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CLIMATE CHANGE & SUMMER STREAMFLOWS

CLIMATE CHANGE INFLUENCE ON SUMMER STREAMFLOWS

UNANTICIPATED DISCOVERY WHILE STUDYING OTHER INFLUENCES

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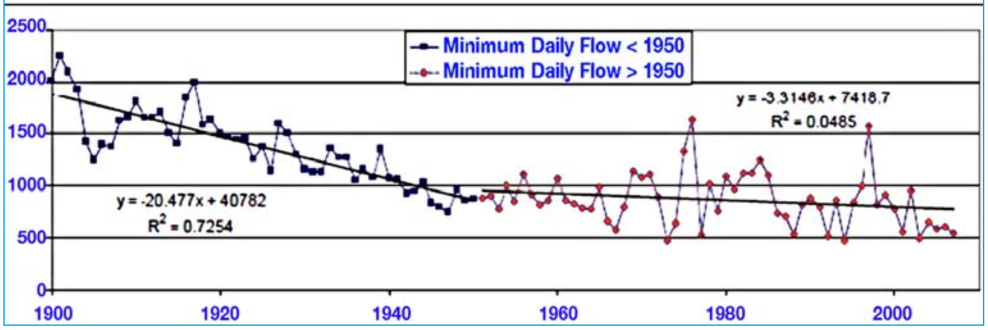
Introduction

In recent years, much attention and discussion has occurred in the Spokane Valley of eastern Washington and the Rathdrum Prairie of northern Idaho regarding continued declines in the seasonal low flows of the Spokane River. Using streamflow data collected since 1900 at a gage in the lower part of the watershed (in downtown Spokane), a study by Washington State University (Barber and others, 2011) found that average daily river flow rates in August (the lowest flow month) have shown a gradual, but statistically significant, decline throughout the 20th century and the first decade of the 21st century (see Figure 1). This flow rate decline occurred despite: (1) less consumptive water loss as urbanization reduced the amount of agricultural water use; and (2) a shift in the region's water use from primarily river water during the first half of the 20th century to exclusively groundwater from the Spokane Valley-Rathdrum Prairie (SVRP) Aquifer since the late 1960s. In 1978, the SVRP Aquifer was designated as a sole-source aquifer by the US Environmental Protection Agency (EPA). The SVRP Aquifer remains the sole source of water supply to the Spokane, Washington / Coeur d'Alene, Idaho metropolitan region and adjoining outlying areas, with the water being used for urban and agricultural uses over and outside of the aquifer's footprint.

In 2014, two parallel and separate studies were initiated to evaluate the degree to which peak-season pumping of groundwater from the SVRP Aquifer might be influencing the river's summer low flows. One study was conducted by the Idaho Department of Water Resources (IDWR) (Ralston Hydrologic Services [Ralston], 2015). The other study was conducted by the Spokane Aquifer Joint Board, which is a public entity whose members

Figure 1
Trends in Seasonal Low Flows at Spokane Gage through 2001 (from Barber et al. 2011)



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include the City of Spokane and other public and private water purveyors who pump groundwater from the Washington portion of the SVRP Aquifer. This article describes the Spokane Aquifer Joint Board study and focuses on how the initial examination of groundwater pumping influences led to the need to conduct a deeper examination of other historical factors governing seasonal low streamflows. This further examination ultimately resulted in discovering a climate change signal through a process of eliminating other potential causes of declining streamflows.

Background

Two Sources of River Flow

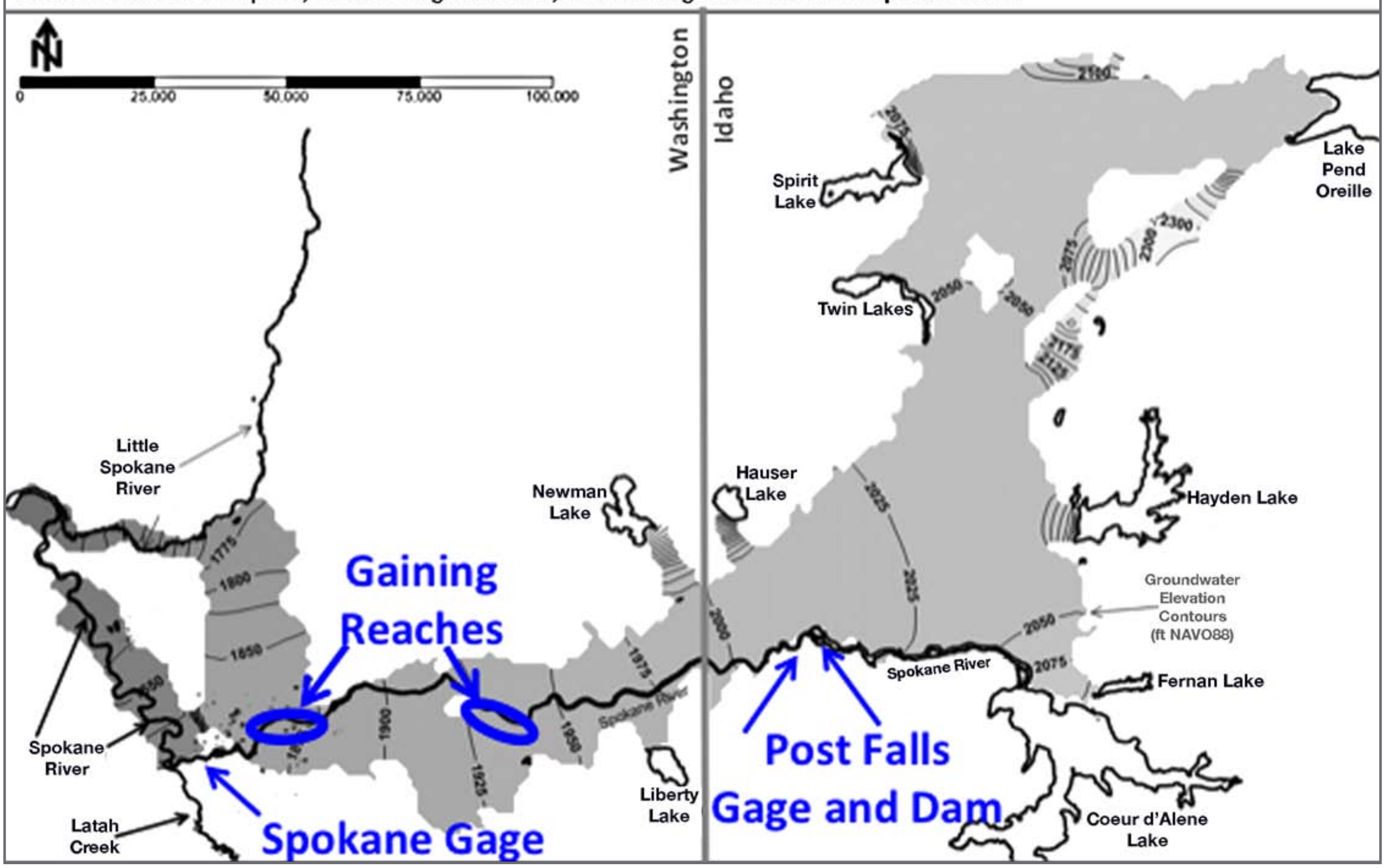
River flows in downtown Spokane derive from two sources of water: (1) releases from Coeur d'Alene Lake, as regulated at Post Falls Dam; and (2) groundwater inflows at locations between the upstream dam and the downstream Spokane Gage in downtown Spokane (see Figure 2). Both of these sources of water inflow to the river can vary on a seasonal basis:

- From May through early September, the releases from Coeur d'Alene Lake are managed so as to maintain a high and steady lake level to support tourism and recreational uses in and around the City of Coeur d'Alene, which sits next to the lake. During the remainder of the year, releases from the dam are managed without as stringent a requirement for maintaining a given water level in the lake.
- Groundwater discharges from the SVRP Aquifer into the river throughout the year along the two primary gaining reaches of the river, shown on Figure 2. Groundwater levels vary seasonally in response to ambient (natural) seasonal variability in aquifer and watershed hydrology, and also in response to seasonal fluctuations in demand-driven groundwater pumping from the aquifer. These seasonal variations in groundwater elevations in turn have a direct hydraulic influence on the rate at which groundwater discharges into the gaining reaches of the river.

River Flow Declines Have Continued

The analysis by Barber and others (2011) was particularly striking because it showed that the declining trend in the river's seasonal low flows continued after surface water diversions had ceased in the watershed, albeit at a much lower decline rate than before. A prior study, conducted jointly by the US Geological Survey (USGS) and the Washington Department of Ecology (Ecology) (Hortness and Covert,

Figure 2
Locations of SVRP Aquifer, Stream Gage Stations, and Gaining Reaches of the Spokane River



Climate & Streamflow

Decline

2005), examined river flow data through 2002 at gages located upstream of Coeur d'Alene Lake and found no discernible trends in summer streamflows into the lake. Based on that finding and on the consistent management of lake levels for decades, local regulators were concerned that the continued decline in streamflows below Coeur d'Alene Lake documented by Barber and others (2011) were arising from increases in the population and urban water demands of the Spokane/Coeur d'Alene metropolitan area. However, data collected since the 1960s by the groundwater users in the Washington portion of the aquifer show no long-term sustained decline in groundwater levels.

The Initial Focus: Groundwater Pumping

City of Spokane / Spokane Aquifer Joint Board - Numerical Groundwater Flow Model

Flow Model

The City of Spokane (City) and the Spokane Aquifer Joint Board (SAJB) jointly maintain a three-dimensional numerical groundwater flow model of the SVRP Aquifer. The model uses finite-element simulation methods to allow for simultaneous modeling of regional aquifer conditions and near-field highly localized groundwater flow patterns in and around wellfields and along the Spokane River. The model was first developed for the Washington portion of the aquifer during the mid-1990s by the City, to support the City's wellhead protection planning efforts (CH2M HILL, 1998). After the formation of the SAJB in 1995, the model was further adapted for wellhead protection planning by each of the SAJB members (CH2M HILL, 2000). In 2012, the model was subsequently expanded to encompass the entire SVRP Aquifer within Idaho and Washington — this work was undertaken by the City, SAJB, and GSI Water Solutions, Incorporated, (GSI, 2012).

Modeling Peak Pumping Effects on River Flows

Peak Season Demands

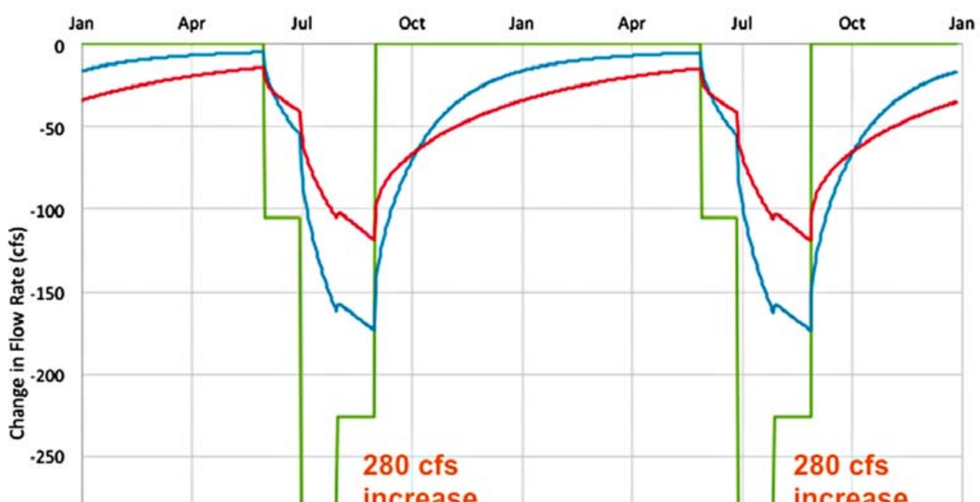
In 2014, GSI used the model to evaluate changes in river flow that arise from the summer-season groundwater withdrawals by the SAJB members' individual and collective pumping. The model used 2013 pumping data to define the amount and timing of pumping for peak-season demands versus seasonal-low and shoulder-season demands (*see* Figure 3). For the collective group of SAJB members, pumping during June, July, and August 2013 (black line) was found to increase to as high as 465 **c**ubic **f**eet per **s**econd (cfs), which was 280 cfs higher than the year-round baseline pumping for other water use purposes from September through May. This three-month period of peak pumping was simulated in the model and repeated for many years, to estimate the amount of change that might occur in groundwater discharges to the river — not just during these peak-months, but also during ensuing months and over multiple years of repeated peak-season pumping. Multiple simulations also were conducted to evaluate the inherent uncertainty in the modeling analysis, primarily through testing different values of the aquifer's storage coefficient (which affects the timing and magnitude of pumping impacts to the river).

Peak-Season Pumping Has a Short-Term Effect on the River

River Flow Effect

Figure 3 shows the seasonality of the peak pumping rates (green line) and the resulting model-estimated changes in river flow rates (red and blue lines) for the range of aquifer storage coefficients that were examined (a low value of 0.10 which creates a rapid effect on the river, and a high value of 0.30 which creates a slower effect and slower river response). As shown in the box in the lower right corner of Figure 3, an additional 280 cfs of peak-season pumping (as occurred during the summer of 2013) is estimated to decrease river flows by 120 to 175 cfs, or about 42 to 62 percent of the peak pumping rate (depending on which aquifer storage coefficient value is used). This modeling analysis tells us that once the peak pumping season ends, the effect on the river begins to dissipate immediately, though a small effect lingers into the next calendar year. The analysis also shows that over many years, a repeat of this same pumping pattern does not cause long-term depletion of groundwater, as indicated by the consistent magnitudes of the river impact during any given month from one year to the next.

Figure 3
Model-Estimated Effects of Peak-Season Pumping on the Spokane River by SAJB Members



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Effects by Individual Pumpers Can Differ Dramatically

Variable Impacts

The groundwater modeling analysis indicated that peak-season pumping by individual groundwater users in the Washington portion of the SVRP Aquifer could cause river flow reductions to range from as much as 90 percent of the peak-season pumping rate for pumpers closest to gaining reaches of the river, to as low as 15 percent for pumpers farther from gaining reaches. Additional tests showed that Idaho's pumpers have even less of an influence (generally no higher than 10 percent) because the river's two gaining reaches are 7 miles and 14 miles west of (downstream of) the Washington/Idaho state line.

A Separate Model Produces Similar Conclusions

Pumping Influence

Similar results were found by the IDWR study (Ralston, 2015), which used a USGS regional-scale model (Hsieh and others, 2007) to examine the temporal effects of groundwater pumping on the gaining reaches of the Spokane River. GSI and Ralston conducted independent comparisons of a hypothetical pumping scenario in which peak-season pumping is moved from a well near the river to a more distant well. As discussed by Ralston (2015), the USGS model predicts somewhat less of a pumping influence on streamflows than the City/SAJB model, as well as a shorter duration of groundwater pumping influences on the river. While differences exist between the two groundwater flow models, both models and both studies (by IDWR and SAJB) indicated that the amount of groundwater production during the summer peak-demand season indeed influences the amount of flow in the Spokane River, though by amounts that are less than the incremental volume and rate of groundwater pumping that is specific to the peak-pumping season.

Phase 2: Looking for In-Watershed Causes of Declines in River Flows

Examining Historical Conditions & Hydrologic Processes

Streamflow Decline Cause

While the modeling studies by IDWR and SAJB indicated that groundwater pumping has an effect on river flows, those analyses do not identify the potential causes of declines in river flows. Accordingly, in 2015, the SAJB initiated a study of historical land use, water use, river flow, and groundwater data. The objective of "Phase 2" of the SAJB study was to evaluate whether changes in water use, water supply sources, and/or aquifer conditions could be the cause of the continuing decline in seasonal low streamflows.

Certain hydrologic processes within the watershed were identified at the time as requiring evaluation. GSI and SAJB identified climate change as one of the potential hydrologic processes to consider as a potential influence on the river. However, climate change was not the focus of Phase 2 of the study because of the earlier USGS/Ecology study's conclusion that inflows to Coeur d'Alene Lake were not changing and were not experiencing detectable climate change effects (Hortness and Covert, 2005). Based on that finding and the known history of maintaining a specific lake level throughout the summer for the past many decades, the Phase 2 study was designed and conducted on the assumption that changes were occurring downstream of Coeur d'Alene Lake, rather than in the lake or upstream of the lake.

Increasing Municipal and Industrial Demands

M&I Use

Historical records from public water providers and large industrial water users indicate that — irrespective of the source of water — **m**unicipal and **i**ndustrial (M&I) water use in the Washington portion of the Spokane/Coeur d'Alene metropolitan area rose dramatically from 1940 through the 1980s as a result of urbanization. During this period, M&I use increased from about 70 cfs to about 225 cfs. In Idaho, M&I use was less than 25 cfs prior to 1975, and has risen gradually since then to approximately 75 cfs. Accordingly, M&I use in the Spokane/Coeur d'Alene metropolitan area totaled approximately 300 cfs by 2010. Since the mid-1980s, M&I water use has leveled off in Washington but continues to rise in Idaho.

Lower Per-Capita Demand

Per Capita Demand

In the Washington portion of the metropolitan area, per-capita demands for M&I water peaked in the mid-1980s (approximately 375 gallons/person/day) and have since declined by 20 to 30 percent (to about 270 to 300 gallons/person/day).

Less Consumptive Use and More Return Flow

Reduced Ag Use

The continued increase in M&I use has been accompanied not only by decreasing per-capita water use, but also by a significant reduction in agricultural water use in both states.

This reduction in agricultural water use is important for three reasons:

1) Agricultural water use occurs primarily in the summer, which is the period of concern for flows in the Spokane River.
2) During the summer months, only a portion of the agricultural water volume formerly used on a given acre of land is needed to support new urban development on that same acre.
3) The percentage of the consumed water that is returned to the river-aquifer system is less in the case of irrigated agriculture than in urban settings for two reasons:
   a. Agricultural return flows consist primarily of conveyance losses and seepage past the root zone of irrigated crops. These return flows have been estimated to amount to approximately 40

Return Flow

Climate & Streamflow

Urban Return Flow

Use Reduction

Land Use Conversion

Idaho's Pumping

percent of agricultural land-applied water (Hsieh and others, 2007).

b. In urban settings, the return flows consist of conveyance losses plus the return of indoor-consumed water to treatment plants or septic systems. Spokane County (2013) estimates that on an annual basis, approximately 63 percent of urban water use in the region consists of indoor water use, most of which returns to the river-aquifer system. Additionally, a small percentage of urban outdoor water use returns to the river-aquifer system.

Idaho's Estimates of an Improving Water Use Picture

As noted above, groundwater pumping has been the sole source of water use in this part of Idaho (Rathdrum Prairie region) for many decades. Although groundwater production volumes have increased in Idaho, the percentage of summer-season water use that is lost to evaporation from irrigation in agricultural and urban areas is actually decreasing over time as cities expand onto irrigated farmland. The Idaho Water Resources Research Institute (IWRRI) conducted a detailed study of: current water rights availability; current and future water usage; and projected urban growth (Solomon, 2015). IWRRI estimated that the amount of summer-season pumping that will be needed to meet maximum day demands in the year 2045 is likely to decrease by 47 cfs. This decrease would result in a 15 percent reduction in region-wide average daily water use during the summer months across the portion of the State of Idaho that relies on the SVRP Aquifer for urban and agricultural water supply.

Water Demands Now Ruled Out

Looking at Idaho and Washington together, the nature, locations, and amounts of water use in recent decades appear to have been beneficial for both groundwater and the river. The region-wide increase in urban water demands has been accompanied by a decline in agricultural water demands. For example, a retracing of historical water uses for agricultural and urban water needs in the Washington portion of the metropolitan area (Figure 4) shows that total water use during the summer (between about 250 cfs and 280 cfs since 1990) has been 150 cfs to 200 cfs lower than was the case during the middle of the 20th century, when agricultural demands were still near their historical high values (with peak-season demands of about 425 to 450 cfs). The land use conversion that occurred during the middle and latter parts of the 20th century created less water demand on a per-acre basis during the summer. Area urbanization has resulted in a higher percentage of returns (on a per-acre basis) of used water (in the form of treated water derived from indoor water use) to the river-aquifer system than was the case under agricultural development. Additionally, the effect of Idaho's seasonal groundwater pumping on the Spokane River is small because of this area's significant distance from the gaining reaches of the river.

Figure 4: Historical Surface Water & Groundwater Diversions in Washington Region

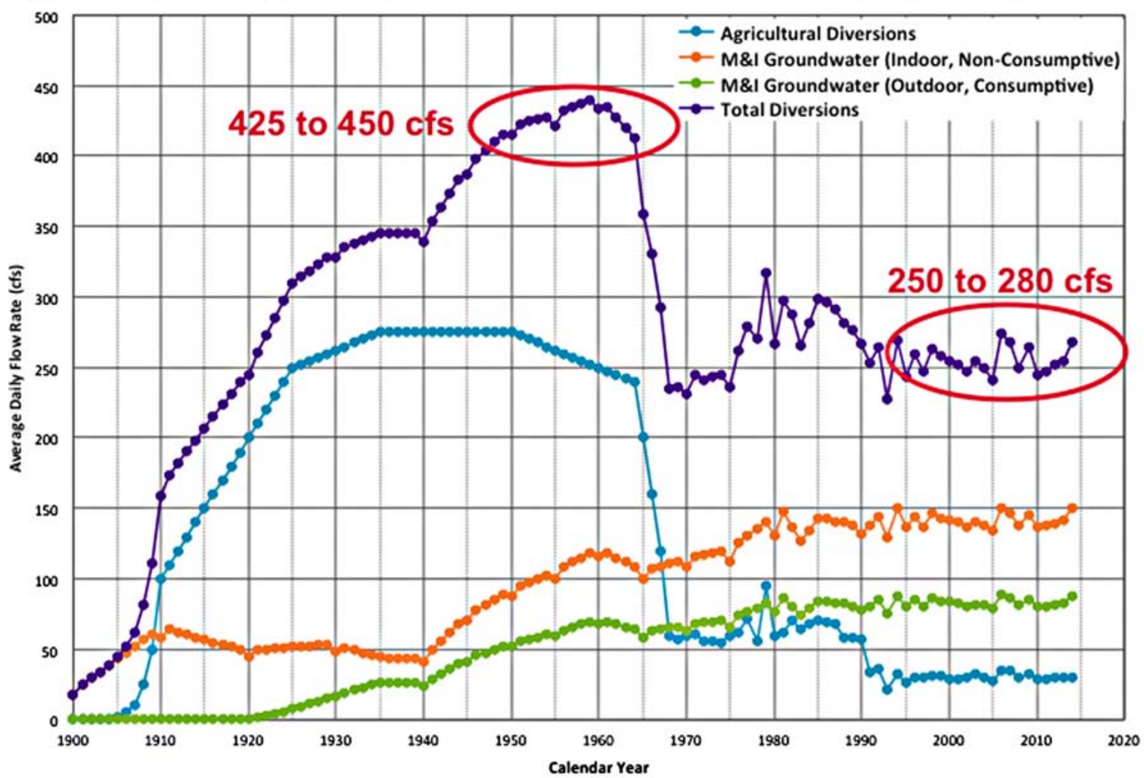
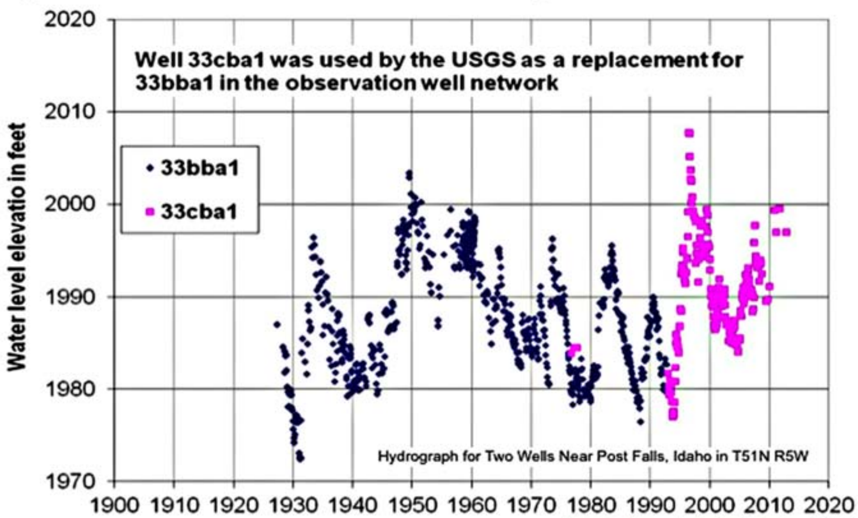
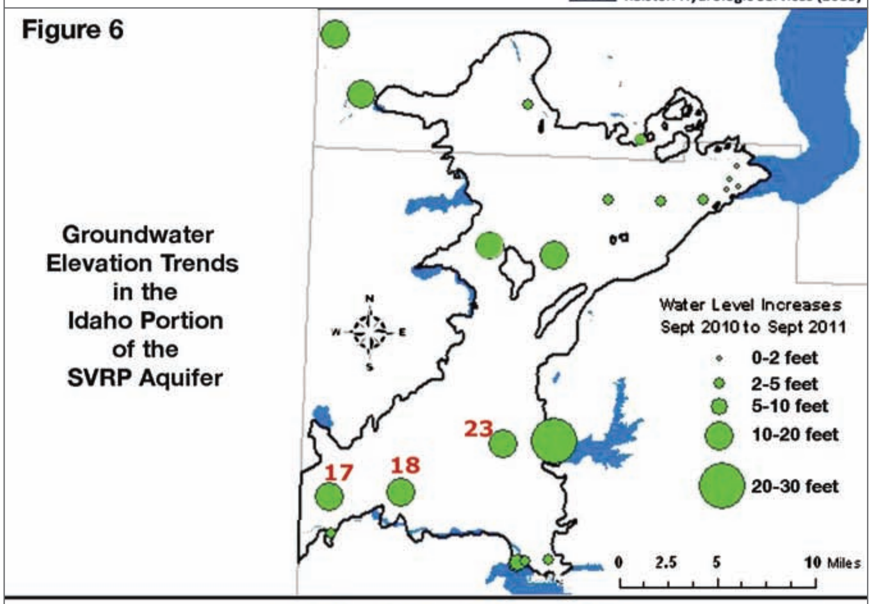


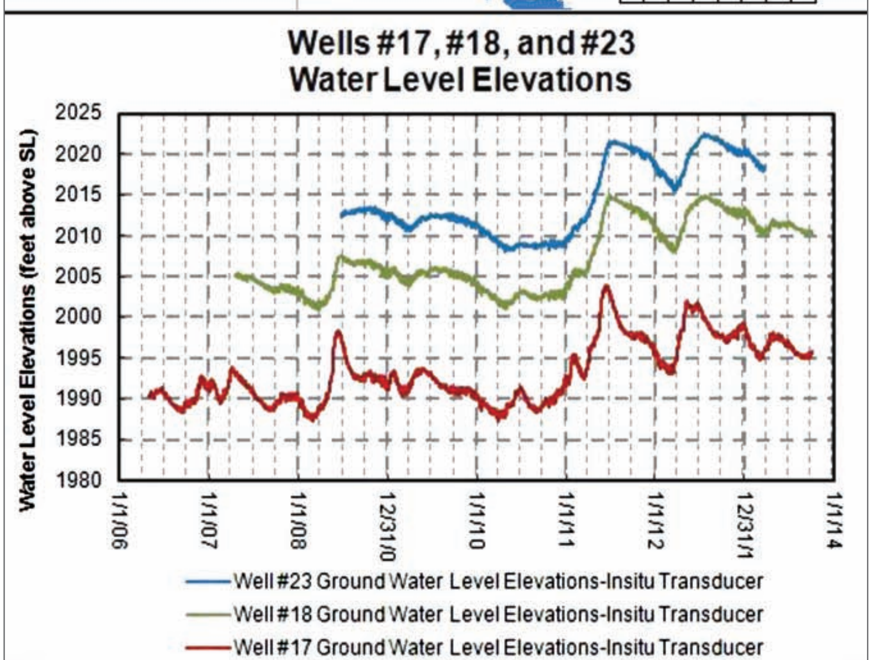
Figure 5: Groundwater Elevation Trends in Washington Near the Idaho State Line



Source Ralston Hydrologic Services (2015)

Figure 6





Source: Kenneth Neely, Idaho Department of Water Resources, Personal Communication, February 2016

Consistent with Groundwater Elevation Trends

Long-term groundwater elevation records at a pair of observation wells immediately west of the state line show 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 (*see* Figure 5). Similarly, data from state groundwater monitoring programs in Idaho are not showing long-term sustained decreases in groundwater levels in the Idaho portion of the SVRP Aquifer (see Figure 6).

Demand Changes are Showing Up in the River

The reduction in demands after the 1960s and the continued conversion of water needs from agricultural to urban uses is apparent from an inspection of the August mean daily streamflows, at both the upstream gage at Post Falls Dam (*see* the red line in Figure 7) and the downstream gage in downtown Spokane (*see* the blue line in Figure 7). As shown by the circled arrows, the difference in flow between the two gages (Figure 7) has been much less after 1975 (by about 150 to 225 cfs) than was the case during the first half of the 20th century. This change in the difference between the two gages also is observed whether or not the City of Spokane's treated water discharges are included in the analysis (discharges which have varied over time and occur downstream of the Spokane Gage). The 150 cfs to 225 cfs change in the flow difference between the upstream and downstream gages resulted from the cessation of river water diversions that once occurred at Post Falls Dam to meet agricultural irrigation needs. Note that rainfall in the area (as measured near the City of Coeur d'Alene; *see* the green line in Figure 7) has not shown any long-term changes that would explain the change in river flow conditions.

Conditions Favor Increases in Seasonal Low Flows

Of the most significance to this Phase 2 study by the SAJB was how the 150 cfs to 225 cfs increase in flows at Post Falls is similar in magnitude and timing to the 150 cfs to 200 cfs estimated reduction in water use shown in Figure 4 (which arose from reductions in agricultural irrigation diversions). These changes from the early equilibrium period to the new equilibrium period together indicate that the river-aquifer system as a combined entity experienced (after irrigated agriculture had been dramatically reduced) an improvement whose magnitude can be estimated from both the river flow data and the water use data. This similarity in the amount of reduced water use and the increased amount of river flow at Post Falls 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

Climate & Streamflow

Expectations v. Continued Decrease

External Force

Upstream Hydrology

river-aquifer system. Accordingly, there is now a clear indication that changes in land and water use and their accordant effect on the river and the SVRP Aquifer should have resulted by now in a cessation of the long-term decline in summer-season low flows in the Spokane River. Specifically: direct diversions of river water are no longer occurring; peak-season groundwater pumping is not increasing; rainfall recharge has not decreased; urbanization has promoted runoff to dry wells in many areas and directly to the river in other areas; and groundwater elevations are stable or even increasing slightly.

Process of Elimination Leaves Only One Possibility for Observed Decreases in Flow

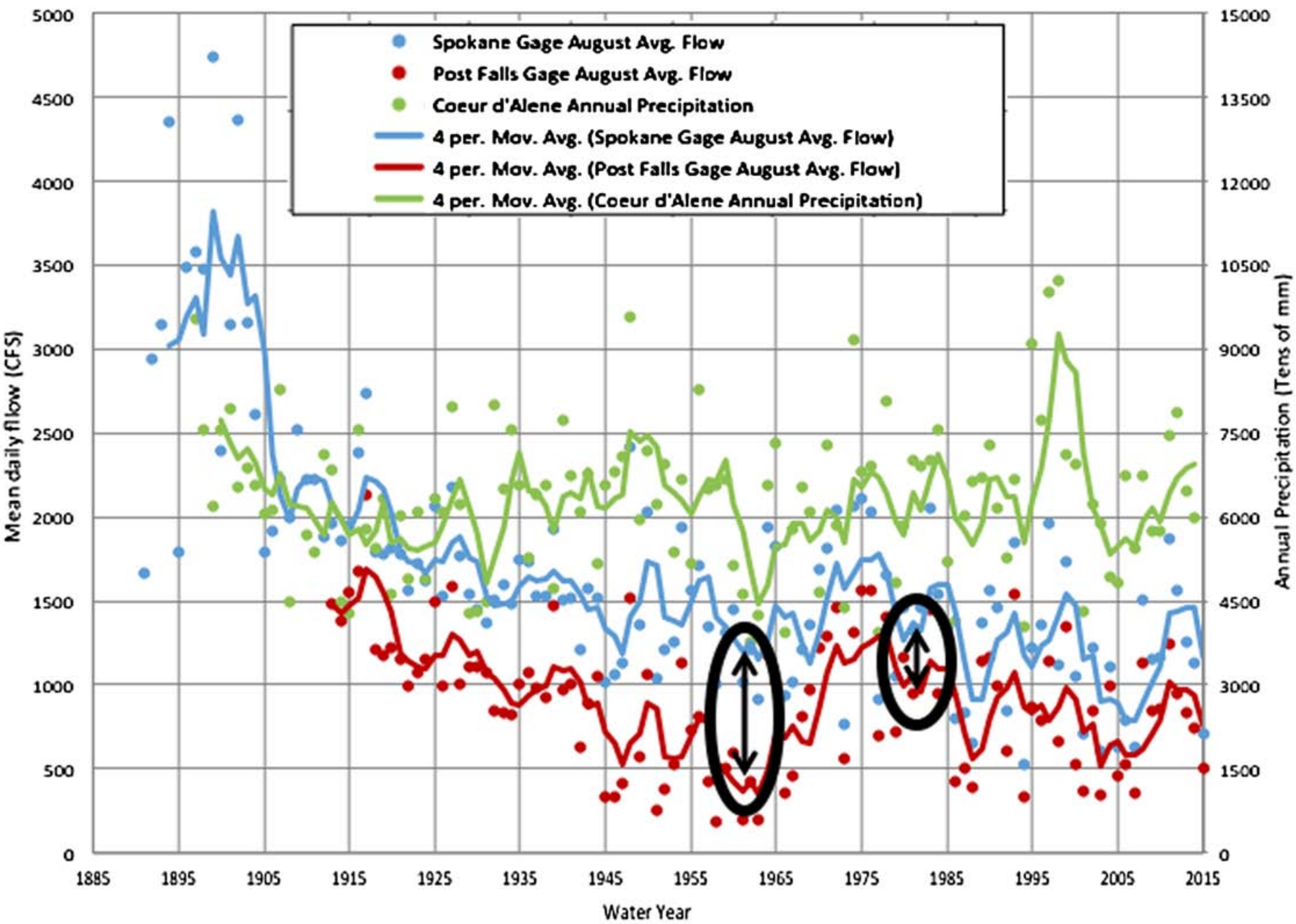
Even though the in-basin conditions are favorable for the stabilization or potential increase in seasonal low flows, the seasonal low flows continue to decrease at both stream gages. This suggests, by process of elimination, that an external force is responsible for the decreased low flows in the Spokane River. Given that the lake level in Coeur d'Alene Lake is unchanged throughout the summer and has been maintained during the summer at the same elevation for several decades, only one potential explanation for the decreased river flows remains — that being a decrease in river inflows to Coeur d'Alene Lake.

Phase 3: Looking for the Climate Change Signal in the Coeur d'Alene Lake Watershed

Hydrologic Processes in the Contributing Watershed

In early 2016, the SAJB initiated "Phase 3" of the study, which examined the hydrologic processes in the upstream contributing watershed that could be affecting inflows to Coeur d'Alene Lake, and accordingly the outflows from the lake at the headwaters of the Spokane River. The hydrologic processes that were examined in the contributing watershed were: snow accumulation volumes; the timing of snowmelt runoff; daily minimum and maximum air temperatures; and streamflows into Coeur d'Alene Lake.

Figure 7: Mean Daily Streamflows at Upstream and Downstream Gages, and Annual Precipitation



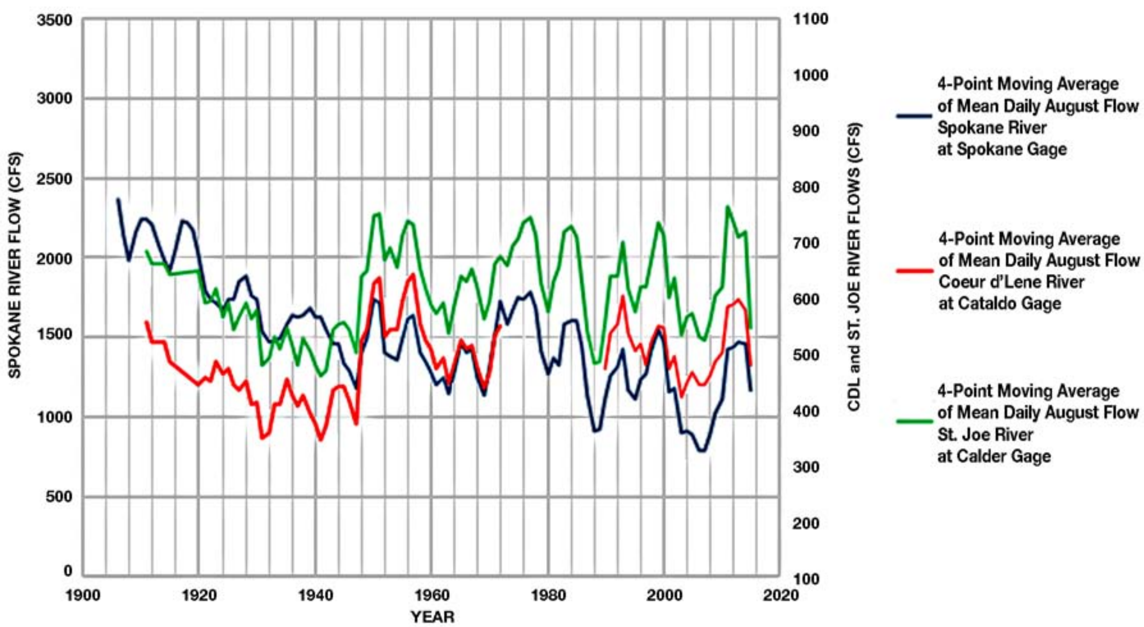
Climate & Streamflow

Stream Inflows (August)

Lake Inflows and Outflows

The stream inflows to the lake were the first of these variables to be examined during Phase 3 of the study. Figure 8 compares August flow rates in the Spokane River at the Spokane Gage (dark blue) with August flow rates in the two primary rivers feeding Coeur d'Alene Lake (the Coeur d'Alene River — shown in red and the St. Joe River — shown in green). The plot shows the four-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.

Figure 8:
August River Flow Rates at Downstream Spokane Gage & Upstream of Coeur d'Alene Lake



Upper Watershed Correlation

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 year-to-year fluctuations in August streamflows are very similar in direction (i.e., increasing or decreasing) at these three gages, which suggests that the August inflows to Coeur d'Alene Lake from the upper portion of the watershed have a strong bearing on the August flows in the lower portion of the watershed (in downtown Spokane). This observation in turn suggests that processes in the upper watershed are affecting flow rates in the lower portion of the watershed, as was already suspected from the results of the Phase 2 study described previously.

Snowpack Research

SNOTEL Snow Monitoring Sites

Accordingly, much of the Phase 3 study work focused on evaluating data from five **sno**w **tel**emetry (SNOTEL) sites located in the contributing watershed, upstream of Coeur d'Alene Lake. Data from the SNOTEL sites were studied for changes in precipitation, snowpack, and air temperature. The five SNOTEL sites have been in operation since the early 1980s, and are located at elevations that range from 4,250 feet to 6,110 feet above mean sea level. As the evaluation of the data from all five sites progressed, the data from the two highest-elevation stations (Sunset and Lost Lake, elevations 5,540 feet and 6,110 feet, respectively) became the focus of the study because of the significant changes in air temperature and snowpack that were seen at these two stations.

Temperature Trends Increase

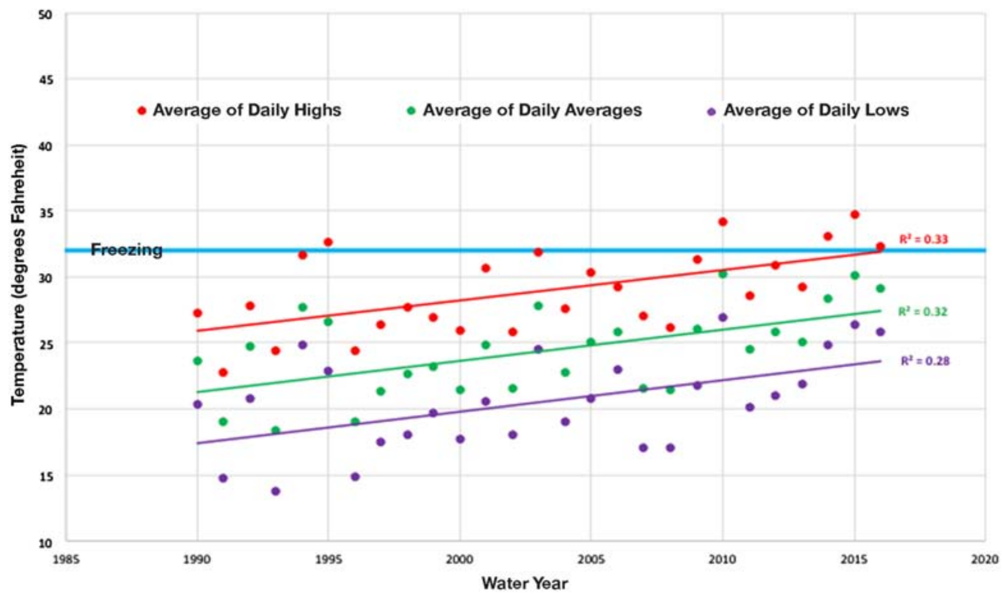
Temperature Trends

Figure 9 shows average daily temperatures from year to year during the month of January at the Sunset SNOTEL station. This plot evaluates the 27 years of January temperatures for the period of water years 1990 through 2016. The plot shows a strong upward trend in January temperatures at the Sunset SNOTEL station, as indicated by the high values of the coefficient of determination (R2) for all three of the temperature data sets (daily high, daily low, and daily average temperature). A similar trend was found for January at the higher-elevation Lost Lake SNOTEL station. During the following month (February), daily low and daily average temperatures at the Sunset SNOTEL station (Figure 10) also show a strong upward trend (R2 values of 0.27 and 0.23, respectively). Additionally, the daily high temperature in February rose above the freezing mark frequently from 2005 through 2016. In March, daily high temperatures at Sunset were consistently above the freezing mark, while daily low temperatures showed a visible upward trend (R2 of 0.10) but remained below the freezing mark (Figure 11).

Climate & Streamflow

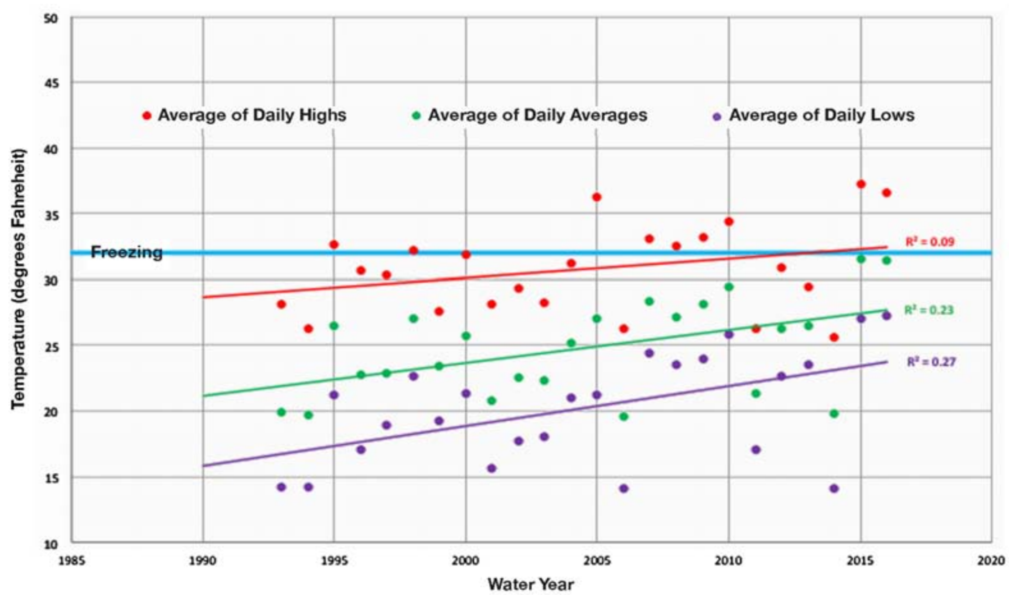
January

Figure 9: Averages of Daily High, Daily Average, and Daily Low Temperatures
January Values for Water Years 1990-2016, Sunset SNOTEL Station, Elevation 5540 Feet



February

Figure 10: Averages of Daily High, Daily Average, and Daily Low Temperatures
February Values for Water Years 1993-2016, Sunset SNOTEL Station, Elevation 5540 Feet



March

Figure 11: Averages of Daily High, Daily Average, and Daily Low Temperatures
March Values for Water Years 1990-2015, Sunset NOTEL Station, Elevation 5540 Feet

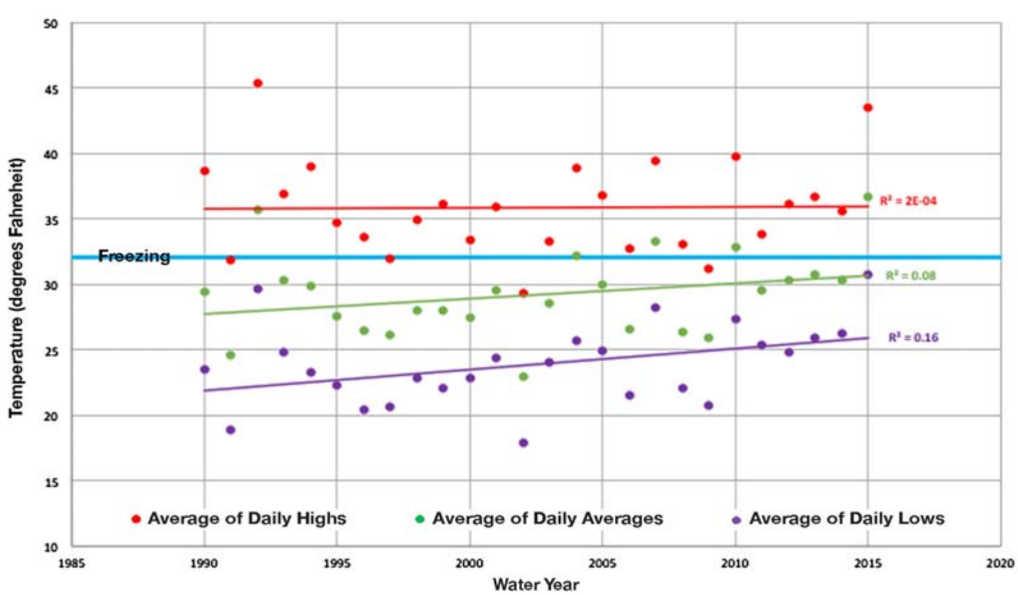


Figure 12: January — Binned Frequency of Occurrences of Snow Water Equivalent, Sunset NOTEL Station

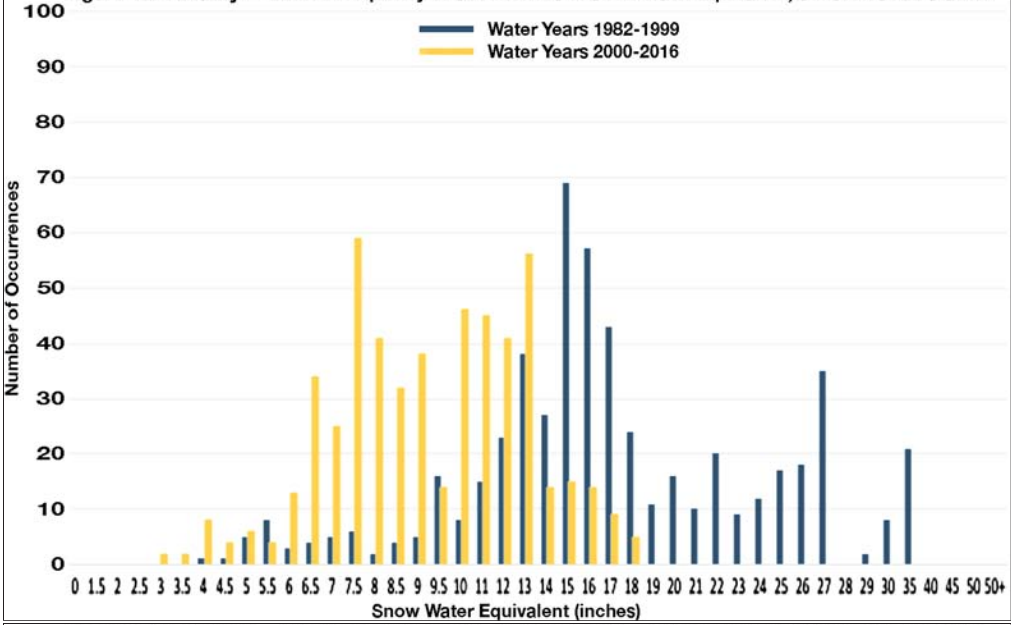


Figure 13: February — Binned Frequency of Occurrences of Snow Water Equivalent, Sunset NOTEL Station

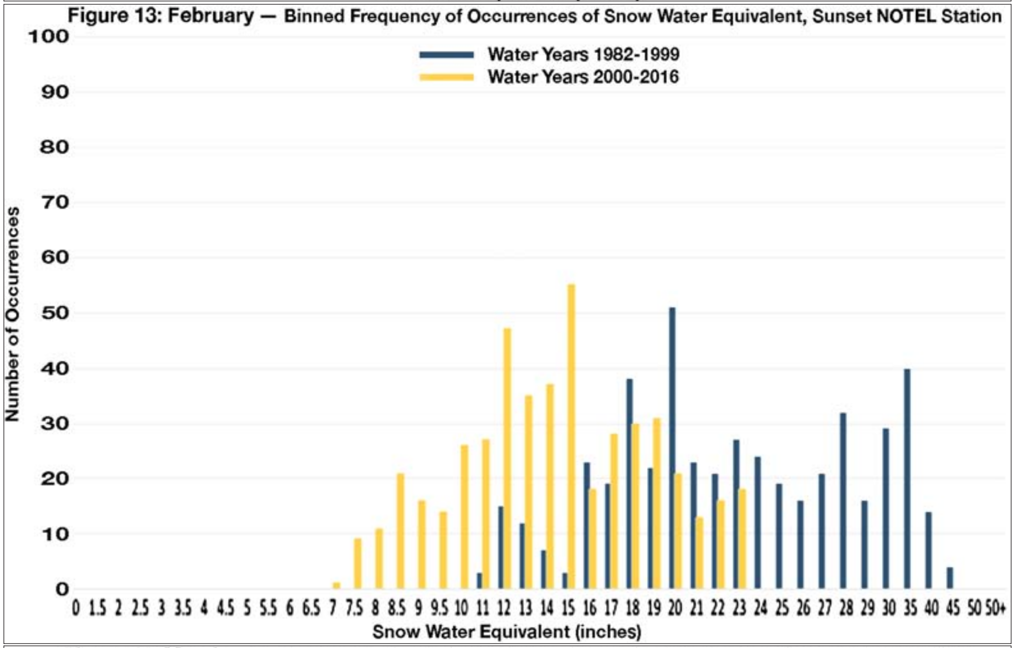
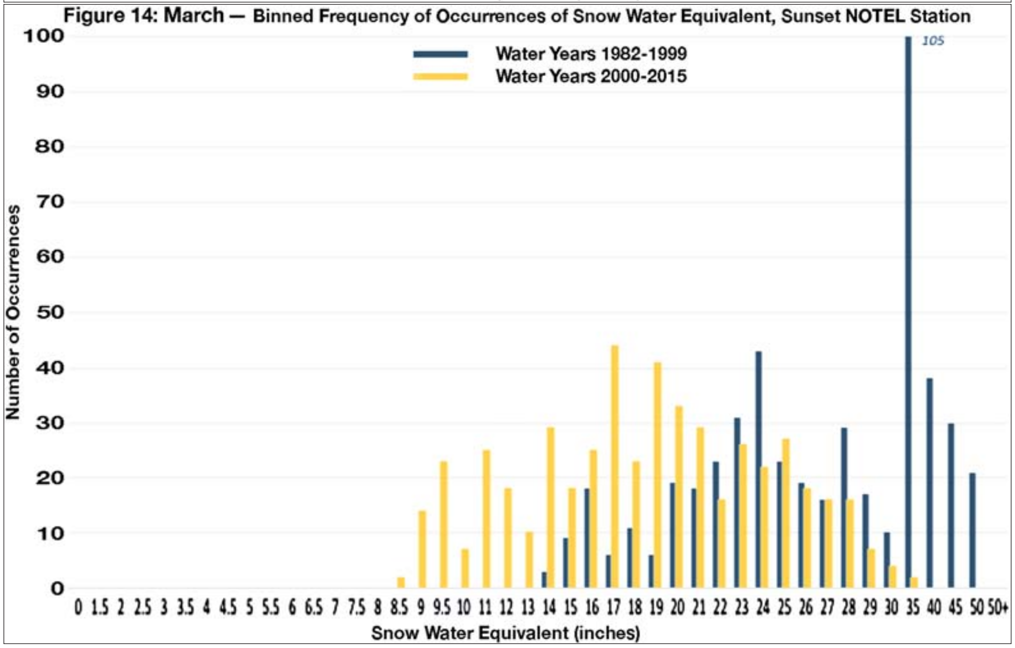


Figure 14: March — Binned Frequency of Occurrences of Snow Water Equivalent, Sunset NOTEL Station



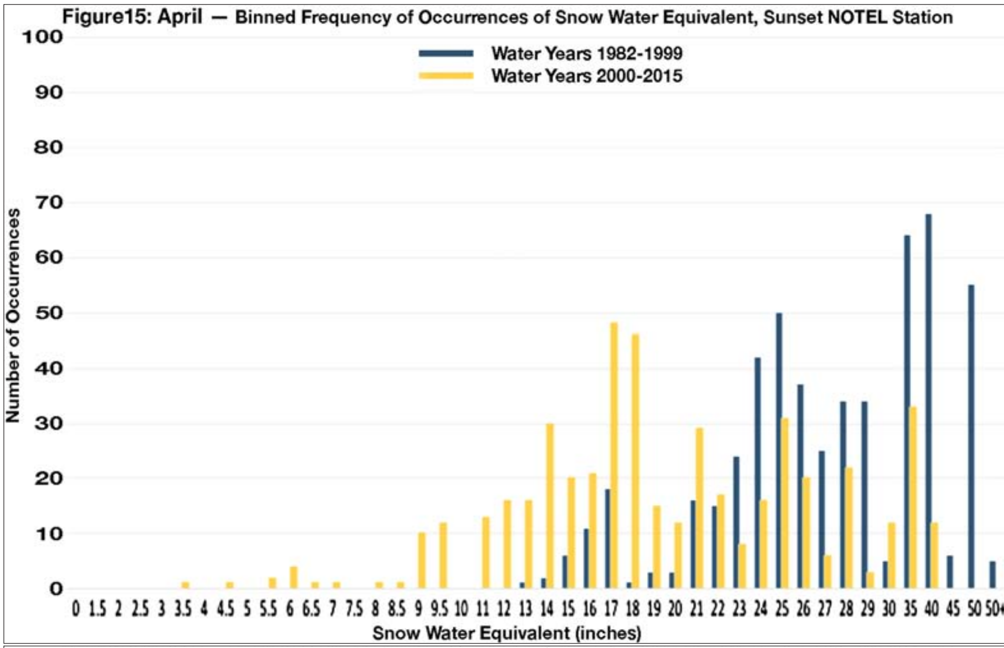
Snowpack Trends

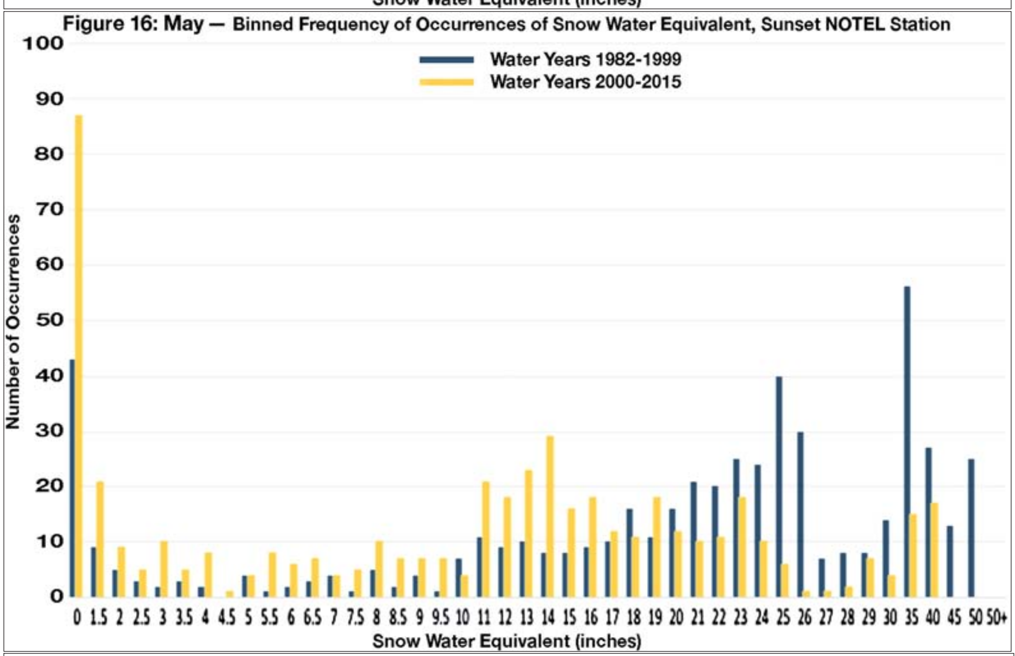
To understand whether the suggested temperature increases were causing changes in the amount of snowpack and the timing of snowmelt, histograms (frequency diagrams) were constructed for each month of the snow accumulation and snowmelt periods. Each histogram compares the number of occurrences of daily **s**now **w**ater **e**quivalent (SWE) values during two different time periods: (1) the period from the early 1980s (the beginning of SNOTEL monitoring) through water year 1999; and (2) the period from water year 2000 through water year 2015 (and the first few months of water year 2016, when Phase 3 of the study was conducted). Figures 12, 13, and 14 show the histograms for the snowpack accumulation months of January, February, and March, respectively. All three of these figures show a distinct leftward shift in the recent-period SWE values (yellow bars) compared with the higher SWE values of the pre-2000 period (blue bars). This shift also appears in April (Figure 15), which is a transition month when SWE values are similar to, or slightly below, the March SWE values. In May, Figure 16 shows a less apparent shift between the two SWE data sets; however, the number of occurrences of zero snowpack is twice as high in the recent time period than in the pre-2000 time period (even though the two time periods have similar durations).

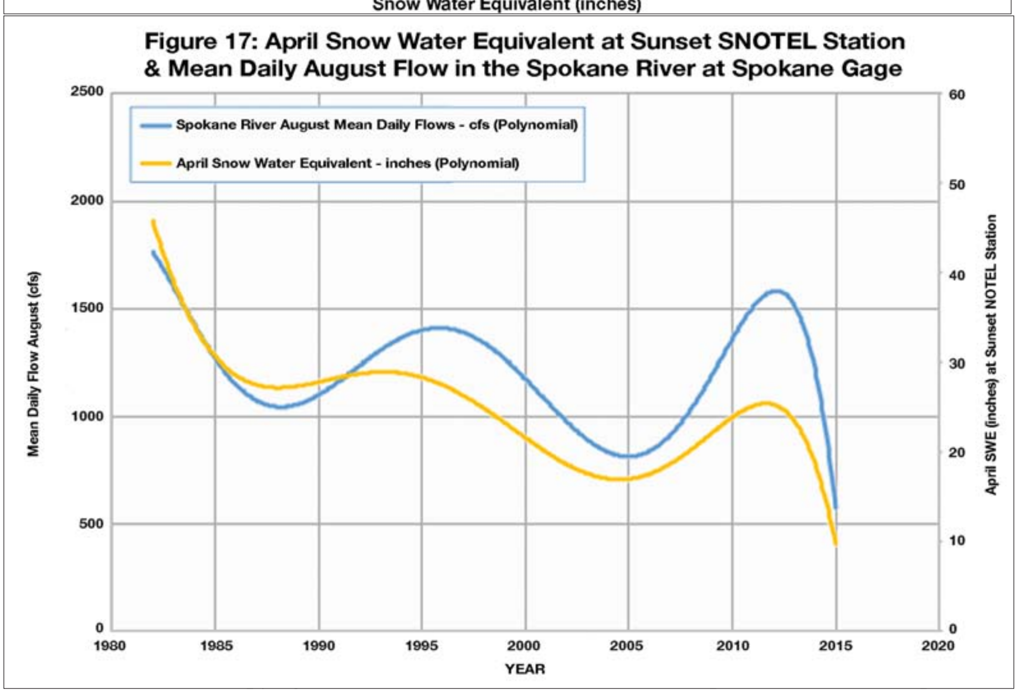
Snowmelt Trends and Summer River Flow Trends

The April and May snowpack volumes appear to be additional indicators of the magnitude of August flows at the Spokane Gage. Figure 17 shows polynomial functions for the April snowpack (yellow) and for the mean daily August flows in the Spokane River at the Spokane Gage (blue). [A polynomial function is a mathematical tool that can be used to search for trends in a data set. It is most useful when the data being examined (in this case snowpack values or river flow rates) have values that fluctuate over time.]

The plot is constructed for the time period 1982 through 2015.







Compared with annual or monthly data sets, the use of a high-order polynomial function 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 in the Spokane River 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 2012, when the August flows (in blue) rise more sharply than the rise in April snowpack (in yellow). A similar comparison of the May snowpack and the August river flows (Figure 18, next page) shows a striking similarity between the short-term and long-term trends in these two data sets, including in 2012.

Figures 17 and 18 together show that the temperature and snowpack conditions of the upper watershed are indicative of: (1) the upstream watershed's strong influence on August river flows in the lower watershed; and (2) a climate change effect on August river flows. Specifically, temperature changes (Figures 9 through 11) are changing the magnitudes of snowpack accumulation during the winter (Figures 12 through 14) and creating an earlier snowmelt season (Figures 15 and 16), which is directly causing changes in August flows into and out of Coeur d'Alene Lake and, accordingly, changing the August flows in the Spokane River (Figures 17 and 18).

Conclusions from the Unintentionally Phased Study

The study that is described in this article initially was not envisioned to involve exploring anything more than the magnitude and timing of groundwater pumping effects on the Spokane River. That analysis was conducted with the thought that transfers of pumping away from near-river areas might provide notable increases in seasonal low river flows. The SAJB members continue to consider possible relocations of their peak-season groundwater pumping activities. However, the findings from that first phase of the study pointed to

Climate & Streamflow

the need to conduct additional analyses. The second and third phases of the study were forensic in nature because of the need to understand the relative influences of the many hydrologic processes that affect: (1) surface water and groundwater conditions within the local watershed; and (2) the yield of the upstream adjoining watershed that contributes flow to the headwaters of the Spokane River (through Coeur d'Alene Lake).

Conclusions

Specific conclusions regarding the trends in Spokane River flows, regional water use, and hydrologic processes in the Spokane River/Coeur d'Alene Lake watershed are as follows:

Summer Pumping

The rate of summer-season groundwater pumping for municipal and industrial water uses does not cause an equal depletion in river flows. In Washington, where nearly all pumping from the SVRP Aquifer is for municipal and industrial purposes, the effect on summer-season low flows in the Spokane River is approximately 42 to 62 percent of the rate at which groundwater is pumped by SAJB members, over and above the year-round pumping rate that occurs to meet indoor water demands. The effect of Idaho's summer-season increase in pumping on seasonal low flows in downtown Spokane is less than 10 percent of the increased seasonal pumping that occurs in Idaho.

Urbanization Benefits

On formerly irrigated agricultural lands, urbanization of those lands has been beneficial to the river-aquifer system. Indoor uses of water are increasing, and less consumptive use (loss) occurs nowadays during the summer irrigation season than in the past. Accordingly, more of the consumed water is returned to the river-aquifer system. Groundwater levels have been stable, if not higher. These conditions together are favorable for increasing flows in the Spokane River.

Continued Decline

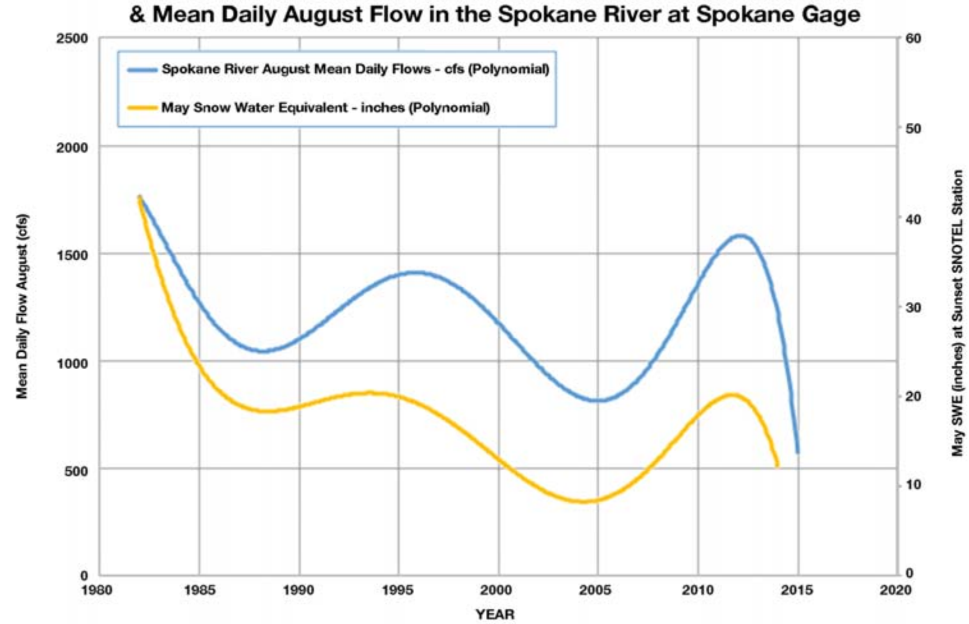
The continued decline in seasonal low flows in the Spokane River is occurring despite two positive trends: declining per-capita water usage during the past three decades, and reduced summer demands in both states arising from the agricultural-to-urban conversion of land and water use.

Climate Change

Hydrologic changes in the contributing watershed to Coeur d'Alene Lake are occurring and are the dominant causes of continued declines in Spokane River seasonal low flows. These climate-associated changes consist of lower snowpack accumulation volumes, smaller snowmelt runoff volumes, an earlier snowmelt runoff season, and accordantly lower stream inflows to the lake during the ensuing summer season.

By finding that the continued declines in the Spokane River's seasonal low flows have coincided with: 1) less consumptive use of groundwater; 2) stable or slightly increasing groundwater levels; and 3) recent reductions in snowpack in the contributing watershed, the local water purveyors have established an important framework that is expected to focus current and future regional water supply planning efforts on considering more than just traditional methods of regulating M&I groundwater pumping. For example, the study results reinforce the value of existing water conservation programs and of encouraging less water-intensive landscape design in new developments. Also, the finding that a climate-change influence has already occurred in the watershed is now a frequent point of discussion at local water forums. As GSI has presented these results at local bi-state forums, local water purveyors and other local stakeholders have expressed a desire to work together collaboratively to find strategies that are practical and effective for improving the river's seasonal low flows, given: 1) the region's reliance on the SVRP Aquifer for its sole water supply; and (2) the need to simultaneously manage hydropower, recreation, and instream flow needs in the Spokane River / Coeur d'Alene Lake system.

Figure 18: May Snow Water Equivalent at Sunset SNOTEL Station & Mean Daily August Flow in the Spokane River at Spokane Gage



Causes & Effects

The case study presented in this article demonstrates how a thorough and complete analysis of historical hydrology and water uses provides important context and value to local water communities by illustrating causes and effects that might not be evident from a review of hydrologic and water use data during a much shorter and recent time period.

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Climate & Streamflow

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Ty Wick is the founder of the Spokane Aquifer Joint Board and served as its President from 1995 to 2017. Ty is also the General Manager of Spokane County Water District No. 3, which is comprised of eight separate public water systems in the Spokane area. Ty holds a Bachelor's degree in animal science and agricultural economics (Washington State University, 1974) and completed one year toward an MS degree in engineering management (Eastern Washington University, 1983). Ty is a certified Water Distribution Manager 4 (WDM4) in Washington. This past March, Ty received the first-ever Water Stewardship Award from the Spokane River Forum, honoring his many years of dedication to ensuring that the more than 500,000 residents of the region have access to a safe and reliable supply of drinking water.

SAN JOAQUIN VALLEY SUBSIDENCE

Edited/Condensed from California Department of Water Resources Februay 8, 2017 press release

Editors' Note: The following is a condensed version of a press release issued by the California Department of Water Resources, provided as an introduction to the following article, which presents a detailed discussion of methodology and practical applications by the authors of *Progress Report: Subsidence in California, March 2015 — September 2016.*

NASA Report: San Joaquin Valley Land Continues to Sink

GROUNDWATER PUMPING CAUSES SUBSIDENCE, DAMAGES WATER INFRASTRUCTURE

SACRAMENTO – New NASA radar satellite maps prepared for the California Department of Water Resources (DWR) show that land continues to sink rapidly in certain areas of the San Joaquin Valley, putting state and federal aqueducts and flood control structures at risk of damage.

"The rates of San Joaquin Valley subsidence documented since 2014 by NASA are troubling and unsustainable," said DWR [now former] Director William Croyle, "…the current rates jeopardize infrastructure serving millions of people. Groundwater pumping now puts at risk the very system that brings water to the San Joaquin Valley. The situation is untenable."

A prior August 2015 NASA report prepared for DWR documented record rates of subsidence in the San Joaquin Valley. The current report shows that two main subsidence bowls covering hundreds of square miles grew wider and deeper between spring 2015 and fall 2016. Subsidence also intensified at a third area, near Tranquillity in Fresno County.

Additional aircraft-based NASA radar mapping was focused on the California Aqueduct, the main artery of the State Water Project (SWP), which supplies 25 million Californians and nearly one million acres of farmland. The report shows that subsidence caused by groundwater pumping near Avenal in Kings County has caused the Aqueduct to drop more than two feet. As a result of the sinking, the Aqueduct at this stretch can carry a flow of only 6,650 **c**ubic **f**eet per **s**econd (cfs) — 20 percent less than its design capacity of 8,350 cfs. To avoid overtopping the concrete banks of the Aqueduct in those sections that have sunk due to subsidence, water project operators must reduce flows.

DWR, which operates the SWP, is analyzing whether the subsidence-created dip in the Aqueduct will affect deliveries to Kern County and Southern California water districts. If the SWP allocation is 85 percent or greater, delivery may be impaired this year due to the cumulative impacts of subsidence in the Avenal-Kettleman City area.

The NASA analysis also found subsidence of up to 22 inches along the Delta-Mendota Canal, a major artery of the Central Valley Project (CVP), operated by the US Bureau of Reclamation. The CVP supplies water to approximately three million acres of farmland and more than two million Californians.

Also of concern is the Eastside Bypass, a system designed to carry flood flow off the San Joaquin River in Fresno County. The Bypass runs through an area of subsidence where the land surface has fallen between 16 inches and 20 inches since May 2015 — on top of several feet of subsidence measured between 2008 and 2012. DWR is working with local water districts to analyze whether surface deformation may interfere with flood-fighting efforts, particularly as a heavy Sierra snowpack melts this spring. A five-mile reach of the Eastside Bypass was raised in 2000 because of subsidence, and DWR estimates that it may cost in the range of $250 million to acquire flowage easements and levee improvements to restore the design capacity of the subsided area.

There are thousands of groundwater wells near state infrastructure that could be contributing to the subsidence recorded by NASA.

In response to the new findings, state officials said they will investigate any legal options available to protect state infrastructure. DWR also will investigate measures for reducing subsidence risk to infrastructure, including: groundwater pumping curtailment; creation of groundwater management zones near critical infrastructure; and county ordinance requirements.

DWR is conducting its own study of the effects of subsidence along the 444-mile-long California Aqueduct and other SWP features and in coming months will identify potential actions to remediate damage. A comprehensive rehabilitation to restore the full California Aqueduct to its original design capacity would likely cost in the hundreds of millions of dollars. A focused triage to address conveyance losses in the most affected portions of the canal may cost tens of millions of dollars per location.

Long-term subsidence already has destroyed thousands of public and private groundwater well casings in the San Joaquin Valley. Since the 1960s, subsidence has required repairs such as the raising of canal linings, bridges, and water control structures on the Aqueduct and on the CVP's Delta-Mendota and Friant-Kern canals. Over time, subsidence can permanently reduce the underground aquifer's water storage capacity. Subsidence-related repairs have cost the SWP and CVP an estimated $100 million since the 1960s.

DWR will work with local water managers to identify specific actions to reduce long-term subsidence risk and consider whether to incorporate further emphasis on reduction of subsidence risk into the ongoing implementation of California's Sustainable Groundwater Management Act (SGMA).

For Additional Information:

California DWR website: www.water.ca.gov/groundwater/landsubsidence/LSmonitoring.cfm

Groundwater & Subsidence

GROUNDWATER & SUBSIDENCE

MEASURING LAND SUBSIDENCE IN CALIFORNIA USING EARTH-OBSERVING RADAR

by Cathleen E. Jones, Tom G. Farr, Zhen Liu

Jet Propulsion Laboratory, California Institute of Technology (Pasadena, CA)

Introduction

Land Surface Changes

Subsidence caused by groundwater pumping in the Central Valley has been a problem for decades. During the 2012-2016 drought, the California Department of Water Resources (DWR) engaged scientists at the Jet Propulsion Laboratory (JPL), California Institute of Technology, to determine where and by how much land surface elevation in the California Central Valley was changing during the drought. JPL is the National Aeronautics and Space Administration's (NASA's) only Federally Funded Research and Development Center and has been instrumental in the development and management of numerous major Earth Science satellite missions and airborne science programs.

Large & Small Scale

To determine how the land was changing, JPL applied radar remote sensing methods developed to study geophysical processes that cause deformation of the Earth surface, e.g., earthquakes or volcanos, to measuring subsidence across the Central Valley. Subsidence was measured both at the large scale — to identify the major subsidence bowls — and at the small scale — to locate where subsidence was directly impacting the California Aqueduct. More recently, the project has expanded to look at subsidence in other groundwater basins within California. The results have been provided in two separate reports to DWR, one published in 2015 that reported subsidence through early 2015 [Farr et al., 2015], and another in 2017 that extended the subsidence measurements through mid-2016 [Farr et al., 2017].

Subsidence Problems in the Central Valley Groundwater Basins

The aquifer system of the southern Central Valley and many other alluvial basins of California has both unconfined and confined portions caused by alternating layers of coarse and fine-grained sediments.

"Elastic" Compaction

Water in the coarse-grained, unconfined (or "water-table") aquifers can be extracted or recharged easily and causes only minor "elastic" compaction. This minor compaction is observed as seasonal subsidence followed by rebound of water levels and the land surface.

Rebound Capability

However, many water wells exploit the deeper confined aquifers. Withdrawal of water from these aquifers causes drainage of the fine-grained confining layers called aquitards. A significant amount of water is available from the aquitards; however, they can be compacted past the point where they can fully rebound. In general, if water levels are not drawn too low, when pumping ceases water recharges the aquitards and their structure expands. However, if water levels are drawn too low, an irreversible compaction of the fine-grained aquitards occurs. The water cannot recharge the layers, causing permanent subsidence and loss of some groundwater storage capacity (*see* Galloway et al., 1999 pages 8-13; Bertoldi et al., 1991 for reviews). Compaction to the point where there is loss of rebound capability is called "inelastic" compaction. Aquitards drain slowly and compact both elastically and inelastically. The more that pumping occurs without recharge the more likely it is that collapse will occur. Collapse causes permanent loss of groundwater storage capacity in the aquitard.

Subsidence

Consequences of subsidence extend beyond loss of groundwater storage. Areas that have subsided are more prone to flooding as the change in slope of the land alters drainage patterns. In this way, historically high land can unexpectedly become the pathway for floodwaters. There have been multiple effects of subsidence on infrastructure: roads have been broken by fissures; pipelines have been exhumed; and aqueduct flow capacity has been reduced. This last effect has been observed in water conveyance structures, including: the US Bureau of Reclamation's Delta-Mendota Canal; the California Department of Water Resources' (DWR) California Aqueduct; and local agency irrigation canals — where canal linings have required repairs or sides have been raised.

Probable Cause

Measuring and understanding subsidence as a function of groundwater dynamics can greatly improve management of this important resource. Measurement provides information about the levels of pumping that result in only elastic compaction, without reaching the the more problematic inelastic threshold. Identifying the location and probable cause of subsidence is particularly important in areas where economic and social costs are high.

Groundwater & Subsidence

Surface Deformation

Vertical Change Sensitivity

Subsidence Maps

2021 Launch

Infrastructure Effect

Airborne and Satellite Radar Remote Sensing of California Groundwater Basins

NASA and a number of other countries' space agencies have launched missions to observe the Earth from space using different types of sensors. Radar instruments of a particular type called Synthetic Aperture Radar (SAR) can be used to image the surface at relatively high resolution (1-30 meters (m)) and measure surface deformation using a technique known as **In**terferometric SAR (InSAR). A number of satellite systems have been flown over the years to provide InSAR data (Table 1). Although the satellites each operated only over a span of a few years, when combined together the instruments provide a continuous time series because their operating periods overlap in time. That is a focus of ongoing research by our group at JPL.

Phased Array type L-band Synthetic Aperture Radar (PALSAR) is an active microwave sensor using L-band frequency to achieve cloud-free and day-and-night land observation. PALSAR images spanning the period June 2007 – December 2010, Radarsat-2 images for the period May 2014 – January 2015, and Sentinel-1A images from May 2015 – August 2016 were processed to independent time series of subsidence within the Central Valley. Over the last few years, satellite InSAR has been used to produce maps of subsidence with vertical change sensitivity of less than an inch between two individual scenes.

Satellite	Dates	Resolution (feet)	Swath (miles)	Incidence Angles	Minimum Revisit (days)	Band*/pol
ERS 1,2	1991-2010	75	60	25°	35	CVV
Envisat	2002-2010	75	60	15-45°	35	CVV, CHH
PALSAR	2006-2011	30-300	25-200	10-60°	46	L-quad
Radarsat 1	1995-2013	30-300	25-300	20-49°	24	CHH
Radarsat 2	2008-	10-300	25-300	10-60°	24	C-quad
TerraSAR-X	2007-	3-50	3-60	15-60°	11	X-quad
Cosmo-Skymed	2007-	3-300	5-120	20-60°	1	X-quad
PALSAR-2	2014-	10-300	30-200	30-45°	14	L-quad
Sentinel-1	2014-	15-120	150	20-45°	12	C-dual
NISAR	2021	100	200	15-60°?	8?	L-quad

* wavelengths: X ~ 1 in., C ~ 2 in., L ~ 10 in.

Table 1. Past, present, and future radar satellites. The resolution specified is the value for the instrument prior to spatial averaging. When a range of spatial resolutions is given, it indicates that different operating modes of the instrument can be used. Finer resolution corresponds to the narrower swath width.

NASA does not have a SAR in Earth-observing orbit that can provide InSAR data at present. However, an instrument is currently being built for launch in 2021 as part of NASA's NISAR Mission (*see* https://nisar.jpl.nasa.gov) being conducted in concert with India's space agency. The NASA Airborne Science Program operates an airborne SAR that is a prototype instrument for NISAR, called UAVSAR (https://uavsar.jpl.nasa.gov).

UAVSAR, which is flown on a Gulfstream-3 aircraft, operates at 1.257 GHz in the L-band of the electromagnetic spectrum. This airborne SAR has a much higher signal-to-noise ratio than satellite SARs, usually achieving a factor of 100 increase in signal through the use of a high-power instrument transmitting from 41,000' altitude rather than from Earth orbit. It also has higher spatial resolution than the satellite SARs, with 1.7m x 0.6m instrument ground resolution (with spatial averaging being done during processing to improve the accuracy of the deformation measurement). UAVSAR products are processed to ~7m resolution and the satellite SAR data processed to ~100m resolution. The effect of subsidence on infrastructure can be better monitored using the airborne SAR data, which has higher spatial resolution.

The use of InSAR for measuring subsidence is not new to this study. Subsidence due to groundwater withdrawal in the western United States, evaluated based on satellite InSAR, has been done for: Los Angeles (Bawden et al., 2001); the Antelope Valley (Galloway et al., 1998); Las Vegas (Hoffmann et al., 2001; Bell et al., 2008); the Santa Clara Valley (Sneed et al., 2003; Chaussard et al., 2017); the Coachella

Groundwater & Subsidence

Remote Monitoring

"Interferogram"

Displacements History

Processing Results

Agricultural Activities

Corrections

Valley (Sneed and Brandt, 2007); and the southern Central Valley (Farr and Liu, 2015; Sneed et al., 2013; Borchers and Carpenter, 2014; Smith et al., 2017). Previous InSAR results from UAVSAR include: measurements of subsidence in the Sacramento-San Joaquin Delta (Sharma et al., 2015); fault slip in California (Donnellan et al., 2014); and landslides along the San Andreas fault (Scheingross et al., 2013).

Using InSAR to measure subsidence impacts to the California Aqueduct is a more recent application.

InSAR: How Interferometric Synthetic Aperture Radar Works

InSAR is a technique whereby surface change occurring between two radar imaging passes can be measured and mapped to high precision (see Madsen and Zebker, 1998; Massonnet, 1997 for reviews). The ability to map surface deformation of a fraction of an inch over large areas at spatial resolutions of 100 feet or finer has opened up new possibilities for remote monitoring of groundwater resources.

The InSAR technique works by acquiring images from the same viewing geometry at two different times between which a change in the surface position has occurred. The phases of the returning radar waves from the two acquisitions are subtracted to create a phase-difference map — called an "interferogram" — that can be processed to create a map of changes in distance along the line-of-sight direction. The interferogram is precise to fractions of the radar wavelength (typical wavelengths are 1-10 inches).

After many pairs of radar images over an area have been processed into interferograms, they can be further analyzed to create a time series of surface deformation. What is actually measured is not the change in surface elevation, but rather the change in distance along the line-of-sight direction between the ground and the radar. In addition, the change is measured relative to a location in the scene which is selected during processing.

Our analysis also measures change relative to the first date of the time series. The InSAR time series analysis produces a history of line-of-sight surface displacements similar to Global Positioning System (GPS) time series observations — but with much greater spatial coverage. InSAR time series recover both long-term mean velocities and the time varying components. This technique has been applied successfully for imaging: non-steady-state deformation at volcanoes (Lundgren et al., 2004); deforming plate boundaries (Lundgren et al., 2009); and aquifer dynamics (Farr et al., 2015; Lanari et al., 2004).

After the initial time series inversion, averaging in both space and time is applied to reduce random errors noise and smooth the deformation time series. The satellite results shown here have been averaged to 300' pixels in order to reduce the random errors. Since atmospheric noise is spatially correlated but temporally uncorrelated, its net effect on the InSAR time series is usually negligible. A final step in post-processing is to project the line-of-sight measurements to the vertical direction under the assumption that there is no significant horizontal surface movement gradient and that all of the measured deformation comes from subsidence/uplift. This allows measurements from multiple satellites with different imaging geometries to be compared with each other. The results can also be compared with vertical surface change measured with GPS and traditional surveying methods.

Error Factors and Precision

There are some potential error factors which must be considered when processing and interpreting InSAR because they can either mimic deformation signals or cause greater noise in the measurements. The most significant are: orbital or track position error; atmospheric noise; topography-induced errors; and changes in the surface properties between image acquisitions (temporal phase decorrelation), which can arise from changes in soil moisture or grazing and agricultural activities. This latter effect is especially acute in agricultural areas like the Central Valley, where many areas regularly experience small-scale surface changes near the scale of the radar wavelength. Crops blowing in the wind or fields plowed between radar image acquisitions can cause loss of information. This effect can be ameliorated by using a longer wavelength, e.g., L-band (which is used for UAVSAR and PALSAR) and by selecting pairs of images for which there is small orbital track (baseline) separations and short time intervals between acquisitions.

Of the other error terms, the orbital errors and topographic errors can be corrected during processing. Atmospheric water vapor and other variations in the Earth's troposphere and ionosphere remain a large error source because changes in meteorological conditions and total electron count in the ionosphere introduce phase delays that mimic surface changes. Aircraft fly below the ionosphere, so airborne SARs are not subject to the ionospheric error source. Tropospheric variations are usually mitigated by analyzing many interferometric pairs and averaging (stacking), under the assumption that ground deformation is steady and atmospheric phase is random in time. The longer the time series of images used in determining subsidence trends, the greater the reduction of atmospheric noise effects.

The estimated measurement precision for InSAR time series is generally a small fraction of a wavelength, depending on the InSAR acquisitions and noise levels (Galloway et al., 1998; Ozawa and Ueda, 2011; Chaussard et al., 2013).

Groundwater & Subsidence

Main Bowls

Broad-Scale Subsidence in the San Joaquin Valley

Maps of subsidence in the San Joaquin Valley were made for the period May 7, 2015 – September 10, 2016 (Figure 1). Two main subsidence bowls can be seen in the maps of total subsidence: a southern one in the Tulare basin about 25x65 miles centered on Corcoran; and a northern one about 15x25 miles centered south of the town of El Nido. The highest magnitude cumulative subsidence during this time period in the Tulare Basin was ~22" near Corcoran. The maximum subsidence southeast of El Nido was approximately 16". These patterns are generally similar to the earlier PALSAR and Radarsat-2 results (Farr et al., 2015), but we see continued development of a diffuse area northwest of Corcoran with subsidence of up to 12". Subsidence of over 12" extends west to the California Aqueduct near Avenal — at the aqueduct is a small patch of total subsidence of almost 18" which occurred during two periods: May-Oct. 2015 and Apr.-Aug. 2016 (Figure 2). This is better resolved in the UAVSAR results, discussed in the next section, because less spatial averaging was applied to the data.

Northern Bowl

The northern subsidence bowl southeast of El Nido subsided ~16" during this 16-month time period, with pockets subsiding up to 20". The Eastside Bypass runs right through the main area of subsidence. A relatively new area of subsidence has been observed near Tranquility about 10 mi southeast of Mendota. This was first noted in the subsidence measured with Radarsat-2 in late 2014, but has intensified since then. The area is about seven miles in diameter. Its history of subsidence (Figure 2) shows it subsided in two stages, first in early May – October 2015 and later in April – August 2016.

Northern Bowl (Eastside Bypass)

Corcoran Bowl (Southern)

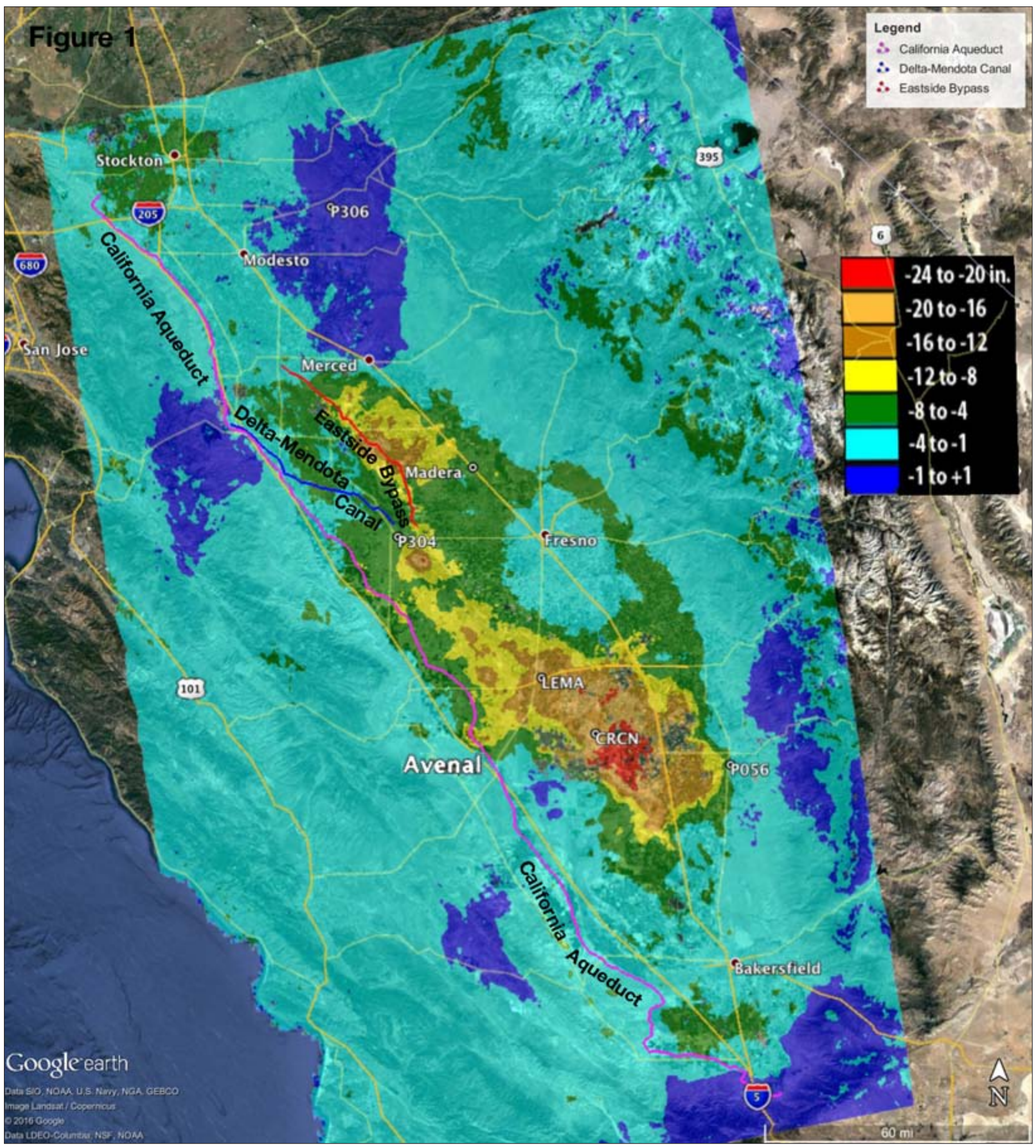

Figure 1. Total subsidence in the San Joaquin Valley for the period May 7, 2015 – September 10, 2016 as measured by the European Space Agency's Sentinel-1A, and processed at JPL. Two large subsidence bowls are evident: 1) centered on Corcoran; and 2) southeast of El Nido. There is also a small, newly developed subsidence feature between them, near Tranquility. An arm of the large Corcoran bowl extends to the California Aqueduct near Avenal.

Groundwater & Subsidence

Rain Effect

The deformation histories of a few selected locations in the San Joaquin Valley are plotted in Figure 2. The large maximum subsidence in the Corcoran area is clear and shows virtually no recovery at any time during the period of measurement. The maximum subsidence location near El Nido shows some flattening between October 2015 and March 2016. This flattening is probably related to relatively abundant rainfall that winter. The relatively new subsidence feature at Tranquility and the history of the aqueduct feature near Avenal also show a flattening between October 2015 and March 2016, but renewed subsidence after April 2016. More recent data acquisitions show cessation of subsidence in many areas due to the recent heavy winter rains.

Subsidence History

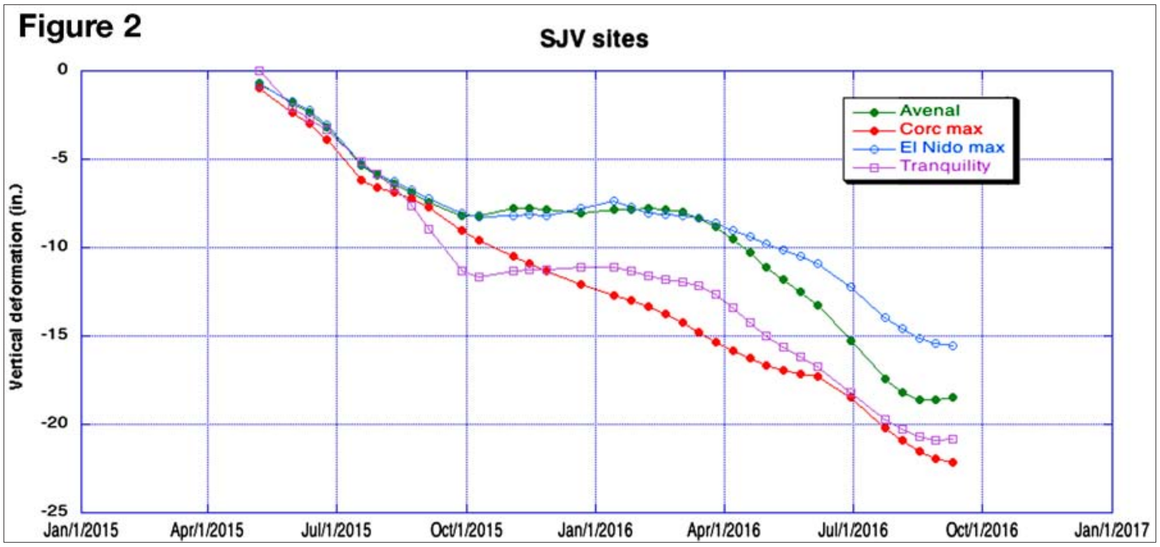

Figure 2. Subsidence histories of a few locations in the San Joaquin Valley. "Avenal" is located at the maximum subsidence measured near the California aqueduct near the town of Avenal. This was also mapped by UAVSAR (Figure 5). "Corcoran max" is located in the maximum subsidence pocket south of Corcoran. "El Nido max" is located in the pocket southeast of El Nido. "Tranquility" is located at the maximum subsidence nine miles southeast of Mendota, between the two main subsidence bowls.

Total Subsidence: CA Aqueduct & Eastside Bypass

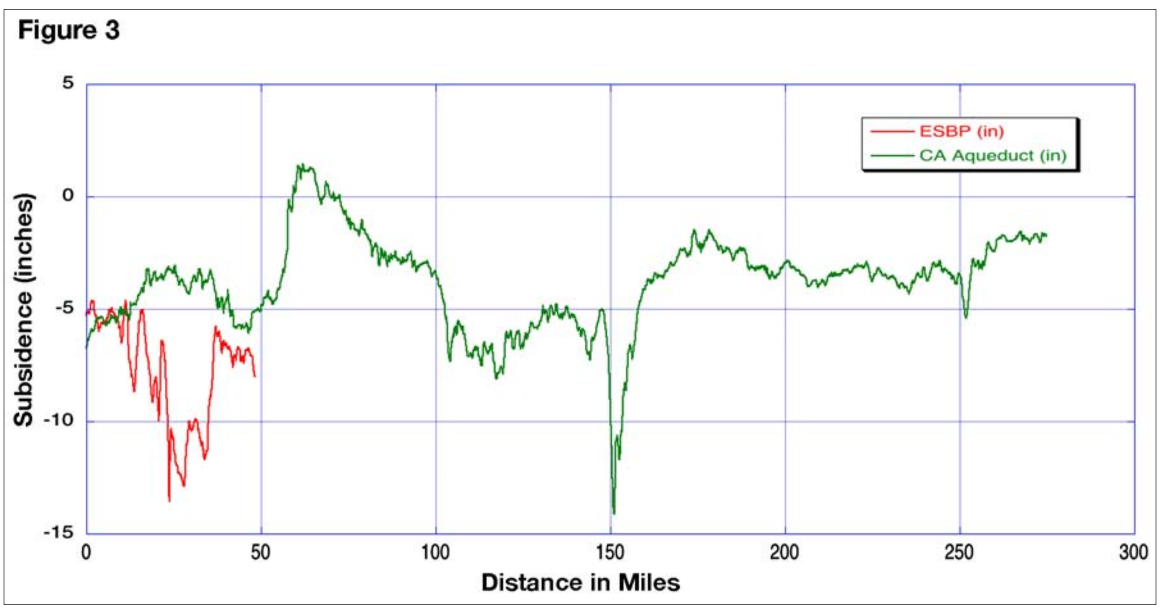

Figure 3. Transects showing total subsidence along the California Aqueduct and the Eastside Bypass. The transects extend from north to south and represent total subsidence from May 7, 2015 – May 25, 2016. Note the deep subsidence about midway along the Eastside Bypass. That corresponds to the main subsidence bowl on the map (Figure 1). The sharp pit near mile 150 on the California Aqueduct corresponds to the feature near Avenal as shown in Figure 2 and in Figure 4.

Avenal Feature

The transects shown in Figure 3 give a more detailed picture of the total subsidence measured in the vicinity of the California Aqueduct and the Eastside Bypass over the period of measurement. It is clear that the Eastside Bypass has suffered significant subsidence, concentrated in its central area. In contrast, most areas in the vicinity of the California Aqueduct experienced only a few inches of subsidence. The

Groundwater & Subsidence

exception is the subsidence concentrated near Avenal and plotted near mile 150. These amounts correspond to averages over the processed pixel (about 300' (~100m) on each edge), not the values on the aqueduct structure itself. UAVSAR provides a more detailed look, as discussed below.

In the case of the Sentinel-1A measurements used for the subsidence measurement, uncertainties associated with the vertical displacement (subsidence/uplift) measurements were determined to be less than 1" and usually less than 0.5".

"Hot Spot" - Localized Subsidence Along the California Aqueduct and Delta Mendota Canal

To evaluate subsidence on or near the aqueduct, data were collected with the NASA UAVSAR airborne platform over two rectangular swaths roughly centered on the California Aqueduct (Figure 4). The northern swath covers the California Aqueduct from the area immediately north of San Luis Reservoir to just south of Kettleman City, and the southern swath covers the California Aqueduct from due west of Buttonwillow to the Edmonston Pumping Plant.

Highly Variable

Time series analysis shows subsidence to be highly variable across this extent. The values shown are cumulative for the period of measurement, starting in mid-2013 (northern line) or spring-2014 (southern line) and extending through June 2016. The northern imaged area has many locations experiencing significantly greater subsidence than is observed in the southern swath. Overall the trends are similar to what was reported previously (Farr et al., 2015), with higher subsidence in the San Luis Field District section of the aqueduct. We note that subsidence values measured with UAVSAR InSAR are averaged across a pixel of area ~7m x 7m (~20' x 20'), so maximum values measured on the ground could be higher at locations within the pixel.

Hot Spot (Avenal)

The fastest subsidence is observed along the northern stretch of the aqueduct at the Avenal Cut-off Road hot spot first identified in summer 2014, where both the amount of subsidence of the aqueduct and the extent of aqueduct experiencing high subsidence has increased substantially since March 2015 (Figure 5). This feature has deepened to 27.6" at its maximum and expanded so that the aqueduct has subsidence as much as 25", with the greatest subsidence near the previous maximum subsidence location directly west of the hot-spot center.

Aqueduct Impact

The area of impact from the hot spot has dramatically increased, with ~4.7 miles of the aqueduct experiencing 10" or greater subsidence since the measurements started in July 2013 and most of that occurring since summer 2014. For reference, the previously reported values for the period July 2013 - March 2015 were 13" maximum subsidence of the aqueduct and >8" of subsidence along a 1.3 mile stretch of the aqueduct [Farr et al., 2015]. A comparison between results for the Avenal hot spot from Sentinel (Figures 1, 2, and 3) and UAVSAR (Figure 5) for the Avenal area show a similar rate of subsidence.

California Aqueduct

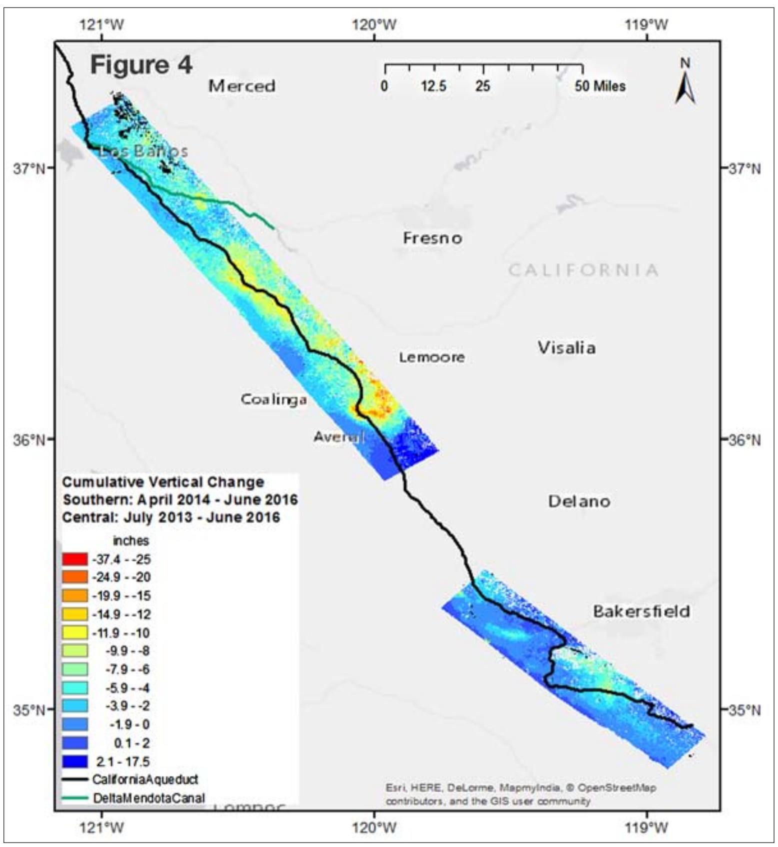

Figure 4. Overview of subsidence measured in the two UAVSAR image swaths covering the California Aqueduct. These swaths were planned specifically to image the California Aqueduct, and therefore miss the large subsidence bowls to the east that are seen in the satellite SAR results. The swath to the south, which covers part of the aqueduct in the San Joaquin Field District, shows cumulative subsidence between April 2014 and June 2016. The swath to the north, which covers the central section of the California Aqueduct (San Luis Field District), shows cumulative subsidence between July 2013 and June 2016. Part of the Delta Mendota Canal is included in the northern swath.

Groundwater & Subsidence

Avenal Hot Spot

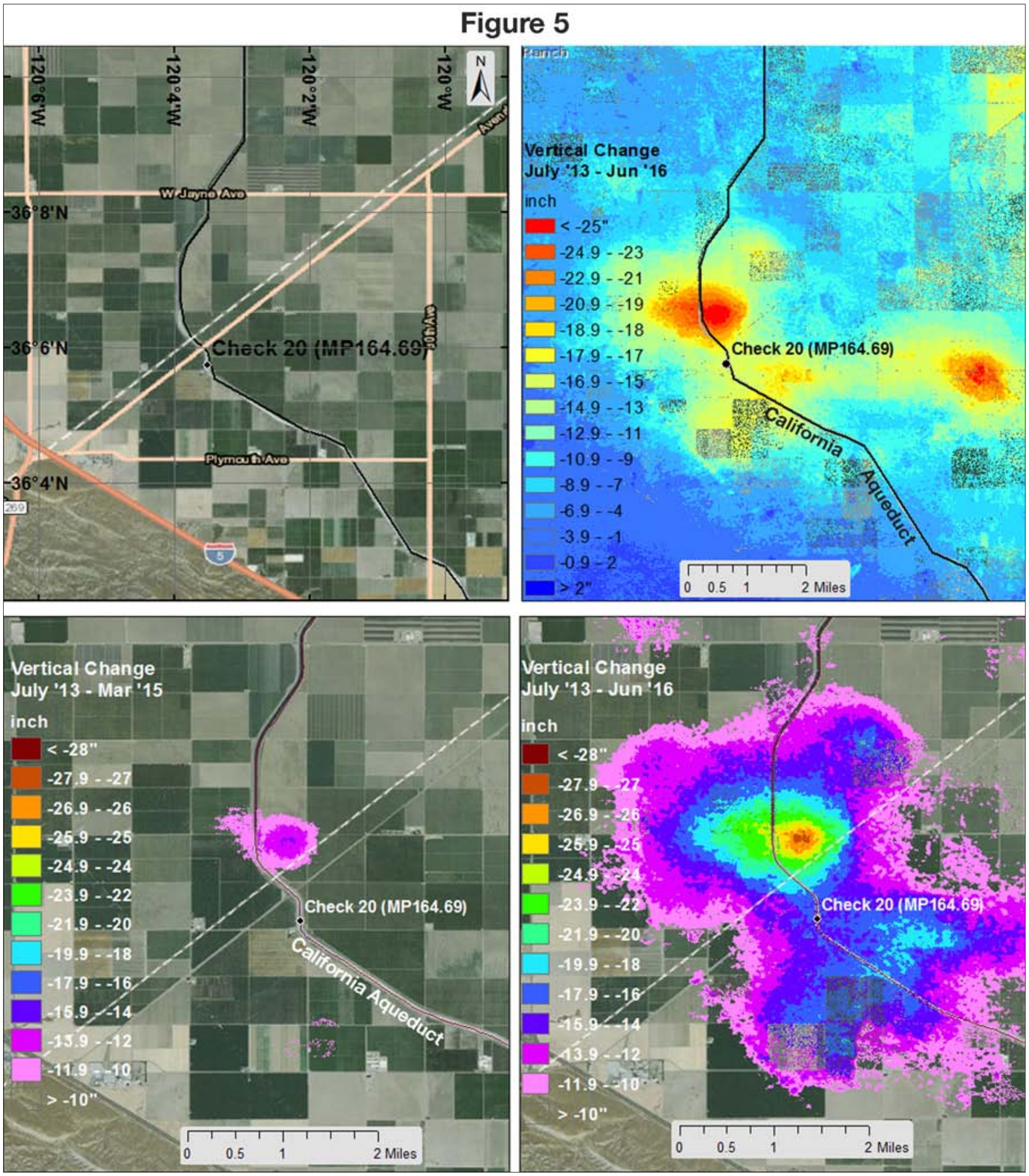

Figure 5. Optical image with latitude/longitude specified (top left) and subsidence map (upper right) showing the subsidence hot spot centered just north of Avenal Cut-off Road and <0.5 mi east of the California Aqueduct. Much smaller hot spots are potentially forming centered <1 mile from the aqueduct to the northeast and southeast of the main subsidence bowl. Another large and localized subsidence bowl several miles to the east of the aqueduct has also deepened and expanded (upper right). The bottom two maps show the relative expansion of the subsidence bowl between March 2015 (bottom left) and June 2016 (bottom right). The same color scale is used for both and only areas subsiding >10” are plotted. The aqueduct now shows areas with 25” of subsidence. Approximately five miles of the aqueduct has been lowered by >10”.

Expansion & Deepening Subsidence

Smaller areas of localized subsidence were detected with UAVSAR, which did not show up in coarse-resolution satellite data. Two new localized subsidence features similar in shape to the Avenal hot spot, albeit smaller in magnitude, have been identified. One is located south of San Luis Reservoir and north of Check 14 (3651’50”N, 12046’30”W) (Figure 6, next page) and the other south of the Wind Gap Pumping Plant and north of Check 37 (3459’12”N, 11859’30”W) (not plotted; *see* Farr at al., 2017, for figures).

UAVSAR measured subsidence along part of the Delta-Mendota Canal in addition to the California Aqueduct. Figure 7 (next page) shows the one observed area showing high subsidence along this structure, located east of the Russell Avenue Bridge.

Figure 6

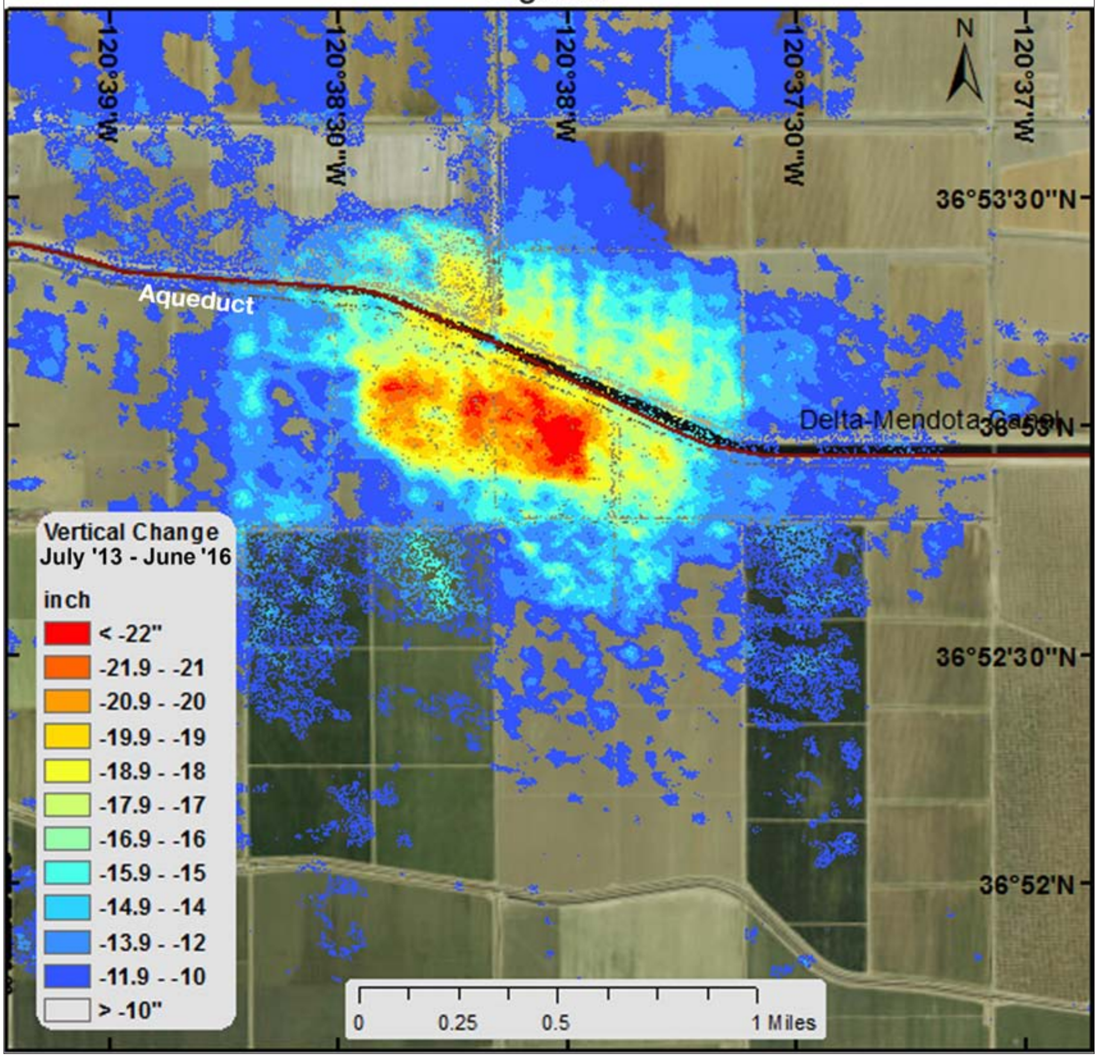

Figure 6. Localized subsidence adjacent to and extending into the California Aqueduct, located north of Check 14 (3651’50”N, 12046’30”W) Here the maximum subsidence between July 2013 and June 2016 was ~10” at the feature’s center and the maximum subsidence of the aqueduct directly was ~8” on the east side. This feature isn’t visible in the Sentinel-1A results.

Figure 7

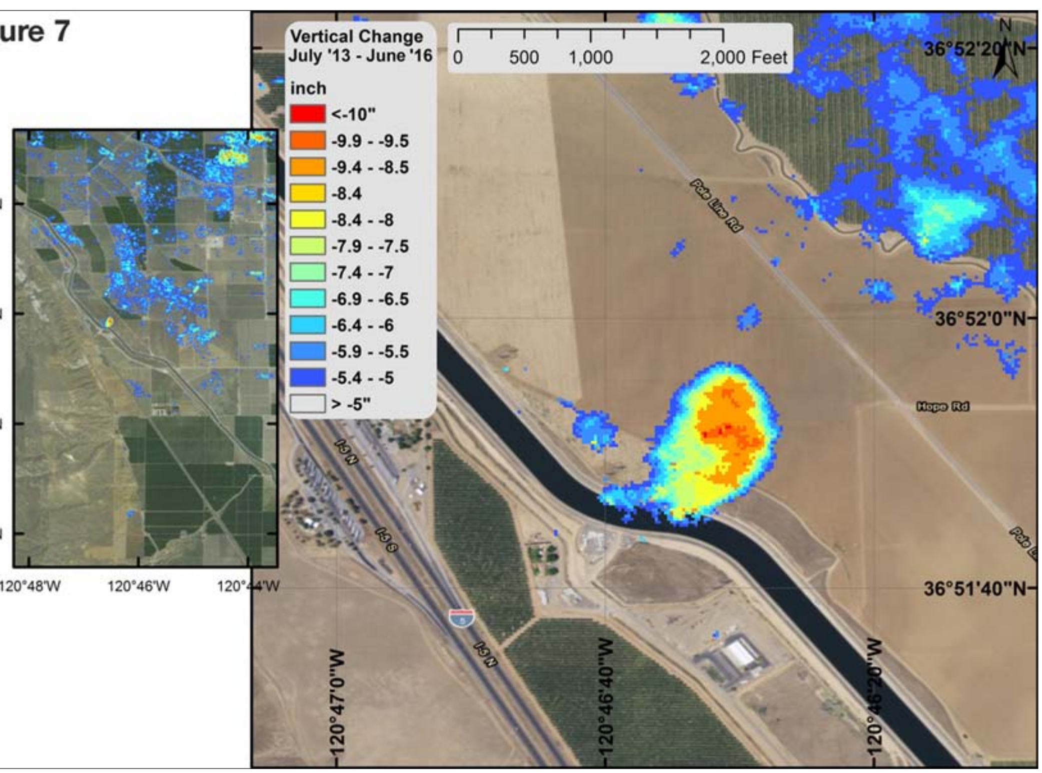

Figure 7. Subsiding section of the Delta-Mendota Canal near 3653’N, 12038’W.

Groundwater & Subsidence

Broad-scale Subsidence in the Sacramento Valley: Groundwater Declines

A subsidence map for the Sacramento Valley was also produced using Sentinel-1A data covering the period March 1, 2015 to May 30, 2016. The Sacramento Valley subsidence map (Figure 8) shows much less deformation than in the San Joaquin Valley to the south. Areas left blank showed too large temporal decorrelation for reliable surface deformation measurement.

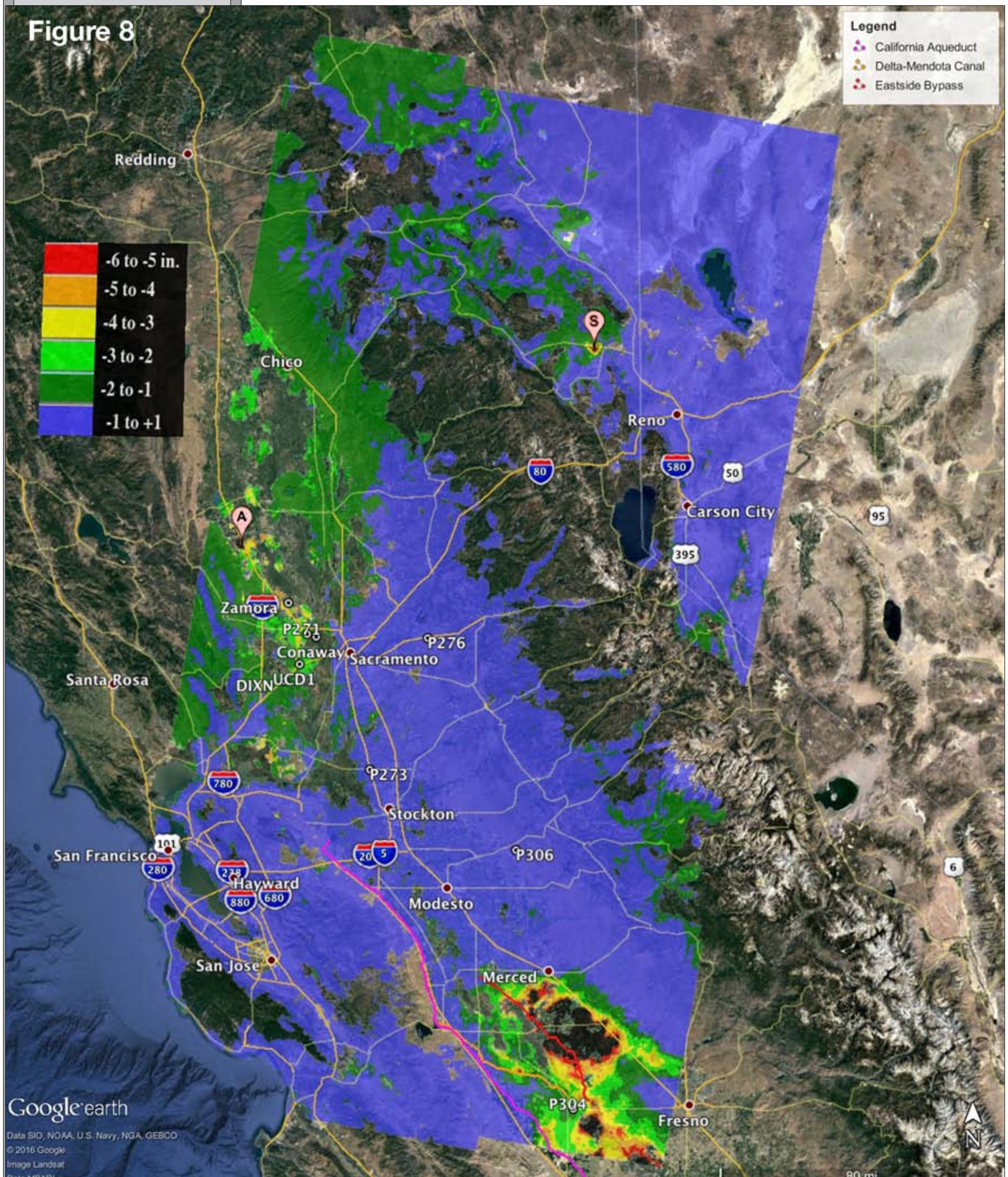

Figure 8. Subsidence map of Sacramento Valley covering the period March 1, 2015 to May 30, 2016 obtained from Sentinel-1A. Note subsidence along the west side of the valley including the Arbuckle area marked "A" and a small area of subsidence in Sierra Valley, marked "S", N of Lake Tahoe. The much larger subsidence in the El Nido area shows up at the bottom of the map (Eastside Bypass aea).

Groundwater Declines Match

Around Woodland and Davis, sites of previous subsidence, subsidence occurs in small areas up to about 2". A small area on the west side of the valley at Arbuckle (marked "A" in Figure 8 above), noted in the previous report continued to subside until the end of 2015. Total subsidence for the period of observations was about 12" (Figure 9). A previously un-reported area of subsidence was found in the map in Sierra Valley (marked "S" in Figure 8). Recent reports indicate increased use of groundwater there along with hydrogeology conducive to compaction and subsidence (CA DWR, 2003; http://sierravalleygmd.org/updates.html). A contour map of groundwater level declines (http://sierravalleygmd.org/updates.html) matches the zone of subsidence. Maximum subsidence in the area was about 6"; the history of deformation of the area is shown in Figure 9 (next page).

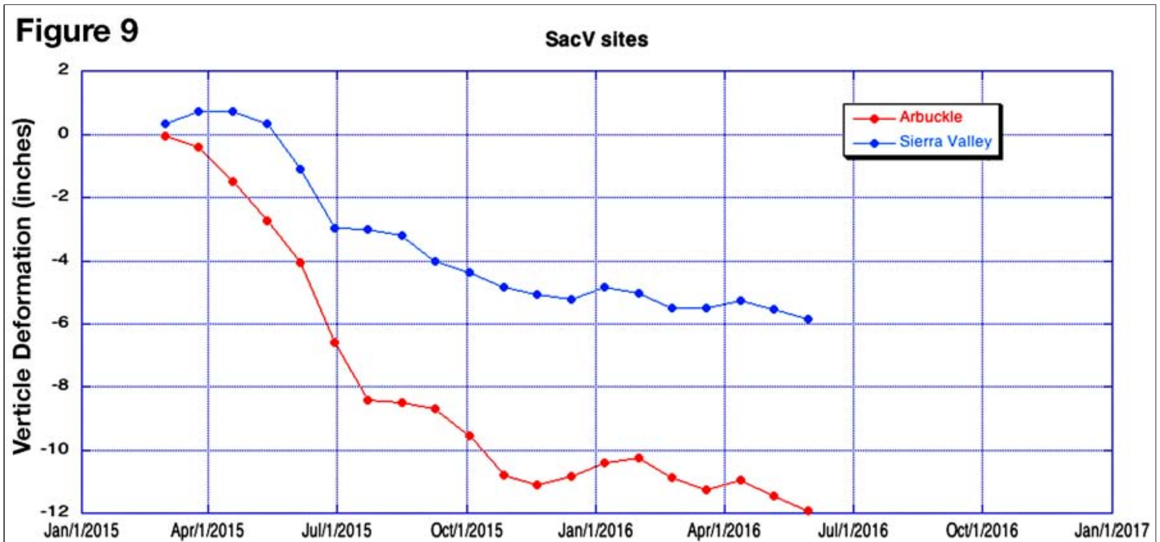

Figure 9. Subsidence histories of two locations in the Sacramento Valley from Sentinel-1A (Figure 8). Note the large subsidence in Sierra Valley which corresponds to an area of significant drawdown in the local wells. Arbuckle was identified in the previous report as having exceptionally large subsidence. The trend continued until about November 2015 when subsidence slowed.

Groundwater & Subsidence

Coastal Floodplain Subsidence

Subsidence in the South-Central Coast Region

The same Sentinal-1 scene used in the San Joaquin Valley also covered the south-central coastal region of California (Figure 10). The main interest was the coastal floodplain of the Santa Clara River (Oxnard Plain). However, the processed area extended west along the coast to Point Conception, east into the Los Angeles basin, and north to the south end of the San Joaquin Valley. For the processed period (May 7, 2015 – August 17, 2016) isolated areas of up to 2" of subsidence were noted in the Oxnard Plain as well as a fairly large zone of up to 2.5" subsidence in the foothills north of Carpinteria. The known subsidence of Cuyama Valley also shows up as well as various isolated areas in other alluvial basins in the area. Pixel histories are shown in Figure 11 for two of these features.

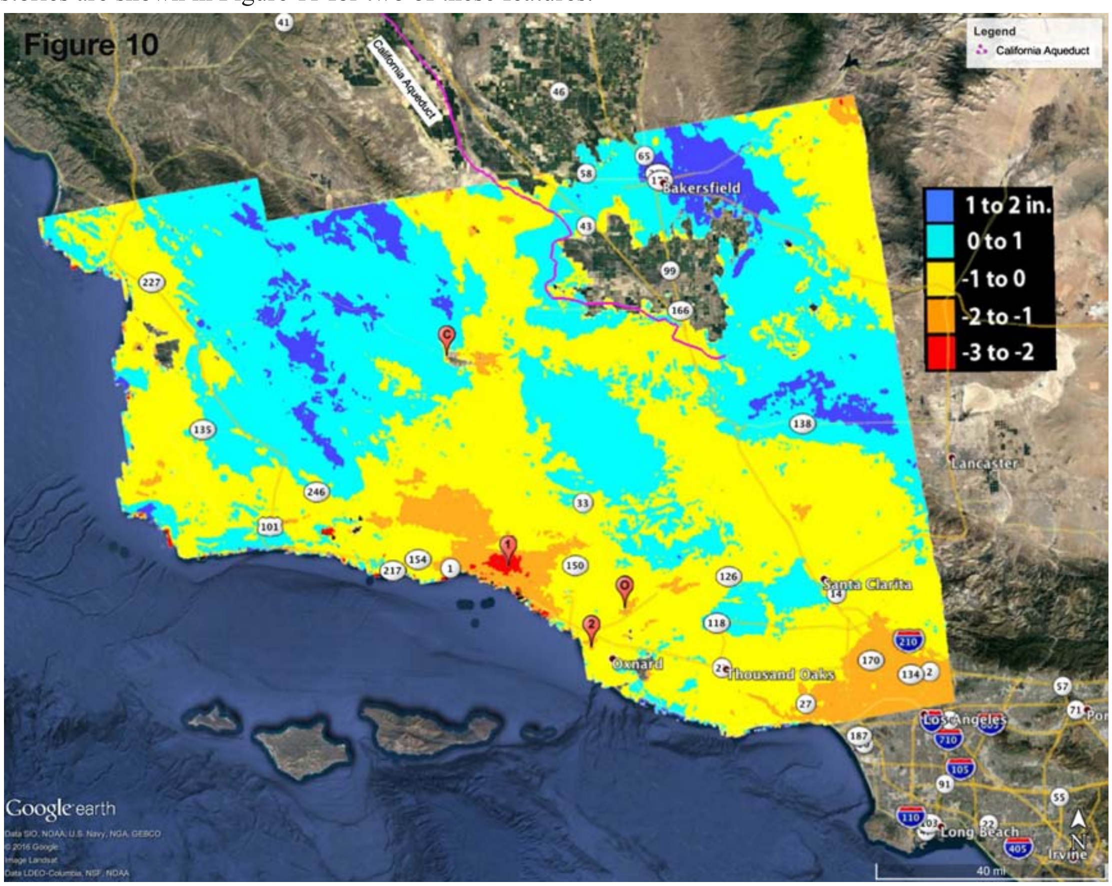

Figure 10. Subsidence in the south-central coast region of California, including Ventura, Santa Barbara and north to the San Joaquin Valley covering the period May 7, 2015 – August 17, 2016. This path (ascending #137) covers the Central Valley as well (Figure 1). Note a large area in the foothills above Carpinteria (#1) which could be due to atmospheric water vapor, small patches of subsidence in the Oxnard Plain (#2, O), and subsidence in the Cuyama Valley (C)

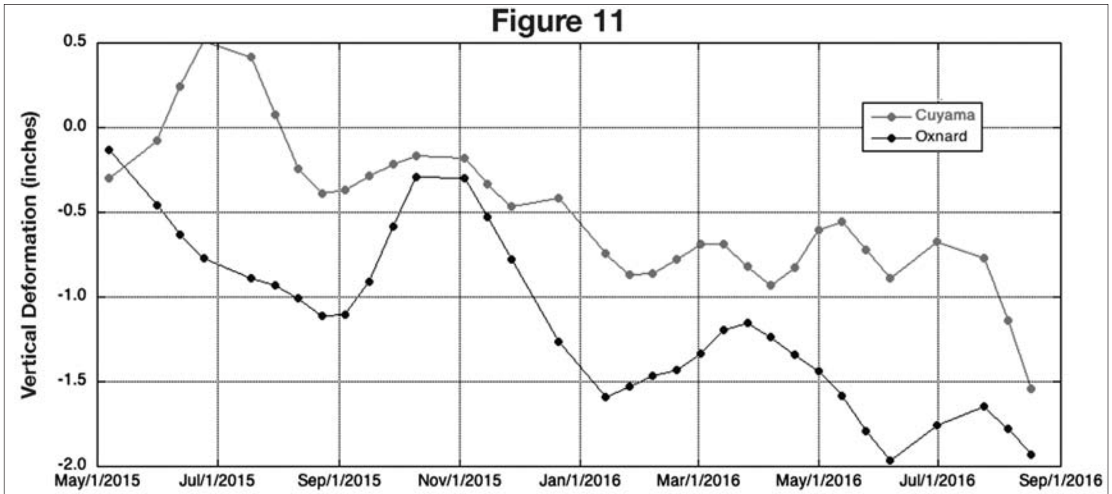

Figure 11. Subsidence histories for two locations in the south-central coast region from Sentinel-1A (Figure 10). The curves are indicated on the map: C= Cuyama Valley, O = site in Oxnard Plain near Saticoy.

Conclusions and Future Plans: Subsidence Impacts

JPL is continuing to work with the California Department of Water Resources, providing both satellite and airborne SAR analysis for subsidence mapping. The high spatial resolution and low instrument noise of the UAVSAR is shown to accurately measure subsidence along the California Aqueduct and elsewhere in its swath both over large areas and, of particular value, on a much more localized scale.

Localized Scale

The UAVSAR analysis for the State of California focuses on showing the small-scale subsidence directly impacting the aqueduct and other critical infrastructure, and this will continue through 2019. Sentinel-1A, launched in April 2014, has proved to be useful for making maps of subsidence in alluvial basins of California. Maps as well as pixel histories of subsidence and transects showing temporal and spatial details of subsidence can be produced from the InSAR data.

Updates of the subsidence maps for California will continue to be generated for California DWR with Sentinel-1B, launched in April 2016, joining its twin in orbit. The first acquisitions for California by Sentinel-1A were in late 2014 and are continuing, in general every 12-24 days. Early acquisitions over California were more sporadic, but have become more reliable as the coverage area has expanded along with the European Space Agency's capability to collect and process the data. JPL has begun downloading and processing Sentinel-1 data for other basins of California, including Antelope Valley, Coachella Valley, Borrego Valley, Imperial Valley, and the Salinas Valley, along with coastal areas. As the database expands, we expect to be able to present maps of those areas, as well as continuing monitoring of the Central Valley.

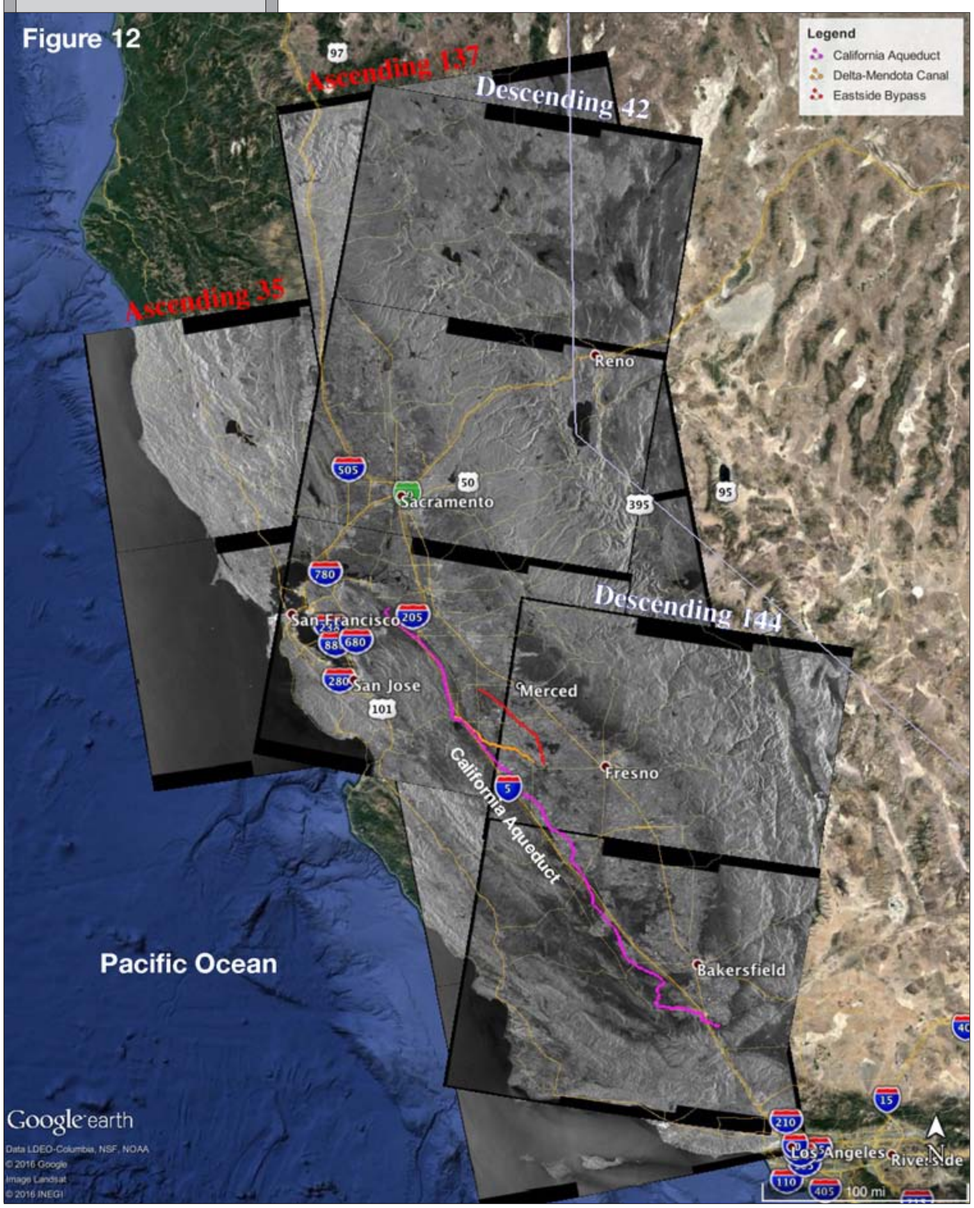

Figure 12. Coverage of Sentinel-1A over California used for this report. Ascending (SE-NW) path 137 passes from Ventura through the San Joaquin and Sacramento Valleys and descending (NE-SW) path 42 covers the Santa Clara and Sacramento Valleys. Other paths have been acquired and processed for cross-calibration and verification purposes.

Groundwater & Subsidence

Acquisition Dates

The InSAR time series produced are essentially series of maps representing the change in surface elevation for each satellite or airborne radar acquisition date relative to the first acquisition. For the satellite results we have found that a convenient format for storage and post-processing is a multi-band GeoTiff format, where each "band" is an acquisition date. Most common Geographic Information System (GIS) software packages recognize this format and can display map products from the data. JPL furnishes all of the satellite products to the DWR in this format for their use and generation of additional products. The UAVSAR data files for each time step are so large that the files are delivered as GIS rasters with header files for each time step. The cumulative vertical displacement for the entire time series is in the file corresponding to the last acquisition date of the series.

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California DWR website: www.water.ca.gov/groundwater/landsubsidence/LSmonitoring.cfm

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Tom Farr received BS and MS degrees from Caltech, and a PhD from the University of Washington, all in Geology. After a short time as an engineering geologist, he joined the Radar Sciences Group at the Jet Propulsion Laboratory, where he has been since 1975. At JPL, he helped develop the first geologic applications of imaging radar using aircraft, satellites, and the Space Shuttle. He was the Deputy Project Scientist on the Shuttle Radar Topography Mission in 2000 as well as the lead air-to-ground payload communicator. Tom has been a science investigator on European and Japanese satellite programs and has studied the geology of Mars, Venus, and recently Saturn's moon Titan. His current projects include piecing together the history of water in the Sahara with radar images and monitoring of groundwater with orbital radar. He has participated in or led geological expeditions to Tibet, northwestern China, the Egyptian Sahara, and our local deserts, including geology training of Shuttle astronauts.

Zhen Liu received the M.S. and Ph.D. degrees in geophysics and space physics from the University of California at Los Angeles, Los Angeles, CA, USA. He is currently a Scientist with the Science Division, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA. His current research interests include using interferometric synthetic aperture radar and GPS to image and constrain time variable plate boundary deformation and monitor groundwater related subsidence.

Groundwater & Subsidence

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WATER BRIEFS

WATER MARKETS — MIDWEST

OGALLALA AQUIFER ACTIVITY

WestWater Research (WestWater) has just released a report on "*Water Markets in the Ogallala Aquifer*." The Ogallala Aquifer is one of the largest groundwater basins in the US, underlying eight states and supplying over 30% of the groundwater used for irrigation in the entire nation. Roughly $7 billion worth of crops are grown each year with groundwater from the aquifer.

Since 1950, the Aquifer has seen about 270 million acre-feet (AF) of overdraft, which represents a 9% decline in total groundwater storage. In some states, state regulation is sparse and new well permits are still being issued despite notable drawdown in groundwater levels. In other states, water agencies have proactively placed moratoriums on new well permits, limiting pumping, and retiring irrigated lands. Physical and institutional water scarcity are often catalysts for water market development, so WestWater spent time this summer examining water trades in the Ogallala Aquifer in Colorado, Kansas, Nebraska, New Mexico, and Texas. Research was also conducted in Oklahoma, but no water trading activity was found.

Water trading activity in the Ogallala Aquifer region remains limited, with only 270 total water trades found from 2008-2016. This period saw an estimated 441,900 AF of water rights change hands through sales and leases, corresponding to an average of 49,100 AF of annual trading volume. This compares with total groundwater use of roughly 19 million AF/year across 14 million acres served by groundwater. Total value traded over this time period was approximately $250 million, or $27 million per year. By comparison, water rights trading across the rest of the Western US is estimated to be approximately 1.8 million AF/year, with a corresponding annual average value of $385 million. The Ogallala Aquifer region as a whole represents 3% of volume and 7% of value compared to water market activity across the Western US. Sporadic trading activity in the region means that large transactions can skew data trends and averages. For the Ogallala Aquifer, two large water trades in 2008 and 2011 make up about half of the total volume and value traded over the recent period. Removing these two trades shows that water market activity in the Ogallala has dropped since 2008, with a temporary increase around 2014.

Continued overdraft of the Ogallala Aquifer has not prompted significant water market activity, at least over the last ten years. Trading activity remains low across most of the area due to a lack of new water demands to drive the market. Two market drivers — addressing regulatory requirements and municipal demand growth — are expected to continue to be the dominant influences on water trading over the next decade. Nebraska and Colorado could continue to see water trading to address state and local water policy objectives, but likely at levels similar to what has been seen over the past decade. Water market activity in Kansas, the Texas Panhandle, and Eastern New Mexico has been driven by municipal and industrial demands looking for new and alternate sources of water supply. Trading volumes are anticipated to remain small in the near-term, as several buyers have built up their water portfolios in recent years, but are likely to increase into the future as municipal and industrial demands continue to grow and seek supplies in a water-limited region.

For info: Full Report at: www.waterexchange.com ("Market Insight")

INSTREAM FLOWS — NE

FISHERY FLOWS APPROVED

Jeff Fassett, Director of the Nebraska Department of Natural Resources (NDNR), on October 19th signed an order granting application A-19406 to appropriate water for the purpose of instream flows on the Niobrara River to maintain habitat for the fish community. The instream flow permit was granted to the Nebraska Game and Parks Commission, the Upper Niobrara White Natural Resources District (NRD), the Middle Niobrara NRD, the Lower Niobrara NRD, the Upper Loup NRD and the Upper Elkhorn NRD. The permit covers flows on the Niobrara River in a 39-mile stretch between Spencer Dam and the confluence with the Missouri River.

Appropriation A-19406 was approved for seasonally adjusted flow amounts to coincide with the different life cycle stage needs of the fishery, including overwintering, spawning, rearing, and growth. The fish community includes "species of special interest, namely pallid sturgeon, paddlefish, shovelnose sturgeon, sauger, and adult channel catfish." *Application Approval* at 7. The flows will meet habitat needs for whooping crane migration, and piping plover and least tern nesting. The *Approval* contains five "bioperiods" throughout the year, with flows ranging from 1765 to 2270 cubic feet per second. *Approval* at page 5. NDNR concluded in the *Approval* that "there is unappropriated water available in the amounts requested for each bioperiod at least 20% of the time." *Id*.

Instream flow permits are granted only for unappropriated water and are subject to the same "first in time, first in right" requirements of the Prior Appropriation Doctrine that are binding on all surface water appropriations (*see* Nebraska Revised Statutes § 46-2, 119). Only the NRDs and Game and Parks can hold instream flow permits. This water right will have a December 4, 2015 priority date, based on the date the application was filed. The *Approval* also notes that in Nebraska "instream flow application[s] for fish community maintenance should not exceed the minimum amount of flow necessary to achieve its stated purpose. Fish species habitat maintenance flows should be the lowest amount that adequately insures no permanent degradation in the amount of habitat available to the current fish community." *Appoval* at 6.

The instream flows are part of the efforts by the Niobrara River Basin Alliance NRDs and Game and Parks, along with the Nebraska Public Power District, to ensure the long-term sustainability of water in the Niobrara River basin for generations to come. The new instream flow protection is part of the ongoing saga of "War and Peace Over the Niobrara River" involving the conflict's epicenter — the Nebraska Public Power District and its small hydropower facility at Spencer Dam. *See* Blankenau, TWR #142, Dec. 15, 2015 for additional information.

For info: Christy Rasmussen, Game and Fish, 402/ 471-5593 or christy.rasmussen@nebraska.gov; *Application Approval* available at: https://dnr.nebraska.gov/sites/dnr.../A-19406%20Application%20Approval.pdf

HYPOXIA TASK FORCE — US

GULF OF MEXICO IMPACTS

The Hypoxia Task Force (HTF) recently released its 2017 Report to Congress on the actions the federal, state, and tribal members have taken to reduce nitrogen and phosphorus pollution in the Mississippi/Atchafalaya

WATER BRIEFS

River Basin to shrink the size of the Gulf of Mexico hypoxic zone. The 2017 "dead zone" measured 22,720 square kilometers (8,776 square miles). The 2017 dead zone size is above the five-year average (15,032 sq km). It is also more than four times larger than the HTF Goal of 5,000 sq km.

In accordance with the Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2014, these Reports to Congress describe the progress made through activities directed by the HTF toward attainment of the goals of the Gulf Hypoxia Action Plan 2008. The reports are released biennially, starting in 2015. The second and most recent report was released in August 2017.

The Report to Congress discusses: the environmental, economic, and social impacts of Gulf of Mexico hypoxia and harmful algal blooms; the size of the hypoxic zone since 1985; sources of nutrient loading in the MARB; the progress of state nutrient reduction strategy development and implementation; and federal agency programs that support state implementation of nutrient reduction strategies. The Repot also notes recent HTF efforts to track the environmental results of state strategy implementation.

For info: 2017 Report / Hypoxia Task Force available at: www.epa.gov/ms-htf

DIRECT POTABLE REUSE US

IMPLICATIONS OF RISKS

Direct **p**otable water **r**euse (DPR) involves the injection of highly purified wastewater into drinking water systems. DPR is among the newest and most controversial methods for augmenting water supplies, but does not come without risks. In the new article in Water Resources Management — "*Of Dreamliners and Drinking Water: Developing Risk Regulation and a Safety Culture for Direct Potable Reuse*" — Mike Kiparsky and co-authors examine the implications of risks. They find that conventional drinking water risk regulation may not sufficiently account for the risk of acute failure of complex systems like DPR.

Drawing on lessons from other sectors that have a similar risk profile, the authors argue that building a new comprehensive risk management system is necessary in order to expand direct potable reuse. The system should include industry-wide oversight and active development of a safety culture.

A drinking water system mishap could have high "signal potential," and could easily set back public acceptance. DPR is already struggling against: consumers' psychological barriers (the "yuck factor"); a lack of broader societal legitimacy; and the industry's general challenges with innovation. The industry could proactively address low-probability/high-consequence risks upfront. Examples from the aviation, nuclear, and oil industry show that such interventions do not necessarily require new layers of regulation, but can be designed in efficient, participatory, voluntary, ways.

For info: Mike Kiparsky, Director of the Wheeler Water Institute at Center for Law, Energy & the Environment, 510/ 643-6044 or kiparsky@berkeley.edu; Full Article available at: https://link.springer.com/article/10.1007/s11269-017-1824-1

WATER EXCHANGE OR

NESTLÉ APPLICATION NIXED

On October 31, the Oregon Department of Fish & Wildlife (ODFW) sent the Oregon Water Resources Department (OWRD) a letter notifying OWRD that ODFW was withdrawing its water exchange application T-11109, which had been filed to exchange .5 cubic feet per second of water rights owned by OWRD from Oxbow Springs with a like amount of groundwater rights owned by the City of Cascade Locks. The exchange would have enabled Nestlé SA (a Swiss transnational food and drink company) to establish a plant to bottle spring water from Oxbow Springs rather than using the City's well water. Governor Kate Brown earlier made a request to ODFW to withdraw the exchange application. *See* Water Briefs, *TWR* #165 for additional information.

On the basis of ODFW's letter, OWRD issued a final order on November 2nd ordering that application T-11109 "is withdrawn and of no further force or effect."

For info: Diana Enright, OWRD, 503/ 986-0874 or Diana.M.Enright@oregon.gov

ANTI-SPECULATION OR

APPLICATION DENIED

On November 15, the Oregon Court of Appeals (Court) upheld a final order denying Willamette Water Company's controversial application for a permit to withdraw 34 cubic feet per second (22 million gallons per day) from the McKenzie River for a quasi-municipal use, based on the failure to meet a statutory deadline for completion of the project. *Willamette Water Co. v. WaterWatch of Oregon*, 288 Or App 778 (2017) (*Willamette*). The Court's decision affirms an earlier decision issued in May 2014 by the Oregon Water Resources Commission (Commission) to deny the water permit application. That decision had affirmed an Oregon Water Resources Department (OWRD) order in March 2014, as well as the ruling of an administrative law judge in 2012 that the permit application be denied. Importantly, the Commission found as part of the decision upheld by the Court, "[I]n view of that conflict with the statutory timeline for development, the commission concluded that the company's proposed use was not a beneficial one." *Willamette* at 786.

WaterWatch of Oregon (WaterWatch) protested the permit application on March 12, 2010, on grounds that it did not conform to state requirements and that the applicant showed no need for the water. OWRD initially issued a **p**roposed **f**inal **o**rder (PFO) recommending the issuance of the requested permit with certain conditions. The administrative law judge, Jim Han, stated in his April 27, 2012 order (after a contested case hearing) that the "[a]pplication proposes a speculative use for more water than the Company could establish it could put to actual beneficial use" as required by law. He found that granting the permit would impair or be detrimental to the public interest and that the permit application should be denied. For additional background, *see* Moon, *TWR* #94, Water Briefs, *TWR* #99 and #122.

"We are pleased that the Oregon Court of Appeals has upheld the Oregon Water Resource Commission's decision to deny this speculative water proposal by Willamette Water Company," said Lisa Brown, Staff Attorney for WaterWatch. "Under Oregon law, Oregon's waters belong to the public — not to private water companies hoping to profit by monopolizing the resource for future sale." The company proposed to lock up a large amount of McKenzie River water but failed to identify any committed customers, could not complete the water development project in the time allowed, and failed to apply for needed land use approvals for developing the water project.

WATER BRIEFS

The Court focused primarily on the statutory time limit for completion. "Under the plain terms of the statute, the question is whether the work will be completed within the five-year period, not whether it can be started before five years have elapsed. Here, the finding that the permit will take a minimum of 10 years to complete establishes that the company's proposal does not comport with the ORS 537.230(1) timeline." *Willamette* at 791.

The Court specifically differentiated this case from a previous court ruling involving a municipal applicant, on the basis that the applicant here (a quasi-municipal use) was not a municipal applicant. Municipal applications are no longer subject to the five year development requirement following legislation passed in 2005 (HB 3038), which "amended ORS 537.230(1) to change the law with respect to municipalities, and also restricted judicial review of certain challenges regarding the construction of water projects by municipalities." *Id.* at 791-792.

"In sum, under *WaterWatch*, it is error for the commission to approve a permit for a nonmunicipal water use when the facts before the commission establish that the work under the permit cannot be completed within the five year period specified by ORS 537.230(1). *WaterWatch*, 193 Or App at 113. The commission therefore did not err when it concluded that ORS 537.230(1) precluded it from approving the company's permit application in view of the factual finding that it will take 10 years, if not longer, for the company to complete construction on the work proposed under the permit." *Id*. at 792.

The parties have a 35-day period in which to file a petition for review with the Oregon Supreme Court.

For info: Order available at: http://waterwatch.org/ >> Press Releases; Lisa Brown, WaterWatch, 503/ 295-4039 or lisa@waterwatch.org

GROUNDWATER PROJECT CA

PIPELINE EASEMENT ISSUE

On November 28, conservation and health-safety groups filed suit in federal court challenging the Trump administration's approval of a large groundwater-mining and pipeline project in Southern California. *Center for Biological Diversity and Center for Food Safety v. U.S. Bureau of Land Management, et al*., Case No. 2:17-cv-08587 (Nov. 28, 2017). The Cadiz Water Project (Cadiz Project), approved without environmental review, includes the construction of a pipeline through the Mojave Trails National Monument and other public lands. As noted in the lawsuit, the Trump administration reversed two Obama administration decisions and instead concluded that the Cadiz Project's 43-mile pipeline did not require any US Bureau of Land Management (BLM) permits or approvals due to the fact that the proposed water conveyance pipeline and appurtenant improvements would occur on an existing railroad right-of-way. BLM's decision would allow the developer to build the pipeline within the railroad right-of-way, paving the way for Cadiz to pump 16 billion gallons of water a year from the desert aquifer into the Colorado River Aqueduct so it can be sold to water districts for developments in Southern California.

Plaintiffs' Center of Biological Diversity (CBD) and the Center for Food Safety (represented by Earthjustice) are opposed based on their view that the Cadiz Project is "an unsustainable water-privatization scheme. Pumping ancient groundwater from the Mojave Desert to water suburban lawns in Orange County will devastate desert wildlife and the entire ecosystem relying on that water for survival," said Ileene Anderson, a senior scientist with CBD.

The decision in the lawsuit will eventually be determined by interpretation of the 1875 General Railroad Right-of-Way Act (1875 Act). The plaintiffs maintain that BLM "improperly concluded that the Cadiz Project pipeline 'falls within the scope' of an existing right-of-way easement granted to the Arizona California Railroad" under the 1875 Act. "BLM therefore wrongly determined that Cadiz, Inc. may contract to build and operate its pipeline within the railroad's right-of-way without prior authorization from BLM, which would be contingent legally upon environmental review, an opportunity for public review and comment, and compliance with federal environmental laws." *Complaint* at 2.

The extent of the railroad's right-of-way easement will involve the question of whether the 1875 Act requires that activities within the right-of-way must "derive from or further a railroad purpose." *Id*. The plaintiffs argue that "the Cadiz Project pipeline 'does not derive from or further a railroad purpose' and thus cannot be built on public land without federal review and approval." *Id*. at 3. The plaintiffs' assertions include the following: "The plain language and legislative history of the 1875 Act also confirm that the statute grants only those property rights necessary for the purpose of constructing and running the railroad itself. Activities that do not further a railroad purpose are beyond the scope of an 1875 Act right-of-way easement." *Complaint* at 11. The plaintiffs also raised issues based on the Federal Land Policy & Management Act of 1976 (FLPMA) concerning requirements to prepare an environmental impact statement for the Cadiz Project before granting a right-of-way under FLPMA. *See Complaint* at 11-13.

Cadiz maintains that the "proposed use of an active railroad right-of-way for its water conveyance pipeline and appurtenant improvements…provide critical railroad benefits to the host railroad." Cadiz Statement, November 28, 2017. Cadiz' Statement also asserted that: "The new evaluation issued by the US Bureau of Land Management in October 2017 correctly applied applicable law, returned to long-established federal policy and was widely supported. Rather than challenging this new determination — one which actually protects federal lands — CBD could be working with Project proponents to provide needed water and aquifer storage in Southern California and a host of environmental benefits. Instead, CBD is pursuing a flawed legal strategy that appears to only benefit its fundraising efforts."

Notably, Cadiz is not a party to the lawsuit and will rely on BLM's attorneys to maintain that the proposed use of the easement is within the grant of the 1875 Act.

The scope of the easement granted under the 1875 Act — limited to railroad purposes only or for other activities that "provide critical railroad benefits to the host railroad" — will determine who prevails in the lawsuit.

For info: *Complaint* available at: www.biologicaldiversity.org/news/press_releases/2017/cadiz-11-28-2017.php

CALENDAR

December 19 WA
2017 AWRA-WA Annual Meeting & Presentations: Work of Living Earth Institute & Friendly Water for the World, Seattle. Naked City Brewery, 8564 Greenwood Avenue N. Presented by Washington Section of the American Water Resources Association. For info: www.waawra.org

December 20 WEB
Water Infrastructure Finanace & Innovation Act (WIFIA) Application Process:Tips for Submitting a Letter of Interest, WEB. 2-3:30 pm. For info: https://register.gotowebinar.com/register/2620872168072096514

January 9 WY
Wyoming Water Forum: Kim Johnson, WY Dept. of Homeland Security. "National Flood Insurance Program (NFIP) and Flood Risk Management", Cheyenne. Wyoming Water Development Commission at 6920 Yellowtail Rd. Presented by Wyoming State Engineer's Office. For info: http://seo.wyo.gov/interstate-streams/water-forum

January 9-10 OK
Oklahoma Ground Water Association Conference & Trade Show, Norman. Embassy Suites Hotel & Conference Center. For info: www.okgroundwater.org

January 10 WA
SEPA & NEPA: 15th Annual Seminar, Seattle. Washington State Convention Ctr., 800 Convention Place. For info: Law Seminars Int'l, 206/ 567-4490 or www.lawseminars.com

January 10-12 NV
38th Annual Utah Ground Water Association Conference & Expo, Mesquite. CasaBlanca Resort. For info: http://utahgroundwater.org/meetinginfo.php?id=25&ts=1502995484

January 11-12 CO
Colorado Water Well Contractors Association Annual Conference, Denver. Denver Marriott Tech Center. For info: http://cwwca.org/2017/03/15/cwwca-annual-conference-2/

January 16-18 ID
Idaho Water Users Assoc. Annual Convention, Boise. The Riverside Hotel. For info: IWUA, 208/ 344-6690 or www.iwua.org/

January 17 DC
Water Infrastructure Finanace & Innovation Act (WIFIA) Information Session, Washington. EPA Headquarters, William Jefferson Clinton East Bldg., 1301 Constitution Avenue, NW. For info: https://events.r20.constantcontact.com/register/eventReg?oeidk=a07eeq8d6abafcc5e55&oseq=&c=&ch=

January 18-19 KS
Kansas Ground Water Association Convention 2018, Mulvane. Kansas Star Event Center. For info: https://kgwa.org/events/

January 24-26 CO
Colorado Water Congress 2018 Annual Convention, Denver. Hyatt Regency Denver Tech Center. For info: http://www.cowatercongress.org/annual-convention.html

January 24-26 TX
Texas Ground Water Association Annual Convention, San Marcos. Embassy Suites in San Marcos. For info: www.tgwa.org/

January 24-26 WY
Wyoming Water Well Association Annual Convention, Casper. Ramkota Hotel & Conference Center. For info: www.wywaterwell.org/convention

January 25-26 WA
25th Annual Endangered Species Act Conference, Seattle. Crowne Plaza Downtown. For info: The Seminar Group, 800/ 574-4852, info@theseminargroup.net or www.theseminargroup.net

January 25-27 BC
2018 Environmental & Energy, Mass Torts & Products Liability Committees' Joint CLE Seminar, Whistler. Westin Resort & Spa. Presented by ABA Sections. For info: https://shop.americanbar.org/ebus/ABAEventsCalendar/

January 30-Feb. 1 ID
Idaho Ground Water Association Annual Convention & Trade Show, Boise. JUMP, 1000 W. Myrtle. For info: http://www.igwa.info/events.html

February 1 TX
Central Texas Water Conservation Symposium, Austin. For info: http://www.texaswater.org/

February 6-8 WA
16th Annual Stream Restoration Symposium, Stevenson. Skamaia Lodge. Presented by River Restoration Northwest. For info: http://www.rrnw.org/

February 7-9 MT
Montana Water Well Drillers Association 2018 Convention, Great Falls. Heritage Inn. For info: www.mwwda.org/convention

February 8-9 DC
Environmental Law Conference, Washington. Washington Plaza. Presented by American Law Institute. For info: www.ali-cle.org/index.cfm?fuseaction=courses.course&course_code=CZ014

February 8-9 NV
Western Water Law 23rd Annual Conference: Federal, Tribal, State & Local Considerations, Las Vegas. Caesars Palace. For info: CLE Int'l, 800/ 873-7130 or www.cle.com

February 8-9 NV
Mountain States Ground Water Expo, Laughlin. The Aquarius Resort Casino. For info: http://mountainstatesgroundwater.com/

February 12-13 LA
Endangered Species Act, Wetlands, Stormwater & Floodplain Regulatory Compliance for Energy & Utilities Conference, New Orleans. Hyatt Regency New Orleans. For info: www.euci.com/event

February 13 WY
Wyoming Water Forum: Paige Wolken, U.S. Army Corps of Engineers. "Compensatory Mitigation", Cheyenne. Wyoming Water Development Commission at 6920 Yellowtail Rd. Presented by Wyoming State Engineer's Office. For info: http://seo.wyo.gov/interstate-streams/water-forum

February 13-15 NE
2018 Nebraska Water Industries Convention & Trade Show, Lincoln. For info: http://www.nebraskawelldrillers.org/

February 15-16 AK
Alaska Water Well Association 2018 Conference, Anchorage. Lakefront Hotel. For info: www.alaskawellwater.org/convention

February 22-23 WY
Oklahoma Water Law Conference, Oklahoma City. Sheraton Downtown. For info: CLE Int'l, 800/ 873-7130 or www.cle.com

February 22-23 NV
Family Farm Alliance Conference: One Year In - What's Changed & Where Are We Going in Western Water? Reno. Eldorado Resort Casino. For info: www.familyfarmalliance.org

March 1-2 AZ
Law of the Colorado River Superconference, Tucson. Hilton El Conquistador Resort. For info: CLE Int'l, 800/ 873-7130 or www.cle.com

March 5-6 TX
Texas Wetlands Conference, Austin. Omni Hotel at Southpark. For info: CLE Int'l, 800/ 873-7130 or www.cle.com

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CALENDAR

(continued from previous page)

March 5-7 CA
16th Biennial Symposium on Managed Aquifer Recharge, San Diego. The Dana on Mission Bay, 1710 W. Mission Bay Drive. Presented by Groundwater Resources Assoc. of California and the Arizona Hydrological Society. For info: www.grac.org/events/99/

March 8 OR
Faces of Freshwater Event, Portland. Castaway Portland, 5:30 - 9:00 pm. Presented by The Freshwater Trust. For info: www.thefreshwatertrust.org/get-involved/events/

March 13 WY
Wyoming Water Forum: "Updates on Governor's Water Strategy Fish Passage Initiative", Cheyenne. Wyoming Water Development Commission at 6920 Yellowtail Rd. Presented by Wyoming State Engineer's Office. For info: http://seo.wyo.gov/interstate-streams/water-forum

March 16-17 OR
2018 Pacific Northwest Ground Water Exposition, Portland. Red Lion Hotel on the River - Jantzen Beach. For info: http://www.pnwgwa.org/

March 18 CA
Water Gala '18, San Francisco. Mezzanine. Presented by Alliance for Water Efficiency. For info: Nashelley Kaplan-Dailey, 415) 828-6344 or nashelley@imagineh2o.org

March 22 TX
Gulf Coast Water Conservation Symposium, Houston. For info: http://www.texaswater.org/

March 22-23 OR & WEB
The Mighty Columbia Conference, Portland. Embassy Suites Portland. For info: The Seminar Group, 800/ 574-4852, info@theseminargroup.net or www.theseminargroup.net

March 25-28 OR
Capacity Building in Environmental Conflict: An Intensive 30-Hour Workshop, Troutdale. McMenamins Edgefield. Organized by Four Worlds LLC. For info: Dena Marshall, 503/ 489-9111, dmarshall3587@gmail

March 25-28 WA
Sustainable Water Management Conference, Seattle. Renaissance Seattle. Presented by American Water Works Association. For info: www.awwa.org/conferences-education/conferences/sustainable-water-management.aspx

March 29-30 MT & WEB
Buying & Selling Ranches Seminar, Billings. Northern Hotel, 19 N. Broadway. For info: The Seminar Group, 800/ 574-4852, info@theseminargroup.net or www.theseminargroup.net

April 3-4 CA
Solving Water Challenges Through Partnerships - P3 Water Summit, San Diego. Grand Hyatt Hotel. For info: www.p3watersummit.com

April 5-6 NM
18th Annual Law of the Rio Grande Conference, Santa Fe. La Fonda. For info: CLE Int'l, 800/ 873-7130 or www.cle.com

April 9-11 DC
Federal Water Issues Conference - National Water Resources Assoc., Washington. Embassy Suites. For info: NWRA, www.nwra.org/upcoming-conferences-workshops.html