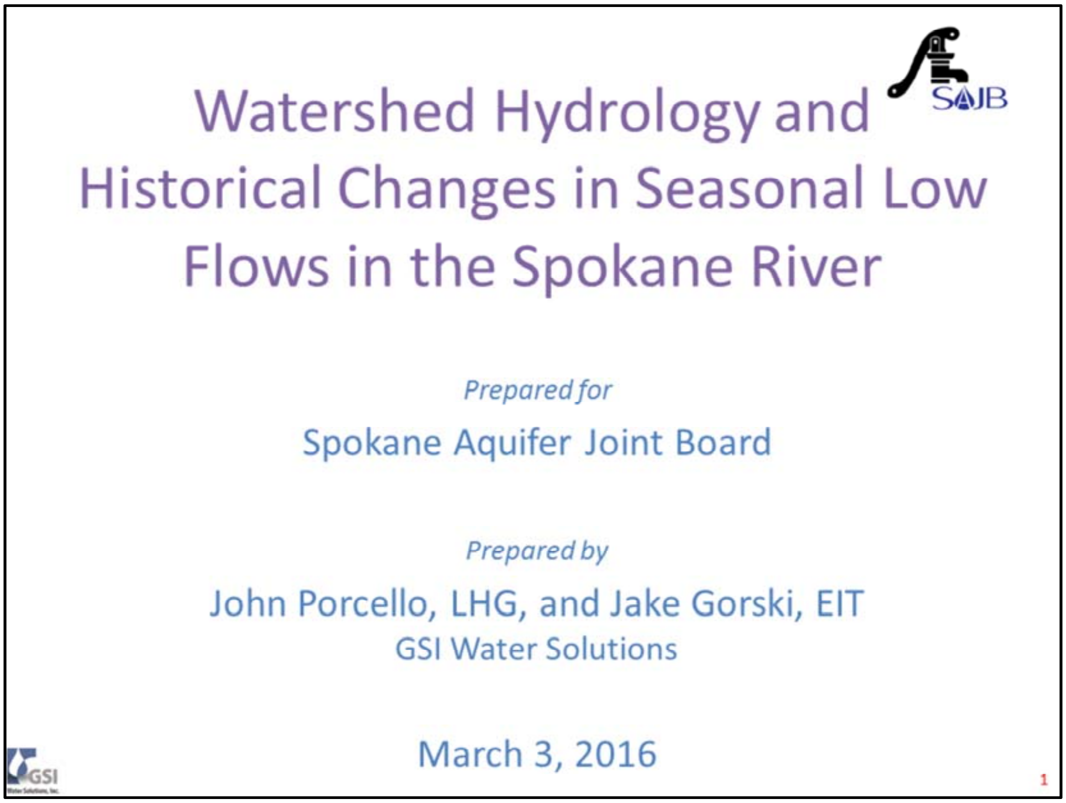
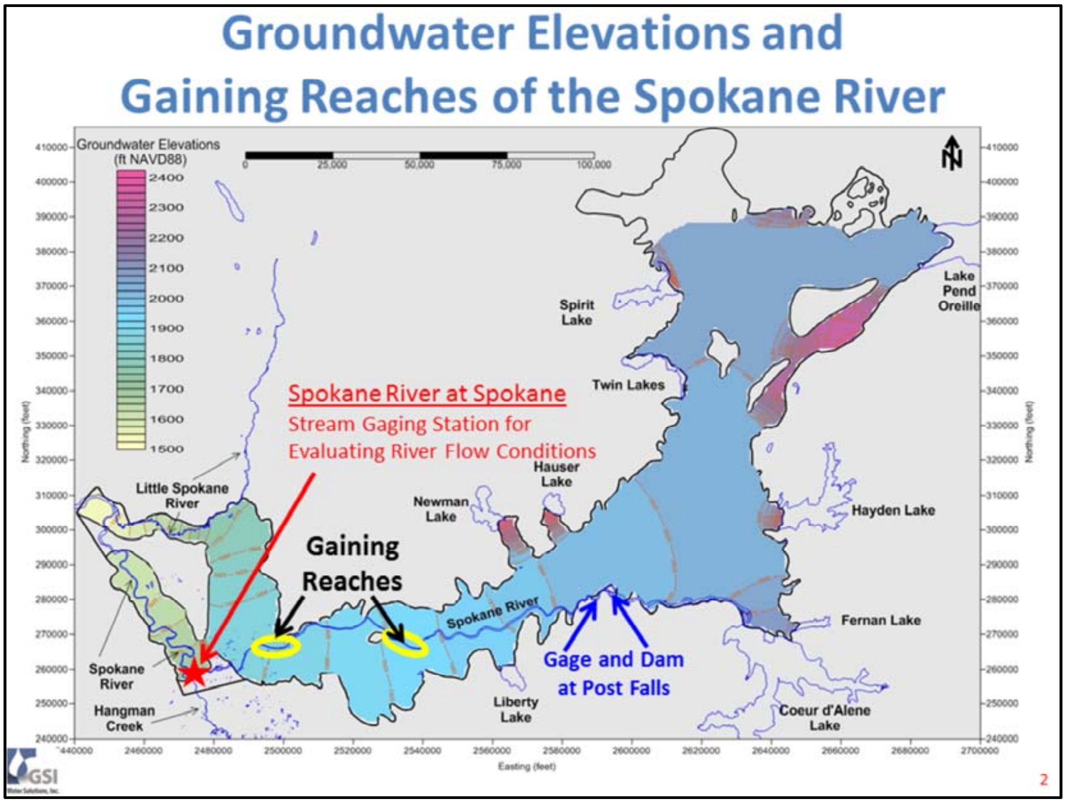
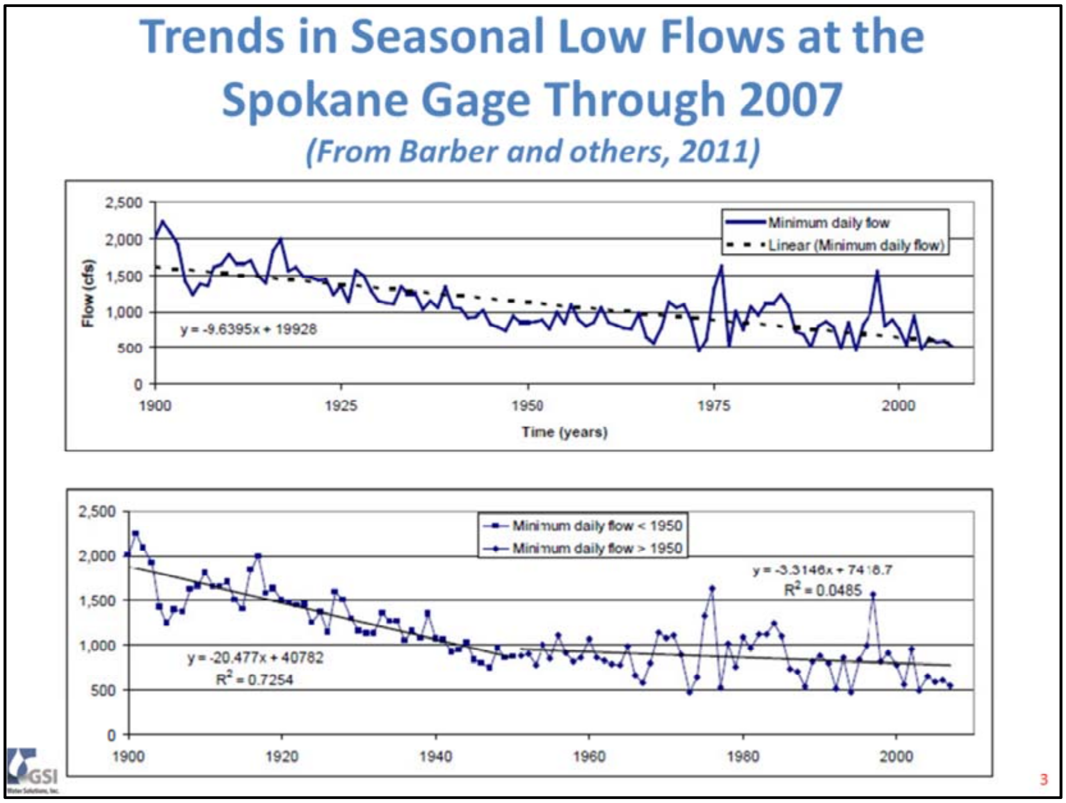


In a previous presentation to the SAJB on December 3, 2015, GSI Water Solutions (GSI) examined low flow trends in the Spokane River and evaluated the extent to which a variety of current and historic hydrologic processes might be responsible for those trends. From that work, we concluded that changes in watershed conditions upstream of Coeur d'Alene Lake might be the primary factor contributing to a declining trend in August flows in the river during the past 3 to 4 decades, as measured at the Spokane Gage in downtown Spokane. This presentation examines the upstream hydrologic data and compares trends in those data with the trends at the Spokane Gage.



In the prior presentation, GSI evaluated trends in the seasonal low flows of the Spokane River, as measured at two gages with long-term records: the Spokane Gage (in downtown Spokane) and the Post Falls Gage (located just downstream of Post Falls Dam). The river has two localized gaining reaches between Coeur d'Alene Lake and the Spokane Gage (at the locations of the yellow circles); the rest of this reach is losing, with significant volumes of water seeping out of the river to provide an important component of groundwater recharge.

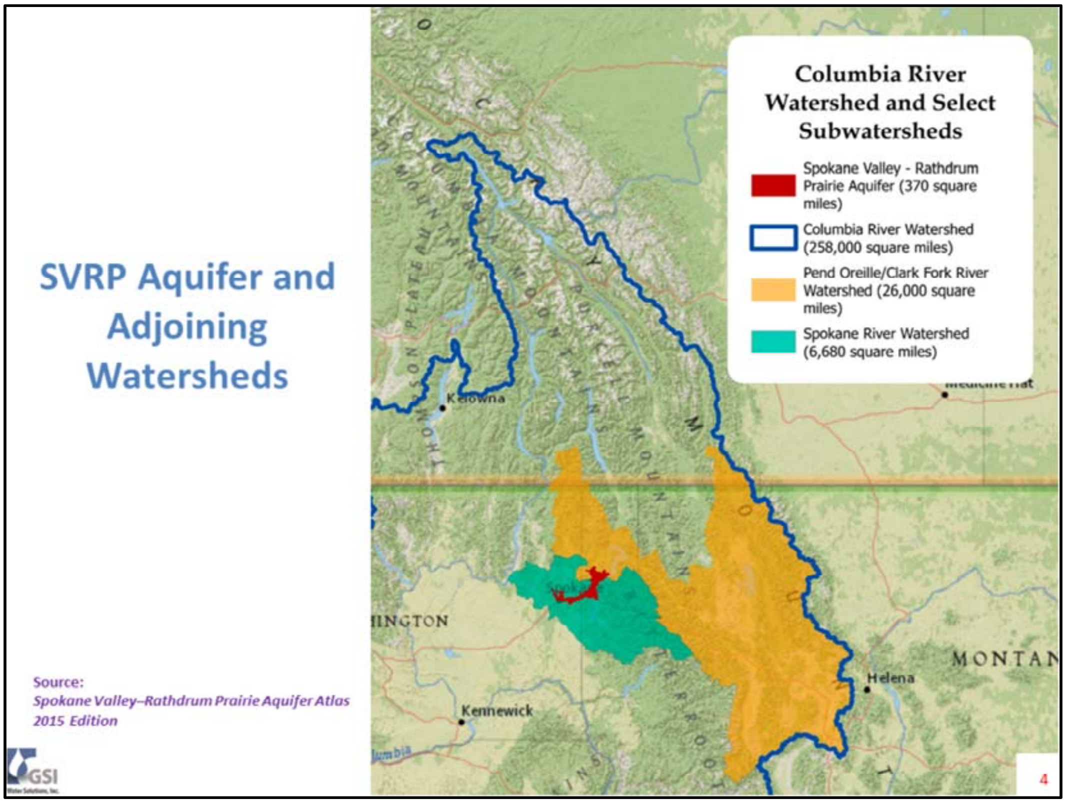


A 2011 study by Washington State University included a plot of the minimum daily flow at the Spokane Gage for each year between 1900 and 2007 . The authors drew two trends lines in the lower plot: one from 1900 through 1950, and one from 1950 through 2007.

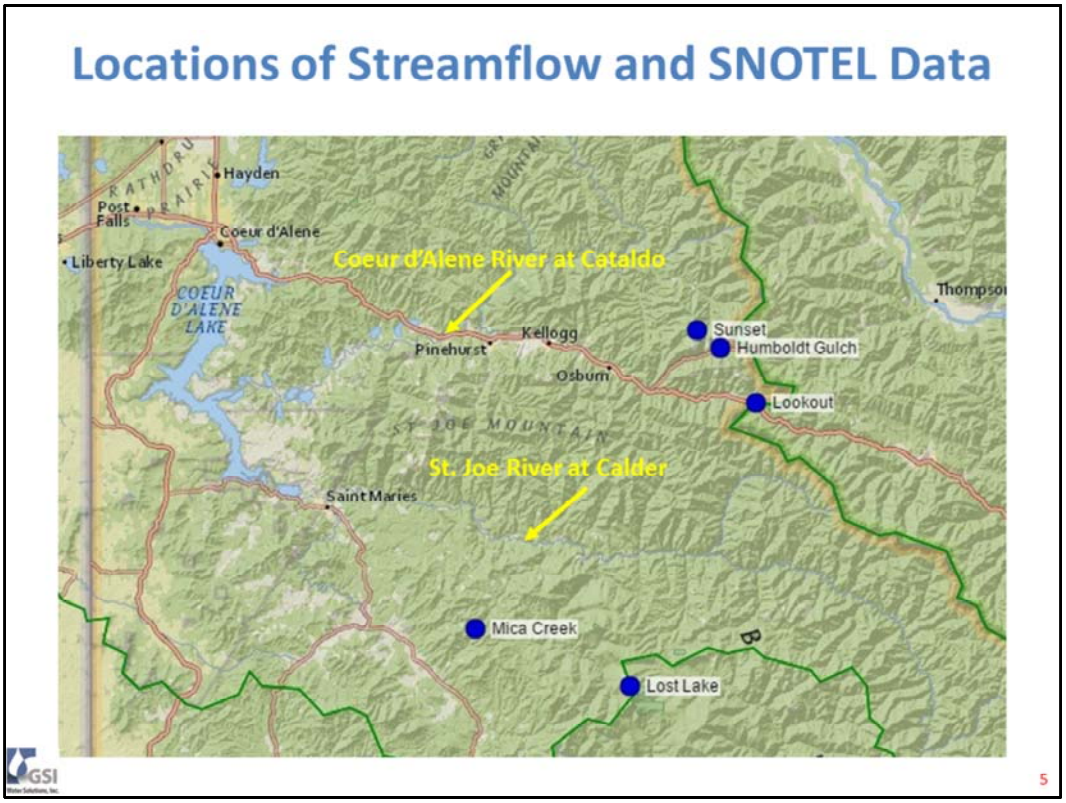
There are multiple metrics for measuring low flows within a stream. Typically the annual 1-day low flow (shown in these figures) and/or the annual 7-day low flow are used. The annual 7-day low flow is the lowest average flow rate observed over 7 consecutive days during a given year. Likewise the annual 1-day low flow is the lowest mean daily flow rate observed in a given year. As seen in these two plots, the 1-day low flow has been steadily decreasing. Typically low flow for the Spokane River occurs in August. For our analyses in the prior and current presentations, GSI has examined the year-to-year variations in the daily average flow rate during the entire month of August.

As discussed in the December 3, 2015 presentation, an historic analysis found that agricultural water use was the primary cause of the rate of decline in low flows during the first half of the 20th century.

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.



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.



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 from the two stream gaging sites shown on this map were the principal data sources used by GSI to evaluate the extent to which changes have occurred in the hydrology of the contributing watershed to Coeur d'Alene Lake.

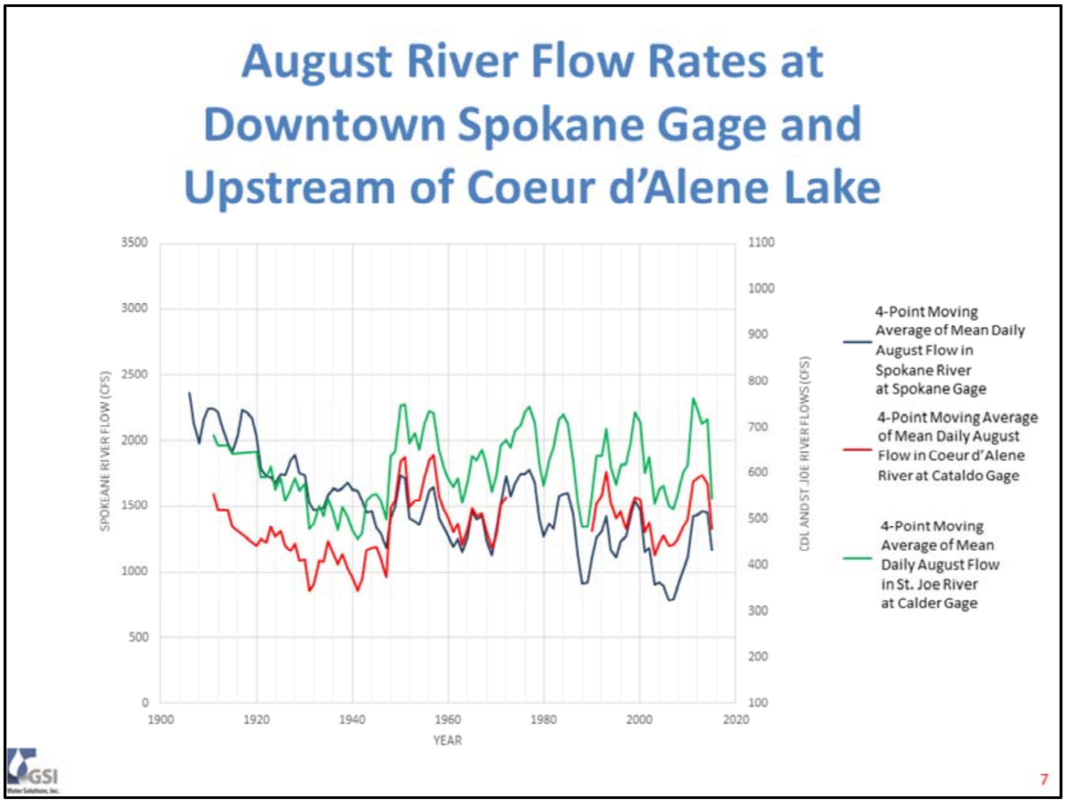
Citation: Hortness, J.E. and J.J. Covert. 2005. *Streamflow Trends in the Spokane River and Tributaries, Spokane Valley/Rathdrum Prairie, Idaho and Washington.* U.S. Geological Survey Scientific Investigations Report 2005-5005, 17 p.

Summary of Streamflow and SNOTEL Data

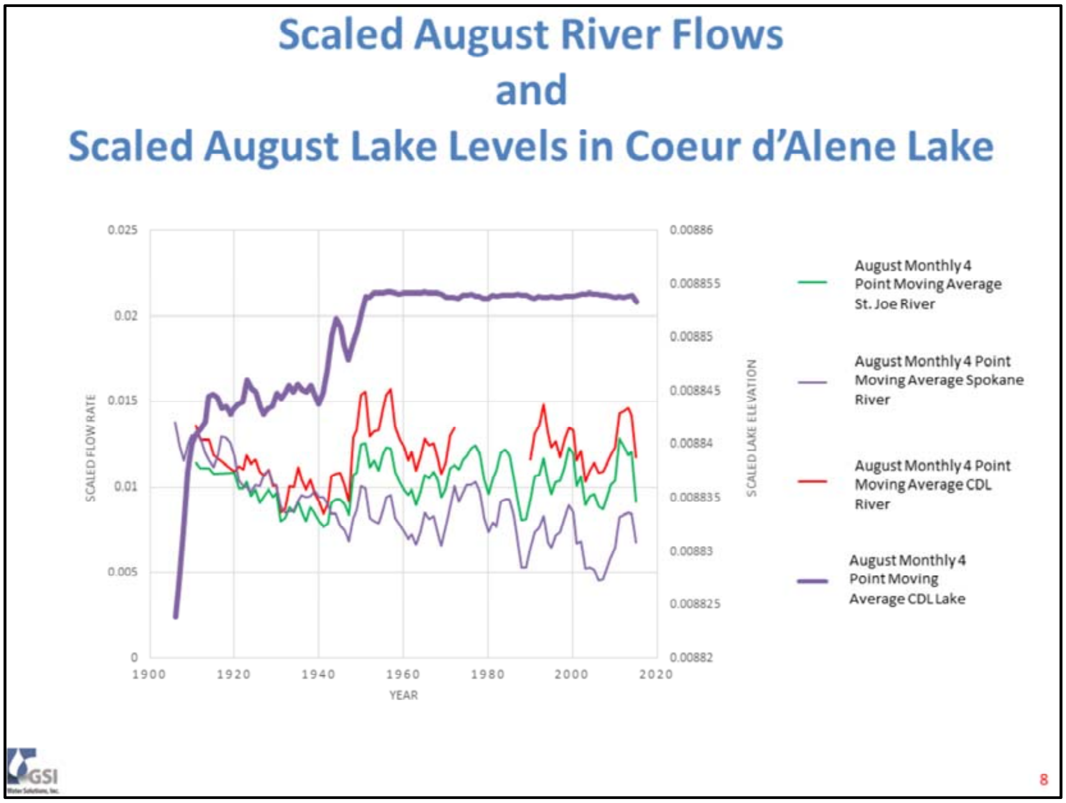
Station Name	Station type	Initial data taken for analysis	Data time span	Station Elevation (ft)
Sunset	SNOTEL	Daily snow water equivalent, max daily temperature, average daily temperature, minimum daily temperature	1981-2015	5540
Lost Lake			1982-2015	6110
Humboldt Gulch		Daily snow water equivalent	1981-2015	4250
Lookout			1981-2015	5140
Mica Creek			1990-2015	4510
Coeur d'Alene River at Cataldo	USGS gage	Average daily flow rate	1911-2015	
St. Joe River at Calder			1911-2015	

Note: Flows into Coeur d'Alene Lake are measured at two gages, which are the Coeur d'Alene River at Cataldo (gage 12413500) and the St. Joe River at Calder (gage 12414500). Prior studies have found that these gages account for about 92 percent of total inflows to Coeur d'Alene Lake

GSI Water Solutions, Inc.



This plot compares August flow rates in the Spokane River at the Spokane Gage (blue) with August flow rates in the two primary rivers feeding Coeur d'Alene Lake – the Coeur d'Alene River (red), and the St. Joe River (green). The plot shows the 4-year moving average of the mean daily flows during August at each of these three gages. Different vertical scales are used for the two gages upstream of Coeur d'Alene Lake versus the Spokane Gage, because of the large differences in flow values. The use of two different vertical scales allows us to more readily compare the trends from one gage to another. The plot shows that the trends in these three gages are similar at most times.



This plot takes the plot on Slide 7 and adds the August mean daily lake levels at Coeur d'Alene Lake from one year to the next. Note that the scaled values for the lake levels are plotted using a very small range of values, compared with the larger range of scaled values for the three stream gages. The plot shows how lake levels during August have been very stable from year to year since about 1950, whereas the stream gages show greater fluctuation in August river flows into and out of the lake.

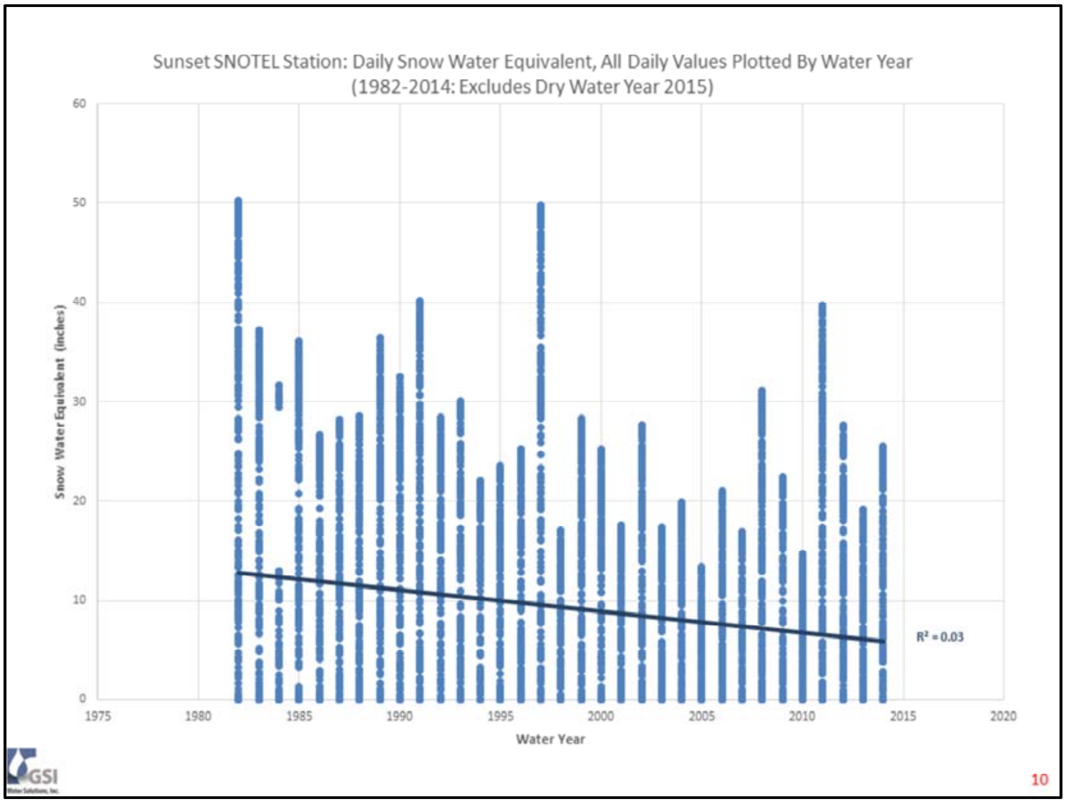
Because we are now plotting at three different scales in order to view the comparisons, we have used scaled values (rather than absolute values) of the 4-year moving averages of each of these data sets. As an example of what a scaled value is, let's assume we have 100 years of record for a given data set. The computation of a 4-year moving average results in 97 values – i.e., a value for every year except the first 3 years of data. To convert those 97 values into 97 scaled values, we total up the 97 values and then divide the value for each individual year by the sum of the 97 values. By doing this, the individual years with the highest 4-year moving average will have the highest scaled values of the 4-year moving average. Similarly, years with the lowest 4-year moving average will have the smallest scaled values of the 4-year moving average.

An important detail about the calculation of scaled values is that the scaled values for a given stream gage are calculated independently of the data at the other two stream gages. Likewise, the scaled lake stage values are calculated independently of the stream gage data.

What Hydrologic Factor Could be Causing Low River Flows?

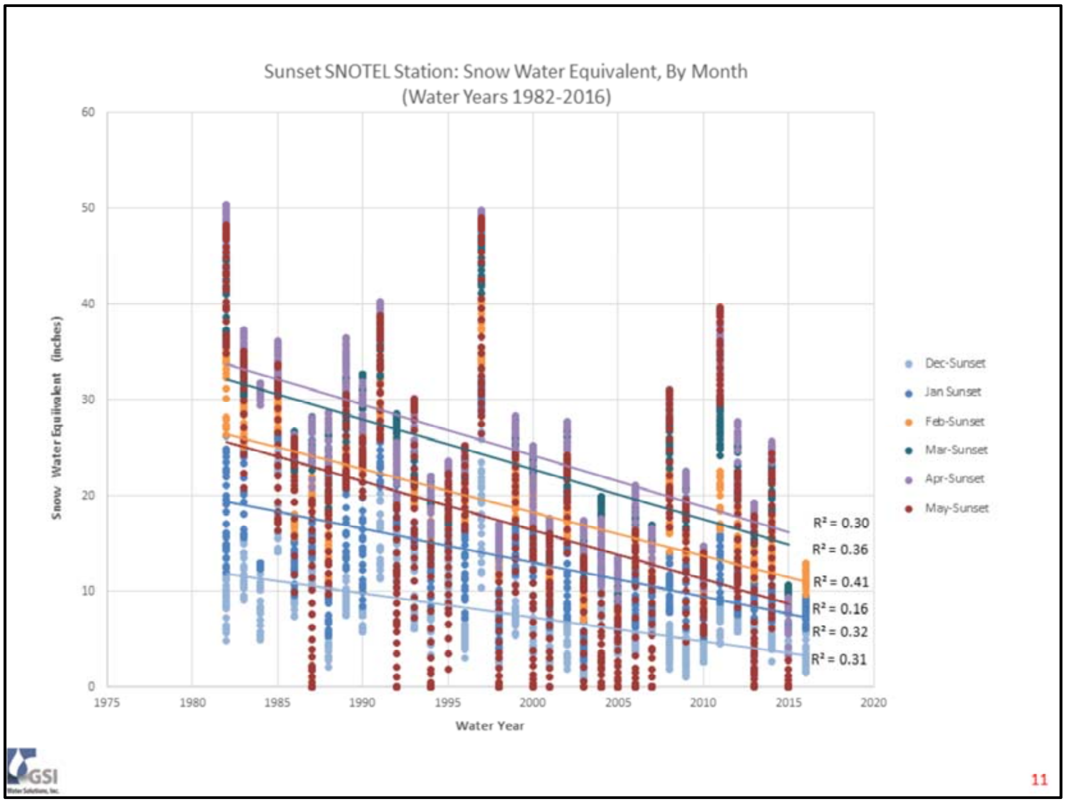
- The precipitation gage at the City of Coeur d'Alene is not showing long term trends.
  - See December 2015 presentation
- Are there changes in the snowpack?
  - Warmer temperatures = lower snowpack
  - Warmer temperatures = early snowmelt
  - Lower snowpack + early snowmelt = reduced late summer stream flows

GSI



In this plot for the Sunset SNOTEL station (which lies at elevation 5,540 feet), we have plotted for each individual year the 365 or 366 daily readings of snow-water-equivalent values for that entire year. Those values are plotted for each year from water year 1982 through water year 2014. Because we are looking for whether a declining trend has occurred over time, we have chosen to not include the dry water year of 2015, because its inclusion could potentially create a biased conclusion of a declining trend.

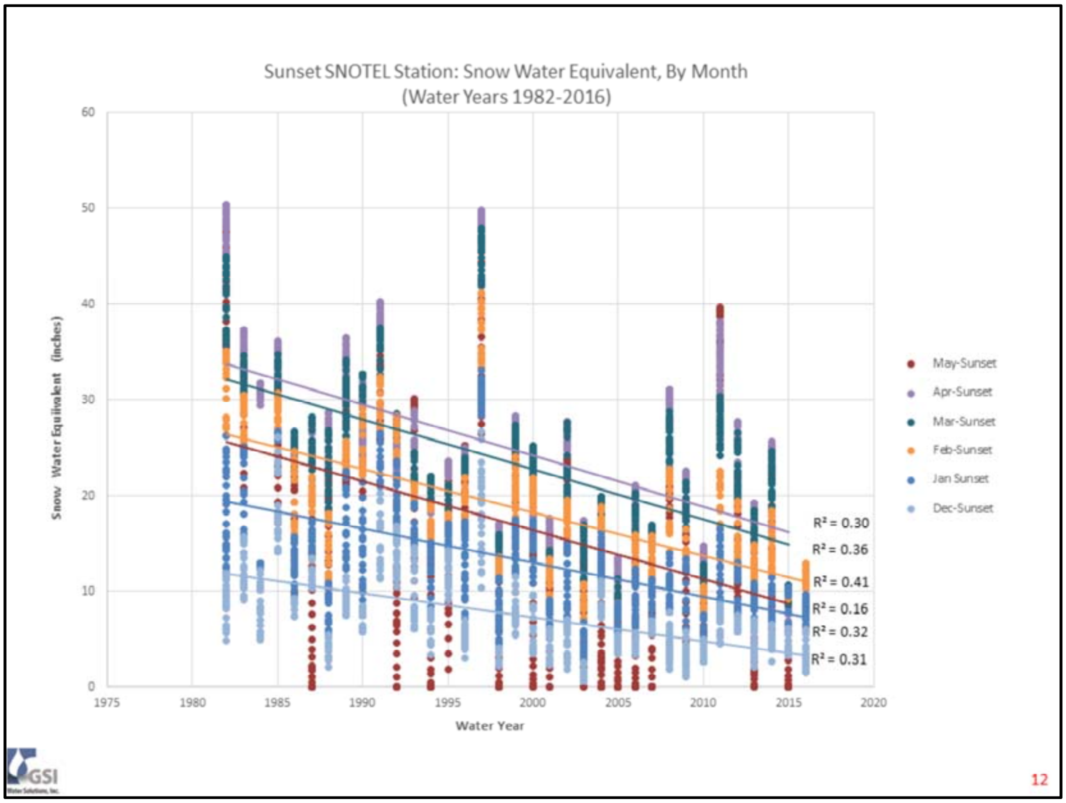
A trend line shows a possible declining trend over the 33-year period shown on this plot. However, the trend is not strong, as indicated by the small magnitude of the coefficient of determination (the low R^2 value). This indicates that the snowpack amount for the entire winter/spring season may be changing only slightly. The question now becomes whether the snowpack changes significantly in certain months, particularly those governing the snowmelt.



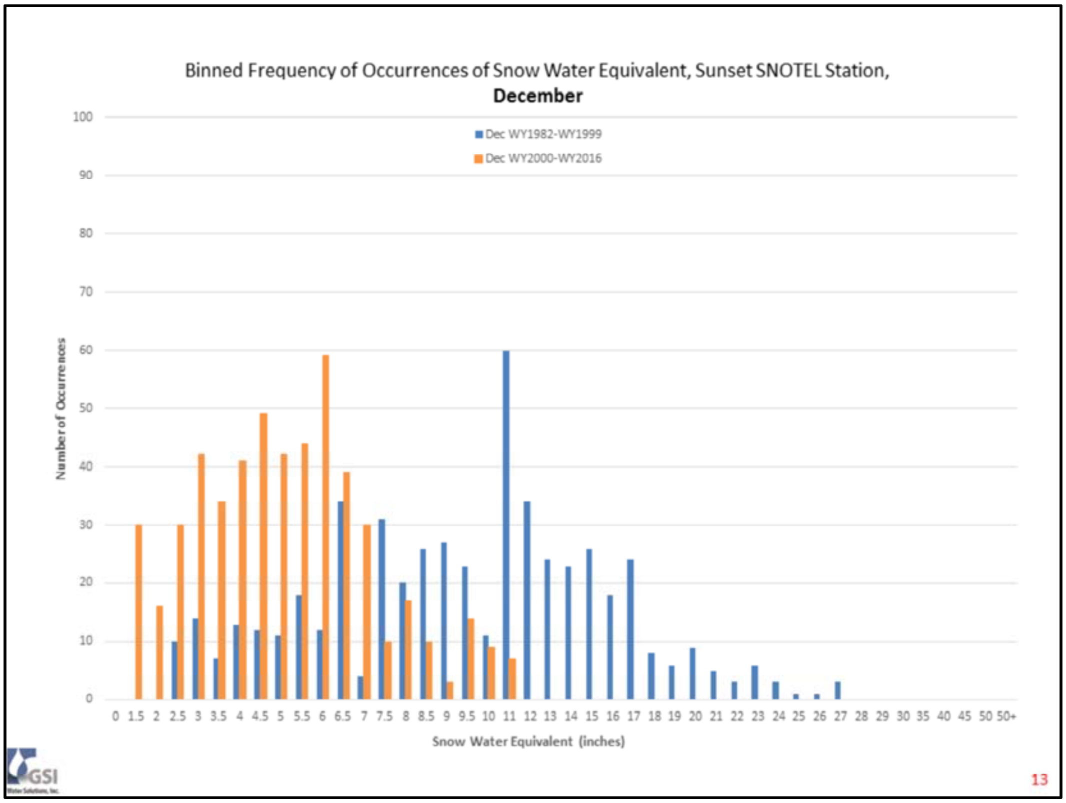
In contrast, to Slide 10, we see significant decreasing trends over time when we consider the daily data for just a given month. This plot shows the water year 1982 to water year 2016 values for December, then separately for January, then separately for February. The plot also shows the water year 1982 to water year 2015 values for each of the next three individual months in the late winter and spring (March, April, and May). (March through May data for water year 2016 were not yet available as of the time of this study.)

All six months (considered independently of one another) show coefficient pf 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.

Because of the way the data are plotted, the dots for the later months tend to plot on top of the dots for the earlier months in some cases. The next slide will plot the sequence the opposite way, to make the data for the early months more visible.

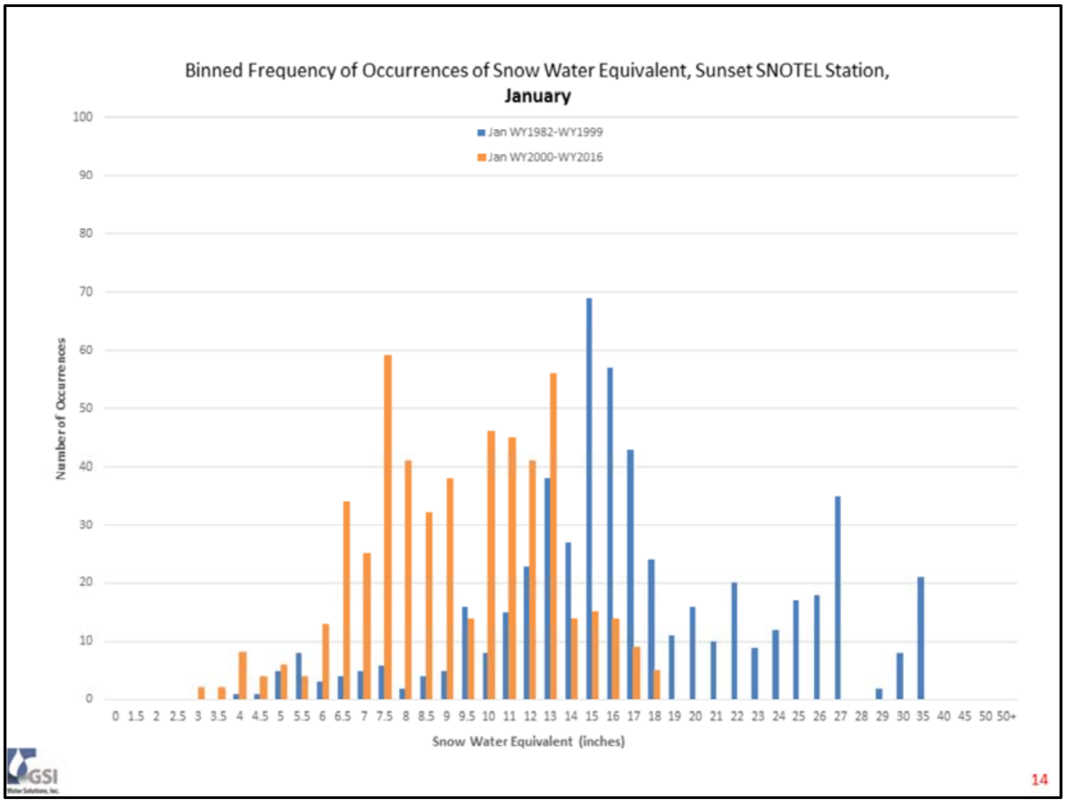


This is the same as Slide 11, except the data are plotted in reverse order, so that the first four months of data are more visible. The trend lines and coefficients of determination (R^2 values) are unchanged from Slide 11.

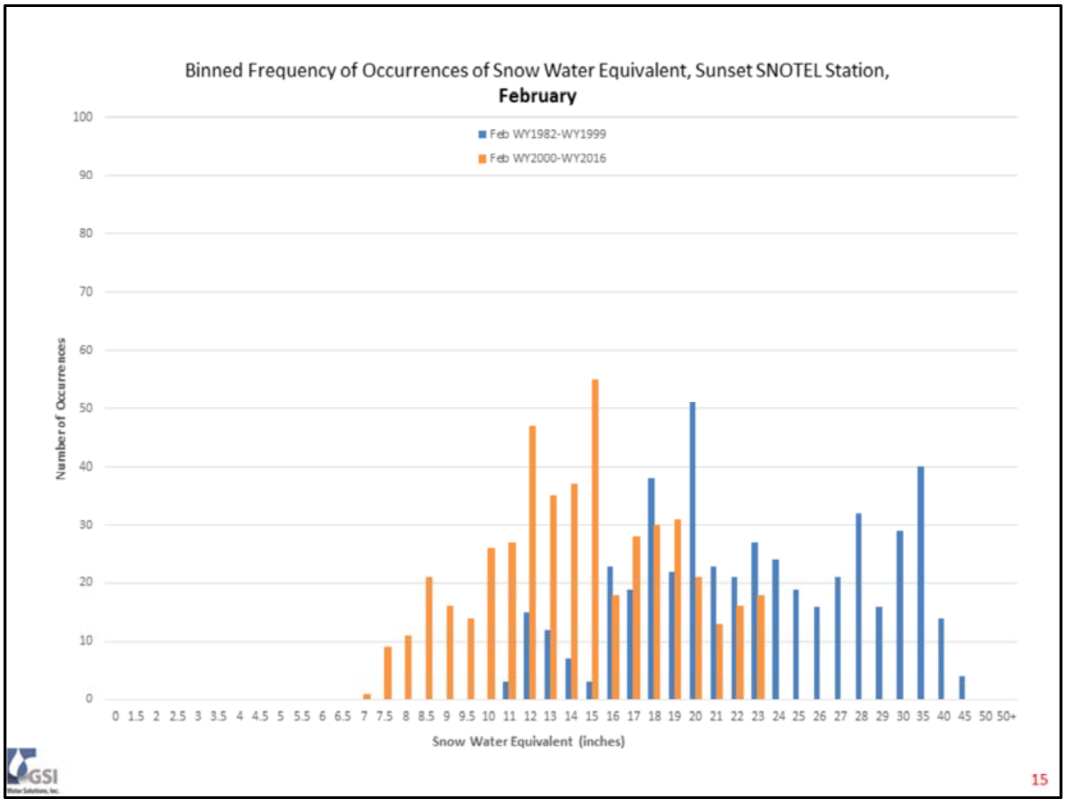


This histogram shows the number of occurrences of various daily snow-water-equivalent (SWE) values during December. This is shown for Decembers during water years 1982 through 2016 (i.e., December 1981 through December 2015). The data have been binned into two time periods: water years 1982 through 1999 (December 1981 through December 1998), shown in blue, and water years 2000 through 2016 (December 1999 through December 2015), shown in orange.

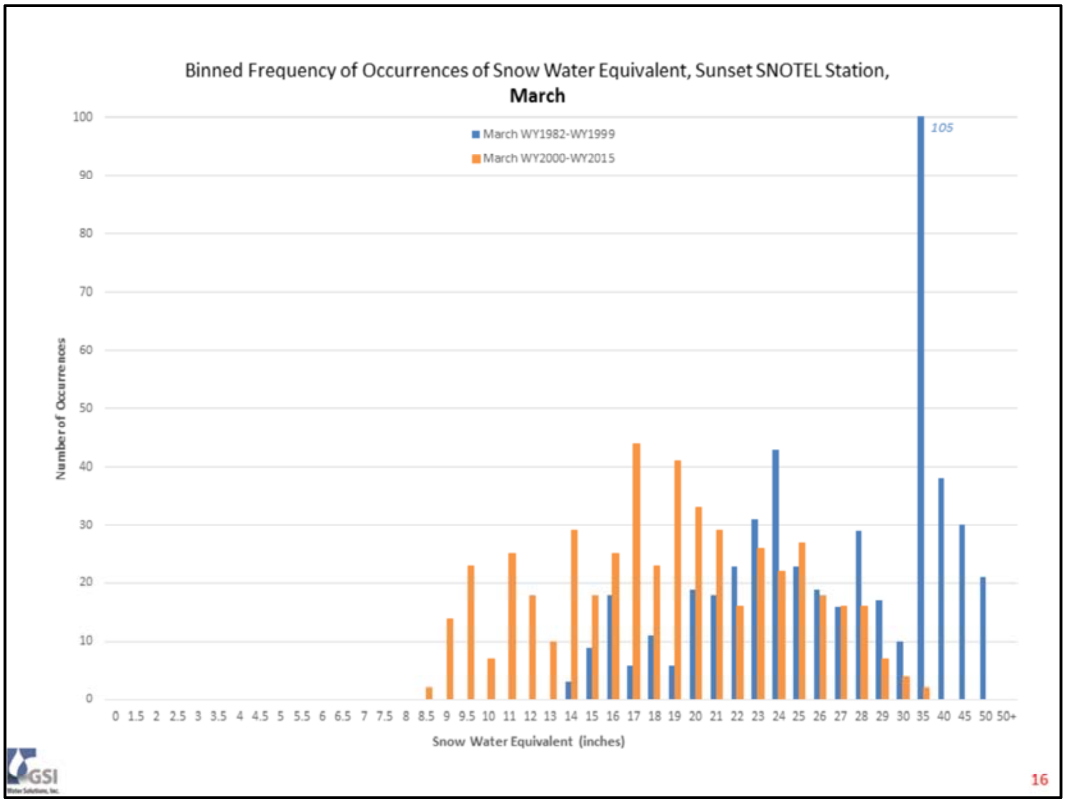
This histogram shows a left-ward shift from the first time period to the second time period, which indicates that the water content in the December snowpack has been notably lower during the past 17 years than during the prior 18-year period.



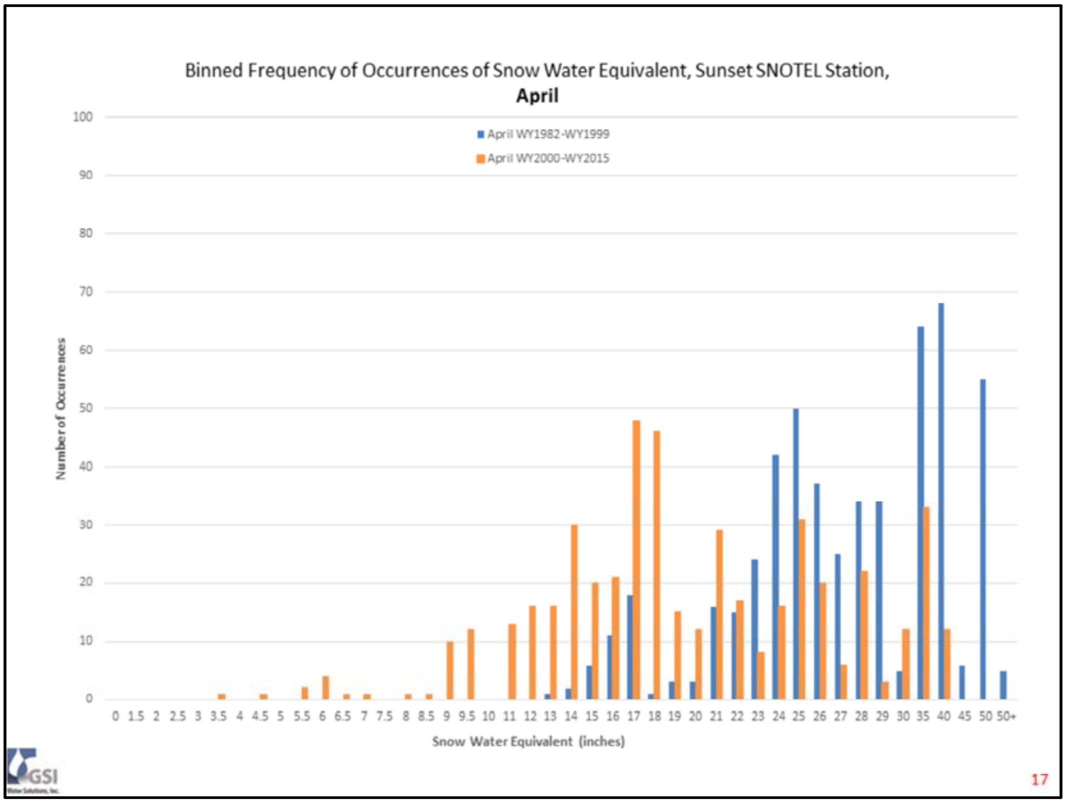
This is the January histogram for the same water years (1982 through 1999 in blue, and 2000 through 2016 in orange). Compared with the prior plot for December, both plots are further to the right. However, as with December, the histogram shows a left-ward shift from the first time period to the second time period, which indicates that the water content in the January snowpack has been notably lower during the past 17 years than during the prior 18-year period.



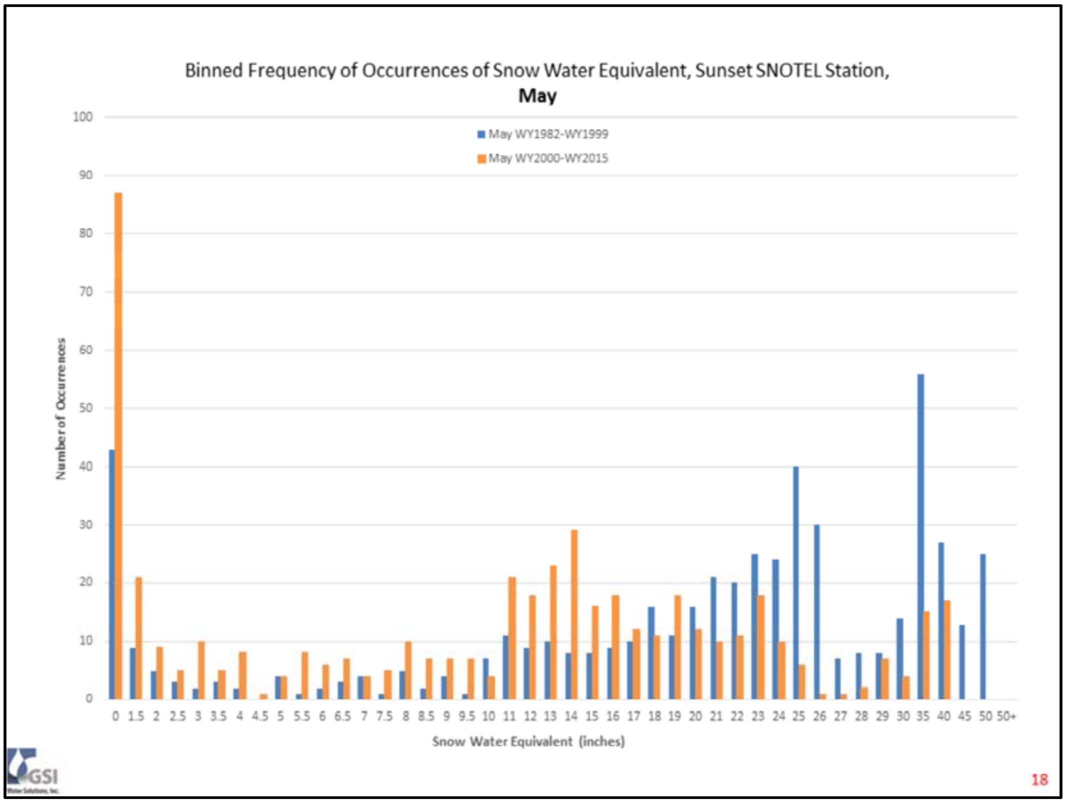
This is the February histogram for the same water years (1982 through 1999 in blue, and 2000 through 2016 in orange). Compared with December and January, both of these water year groups plot further to the right. However, as with December and January, the histogram shows a left-ward shift from the first time period to the second time period, which indicates that the water content in the February snowpack has been notably lower during the past 17 years than during the prior 18-year period.



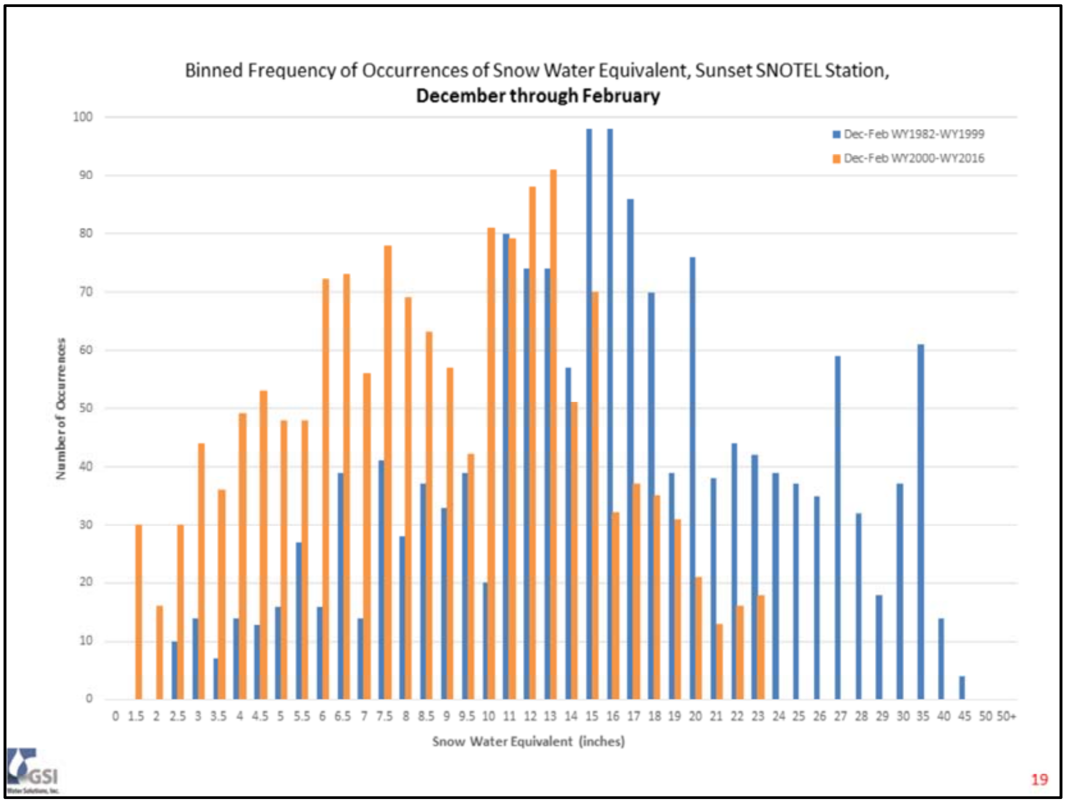
This is the March histogram for water years 1982 through 1999 in blue, and water years 2000 through 2015 in orange. Compared with December, January, and February, both of these water year groups plot further to the right. However, as with December, January, and February, the histogram shows a left-ward shift from the first time period to the second time period, which indicates that the water content in the March snowpack has been notably lower during the past 16 years than during the prior 18-year period.



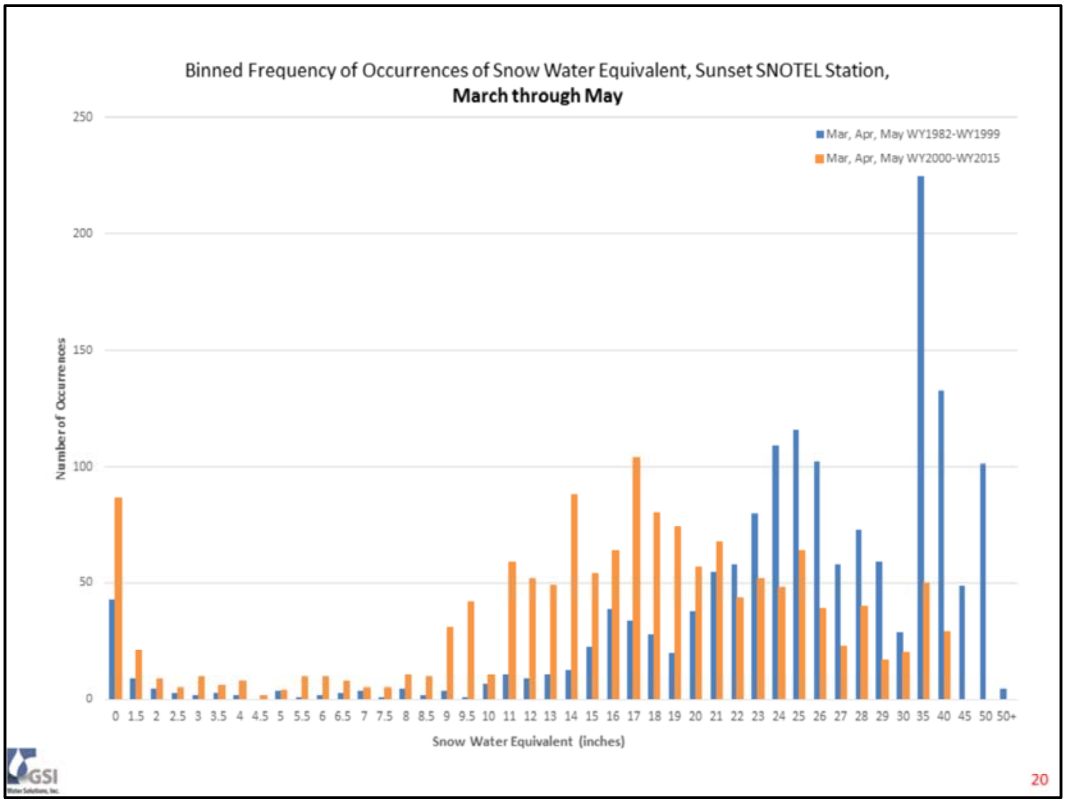
This is the April histogram for water years 1982 through 1999 in blue, and water years 2000 through 2015 in orange. Both of these water year groups plot towards the right side of the plot, as was the case in March. However, as with December, January, February, and March, the histogram shows a left-ward shift from the first time period to the second time period, which indicates that the water content in the April snowpack has been notably lower during the past 16 years than during the prior 18-year period.



This is the May histogram for water years 1982 through 1999 in blue, and water years 2000 through 2015 in orange. As with the earlier months, the histogram shows a left-ward shift from the first time period to the second time period, which indicates that the water content in the May snowpack has been notably lower during the past 16 years than during the prior 18-year period. Particularly striking is the substantially greater number of occurrences of no snowpack during the recent period (87 occurrences) versus the prior period (43 occurrences).

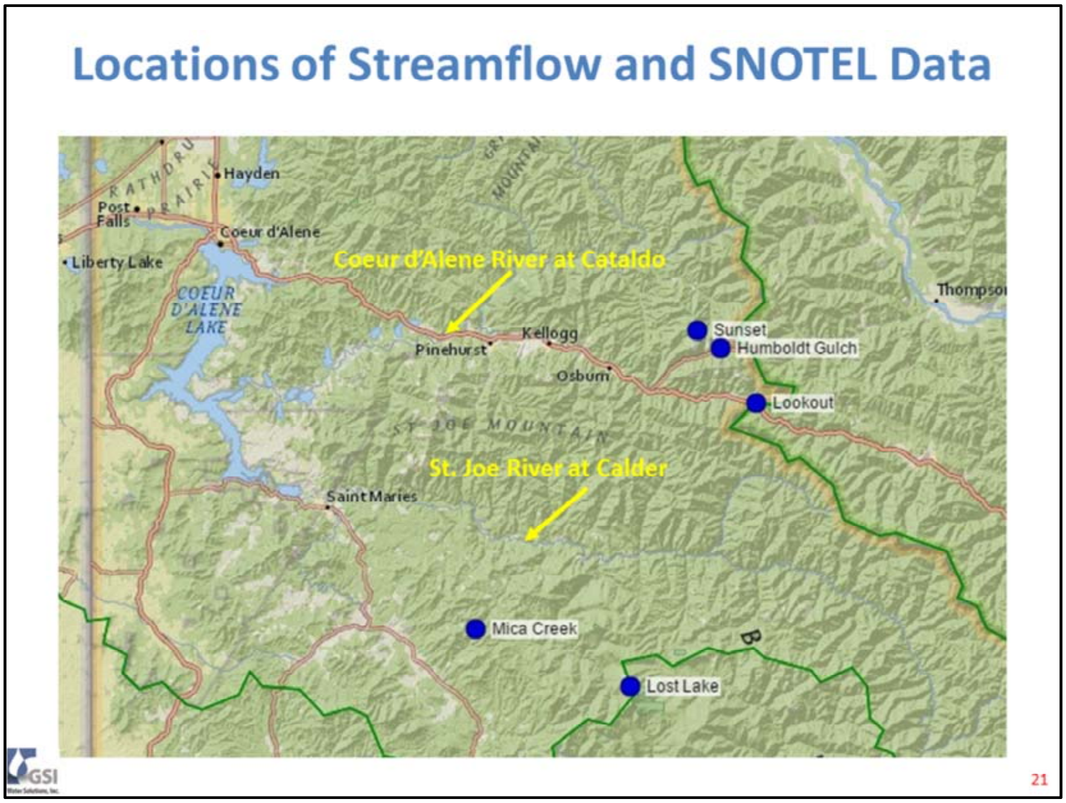


The snow-water-equivalent data at the Sunset SNOTEL station were also examined for three-month long time periods. This histogram is for the first three winter months (December through February), and like the individual months shows a left-ward shift over time when comparing the 17 most recent years (orange) with the first 18 years (blue).

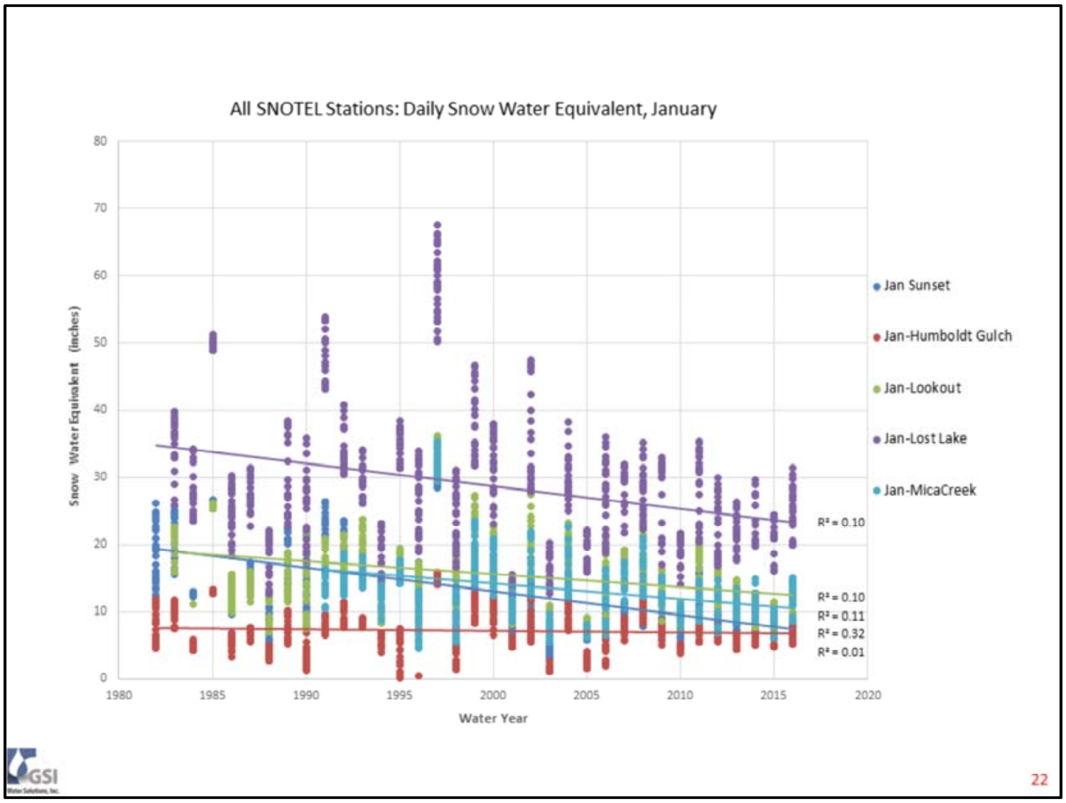


This histogram is for the next three months in late winter and early spring (March through May). Note the different vertical scale compared with the prior histograms, because of the very high snowpack amounts that occurred in the past (the blue bars).

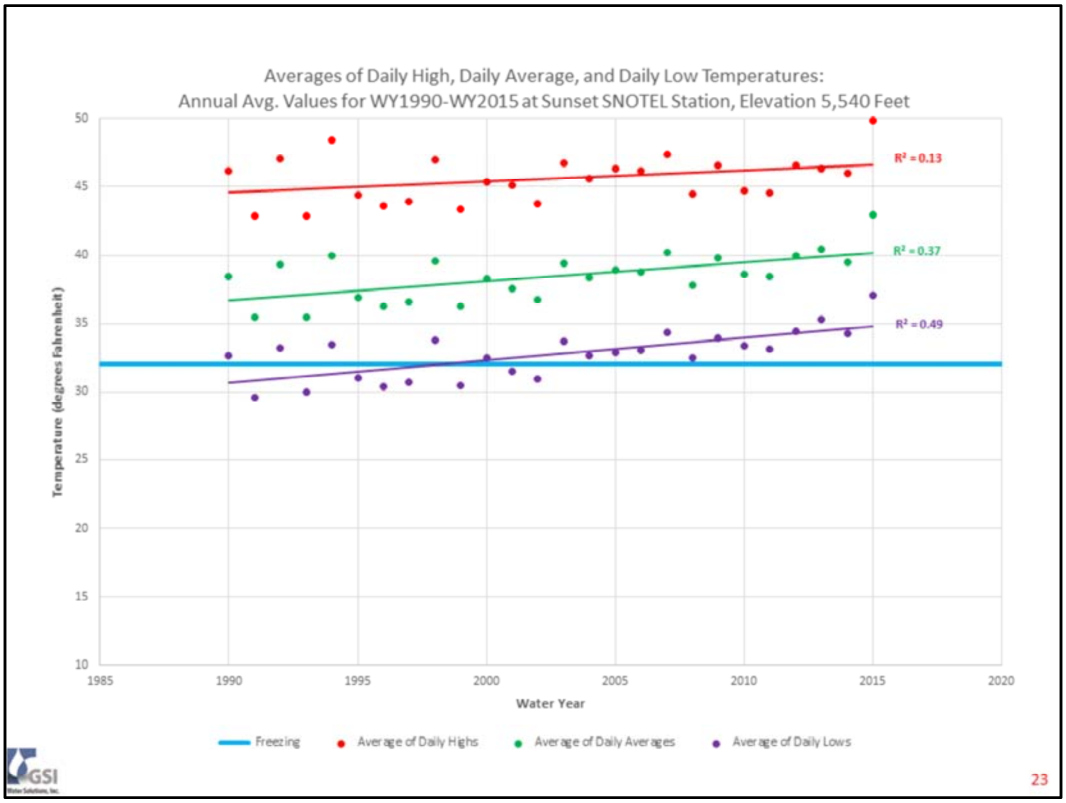
The histogram shows a left-ward shift over time. Note in particular that the number of occurrences of a zero snowpack during the March-through-May season increased from 43 occurrences (prior to water year 2000) to 87 occurrences during water years 2000 through 2015.



The Sunset station is the second highest in elevation of the SNOTEL stations shown on this map. Let's see if we might find similar trends at the other stations, particularly the highest station (Lost Lake).

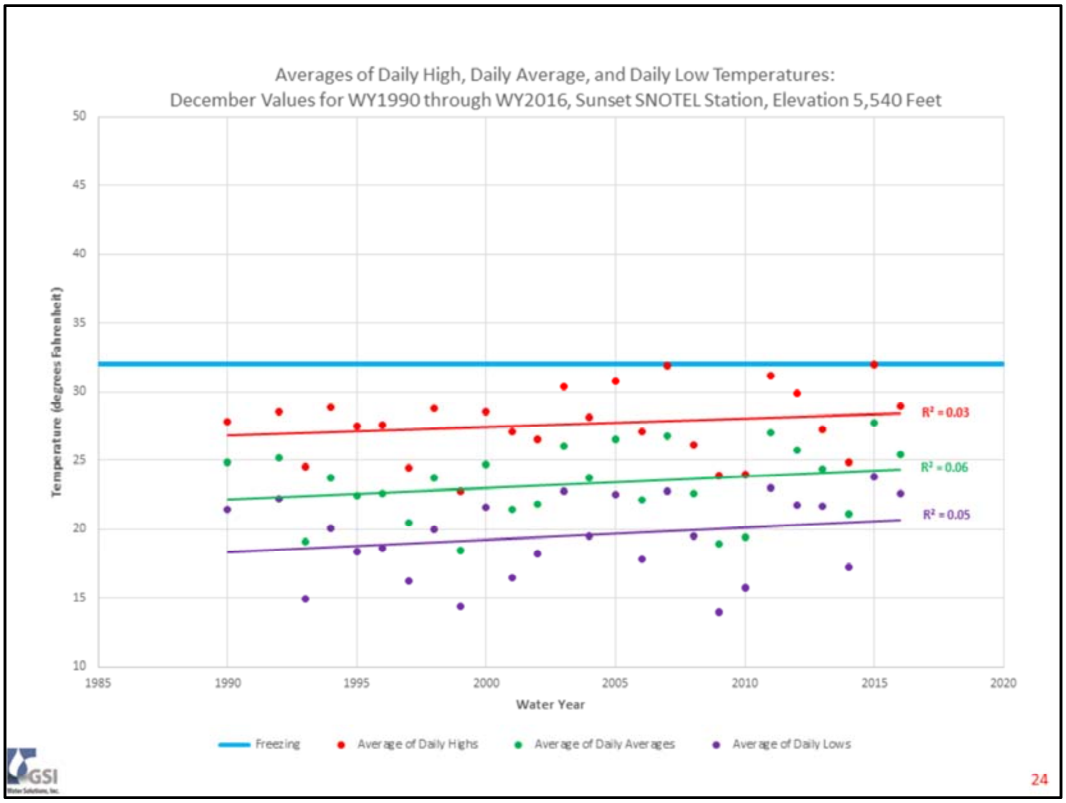


This plot shows the January trends since water year 1982 at each station. Note that the R^2 values are on the order of 10 percent for three stations (Lookout [elevation 5,140 feet], Lost Lake [elevation 6,110 feet], and Mica Creek [elevation 4,510 feet]) and 32 percent for a fourth station (Sunset [elevation 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.

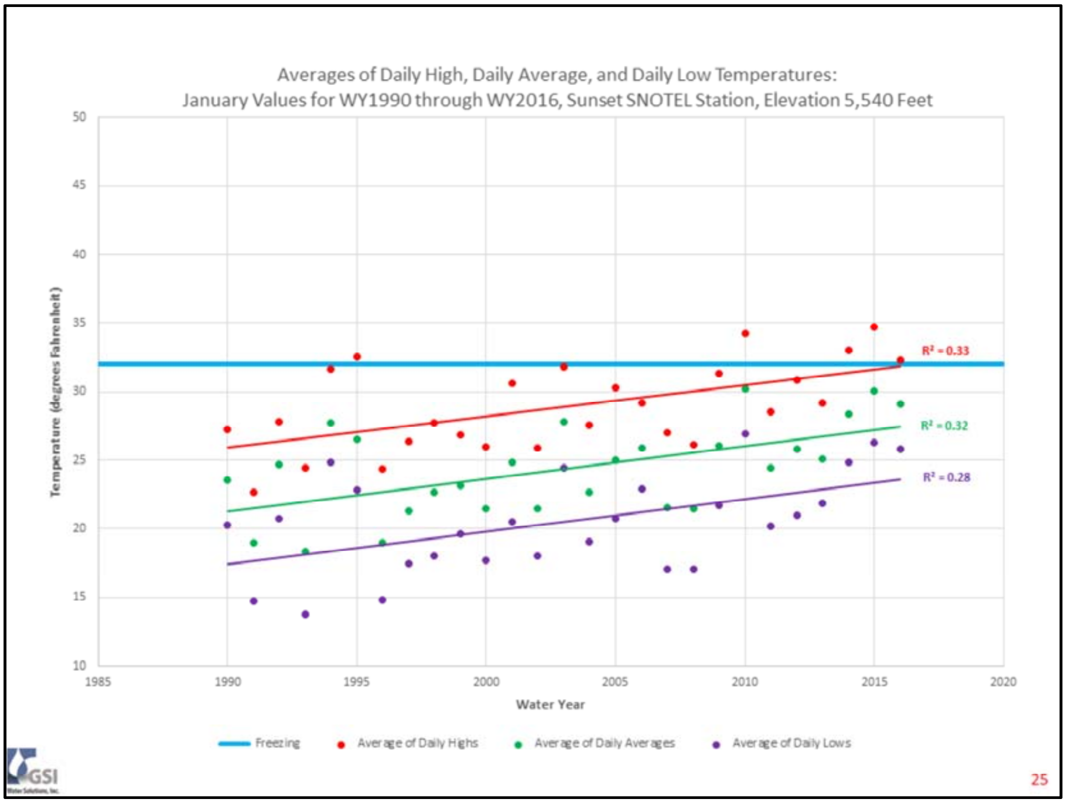


The analyses of snow-water-equivalent data in the prior slides help us understand the volume of water in the snowpack, and how this has changed from one year to the next. To understand how the timing of snowmelt might be changing, we need not only the snow-water-equivalent data, but also the temperature data. Here is a plot showing average daily temperatures from year to year, using all days in a given year to compute that year's value. In a year containing 365 days, this is shown for the average of the 365 daily high temperatures, the average of the 365 daily low temperatures, and the average of the 365 daily average temperatures.

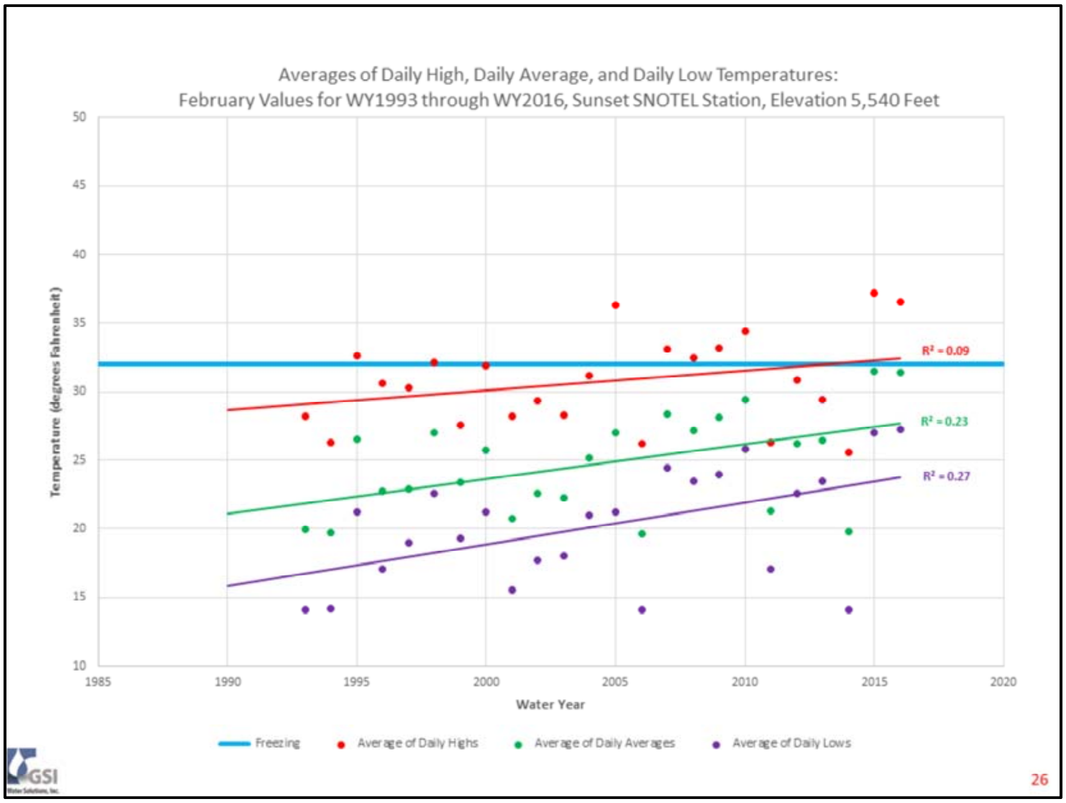
This plot shows a distinct upward trend, particularly in the annual average daily low temperatures at the Sunset SNOTEL station. We also can see that the average daily low temperatures have consistently been the freezing mark (32 degrees Fahrenheit, shown by the sky blue colored line) since 2003. While this is useful for understanding the watershed temperature changes on a long-term basis, this does not by itself help us understand snowmelt because the plot is constructed using data for the entire calendar year. On the next 5 slides, we examine what these plots look like on a month-to-month basis during the winter and early spring (from December through April).



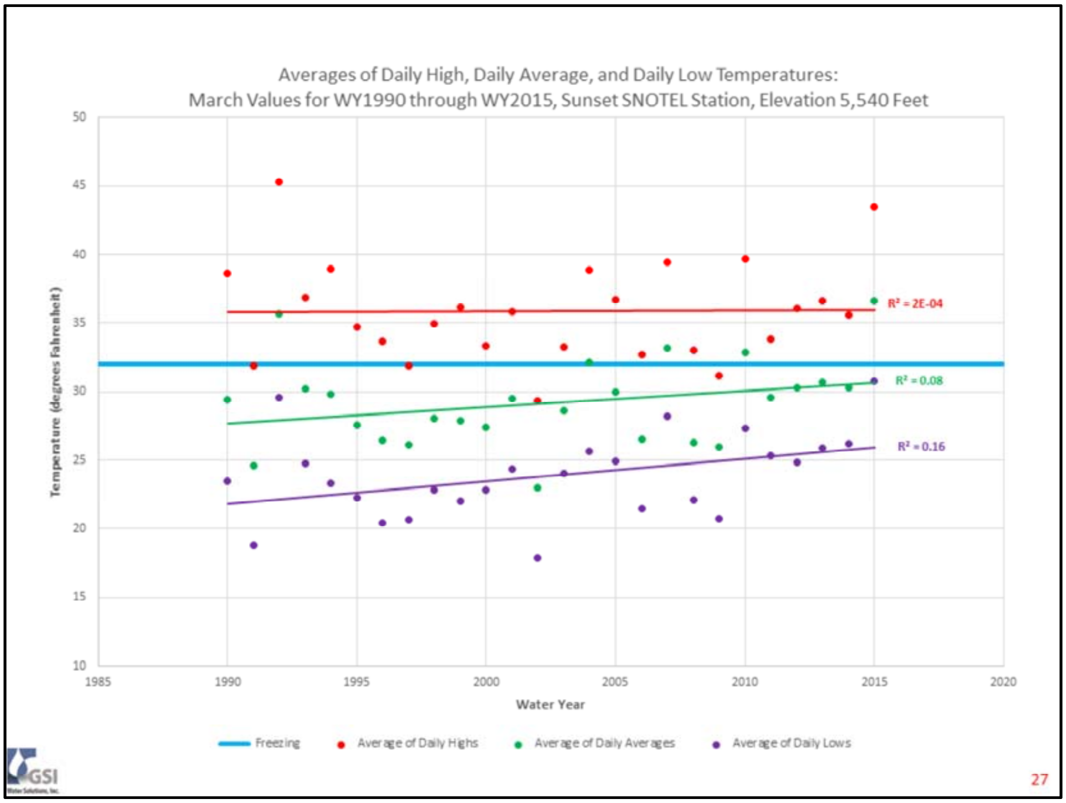
The December plot shows temperatures that are generally below the freezing mark in all years, or at freezing in a few years in the case of the daily high temperature. The coefficients of determination (the R^2 values) are low, indicating that December is not showing a significant temperature change during the past 27 years at this particular SNOTEL station.



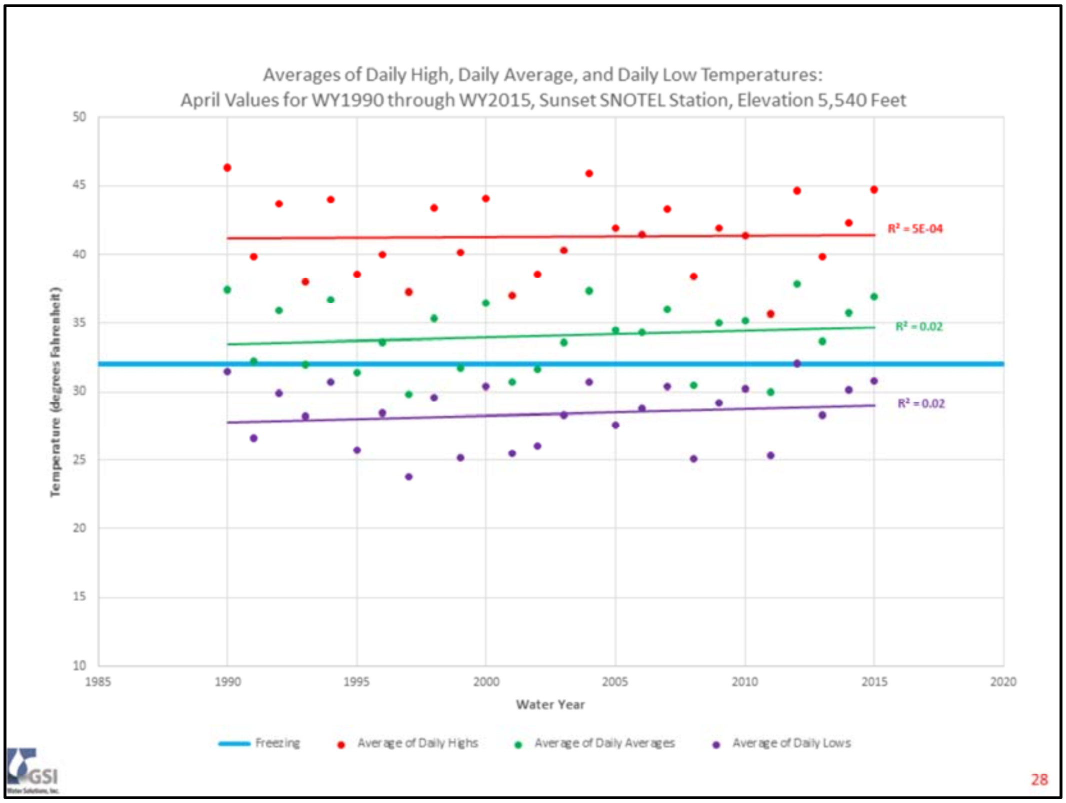
Unlike December, the month of January shows a strong upward trend in temperatures at the Sunset SNOTEL station during the past 27 years. This is indicated by the high values of the coefficient of determination (R^2), which are on the order of 0.3 for all three temperature data sets in January. Also, in comparing this slide and the prior slide, we can see that before 2010, the January temperatures were often similar to, or lower than, the December temperatures. However, this has changed since 2010, with January temperatures having been warmer than the December temperatures. This is especially the case for the daily average high temperatures, which have reached or exceeded the freezing mark several times since about 2008.



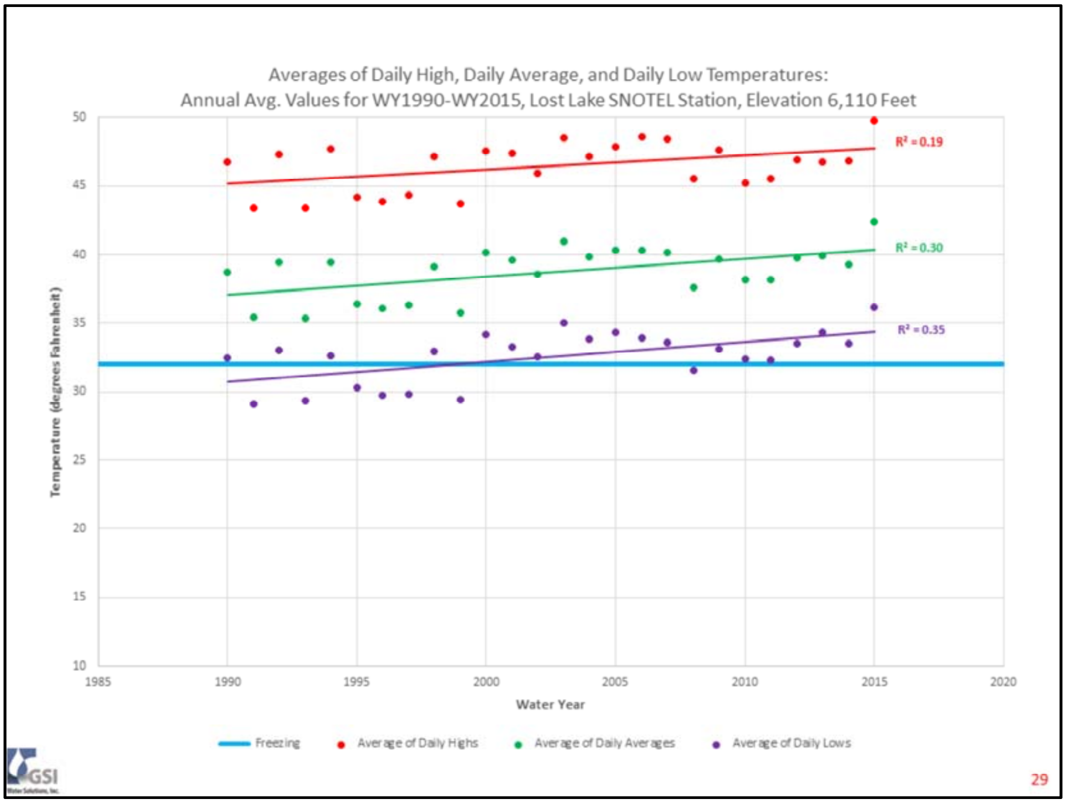
The February low and average temperatures show a strong upward trend (coefficient of determination [R^2] values of 0.27 and 0.23, respectively). A modest trend is apparent in the daily high temperatures (R^2 value near 0.1), which rise above the freezing mark in several years from 2005 through 2016.



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.

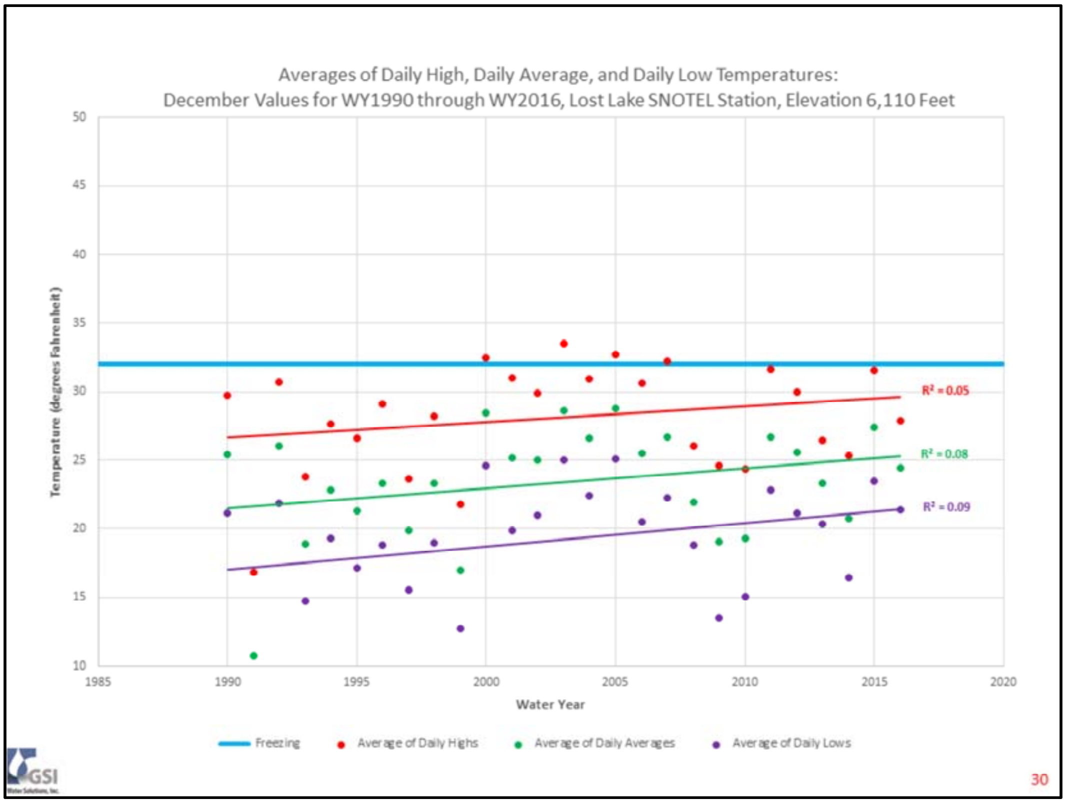


April temperatures trends are not significant. Hence, the primary temperature changes at the Sunset SNOTEL station occur in January and February, plus an increase in daily low temperatures during March. It is for those three months that greater snowmelt is likely occurring in recent years than in the past.

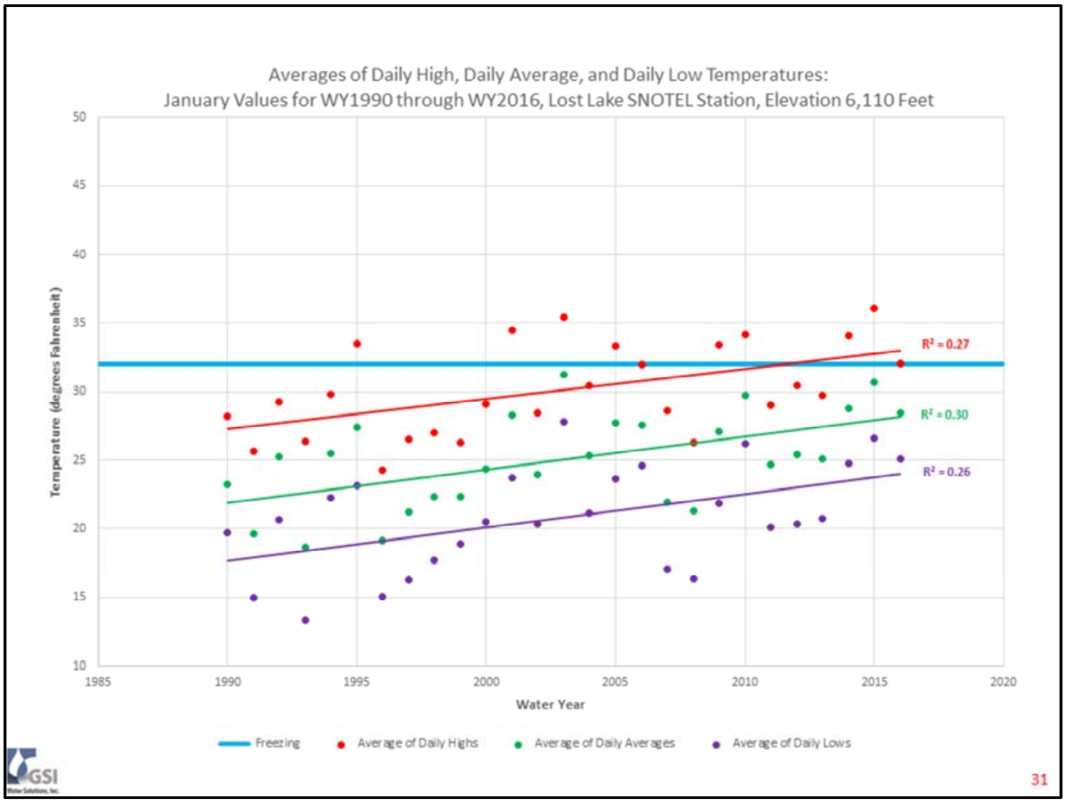


The Sunset SNOTEL station is the second highest station in the local network. Let's conduct a similar examination of temperature at the highest SNOTEL station in the Coeur d'Alene Lake watershed – the Lost Lake station, which lies about 600 feet higher than the Sunset station.

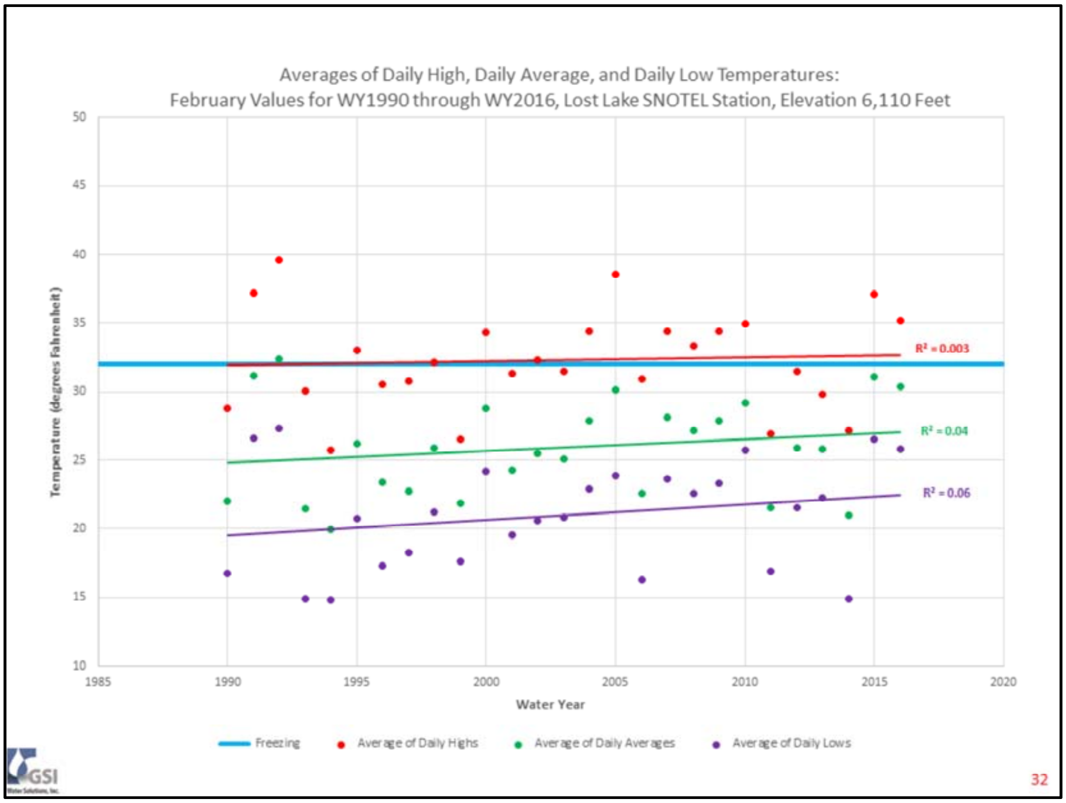
This is the annual average plot for Lost Lake, which shows significant upward trends on an annual basis, as was seen in the annualized data at the Sunset station (slide 23). Let's now examine the monthly plots from December through April at the Lost Lake station.



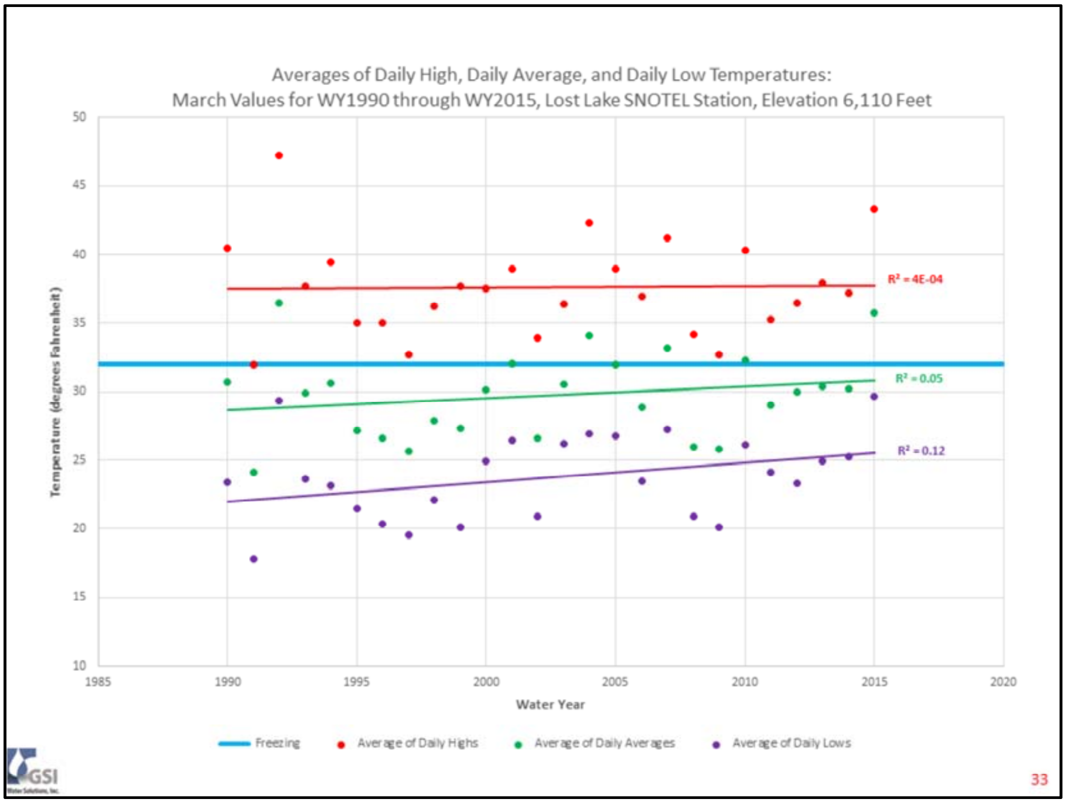
For December, the Lost Lake station shows a possible upward trend in temperatures, particularly in the daily low (R^2 value of nearly 0.1). The upward trends in the December data are slightly stronger at the Lost Lake station (this slide) than at the Sunset station, where there was only minimal suggestion of a possible upward trend (see slide 24).



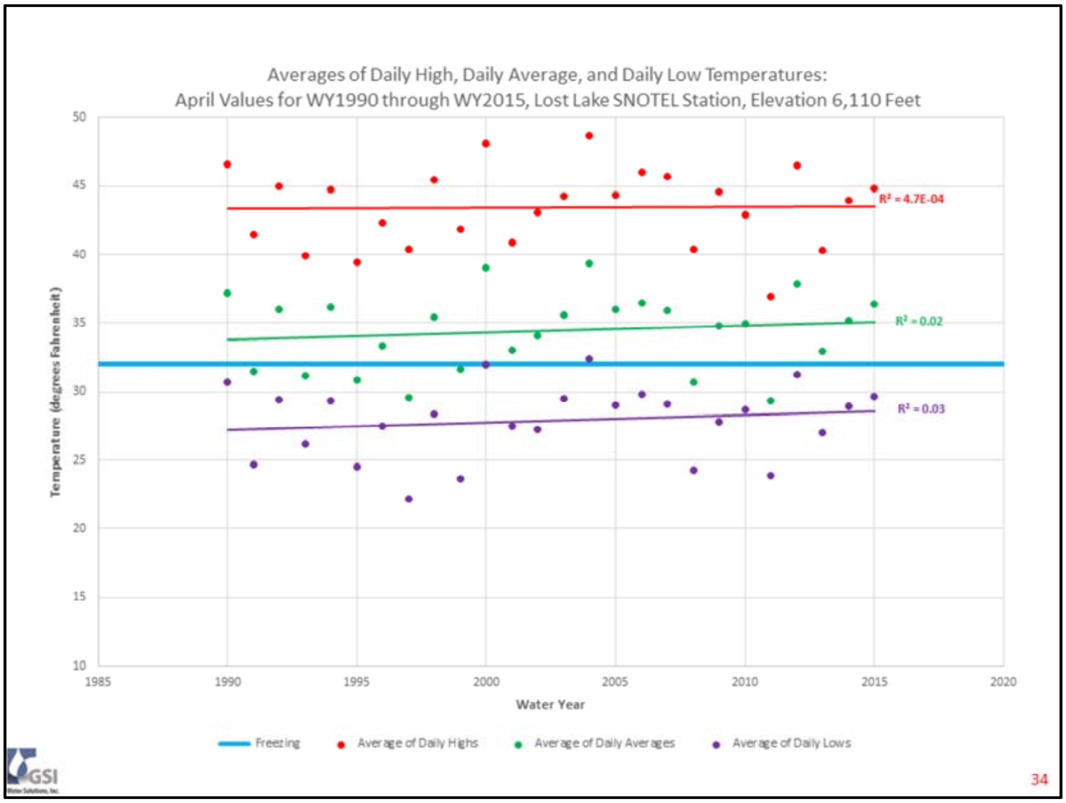
In January, as was the case at the Sunset station (slide 25), the Lost Lake station shows a strong upward temperature trend. This is indicated by the high values of the coefficient of determination (R^2), which range from 0.26 to 0.30 for the three temperature data sets in January.



In February, a slight upward trend in daily low temperatures may be occurring at Lost Lake. But the values for the coefficient of determination (R^2) indicate these trends are less than at the Sunset station (slide 26).

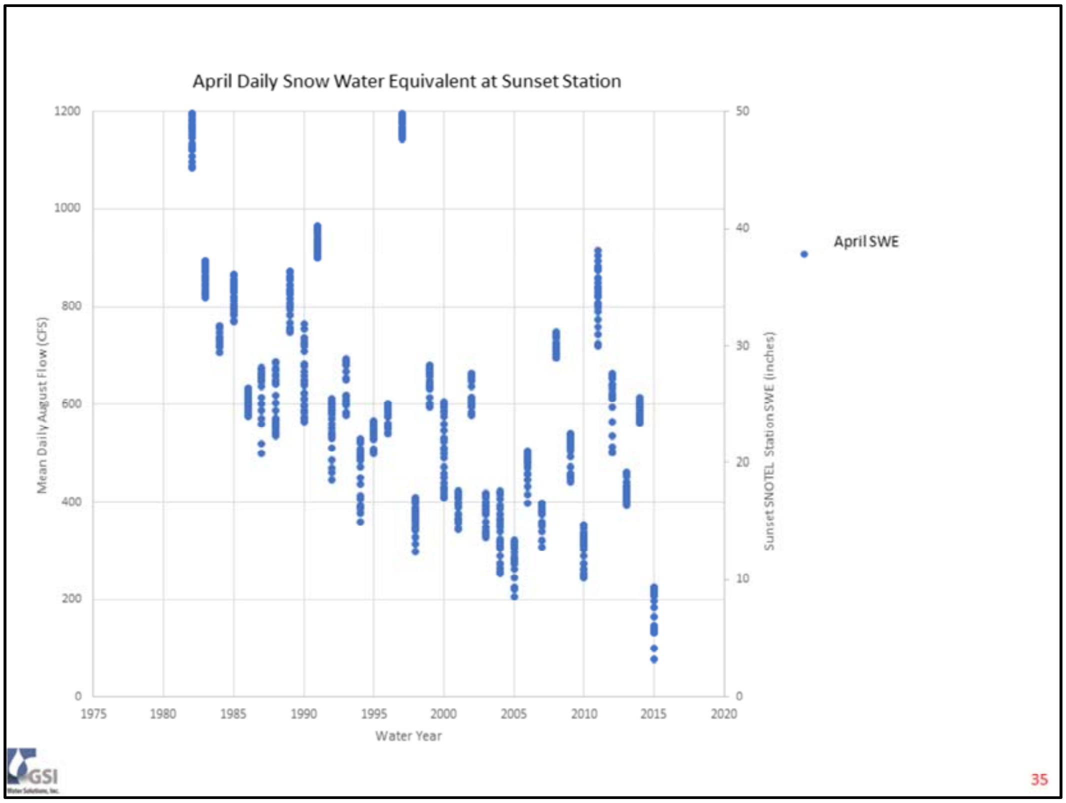


Similarly to the Sunset station (slide 27), the Lost Lake station shows a modest upward trend in daily low temperatures during March, but no trend in daily high temperatures.

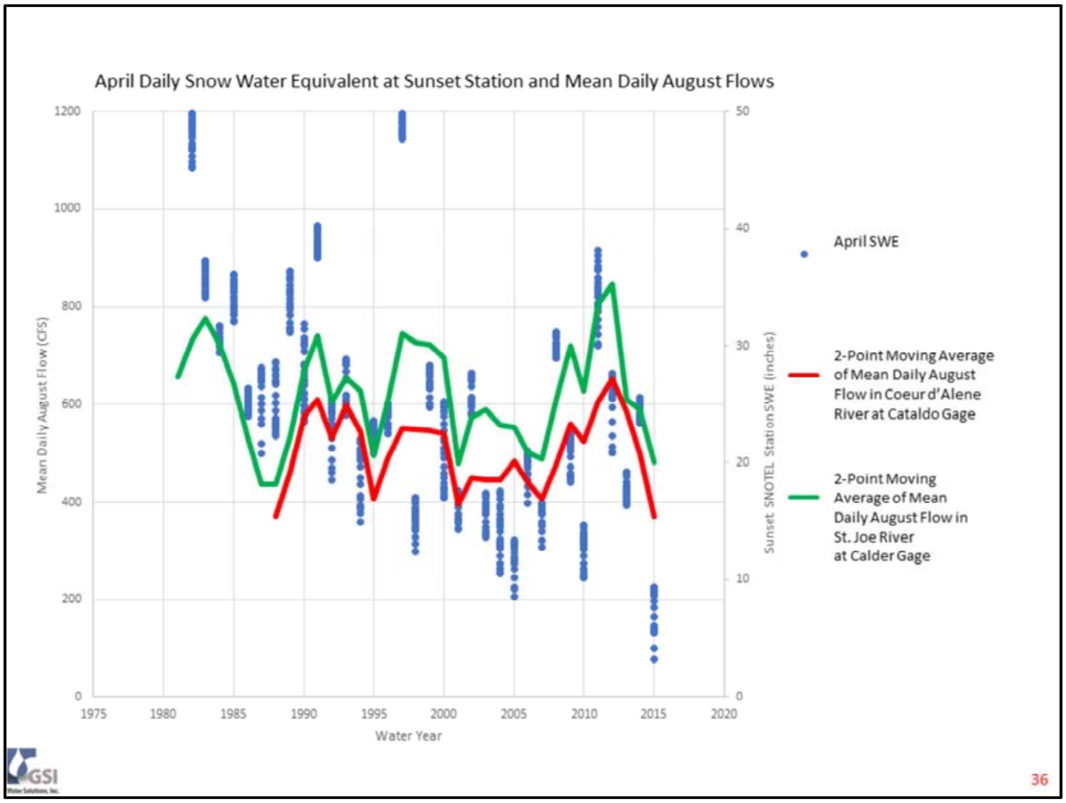


As was the case at the Sunset station (slide 28), the April data at Lost Lake show no significant upward trends in temperatures.

Hence, the primary temperature changes at the Lost Lake SNOTEL station occur in January and to a lesser extent in December and February, plus a possible slight increase in daily low temperatures during March. It is in January and possibly February and March that greater snowmelt is likely occurring in recent years than in the past at Lost Lake.

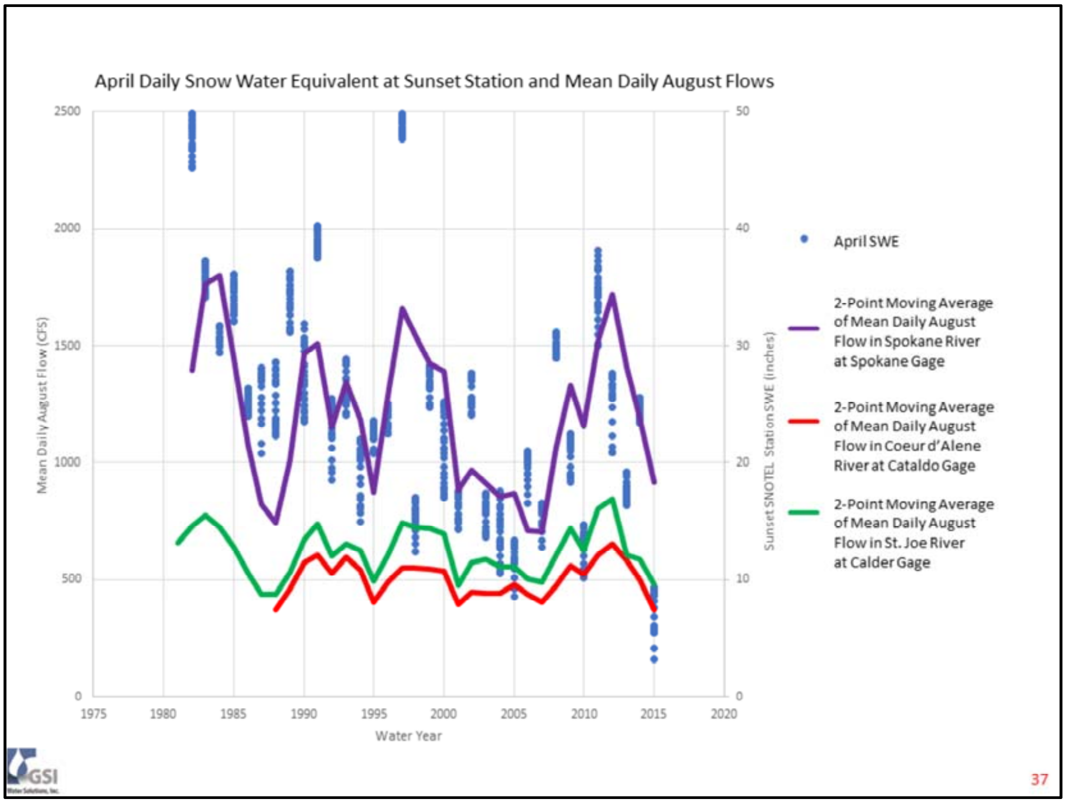


In slides 10 through 34, we examined the snow-water-equivalent data and temperature data at the SNOTEL sites during the past 25 water years. Those data sets indicate that the snowpack generally has been decreasing over time and that temperatures at the two highest-elevation stations have been rising during an approximately two-month period (January and February) that comprises much of the core winter season. Although the March and April snow packs (slides 16 and 17) generally continue to be higher than in December through February (slides 13 through 15), the snowpack volumes in all five of these months have decreased because of the higher temperatures. Those evaluations provide an indication that changes have occurred in the timing and volumes of snowmelt accumulation and runoff, which in turn creates a changing antecedent seasonal condition for stream flow rates later in the year, including during the late-summer critical low-flow season in the Spokane River. Let's examine this potential cause-and-effect relationship by comparing the mid-spring (April) snowpack (this slide) with the August seasonal low flows (the next two slides).

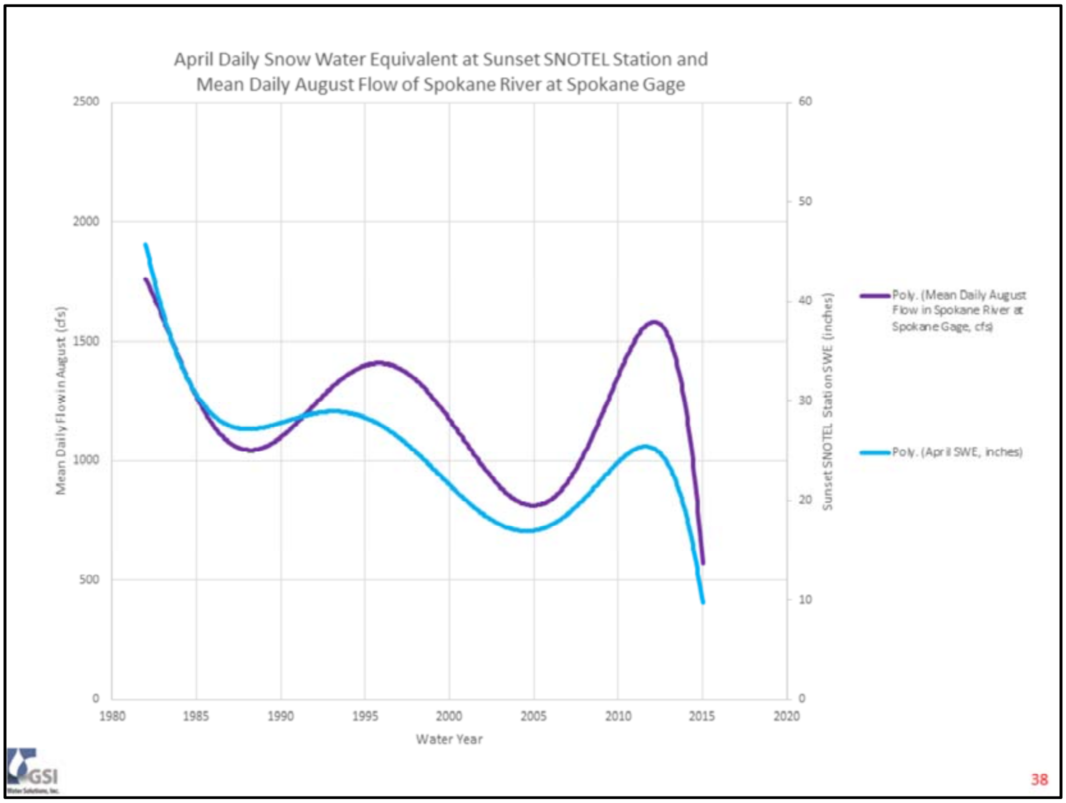


This slide shows the April snow-water-equivalent values at the Sunset SNOTEL station (blue dots) and the 2-point moving average of averaged mean daily August flows in the two rivers (Coeur d'Alene and St. Joe) which are reported by the USGS to provide 92 percent of the inflow to Coeur d'Alene Lake. The periodic sharp upward slopes of the river flow curves generally correspond to the years of increased April snowpack. See for example the rises during water years 1982, 1991, 1997, and 2011. The river flow curves also show sharp downward trends in periods such as water years 1985 through 1987, 1994, 2000, 2001, and 2013 through 2015 when the April snowpack was notably lower than in preceding years.

While the increases in August flow seem to track the increases in April snowpack, the relationship is less consistent during low snowpack years, when river flows sometimes decrease only modestly (such as during the period 2003 through 2005). However, in general, the years of lowest snowpack do correspond with the years of lowest August flows in the tributaries to Coeur d'Alene Lake.

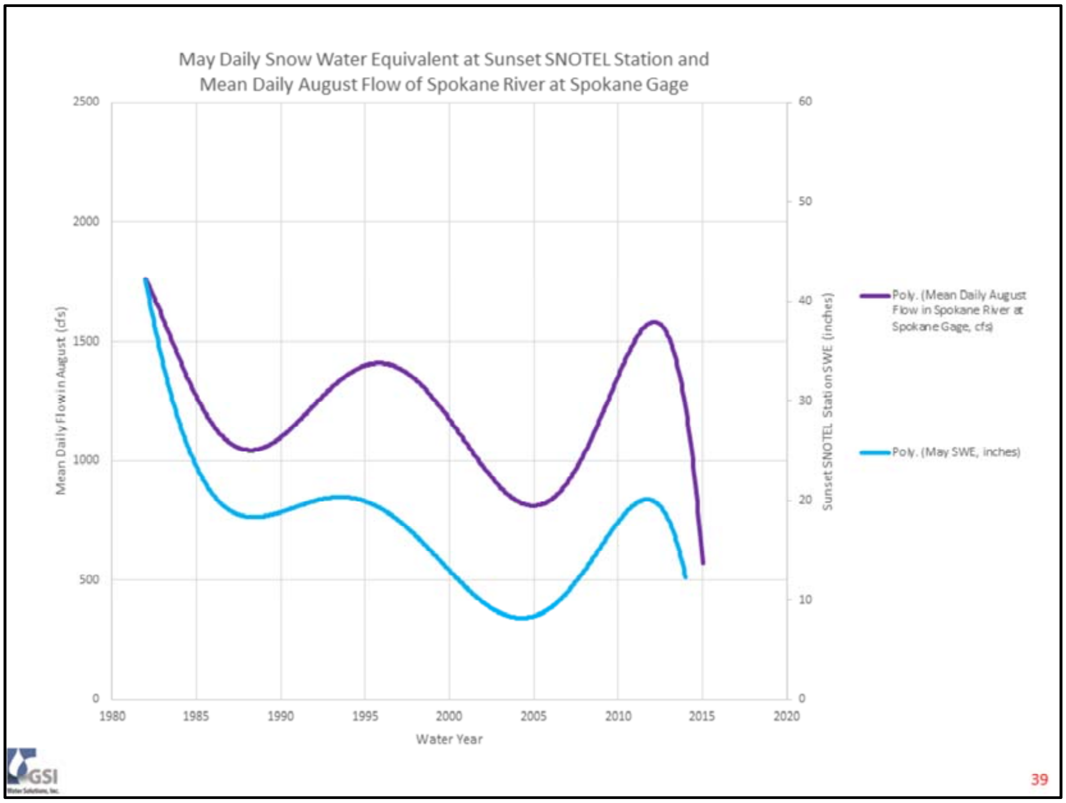


This slide adds the Spokane River's August flows at the Spokane Gage in downtown Spokane. The fluctuations at this gage track the fluctuations in April snowpack and the August flows in the Coeur d'Alene River and the St. Joe River. This plot indicates that April snowpack is a good indicator of August flows upstream and downstream of Coeur d'Alene Lake.

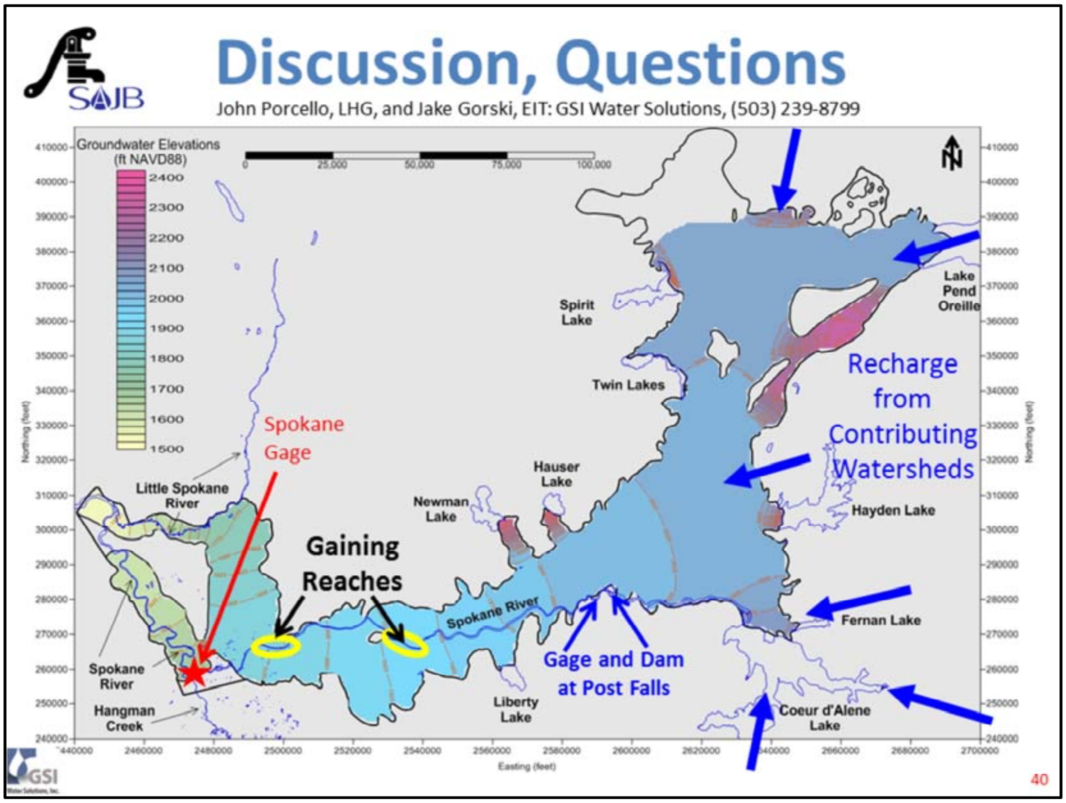


To further illustrate the effect of April snowpack on August flows at the Spokane Gage, this plot shows 6^{th}-order polynomial functions for the April snowpack (light blue) and for the mean daily August flows in the Spokane River at the Spokane Gage. The plot is constructed for the time period 1982 through 2015. Unlike the prior two slides, the river 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 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 in those two years 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.


Discussion, Questions
John Porcello, LHG, and Jake Gorski, EIT: GSI Water Solutions, (503) 239-8799
SAJB
Groundwater Elevations (ft NAVD88)
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
Spirit Lake
Twin Lakes
Lake Pend Oreille
Recharge from Contributing Watersheds
Spokane Gage
Little Spokane River
Hauser Lake
Newman Lake
Hayden Lake
Gaining Reaches
Spokane River
Fernan Lake
Gage and Dam at Post Falls
Liberty Lake
Coeur d'Alene Lake
Spokane River
Hangman Creek
Easting (feet)
Northing (feet)
GSI
40