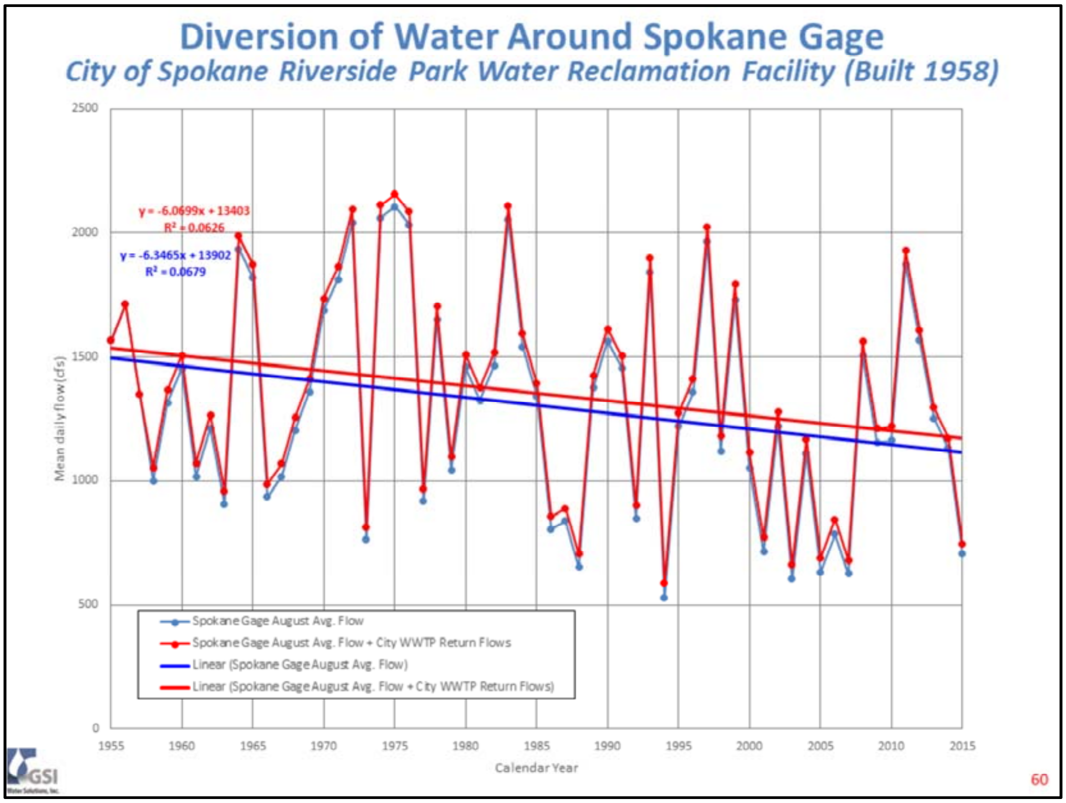
(Note: flows from Spokane County's new water reclamation facility and from water reclamation facilities in Idaho are not evaluated because those flows occur upstream of the Spokane Gage, and therefore are "accounted for" by the flow measurements at the Spokane Gage.)



Here is a simple plot of the average August daily flow from one year to the next at the Spokane Gage. This is plotted for the period 1955 through 2015. The City's Riverpark Water Reclamation Facility was built in 1958.



A best-fit regression line indicates that the August average daily flows are declining gradually over time, though the decline is not statistically significant (because the R^2 value is less than 0.1).



On this slide, we now add to the Spokane Gage data the July-August average daily rate of discharge of treated water from the City of Spokane's water reclamation facility, for each year starting in 1958. This combined flow is shown in the data set and trend line that are each plotted in red. We see an overall upward shift equal to about 35 cfs during August, and this is pretty consistent from one year to the next. Note that the slope of the red trend line is very similar to that of the blue line; this similarity arises because the July-August volumes of treated water discharges into the river have remained fairly constant from one year to the next.

The plot shows an overall change in the magnitude of flow rates, but the suggested long-term rate of decline in river flows remains unchanged after factoring in the contribution from the City of Spokane's water reclamation facility.

Which Hydrologic Processes Might Have Changed and Where?

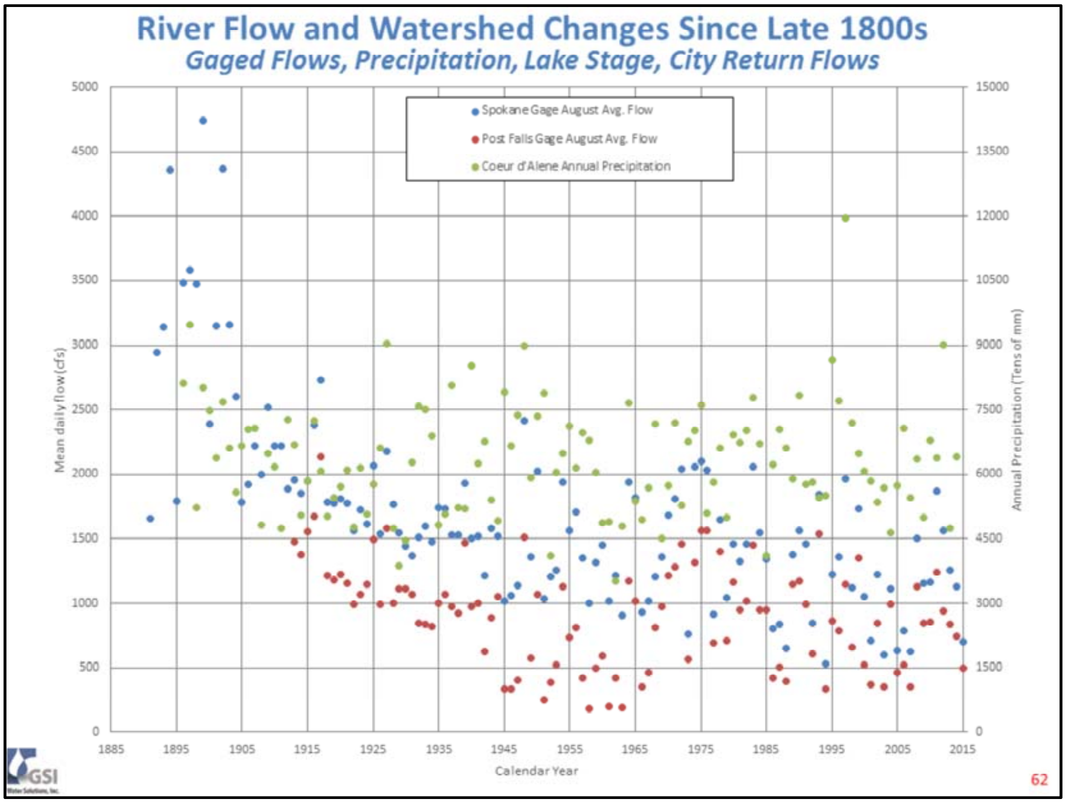
Processes Within the River-Aquifer System	Processes Upstream of the River-Aquifer System
Past agricultural diversions from river *(direct diversions, little return flow)* *(high consumptive use)*	Water level management at CDA Lake
Groundwater use *(municipal and industrial)*	Watershed climate and runoff ***(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)~~*	

GSI

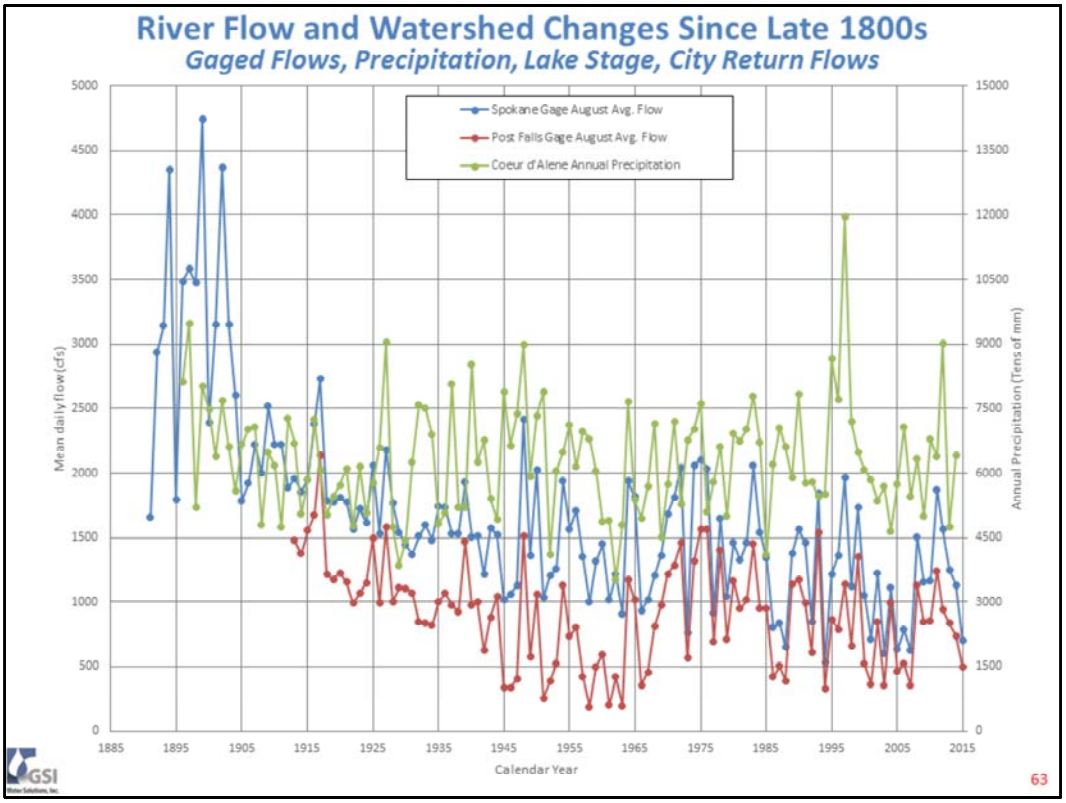
61

Although the trends in seasonal low flows do not appear to have been affected by the return flows that occur from the City of Spokane's water reclamation facility, GSI has elected to leave that process on this list because it is important not to forget about this flow volume whenever absolute flow rates are being evaluated at the Spokane Gage.

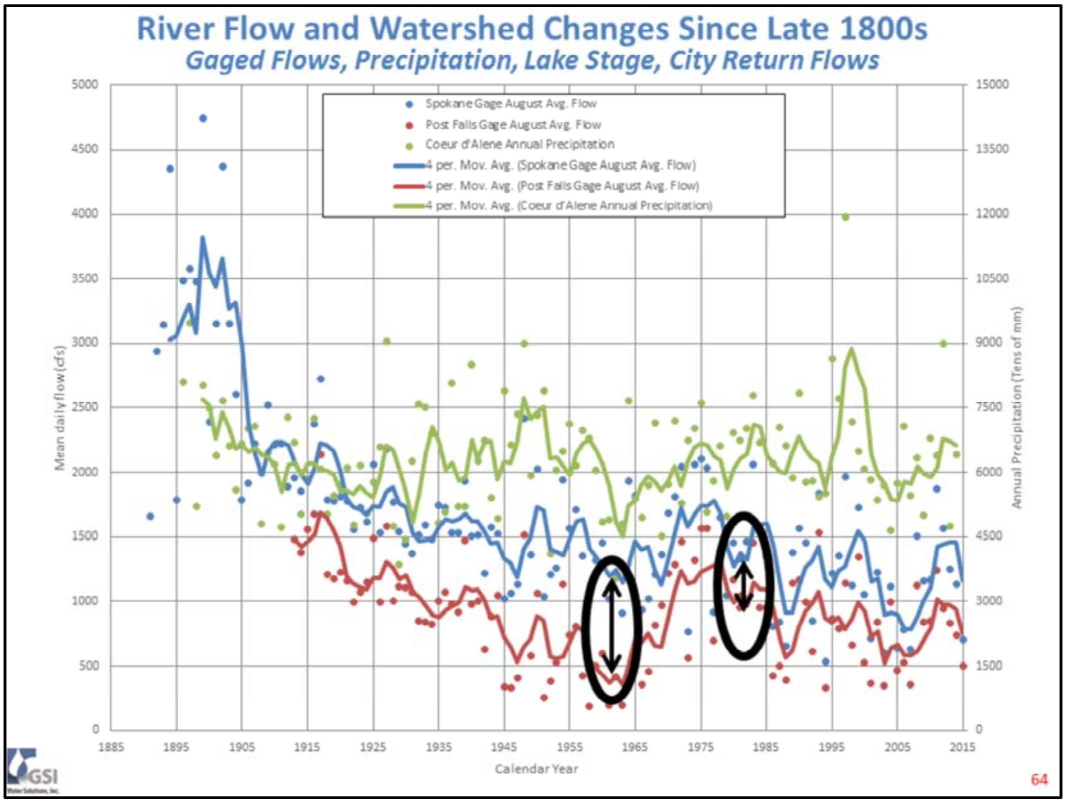
We will now embark on summarizing an extensive evaluation that GSI conducted to examine the potential roles of Coeur d'Alene lake level management and ambient watershed climate and runoff conditions on seasonal low flows in the Spokane River.



To see how watershed climate influences trends in seasonal low river flow rates, GSI first constructed a simple time-series scatter plot of the Post Falls Gage flow data, the Spokane Gage flow data, and annual precipitation as recorded in the City of Coeur d'Alene. Again, for the flows, after a review and analysis of the available data sets, GSI focused its analysis on average daily flow rates in August, rather than evaluating the lowest-day flow in any given year. This decision was made because Labor Day falls on different dates each year, which means the lowest day flows (which are often on or near Labor Day) can occur earlier in some years than in other years. Because there is a year-to-year difference in the date on which Labor Day falls, the use of lowest-day flow values could introduce false artifacts when evaluating trends from year to year and over longer periods. For that reason, GSI chose to look at average daily flows in August. Additionally, GSI used total annual precipitation at Coeur d'Alene as an indicator of watershed conditions, because of the ability of annual (rather than August) precipitation data to capture how the combination of winter snowpack and spring / summer snowmelt and rainfall in the large contributing watershed to the lake might feed inflows to the lake during the summer season.



Hydrologic data sets are often highly variable from one year to the next, as is the case here. This data is too noisy by itself to clearly evaluate long-term trends and potential cause-and-effect relationships, especially after 1965.



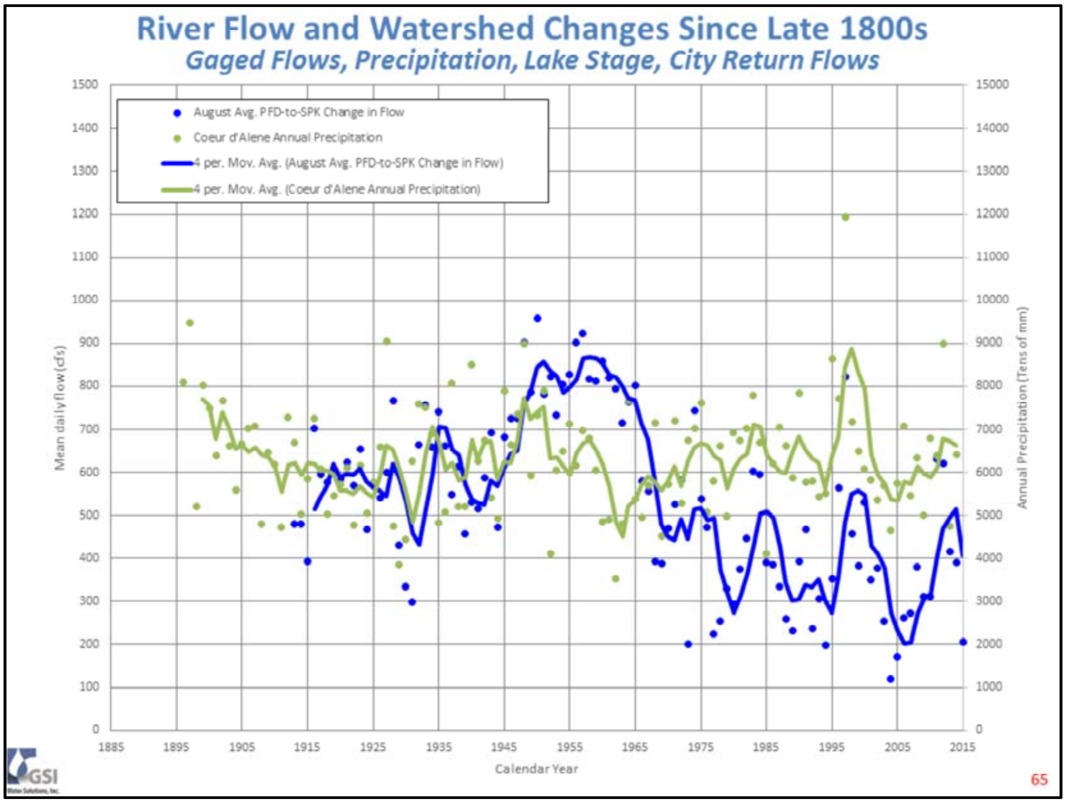
Here is that same data set with a 4-year moving average applied to the data. To extract more meaningful trends and reduce the data noise, we examined the data in many ways and concluded that a 4-year moving average provides the best data set for analysis. Some initial observations from this plot are as follows:

1) Precipitation shows a fair degree of long-term stability back to 1900. However, year-to-year and decadal oscillations are possibly becoming greater after the 1920s.

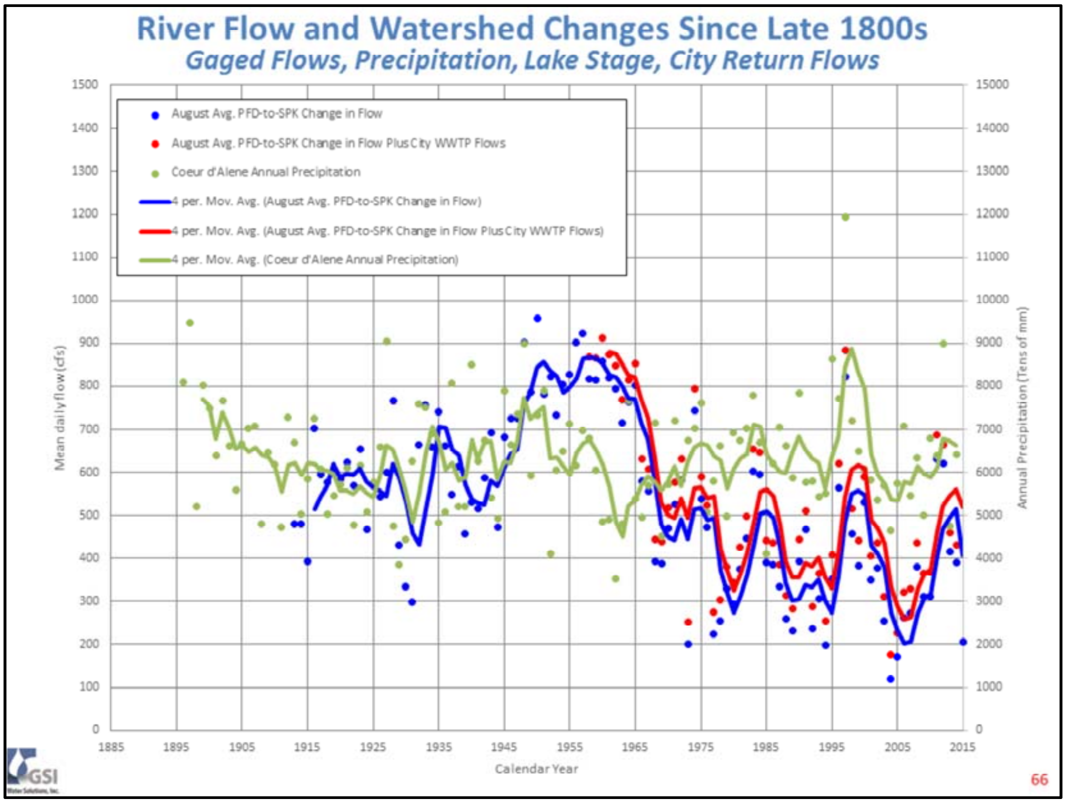
2) The year-to-year flow rates at the two gages appear to respond closely to year-to-year variations in precipitation.

3) The steep decline in August mean daily flows in the early 1900s at the Spokane Gage is accompanied by an apparent long decline in precipitation that did not end until about 1920 or 1925.

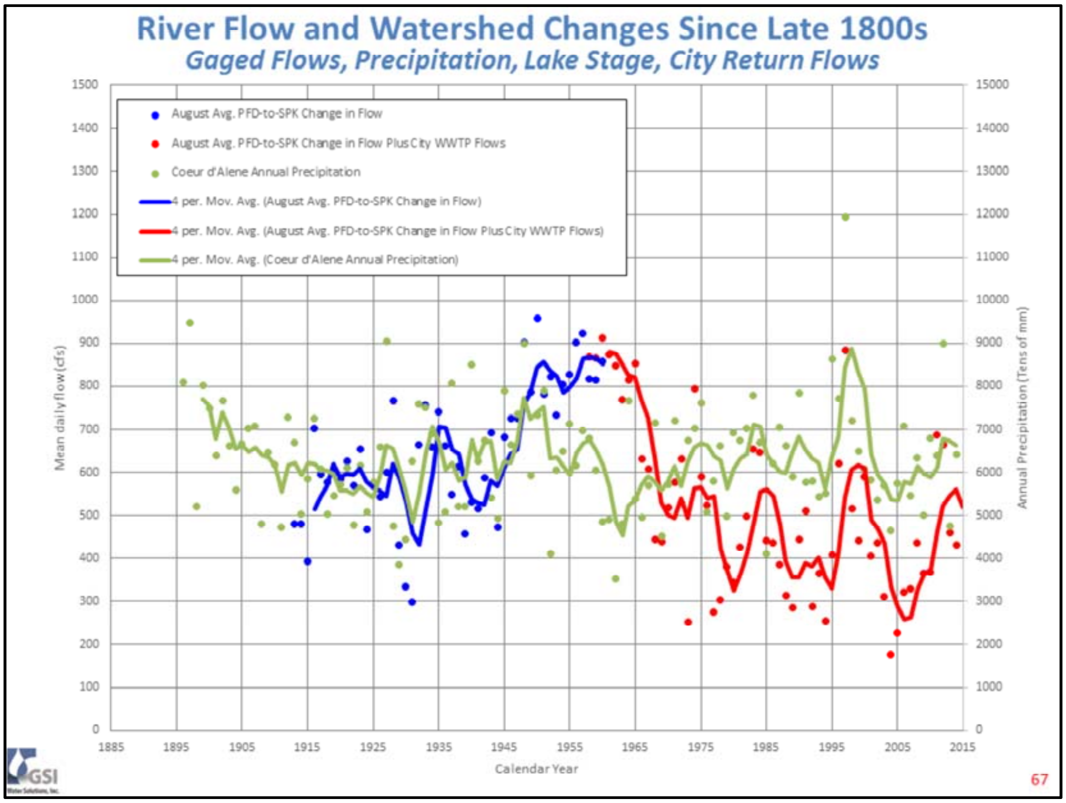
4) Both of the river flow gages show strong decreases in August daily flows from the early 1900s through about 1965. During this period, the difference between flow rates at the two gages becomes increasingly greater, primarily because of a steep decrease in flows at the Post Falls Gage. Starting in 1965, the curve for the Post Falls Gage rises sharply and reduces the difference between Post Falls Gage flow rates and Spokane Gage flow rates. (See the two black arrows.) In the next few slides we will examine this temporal change in the flow rate difference term between these two gages.



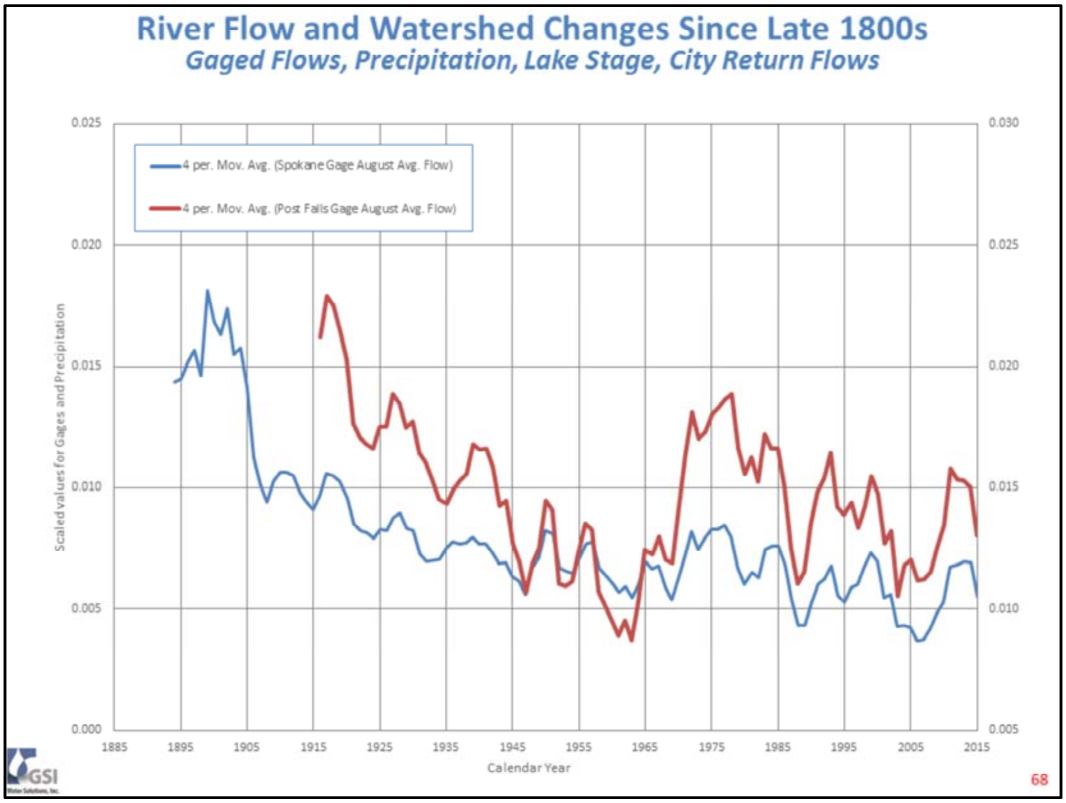
In plotting the difference between August average daily flows at the Post Falls Gage versus the Spokane Gage, a number of trends are apparent. First, we see that the flow difference between the two gaging stations closely follows precipitation trends until 1941. Starting in 1941 or 1942, lake operations were changed to maintain a 1.5-foot higher lake level in Coeur d'Alene Lake. Historical reports indicate that this change occurred because of increased hydropower production, which was necessary for the rapid industrialization that was occurring as the U.S. entered into World War II. In 1965, all canal irrigation stopped, which caused the post-1965 August flows in the Spokane River at Post Falls to be markedly higher than during the years that the Corbin Ditch was operating. Hence, with the end of canal irrigation, Post Falls Gage flows were higher (because the Corbin Ditch was no longer withdrawing water upstream of the Post Falls Gage), which reduced the large difference in flows between the two gages that had been present for many years during canal operations..



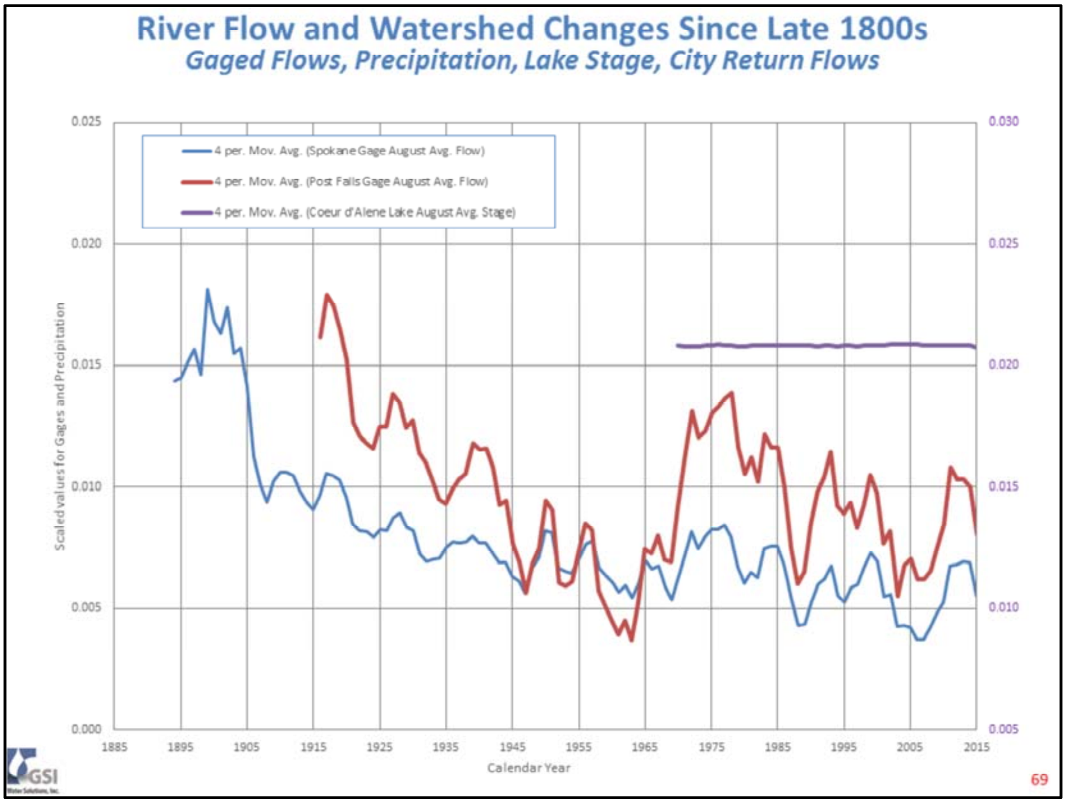
But the prior plot is missing an important flow term … the amount of water being added to the river at the City of Spokane's water reclamation facility downstream of the Spokane Gage. The red line adds this flow to the Spokane Gage data, which in turn increases the difference between the amount of river water leaving the "river-aquifer bucket" at Nine Mile Dam and the amount of water at the Post Falls Gage.



This is the same plot, but now showing just the red line starting in 1958. This plot provides the most complete picture of the annual variation in the difference between river flows at the upstream end of the "river-aquifer bucket" (at the Post Falls Gage) versus the downstream end of the bucket (at Nine Mile Dam).



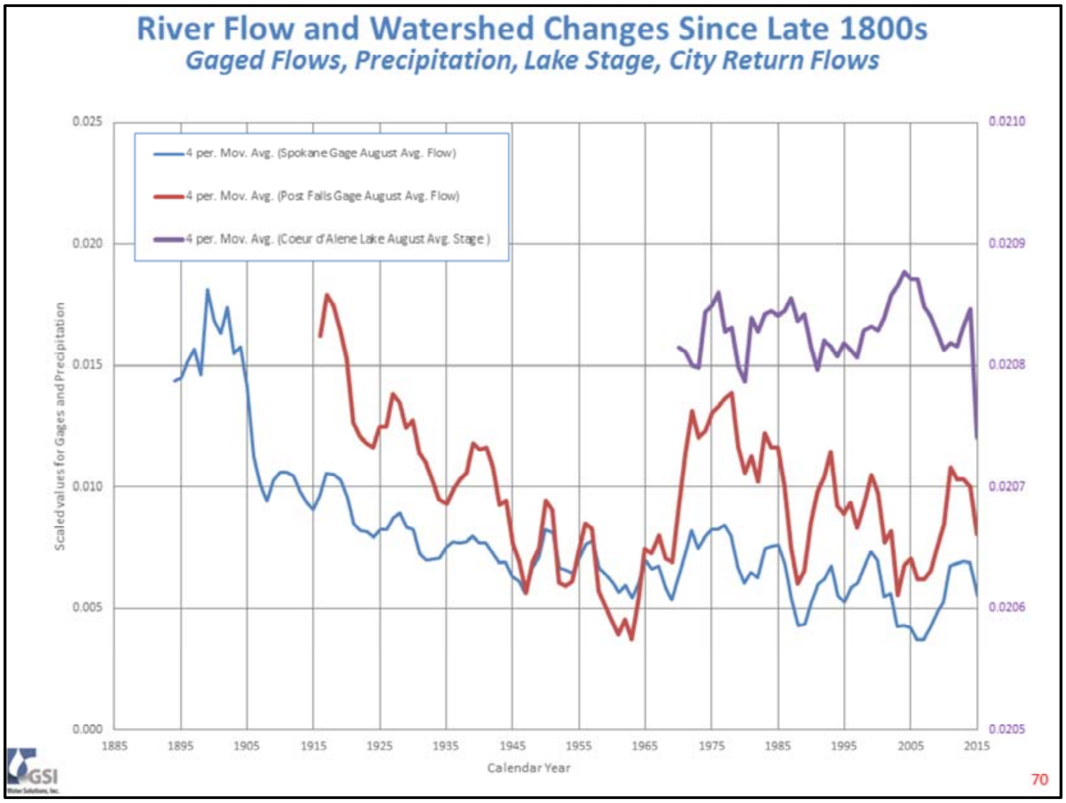
The prior slides evaluated historical trends using the 4-year moving averages of two sets of data … flow data (plotted on the left vertical axis) and precipitation data (plotted on the right vertical axis). But there is one additional data set (the 4-year moving average of lake levels in Coeur d'Alene Lake) that we want to add to several of those plots, and it has different measurement units. To simultaneously show multiple data sets that together have three or more different units of measure, a standard approach is to calculate scaled values of each data set. As an example of what a scaled value is, let's consider the data at the Spokane Gage. Records are available dating back to 1891, which provides 125 years of data for August (through the year 2015), and hence 122 years of 4-year moving average values. First, we total up all 122 values of the 4-year moving average of the mean daily August flow rate. Then, we take a given year's value and divide by that 122-year sum total value to obtain our scaled value for that year. This means that the years with the highest flow rates at the Spokane Gage (which were in the early 1900s) will have the highest scaled values of the 4-year moving average, as shown on this plot. Similarly, years with the lowest flow rates will have the smallest scaled values. We then conduct a similar process for the Post Falls Gage. Note that the scaled values are calculated for each data set independently of the other data sets. For example, the values for the Post Falls Gage are computed using just Post Falls data, without any use of the Spokane Gage data, and vice versa. The scaled sensitivity values for both Spokane and Post Falls are plotted using the left vertical axis.



Now let's add a line showing scaled values of the 4-year moving average for daily mean lake levels during August for Coeur d'Alene Lake. The scaled values of 4-year moving averages for August lake stage are plotted on the right vertical axis, which on this particular slide intentionally uses the same vertical increment for displaying these scaled lake stage values as is used on the left vertical axis for displaying scaled river flow values. Notice that the purple line for the year-to-year scaled lake stage is very flat; this is consistent with the long-standing operating goal for the lake, which (for recreational and hydropower generation purposes) is to maintain as stable a lake level as possible each summer … and at the same achieve a specific target elevation for the lake stage (2,128 feet) to the greatest extent possible throughout the summer during each and every year.

Lake stage data are available for the period from 1967 through 2015 (48 years of record, which provides 44 years of the 4-year moving average). GSI's inspected the raw lake stage data and found that the August average lake stage elevation varied within only a 0.34-foot range from 1967 through 2014. But summer lake operations changed considerably in 2015, causing the average stage in August 2015 to be 0.6 feet lower than the average value of the August stages that occurred from 1967 through 2014.

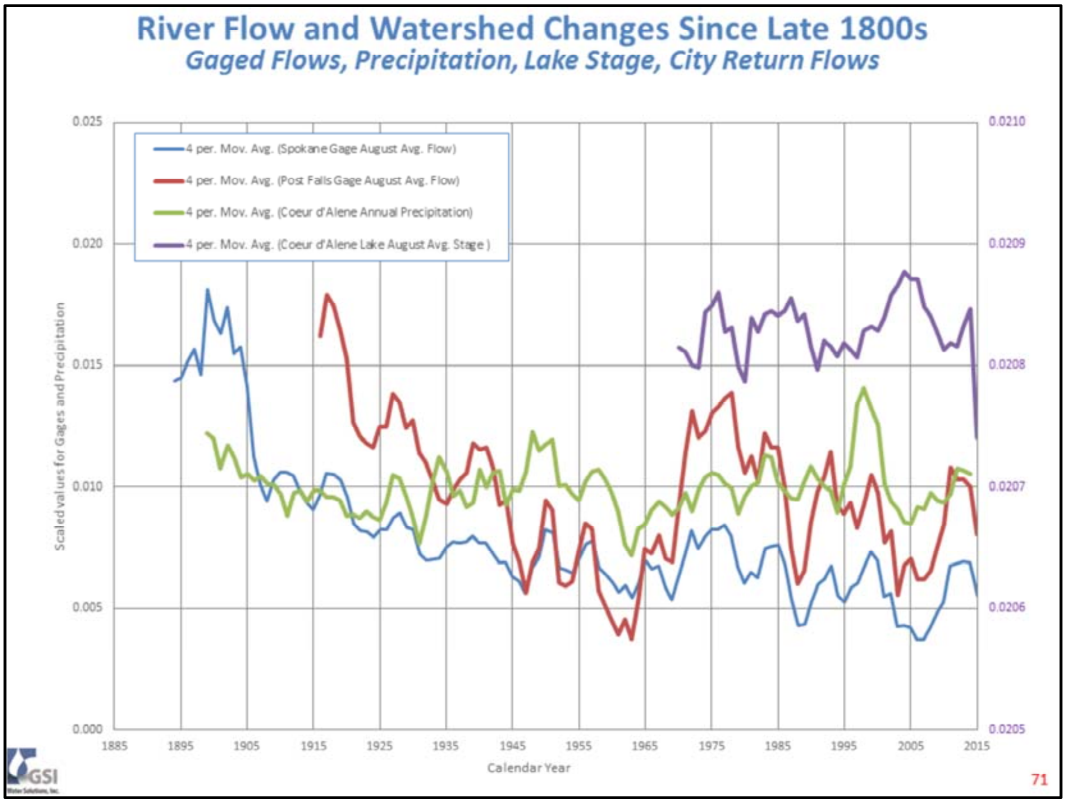
Let's see if it is possible to zoom in on the purple line and the scale of the right vertical axis in an effort to better understand two things: (1) what effect the 2015 change in operation might have had on river flows during August 2015, and (2) whether there are observable trends that are consistent between the August lake stage and river flow data sets during and/or prior to 2015.



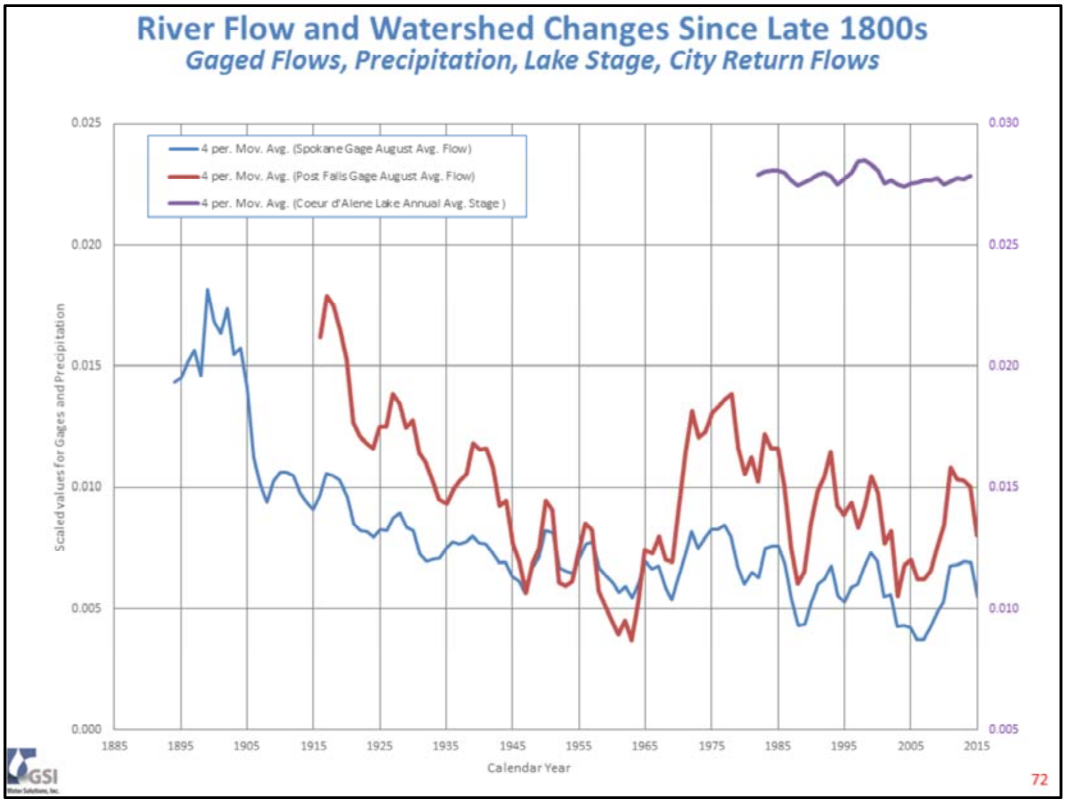
Now we have blown up the right vertical axis considerably. The scaled values on the top and bottom of that particular axis span a range of only 5 x 10^{-4}, whereas they span a range of 2.5 x 10^{-2} on the left vertical axis. In other words, the right vertical axis is blown up by almost two orders of magnitude more than the left axis, just so that we can make out some trends in August lake stages. So we are looking at very subtle differences from year to year.

From about 1970 until 1985, the trends in August river flows at the Post Falls Gage seem to track the August lake stage trends from one year to the next. But starting around 1985, it appears there is possibly an inverse relationship in the trends, where increases in lake levels cause declines in Post Falls flows, and decreases in lake levels increase the flow at Post Falls. Interestingly, in 2015, both the lake level and the Post Falls flows dropped noticeably compared to the prior years.

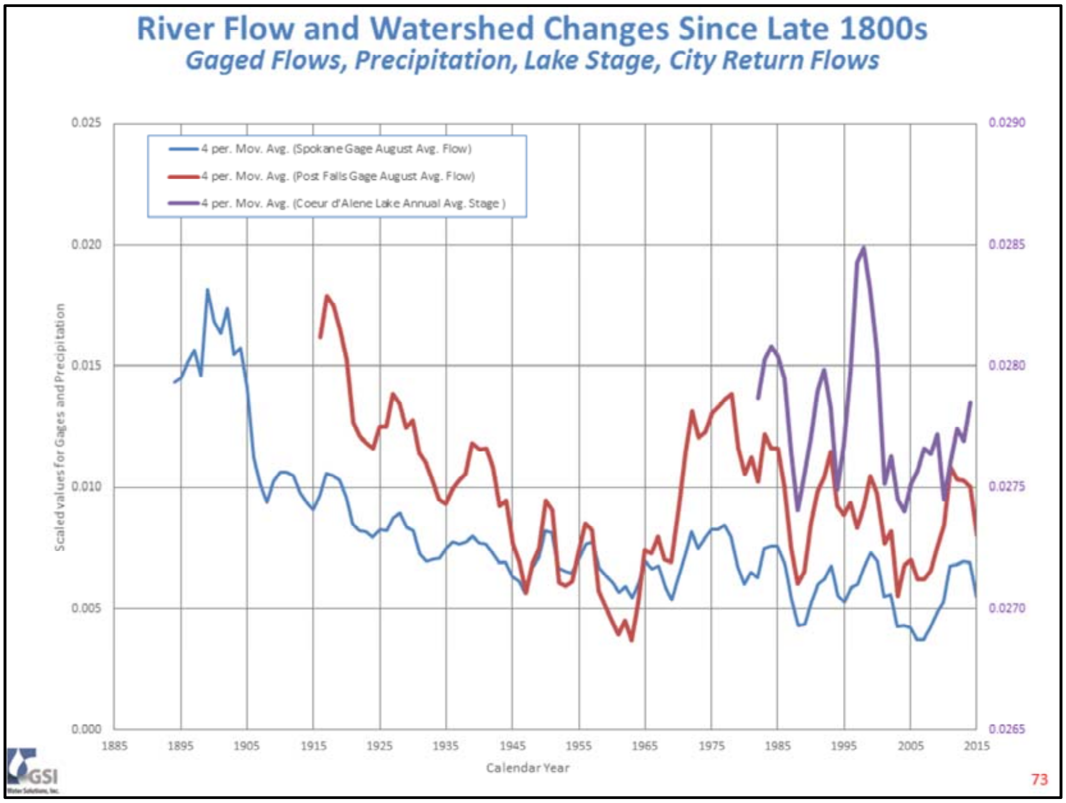
These changes though are very subtle, and they suggest that there is more at work than just the lake stage itself … especially when considering what happened in 2015. Maintaining stable lake elevations in August each year means that for several days or a few weeks, there is little to no difference in the volume of water being stored in the lake. This means that in any given year, during August the rate of outflow from the lake (as measured at Post Falls) must be very similar to the rate of inflow to the lake. But that similarity between lake inflows and lake outflows in August is just within that short 31-day period <u>of a single year</u>. When comparing August <u>from one year to the next</u>, this plot shows that there is a difference between what a stable daily condition looks like in one year versus what it looks like in the next year or any other year. So this begs the question of why we would have a generally stable condition during August of each year when these curves are also showing differences from one August to the next August a year later. The only possible explanation is that there are differences in the absolute magnitudes of the amount of flow during August that are coming into (and also leaving) the lake. Watershed science tells us that in any given year, the magnitude of August flow into the lake will be driven in part by antecedent conditions for the several months leading up to August, and even the conditions that occur for a year or a few years prior to that particular August. The variability in August lake stage from one year to the next is telling us that there are variable hydrologic conditions within the contributing watershed from one year to the next. We will now explore this logic further in the next several slides.



Here is the prior plot, but with Coeur d'Alene annual rainfall added (on the left vertical axis). The seasonal flow trends at Post Falls appear to track the annual rainfall trends quite well. Because the August-to-August lake stage trends are subtle, and because the Post Falls seasonal low flow trends seem to track trends in annual rainfall, let's next look at annual average values of the lake stage rather than just the August lake stage.



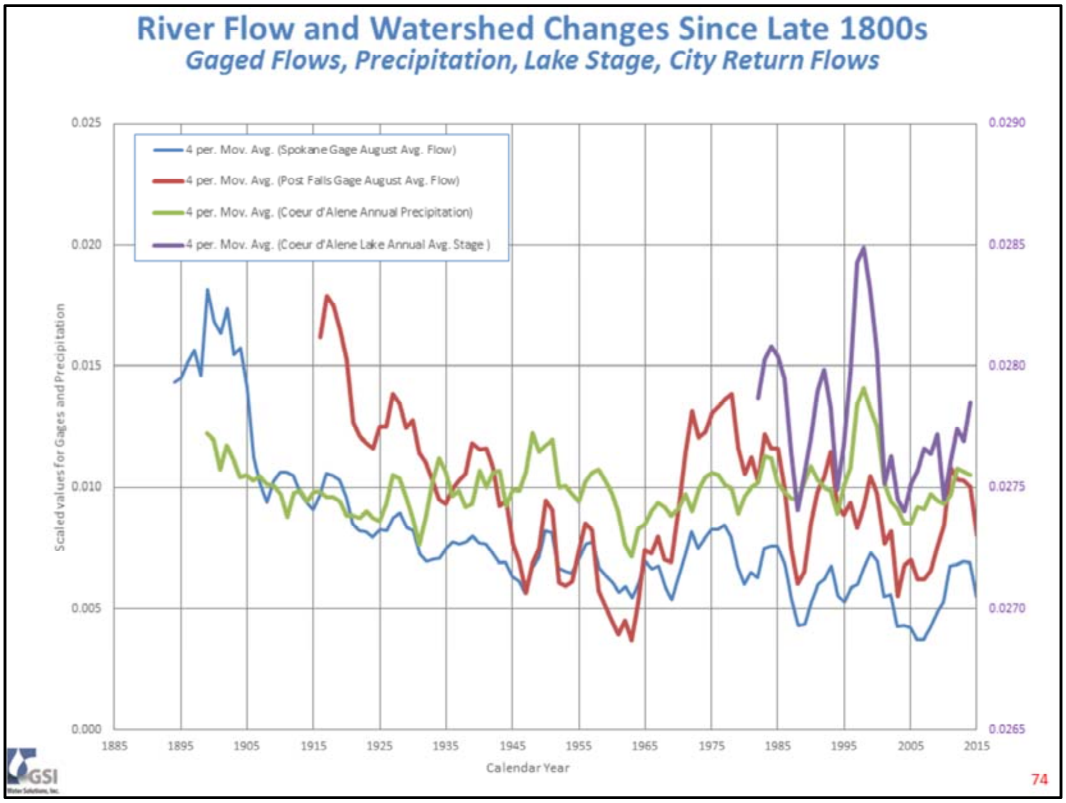
The <u>annual</u> average lake stage captures the antecedent conditions that we discussed in slide 70. The annual average lake stage reflects the year-to-year differences in lake inflows and outflows that are caused by conditions not during the summer period of relatively stable lake levels, but instead the condition at other times of the year (particularly the winter through late spring/early summer, which is the period of high snow/rainfall and subsequent watershed runoff). The use of the annual average stage (rather than August stage) in calculating scaled values of the 4-year moving average begins to reveal some year-to-year differences in watershed hydrologic conditions. But the annual lake stage data are plotted at the same vertical scale (right axis) as is used for the flow data (left axis). We need to zoom in on this annual lake stage data more if we are to determine whether variations in annual average lake stage are having a bearing on year-to-year and longer-term trends at the two river gages.



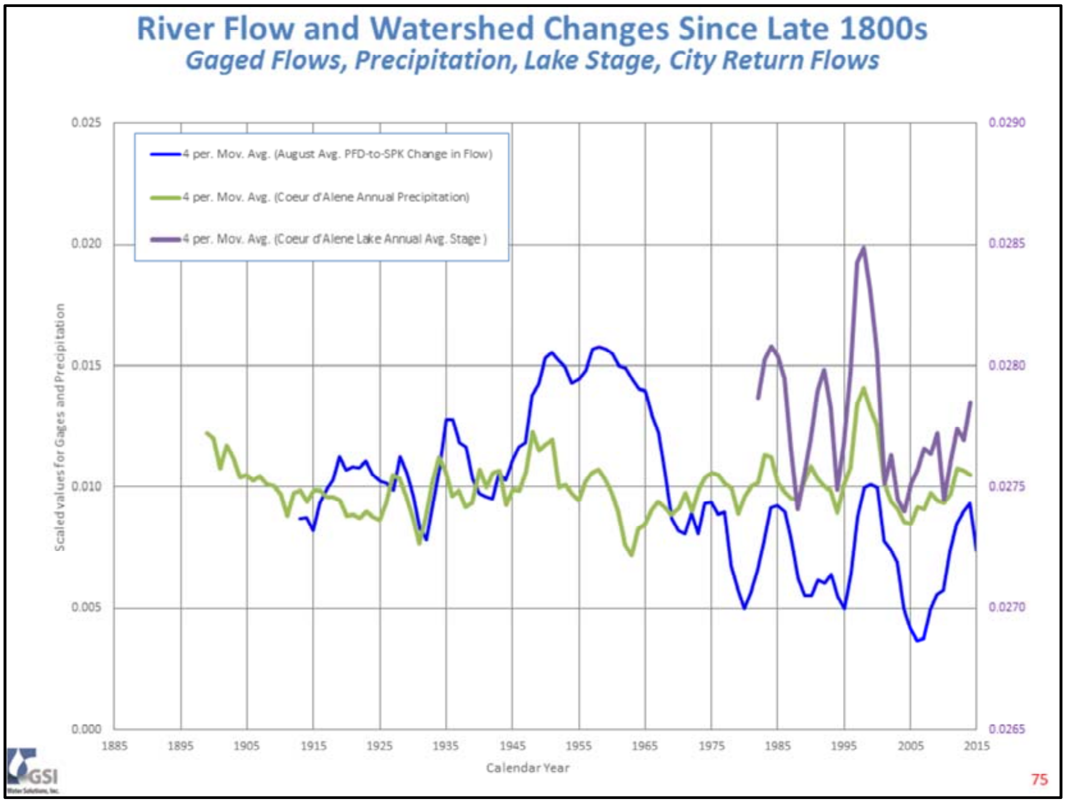
This slide zooms the right vertical axis in a manner that allows us to now see fluctuations in the annual lake stage more clearly. Note that we did not need to zoom in as much on this annual lake stage data (vertical axis range is 2.5 x 10^{-3}) as we did for the August lake stage (vertical axis range of only 5 x 10^{-4} as shown on slides 70 and 71). So this data set shows more lake stage variability from year to year than the August data set.

The plot show that trends in August flows at Post Falls seem to track the annual average lake stage reasonably well, which is in contrast to the plots on slides 70 and 71 that showed an apparent opposite trend between Post Falls flows and August lake stages. This is a sign that antecedent conditions in the watershed indeed affect trends in seasonal low flows at the Post Falls Gage, as well as at the Spokane Gage.

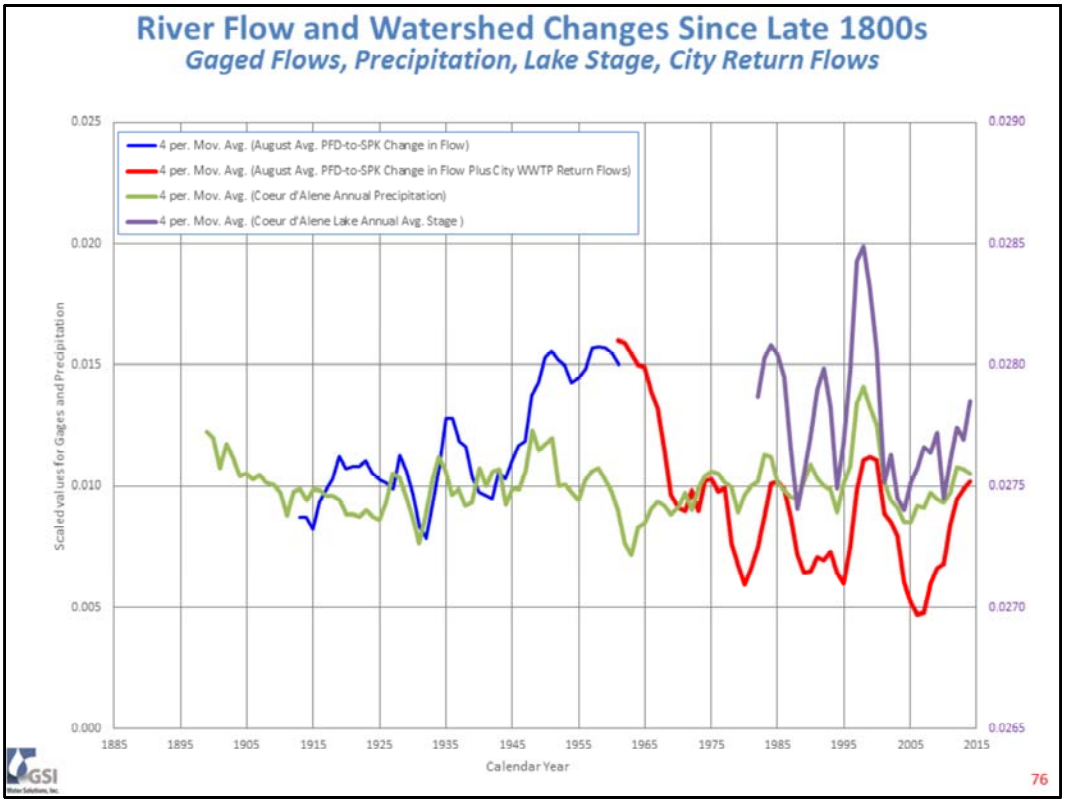
Keep in mind that we don't care about the magnitudes of the fluctuations in these data sets. Rather, we look at whether increases in flows at either river gage coincide closely in time with increases in the lake stage, and whether decreases in flows at either gage coincide with decreases in lake stage. As with the prior plots on slides 68 through 72, all of the data plotted here are scaled values of 4-year moving averages, and the plot is evaluating the potential effects of fluctuations and directional trends in annual average lake stage on late-season (August) flows in the Spokane River at both gaging stations.



Let's take the prior plot and add the scaled values of the 4-year moving average for <u>annual</u> Coeur d'Alene rainfall. We are using <u>annual</u> rainfall (rather than August rainfall) for the same reasons (discussed on slide 70) that we are using annual lake stage data. This scaled plot shows that the rainfall and lake stage trends are very similar in direction from one year to the next, and that the two stream gages are also tracking the rainfall and annual average lake stage. Again, we are focusing just on directional trends … not on whether one data set is higher on the plot than another, or whether one data set shows more variation than another (because those two topics mean nothing on a scaled plot).



As we discussed on slides 64 through 67, GSI noticed that the difference between flows at the Post Falls Gage versus the Spokane Gage changed over time. Here is a plot of that scaled change, compared with the scaled plots of annual rainfall and annual average lake stage. All lines are 4-year moving averages. After the Corbin Ditch shut down in 1965, the difference in flow between the two gages generally seems to have trended in the same direction as annual rainfall and annual average lake stage.



The observations on the prior slide do not change when we add the flows that enter the river below the Spokane Gage (from the City of Spokane's water reclamation facility). The trends that occur after 1965 for the flow difference between the Post Falls and Spokane gages are tracking the trends in annual average rainfall and average annual lake stage at Coeur d'Alene Lake.

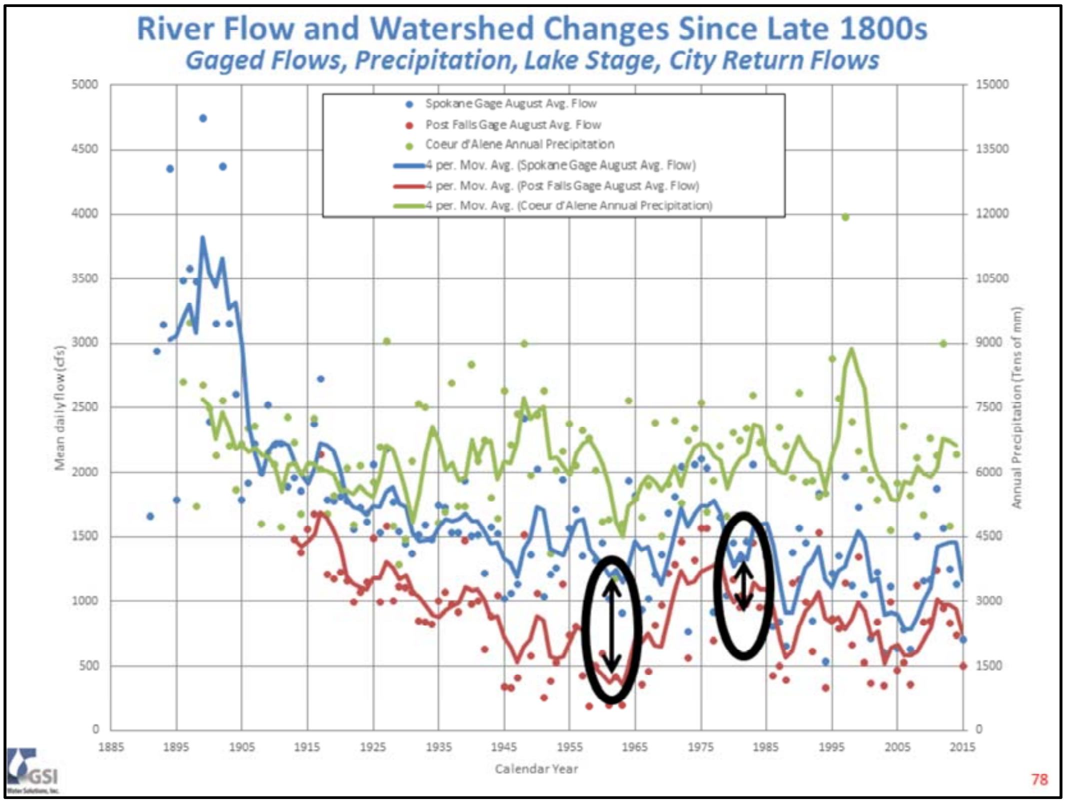
Note too that after the mid to late 1960s, the red line appears to be in a long-term equilibrium condition, despite the occurrence of short-term fluctuations. This means that the aggregate group of water use and hydrologic processes within the local river-aquifer bucket are creating an unchanged condition in the river within this same bucket. This in turn means that the net amount of water being added to the river in the local bucket (between Coeur d'Alene Lake and Nine Mile Dam) is not changing! Changes to the amount of water in the river are occurring upstream of the bucket, not within the bucket.

Topics

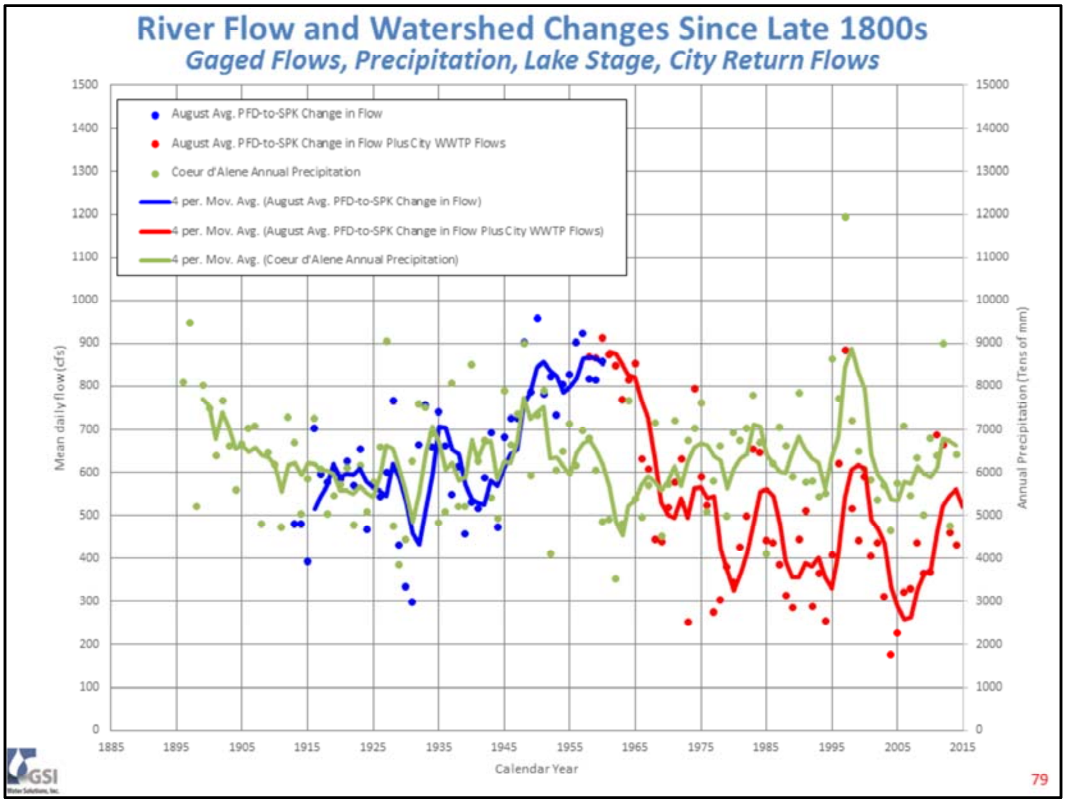
1. Why evaluate historical changes
2. Define processes that theoretically could have been the cause of decreasing river low flows
3. Evaluate each process in depth (many slides)
4. Conclusions regarding dominant processes and what it all means

GSI

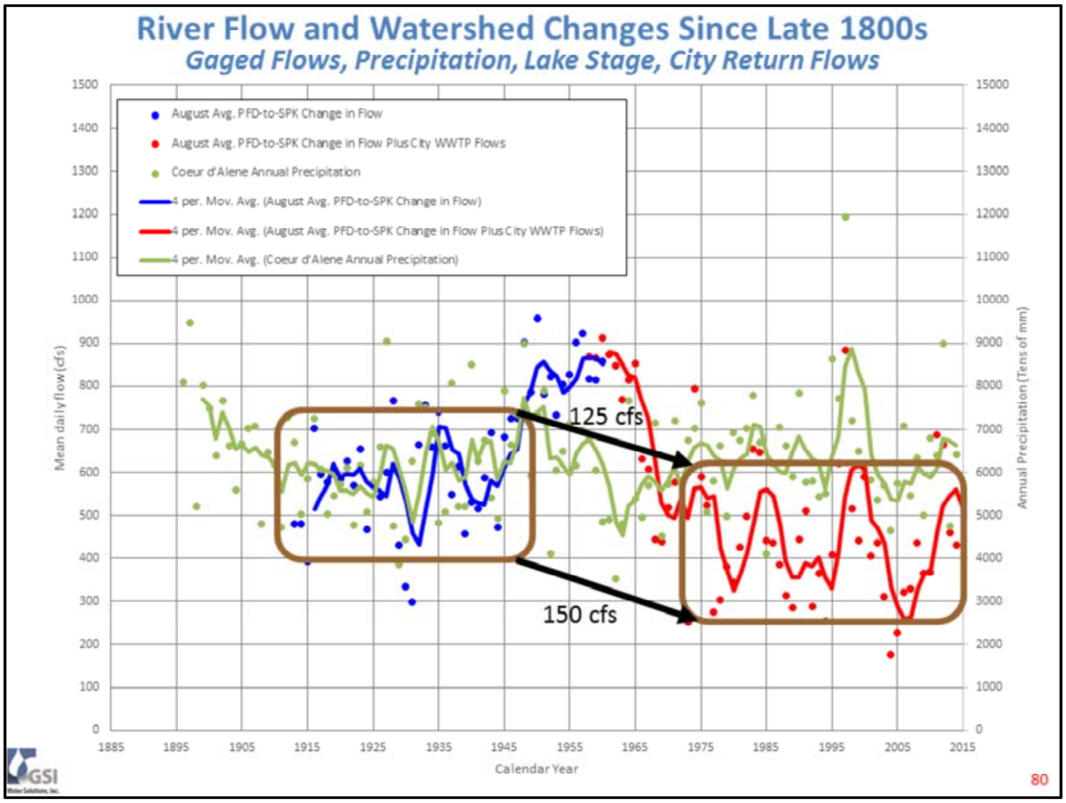
77



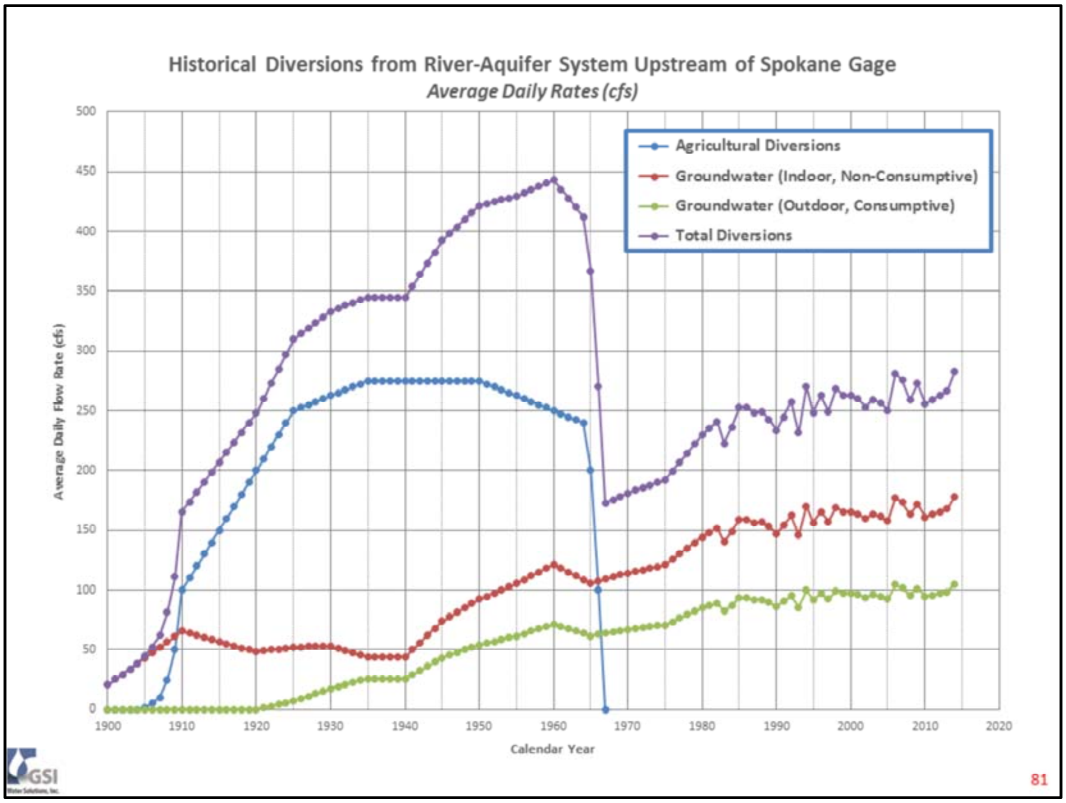
To think about what all those charts mean in a broad sense, let's again consider the difference between the 4-year moving average values of mean daily flows at the Spokane Gage versus the Post Falls Gage. As shown on the plot, the differences between the two gages was growing notably as the Spokane Valley's agricultural years progressed, and this continued all the way to 1965. After Corbin Ditch water diversions ended in 1965, the mean daily August flows at Post Falls rose sharply over the next few years. The two black arrows show the magnitude of the difference between the two gages in about 1960 and about 1980. As shown, the difference has been much smaller after 1965 during the period after agricultural irrigation ended than was the case before 1965.



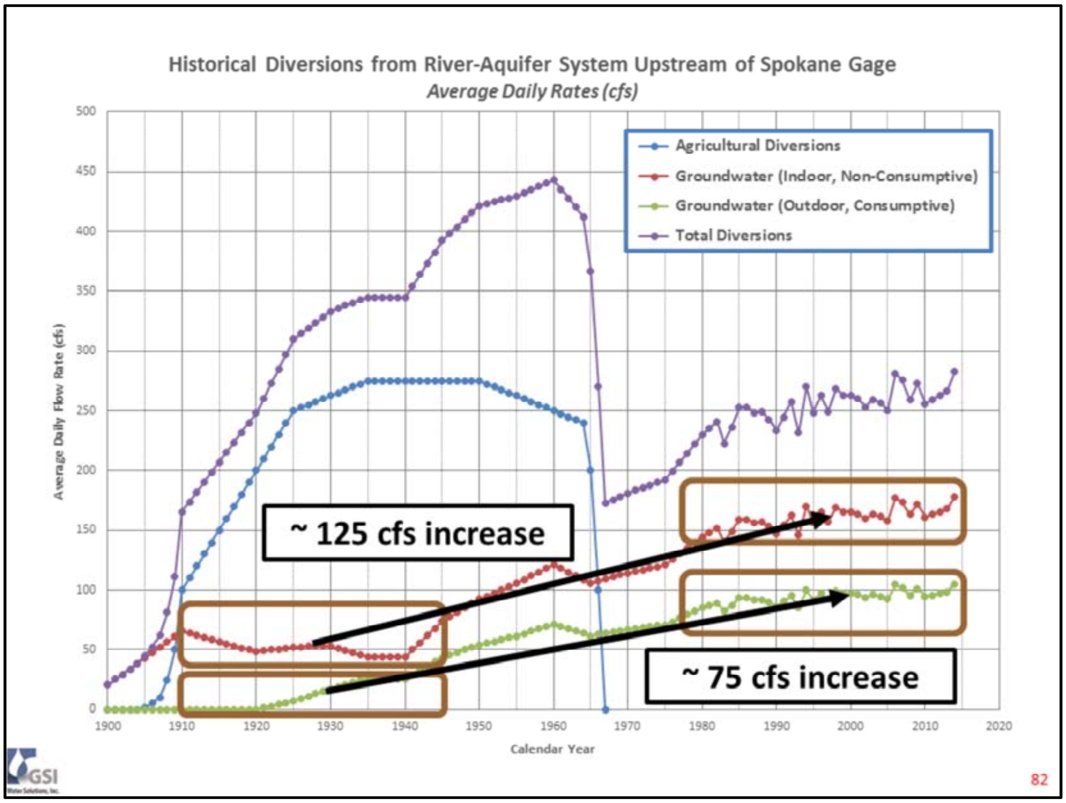
Here is that difference, plotted over time. This is the same as slide 67, and shows the difference between the August gaged flows at Post Falls and Spokane varies over time historically, including after accounting for return flows to the river from the City of Spokane's water reclamation facility beginning in 1958. Let's study this plot a bit more closely.



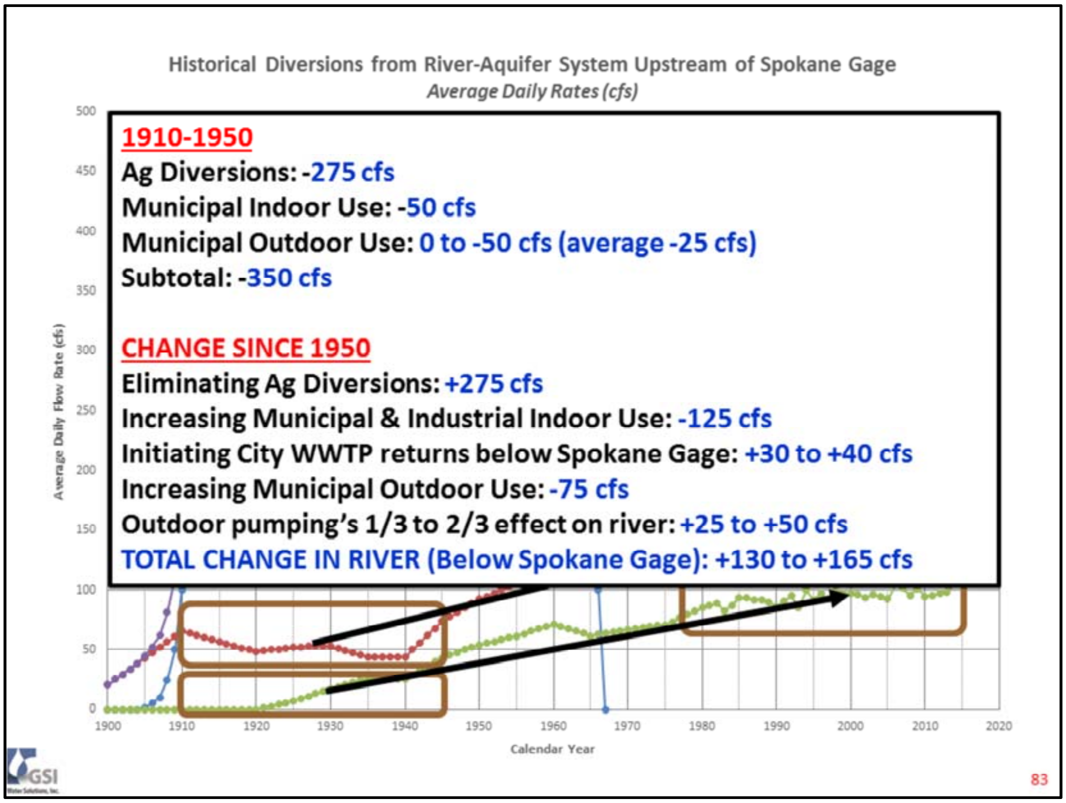
We see two periods of long-term equilibrium: 1900 through about 1945 or 1950, and then from about 1970 or 1975 to the present. (The term "equilibrium" refers to what is happening with the difference in flow rates between the Post Falls Gage and the Spokane Gage.) The current long-term equilibrium is characterized by a smaller difference in flow rates between the two gages than occurred during the earlier period. To understand why this occurred, let's revisit on the next slides the history of direct water diversions from the river, groundwater pumping volumes, and total water consumption inside the "river-aquifer bucket."



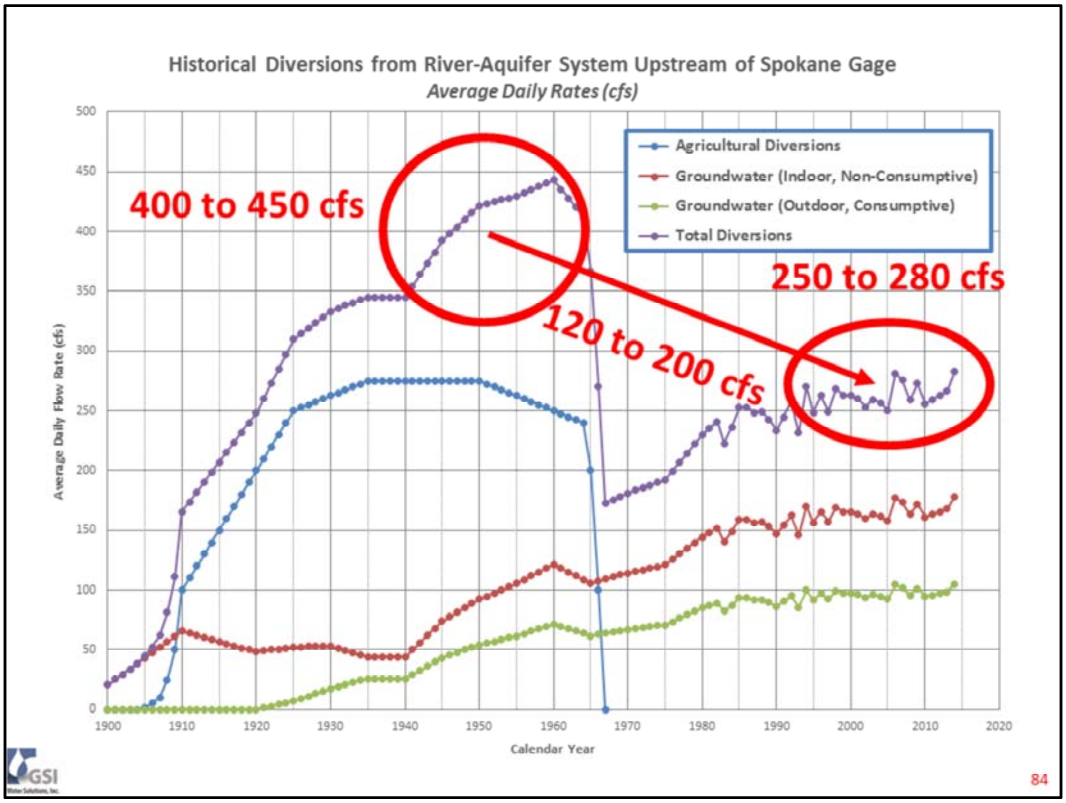
Here is slide 44 again, showing total water use and water withdrawal from the "river-aquifer bucket" over time, plus the components comprising that total use and withdrawal.



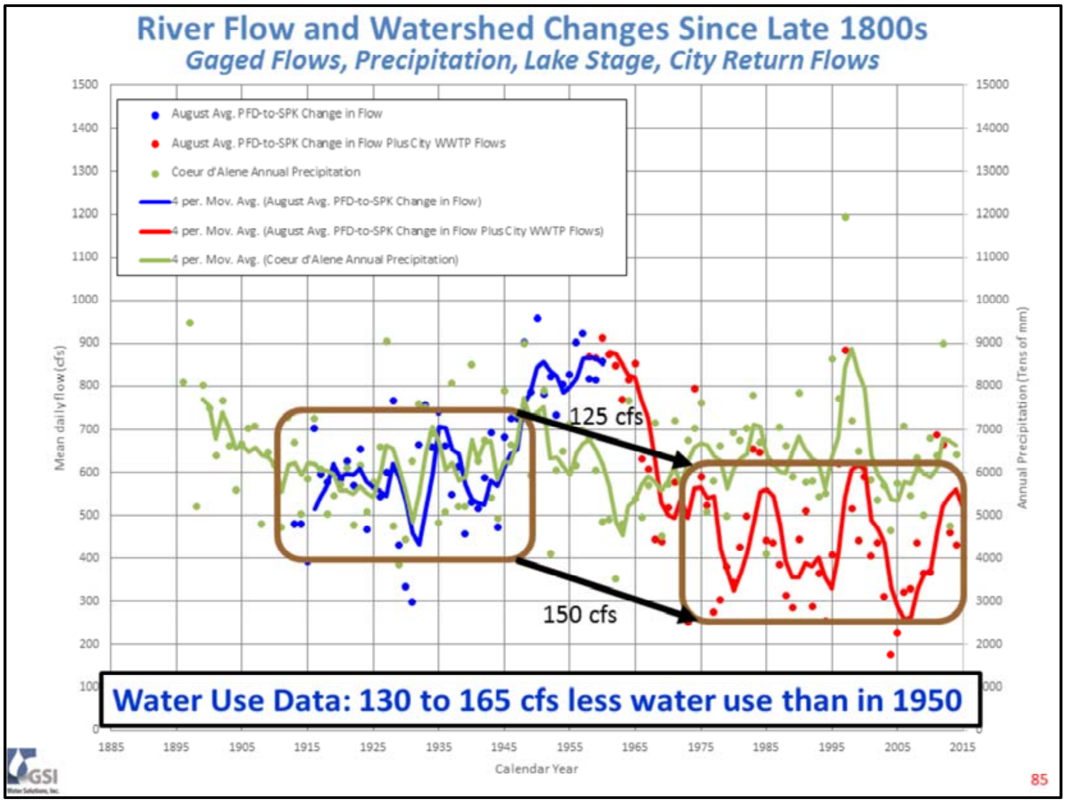
Here is how much the groundwater use changed between those same two time periods of long-term equilibrium that are shown on slide 80. Indoor uses of groundwater across the SVRP (Washington and Idaho together) average about 125 cfs higher in the recent period than in the early period, and outdoor uses of groundwater across the SVRP average about 75 cfs higher in the recent period than in the early period. Notice that when agricultural diversions ended in the mid-1960s, the first few years afterwards (in the late 1960s) had total water uses that were lower than at any time seen since about 1910.



Let's prepare an accounting of average water use during the first time period (1910-1950), and then compute the change that occurred in water use between that period and today. This accounting is shown in the table, and its primary finding is that the "river-aquifer bucket" has actually gained between about 130 and 165 cfs of water as a result of the changes that occurred after 1950. This decrease in overall water use is due to (1) the cessation of irrigated agriculture and (2) the less intensive water use that occurred as agricultural lands were converted to urban and suburban uses. Additionally, the increased urban water use of the SVRP occurred not only in areas overlying the SVRP, but also in adjoining areas. Despite the fact that SVRP-dependent urbanization expanded to lands outside the SVRP itself, total water use from the SVRP has remained much lower than was the case from about 1920 through 1950.

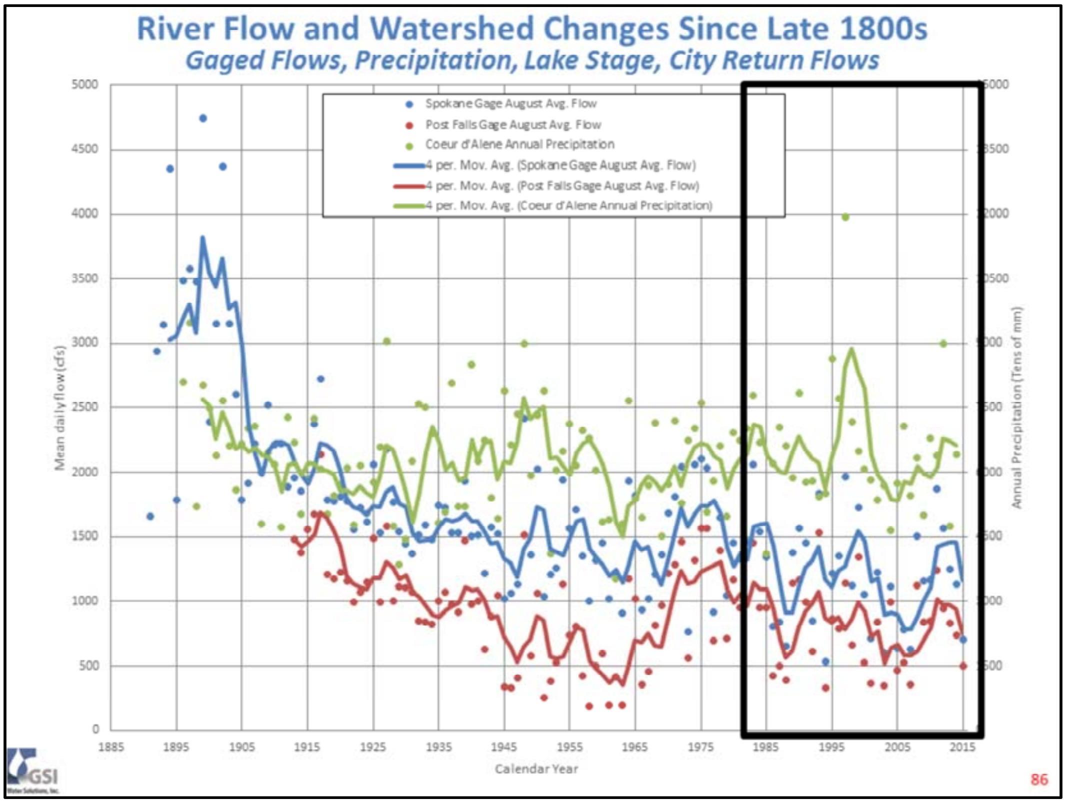


We can see that total water use was peaked at a rate of between 400 and 450 cfs during the 20-year time period from about 1945 through 1965. In contrast, water use from about 1990 to the present has been in the range of 250 to 280 cfs, which is 120 to 200 cfs lower than during the earlier period.

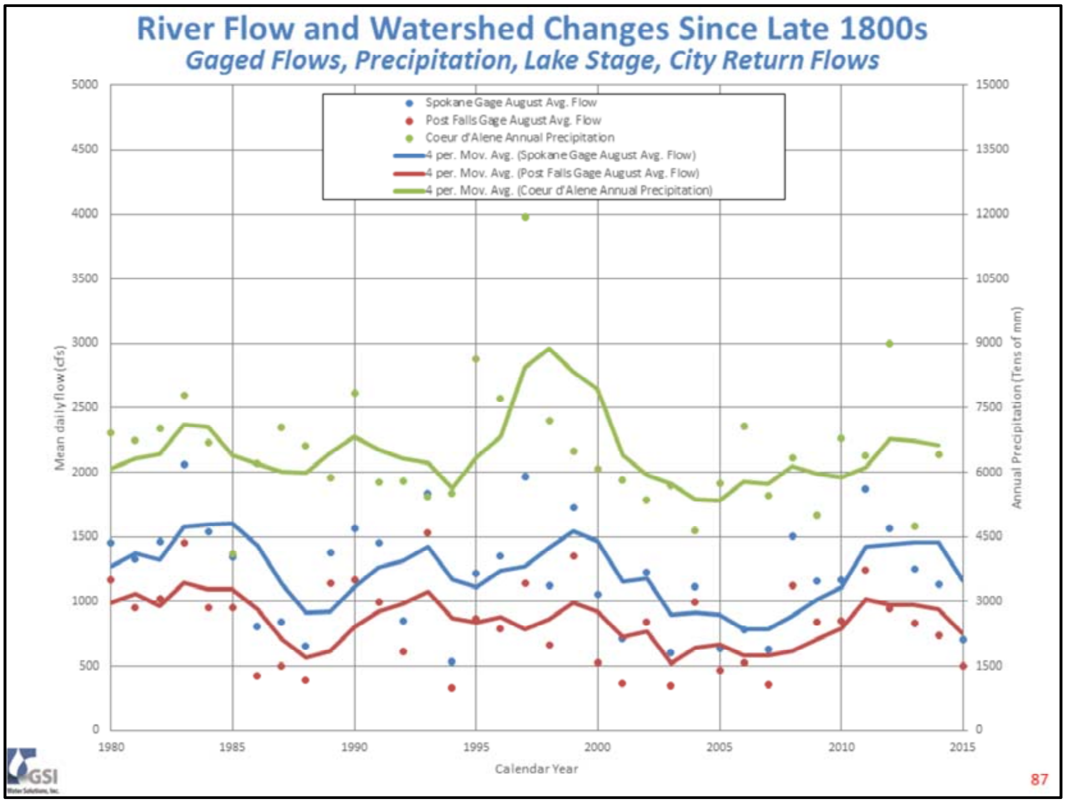


The water use reduction of 120 to 200 cfs shown on the prior slide spans the range of 125 to 150 cfs improvement in the flow difference between the Post Falls Gage and the Spokane Gage that is shown on this slide. GSI has concluded that for those two equilibrium periods, the average water use improved over a narrower range of 130 to 165 cfs (see slide 83). This means that the water use numbers and the flow numbers are in similar agreement, and that the "river-aquifer bucket" experienced (after irrigated agriculture ended) an improvement whose magnitude can be estimated from both the flow data and from the water use data. This indicates that the historical water use projection model is well-calibrated to the river flow data, and that these two pieces of information paint similar pictures of hydrologic conditions within the local river-aquifer bucket.

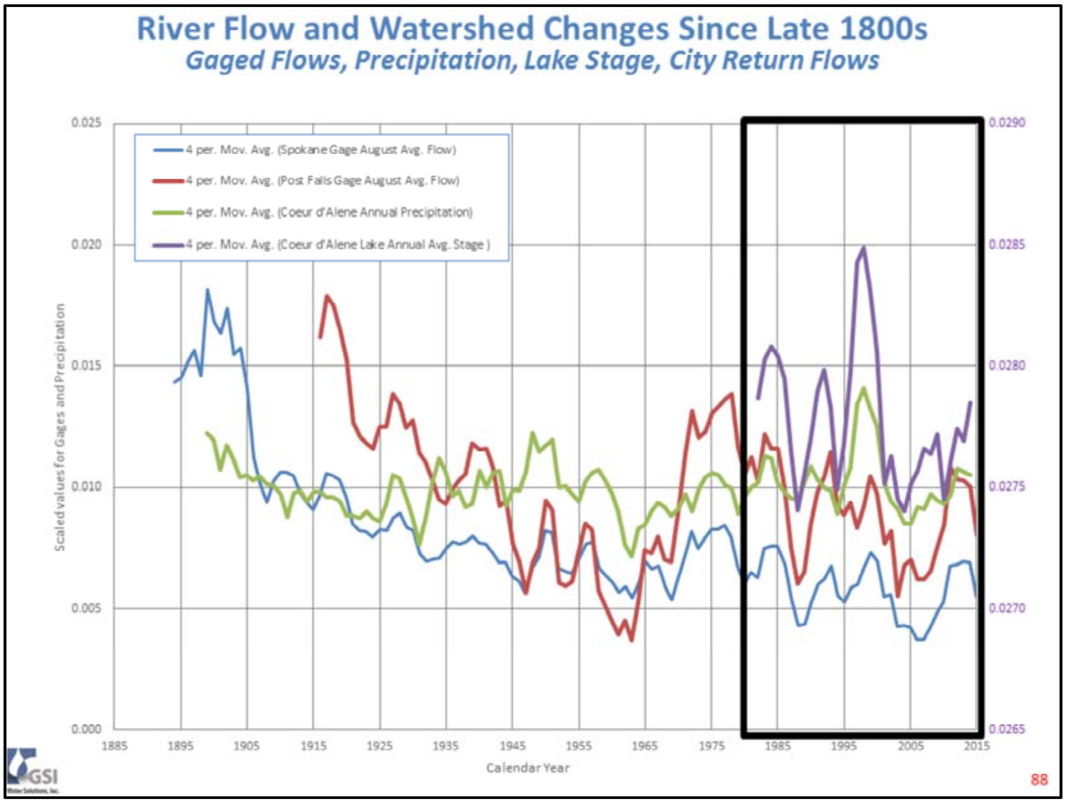
The fact that a new equilibrium has been established means that the past is now behind us – i.e., the past perturbation of the "river-aquifer bucket" by canal diversions is no longer manifesting itself to this day. The bucket itself has reached a new equilibrium, particularly in the SVRP aquifer itself. However, even though the difference between Post Falls Gage flows and Spokane Gage flows is now less than before (because of the cessation of canal diversions from the river), this does not mean that seasonal low flow rates at each gage have improved. The seasonal low flow rates at each gage have continued to slowly decline, as we have seen on prior slides. So we will now examine the recent years' trends in seasonal low flows in the next several slides.



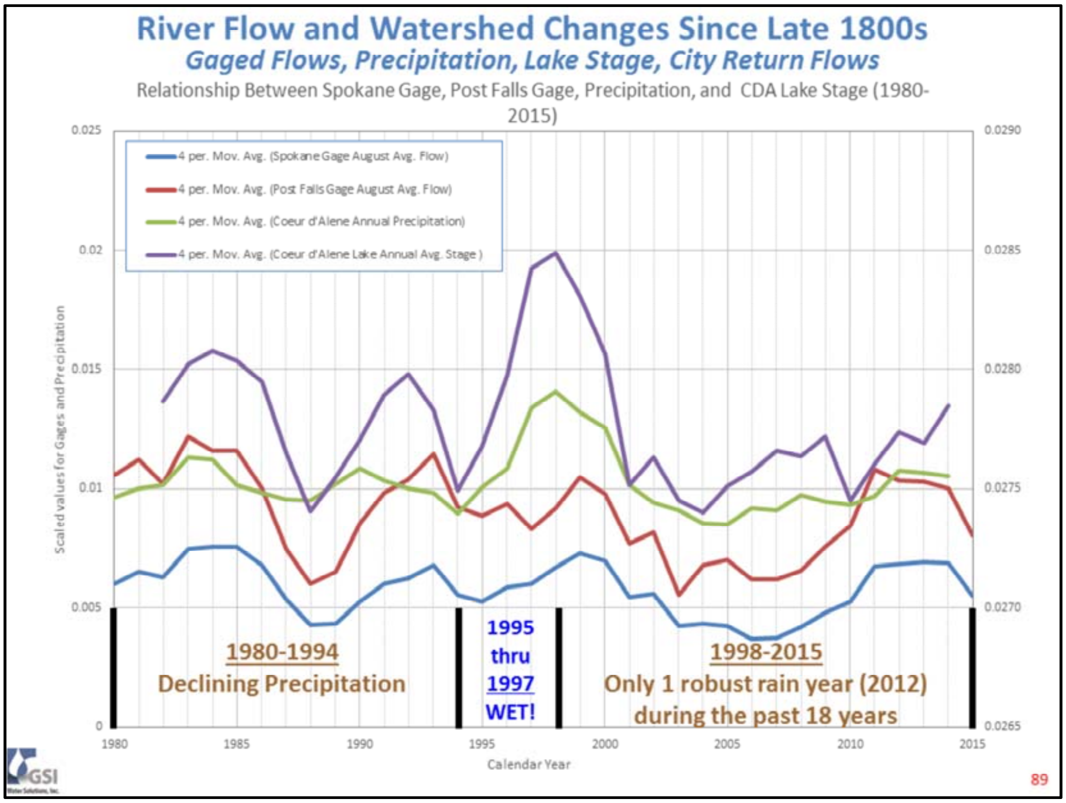
Let's go back to the plots of the 4-year moving averages (in cfs for mean daily August flow, and tens of millimeters for annual rainfall), and let's zoom in on the past 35 years.



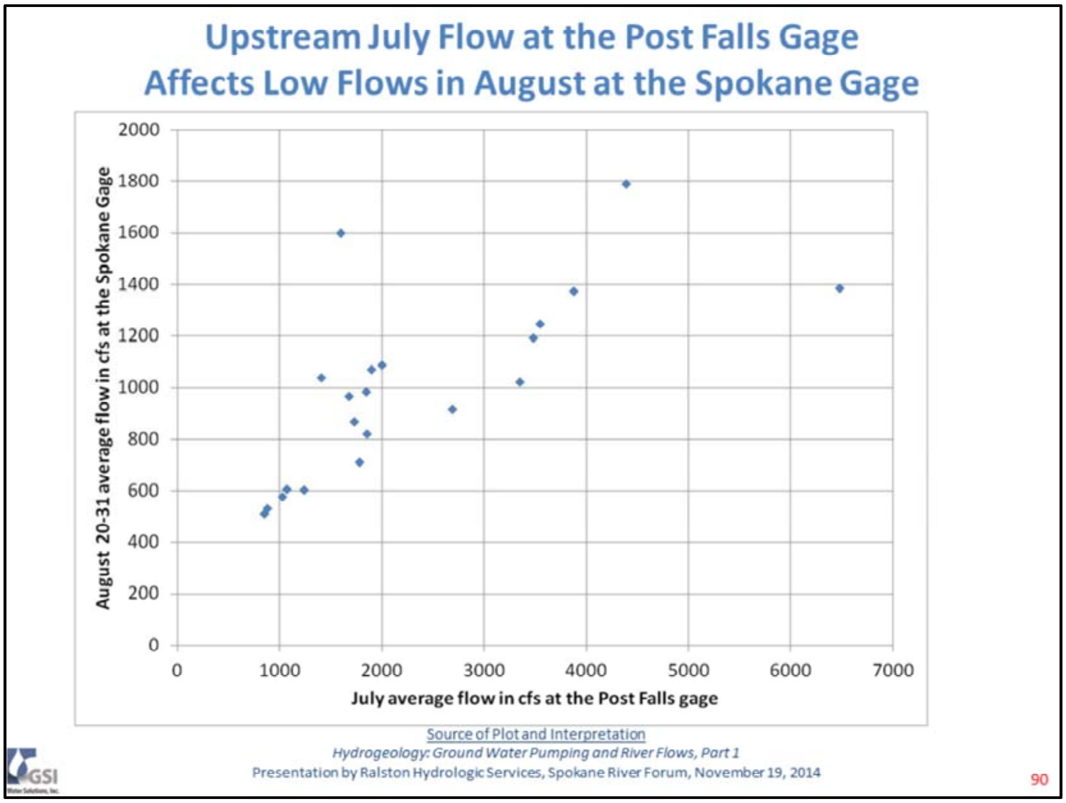
Our eyes can make out an apparent downward trend in mean daily August flows at both river gages, plus a possible downward rainfall trend, during two time periods: prior to about 1995, and from about 1998 through 2004. Sharp rises in all curves are visible in 1995 through 1997, and a modest rise is visible in all curves from about 2005 through 2012, followed by a leveling off and subsequent decreasing trend during the past 2 to 3 years.



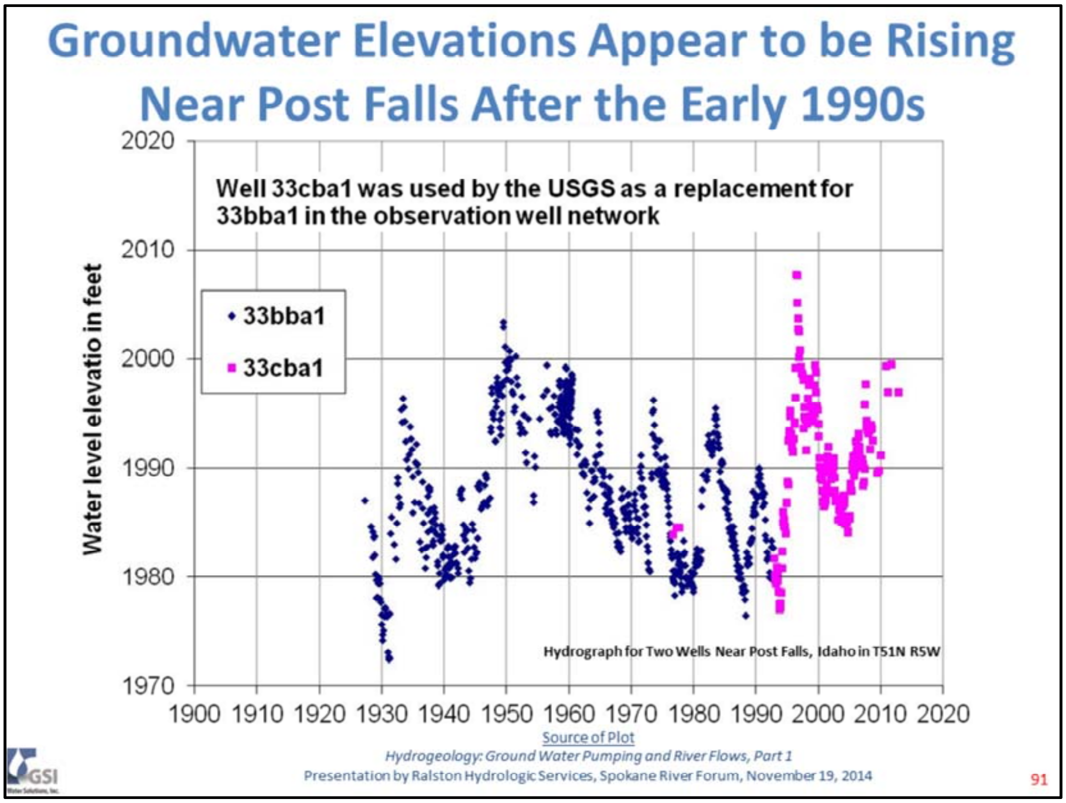
Let's go back to the scaled plots (which add the annual average lake stage), and let's zoom in on the past 35 years.



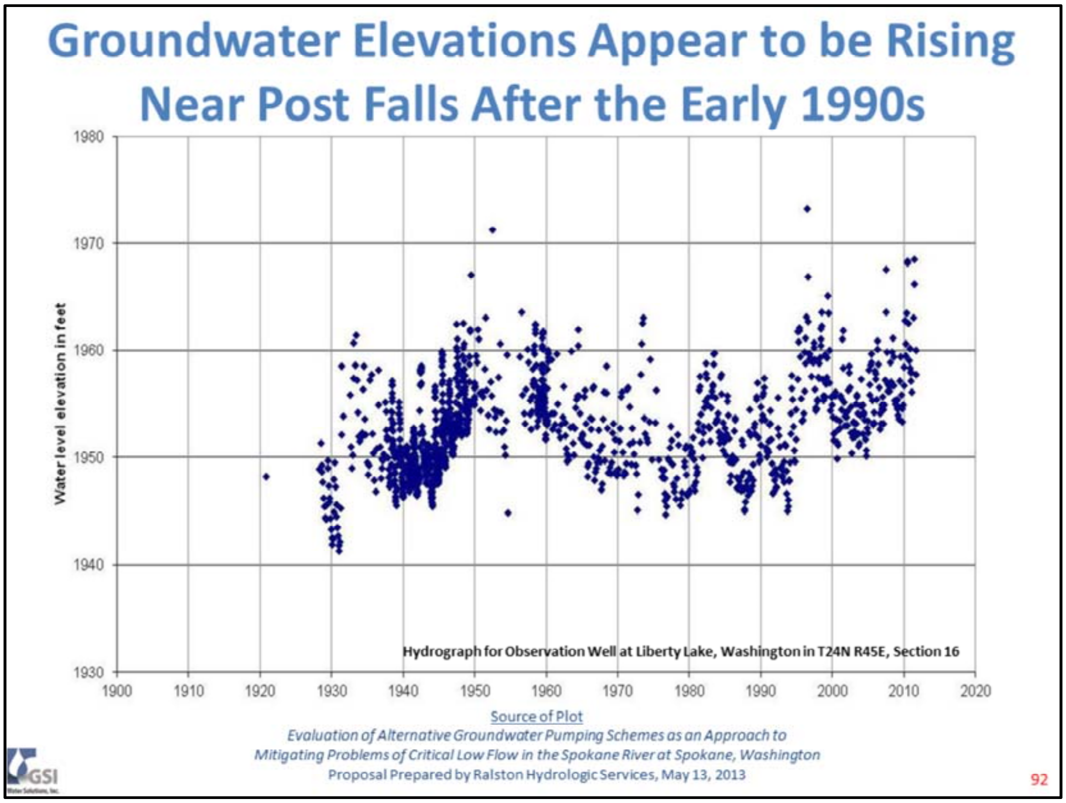
The lake level trends track the trends in annual precipitation and mean daily August river flow reasonably well. The plot shows three distinct time periods hydrologically, particularly when considering the precipitation trends. Of particular significance is the observation that substantial precipitation events from 1995 through 1997 interrupted a prior downward trend in mean daily August river flows. Afterwards, the mean daily August river flows resumed their downward trend, then experienced a modest overall rise from 2005 through 2012, followed by another decline. But large-scale / high-magnitude events such as that of 1995 through 1997 have not occurred since that time. The mean daily August river flows are declining in spite of an improvement and stabilization of conditions within the "river-aquifer" bucket (see slides 78 through 85), which indicates that the ambient hydrology of the contributing watershed is the primary driver for the continued long-term declines that appear to be continuing for seasonal low river flows at both gaging stations. Additionally, although lake stage management during August can affect the seasonal low flows (see slides 70 and 71), that relationship actually appears to be a manifestation (outcome) of watershed conditions, rather than a controlling process unto itself.



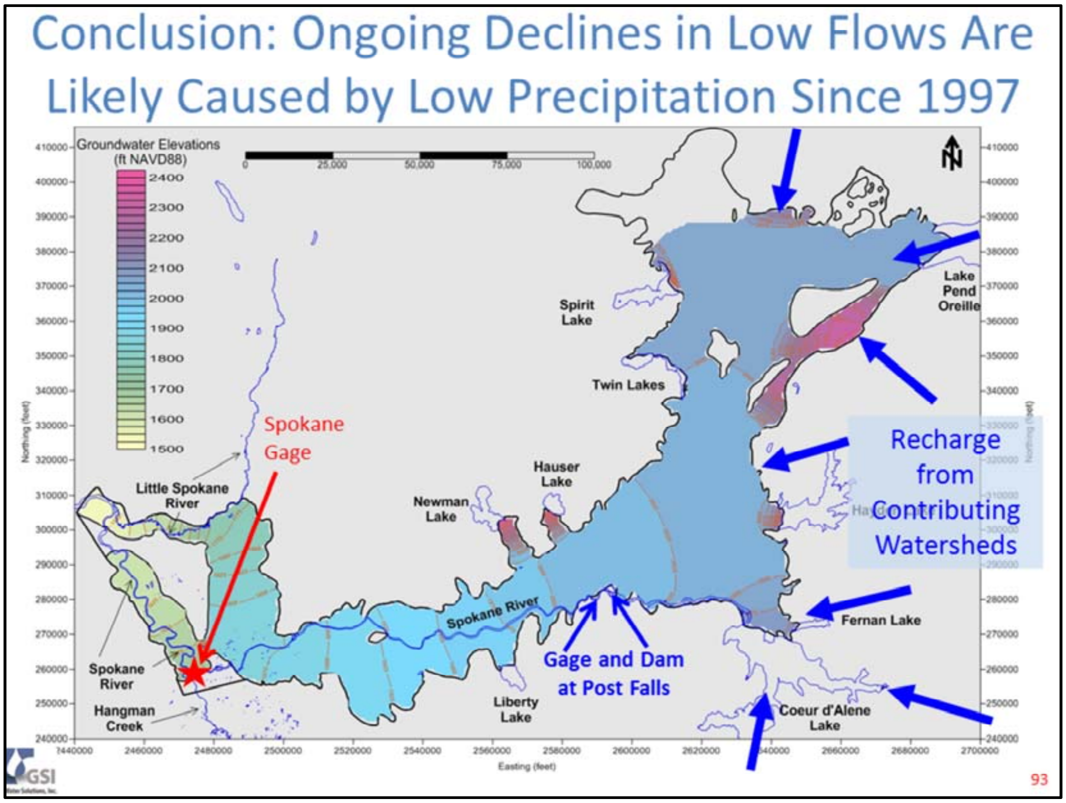
The conclusion that watershed conditions are affecting seasonal low flows is consistent with an interpretation made by Dr. Dale Ralston in 2014. Dr. Ralston noticed that seasonal low flows at the Spokane Gage (in late August) appear to be related to the magnitude of July flows at Post Falls, as shown on this plot that he prepared for the Spokane River Forum conference that was held in November 2014. This plot and Dr. Ralston's discussions of this plot at the conference focused on how antecedent conditions prior to late August likely play a significant role in determining the magnitude of late August flows in any given year at the Spokane Gage.



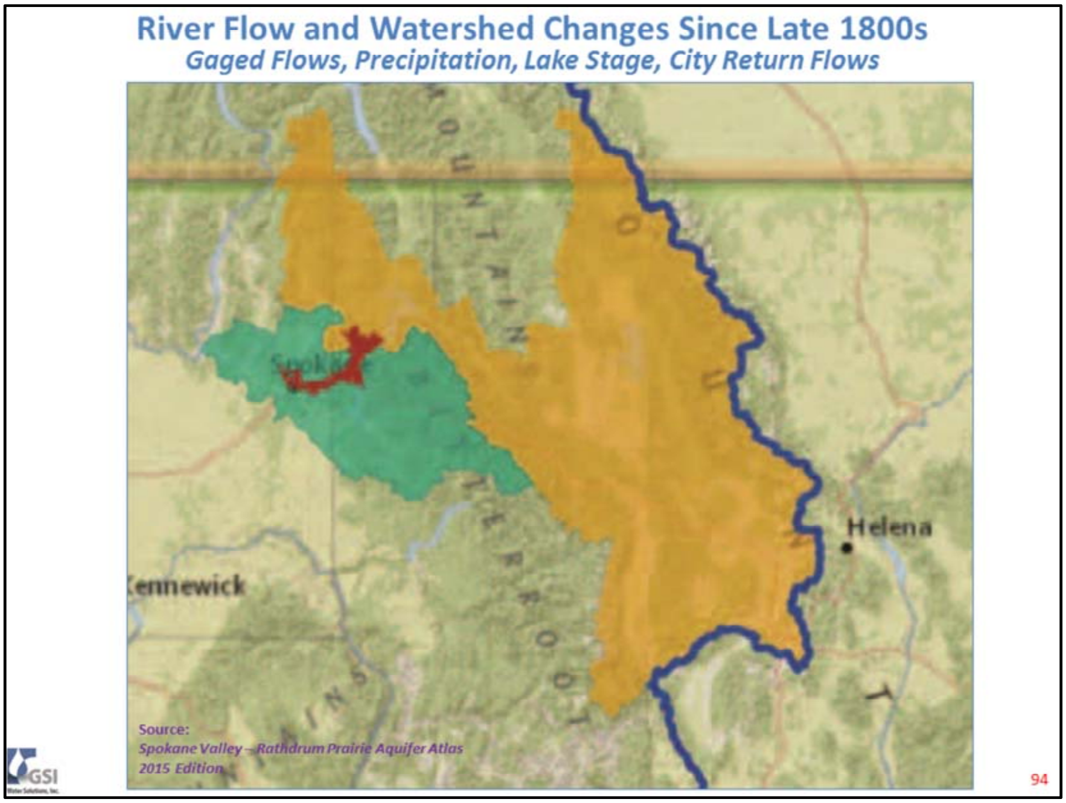
Dr. Ralston also prepared plots of historical groundwater elevations in the SVRP at two locations near the river (near Post Falls and at Liberty Lake). This plot shows a long-term groundwater elevation monitoring record at a well cluster near Post Falls. The plot shows that groundwater elevations have been higher during the past 15 to 20 years (i.e., after the early to mid 1990s) than was the case during the two decades before that.



Dr. Ralston's similar plot for a groundwater level monitoring well near Liberty Lake shows a similar upward trend beginning after the mid 1990s. This groundwater elevation hydrograph and the prior hydrograph (slide 91) together provide further indication that water use and hydrologic conditions <u>within</u> the "river-aquifer bucket" itself (downstream of the Post Falls Gage) are not the cause of the continued decline in seasonal low flows in the Spokane River at either the Spokane Gage or the Post Falls Gage, and that the primary cause of the declines can be attributed to conditions "upstream" of the bucket (through lake management processes and/or, more significantly, hydrologic conditions in the contributing watershed to Coeur d'Alene Lake).



GSI's primary conclusion from this study is that the apparent continued decline in the Spokane River's seasonal low flows is the result of hydrologic conditions in the contributing watershed upstream of the river. The hydrologic processes in the upstream contributing watershed that could be affecting lake levels and river flows are likely to be one or more of the following: rainfall volumes and timing, snow accumulation volumes, the timing of snowmelt runoff, air temperatures, and water temperature. Additionally, it is possible that the influence of the upstream contributing watershed on seasonal low river flows is not just limited to Coeur d'Alene Lake and its contributing watershed, but also may involve Lake Pend Oreille and its much larger watershed.



As shown by this map, the SVRP aquifer (in red) is a relatively small area lying within a much larger adjoining contributing watershed. Note too the even larger size of the watershed (shown in orange) that contributes hydrologically to Lake Pend Oreille.

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

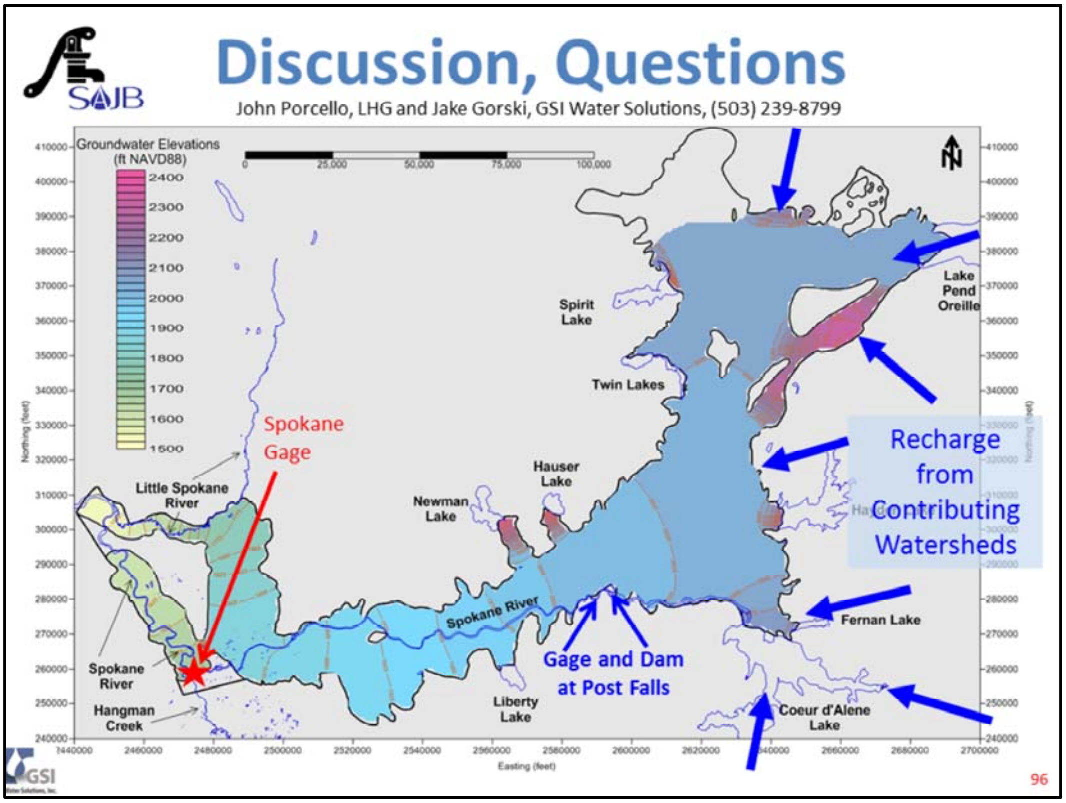
Processes Within the River-Aquifer System	Processes Upstream of the River-Aquifer System
~~Past agricultural diversions from river~~ ~~*(direct diversions, little return flow)*~~ ~~*(high consumptive use)*~~	Water level management at CDA Lake (indirectly)
Groundwater use - Washington (no) - Idaho (minor)	**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.

95

In summary:

1. Climate and runoff in the watershed that feeds the headwaters of the Spokane River are likely the primary causes of the apparent declines in seasonal low flows that have continued since agricultural diversions ended in 1965.
2. Water level management at Coeur d'Alene Lake may also play a role, but is itself affected by (and controlled by) antecedent conditions in the contributing watershed.
3. Groundwater use is not the cause of the declining seasonal low flows. Water use has not increased in the Washington portion of the SVRP since at least the late 1990s, and the 10 cfs of increased water use from the SVRP in Idaho since the late 1990s is small compared with the amount of decline that has occurred in seasonal low flows.
4. Diversions of water around the Spokane Gage (in the form of indoor water uses that are returned to the river at the City of Spokane water reclamation facility) affect the amount of water in the river downstream of the Spokane Gage. However, these return flows do not explain the trends in (a) measured river flows at the Spokane Gage or (b) estimated flows downstream of the water reclamation facility, because (as with water use) these return flow volumes are not increasing over time.


Discussion, Questions
John Porcello, LHG and Jake Gorski, GSI Water Solutions, (503) 239-8799
Groundwater Elevations (ft NAVD88)
Spokane Gage
Little Spokane River
Spokane River
Hangman Creek
Newman Lake
Hauser Lake
Spirit Lake
Twin Lakes
Lake Pend Oreille
Recharge from Contributing Watersheds
Fernan Lake
Gage and Dam at Post Falls
Liberty Lake
Coeur d'Alene Lake
Easting (feet)
Northing (feet)
96