Idaho Climate-Economy Impacts Assessment

Water Report

Karen Humes[1], Riveraine Walters[2], Jae Ryu[3], Robert Mahler[4], Craig Woodruff[5]

[1]Professor, Department of Geography and Geological Sciences, College of Science, University of Idaho
[2] Research Assistant, Department of Soil and Water Systems, College of Agricultural and Life Sciences and Graduate Affiliate, Idaho Water Resources Research Institute, University of Idaho
[3]Associate Professor, Department of Soil and Water Systems, College of Agricultural and Life Sciences, University of Idaho
[4]Professor, Department of Soil and Water Systems, College of Agricultural and Life Sciences, University of Idaho
[5]Research Assistant, Department of Chemical and Biological Engineering, College of Engineering, University of Idaho

Recommendation citation: Humes, K., Walters, R., Ryu, J., Mahler, R., Woodruff, C. 2021. Water Report. *Idaho Climate-Economy Impacts Assessment*. James A. & Louise McClure Center for Public Policy Research, University of Idaho. Boise, ID.

1. Overview of Water in Idaho and Connections to Climate Change

The availability of clean water, in the right place and time, is central to many aspects of Idaho's economy, as well as the health and wellbeing of Idahoans. The water cycle in Idaho is dominated by the accumulation of snowpack in the mountains, which serves as vast natural reservoirs for water storage in the winter and spring. The gradual melting and runoff of that water in the spring and summer months provides streamflow in the warmer, drier months. The seasonal rhythms of this cycle of snow accumulation and snowmelt support both terrestrial and aquatic ecosystems that have evolved under these temporal patterns, as well as important economic activities in Idaho, such as agriculture (both dryland and irrigated), aquaculture, the generation of electricity using hydropower, recreation, and tourism.

Many impacts of climate change in Idaho are transmitted to economic sectors via changes to this water cycle. Changes in the spatial and temporal patterns of precipitation and temperature that drive this seasonal cycle across the state impact terrestrial ecosystems, the volume and timing of runoff from both storms and snowmelt, and the occurrence and severity of floods and droughts. Changes in water temperature and streamflow can have major impacts on aquatic ecosystems, water supply for irrigation, hydropower, and domestic, commercial, municipal, and industrial (DCMI) uses, as well as on water quality in streams, lakes, and reservoirs.

This report is divided into seven sections. Section 1 provides an overview of water resources in Idaho. Section 2 discusses how changes in climate impact water resources. Section 3 explores observed and forecasted changes in streamflow. Section 4 dives into drought, floods, and water storage. Section 5 looks at climate impacts on water quality. Section 6 notes interacting influences of other factors in water use, both present and future. Finally, Section 7 provides a synthesis and summary of the research presented in this report.

1.1 Major basins and variation in water resources across Idaho

The material in this section is drawn primarily from the most recent *State of Idaho Water Resource Inventory* created by the Idaho Water Resources Board (IWRB, 2010). The annual precipitation totals (Figure 1), computed as the climatological mean from 1980 to 2010, are quite variable across Idaho, ranging from 8 to 12 inches[1] in the lower elevation semi-arid shrub-steppe regions of southern Idaho, to 20-30 inches of rainfall in the lower elevation temperate grasslands and forests of central and northern Idaho, to greater total precipitation in mountainous areas where the majority of precipitation is in the form of snow. The distribution of these precipitation totals varies across Idaho as well, with drier areas of the state receiving more uniform amounts of precipitation throughout the year and the wetter portions of the state receiving the majority of precipitation from October through March. For example, average monthly precipitation values are shown in Figure 2 for the municipalities of Pierce (north central, mid-elevation), Salmon (central), and Boise (south).

The five major river basins in Idaho are shown in Figure 3, with the average annual runoff volume for each basin presented in Figure 4. The main tributaries, major economic sectors, and water quality issues of concern for the five major basins are summarized in Table 1.

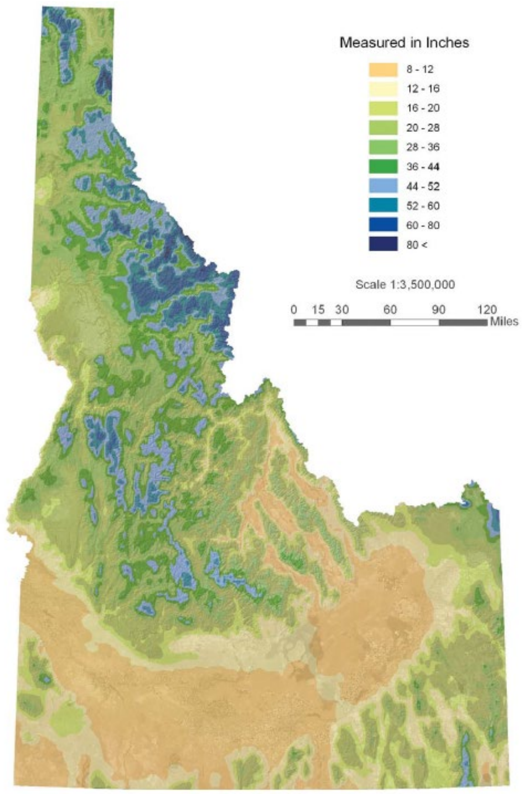


Figure 1: Precipitation in Idaho (IWRB, 2010).

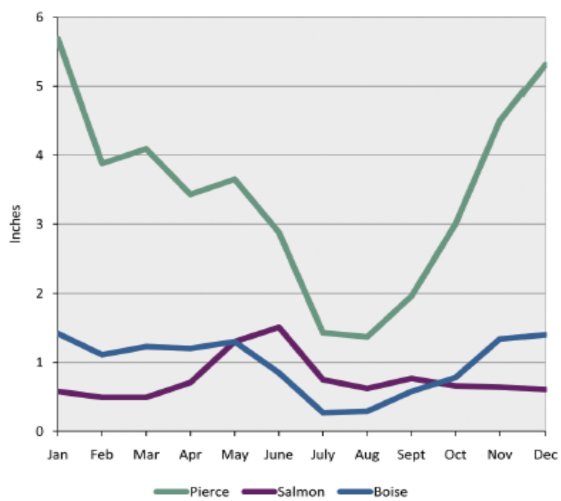
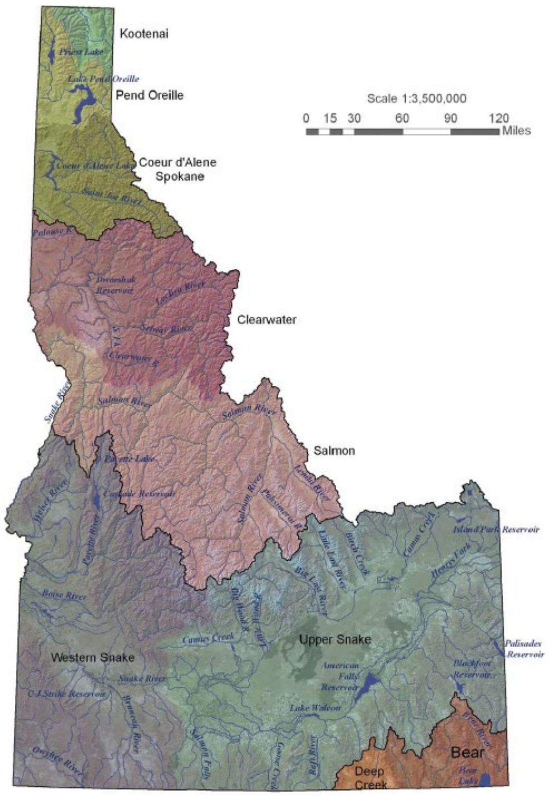


Figure 2: Average monthly precipitation totals for Pierce, Salmon, and Boise (IWRB, 2010).

[1] The use of English and metric units is varied throughout the report. Water managers use English units and often scientific literature uses metric units.



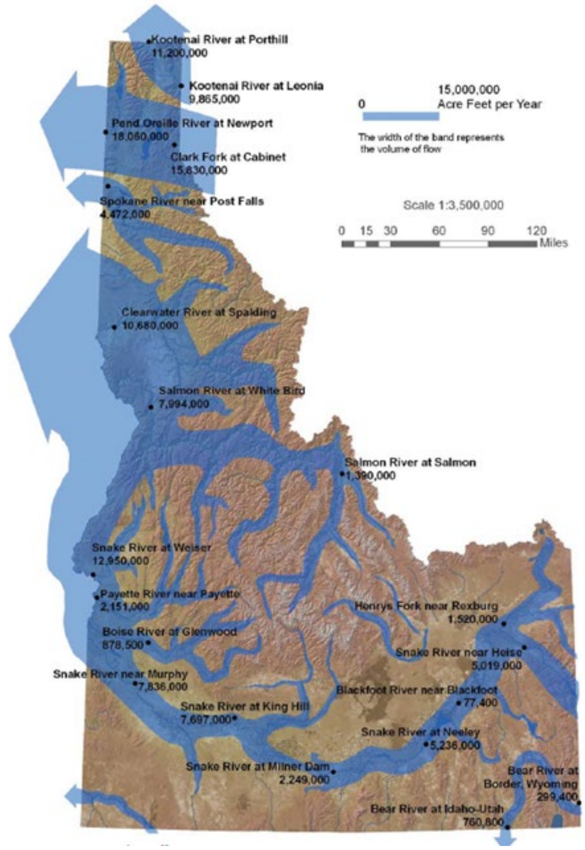


Figure 3: Runoff from major basins (IWRB, 2010).

Figure 4: Major river basins in Idaho (IWRB, 2010).

Region	Key Water Resources	Economic Sectors	Water Quality Concerns[2]
Bear	Largest tributary of Great Salt Lake; managed by Bear River Compact among Utah/Wyoming/Idaho	Agriculture, hydropower	Nutrient inputs, sedimentation, thermal pollution
Clearwater-Salmon	North Fork Clearwater; Lochsa; Selway; Pahsimeroi; Lemhi; South, Middle, and North Forks; Little Salmon	Agriculture, lumber, manufacturing, mining	Heavy metals, nutrients, sedimentation
Panhandle	Kootenai, Pend Oreille, Coeur d'Alene-Spokane, Priest	Agriculture, lumber, manufacturing, metal products, mining, tourism	Heavy metals, nutrients, sedimentation
Upper Snake	Big and Little Lost, Big Wood, Birch Creek, Blackfoot, Eastern Snake Plain, Henry's Fork, King Hill, Portneuf, Raft, Salmon Falls Creek, Upper Snake, Willow Creek	Agribusiness, agriculture, chemicals, food processing, high-tech manufacturing, mining, nuclear research	Hazardous materials, heavy metals, manufacturing waste streams, nutrient inputs, sedimentation, thermal pollution, urban runoff
Western Snake	Snake, Boise, Payette, Weiser	Agriculture, food products, metal products, microelectronics/computer products	Manufacturing waste streams, nutrients, thermal pollution, urban runoff

Table 1:The five major river basins in Idaho (IWRB, 2010), including major economic sectors and water quality concerns.

[2] Water quality concerns are listed on various Idaho Department of Environmental Quality (IDEQ) webpages.

As a result of the development of water resources for the needs of various economic sectors, particularly agriculture and hydropower generation, a complex infrastructure consisting of dams, reservoirs, irrigation canals, and wells has been constructed over time. A detailed history of this development is provided in Slaughter (2004).

The major components of water storage infrastructure in Idaho are shown in Figure 5 and major groundwater sources are shown in Figure 6. The Eastern Snake Plain Aquifer (ESPA) in southern Idaho is notable both for its large storage capacity, as well the high degree of interconnectivity with surface water resources in some areas. The rapid rate of infiltration and recharge in the heavily irrigated ESPA meant that unlined irrigation canals and flood irrigation practices that were common in past decades provided significant recharge of the aquifer from surface water resources. At the western edge of the ESPA, springs directly discharge water from the ESPA to surface water resources. The IWRB and the Idaho Department of Water Resources (IDWR) have developed and maintain Comprehensive Aquifer Management Plans (CAMPs) for three aquifers in Idaho: The ESPA, Treasure Valley Aquifer, and Rathdrum Prairie Aquifer.

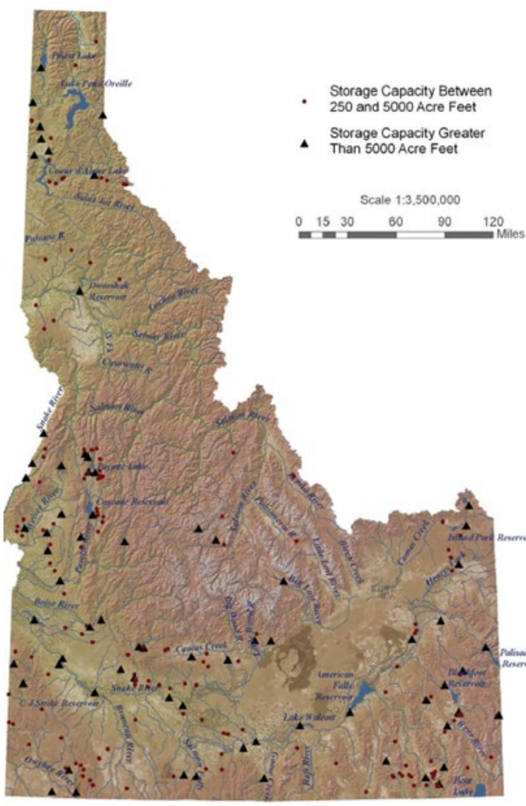


Figure 5: Major water storage infrastructure (IWRB, 2010).

Figure 6: Major groundwater resources (IWRB, 2010).

1.2 Water withdrawals and use

Using data reported by state-level entities, the U.S. Geological Survey (USGS) publishes a report on water withdrawals and use by sector (USGS, 2018) approximately every five years. Notably, in 2015, Idaho was 4th in the nation for total withdrawals and 2nd in the nation for water withdrawals used for irrigation. The end uses of the withdrawals in Idaho for the year 2015, by percent to total, are presented in

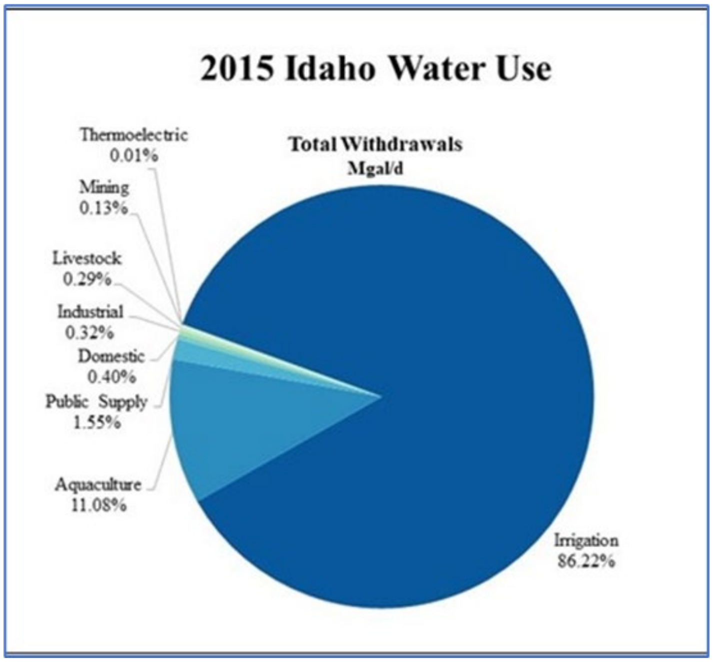


Figure 7. Withdrawal for irrigation comprised 86.22% of the total volume, aquaculture 11.08%, and public supply 1.55%. Withdrawals for public supply, domestic, industrial, livestock, and mining uses each constituted less than 0.5% by volume. Water is used for hydroelectric power generation at numerous facilities in Idaho; since water use in that sector is primarily non-consumptive, "in-stream" use of water, this is not considered a water withdrawal in USGS water use reporting.

Figure 7: Water withdrawals by sector in 2015 (USGS, 2018).

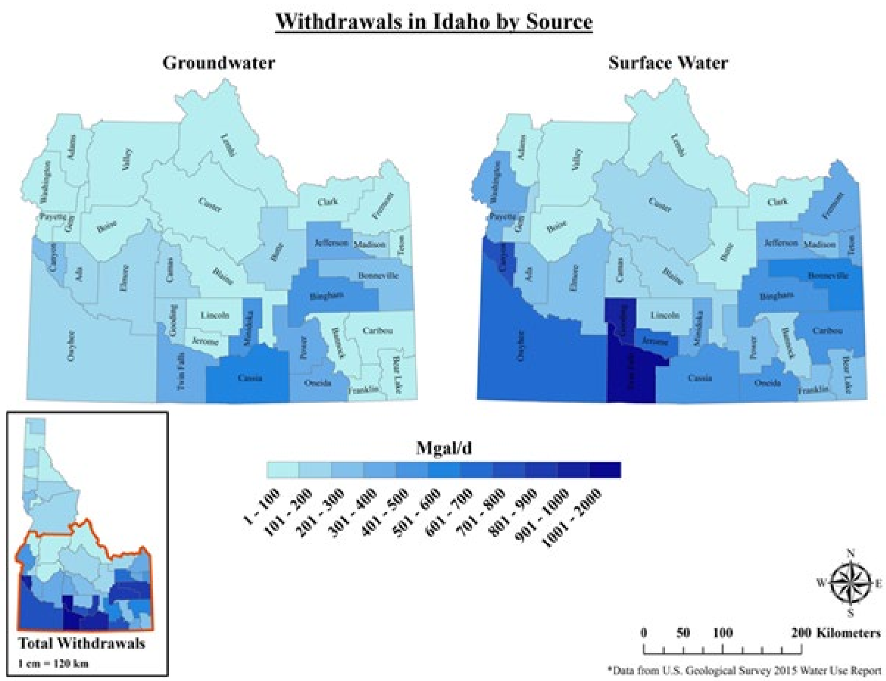


Figure 8: Total water withdrawals for all uses in Idaho in 2015, by county. The inset shows total withdrawals from both groundwater and surface water. The larger figures for southern Idaho show withdrawals from groundwater (left) and surface water (right) (Thompson and Humes, 2021).

As shown in statewide county-level withdrawals in Figure 8 (inset diagram), water withdrawals tend to be higher in southern Idaho than in the central and northern part of the state. This is predominantly due to withdrawals for irrigated agriculture and aquaculture, which account for 97.3% of the total water withdrawals statewide. Although there are some areas of irrigated agriculture in northern Idaho, agriculture in that part of the state is predominantly dryland farming.

1.3 Water supply challenges – present and future

To date, water supply generally has been able to meet water demand in most areas of the state, with some exceptions. The large amount of storage in reservoirs, lakes, and aquifers has enabled sufficient supply in dry years for most water users. However, adjudication procedures have been carried out in the Snake River Basin and the Bear River Basin and are in progress for several northern Idaho basins, including the Coeur d'Alene-Spokane, Palouse, and Clark Fork-Pend Oreille basins. In the Upper Snake River Basin, several major settlements have been negotiated among various water users over the last four decades (e.g., 1984 Swan Falls agreement, 2009 Swan Falls Reaffirmation Settlement, Snake River Basin adjudication, 2015 agreement between surface water and groundwater users; Slaughter et al., 2012; SWC-IGWA Settlement Agreement, 2015), which take into account the connectivity of river and surface water infrastructure (i.e., irrigation canals) within the ESPA, along with use of both surface water and groundwater resources for irrigation and surface water flow needs for hydroelectric power generation.

Going forward, major concerns around water supply and water demand relative to the impacts of climate change on water supply include:

- Anticipated shifts in precipitation from snow to rain, thus decreasing wintertime and early spring water storage capacity in mountains.
- Associated shifts in magnitude and timing of natural streamflow that will impact surface water resources, most notably, forecasts described in Section 3.3 that average summertime streamflows are likely to be lower than in the past.
- Impacts of lower summertime streamflow for all water users, including agricultural production, aquaculture, and hydropower generation.
- Increased water and energy demand for irrigation due to warmer temperatures.
- Pressures of population and economic growth on water demand.
- The impacts of prolonged drought on yield in dryland agricultural regions.

1.4 Water quality challenges – present and future

Although headwater streams and many lakes in Idaho support a robust recreation and tourism industry, there are existing concerns about water quality throughout the state, some of which have potential to be exacerbated by climate change. In southern Idaho, runoff from agricultural fields, as well as chemical fertilizer production, dairies and livestock, food processing, aquaculture, and urban runoff all contribute to water quality degradation due to sediment; excess nutrients, such as nitrogen and phosphorus; and pathogens. In the northern part of the state, the impacts of legacy mining, forestry, and agriculture give rise to water quality concerns about sediment, excess nutrients, and heavy metals. In addition to polluting streams and groundwater, contaminants make their way to lakes and reservoirs, where stratification is a key process by which sediments and contaminants tend to accumulate at the bottom of these resources, reducing storage capacity. These deposits pose additional water quality hazards in the event that they are disturbed due to dredging or modifications in seasonal stratification brought on by changes in temperature and/or magnitude of inflowing water. Wildfire is another factor that impacts water quality and thus the more frequent occurrence and/or increased intensity resulting from the combination of fuel accumulation and climate factors is likely to make those impacts more prevalent.[3]

[3] For more information on water quality, see Section 5.

The presence of dams and reservoirs on controlled systems causes an increase in stream temperatures that threaten aquatic ecosystems, prompting regulations for discharged water temperature. In recent years, harmful algal blooms (HABs) have also become an increasing concern throughout the state (IDEQ, 2021). The broad connection between climate change and water quality impacts is described in Section 2, with detail provided in Section 5.

2. How Changes in Climate Impact Water

2.1. Summary of observed and forecasted changes in climate

The two main variables that define climate are precipitation and air temperature. In locations like Idaho, where the water cycle is dominated by snowmelt, snowpack is a third important variable to be considered. Changes in these climate variables in Idaho, both those observed in recent decades and those forecasted for the future using climate models, are described in detail in the assessment's Climate Report. The general trends, both observed and forecasted, for the three climate variables described in the climate report include:

- Increased air temperature, of a magnitude larger than typical decadal variations.
- Observed values of total annual precipitation amounts are mixed and forecasts projecting slight increases are somewhat uncertain, but observations and more certain forecasts indicate changes in the nature and timing of precipitation, including:
    - less precipitation falling as snow and decreased snowpack (Peacock et al., 2011; Ashfaq et al., 2013; Mankin and Diffenbaugh, 2015; Fyfe et al., 2017);
    - more frequent occurrences of multiple consecutive years of low snowpack, particularly in the northern part of the state (Marshall et al., 2019);
    - April 1 volumetric snowpack storage across Idaho projected to decrease by one-third by mid-21st century under a high-warming scenario relative to the late 20th century (Gergel et al., 2017) – equivalent to the current potential reservoir storage in Idaho;
    - snowmelt and associated runoff occurring earlier in the year (Musselman et al., 2017; Marshall et al., 2019);
    - slight increase in forecasted mean annual precipitation dominated by increases in winter and spring precipitation, whereas precipitation in summer projected to slightly decline (Rupp et al., 2016; USGCRP, 2018); and
    - increased annual maximum flows as a result of increased rainfall magnitudes (Chegwidden et al., 2020; Queen et al., 2021).
- Increased evapotranspiration in spring and early summer, leading to decreased streamflow and heightened stress for water resources (e.g., Hamlet et al., 2010; Xin and Sridhar, 2012; Vano et al., 2015).
- Increased moisture deficits in the summer months, leading to increased risk for wildfires.

2.2 Mechanisms by which changes in climate variables influence water cycle and water quality

A summary of the direct and indirect impacts of changes in climate variables on water cycling and water quality are presented in Table 2. Some impacts, such as observed and forecasted changes in streamflow, have been studied in detail in Idaho and the region and are discussed more in Section 3. Several other major impacts that result in increased hazards (e.g., drought, flooding), although studied widely on a national and international basis, have not been studied specifically in Idaho to the same extent; a summary is presented in Section 4. The connections between forecast climate changes and water quality are discussed in Section 5.

Change	Direct Impacts	Indirect Impacts
Increase in air temperature	• Increased water uptake and transpiration by plants • Increased evaporation from lakes and reservoirs • Higher water temperature in streams, lakes, reservoirs, and canals	• Greater water demand for irrigated agriculture and hydropower • Increased stream temperature, impacting habitat for fish and other aquatic organisms (see the assessment's Fish Report) • More conducive to growth of cyanobacteria and harmful algae • Modifications to usual cycle of stratification in lakes and reservoirs, which can impact water quality
Increase in proportion of precipitation as rain versus snow, particularly in low to mid-elevations	• Decreased snowpack in mid-elevations and thus decreased storage in mountains in winter/spring • Higher streamflow volumes in winter, lower streamflow in summer	• Potential water supply shortfalls in summer months • Changes in aquatic habitat • Changes in seasonal concentration of excess nutrients and contaminants in streams, lakes, and reservoirs
Earlier snowmelt/runoff	• Higher streamflow in spring; lower streamflow in summer	• Impacts to aquatic habitat • Impacts to contaminant concentrations in streamflow, particularly under summer lower flow conditions • Modified streamflow volumes and temperature potentially impact stratification in lakes/reservoirs
More frequent drought	• Increased water demand • Lower streamflow volumes • Increased incidence of wildfire	• Potential water supply shortfalls • Water quality impacts from increased wildfire
Greater variability in precipitation, including changes in location/frequency of rain-on-snow (ROS) events and more frequent extreme weather events	• Flooding	• Mixed influences on concentration of nutrients, contaminants, and sediment in streams, lakes, and reservoirs, as well as water quality impacts of modified stratification in lakes and reservoirs

Table 2: Summary of mechanisms by which changes in climate and hydroclimatologic factors can directly or indirectly impact water supply and quality.

2.3 Forecasted changes in rain-on-snow (ROS) events

As noted in the assessment's Climate Report, one of several changes in precipitation patterns with the potential to impact Idaho is changes in the frequency and magnitude of rain-on-snow (ROS) events (described in detail in Section 4.2). Historically, these events have been the most common cause of flooding in the northern portions of the state. Two examples of this are events in January and March 1997 and March 2017. Both events resulted in federal disaster declarations for Panhandle counties and losses from the March 2017 flooding were estimated to be $10.5M (Idaho Office of Emergency Management (IOEM, 2018)).

Changes in the frequency and/or intensity of ROS events will impact frequency and intensity of flooding events. As noted in Table 2 and explained in more detail in highlight Box 2, the frequency and intensity of these events can also have a significant impact on the loads of contaminants in rivers and streams. The maps presented in Figure 9 (Musselman et al., 2018) show modeled estimates of changes to the average ROS intensity in western states in future decades. These estimates show a mixed picture in Idaho, with ROS events in some portions of northern Idaho to decrease in average intensity, while other areas in Idaho may be impacted by greater intensity and frequency of occurrence of ROS events than in the past.

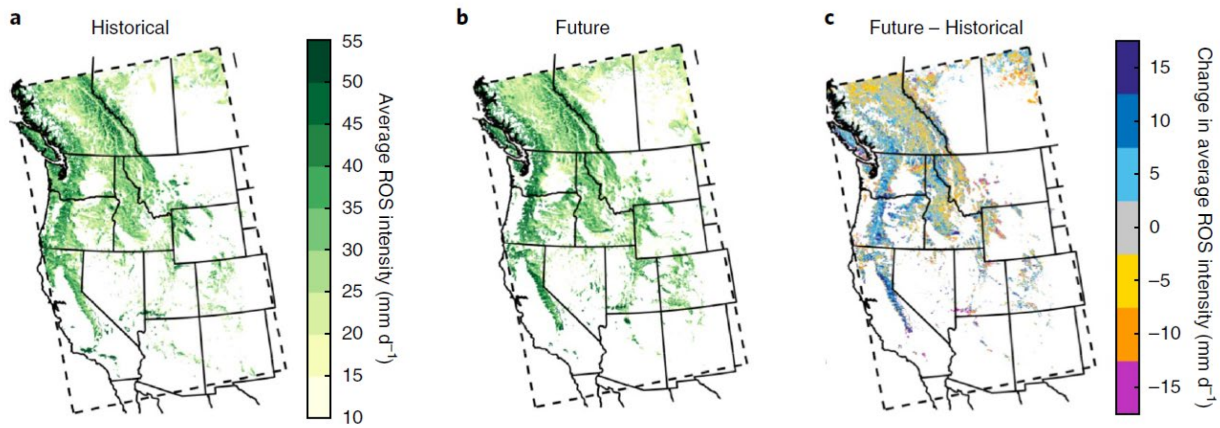


Figure 9: For many mountainous regions, future rain-on-snow (ROS) events will be more intense, largely due to increases in rainfall rather than snowmelt increases. a–c, average daily intensity of ROS runoff (rainfall + snowmelt) meeting the flood potential thresholds in the historical period (a), future scenario (b), and the difference in ROS intensity between the two scenarios (c) (Musselman et al., 2018).

3. Streamflow – Observed and Forecasted Changes

Several recent studies have evaluated changes in the magnitude and timing of streamflow in unregulated streams in Idaho, using observed data from early 20th century until the present. Forecasts of future streamflow using downscaled output averaged over a number of climate models are available for larger streams in the Pacific Northwest. In this section, results of that research are summarized. Changes in observed magnitude and volume of streamflow are examined first, with Sections 3.1 and 3.2 describing observations of changes in recent decades. Sections 3.3 and 3.4 focus on forecasts of streamflow magnitude and timing in future decades using the output of an ensemble of climate models. Synthesis and implications of changes to timing of streamflow are presented in Section 3.5.

3.1 Streamflow magnitude – observed changes in recent decades

Studies of annual mean streamflow in unregulated streams in Idaho and other regions of the Pacific Northwest have tended to show a consistent pattern, with maximum annual flow volumes in the 1950s-1970s followed by declines (Luce and Holden, 2009; Clark, 2010; Kormos et al., 2016). Shown in Figure 10, excerpted from Clark (2010), is the characteristic shape of the trends in annual mean streamflow for many unregulated streams in the Pacific Northwest over the last century.

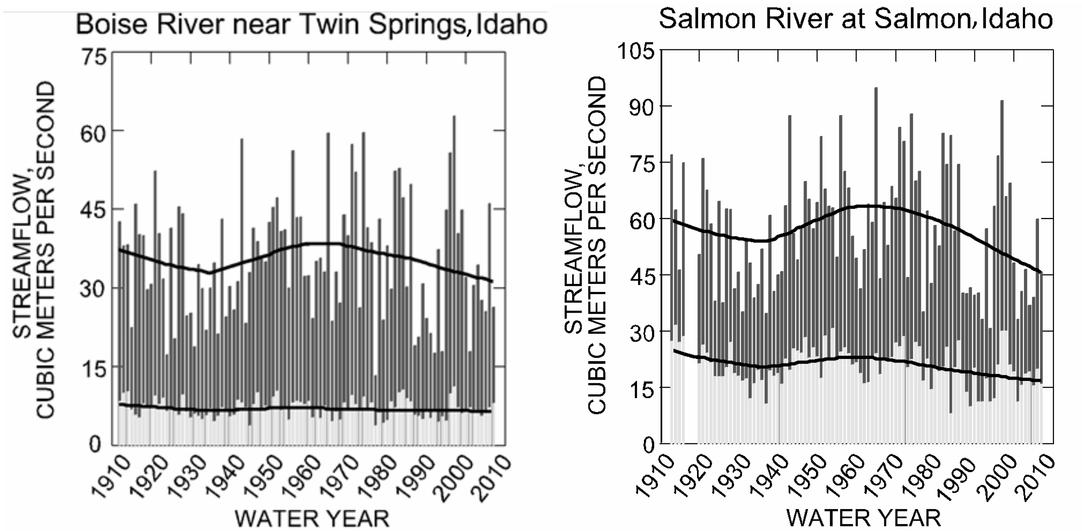


Figure 10: Streamflow runoff in the Boise River near Twin Springs, Idaho (water years 1912-2007) and Salmon River at Salmon, Idaho (water years 1913-2007). Bars represent the annual mean (dark bars) and minimum (light bars) daily streamflow for each water year. Solid lines represent a LOWESS smoothing with a smoothness factor of 0.5 for the mean (top line) and minimum (bottom line) streamflows (Clark, 2010).

In evaluating changes in annual mean streamflow before and after 1980 for streams at gaging stations within and just outside Idaho borders, Clarke (2010) found statistically significant (p-values between 0.01 and 0.07) decreases in both mean daily streamflow and minimum daily streamflow for 9 out of 26 streams evaluated. Values for decreases observed at gaging stations within Idaho for these 9 streams are summarized in Table 3.

Idaho River	**Average Percent Yearly Flow Reduction**	
	Annual Mean Streamflow	**Minimum Daily**
Mainstem Big Lost River	-1.19%	-1.05%
North Fork Big Lost River	-1.05%	-0.42%
Salmon River	-0.98%	-0.94%
South Fork Clearwater	-0.95%	-1.10%
Lochsa River	-0.61%	-0.97%
South Fork Boise River	-0.50%	-0.41%
North Fork Coeur d'Alene	-0.35%	Not Significant

Table 3: Summary of decreases in annual mean and minimum flow values for selected streams (Clark, 2010).

Kormos et al. (2016) evaluated seasonal flows in unregulated streams in the Pacific Northwest. Their results are presented in Figure 11. The 7q10 flows are defined as the annual minimum streamflow for seven consecutive days in a given season (e.g., 7q10 summer, 7q10 winter), with a probability of occurrence of one in 10 years. The 7q10 flows are particularly relevant to the connections between climate change and the regulation of water quality because these flows are often used to allocate the amount of pollutants permitted to be discharged into a stream so that concentrations remain below a legal limit [per Kormos et al. (2016)]. Clarifying the impact of declines in 7q10 summer flows on the regulation of contaminant discharges, lower streamflow values translate into lower amounts of pollutants allowed to be discharged into a stream by permit holders.

In Figure 11, the statistically significant changes in flow for various streams are indicated with circles and the magnitude and direction of the change is denoted by the color. The largest statistically significant changes in streamflow shown from this analysis are the declines in both the 7q10 summer streamflow and August streamflow for numerous gaging sites. The plots for average summer and September flows also show statistically significant declines, but at fewer sites. The plots for the 7q10 winter and mean winter flows show fewer and smaller statistically significant changes.

These observed declines in minimum and summer flows are consistent with the most robust results in the streamflow forecasts for future decades described in Sections 3.3 and 3.4; that is, summer flows are forecast to be lower than historical averages. In the context of describing forecasts from models, "robust results" implies that there is good agreement among the multiple climate models used for generating the forecasts. These observations show very few statistically significant declines in winter flows. This too is consistent with the forecasts shown Section 3.3 and 3.4, in which winter flows in most streams are forecast to stay the same or increase in future decades.

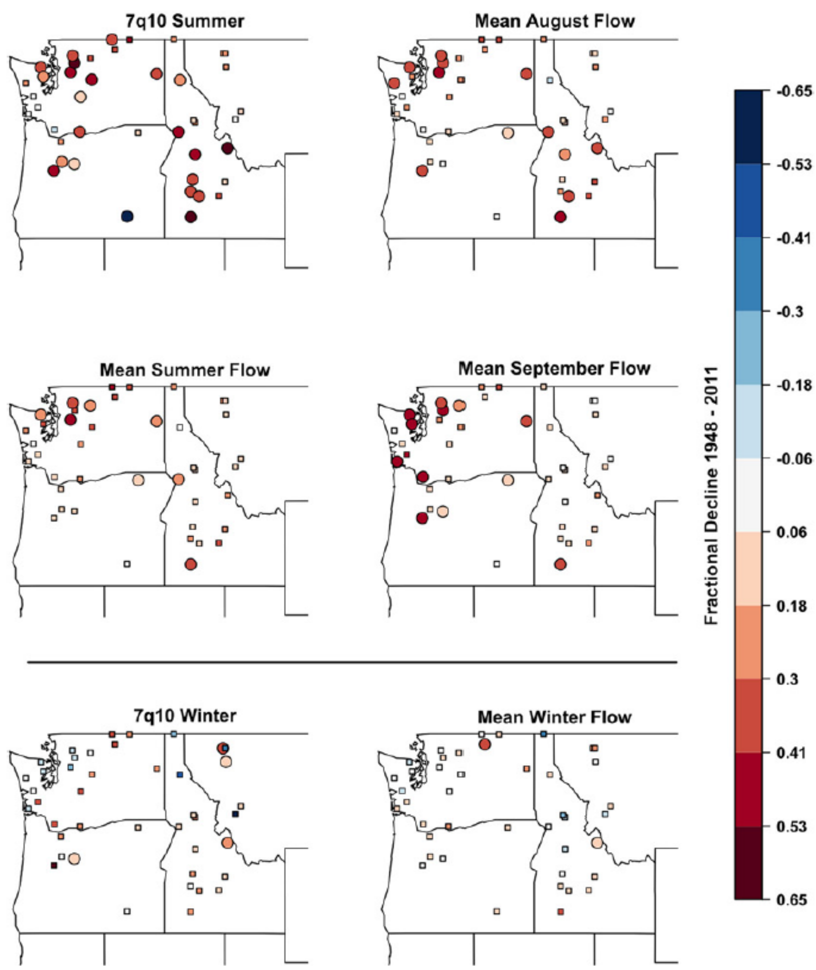


Figure 11: Maps showing mean trends in streamflow at different times of year, with blue tones indicating increases between 1948 and 2011 and red tones indicating decreases. The larger circles indicate streamgages for which the trend is significant at the 0.10 level (Kormos et al., 2016).

3.2 Streamflow timing – observed changes

Researchers also have evaluated changes in the timing of streamflow in unregulated streams in Idaho and other portions of the western U.S. using data from the last several decades (Stewart et al., 2005; Clark, 2010; Klos et al., 2015). On average, the date at which half of the annual flow volume passes the monitored streamgages has advanced by approximately 1-2 weeks over the last several decades. An example of this type of analysis for the Boise River is included in Clark (2010) and is shown in Figure 12.

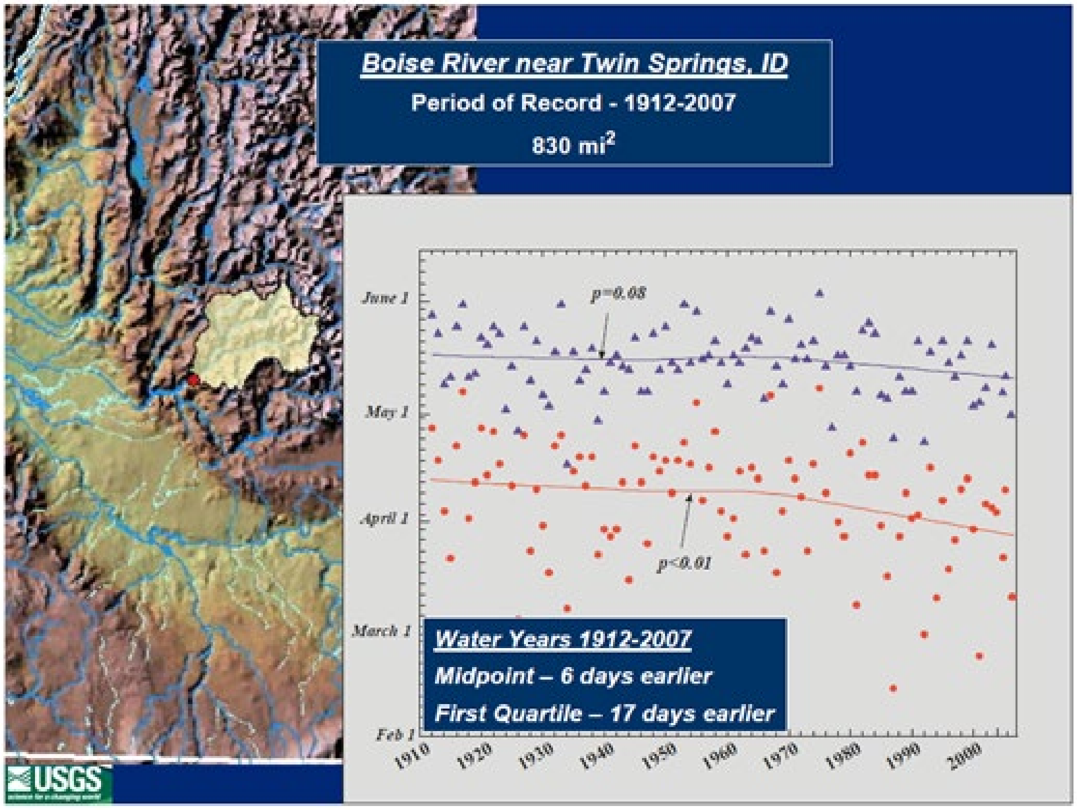


Figure 12: Analysis of timing of midpoint and first quartile flow volumes from 1912 to 2007 on the Boise River at Twin Springs, Idaho (Clark, 2010).

Of the 26 gaging locations within and just outside of Idaho that were evaluated by Clark (2010), 11 showed statistically significant earlier dates at which the midpoint total annual stream discharge passed the gaging stations. The map in Figure 13 shows the locations of the stations that did and did not show statistically significant trends toward earlier streamflow. Streamgage locations at which upstream flow draws from snowpack at lower and mid-elevation ranges would be expected to show stronger trends than gages drawing from higher elevations, where average changes to snowpack over time are not as large. Overall impacts of shifts in the timing of streamflow are highlighted in Box 1.

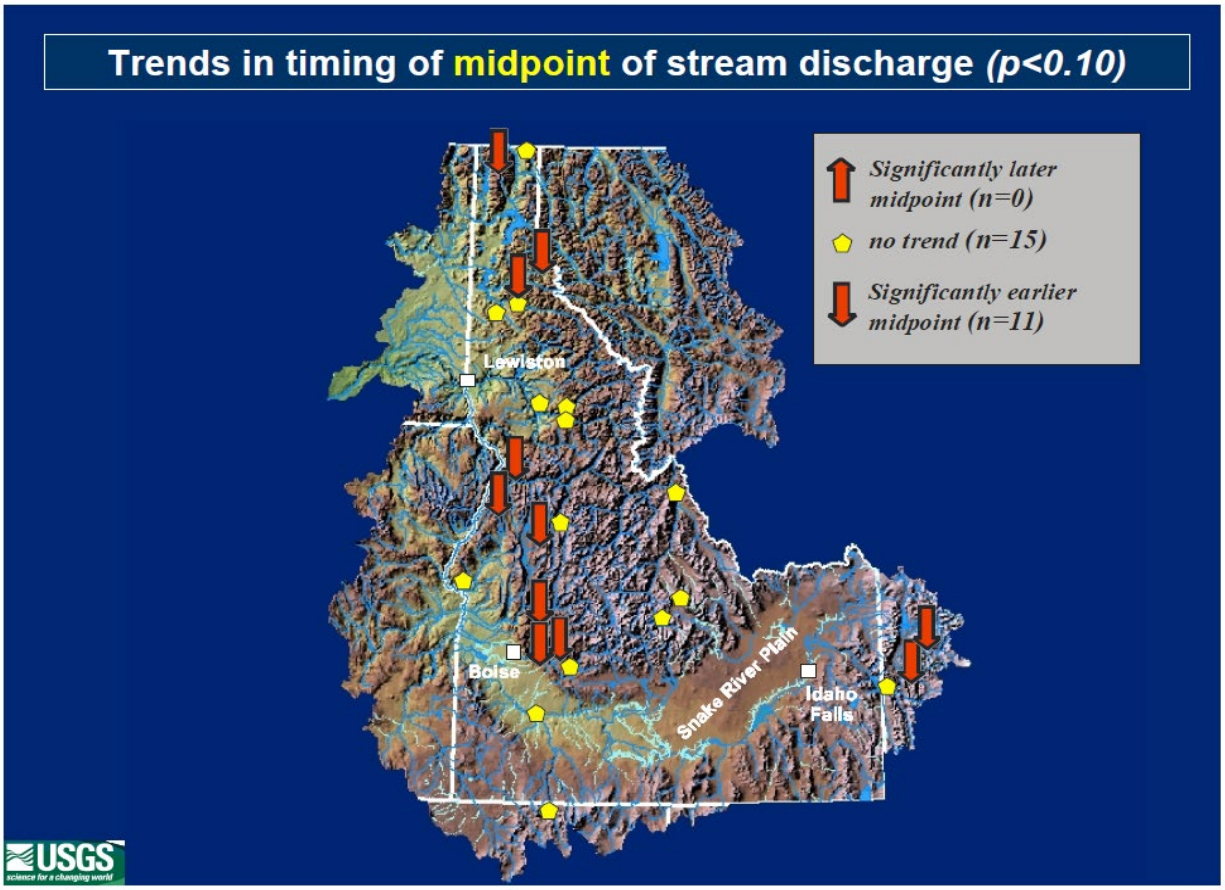
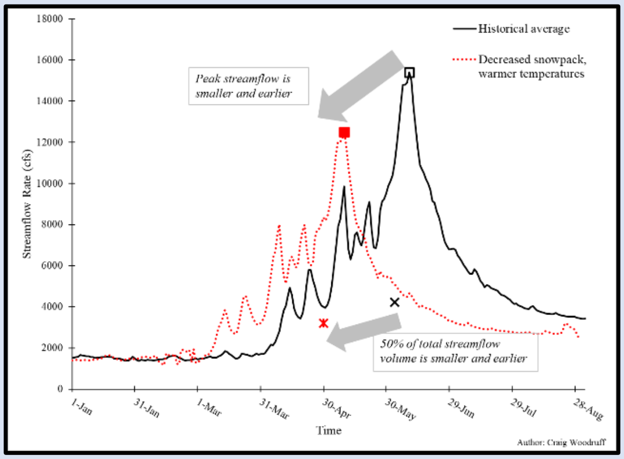


Figure 13: Trends in timing of the annual midpoint, or 50%, of total annual flow volume. Significant trends were noted for sites for which p-values were <0.10 (Clark, 2010).

Box 1: Why do shifts in the timing of snowmelt matter?



The seasonal timing and magnitude of streamflow in our region is tied to the annual cycle of snowmelt accumulation in the mountains, followed by the gradual melting and runoff of that water throughout the spring and summer. Changes in the timing of these key processes have significant impacts on both human and natural systems. When more precipitation falls as rain instead of snow and air temperatures are warmer overall, this runoff occurs earlier in the year, sometimes before that water is needed for irrigation. The diagram at the left, called a hydrograph, illustrates this process. Although total annual volume of water flowing through streams may not change, these shifts make for higher-than-normal flows in the winter months and lower-than-normal flows in the summer.

How does this timing impact water supply?

- As shown in the diagram above, this shift in timing tends to make less water available in the warmer months of the summer, when it is most needed for irrigation, power generation, and recreation.

How does this timing impact water quality?

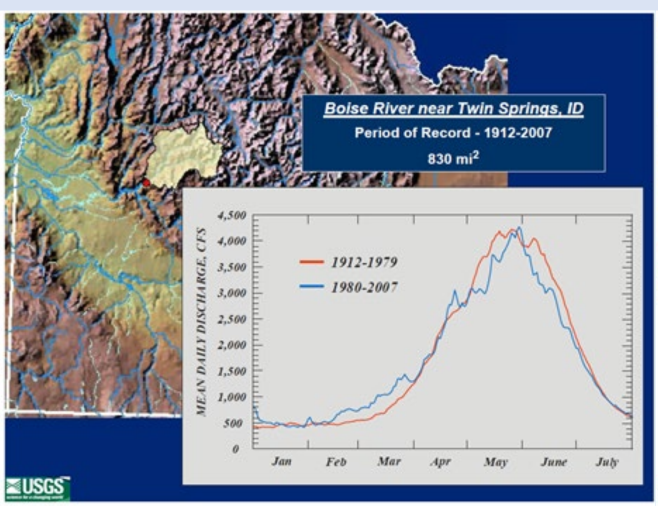
- Lower flows in the summer increase challenges related to warmer water temperatures and concentrations of contaminants, such as excess nutrients from agriculture, heavy metals from legacy mining, sedimentation from agricultural runoff, or development of harmful types of algae.
- Changes in flows and water temperature over the year also may impact the seasonal stratification and destratification in lakes and reservoirs, increasing concentrations of contaminants near the surface and at reservoir outflow points.

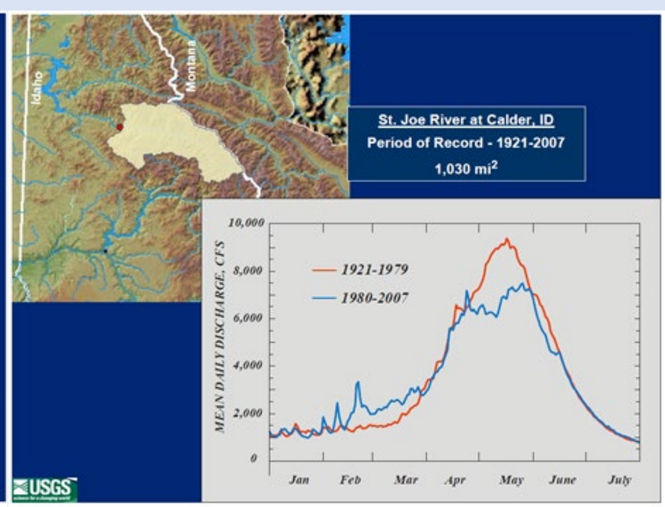
Have these types of shifts been observed in Idaho streams?

- Yes, to a lesser degree than the generalized future flow shown in the diagram above. Although not all streams in Idaho have yet exhibited what scientists refer to as "statistically significant" shifts in streamflow (see Figure 13 in the main text, as well as the examples below), watersheds currently dominated by mid-elevation snowpack tend to be the most impacted. The plots below are examples of the type of data that went into the conclusions of Clarke (2010) and other scientists: on average, over the last several decades, the date at which half the annual streamflow volume flows past gages on uncontrolled streams in Idaho has occurred approximately 1-2 weeks earlier since 1980 than in earlier decades of the 20th century.

What is the forecast for the future related to these shifts?

- There is strong agreement among the various models that with time, these shifts will become more pronounced. See Figure 15 for examples of forecasted future streamflow at 8 different gaging stations across Idaho.





3.3 Streamflow magnitude – forecasts

The River Management Joint Operating Committee (RMJOC), comprised of the Bonneville Power Administration, United States Army Corps of Engineers, and United States Bureau of Reclamation (USBR), commissioned a study that used the output of a suite of multiple climate models, combined with models of land surface hydrologic processes, to forecast changes to streamflow magnitude in future years under various scenarios for future climate characteristics for control points along major streams in the Pacific Northwest (RMJOC-II, 2018). Since many of these streams are regulated above the control points, the RMJOC (2018) analysis compared projected unregulated flows under future climate conditions with estimated unregulated flows for "historic" climate conditions. The "historic" period in this analysis is taken to be 1976-2005. The full report (RMJOC-II, 2018) contains comparisons between historic and several different future time periods.

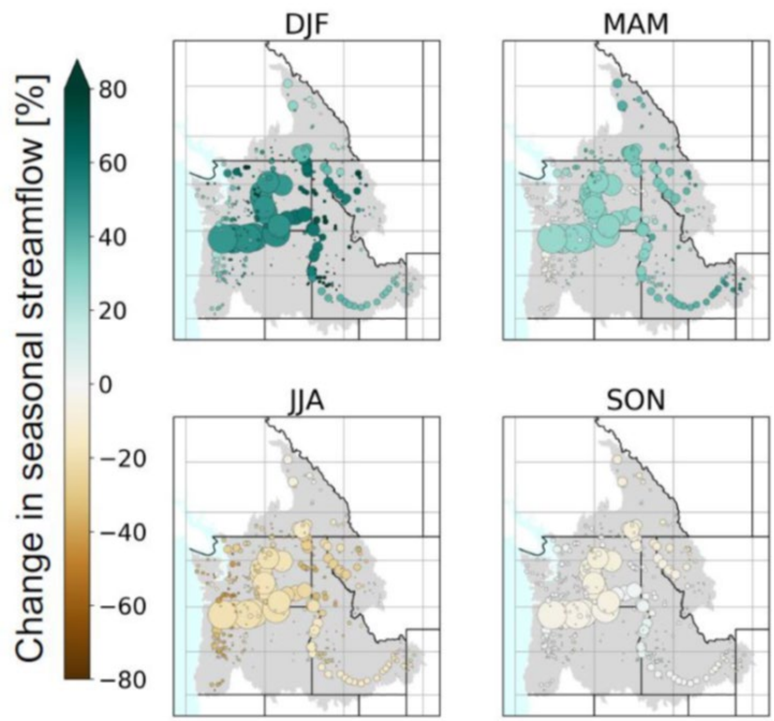


Figure 14: Percent change in seasonal streamflow volume for the future time period (as defined in text below) relative to the historical time period. Each circle is a control point along a stream, with circle size proportional to annual volumes in the historical period. The colors indicate net increases or decreases in seasonal streamflow at each control point relative to the historical period. (DJF: December-February/Winter, MAM: March-May/Spring, JJA: June-August/Summer, SON: September-November/Fall) (RMJOC-II, 2018)).

Shown in Figure 14 is the forecasted change in seasonal streamflow at the control points along the streams in the 2030s (i.e., using estimated climate conditions forecast for the years 2020-2049, as computed by ten climate models under the future climate scenario referred to as Representative Concentration Pathway (RCP)8.5, sometimes referred to the "business-as-usual" scenario or high-warming scenario, relative to seasonal streamflow in the historic period. Mid-century projections are less sensitive to choice of RCP; differences between RCP4.5 (moderate-warming) and RCP8.5 are most important for late century projections. The magnitude of the seasonal streamflow changes depicted in Figure 14 is the reported average among the ten climate models used in the analysis (RMJOC-II, 2018). The full report also includes analysis and visualization, for each control point in the study, the degree of model agreement (high to low) among the multiple climate models used, and the spread in the results calculated by the individual models (RMJOC-II, 2018).

The most robust findings from this study (i.e., those findings that are most consistent among the ten models used; RMJOC-II, 2018) relate to the forecasted decreases in summer streamflow shown in the bottom left corner (Figure 14). While results on total annual streamflow volume vary, qualitative analysis indicates that decreases in warm season streamflow and increases in winter and spring streamflow are consistently predicted (RMJOC-II, 2018).

3.4 Streamflow timing – forecasts

The results of analyses vary similar to those described in the previous section have been tabulated in a manner such that non-experts in climate models can use a tool within the Climate Toolbox[4] application to generate forecast hydrographs for various control points along streams in the Pacific Northwest, under a range of future climate scenarios, and for different forecast time periods. Examples of future hydrographs are shown in Figure 15 for 8 control points in Idaho. These hydrographs were generated using estimated climate variables under the RCP8.5 scenario. To varying degrees at different time periods, the hydrographs show the patterns of shifts in streamflow toward higher flow in the late winter and spring and decreases in streamflow in the summer, as noted in highlight Box 1 and in other sections of this report.

3.5 Synthesis and implications of changes to timing of streamflow

Most climate forecast models predict that total annual precipitation in Idaho will either remain the same or potentially increase. Thus, total volume of streamflow is expected to do the same. However, changes in the form of precipitation shifting from snow to rain have major implications for the distribution of streamflow through the year. Forecast models indicate that throughout the state, winter and early spring streamflow will tend to be higher and summer streamflow will be lower than historic means. Peak runoff in unregulated streams deriving from snowmelt will occur earlier in the spring. Observations from recent decades indicate that changes of this nature have begun to occur in some streams (Clark et al, 2010; Kormos et al., 2016).

Changes in the timing of streamflow present challenges for both freely flowing and managed river systems. For instance, decreases in summer streamflow could threaten environmental minimums on the Salmon River or the ability to meet negotiated required flows at Swan Falls Dam.

In managed river systems, storage in lakes and reservoirs can potentially serve as a partial buffer to these changes in streamflow timing. However, management of these resources is already highly constrained to serve the needs of streamflow minimums for fish and hydropower generation, supply for irrigation and other uses, and flood control functions. More in-depth analysis of critical river systems and associated storage is required in order to better understand the full impacts of these changes to managed systems and identify feasible management possibilities. Further, changes to the timing, temperature, and magnitude of streamflow have implications for water quality in streams, lakes, and reservoirs. These impacts are discussed further in Section 5.

[4] The Climate Toolbox is available at: https://climatetoolbox.org/

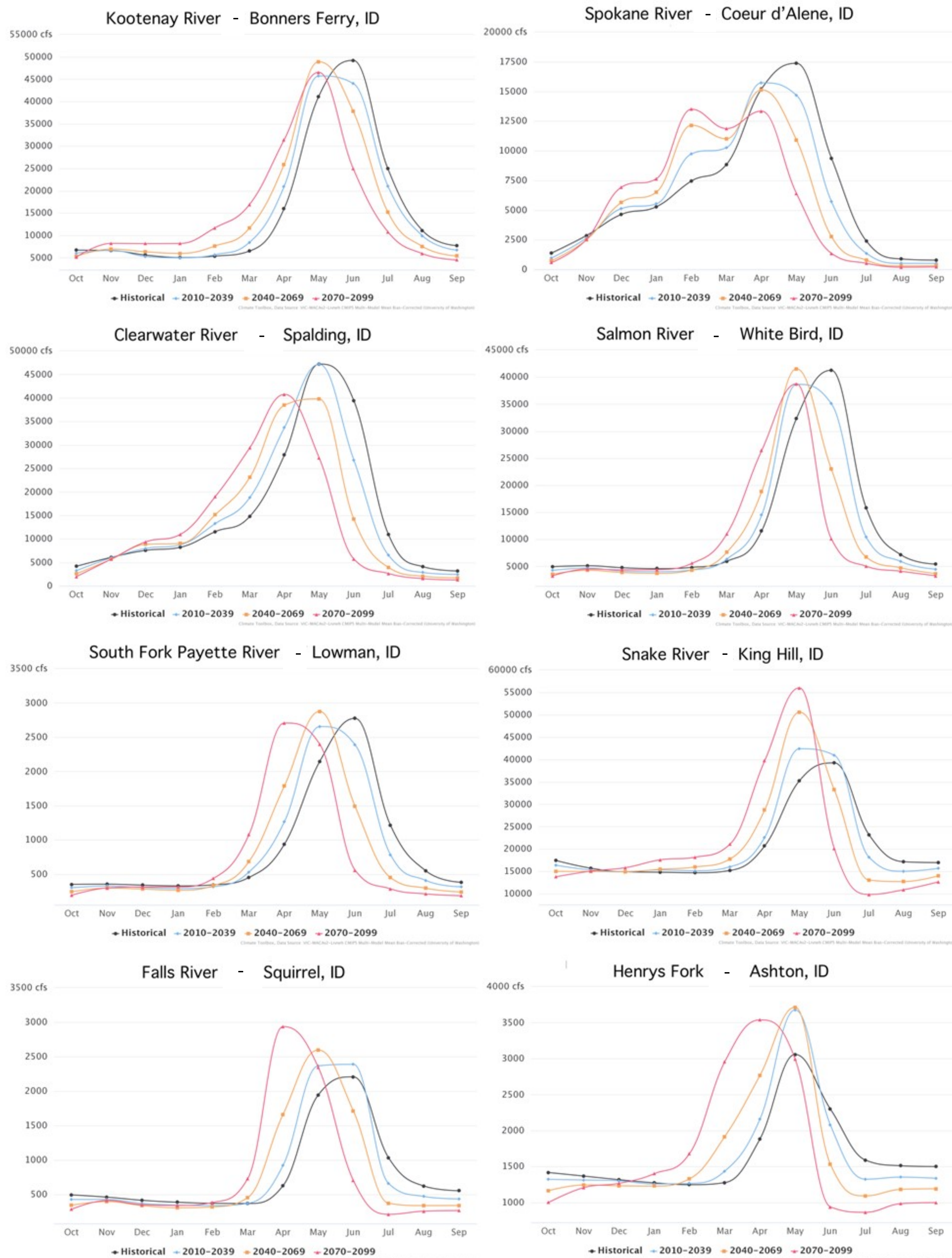


Figure 15: Historical versus forecasted streamflow for Idaho rivers based on a 10-model mean of the RCP8.5 ("business-as-usual") emissions scenario (Hegewisch et al., 2021).

4. Drought, Floods, and Water Storage

4.1 Drought

Drought and the impacts of drought occur on several different time scales. Flash drought (Lisonbee et al., 2021) is the term applied to rapid-onset events that occur on the order of weeks to months, while long-term droughts can last for years. Because Idaho's water supply is dominated by snowmelt and the largest water user is the agriculture sector, drought and water supply are often measured on a water year scale. A water year begins October 1 and ends the following September 30.

Since 1895, Idaho has had 8 years of extreme drought statewide: 1924, 1931, 1966, 1977, 1988, 1994, 2001, and 2021. Extreme drought is defined as an event less than or equal to the 5th percentile by the United States Drought Monitor (USDM). Idaho has also experienced three major multi-year drought events 1929-1937, 1987-1994, and 2000-2004.

The most recent State of Idaho Hazard Mitigation Plan, written by the IOEM (2018), provides an overview of Idaho counties most impacted by drought since 1977. The occurrence of drought is often characterized by various drought indices, some of which are designed to characterize meteorological drought, such as the Palmer Drought Severity Index (PDSI) described in the assessment's Climate Report. Meteorological drought indices are valuable for assessing drought occurrence in forests, rangelands, and non-irrigated agricultural areas. Other indices are typically applied to areas with large-scale irrigated agriculture, such as the Natural Resource Conservation Service (NRCS) Surface Water Supply Index (SWSI) (Dezman et al., 1982) and Surface Water Delivery Index (SWDI) (Hoekema and Ryu, 2016), characterize hydrological drought using variables, including snowpack, streamflow, and storage volume from year-to-year, in order to quantify shortfalls in stored water supply relative to demand.

Understanding how forecasted changes in climate impact the occurrence and frequency of drought is somewhat difficult to assess quantitatively due to the complexities in assessing drought occurrence with these various drought indices. Most indices presently used for monitoring drought in past and current conditions rely on month-to-month accounting of moisture that requires more detailed precipitation information than is available for forecasts into the future. As noted above, different drought indices are typically applied to irrigated regions with large-scale water storage than to other regions and rely on an accounting of year-to-year storage that is difficult to forecast.

However, several of the key hydroclimatic variables used in various drought indices for which there is confidence in forecasted trends include:

- Increased air temperature, which increases water demand for crops and natural vegetation.
- Declines in winter snowpack.
- Declines in summer streamflow.
- Declines in summer soil moisture in non-irrigated areas.

These changes, documented in more detail in earlier sections, all point to more frequent occurrences of both short- and long-term drought events.

The environmental impacts of drought can include:

- Low baseflow and warm water, resulting in increased fish mortality, increased algal blooms, and changes in lake and reservoir levels and stratification, which can lead to additional water quality concerns.

- Reduced agricultural production.
- Significant aquifer declines.
- Domestic wells going dry.
- Limited forage for livestock on public and private lands.
- Increased risk for wildfires in forests and rangelands.
- Increased susceptibility to forest insect and disease due to plant stress.
- Increased vulnerability of threatened animal species and vegetation communities, such as salmon populations and greater sage-grouse populations/habitat.

The economic and societal impacts of drought can include (IOEM, 2018):

- Losses for crop, dairy and livestock, timber, and fishery production and associated businesses.
- Losses for recreation providers and associated businesses.
- Losses related to increased costs resulting from increased energy demand and from energy shortages caused by reduced hydroelectric generation capacity.
- Revenue losses for governments from a reduced tax base and for financial institutions from defaults and postponed payments.
- Losses from impaired navigability of streams, rivers, and canals.
- Long-term loss of economic growth and development.

In the past, a large system of mostly federal dams in southern Idaho provided an adequate supply of stored water to help most water users weather a year or two of drought. Going forward, however, the operation of these reservoirs may need to be adjusted in accordance with changes in magnitude and timing of streamflow detailed in Section 3 (see for example, USBR (2008), summarized in the next section). More Idaho-specific studies are required to better understand how the combined impacts of changes in snowpack and streamflow will impact the ability of these dams to buffer some water users from the impacts of drought.

4.2 Floods

The State of Idaho Hazard Mitigation Plan (IOEM, 2018) states:

> *"Types of flooding experienced in Idaho are numerous and include: riverine flooding, flash floods, alluvial fan flooding, ice/debris jam flooding, levee/dam/canal breaks, stormwater, sheet or areal flooding, and mudflows (especially after a wildfire). Flooding has produced the most damaging and costly disasters in Idaho, and significant events have occurred regularly throughout the history of the State."*

The plan goes on to report that according to National Oceanic and Atmospheric Administration (NOAA)'s National Centers for Environmental Information (NCEI) storm events database, Idaho experienced 617 flooding events between 1950 and 2017. Total property damage due to flooding of various types over this time period was estimated at over $180 million and total crop damage was estimated at over $20 million. The plan also describes the various flood types and causal mechanisms, the predominance of which varies across the state. For example, most recent major floods in northern Idaho have occurred in the late winter or early spring as a result of ROS events, in which large, warm, extremely wet tropical air masses move slowly across the Pacific Northwest. The high precipitation amounts, coupled with the warmth contained in the rain itself, cause rapid snowmelt, resulting in extremely high snowmelt volumes. In other parts of the state, flooding events are more frequently caused by shorter-term but intense precipitation associated with convective storms, high-volume snowmelt in the spring of years in which the snowpack is particularly high, or ice jams.

Changes in temperature and precipitation (rain vs. snow, magnitude and intensity of precipitation, seasonal distribution) will impact these various flooding mechanisms in different ways, potentially reducing flood risk in some areas, while increasing it in others. For example, as noted in Section 2.3, the probability of ROS events is expected to decrease in some parts of the state while increasing in other parts of the state where it has not previously been a dominant mechanism for flooding. Although difficult to predict impacts in specific portions of the state without using focused modeling studies with downscaled data from various ensembles of climate models, as noted in the assessment's Climate Report, hydrologic simulations suggest that there will be increases in annual maximum streamflow across the Pacific Northwest as a result of increased rainfall magnitudes (Chegwidden et al., 2020; Queen et al., 2021). Additionally, these studies indicate that the conditions under which annual maximum flows occur may shift for some streams (e.g., streams for which annual maximums occur at the peak of snowmelt season may instead incur the annual maximum flow from rainfall events).

Although major reservoirs in the state are managed for flood control, the changing storage requirements resulting from shifts in the hydrograph described in highlight Box 1 make that task more challenging. For example, an initial assessment by the USBR of climate change impacts on the operation of Boise River reservoirs (USBR, 2008) detailed those challenges. They concluded that it will be more difficult to manage river flows through Boise prior to April 1, the date by which current operation rules call for maximum space evacuation in the reservoir, leading to increased risk of winter and early spring flooding. More recently, the IWRB partnered with the USBR to evaluate the feasibility of adding more storage to the Boise River Drainage. The resulting recommendations included raising the height of the Anderson Ranch Dam by 6 feet, which would result in 29,000 additional acre-feet (AF) of storage.[5] Although, the integration of Anderson Ranch Dam with other dams on the Boise River is projected to limit the utility for flood storage purposes.

An example of a basin-specific study to evaluate flood potential due to climate change, Kim and Ryu (2019) modeled the uncontrolled flow in the Boise River using downscaled projected precipitation and temperature from two different climate models. Some of the results are presented in Figure 16, in which the percent change in streamflow (relative to simulations of current uncontrolled flows) are shown for each calendar month. The various lines on the two charts represent different RCP scenarios for climate change between now and 2100. The two charts represent forecasts from two different climate models described in the figure caption. Consistent with regional studies referenced in Section 3, the results from both models and for all scenarios show increased flow in the winter months and decreased flow in the summer months.

[5] https://idwr.idaho.gov/iwrb/projects/boise-river/

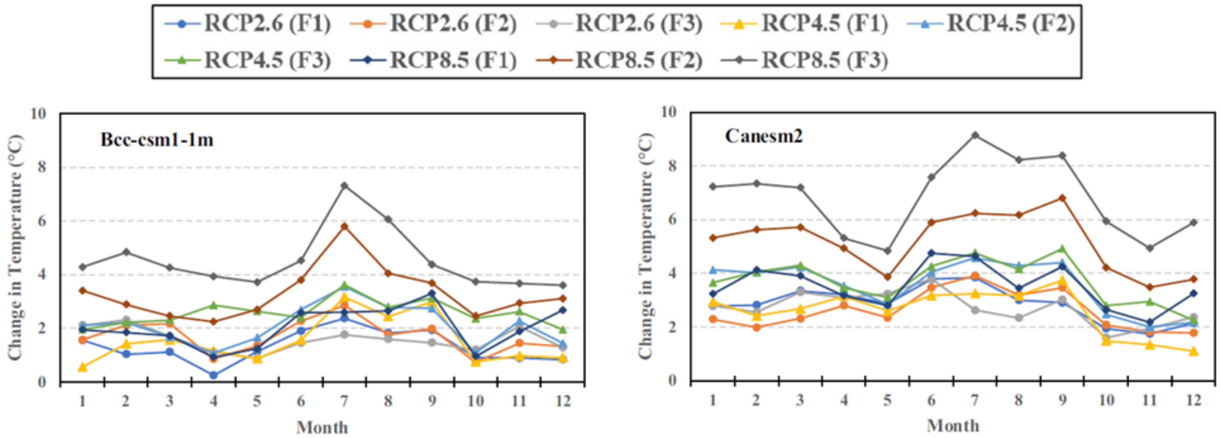


Figure 16: Monthly change in streamflow (by % relative to current values) as modeled by Kim and Ryu (2019) using different future climate scenarios (or RCPs) and two different climate models (one from the Chinese Climate Center (referred to as Bcc-csm-1m) and a model from the Canadian Center for Climate Modeling and Analysis (referred to as the Canesm2 model)) for three future periods (F1: 2021-2045, F2: 2046-2070, F3: 2071-2095). Calendar months are shown in sequential order (i.e., 1 represents forecast flows in January and 12 represents forecast flows in December). RCP4.5 (moderate-warming) and RCP8.5 (high-warming) are described in Section 3.3. RCP2.6 (low-warming) assumes a rapid reduction in emissions and implementation of negative carbon dioxide emission technologies.

4.3 Dams and storage

In Idaho, there is a maximum storage capacity of almost 22 billion cubic meters of water from the 111 major dams in the state, which were primarily built for irrigation, hydropower, and flood control, as well as ecological protection, debris management, mine tailings management, fire protection, recreation, navigation, and water supply enhancement (Hansen et al., 2014). According to the 2012 Idaho State Water Plan, there is approximately 1.4-1.6 million AF of storage capability remaining through additional enlargement or development of reservoir sites in the Weiser River (900,000 AF), Teton River (300,000 AF), Boise River (70,000-300,000 AF), Snake River (67,000 AF), Bear River (48,000 AF), and the Lost Valley River (20,000 AF). Qualls et al. (2013) evaluated irrigation and water delivery infrastructure in Idaho in the early 2010s and concluded that it was adequate to cover needs in drier years as had occurred in the past. However, they concluded that current resources were not sufficient to take full advantage of storing water in wetter years in the record prior to 2013.

Going forward, however, the general future trends described in previous sections (i.e., significantly warmer average temperatures, increased evapotranspiration by crops, lower streamflow in the summer months and higher streamflow in the winter months, shifts in the timing of snowmelt runoff) all suggest a need for additional storage to capture the increased runoff in the winter and early spring to mitigate shortages in the warmer months. In addition, increased frequency and/or intensity of ROS events will increase flood risks in some parts of the state; additional flood control measures may also be necessary. Further study of storage needs connected to future climate and streamflow variability in Idaho is needed.

4.3.1 Water storage in the Eastern Snake Plain Aquifer (ESPA)

As noted in earlier sections, the ESPA is a massive groundwater resource with considerable connectivity to surface water resources due to both natural discharge points and man-made infrastructure (e.g., unlined irrigation canals and managed recharge sites). Most of the discharge from the ESPA to the Snake River occurs in two locations: a) the Snake River above and within American Falls Reservoir and b) the Snake River Canyon between Milner Dam and King Hill, Idaho. The discharge of the ESPA into the Snake River Canyon supports an extensive aquaculture industry, agriculture, and hydropower production. The discharge of the Snake River into and above American Falls Dam provides a key water supply to the members of the Surface Water Coalition (see SWC-IGWA Settlement Agreement, 2015).

The USGS estimated that from 1912 to 1950, the volume of the ESPA increased by over 16,000,000 AF (Kjelstrom, 1995a). This large increase in aquifer volume was due mostly to incidental recharge—seepage from unlined canals and seepage of excess irrigation water from flood irrigated fields (Johnson et al., 2007). The increase in aquifer storage led to a dramatic increase of aquifer discharge into the Snake River Canyon between Milner Dam and King Hill, Idaho (Kjelstrom, 1995b). When irrigation by groundwater began in the 1950s, groundwater levels, and therefore total storage of water in the aquifer, began to decrease, as did discharge from the aquifer back into the river in the Snake River Canyon at Thousand Springs (see Figure 17). The decline in aquifer levels eventually led to the 1984 Swan Falls Agreement, Snake River Basin Adjudication, and numerous lawsuits between users of the springs in the Snake River Canyon and groundwater users. It also gave rise to the ESPA CAMP coordinated by the IWRB, which included evaluation and implementation of artificial recharge projects in various locations (IWRB, 2009; IWRB, 2020).

At and above the American Falls Reservoir, the declines in ESPA aquifer discharge led to a water call by the Surface Water Coalition (SWC) against the Idaho Groundwater Appropriators (IGWA). The members of IGWA agreed to reduce groundwater pumping by 240,000 AF annually and all parties agreed to support the IWRB aquifer recharge program goal to recharge 250,000 AF annually, which utilizes some of the SWC canals, as well as artificial recharge sites (SWC-IGWA Settlement Agreement, 2015).

In summary, the ESPA is a large, vital, and dynamic resource that has undergone significant changes in stored water volume in the last century. It represents a potential resource for water storage, however, and remains an important area of study and planning by users and state agencies.

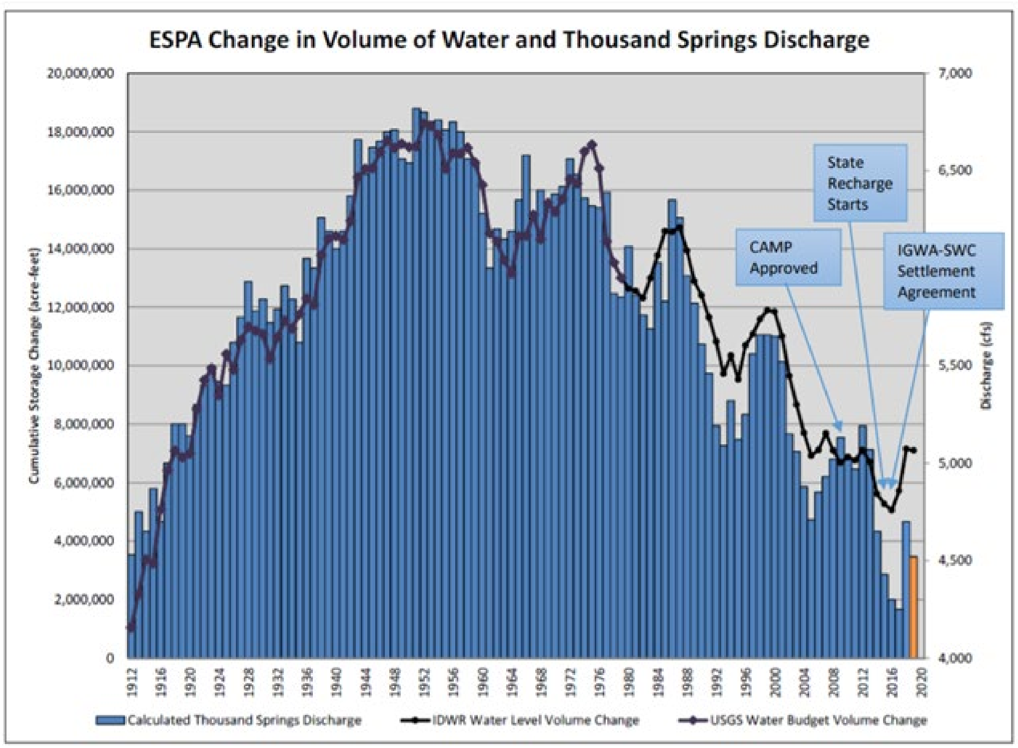


Figure 17: Left axis and bars show cumulative storage change in the ESPA over time. Right axis and solid line show discharge into the Snake River at Thousand Springs (IWRB, 2020).

5. Water Quality and Climate Change

As noted in Section 1.4, several existing water quality concerns in Idaho have the potential to be impacted by changes in air temperature, as well as variations in the timing and magnitude of streamflow. These include contributions of sediments; excess nutrients, such as nitrogen and phosphorus; pathogens; heavy metals and other contaminants that arise from runoff associated with agricultural fields; chemical fertilizer production; dairies and livestock; food processing; aquaculture; urbanization; forestry; and legacy mining. Contaminants often make their way from streams into lakes and reservoirs, where temperature and density-based stratification in those large water bodies tends to allow them to accumulate.

Specific examples of the mechanisms by which climate-related factors can exacerbate or cause increased risks related to these existing water quality issues are noted below.

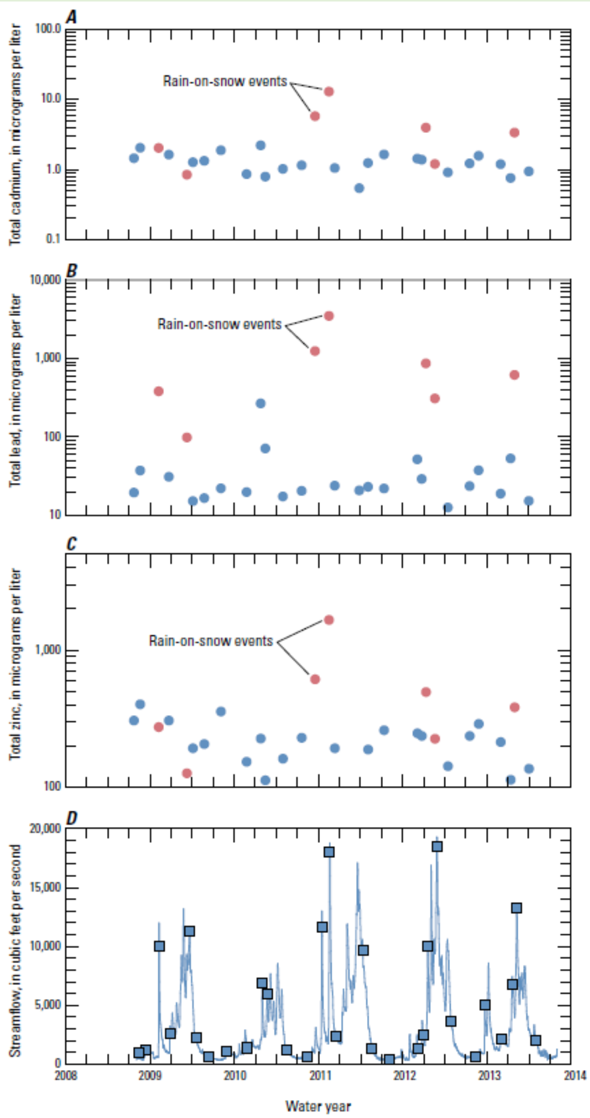
- Warmer air temperature causes warmer water temperature in streams, lakes, reservoirs, and irrigation canals, with impacts, such as:
    - Warmer water temperatures in streams are harmful to cold-water fish species, such as trout and salmon. Ecological and economic impacts are described in more detail in the assessment's Fish Report.
    - Warmer water temperatures in lakes, reservoirs, and irrigation canals create conditions more conducive to the development of HABs, which can impact both aquatic ecosystems and human health (Carey et al., 2012; Newbombe et al., 2012; O'Neil et al., 2012).

- Decreased streamflow in the summer months, as is expected to occur, with impacts, such as:
    - Exacerbating increases in water temperature in streams arising directly from increased air temperature due to decreased water volumes for mixing.
    - Increasing the concentration of sediment and contaminants in streams, even without increasing the absolute amounts of those materials reaching streams due to smaller water volumes available for mixing, thus impacting aquatic systems, as well as the ability to meet existing Total Maximum Daily Loads (TMDLs) (Kormos et al. 2016).

- Increased streamflow in the winter and early spring, and particularly the large streamflow volumes associated with ROS events, can impact water quality in lakes and reservoirs by bringing large pulses of contaminants into those systems over a short period of time. Further, these intense pulses of water and contaminants bring greater risk for changes in stratification of those water bodies, with the potential to disturb existing contaminants residing there. An example of observed correlations between high-flow events and concentrations of heavy metals in Lake Coeur d'Alene is provided in highlight Box 2.

- The length of the wildfire season in Idaho already has expanded by over a month (Klos et al., 2015). Abatzoglou and Lute (2020) provided estimates of the increases in annual burn area for Idaho watersheds. The primary concerns with regard to wildfire and water quality are post-fire hydrophobic soils that increase runoff and result in increased sedimentation rates. The increased runoff also can increase flooding risk and the suspended and dissolved materials can be harmful to aquatic life, waterfowl, and humans (for example, Neary et al., 2008; Smith et al., 2011; Silva et al., 2015).

Box 2: How does streamflow variation impact concentration of heavy metals in Lake Coeur d'Alene?



Concentrations of total (*A*) cadmium, (*B*) lead, and (*C*) zinc (differentiated by samples collected at streamflows greater than and less than 10,000 cubic feet per second), and (*D*) streamflow, in the Coeur d'Alene River near Harrison, Idaho (site 15), water years 2009–13.

Clark and Mebane (2014)

EXPLANATION

- Streamflow less than 10,000 cubic feet per second
- Streamflow greater than 10,000 cubic feet per second
- Streamflow
- Sample collected

The Coeur d'Alene (CdA) Lake Basin is an important region in Idaho, in terms of economic growth, climate change, and water resources. Legacy mining in the upper Coeur d'Alene River watershed continues to contribute high metals concentrations both in lake sedimentation and in dissolved form, resulting in health warnings for lead concentrations (LMP, 2009). As such, the lake proper and upstream areas are being managed by the EPA as Superfund sites for metals remediation. At the same time, the lake receives high nutrient inputs from both the CdA River and St. Joe River, which contribute to algal blooms in the southern portion. Sources of the nutrients include both ambient concentrations from soil, as well as agricultural runoff. In the graphs shown on the left (from Clark and Mebane, 2014), the concentration of cadmium, lead, and zinc (shown in red in A, B, and C, respectively) correspond to the higher flow events shown in D. Notably, higher concentrations of contaminants correspond to the high-flow events. Thus, high-flow pulses from rain-on-snow (ROS) events, if exacerbated or made more frequent by climate change, will increase sedimentation and subsequent nutrient and metals loading into the lake.

Currently, dissolved zinc inputs from legacy mining contamination act as an algicide in the central portion of the lake, inhibiting widespread algal blooms from spreading to the north. However, the combination of lower summer flows and higher temperatures due to climate change, along with the remediation of the sources of zinc inputs to the CdA River, has the potential to spread algal blooms throughout the lake, including harmful algal blooms (HABs), such as toxic cyanobacteria or "blue-green algae."

Another effect of widespread algal blooms is that their normal processes of growth and decay pull dissolved oxygen from the water, which can create hypoxic, or low oxygen conditions, in the lowest layer of the lake above the sediment (*hypolimnion*). These conditions tend to free zinc trapped in the sediments and allow it to be transported to upper layers where it comes in contact with vegetation, aquatic life, wildlife, and human users of the lake. As the lake water spills into the Spokane River, which flows into the state of Washington and ultimately the Columbia River, there are additional interstate challenges. Washington state maintains total maximum daily load (TMDL) limits for metals in the Spokane River and Idaho is legally responsible for managing contributions to keep the Spokane River below exceedance levels.

Lake CdA is also an important historical territory for the CdA Tribe. The Tribe's ownership of the southern third of the lake has been legally affirmed and the Tribe collaborates with the state of Idaho to manage lake conditions. Thus, the lake not only supports Idaho's economy, it is also an important part of Indigenous worldviews and a source of cultural resources, such as freshwater fish and water potatoes (*Sagittaria latifolia*). Therefore, lead and other heavy metals levels are of a particular concern for the Tribe, with respect to contamination of these "first foods" (Campbell et al., 1997).

6. Interacting Factors in Water Use, Both Present and Future

The largest single driver for water demand in Idaho at present is irrigated agriculture (USGS, 2018). However, other major factors influencing the demand for water at present, which will continue into the future, include hydropower generation and growth in DCMI water uses. There is a particularly strong two-way coupling between water and energy in southern Idaho, in that considerable energy (i.e., electricity) is required to pump and distribute irrigation water. Water from that same managed system is required for generating hydropower. With climate change, demand for water for irrigation is expected to increase, while at the same time, water availability for hydropower generation may become more challenging to ensure. An understanding of the linkages between these resources is of benefit for co-management. Energy use for irrigation at present is summarized in Section 6.1. Other drivers of demand for both water and energy that need to be planned for in conjunction with climate-induced changes to water supply and water demand include population increases and economic growth. In Section 6.2, an example analysis is presented that estimates changes in water demand from a change in land use from agricultural to residential.

6.1 Water-energy-climate nexus

There is a strong relationship in Idaho between water and electricity production, in the form of hydropower, as well as energy use. Water storage facilities equipped with hydropower production capabilities provide energy, irrigation water for agriculture, flood control, drinking water, and recreational opportunities. The five largest hydropower facilities in terms of power production are: (1) Brownlee (585 MW), (2) Dworshak (400 MW), (3) Hells Canyon (391 MW), (4) Cabinet Gorge (231 MW), and (5) Oxbow (190 MW). Most of the hydropower generating plants are in southern Idaho. However, two of the five largest plants are in northern Idaho (Dworshak, Cabinet Gorge) and three are on the border between north and south Idaho (Brownlee, Oxbow, and Hells Canyon).

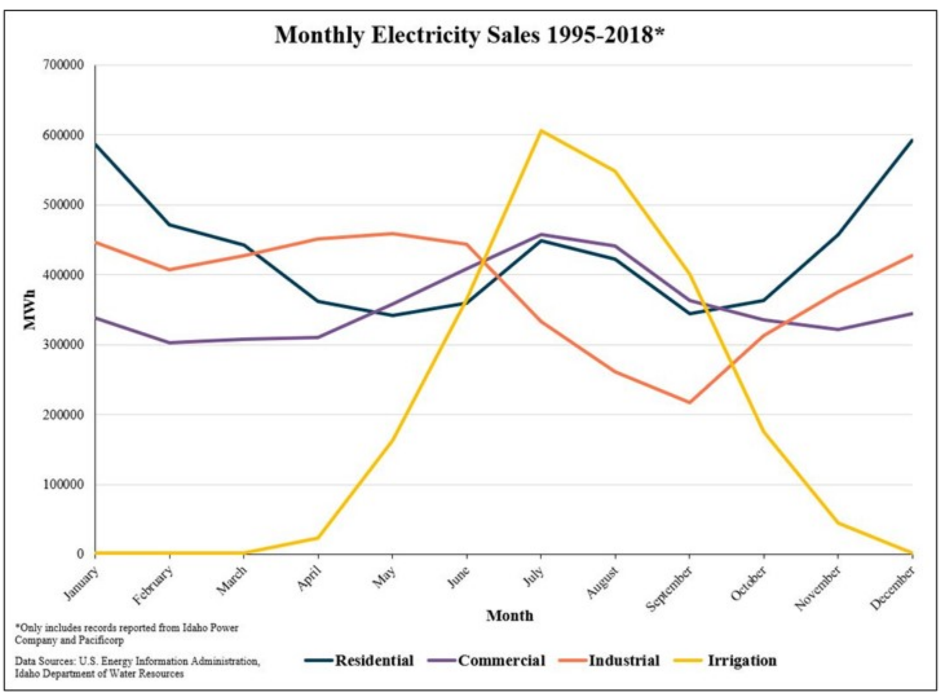


Figure 18: Monthly electricity sales in different sectors by the two largest power companies in southern Idaho, averaged over 1995-2018 (Thompson and Humes, 2021).

Water use in irrigation is a major link between water and energy use in Idaho. Power is used in pumping groundwater to the surface, as well as pressurizing water from both groundwater and surface water to distribute it in large sprinkler irrigation systems. Monthly averages of electricity sales by the two largest power providers in southern Idaho averaged over the period of 1995-2018, differentiated by sector, are shown in Figure 18 (Thompson and Humes, 2021). These data show that water use in irrigation has a considerable impact on the seasonal use of electricity in southern Idaho. In the summer months, peak power use for irrigation coincides with the annual peak use of power in the commercial sector and coincides with the second largest peak in residential use due to demand for air conditioning. An example of the water-energy-climate nexus is that warmer air temperatures increase the evaporative demand by crops (and therefore power demand associated with irrigation) while power demand for air conditioning peaks in the residential and commercial sectors. At the same time, lower summertime streamflow may impact the ability to generate hydropower. One consideration when planning for water resources with a changing climate is to quantify linkages between water and energy use.

6.2 Land use and population growth

Idaho has one of the highest rates of population growth in the U.S. Much of the new development for housing, particularly in the southern part of the state, occurs on land converted from irrigated agriculture. On a per acre basis, water use by irrigated agriculture is quite high. It is sometimes assumed that conversion of land from agricultural to urban uses decreases water demand on a per acre basis. However, the trade-off in water demand between land used for irrigation and urban development depends on the nature and density of development and on water use policies, such as conservation requirements for indoor water use (i.e., low water use appliances and fixtures) and water sources used for external urban water use (i.e., whether yards, parks, and golf courses are irrigated by recycled effluent or fresh water).

6.2.1 Case study: Water demand tradeoffs in the Treasure Valley

An illustrative example to estimate these trade-offs is provided in a study commissioned by the IWRB and the IDWR on Treasure Valley DCMI water demand projections for the period 2015-2065 (SPF Engineering, 2016). This study also attempted to include the impacts of climate change on water demand projections. Study assumptions included, but were not limited to, the following:

- The Treasure Valley population is expected to increase from approximately 624,500 people in 2015 to approximately 1.57 million people by the year 2065, representing an increase of approximately 250%.
- Average temperatures by the year 2065 could increase by approximately 1.9°F to 6.1°F, with evapotranspiration increasing by approximately 5 to 20% as a result of temperature increases.
- Substantial water demand reductions are possible through conservation. The Treasure Valley DCMI water demand projections included assumed reductions in water use of 10 to 30% (compared to 2015 rates).

Several different scenarios were evaluated with respect to the nature and density of the urbanization and likely adoption of conservation practices, each with some inherent uncertainty. For each scenario, the net demand for water was estimated as a function of time. Net demand is the total increase in DCMI demand, minus existing water use for irrigated agriculture in the impacted areas. The computation of net demand assumes that the demand met by currently developed surface water supplies for the irrigated agriculture displaced by the urbanization will be available for urban uses in the areas of projected urban growth. The authors state that their scenario two, which assumed 20% reduction over 2015 rates in indoor use and a 10% across-the-board reduction in outdoor use, was the most probable. Net demand computed for this scenario as a function of time is presented in Figure 19. The authors concluded that there would be a net demand increase of approximately 158,000 AF per year by 2065 for the projected development.

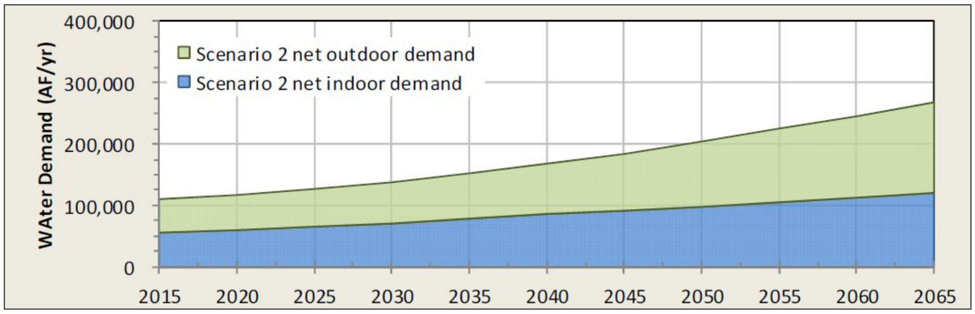


Figure 19: Net demand for DMCI water needs for projected urban development in the Treasure Valley under Scenario 2 described in the SPF report (SPF Engineering, 2016).

The report also includes several suggestions about how to meet this demand, including: (1) diversions from the Boise River (through increased surface water storage, use of flood flows for aquifer storage and recovery, or direct diversions from the Boise River below Star, Idaho); (2) additional use of Treasure Valley groundwater; (3) new diversions from the Snake River; and (4) reuse of treated municipal effluent. It was beyond the scope of the study to comprehensively evaluate the relative advantages or disadvantages of these options.

Key takeaway points from this example include:

- There was net demand for water in the projected scenarios for urbanization (i.e., water demand for the urban area exceeds water demand by previous agricultural uses).
- The magnitude of the net demand was lessened under the scenarios that included conservation requirements for indoor water use and limitations on the sources of water for outdoor use.

7. Synthesis and Summary

There are clear and direct mechanisms by which changes in air temperature, precipitation, and snowpack in Idaho impact the supply, demand, and quality of water in Idaho. Some of the key direct and indirect impacts of these changes in climate variables include:

- Higher streamflow in the winter and late spring due to more precipitation falling as rain and less as snow.
- Less water storage in the mountains in the winter and spring, causing the dates of peak streamflow from snowmelt runoff to shift earlier in the year.
- Lower streamflow in the summer months, particularly in unregulated streams.
- Potential need for additional storage in managed river systems in order to maintain flows for hydropower generation, agreements among water users, and flood control needs and to meet demand for water in the summer months and drought years.
- Increased demand for water in irrigation due to increased evapotranspiration brought on by higher air temperature (in both agricultural and non-agricultural irrigated lands).
- Increased soil moisture deficits in the summer in forests and rangelands, leading to more frequent occurrence of wildfires, which also contributes to water quality impacts.
- A rise in stream temperatures, particularly during lower flow summer months, impacting fisheries and other aquatic systems.
- Water quality concerns in streams, lakes, and reservoirs exacerbated by increases in water temperature and lower flow volumes in the summer months.

- Water quality concerns in lakes and reservoirs, where large pulses of water and contaminants, such as those that occur with ROS events, can bring in heavy contaminant loads, as well as impact the stratification of water and existing contaminants.

Importantly, some of these impacts already have been observed in Idaho recent decades, such as the changes in streamflow noted in Section 3, the occurrence of drought described in Section 4, the occurrence of wildfire described in Section 5, and the increases in stream temperatures described in Section 5. Modeled forecasts for continued changes in snowpack and streamflow inherently involve some uncertainty. However, the projections for which there is strongest agreement among different climate models and analysis approaches all point to the impacts noted above.

References Cited

Abatzoglou, J. and Lute, A. (2020). Projections of Climate and Drought for Selected Sub-Basins in Idaho. Unpublished Manuscript. Moscow, ID: University of Idaho.

Ashfaq, M., Ghosh, S., Kao, S.C., Bowling, L.C., Mote, P., Touma, D., Rauscher, S.A., Diffenbaugh, N. A. 2013. Near-Term Acceleration of Hydroclimatic Change in the Western U.S. *Journal of Geophysical Research Atmospheres* 118(19), 10,676-10,693. DOI: 10.1002/jgrd.50816.

Campbell, J.K., Audet, D.J., McDonald, T.L., Kern, J., Strickland, D., Cernera, P.J. (1997). Heavy Metal Concentrations in *Sagittaria spp*. Tubers (Water Potato) in the Coeur d'Alene Basin, Idaho. Spokane, WA: US Fish and Wildlife Service.

Carey, C.C., Ibelings, B.W., Hoffmann, E.P., Hamilton, D.P., Brookes, J.D. 2012. Eco-Physiological Adaptations that Favour Freshwater Cyanobacteria in a Changing Climate. *Water Research*, 46 (5), 1394-1407. DOI: 10.1016/j.watres.2011.12.016.

Chegwidden, O.S., Rupp, D.E., Nijssen, B. 2020. Climate Change Alters Flood Magnitudes and Mechanisms in Climatically-Diverse Headwaters across the Northwestern United States. *Environmental Research Letters*, 15(9), 094048.

Clark, G.M. 2010. Changes in Patterns of Streamflow from Unregulated Watersheds in Idaho, Western Wyoming, and Northern Nevada. *Journal of the American Water Resources Association*, 46(3), 486-497.

Clark, G.M. and C.A. Mebane. (2014). Sources, Transport, and Trends for Selected Trace Metals and Nutrients in the Coeur d'Alene and Spokane River Basins, Northern Idaho, 1990–2013. USGS Scientific Investigations Report, 2014–5204.

Coeur d'Alene Lake Management Plan – Coeur d'Alene Tribe and Idaho Department of Environmental Quality. (2009). Prepared by staff of the Idaho Department of Environmental Quality. https://www.cdatribe-nsn.gov/lake/wp-content/uploads/sites/7/2020/03/LMP09.pdf, accessed November 2021.

Dezman, L.E., Shafer, B.A., Simpson, H.D., Danielson, J.A. 1982. Development of a Surface Water Supply Index - A Drought Severity Indicator for Colorado. *International Symposium on Hydrometeorology*, June 13-17, Denver.

Fyfe, J.C., Derksen, C., Mudryk, L., Flato, G.M., Santer, B.D., Swart, N.C., Molotch, N.P., et al. 2017. Large Near-Term Projected Snowpack Loss over the Western United States. *Nature Communications*, 8(14996), 1–7. DOI: 10.1038/ncomms14996.

Gergel, D.R., Nijssen, B., Abatzoglou, J.T., Lettenmaier, D.P., Stumbaugh, M.R. 2017. Effects of Climate Change on Snowpack and Fire Potential in the Western USA. *Climatic Change,* 141(2), 287–99. DOI: 10.1007/s10584-017-1899-y.

Hansen, Z.K., Lowe, S.E., Xu, W. 2014. Long-term Impacts of Major Water Storage Facilities on Agriculture and the Natural Environment: Evidence from Idaho (U.S.). *Ecological Economics*, 100:106-118. DOI: 10.1016/j.ecolecon.2014.01.015.

Hegewisch, K.C., Abatzoglou, J.T., Chegwidden, O. (2021). 'Future Streamflows' web tool. Climate Toolbox (https://climatetoolbox.org/), accessed October 2021.

Hoekema, D. J. and Ryu, J. H. 2016. Characterizing Drought in Irrigated Agricultural Systems: The Surface Water Delivery Index (SWDI). *Journal of the American Water Resources Association*, 52(3), 737–755. DOI:10.1111/1752-1688.12426.

Idaho Department of Water Quality (IDEQ). (2021). Cyanobacteria Harmful Algal Blooms. https://www.deq.idaho.gov/water-quality/surface-water/cyanobacteria-harmful-algal-blooms/, accessed October 2021.

Idaho Department of Water Resources (IDWR). (2009). Eastern Snake Plain Aquifer (ESPA) Comprehensive Management Plan. https://idwr.idaho.gov/wp-content/uploads/sites/2/iwrb/2008/20080129-ESPA-CAMP.pdf, accessed October 2021.

Idaho Office of Emergency Management (IOEM). (2018). State Hazard Mitigation Plan.

https://ioem.idaho.gov/preparedness-and-protection/mitigation/state-hazard-mitigation-plan/, accessed October 2021.
Idaho Water Resource Board (IWRB). (2010). State of Idaho Water Resource Inventory 2010. Idaho Department of Water Resources. https://idwr.idaho.gov/files/iwrb/2010/2010-Water-Resource-Inventory.pdf, accessed October 2021.
Idaho Water Resource Board (IWRB). (2020). Restoring the Eastern Snake Plain Aquifer, 10 Year Progress Report. https://idwr.idaho.gov/wp-content/uploads/sites/2/iwrb/2019/20191210-ESPA-CAMP-Progess-Report-Final.pdf, accessed October 2021.
Johnson, G.S., Sullivan, W.H., Cosgrove, D.M., Schmidt, R.D. 2007. Recharge of the Snake River Plain Aquifer: Transitioning from Incidental to Managed. *Journal of the American Water Resources Association*, 35(1), 123-131. DOI:10.1111/j.1752-1688.1999.tb05457.x
Kim, J. and J.H. Ryu. 2019. Modeling Hydrological and Environmental Consequences of Climate Change and Urbanization in the Boise River Watershed, Idaho. *Journal of the American Water Resources Association,* 55(1), 133–153. DOI: 10.1111/1752-1688.12712.
Kjelstrom, L.C. (1995a). Streamflow Gains and Losses in the Snake River and Ground-water Budgets for the Snake River Plain, Idaho and Eastern Oregon. USGS Professional Paper 1408-C. DOI: 10.3133/pp1408C
Kjelstrom, L.C. (1995b). Methods to Estimate Annual Mean Spring Discharge to the Snake River Between Milner Dam and King Hill, Idaho. USGS Water-Resources Investigations Report 95-4055. DOI: 10.3133/wri954055
Klos, P.Z., Abatzoglou, J.T., Bean, A., Blades, J., Clark, M.A., Dodd, M., ... and Jansen, V. S. (2015). Indicators of Climate Change in Idaho: An Assessment Framework for Coupling Biophysical Change and Social Perception. *Weather, Climate, and Society*, 7(3), 238-254. DOI: 10.1175/WCAS-D-13-00070.1
Kormos, P.R., Luce, C.H., Wenger, S.J., & Berghuijs, W.R. 2016. Trends and Sensitivities of Low Streamflow Extremes to Discharge Timing and Magnitude in Pacific Northwest Mountain Streams. *Water Resources Research,* 52(7), 4990-5007. DOI: 10.1002/2015WR018125
Lisonbee, J., Woloszyn M., Skumanich., M. 2021. Making Sense of Flash Drought: Definitions, Indicators and Where We Go from Here. *Journal of Applied and Service Climatology*. DOI: 10.46275/JOASC.2021.02.001
Luce, C.H. and Holden, Z.A. 2009. Declining Annual Streamflow Distributions in the Pacific Northwest United States, 1948–2006. *Geophysical Research Letters*, 36(16). DOI: 0.1029/2009GL039407
Mankin, J. S., Viviroli, D., Singh, D., Hoekstra, A.Y., Diffenbaugh, N.S. 2015. The Potential for Snow to Supply Human Water Demand in the Present and Future. *Environmental Research Letters* 10. DOI: 10.1088/1748-9326/10/11/114016.
Marshall, A.M., Abatzoglou, J. T., Link, T. E., Tennant, C.J. 2019. Projected Changes in Interannual Variability of Peak Snowpack Amount and Timing in the Western United States. *Geophysical Research Letters,* 46(15): 8882–92. DOI: 10.1029/2019GL083770.
Musselman, K.N., Lehner, F., Ikeda, K., Clark, M.P., Prein, A.F., Liu, C., ... and Rasmussen, R. (2018). Projected increases and shifts in rain-on-snow flood risk over western North America. *Nature Climate Change*, 8(9), 808-812. DOI: 10.1038/s41558-018-0236-4
Newcombe G., Chorus, I., Falconer I., Lin T.F. 2012. Cyanobacteria: Impacts of Climate Change on Occurrence, Toxicity and Water Quality Management. *Water Research*. 46(5):1347-8. DOI: 10.1016/j.watres.2011.12.047.
Neary, D.G.; Ryan, K.C.; DeBano, L.F., eds. (2005, revised 2008). Wildland Fire in Ecosystems: Effects of Fire on Soils and Water. Gen. Tech. Rep. RMRS-GTR-42-(4), 250. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
O'Neil, J.M, Davis, T.W., Burford, M.A., Gobler, C.J. 2012. The Rise of Harmful Cyanobacteria Blooms: The Potential Roles of Eutrophication and Climate Change. *Harmful Algae,* 14: 313-334. DOI: 10.1016/j.hal.2011.10.027
Peacock, S.M., Christensen, N.I., Bostock, M.G., Audet, P. 2011. High Pore Pressures and

Porosity at 35 Km Depth in the Cascadia Subduction Zone. *Geology*, 39(5): 471–74. DOI: 10.1130/G31649.1.
Qualls, R.J., Taylor, R.G., Hamilton, J., Arogundade, A.B. 2013. Climate Change Opportunities for Idaho's Irrigation Supply and Deliveries. *Journal of Natural Resources Policy Research*. 5(2-3), 91–105. https://doi.org/10.1080/19390459.2013.81185.
Queen L.E., Mote P.W, Rupp, D.E, Chegwidden, O., Nijssen, B. 2021. Ubiquitous Increases in Flood Magnitude in the Columbia River Basin under Climate Change. *Hydrology and Earth System Sciences*, 25(1):257–272. DOI: 10.5194/hess-25-257-2021
River Management Joint Operating Committee (RMJOC-II). (2018). Climate and Hydrology Datasets for RMJOC Long-Term Planning Studies: Second Edition (RMJOC-II), Part I: Hydroclimate Projections and Analyses. https://www.bpa.gov/p/Generation/Hydro/hydro/cc/RMJOC-II-Report-Part-I.pdf, accessed October 2021.
Rupp, D.E., Abatzoglou, J.T., Mote, P.W. 2017. Projections of 21st Century Climate of the Columbia River Basin. *Climate Dynamics,* 49(5–6), 1783–99. DOI: 10.1007/s00382-016-3418-7.
Ryu, J.H. and Kim, J. 2019. A Study on Climate-Driven Flash Flood Risks in the Boise River Watershed, Idaho. *Water (Basel)*, 11(5), 1039. DOI: doi.org/10.3390/w11051039
Silva, V., Pereira, J.L., Campos, I., Jacob Keizer, J., Gonçalves, F., Abrantes, N. 2015. Toxicity Assessment of Aqueous Extracts of Ash from Forest Fires. *CATENA*, 135, 401-408. DOI: 10.1016/j.catena.2014.06.021.
Slaughter, R.A. (2004). Institutional History of the Snake River 1850-2004. Climate Impacts Group. Seattle, WA: University of Washington.
Slaughter, R.A. (2012). Resource Allocation under Stress: The Snake River in Idaho. Climate Impacts Group (CIG), University of Washington, and Idaho Water Resources Research Institute (IWRRI), University of Idaho. A case study of the impact of institutional design on resource allocation and adaptation. IWRRI Report 201203.
SPF Water Engineering. (2016). Treasure Valley DMCI Water-Demand Projections (2015-2065), Accessed 4/1/21: *https://idwr.idaho.gov/wp-content/uploads/sites/2/publications/20160808-OFR-Treasure-Valley-Water-Demand-2015-2065.pdf*
Smith, H.G, Sheridan, G.J., Patrick, Lane N.J., Nyman, P., Shane H. 2011. Wildfire Effects on Water Quality in Forest Catchments: A Review with Implications for Water Supply. *Journal of Hydrology,* 396(1–2), 170-192. DOI: doi.org/10.1016/j.jhydrol.2010.10.043.
Stewart, I.T., Cayan, D.R., Dettinger, M.D. 2005. Changes Toward Earlier Streamflow Timing across Western North America. *Journal of Climate*, 18(8), 1136-1155. DOI: 10.1175/JCLI3321.1
The Surface Water Coalition and Participating Members of the Idaho Ground Water Appropriators (SWC-IGWA). (2015). SWC-IGWA Agreement. https://idwr.idaho.gov/wp-content/uploads/sites/2/legal/swc-igwa-settlement/SWC-IGWA-Settlement-20150630-SWC-IGWA-Settlement-Agreement.pdf, accessed October 2021.
Thompson, E. and K. Humes. (2021). Working Paper. Coupled Water and Energy Use in a Major Irrigated Agricultural Region. (To be submitted to *Journal of the American Water Resources Association*, Nov. 2021).
United States Bureau of Reclamation. (2008). The Effects of Climate Change on the Operation of Boise River Reservoirs, Boise, Idaho. Boise/Payette Water Store Assessment Study.
United States Geological Survey (USGS). (2018). USGS Circular 1441 – Estimated Use of Water in the United States in 2015.
U.S. Global Change Research Program (USGCRP). (2018). Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. DOI: 10.7930/NCA4.2018.