Summary Presentation

Spokane River Low-Flow Trends

Causes of Low-Flow Trends and the Role of Groundwater Pumping and Water Demands

Prepared for

Spokane Aquifer Joint Board

Prepared by

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GSI Water Solutions

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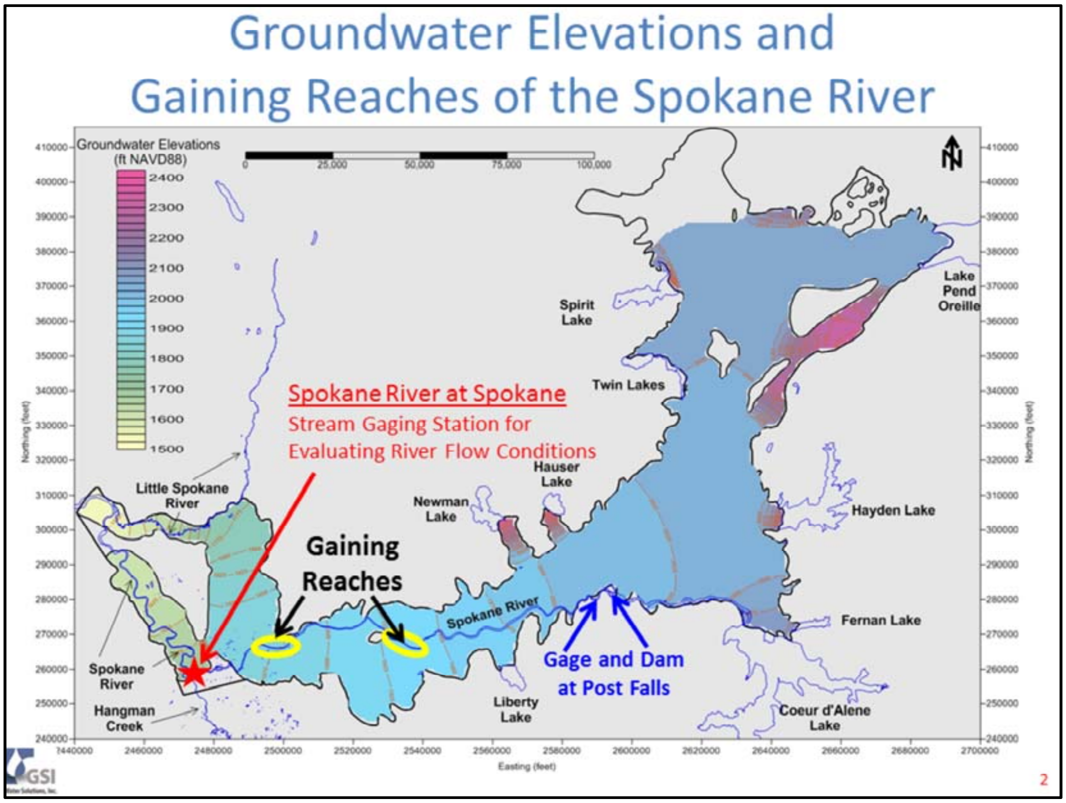
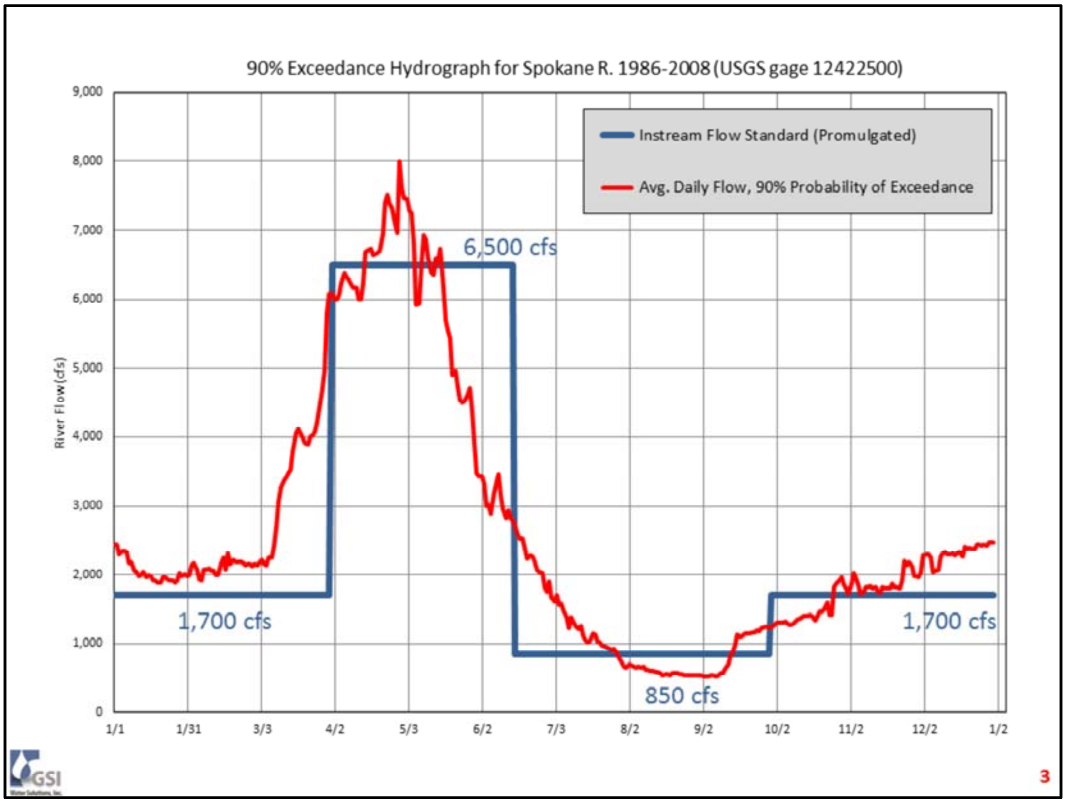
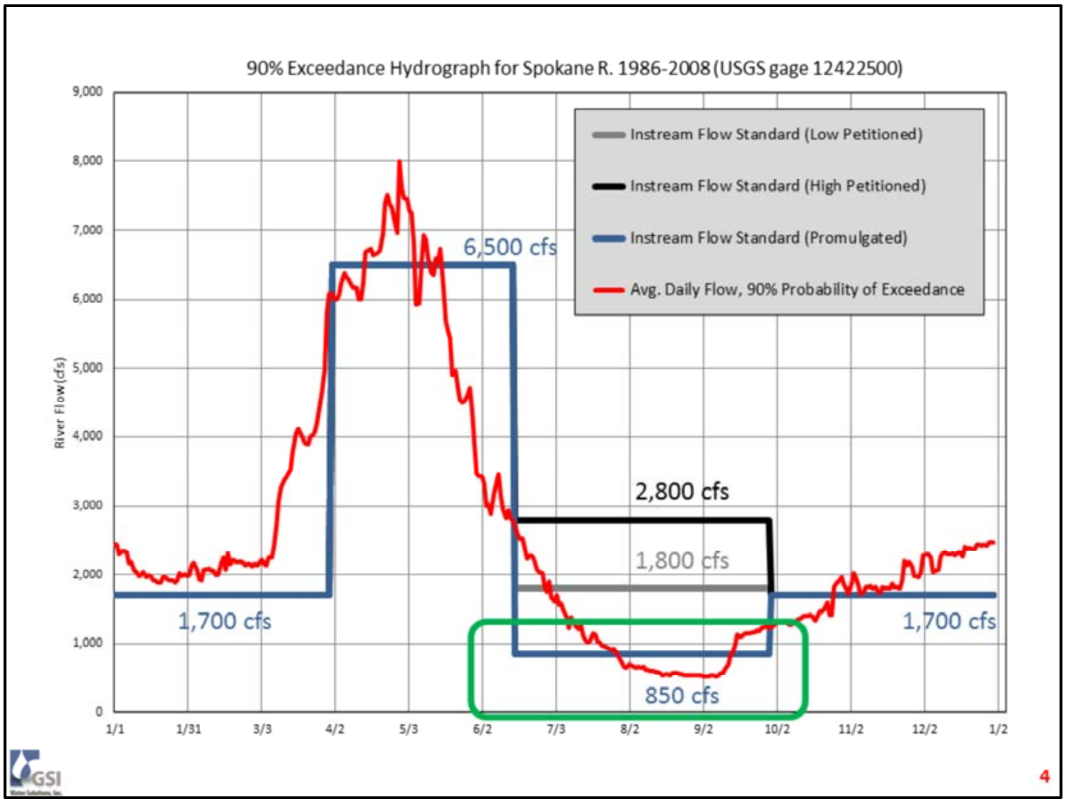


This presentation summarizes a body of work by the SAJB to evaluate historical and recent changes in the seasonal low flows of the Spokane River, as measured at two USGS stream flow gaging stations with long-term records: the Spokane Gage at Spokane (in downtown Spokane) and the Post Falls Gage (located just downstream of Post Falls Dam). The role of groundwater in the Spokane Valley – Rathdrum Prairie (SVRP) Aquifer also will be discussed, particularly with regards to trends in groundwater levels and the degree to which groundwater inflows to the river in two gaining reaches are affected by summer-season increases in groundwater pumping to meet urban and agricultural water demands.

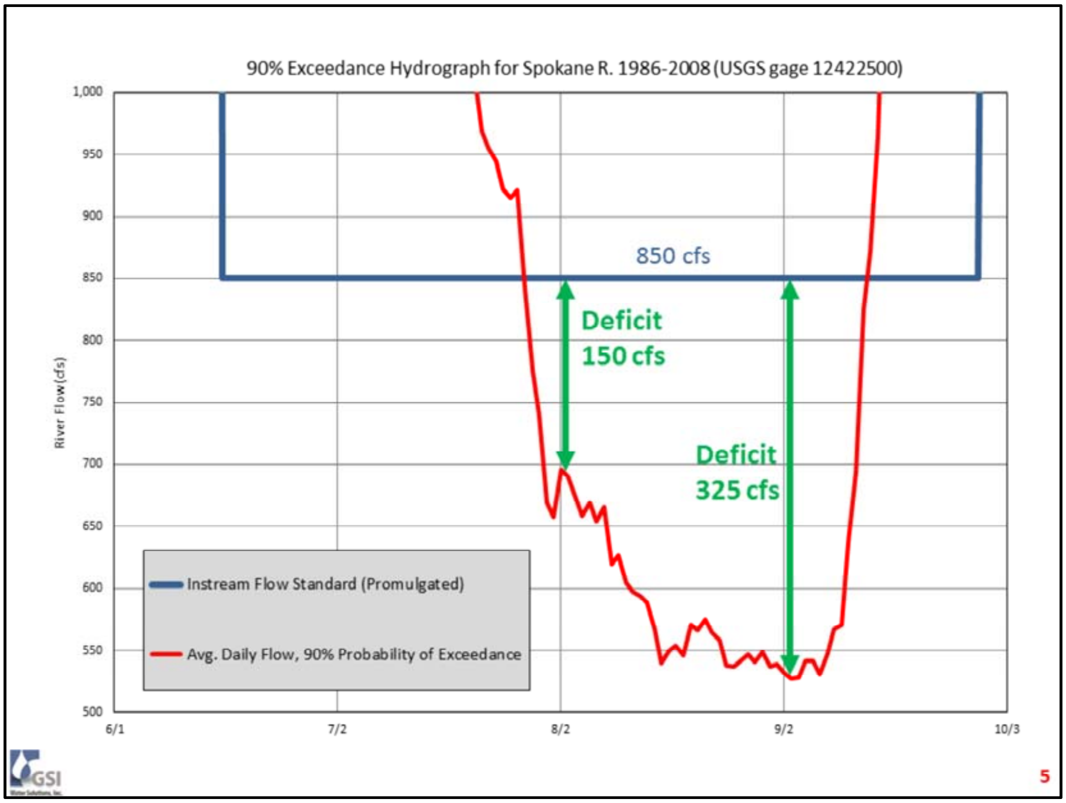


In recent years, much attention and discussion has occurred in the water resources community regarding seasonal low flows in the Spokane River, and the Washington Department of Ecology (Ecology) recently promulgated instream flow standards for flows at the Spokane Gage throughout the year. The red line 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].)

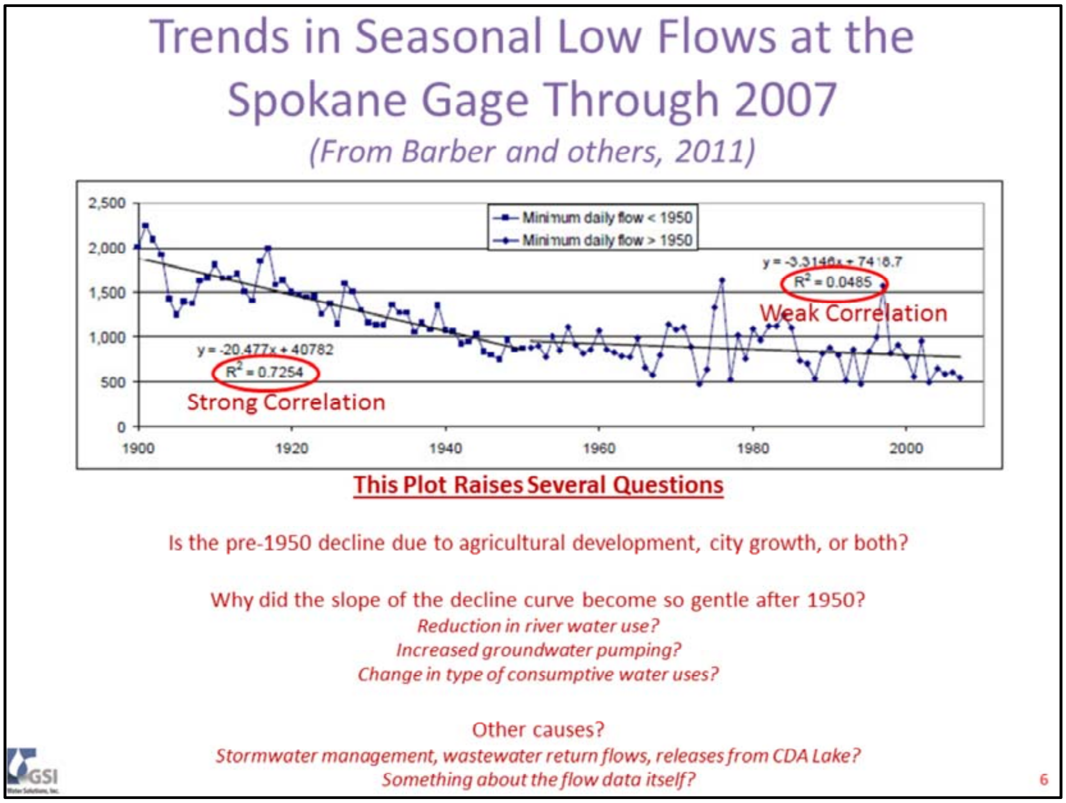


On February 29, 2016, the Western Environmental Law Center and CELP filed a petition with Ecology requesting that the instream flow standard be modified to be a minimum of between 1,800 and 2,800 cfs during the summer months, for the protection of trout and whitefish species. Those petitioned standards are shown in gray and in black.

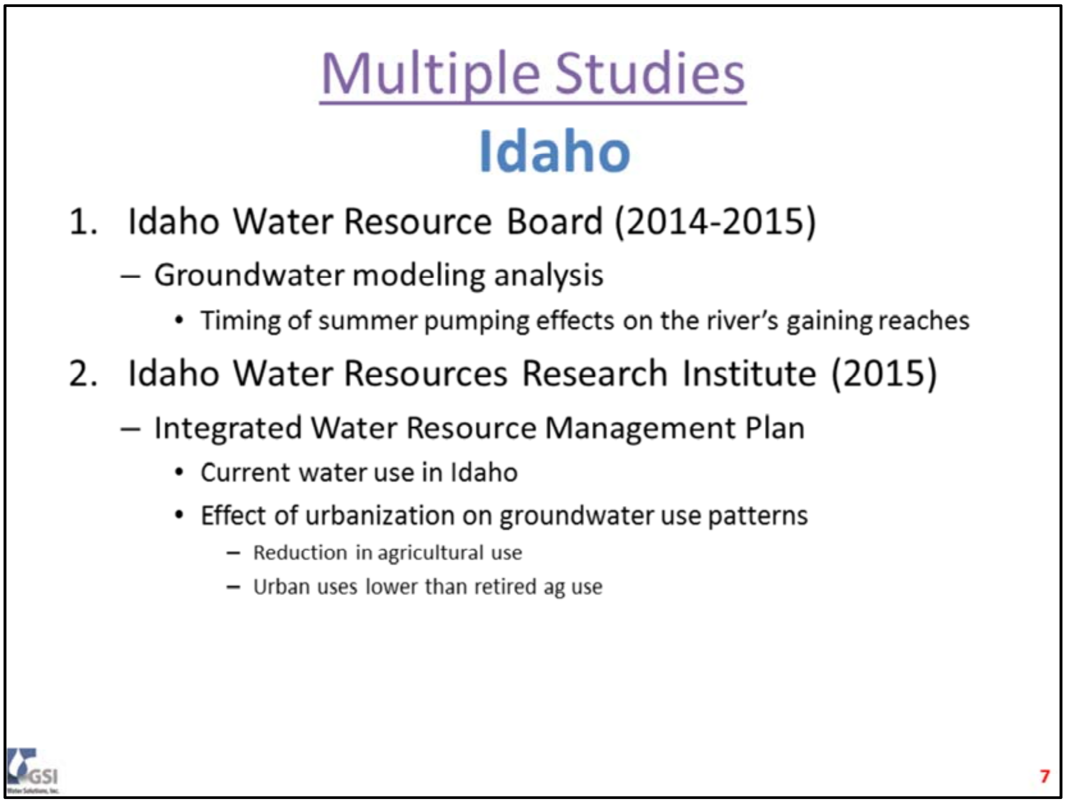
Let's zoom in on this plot to take a closer look at the seasonal low flows and the promulgated instream flow standard during the period shown in the green box.



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.



Recent discussions about river low flows have also arisen as a result of a study by Washington State University that included this plot of the lowest day flow at the Spokane Gage for each year between 1900 and 2007. 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.



Studies and documents conducted in the Idaho portion of the SVRP provide important information on the same topics that SAJB has evaluated in the Washington portion of the SVRP. This slide lists those efforts.

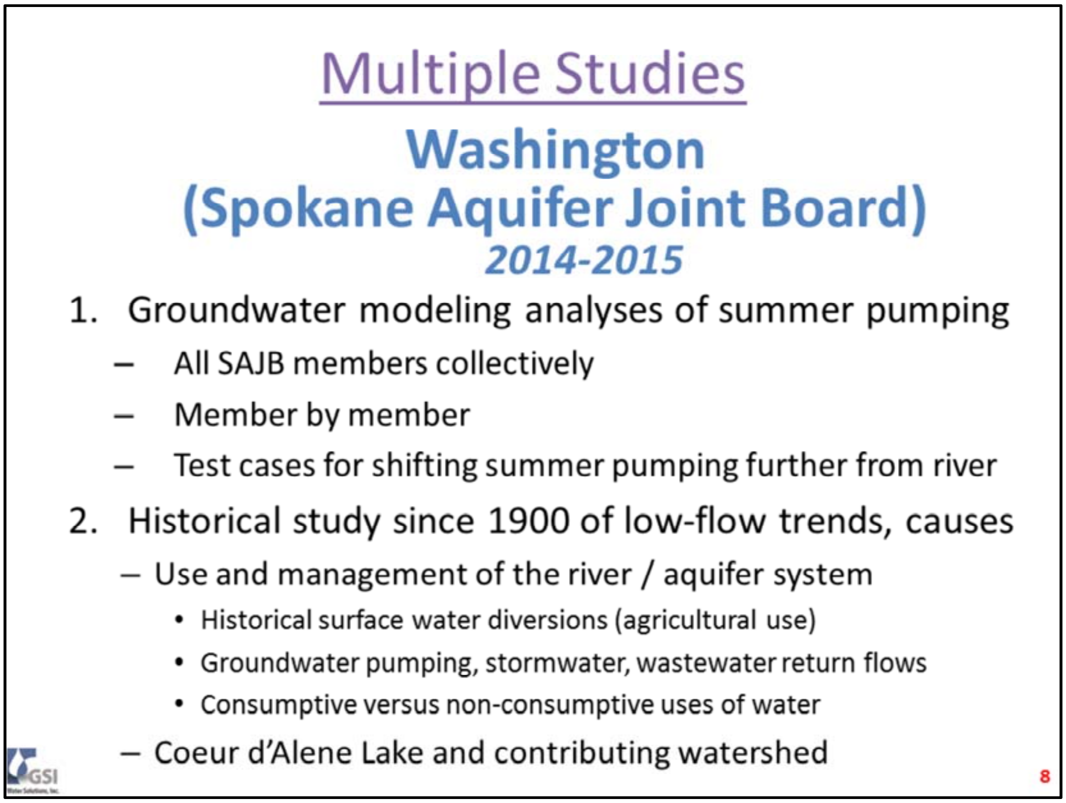
Citations for 2014-2015 work by Idaho Water Resource Board:

Ralston Hydrologic Services. 2014. *Hydrogeology: Ground Water Pumping and River Flows, Part 1.* Presentation prepared for the 2014 Spokane River Forum Conference. Presentation by Dale R. Ralston PhD, PE, PG. November 19, 2014.

Ralston Hydrologic Services. 2015. *Evaluation of Alternative Groundwater Pumping Schemes as an Approach to Mitigating Problems of Critical Low Flow in the Spokane River at Spokane, Washington.* Report prepared for the Idaho Water Resource Board. Prepared by Dale R. Ralston PhD, PE, PG and Gary S. Johnson, PhD, PE. April 2015.

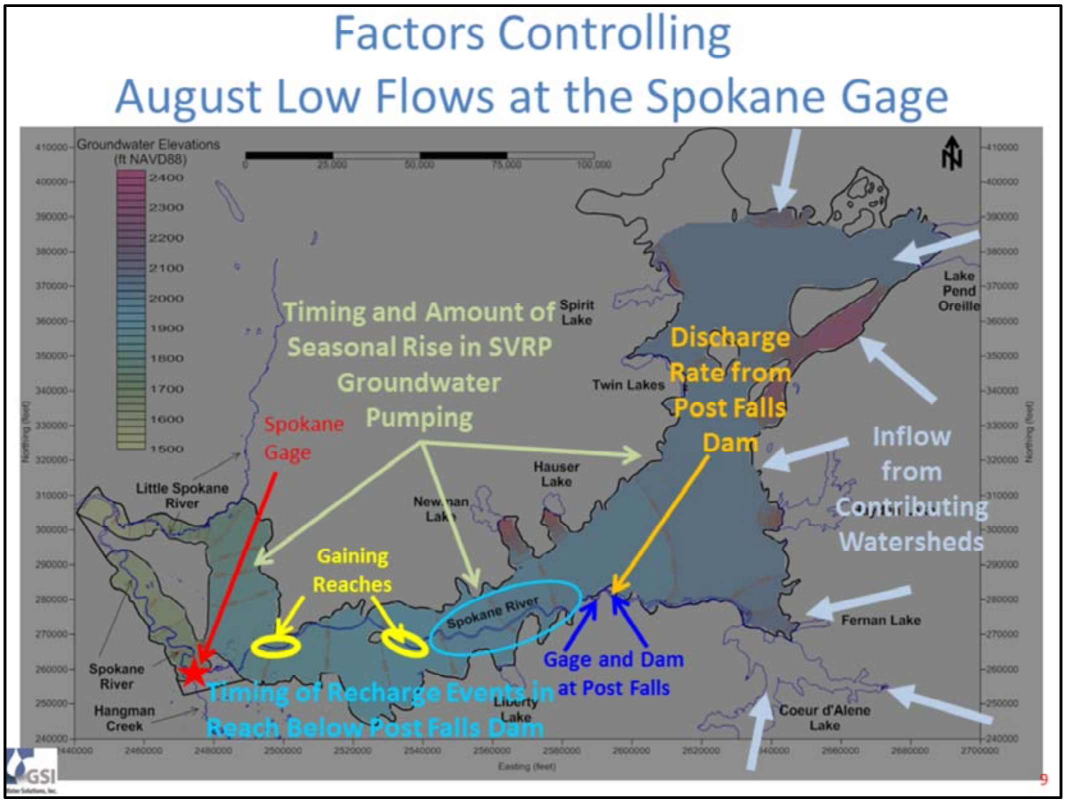
Citation for 2015 work by Idaho Water Resources Research Institute:

Solomon, M. 2015. *Rathdrum Prairie Integrated Water Resource Management.* Idaho Water Resources Research Institute Report #201501. September 25, 2015.



SAJB has conducted a series of work efforts that – like the Idaho efforts – have evaluated groundwater pumping effects on the river and the changes in water demands and sources over time. Those efforts have also considered the role of Coeur d'Alene Lake and the upstream contributing watershed to the lake. Those studies and the presentations describing them are as follows:

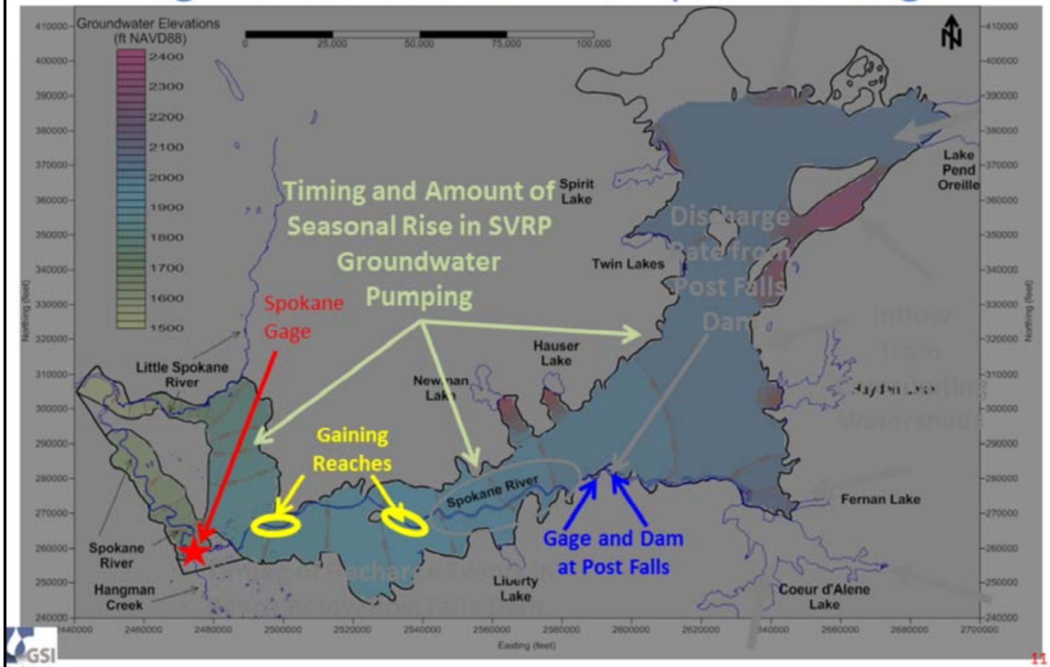
- April 2014 presentation titled *Screening-Level Analysis: Influence on Spokane River Flows of Hypothetical Pumping Relocation Scenarios, Using the City/SAJB Groundwater Flow Model.* April 24, 2014.
- December 2015 presentation titled *Screening-Level Analysis: Causes of Historical Changes in Seasonal Low Flows in the Spokane River.* December 3, 2015.
- March 2016 presentation titled *Watershed Hydrology and Historical Changes in Seasonal Low Flows in the Spokane River.* March 3, 2016.



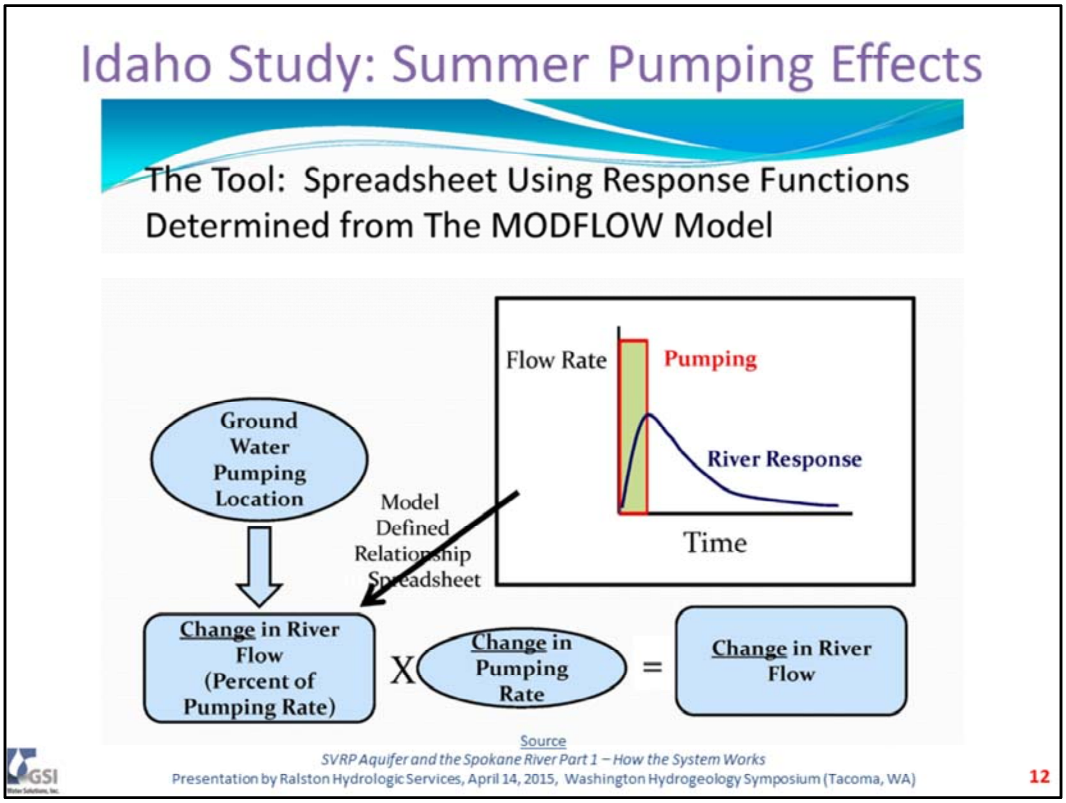
GSI's work for the current (2015-2016) study finds that there are four factors controlling the seasonal low flows of the Spokane River.

Two of those factors have been the primary focus of the SAJB studies over the past two years. These are the focus of the remainder of this presentation.

Role of Pumping on August Low Flows at the Spokane Gage



Let's focus on the groundwater factor first.

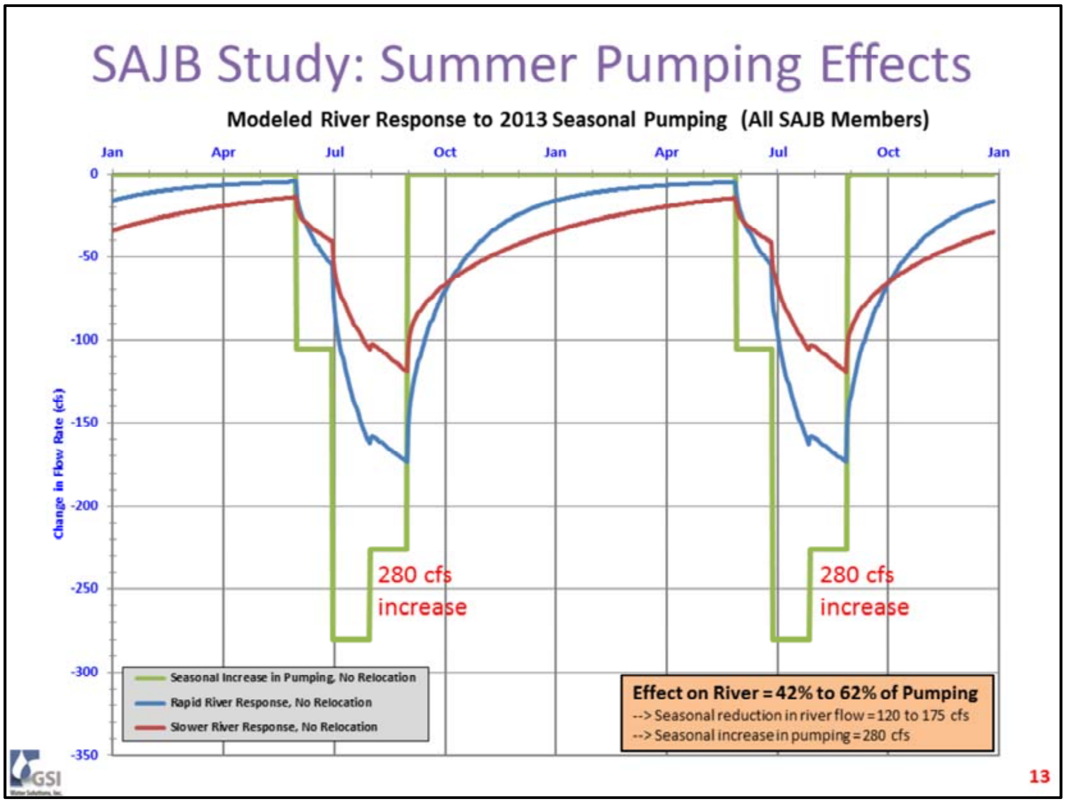


Using the Bi-State Model (Hsieh and others, 2007), Ralston Hydrologic Services (2015) developed an Excel spreadsheet tool that allows a user to vary pumping at a specific location for a finite duration of time, and then obtain an estimate of the timing and amount of change in the flow of the Spokane River at the Spokane Gage. The change in river flow is based on model simulations of the change in groundwater discharges to the river.

Citations:

Hsieh, P.A., Barber, M.E., Contor, B.A., Hossain, Md. A., Johnson, G.S., Jones, J.L., and A.H. Wylie. 2007. *Ground-Water Flow Model for the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho.* U.S. Geological Survey Scientific Investigations Report 2007-5044, 78 p.

Ralston Hydrologic Services. 2015. *Evaluation of Alternative Groundwater Pumping Schemes as an Approach to Mitigating Problems of Critical Low Flow in the Spokane River at Spokane, Washington.* Report prepared for the Idaho Water Resource Board. Prepared by Dale R. Ralston PhD, PE, PG and Gary S. Johnson, PhD, PE. April 2015.



In 2014, GSI Water Solutions conducted numerical modeling to evaluate changes in river flow that arise from the summer-season increase in groundwater pumping that occurs by SAJB members to support urban outdoor uses of water. The model used 2013 pumping data. As shown in this plot, for the collective group of SAJB members, pumping during June, July, and August (shown in green) increased to a July peak-month average rate that is 280 cfs higher than the year-round baseline pumping for indoor water use purposes. The effect of this pumping increase on river flows is shown by the blue and dark red lines, which represent two different model simulations that use a range of values for the specific yield of the unconfined aquifer (0.10 for the blue line, and 0.30 for the dark red line). As shown in the box in the lower right corner of the plot, the decrease in river flows arising from the peak-season pumping increases to as much as 42 to 62 percent of the peak pumping amount, but begins decreasing as soon as the outdoor-season pumping period ends.

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	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

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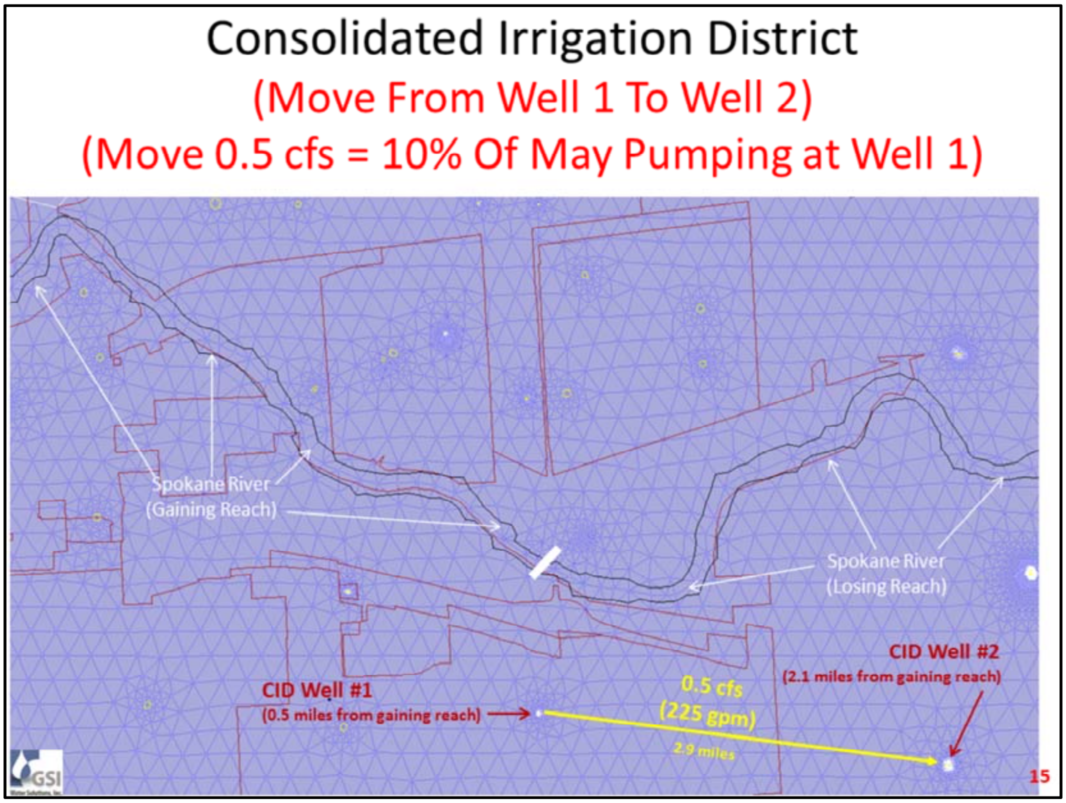
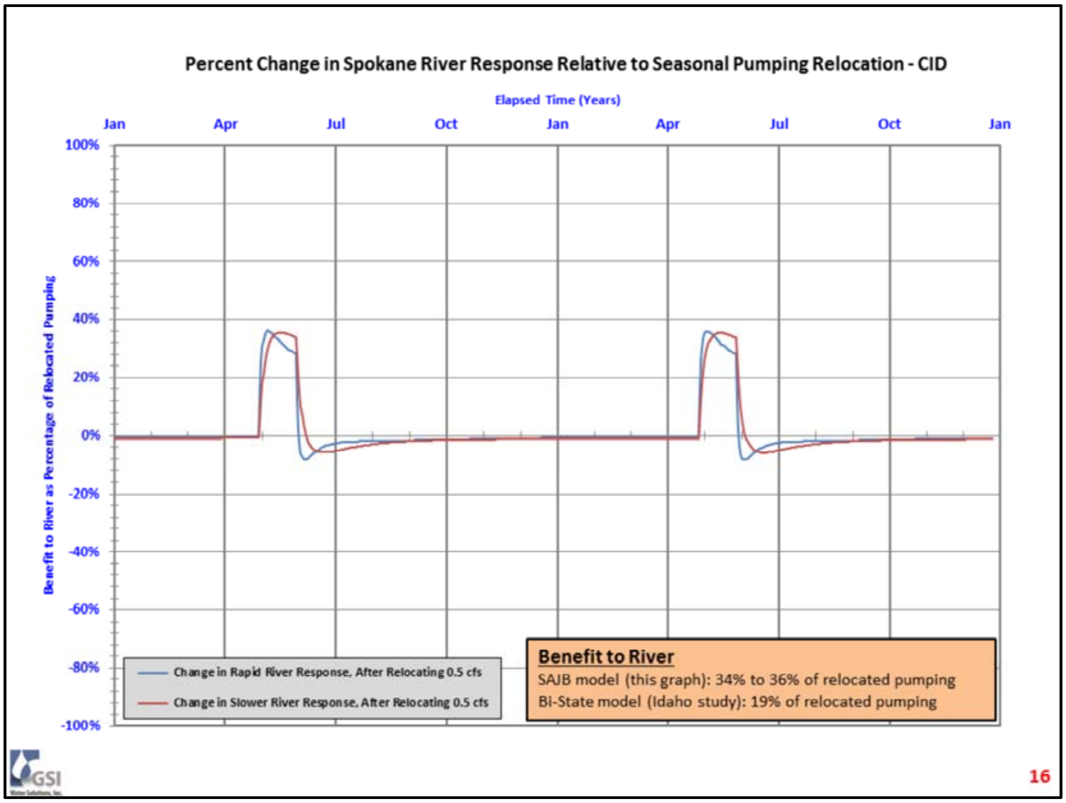
The 2014 modeling study by GSI (on behalf of SAJB) found that the peak-season pumping by several of the SAJB's individual members causes about a 35% to 65% amount of corresponding change in the river's seasonal low flows at the Spokane Gage. (See the right-hand column for the purveyors inside the blue oval.) 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).



In that same 2014 study, some SAJB members identified possible scenarios for moving certain amounts of peak-season pumping away from wells near gaining reaches of the river, and instead pumping that amount from wells farther away from gaining reaches. This example was provided by the Consolidated Irrigation District (CID). In this case, 0.5 cfs of pumping at Well #1 near the gaining reach at Sullivan Road was modeled as being pumped at Well #2 instead of Well #1 for one month. Well #2 is 3 miles west of Well #1 and the upstream end of the nearby gaining reach.



The SAJB model indicated that the scenario contemplated by CID would cause the river flow to increase by about 35% of the transferred water volume during this pumping period.

GSI also tested this in the spreadsheet tool that is coupled with the Bi-State model (as described in slide 12). That analysis estimated that CID's scenario would provide about a 19% increase in river flow.

SAJB and Idaho Studies Conclusions: Role of Groundwater Pumping

Summary

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

This Raises Two Important Questions

Is the aquifer showing sustained declines in groundwater levels?

What has happened to groundwater pumping and uses over time?

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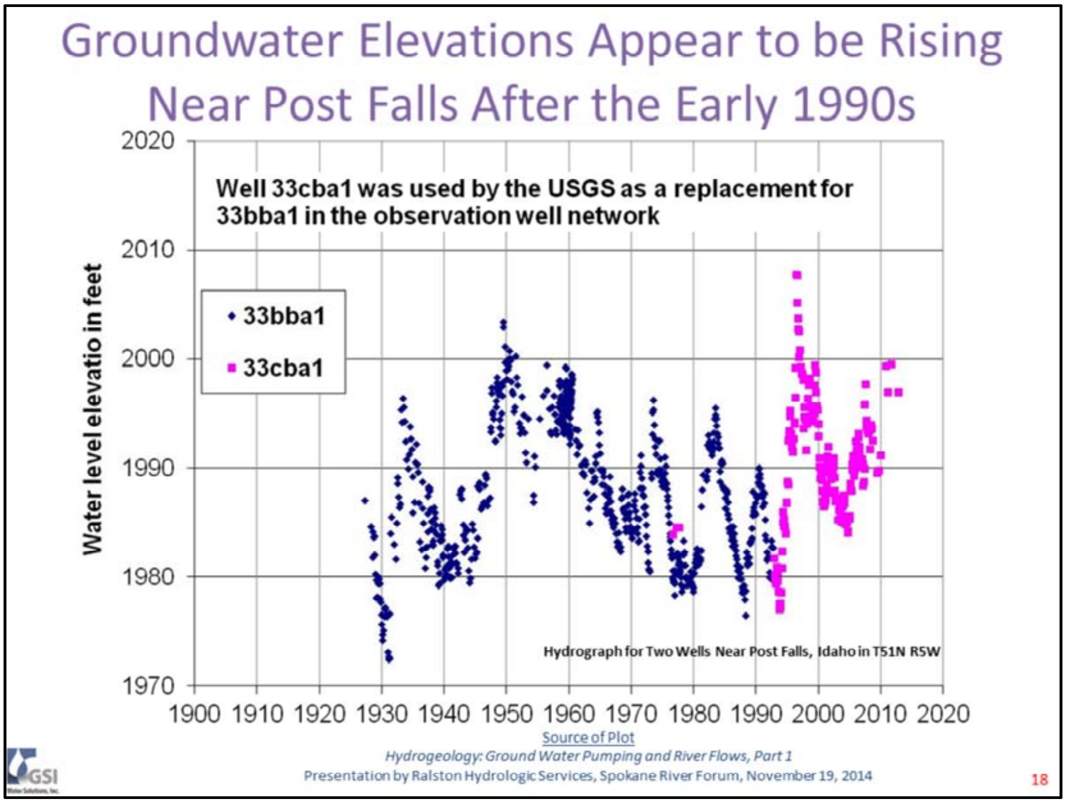
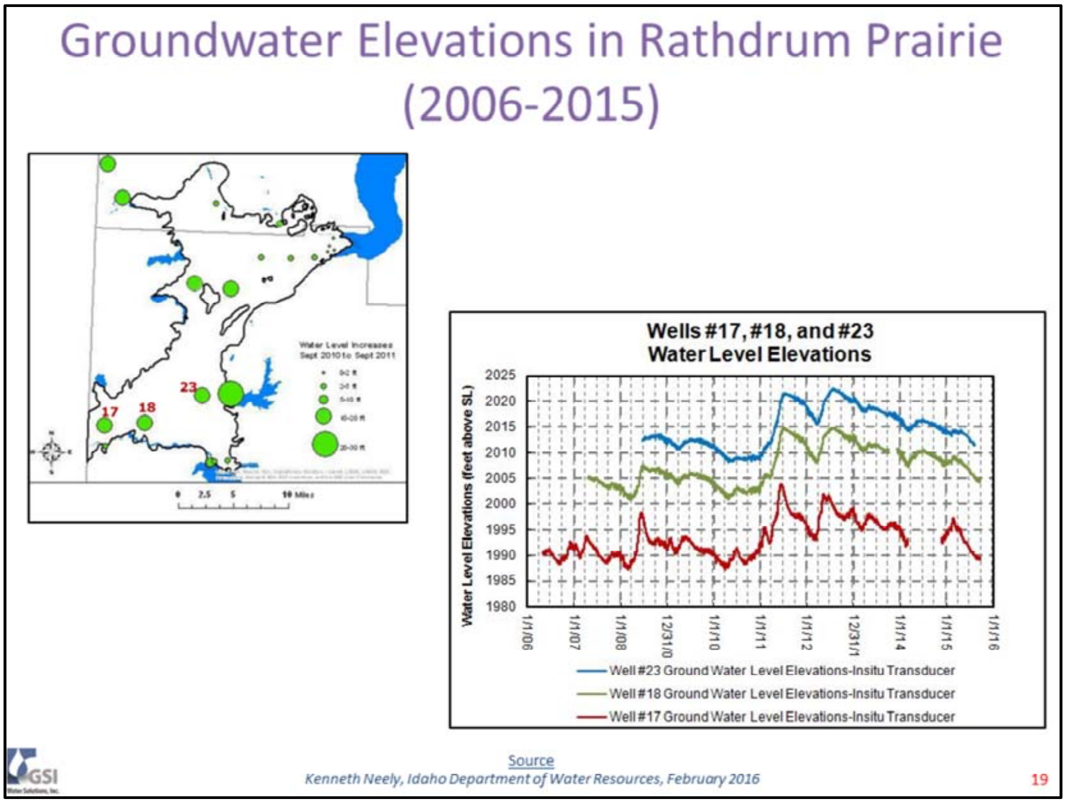
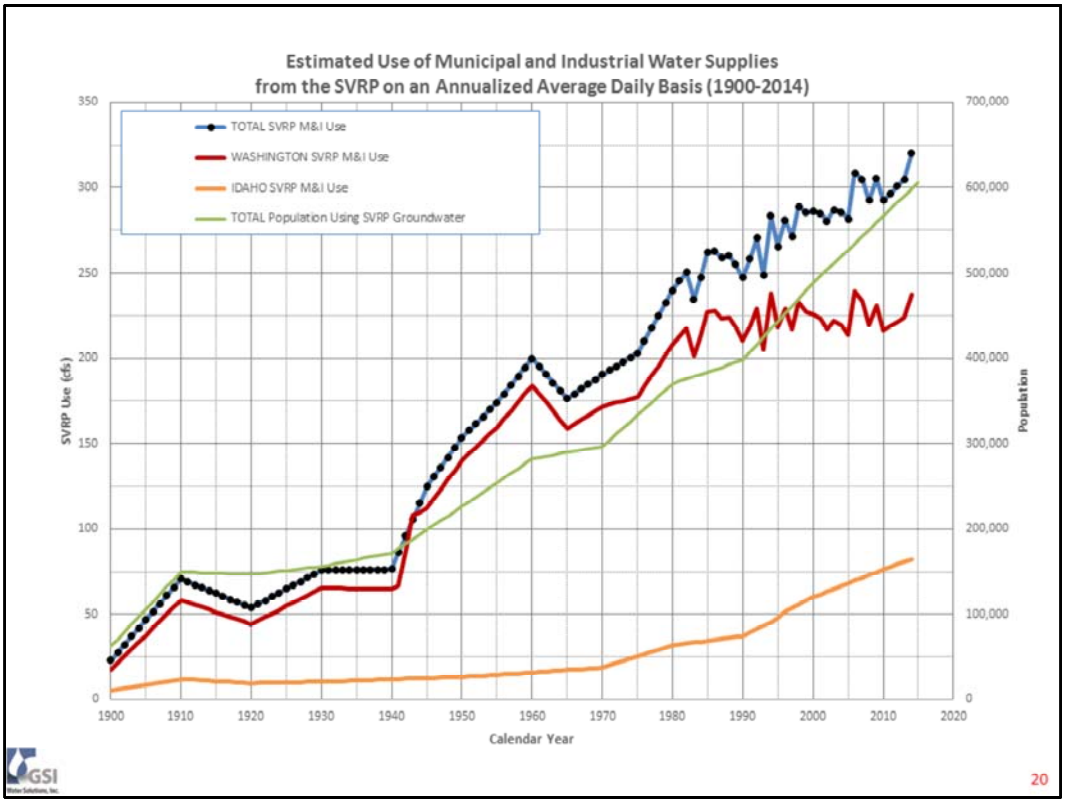


In their study work for the Idaho Water Resource Board, Ralston Hydrologic Services prepared plots of historical groundwater elevations in the SVRP at two locations near the river (near Post Falls and at Liberty Lake). This plot shows a long-term groundwater elevation monitoring record at a well pair 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.



These hydrographs show groundwater elevations at three locations in the southern Rathdrum Prairie, from 2006 through 2015. The groundwater levels in these three wells are not showing a long-term decline, but instead are showing year-over-year fluctuations according to annual variations in watershed precipitation.

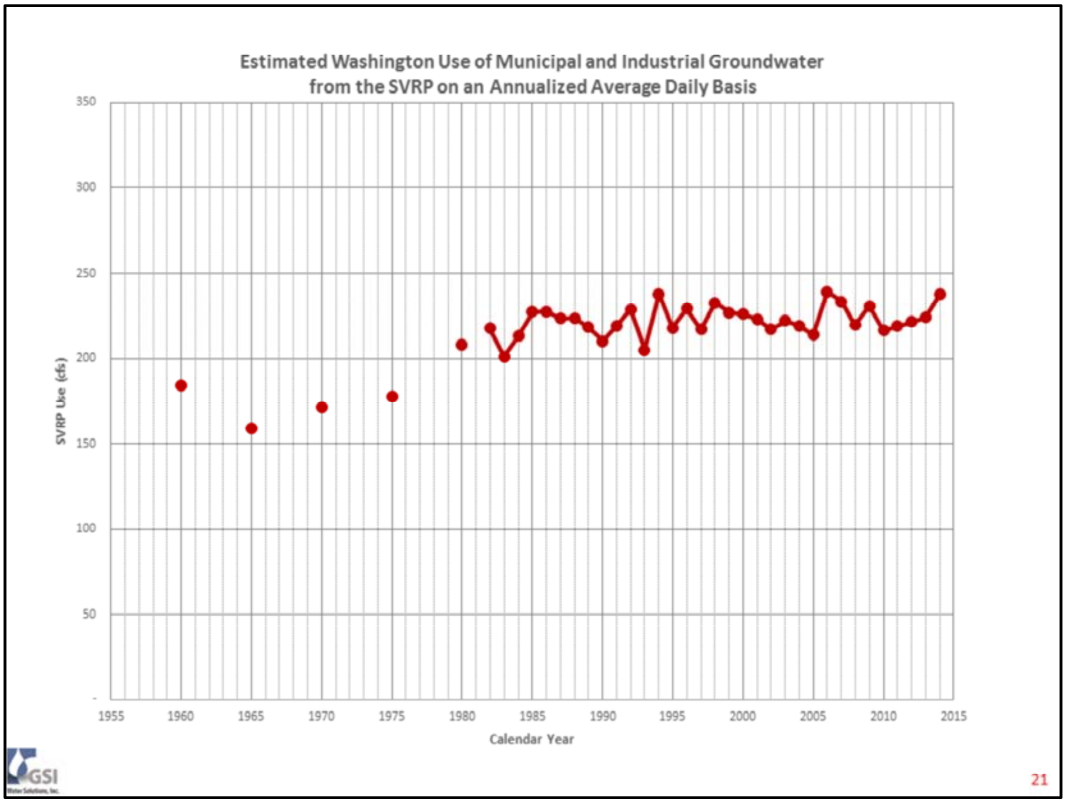


This plot shows GSI's calculations of total estimated SVRP water use since 1900; the portions of that use that occurred historically in Washington versus Idaho; and the population over time for the collective population that relied on SVRP water each year. These estimates are derived from City of Spokane groundwater production records, a 2013 water demand modeling analysis by Spokane County, water use reported for 2009 through 2013 by the Idaho Water Resources Research Institute (Solomon, 2015), and publically available census data. 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 has leveled off since the early to mid 1990s. Let's explore that recent trend in Washington in more detail in the next few slides.

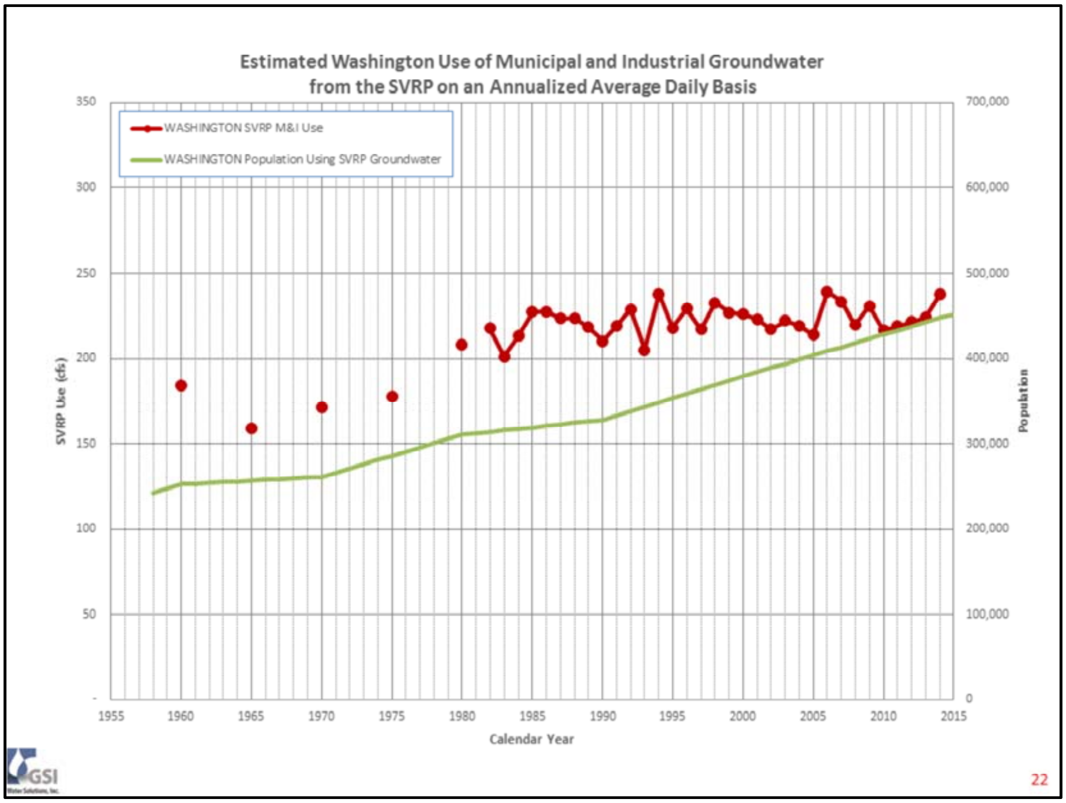
<u>Citations:</u>

Solomon, M. 2015. *Rathdrum Prairie Integrated Water Resource Management.* Idaho Water Resources Research Institute Report #201501. September 25, 2015.

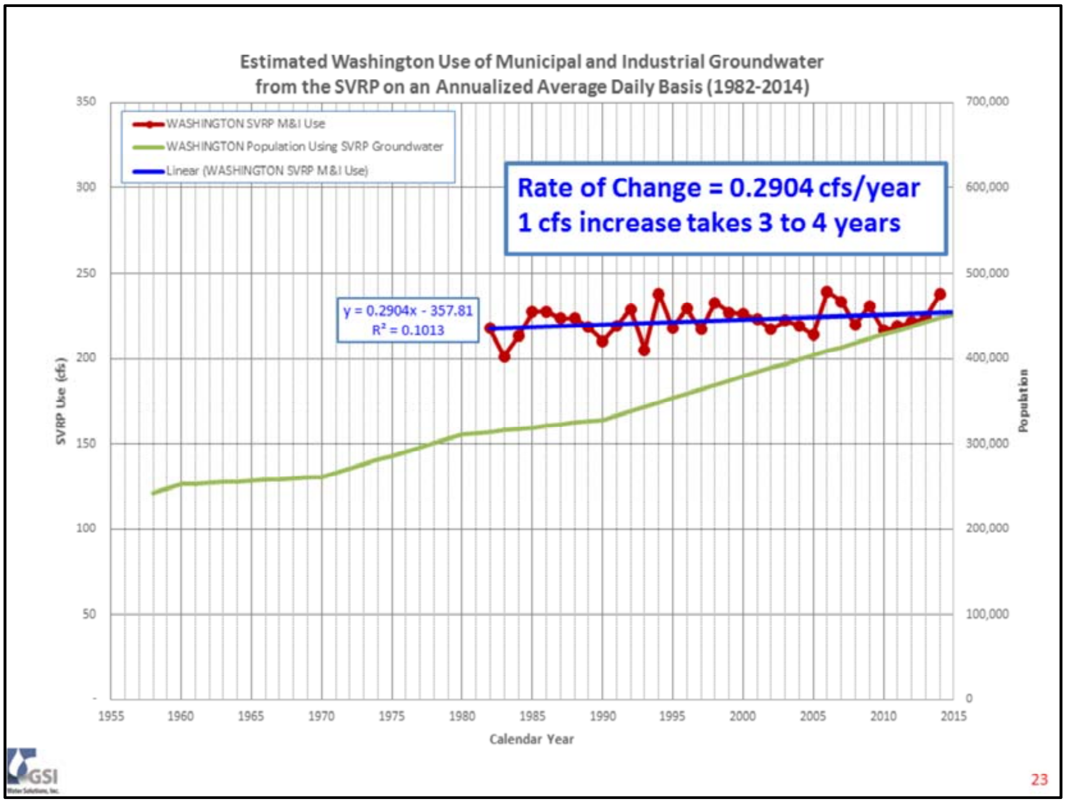
Spokane County Water Resources. 2013. *Spokane County Water Demand Forecast Model: Model 3.0 & 2013 Forecast Update.* June 2013.



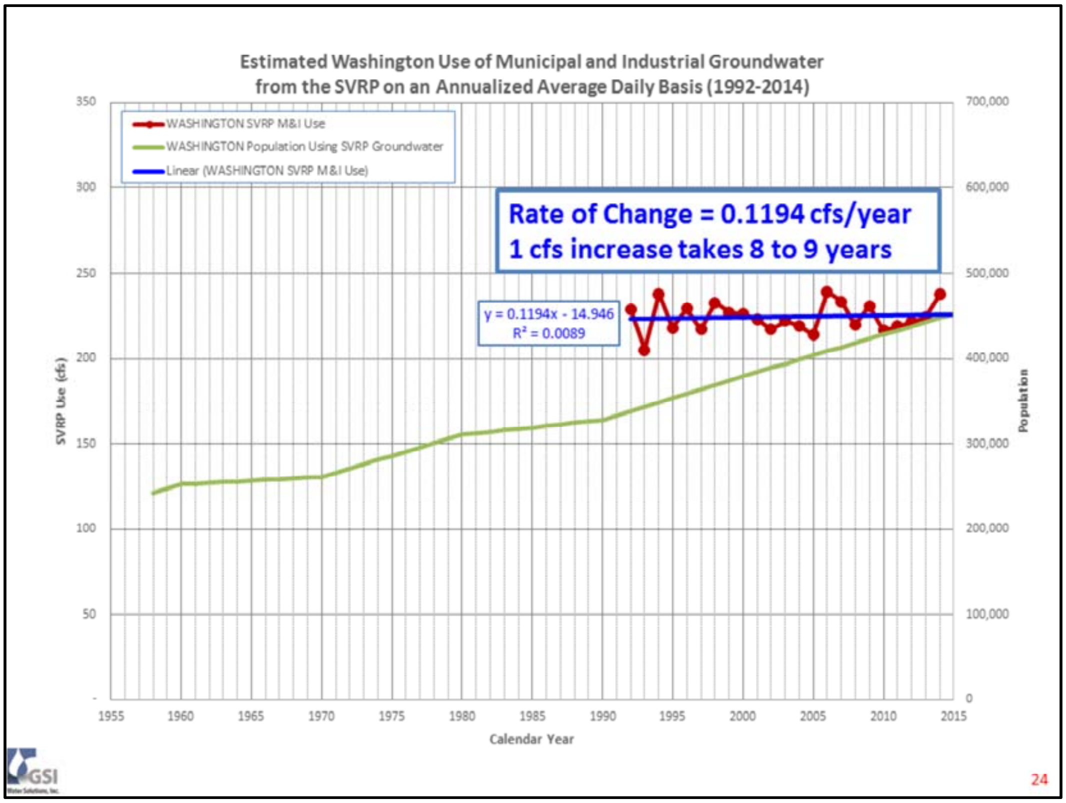
Here are the years in which we have annual water use data from the City of Spokane, and from which total pumping in Washington from the SVRP has been estimated (using the City's data, information contained in Spokane County's water demand model, and census information).



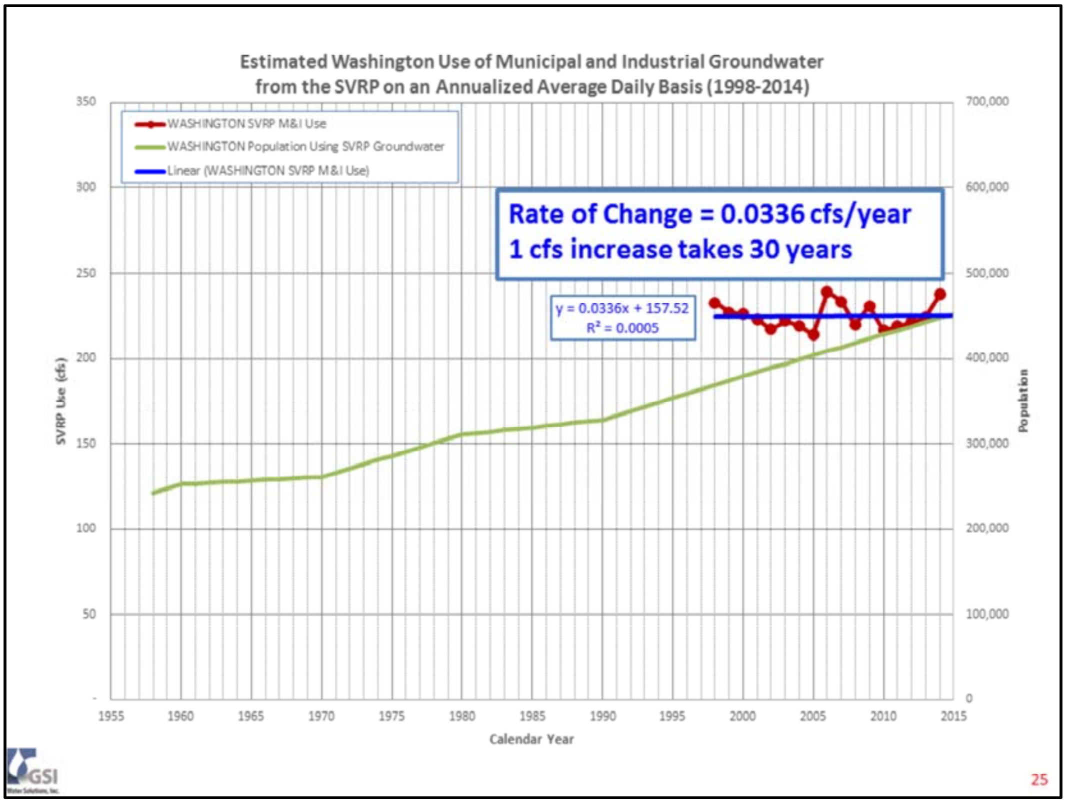
Now add population (the green line, plotted on the right-hand vertical axis).



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.

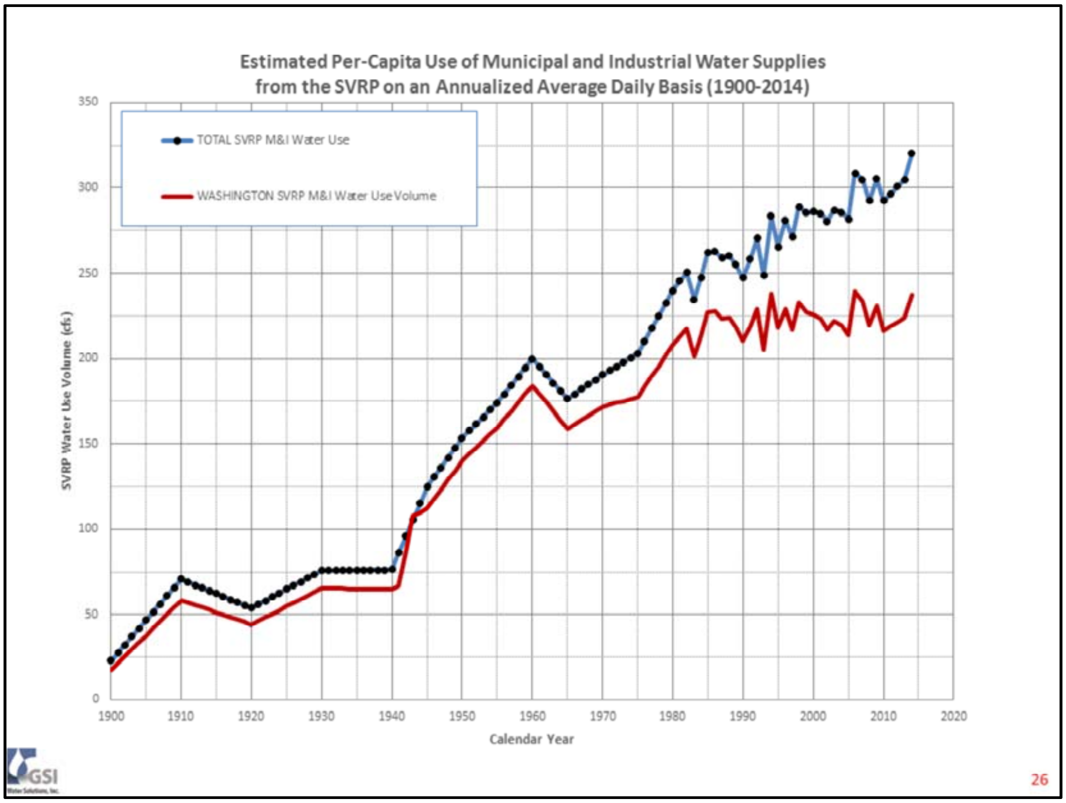


Here is a linear regression trend line for the period that starts in 1992, which is 10 years later than in the prior slide. The slope of the regression line for the 23-year period from 1992 through 2014 is 0.1194 cfs/year, which is equivalent to 1 cfs of increase every 8 to 9 years.

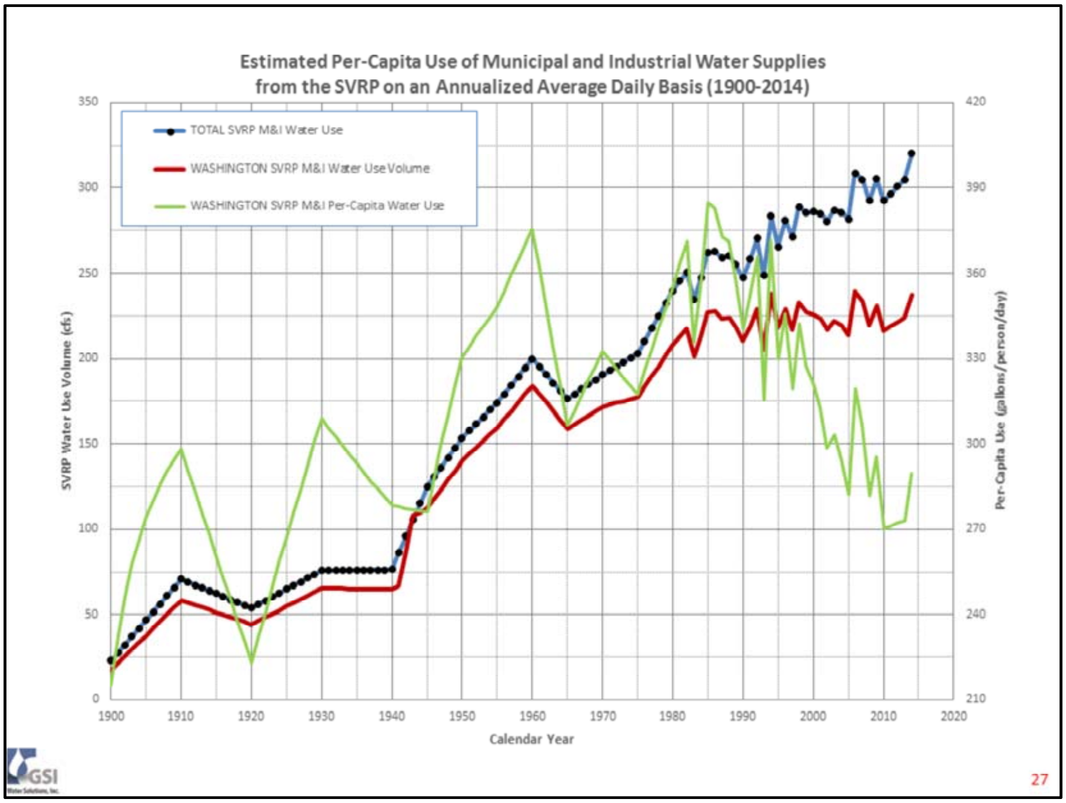


Here is a linear regression trend line for the period that starts in 1998, which examines the last 17 years of the available record. The slope of the line for the period 1998 through 2014 is 0.036 cfs/year, which is equivalent to 1 cfs of increase every 30 years.

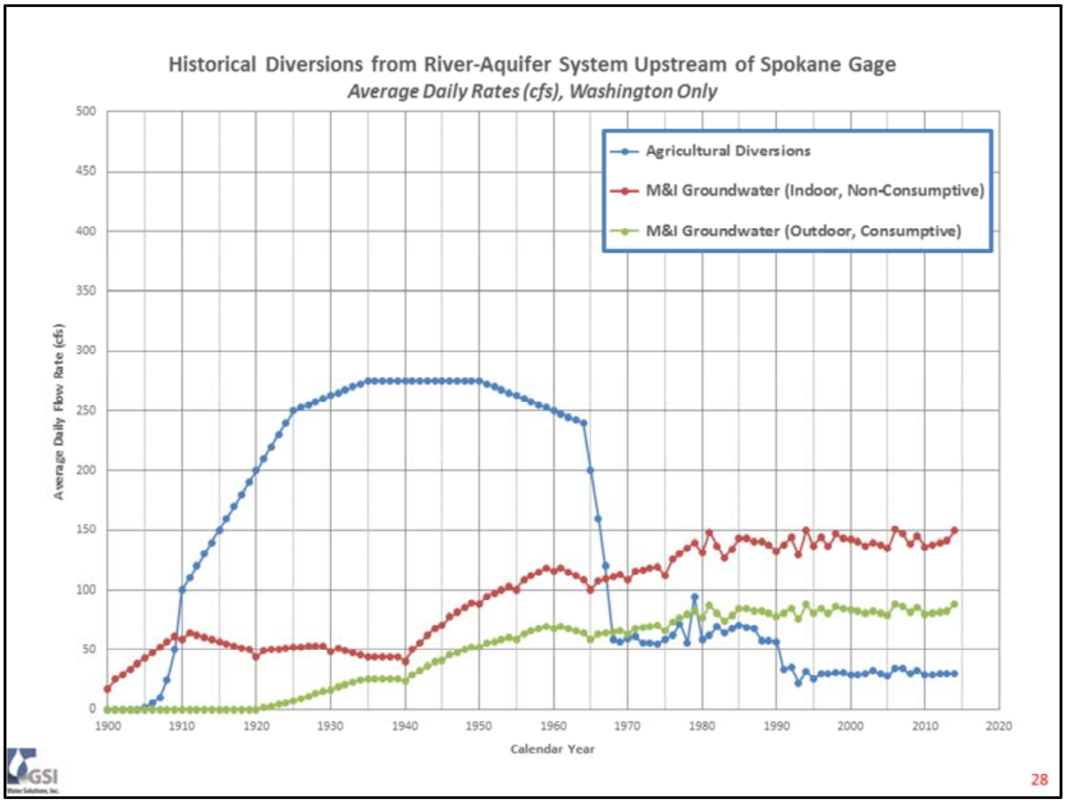
This slide and the three prior slides together indicate that despite a continued increase in population in Spokane County, the use of the SVRP in Washington gradually leveled off beginning in the 1990s, which in turn means that per-capita water use in Washington has been declining for the past 2+ decades.



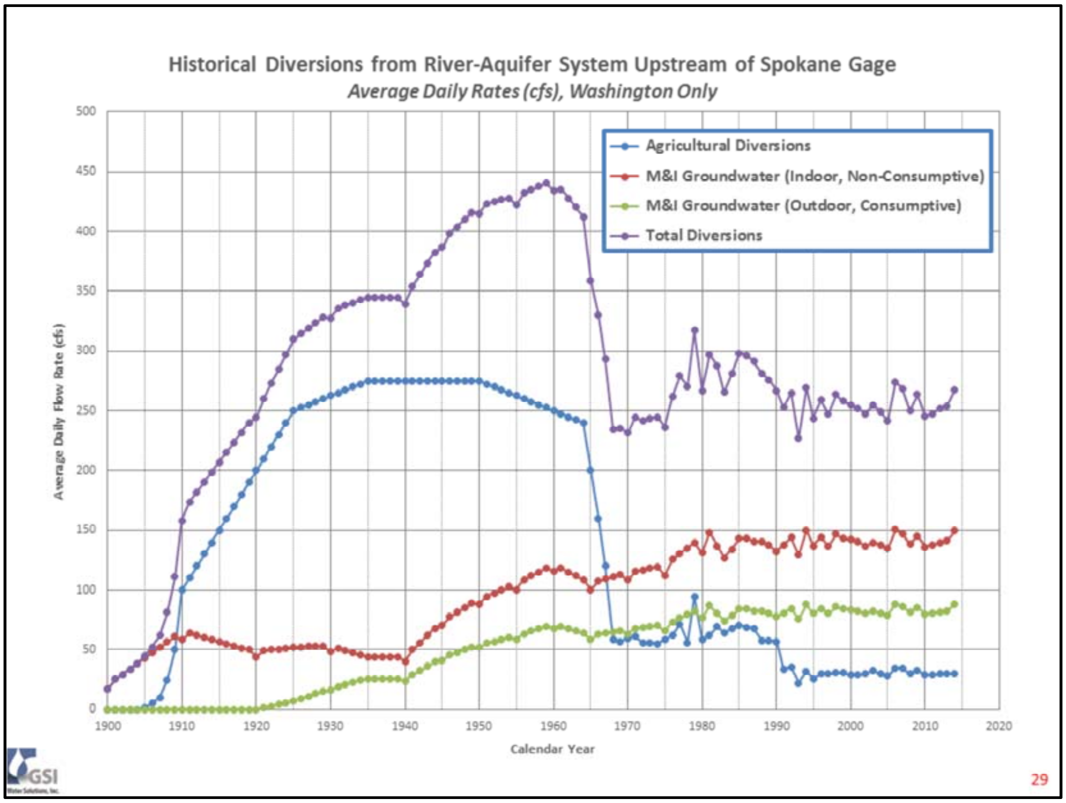
Now let's examine the per-capita rate of municipal and industrial (M&I) water use, particularly in the Washington portion of the SVRP.



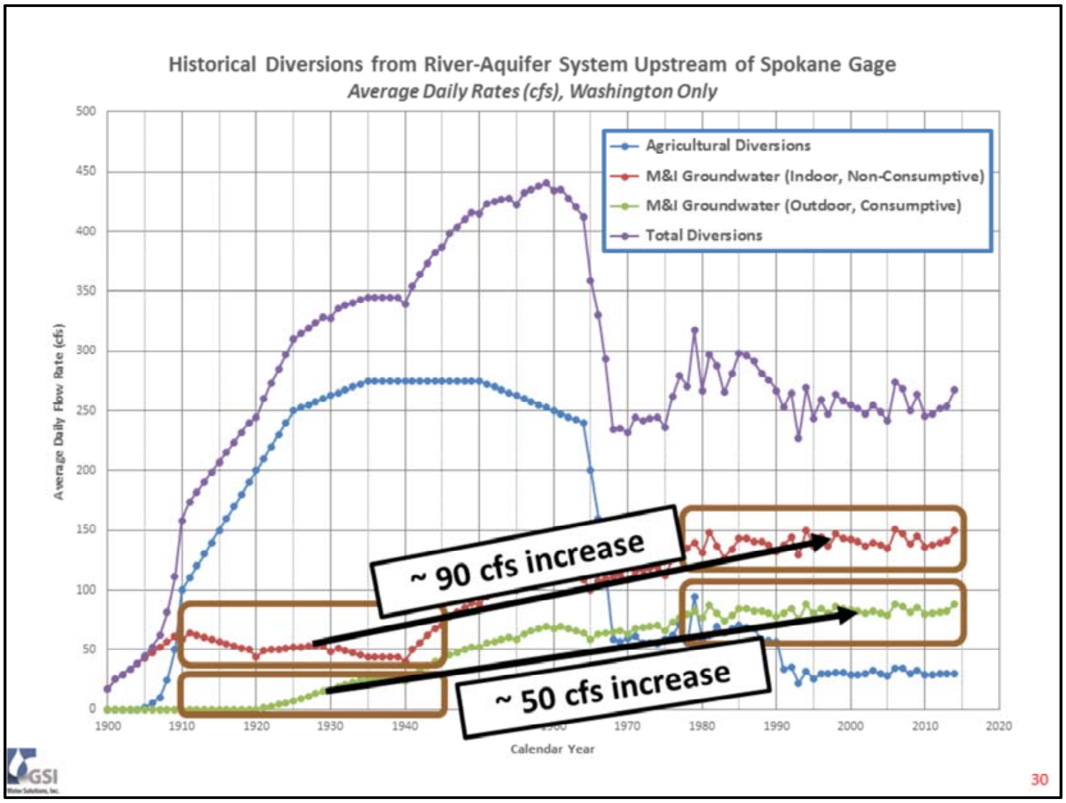
This plot for the SVRP shows the changes over time of total water use across the entire SVRP, Washington's SVRP water use volume, and Washington's per-capita use of the SVRP. Per-capita use of the SVRP in Washington peaked in 1960 and in 1985, since which time a sharp decline has occurred. Per-capita use of water in Washington has remained below 300 gallons per person per day since 2008.



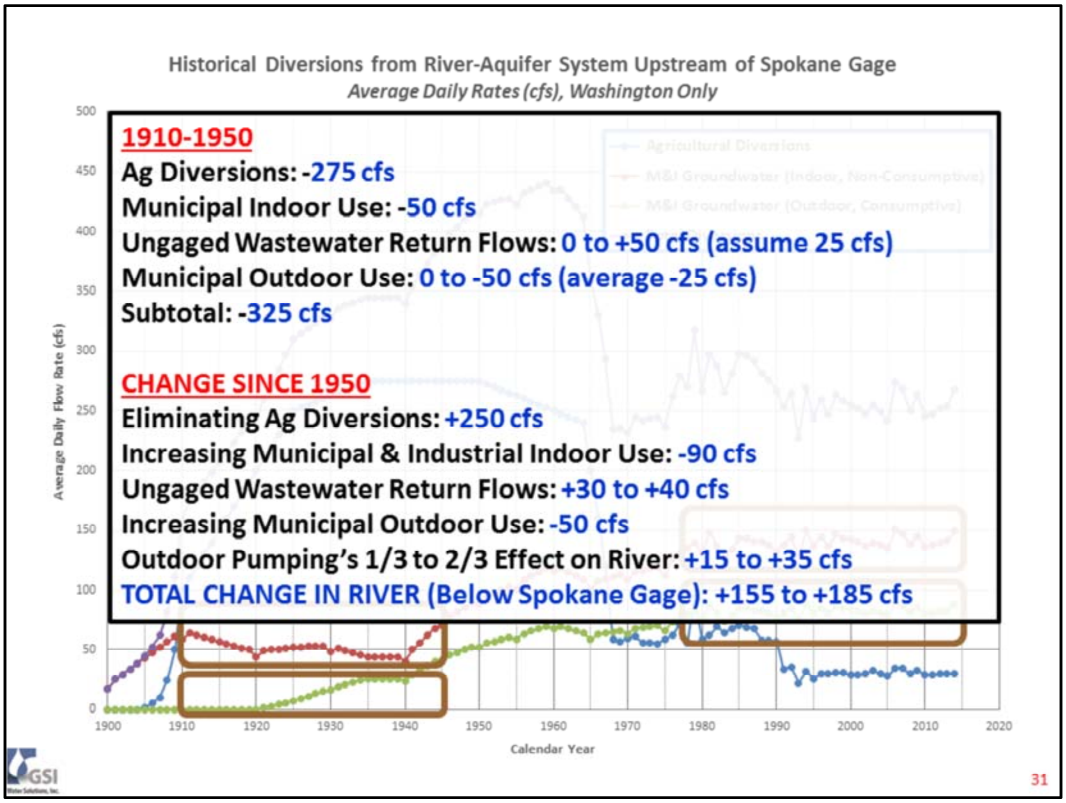
This plot shows GSI’s estimates of historical water use for agriculture and for indoor and outdoor uses of SVRP groundwater. The units are cfs (cubic feet per second). For agriculture, the average daily rates are for the portion of the year when irrigation is occurring. In contrast, the rates for indoor and outdoor uses of SVRP groundwater are computed from estimated annual water use volumes.



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 just below 250 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 1930 and were about 55% of the 1960 peak use rate. Since the mid-1990s, total water use has ranged between about 250 and 280 cfs, which is about 55% to 60% of the peak use in 1960.

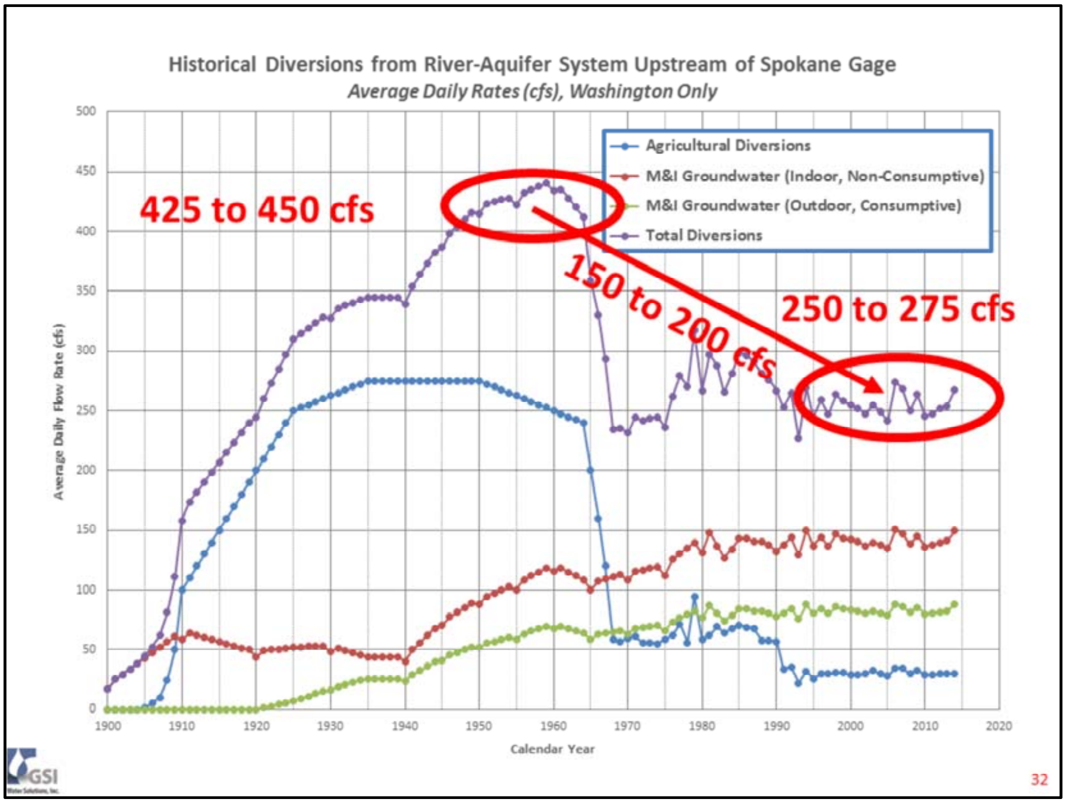


Here is how much the groundwater use changed between those same two time periods of long-term equilibrium that are shown on slide 29. Indoor uses of groundwater in the Washington portion of the SVRP average about 90 cfs higher in the recent period than in the early period, and outdoor uses of groundwater from the SVRP in Washington average about 50 cfs higher in the recent period than in the early period. Notice that when agricultural diversions of surface water 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 1930.

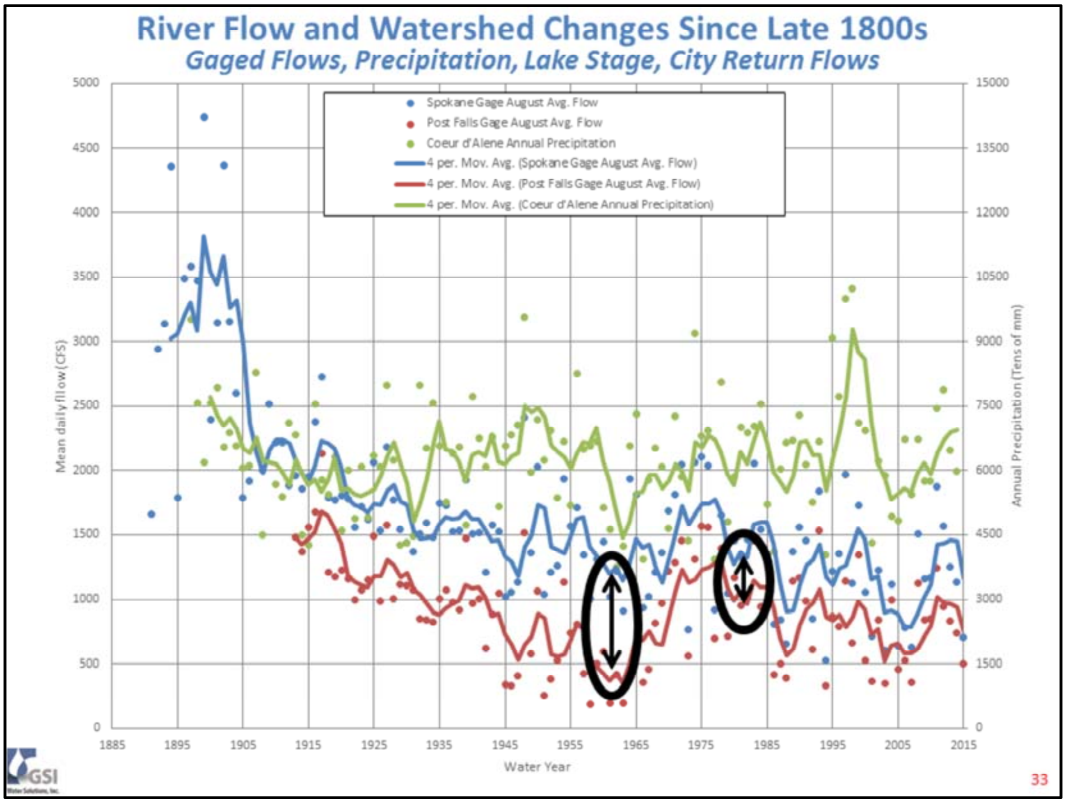


Let's prepare an accounting of average water use during the first time period (1910-1950), and then compute the change that occurred in water use between that period and today. This accounting is shown in the table, and its primary finding is that the "river-aquifer bucket" has actually gained between about 155 and 185 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 consumptive (evaporative) 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 the total water use from the river-aquifer system from about 1930 through 1950.

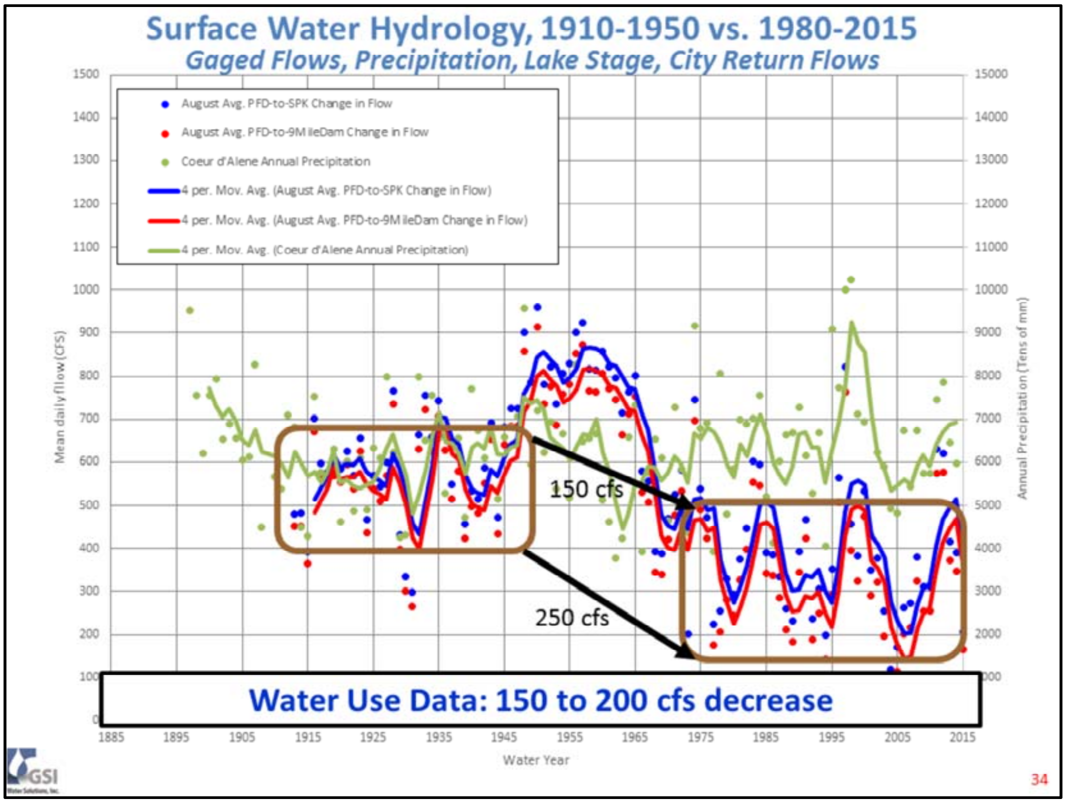
One detail involves the indoor uses. The City of Spokane's return flows below the Spokane Gage (30 to 40 cfs) are only part of the 90 cfs indoor water uses. About 36 cfs of non-consumptive use by self-supplied industries was estimated to occur in 2010, per the 2013 Spokane County Water Demand Model. (See slide 20 for a citation of that model.) This 36 cfs returns to the river upstream of the Spokane Gage. In 2010, Spokane County and the Liberty Lake Sewer and Water District added another 9.1 mgd, or about 14 cfs, according to the 2013 Spokane County water demand model.



We can see that total water use peaked at a rate of between 425 and 450 cfs during the approximately 15-year-long time period from about 1950 through 1965. In contrast, water use from about 1990 to the present has been in the range of 250 to 275 cfs, which is 150 to 200 cfs lower than during the earlier period.



Let's consider the difference between the 4-year moving average values of mean daily flows of the Spokane River at the Spokane Gage (in blue) versus the Post Falls Gage (in dark red). As shown on this 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.



The water use reduction of 150 to 200 cfs shown on the prior slide generally is similar to the range of 150 to 250 cfs improvement in the flow difference between the Post Falls Gage and the Spokane Gage that is shown on this slide (the blue line), as well as the flow difference between Post Falls and Nine Mile Dam (the red line). GSI has concluded that for those two equilibrium time periods, the average water use improved over the narrower range of 150 to 200 cfs shown on the prior slide. 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 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.

For the flow-difference terms shown in blue and red, the fact that a new equilibrium condition (or nearly equilibrium condition) 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 river-aquifer bucket has reached a new equilibrium, particularly in the SVRP aquifer itself. However, even though the difference between the flows at Post Falls and Nine Mile Dam 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 the Post Falls and Spokane gages have improved. The seasonal low flow rates at each gage have continued to slowly decline, as we can see on the prior slide.

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

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

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As discussed in the December 3, 2015 presentation, GSI identified each of the hydrologic processes listed in this table to understand their relative effect on seasonal low flows in the Spokane River. Notice that the processes listed in the left column all occur within the SVRP area, in the river and/or the aquifer. In contrast, the processes listed in the right column occur outside the SVRP and upstream of the river (i.e., in Coeur d'Alene Lake and its contributing watershed). An exception is the river water temperature, which is affected by conditions in the lake and watershed, but which has the potential to affect groundwater recharge to the SVRP via leakage through the riverbed in its losing reaches.

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

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

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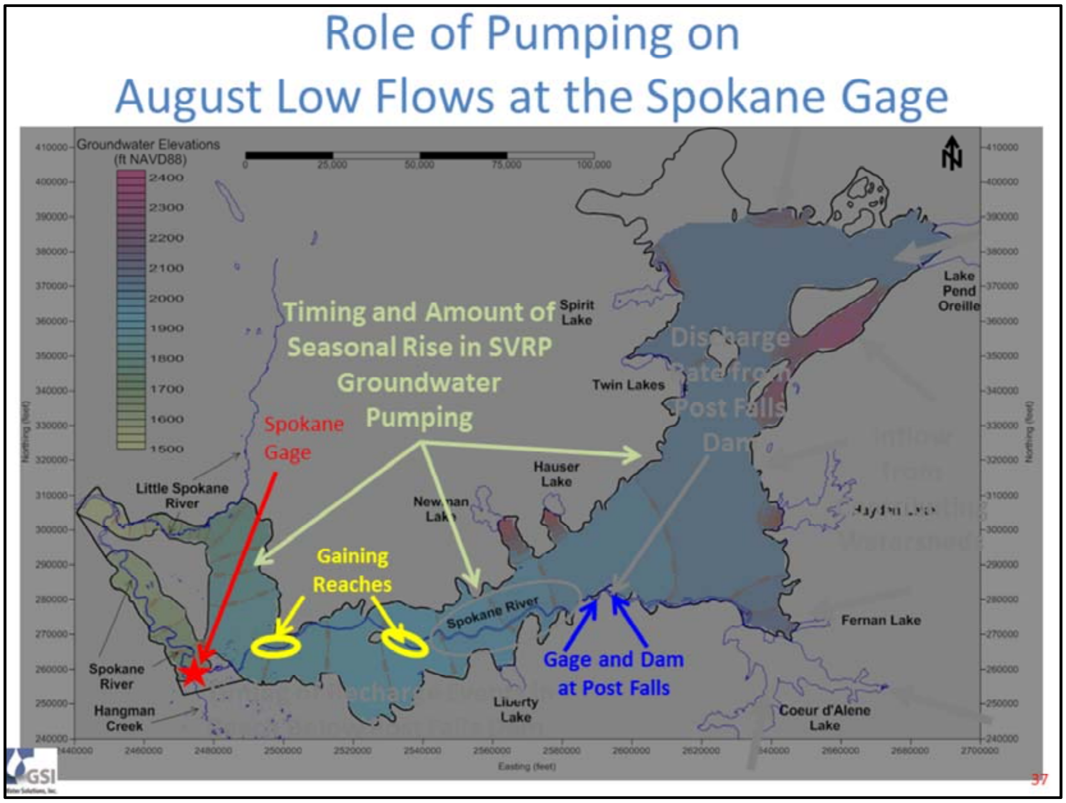
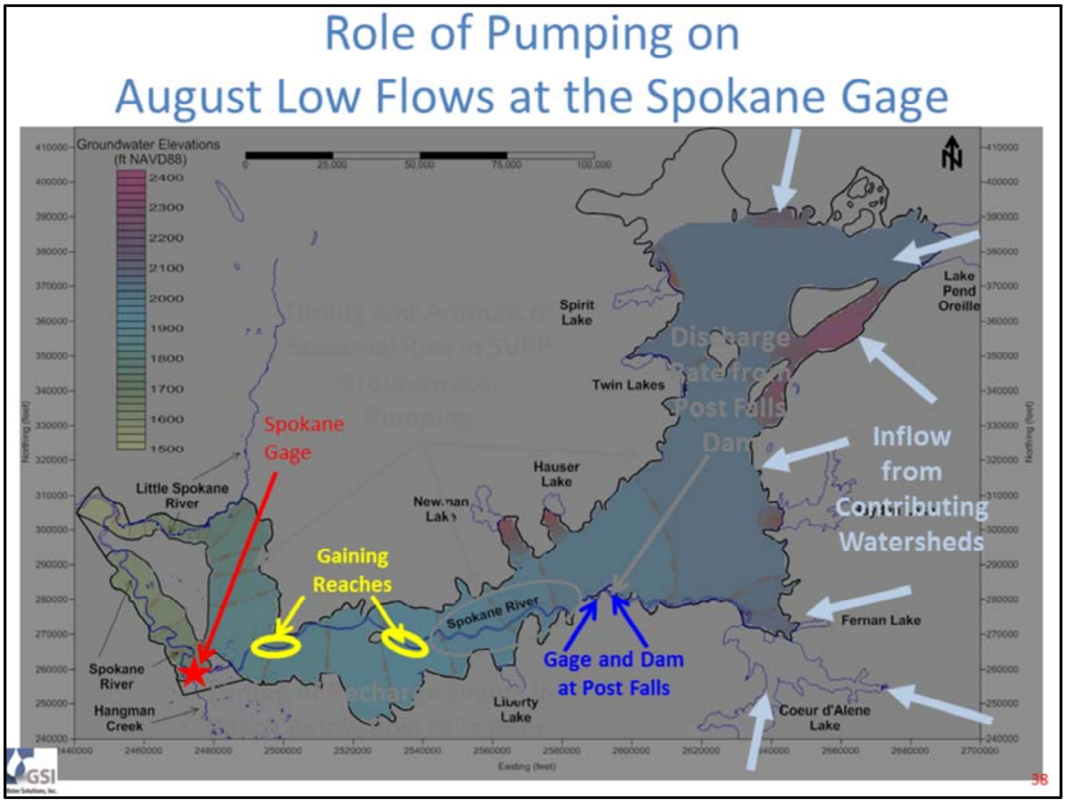
As discussed in the December 3, 2015 presentation, GSI found the following regarding the significance of each of the seven hydrologic processes:

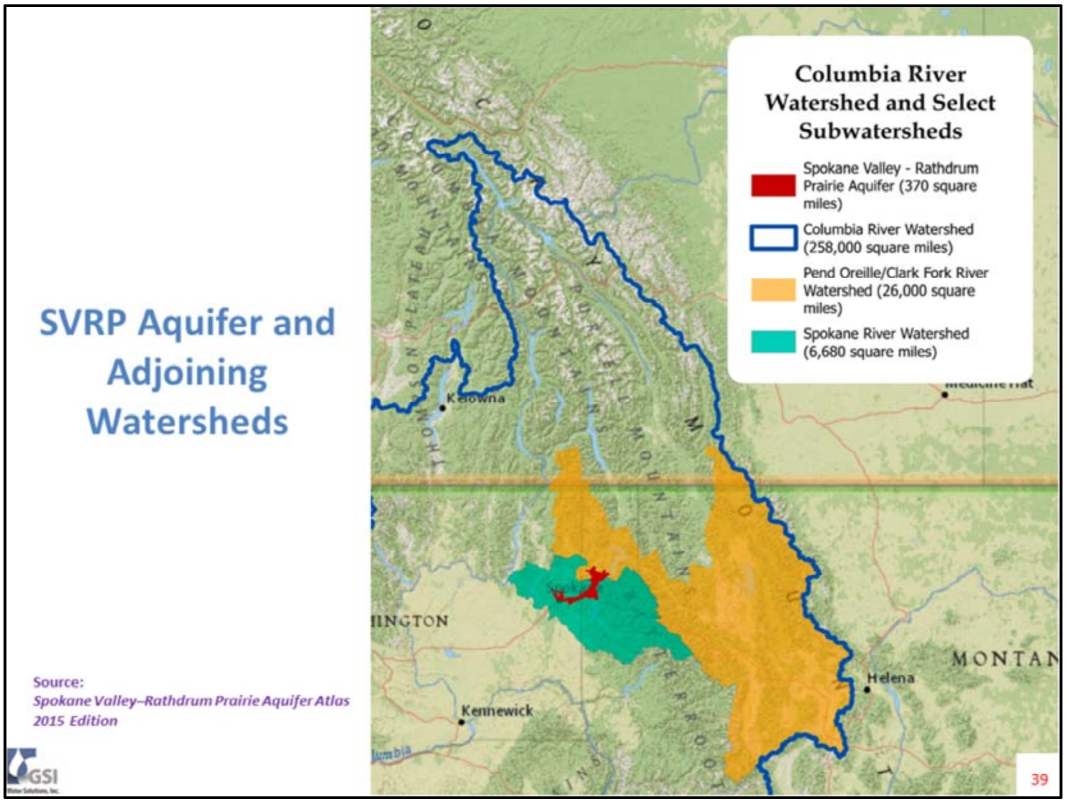
1. Climate and runoff changes in the watershed feeding Coeur d'Alene Lake (and the Spokane River) are likely the primary causes of the apparent declines in seasonal low flows that have continued since agricultural diversions ended in 1965.
2. Water level management at Coeur d'Alene Lake may also play a role, but it is not the cause of continued declining trends in Spokane River low flows – in part because the declining August flows in the Spokane River reflect declining flows into the lake (given that the storage volume of the lake during August does not change appreciably from year to year). This in turn further illustrates the important role that antecedent (prior to August) conditions in the contributing watershed have on summer flows into and out of Coeur d'Alene Lake.
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 the late 1990s. In Idaho, for the fractional portion of increased M&I use that becomes consumptive evaporative loss, this increased loss is too small and too far from the river's gaining reaches to explain the decrease in flows at the Spokane Gage.
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 total water use) these return flow volumes are not increasing over time.



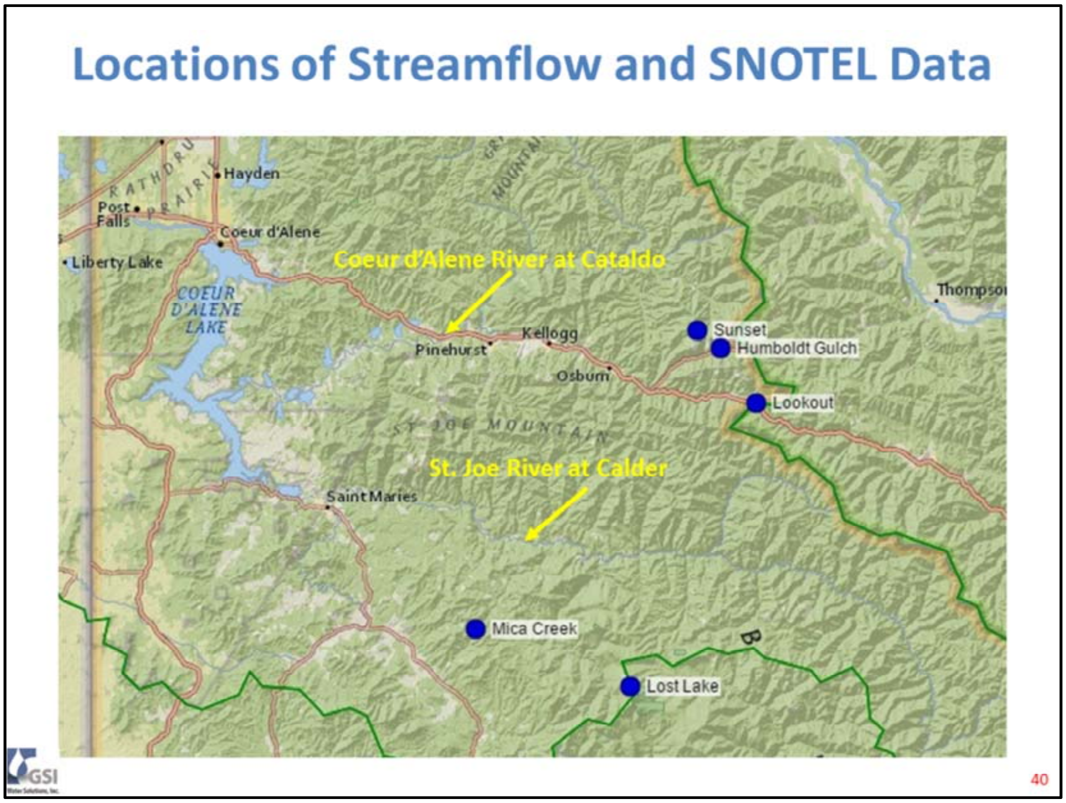
We have evaluated the groundwater influence in slides 12 through 36.



Let’s now turn our attention to the hydrologic conditions in the contributing watershed to Coeur d’Alene Lake.



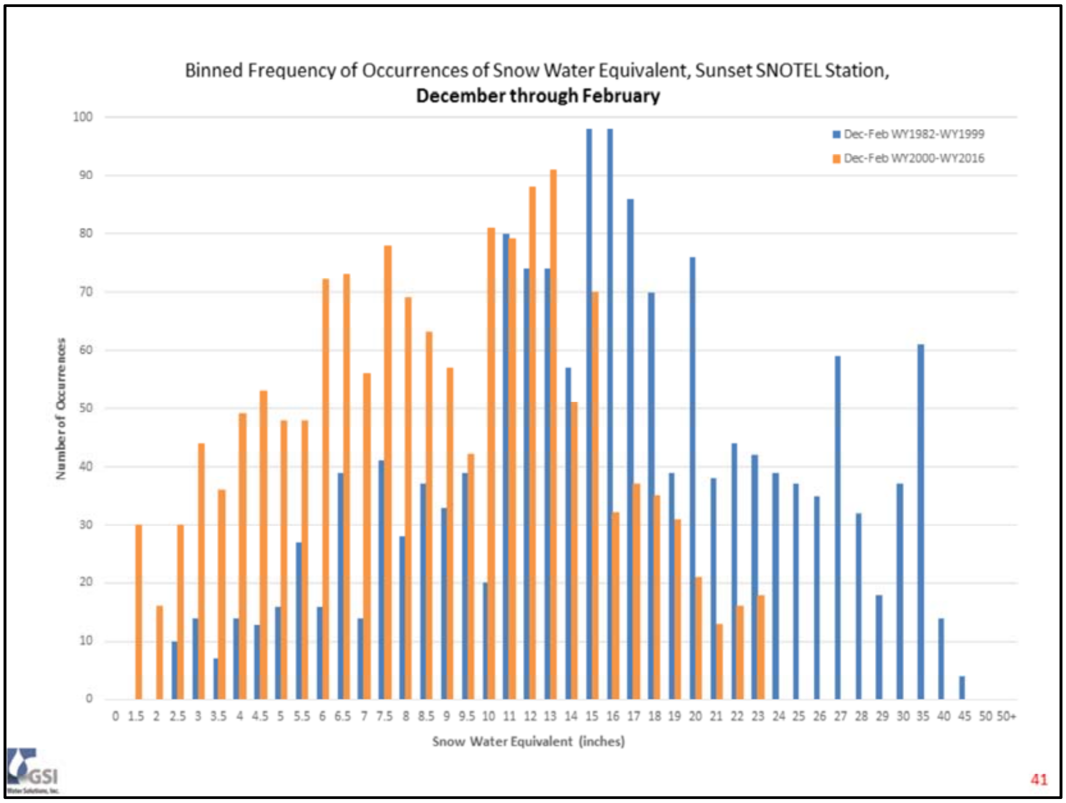
As shown by this map, the SVRP aquifer (in red) is a relatively small area lying within a much larger adjoining contributing watershed. Note the significant size of the watershed for the Spokane River (shown in green), and the even larger size of the watershed (shown in orange) that contributes hydrologically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



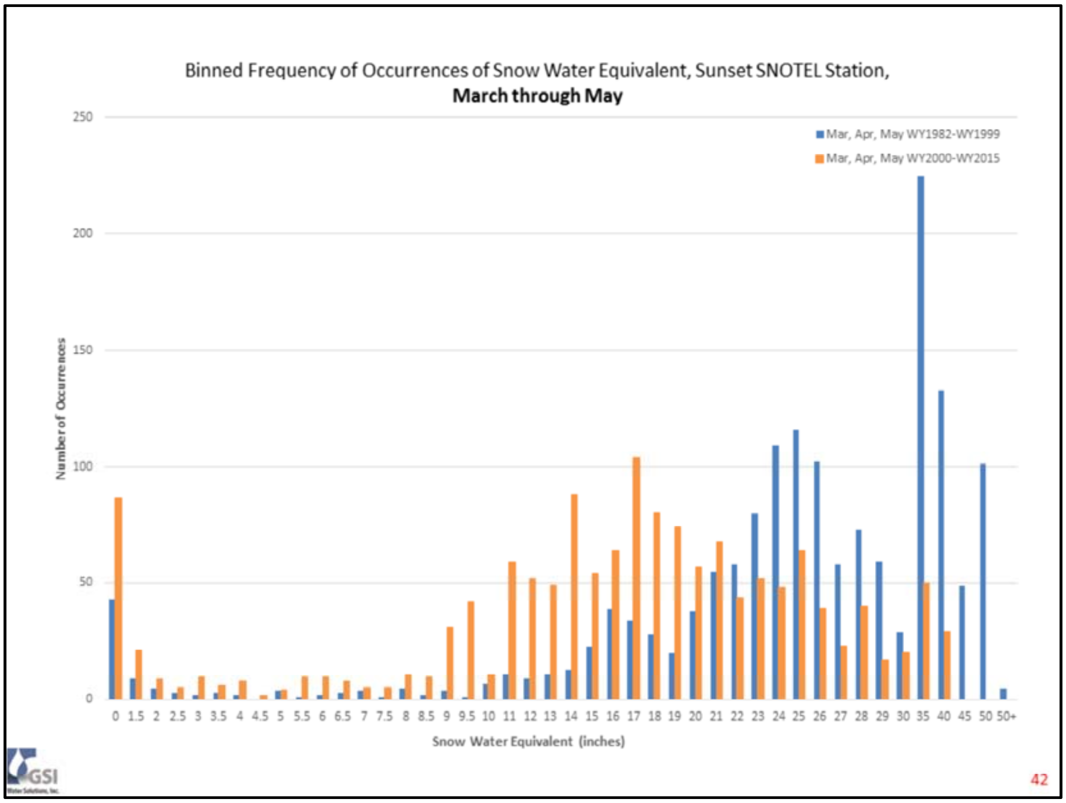
According to the USGS (2005), 92 percent of the inflow to Coeur d'Alene Lake comes from the Coeur d'Alene River and the St. Joe River.

The National Water and Climate Center, which is a division of the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS), maintains five snow telemetry (SNOTEL) sites that measure the snow water equivalent (SWE) and daily low, high, and average air temperatures. The SNOTEL data from these five sites and streamflow data collected at the two stream gaging sites shown on this map have been examined by GSI to evaluate the extent to which changes have occurred in the hydrology of the contributing watershed to Coeur d'Alene Lake.

Citation: 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.



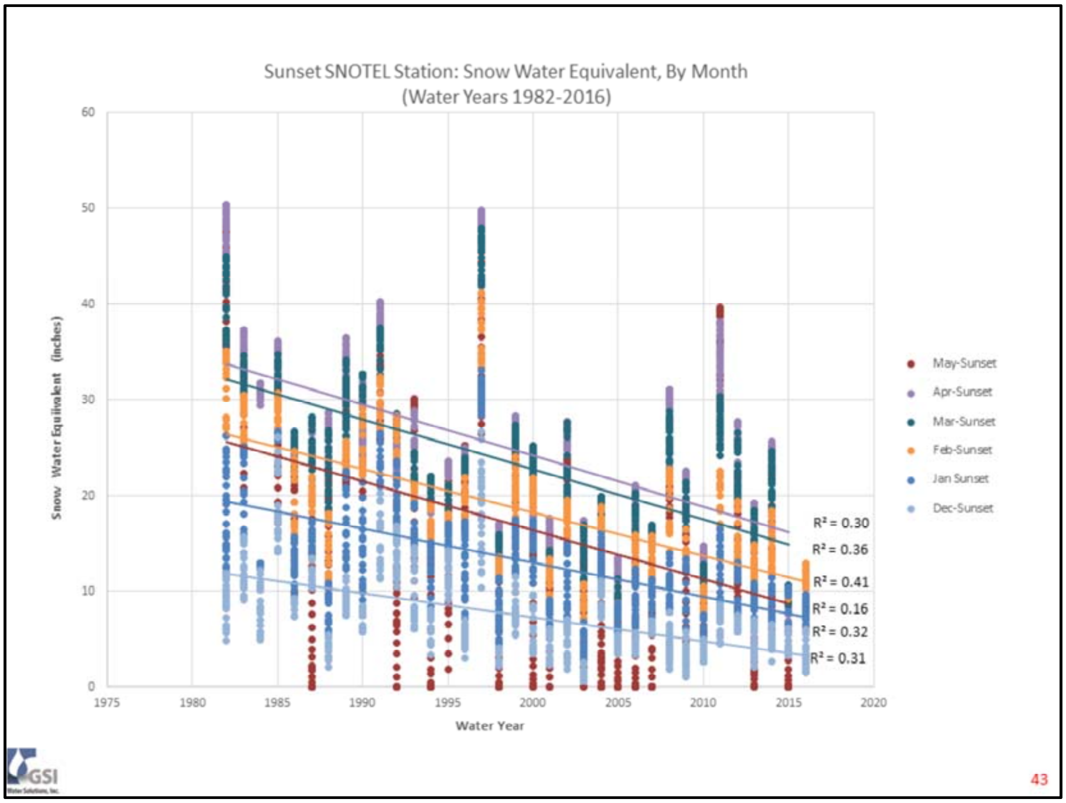
The snow-water-equivalent data at the Sunset SNOTEL station were examined for three-month long time periods. This histogram is for the first three winter months (December through February). A left-ward shift of the histogram (towards lower snow water equivalent values) is apparent when comparing the 17 most recent years (orange) with the first 18 years (blue). Further examination finds similar shifts during each individual month (see slides 13 through 15 of GSI’s other companion presentation dated March 3, 2016).



This histogram is for the next three months, which are in late winter and early spring (March through May). Note the different vertical scale compared with the prior histogram, because of the very high snowpack amounts that occurred in the past (the blue bars).

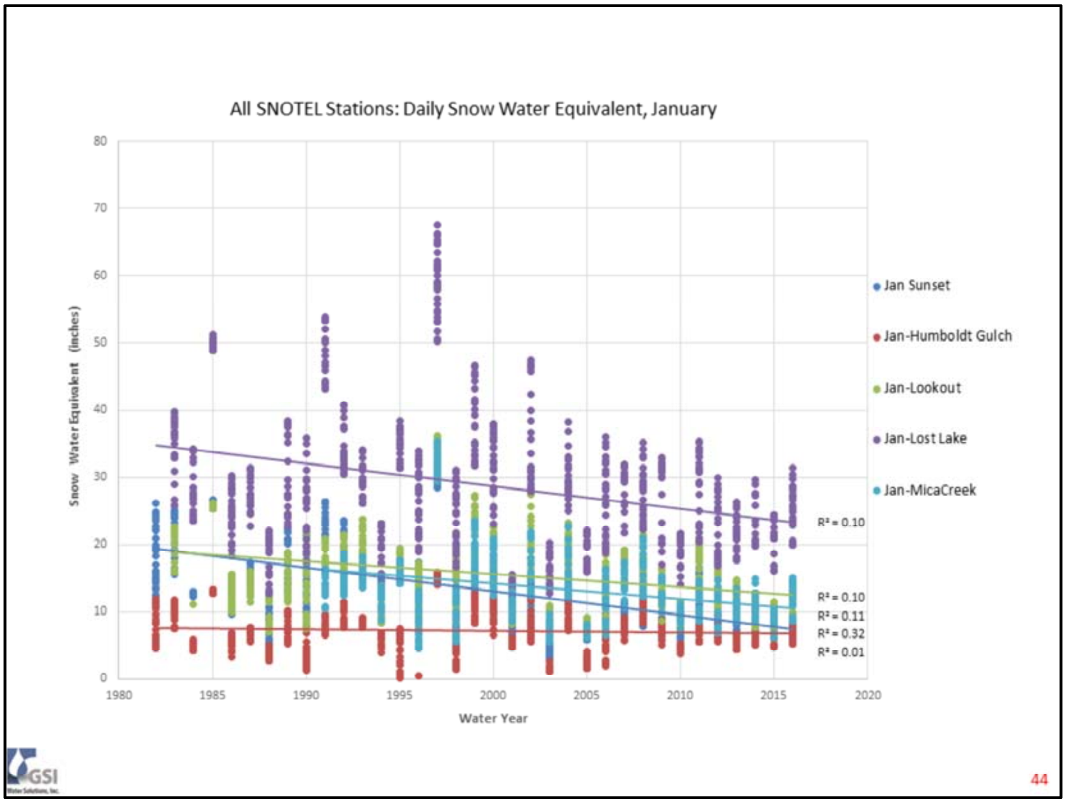
This histogram shows a left-ward shift over time (i.e., a reduction in snow water equivalent values). Further examination finds similar shifts during each individual month (see slides 16 through 18 of GSI's other companion presentation dated March 3, 2016).

Note also that the number of occurrences of a zero snowpack during the March-through-May season increased from 43 occurrences (prior to water year 2000) to 87 occurrences during water years 2000 through 2015.

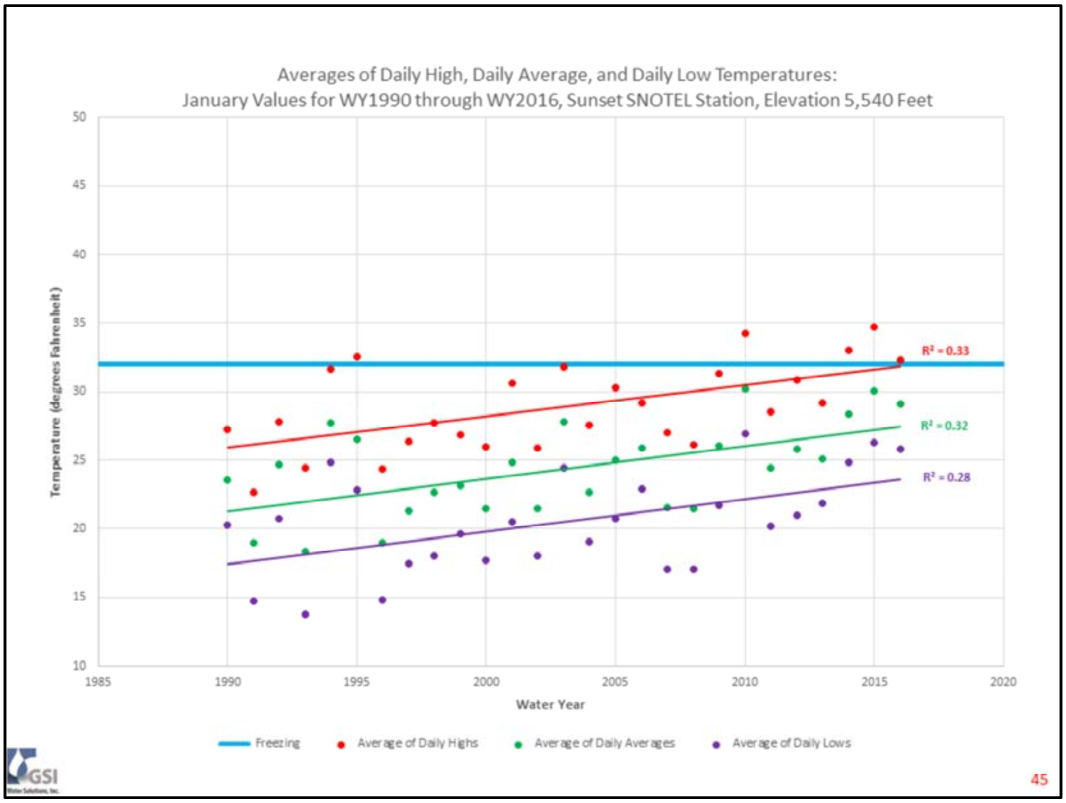


This plot shows the daily data at the Sunset SNOTEL station since water year 1982, color coded by month. For December through February, this plot shows data through water year 2016. Because this analysis was conducted in early March 2016, data for March through May are through water year 2015.

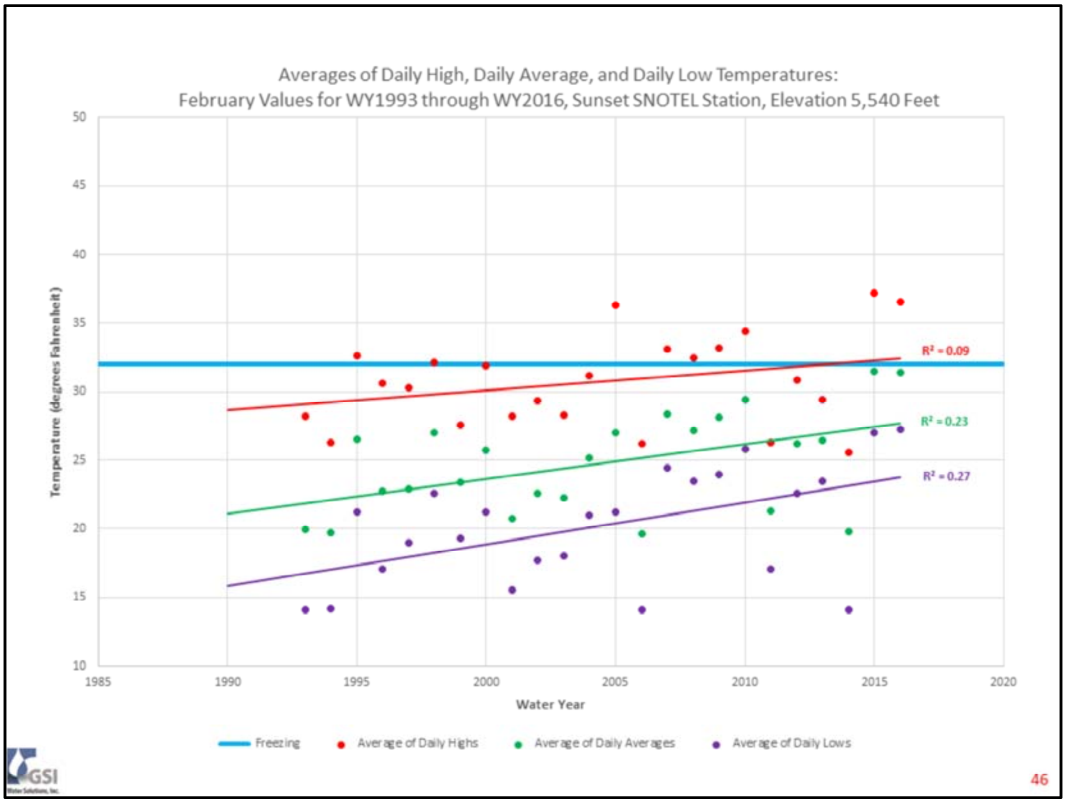
All six months (considered independently of one another) show coefficient of determination values (R^2 values) that are considered high for data sets that describe natural hydrologic processes (such as the snow water equivalent shown here). All R^2 values exceed 10 percent, and all but one of those R^2 values (the value for May) are above 30 percent.



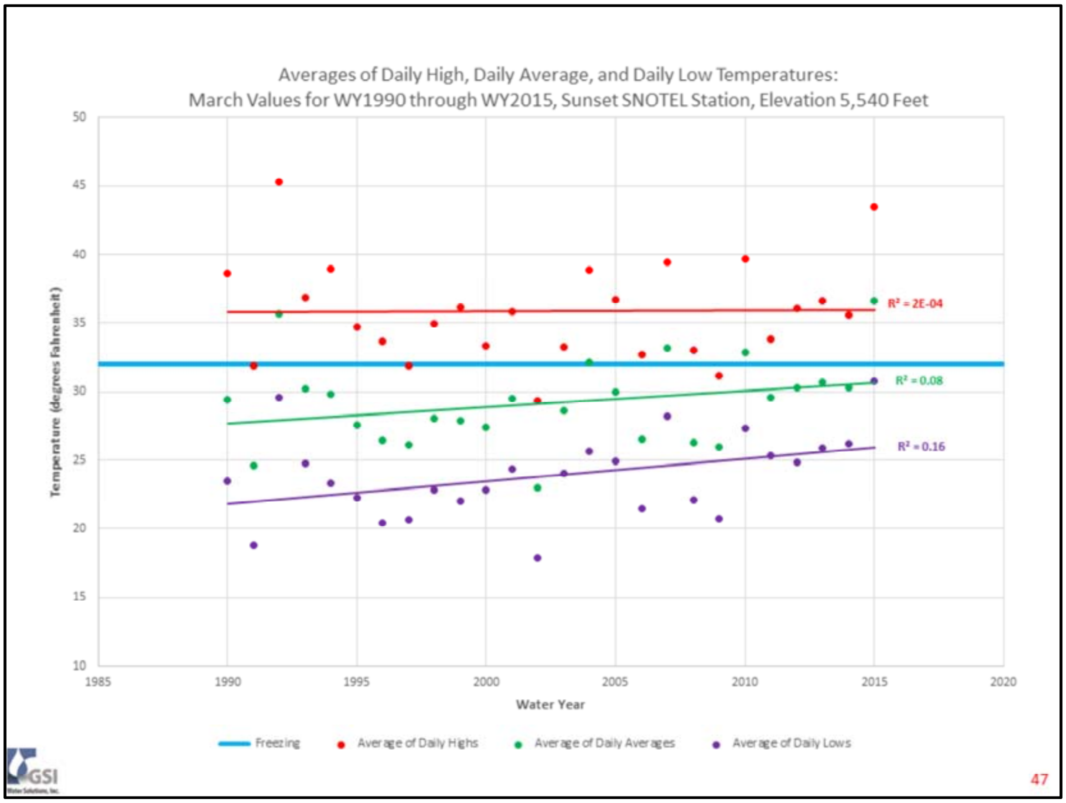
GSI examined the snow water equivalent values at the other SNOTEL stations as well. This plot shows the January trends since water year 1982 at each SNOTEL station in the Coeur d'Alene Lake watershed. Note that the coefficient of determination (R^2) values are on the order of 10 percent for three stations (Lookout [elevation 5,140 feet], Lost Lake [elevation 6,110 feet], and Mica Creek [elevation 4,510 feet)) and 32 percent for a fourth station (Sunset [elevation 5,540 feet]). Only the lowest-elevation station (Humboldt Gulch [elevation 4,250 feet]) shows a lack of a trend (R^2 value of 1 percent), most likely because it is the lowest-elevation station that (as the red dots show) receives notably less snow than the other SNOTEL sites.



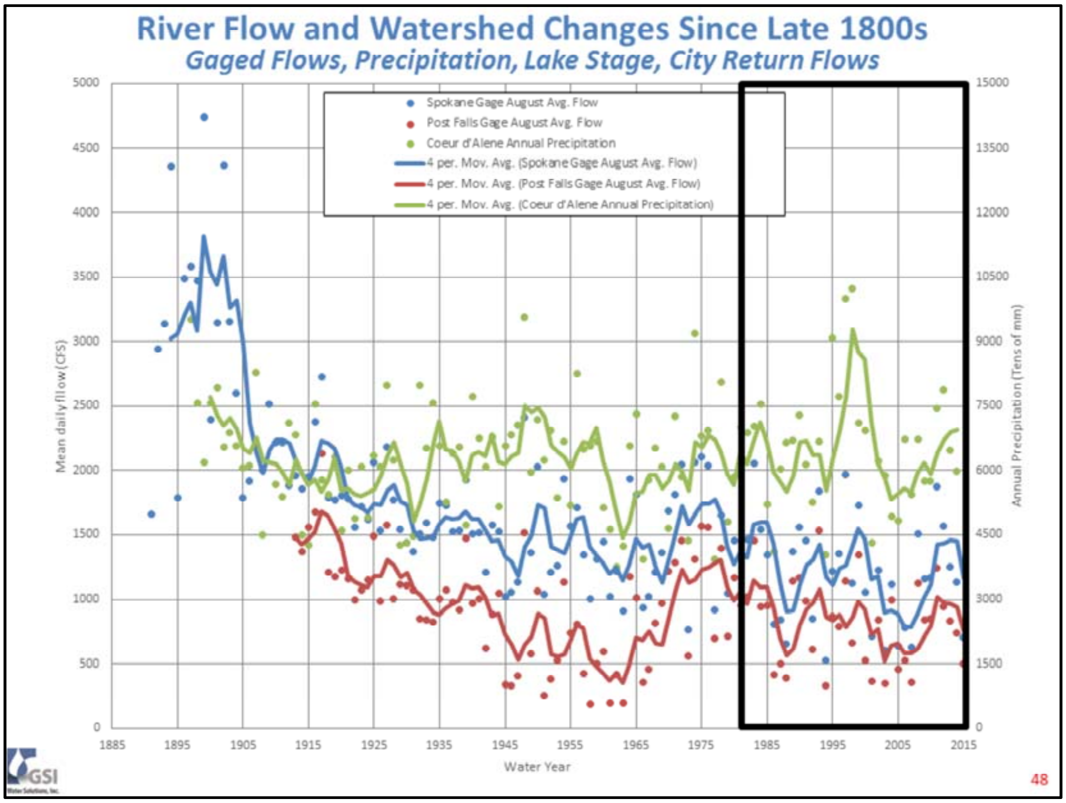
The analyses of snow-water-equivalent data in the prior slides help us understand the volume of water in the snowpack, and how this has changed over time. To understand how the timing of snowmelt might be changing, we need not only the snow-water-equivalent data, but also the temperature data. Here is a plot showing average daily temperatures from year to year during the month of January at the Sunset SNOTEL station. This plot evaluates the past 27 years of January temperatures (water years 1990 through 2016). The plot shows a strong upward trend in January temperatures at the Sunset SNOTEL station during the past 27 years. This is indicated by the high values of the coefficient of determination (R^2), which are on the order of 0.3 for all three temperature data sets during January. A similar trend was found for January at the higher-elevation Lost Lake SNOTEL station as well (as shown on slide 31 of GSI's other companion presentation dated March 3, 2016).



During the following month (February), low and average temperatures show a strong upward trend (coefficient of determination [R^2] values of 0.27 and 0.23, respectively). A modest trend is apparent in the daily high temperatures (R^2 value near 0.1), which rise above the freezing mark in several years from 2005 through 2016. The February trend was less strong at the higher-elevation Lost Lake SNOTEL station (as shown on slide 32 of GSI's other companion presentation dated March 3, 2016).



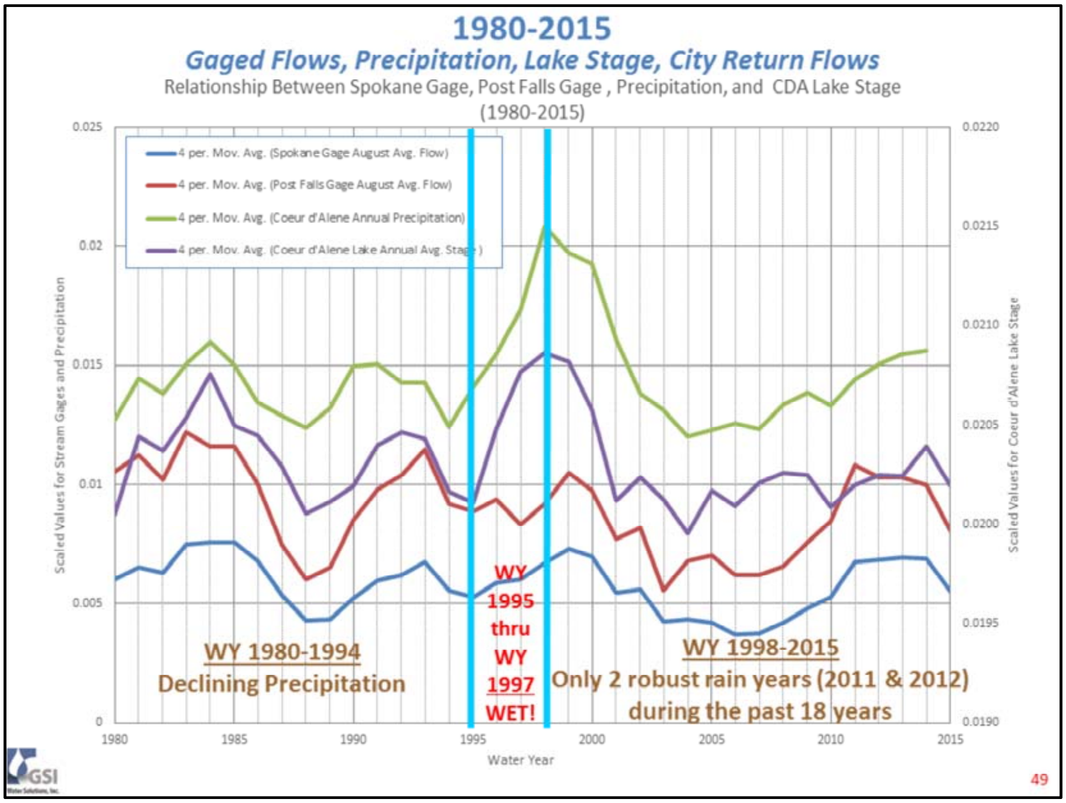
As with February, the daily low temperatures in March show a notable upward trend (R^2 value 0.16). Daily highs are above freezing in virtually all years but do not show a rising trend. Similar trends were seen in March at the higher-elevation Lost Lake SNOTEL station (as shown on slide 33 of GSI's other companion presentation dated March 3, 2016).



Slides 40 through 47 focused on the most recent 3-1/2 decades of snowpack and temperature data in the watershed that feeds Coeur d'Alene Lake. Declining snowpacks are evident throughout the winter and spring, and rising temperatures are also evident in certain months (particularly January through March). Now let's travel back down the watershed and think about river flows and precipitation within the area where the Spokane River and the SVRP aquifer are present (i.e., the area below Coeur d'Alene Lake).

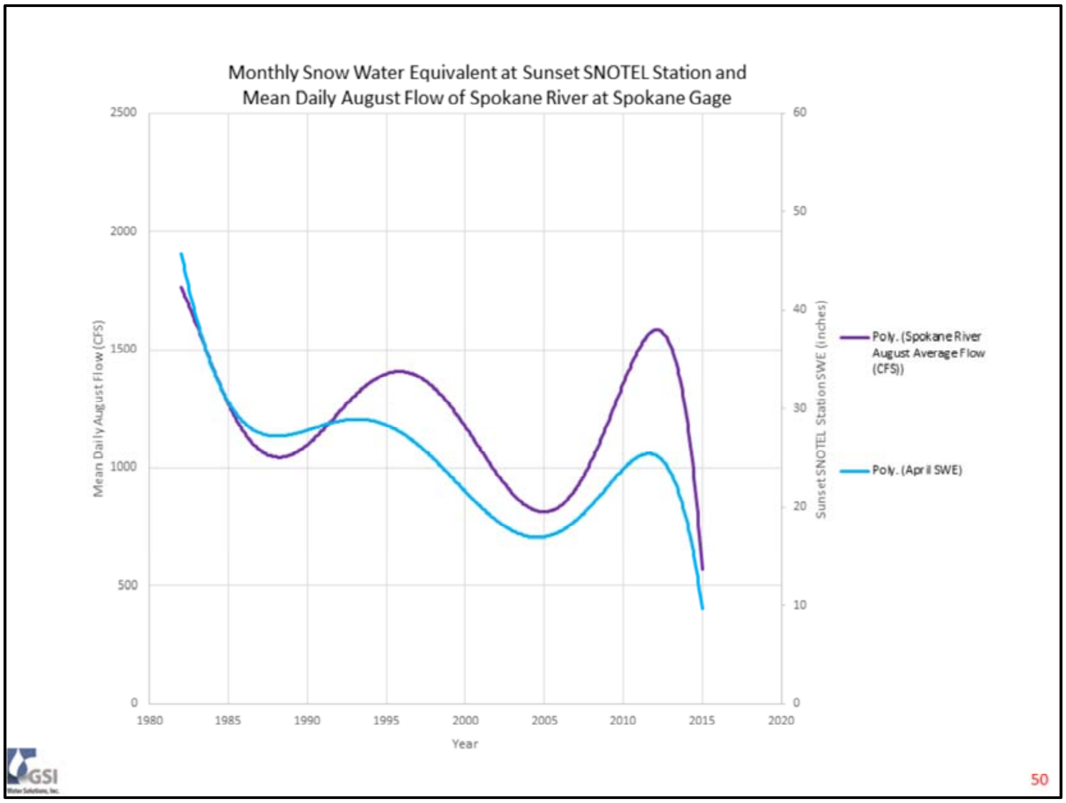
This plot shows the 4-year moving average values of three data sets: mean daily August flows (in cfs) of the Spokane River at Post Falls (in dark red) and at the Spokane Gage (in blue), and annual water-year precipitation (tens of millimeters) at the precipitation gage in the City of Coeur d'Alene (in green). This plot shows the following: (1) no apparent long-term decline in precipitation, (2) a sharp decline in flows at the Spokane gage in the early 1900s followed by a gentler rate of decline, and (3) a decline at the Post Falls gage that is interrupted by a short-term rise when direct diversions of river water for irrigation ended in the mid-1960s.

Let's zoom in on the past 35 years and think about what these data sets mean relative to what we just observed in the SNOTEL data.



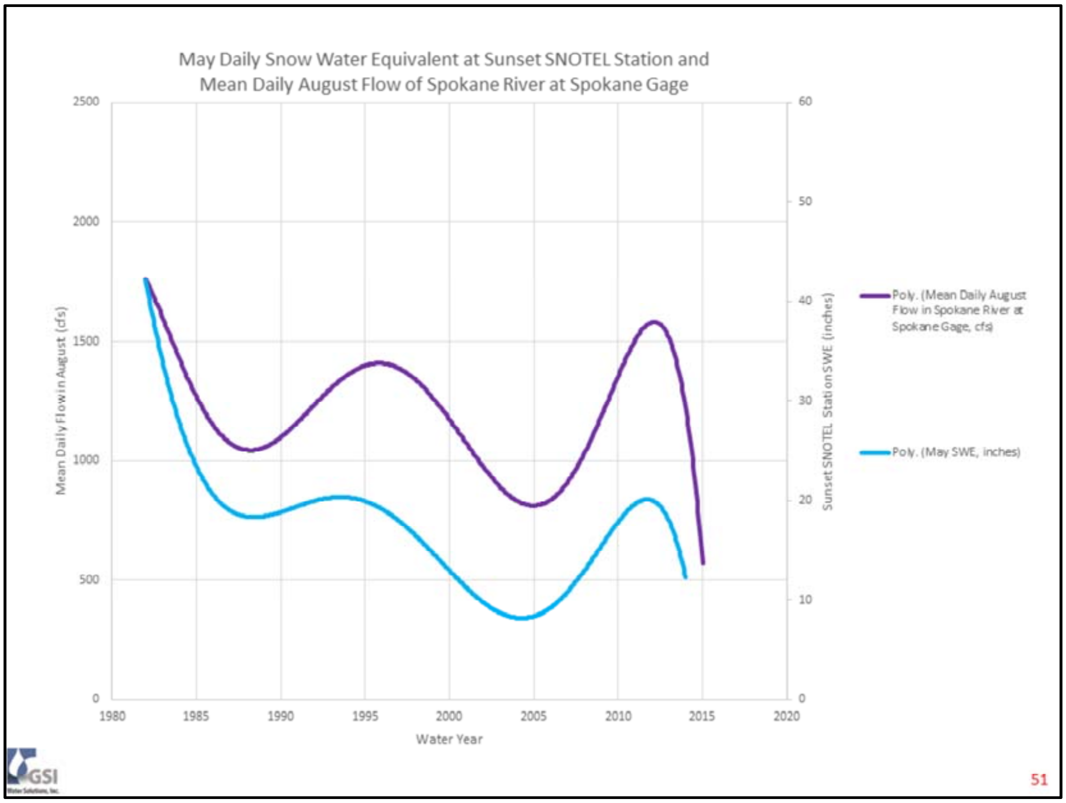
In this plot, we have taken the prior plot on slide 48 and done three things: (1) zoomed in on the period since 1980, (2) added the 4-year moving average of the year-to-year values of mean daily lake stage (in purple), and (3) scaled all four moving-average data sets so that they can be plotted on one figure and compared for similarities or differences in trends. (See slide 8 of GSI's companion presentation of March 3, 2016 for an explanation of the scaling procedure.)

This plot shows that the lake stage 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 during water years 1995 through 1997 interrupted a prior small downward trend in mean daily August river flows. Afterwards, the mean daily August river flows resumed their downward trend, until experiencing a modest overall rise from about 2008 through 2012, followed by another decline in 2015. Large-scale / high-magnitude precipitation events such as that of 1995 through 1997 have not occurred since that time. The mean daily August river flows have declined slightly since 1980, despite an improvement and stabilization of conditions within the "river-aquifer" bucket (as discussed in slides 18 through 34 of this presentation). This observation – together with the observation of declining snowpack volumes and rising temperatures in the Coeur d'Alene Lake watershed – indicates that the ambient hydrology of the contributing watershed is the primary driver for the long-term declines that appear to be continuing for seasonal low river flows at both gaging stations on the Spokane River.

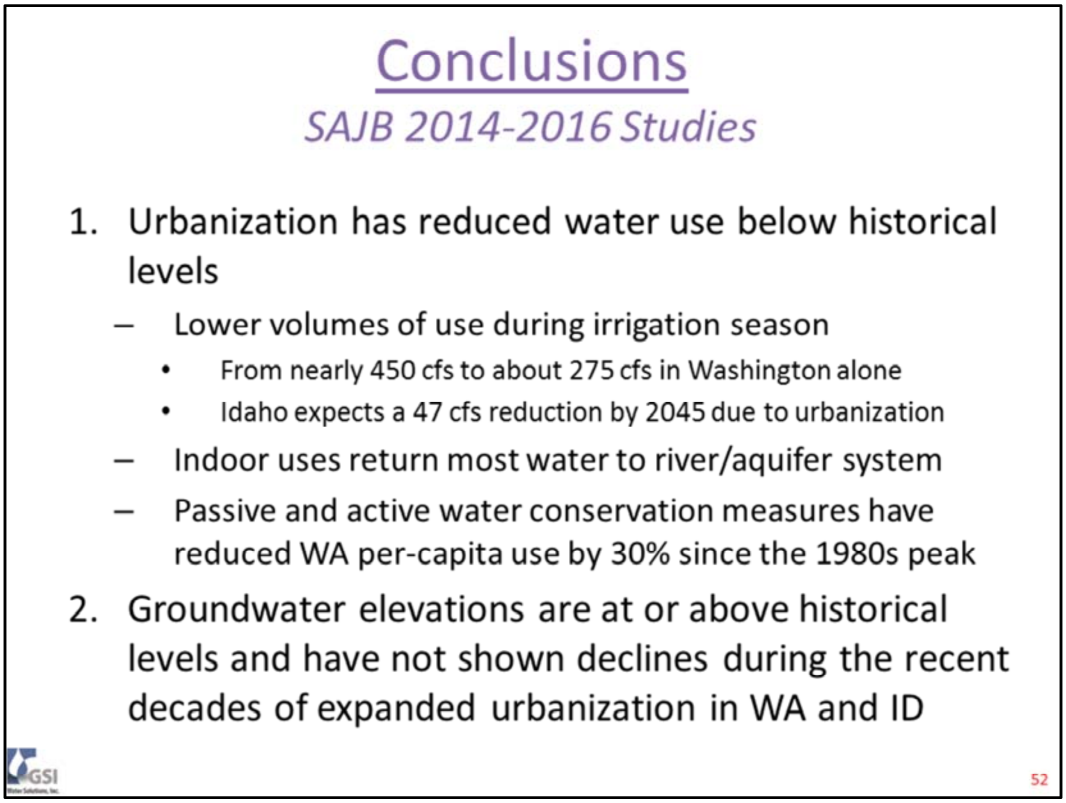


The April and May snowpack volumes appear to be another indicator of the magnitude of August flows at the Spokane Gage. This plot shows 6th-order polynomial functions for the April snowpack (light blue) and for the mean daily August flows in the Spokane River at the Spokane Gage. The plot is constructed for the time period 1982 through 2015. Unlike the prior two slides, the August flow values that were used to construct the polynomial function were not moving averages over multiple years, but instead were the 34 daily average values for August (i.e., one daily average for August of each individual year, during the 34 year period of water years 1982 through 2015).

Compared with annual or monthly data sets, the use of a high-order polynomial allows us to more readily see the long-term nature of the degree to which there is a relationship (if any) between the April snowpack and subsequent mean daily flows during August. The trends in the two functions generally follow each other well through about 2005, and the directions of the trends are consistent at all times. The only deviation is in about 2012, when the August flows (in purple) rise more sharply than the rise in April snowpack (in blue). Specifically, the high August flow in 2012 is actually greater than the high August flow in 1996, despite the April 2012 peak snowpack being lower than the peak April snowpacks prior to 1996. Let’s explore this further by looking at the snowpack during the month of May in the next slide.



This polynomial plot of the May snowpack (in blue) and August river flows at the Spokane Gage (in purple) shows that the high snowpack of May 2012 was similar to the high snowpack that occurred before May 1996. This plot suggests that a late-season snowpack may have helped increase the August river flows at the Spokane Gage. During other years when April snowpack (as shown on the prior slide) and May snowpack (as shown on this slide) were lower, the August flows of the Spokane River at the Spokane Gage showed notable declines.



Slides 52 through 54 summarize the findings of three studies conducted by GSI Water Solutions (GSI) for the Spokane Aquifer Joint Board (SAJB) from 2014 through early 2016. Those studies and the presentations describing them are as follows:

- April 2014 presentation titled *Screening-Level Analysis: Influence on Spokane River Flows of Hypothetical Pumping Relocation Scenarios, Using the City/SAJB Groundwater Flow Model.* April 24, 2014.
- December 2015 presentation titled *Screening-Level Analysis: Causes of Historical Changes in Seasonal Low Flows in the Spokane River.* December 3, 2015.
- March 2016 presentation titled *Watershed Hydrology and Historical Changes in Seasonal Low Flows in the Spokane River.* March 3, 2016.

Conclusions

SAJB 2014-2016 Studies

3. SVRP use increasing in Idaho, but not Washington
4. The Idaho increase has minimal effect on the river
   - Indoor uses return most water to river/aquifer system
   - Pumping for outdoor uses in Idaho is seasonal and occurs too far away from the river's gaining reaches to have a discernable effect during the river's low-flow season
5. The continued decline in seasonal low flows in the Spokane River is occurring despite two positives:
   - Declining usage in Washington (volumetric and per-capita)
   - Reduced water demands in both states arising from the agricultural-to-urban conversion of land and water use

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Conclusions

SAJB 2014-2016 Studies

6. Changing hydrology in the contributing watershed to Coeur d'Alene Lake is the dominant cause of continued declines in Spokane River seasonal low flows
   - Annual precipitation is not showing declines
   - But other critical conditions are affecting the watershed's magnitudes and timing of inflows to the lake
     - Lower snowpack volumes and higher temperatures
   - Implications:
     - Earlier snowmelt
     - Smaller runoff volumes in late winter and spring
     - Lower summer stream inflows

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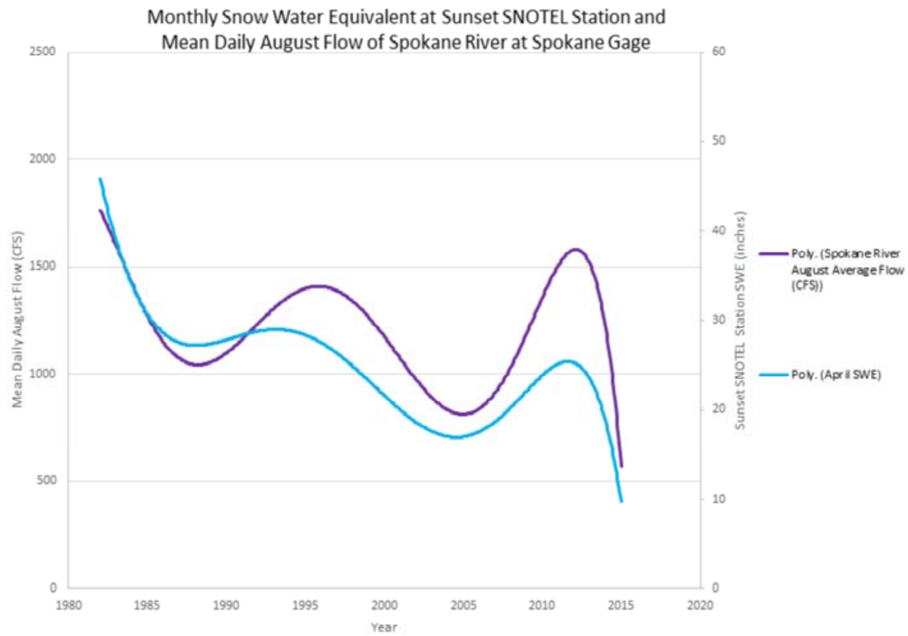
Discussion, Questions

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



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