Snow

Chapter 3—Snowfall Impact Study for Spokane, Washington

"In mountain towns across the United States that rely on winter tourism, snow is currency. For snow lovers and the winter sports industry, predictions of a future with warmer winters, reduced snowfall, and shorter snow seasons is inspiring them to innovate, increase their own efforts to address emissions, and speak publicly on the urgent need for action."
—Elizabeth Burakowski, "The Economic Contributions of Winter Sports in a Changing Climate"

Chapter Summary: Examines historical trends in snowfall for the Spokane region, future climate projections and mountain snow forecasts, and determines what this data can tell us about the future of winter recreation at Spokane's five-area ski resorts (Mt. Spokane Ski & Snowboard Park, 49 Degrees North Mountain Resort, Silver Mountain Resort, Schweitzer Mountain Resort, and Lookout Pass Ski Area).

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Key Findings:

1. All five Spokane-area ski resorts (Mt. Spokane Ski & Snowboard Park, 49 Degrees North Mountain Resort, Silver Mountain Resort, Schweitzer Mountain Resort, and Lookout Pass Ski Area) will likely be impacted by rising temperatures.
2. Projected climate changes at Spokane's five ski resorts by the middle of this century include:

- Increases in mean temperatures under both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5)
- An overall decline in snow on the ground (as measured as snow water equivalent)
- A decrease in the total number of winter days below 32 degrees Fahrenheit, potentially hindering opportunities to make snow
- An over-all decline in the snow season with a later start in the fall and an earlier end in spring

3. Taken together these climate changes pose a continuing threat to the vitality of winter sports recreation in the Spokane region.
4. Reducing greenhouse gas emissions—moving from our current path on the high emissions scenario (RCP 8.5) to the lower emissions scenario (RCP 4.5) —could mean the difference between a degraded but viable ski industry (RCP 4.5) and a nonviable ski industry (RCP 8.5) for all five resorts.

Recommended Resiliency Actions:

1. The primary action for lessening the impacts to snow associated with projected higher temperatures in the Spokane region is to reduce greenhouse gas emissions, specifically to move away from the high emissions scenario (RCP 8.5) to the lower emissions scenario (RCP 4.5).
2. As temperatures in the Spokane region continue to rise, Spokane's regional snow-dependent recreation industries—including skiing, snowboarding, snowshoeing, and snowmobiling—need to prepare for snow seasons that start later, are shorter, have less snow, and potentially provide fewer days cold enough to make snow.
3. Winter recreation industries in the Spokane region should consider diversifying their business model, including emphasizing warmer weather recreation activities.

Note from the review editors at the Pacific Northwest Climate Impacts Research Consortium (CIRC):

This document is still in draft form. Please do not cite this document until it is in a completed form.

This document still needs the following:

1. A review by the chapter's authors.
2. A full copyedit.
3. A further fact check. (The review editors of this document have completed a partial fact check that included checking cited numbers and sources, as well as examining the assumptions and methods used by the chapter's authors.)
4. A second fact check should include the following:
    a. An examination of the assumptions related to temperature and snowmaking
    b. A second review of all numbers
    c. A second review of all proper names in the document
5. Document also needs a discussion of the use of historical simulations to be included in the *Analysis* section.
6. Document should include cross references to full report's other sections where relevant.

Climate Data Story—Projected Future Snow at Mt. Spokane Ski & Snowboard Park

Over the course of this century, projected temperature increases and the increasing likelihood that precipitation will fall as rain rather than snow during the cold months of the year is likely to shrink the length of the ski season and lead to economic impacts to the region's five ski resorts: Mt. Spokane Ski & Snowboard Park, 49 Degrees North Mountain Resort, Silver Mountain Resort, Schweitzer Mountain Resort, and Lookout Pass Ski Area.
For the purposes of this summary climate data story, this chapter's authors focus on future climate impacts at one of these five resorts: Mt. Spokane Ski & Snowboard Park (Mt. Spokane).

By the middle of this century (2040–2069) during the prime ski season (December–February), the average mean temperature at Mt. Spokane is expected to rise from a historical (1971–2000) mean of 25.9 degrees Fahrenheit to a best-case-scenario of 30.6°F under the lower emissions scenario (RCP 4.5) or a worst-case-scenario of 31.8°F under the high emissions scenario (RCP 8.5).

The rise in mean temperatures at Mt. Spokane is expected to correspond to a decline in snow at the ski park. Simply put, as temperatures rise, it becomes for more likely that precipitation will fall as rain rather than as snow. This is what our analysis found. To determine how much snow Mt. Spokane might have by mid-century, or team used the variable snow water equivalent (SWE), which is a measure of how much liquid water is available in a given amount of snow on the ground. By mid-century, our analysis found, SWE accumulated on Mt. Spokane by the date January 1st is expected to decline from a historical mean of 10.74″ to 8.81″ under RCP 4.5 and to 7.52″ under RCP 8.5. What's more, if we examine precipitation projections, we can make the reasonable inference that this loss of snow is due to rising temperatures and not declines in precipitation. By mid-century winter (December to February) precipitation at Mt. Spokane is expected to move from a historical mean of 14.59″ to 15.83″ under RCP 4.5 and to 16.00 ″ under RCP 8.5.

During this same mid-century period, the annual number of days below freezing (32°F) at Mt. Spokane is expected to drop from a historical average of 169 days to 127 days under RCP 4.5 and to 111 days under RCP 8.5. In other words, there is expected to be 42–58 fewer freezing days per year at Mt. Spokane by mid-century compared to what was observed during the last three decades of the 20th century. Having freezing days allows us to make the reasonable interference that, by mid-century, Mt. Spokane will see fewer days cold enough for snow to form in the atmosphere and still on the ground. Fewer days below freezing also means fewer days cold enough to make snow with equipment, which generally requires temperatures below freezing, specially 30°F or lower in the 20s and teens Fahrenheit.

Another way to examine the impact to Mt. Spokane is to examine projected changes in the length of snow season—the period during which snow can accumulate on the mountain—by examining the projected calendar dates of the first of day freezing conditions in the fall (*first fall freeze*) and the last day of freezing conditions in the spring (*last spring freeze*). During the last three decades of the 20th century, the first fall freeze day at Mt. Spokane was around October 1st, while the last spring freeze was around May 16th. By middle-century under RCP 4.5, the first fall freeze is projected to be October 12th (11 days later) while the last spring freeze is expected to be April 28th (18 days earlier) By mid-century under RCP 8.5, the dates move still further to Oct 16th (15 days later) in the fall and April 22nd (24 days earlier) in the spring. Though an indirect indication, it is reasonable to infer that the dates of first fall and last spring freeze establish the broadest possible length of the snow season at Mt. Spokane. Projected rising temperatures means that by mid-century, Mt. Spokane's snow season could shrink from 29 (RCP 4.5) to 39 (RCP 8.5) days.

Larger Context: Climate Change and Snow-based Recreation in the Northwest

"Climate change could decrease snow-based recreation revenue by more than 70% annually in the Northwest under a higher scenario (RCP8.5)."
—*Chapter 24:Northwest, Fourth National Climate Assessment*

The projected rise in temperatures throughout this century is expected to lead to more rain and less snow across much of the American Mountain West (**Lute et al. 2015**). The projected loss of mountain snow this century corresponds to an observed trend in the historical data. From 1955 to 2016, declines in snow were found at over 90% of Western snow monitoring sites with records going back 40 years or more (**Mote et al. 2018**). The effects of this loss of snow on the U.S. ski industry are already being felt. From November 1999 to April 2010, the U.S. downhill ski industry lost $1.07 billion in revenue due to low snow years (**Burakowski and Magnusson 2012**). Economic losses are expected to continue as mountain snow levels decline under projected climate changes. According to an analysis published in the *Fourth National Climate Assessment* released in 2018, snow-based recreation in the U.S. Northwest could decrease by as much as 70% annually under the high emissions scenario (RCP 8.5) (***NCA 4: Chapter 24* 2018**).

Local Context: Climate Change and Spokane's Snow-Based Recreation

"Spokane has all the hallmarks of a great ski town: killer shops dedicated to supporting and growing the local ski community (shout out to Brian at the Alpine House), easy access to a wide variety of skiing ranging from mom-and-pop areas to regional destination resorts – all with amazing terrain, and reliably good snow. … Plus, it's a place where whole families can ski religiously and live affordably while mom and dad maintain steady jobs. In my mind that almost makes it better than many of the more glamorous ski towns out there."
—Kevin Luby, former *Skiing Magazine* senior editor and Spokane native

In the U.S. winter season of 2015–2016, snowboarders and skiers added an estimated $20.3 billion to the U.S. economy, spending money at resorts and hotels, as well as restaurants, bars, and grocery stores. In total more than 20 million people downhill-skied, snowboarded, and snowmobiled during this period (**Hagenstad et al. 2018**). For decades, Spokane-area residents have enjoyed easy access to winter snow sports. Winter recreation, including skiing and snowboarding, are an important part of Spokane's identity and a significant source of winter revenue for our region. Spokane has five ski resorts within a two-and-a-half-hour drive from the city: Mt. Spokane Ski & Snowboard Park (Mt. Spokane), 49 Degrees North Mountain Resort (49 Degrees North), Silver Mountain Resort (Silver Mountain), Schweitzer Mountain Resort (Schweitzer Mountain), and Lookout Pass Ski Area (Lookout Pass) In a 2018 story, the *Spokesman-Review* reported that Mt. Spokane alone attracts about 100,000 visitors annually, creating almost $5 million in revenue for the local economy (**Kramer 2018**) or $50 in revenue per visitor.

It is important to note that much of the economic value of snow-based sports is indirect. For instance, nationally during the 2015–2016 snow season, direct spending at ski resorts, local restaurants, and the like, accounted for roughly 41% of winter sports revenues nation-wide, or roughly $4.7 billion. The other 59% of revenues ($6.7 billion) are from indirect spending, including as retail purchases and spending by resort employees (**Hagenstad et al. 2018**).

The economic value of winter snow sports for Spokane's five-area ski resorts is directly related to the number of visitors to the resorts. A 2006 economic analysis conducted by SE Group on behalf of Washington State Parks provides the visitor averages for the years 1996–2006 and is displayed in ***Table 1*** (**SE Group 2007**).

Table 1: Number of Average Annual Visitors to Spokane's Five Ski Resorts (Mt. Spokane, 49 Degrees North, Silver Mountain, Schweitzer Mountain, and Lookout Pass) for the ten-year-period 1996–2006. Source: SE Group 2007.

Resort	Average Annual Visitors over the years 1996–2006
Mt. Spokane	67,747
49 Degrees North	59,866
Silver Mountain	88,246
Schweitzer Mountain	180,285
Lookout Pass	31,677

At all five Spokane-area ski resorts, winter temperatures are expected to increase over the course of this century under both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5), according to our analysis using the Northwest Climate Toolbox. Projected rising temperatures are expect to lead to a decline in total snow levels, a shorter snow season, and fewer days below freezing (hindering opportunities to make snow) at all five Spokane-area ski resorts.

Taken together, a shorter snow season, less snow, and less opportunities to make snow, will likely lead to fewer visitors at all five Spokane-area ski resorts. If the five resorts see fewer visitors, we can expect that this will lead to economic impacts to Spokane's five ski resorts as well as local businesses in Spokane and the surrounding region that rely on indirect spending connected to snow-based recreation.

Analysis—Geography, Data Tools, Inferences & Limitations, Emissions Scenarios, Timeframes, Multi-model Means, and Climate Data Story

Geography:
To investigate the effects of climate change on Spokane's snow recreation, we chose to look at the five large ski resorts within a 2.5-hour drive from Spokane: Mt. Spokane Ski & Snowboard Park (Mt. Spokane), 49 Degrees North Mountain Resort (49 Degrees North), Silver Mountain Resort (Silver Mountain), Schweitzer Mountain Resort (Schweitzer Mountain), and Lookout Pass Ski Area (Lookout Pass).

Data Tools:
Our team started by examining snow depth measurements recorded at Spokane's five resorts and available from the website On the Snow (www.onthesnow.com) for the years 1996–2006. (Note: Schweitzer Mountain is missing data for 2009.) We then proceeded to examine simulated historical snow data as well as projected future snow data for the five resorts by using the following tools in CIRC's Northwest Climate Toolbox:

- The Climate Mapper Tool
- The Future Boxplots Tool
- Historical Climate Tracker

Note On Multi-model Means:
Many of the data and figures that make up this analysis employ the mean resulting from multiple climate models. In general, the Toolbox uses 20 global climate models (GCMs) to create its climate projections (temperature, precipitation, etc.) and 10 GCMs to create its hydrology projections (snow water equivalent, streamflow, etc.). Using a multi-model mean, as opposed to the results of a single model, is accepted as best practice by the climate science community. However, the multi-model mean does not show the full spread of results from all the GCMs used to create a future projection, but rather the average of that multi-model spread. In other words, actual future climate conditions—when we get to them in the decades ahead—might lie either above or below the multi-model mean. Some Toolbox tools, such as the Future Boxplots Tool, show both the multi-model mean as well as the results of all GCMs used in their projections. Other Toolbox tools, such as the Climate Mapper Tool, show only the multi-model mean.

Inferences & Limitations:
The mapping software available as part of each Toolbox tool was used to locate each resort by simply putting in the name of the resort as the location, as opposed to entering precise latitude and longitudes for the base and summit of the five ski resorts. While a more precise effort to pinpoint the exact summit and lodge locations could have been instructive, such an effort would not been likely to have changed the overall trends revealed in each of the tools. The reason has to do with the *resolution* of the data available. Toolbox data has been downscaled to a grid cell resolution of 2.5 miles. This 2.5-mile resolution meant limited the degree of detail our team could obtain. Our team has made a number of inferences throughout our analysis. For instance, because climate scientists have determined that the high temperature/low snow winter of 2014–2015 looks similar to the high temperature/low snow conditions projected for Washington state for the middle of this century (2040-2069) (**Marlier 2017**), we inferred that how Spokane's five ski resorts fared during that winter could tell us something about how they will fare under similar conditions projected for mid-century. In order to form the inferences that we did, our team used multiple *proxies* throughout our analysis in order to make reasonable inferences (see ***Variables*** below).

Emissions Scenarios:
For this analysis, we utilized both the *lower emissions scenario (RCP 4.5)* and the *high emissions scenario (RCP 8.5)* from phase 5 of the Coupled Model Intercomparison Project (Northwest Climate Toolbox 2019*)*. The RCP 8.5 scenario simulates in a computer what is likely to happen if greenhouse gases continue to be released into the atmosphere at their current rate, and, as result, warming is allowed to continue at its current upward trajectory throughout this century and beyond. The RCP 4.5 simulates a dramatic reduction in greenhouse gas emissions, so that while warming continues throughout this century, warming starts to level off after 2100. In general, the two scenarios start to diverge around the middle decades of this century (2040–2069). At mid-century, warming under RCP 4.5 slows while warming under RCP 8.5 continues at its current rate (CIRC 2019). The two scenarios were

used side by side in this analysis to evaluate whether the climate impacts under RCP 4.5 and RCP 8.5 are meaningfully different in their impact on snow recreation in the Spokane region.

Time Frames:
For our analysis, we examined projected future climate for the middle (2040–2069) and the late (2070–2099) decades of this century. We chose to focus our analysis on the middle of this century (2040–2069) because this time horizon seemed soon enough to be meaningful to current policy makers and winter sport enthusiasts. When comparing impacts between the RCP scenarios, we choose to look at the end of this century because the differences between the RCP 4.5 and RCP 8.5 become more extreme by century's end.

Variables:
Our analysis began by examining snow measurements taken in the field at each of the five Spokane-area resorts for the years 2009–2017 and recorded by the site On the Snow. The data for each resort from On the Snow was available at two elevations: at each resort's base and summit. This historical record provided us with the following variables:

- Average Total Annual Snowfall in inches (**On The Snow**)
- Average Annual Snowfall Days (**On The Snow**)
- Average Snow Depth at the Base of each resort (**On The Snow**)
- Average Snow Depth at the Summit of each resort (**On The Snow**)

While our analysis started by using in-the-field measurements of snow taken at each resort, the Toolbox did not provide variables that were directly comparable to those recorded at the five resorts during the historical period (2009-2017). This meant that we had to evaluate snowfall indirectly by using the variables available in the Toolbox as proxies. For instance, we used simulated historical and projected future data for *snow water equivalent* (SWE)—a common metric used to determine the amount of water contained in the amount of snow present on the ground—as a proxy for the amount of snow on the ground. We made the inference that having an adequate amount of snow present on the ground (as represented indirectly as SWE) at Spokane's five resorts translated into the ability to ski and snowboard at those resorts and hence the ability of those resorts to attract visitors. January 1st was chosen because many resorts make as much as a third of their annual revenue before January 1st (**Russell 2015**). We gathered data from the following variables:

- Total January 1st SWE (in inches) (**Future Boxplots Tool**)
- Projected Percent Change in January 1st SWE (**Climate Mapper Tool, Northwest Climate Toolbox**)

The Toolbox also provided us the ability to evaluate indirectly other accepts of snow by utilizing other climate and hydrology information, including:

- The Amount of Precipitation (Total Winter) (Future Boxplots Tool)
- The Length of the Snow Season (The First Fall Freeze and The Last Spring Freeze) (Future Boxplots Tool)
- The Ability of Ski Resort to Make Snow (Mean Winter Temperature, Annual Number of Days Above Freezing) (Future Boxplots Tool)

Climate Data Story:
While our analysis examined all five Spokane-area resorts, our team focused on impacts at Mt. Spokane for our climate data story (see ***Climate Data Story—Mt. Spokane Ski & Snowboard Park*** above). A *climate data story* is defined by CIRC as "a narrative outlining climate facts and impacts specific to your community" **(Mooney 2019)**.

Historical Climate:

Finding: All five Spokane-area ski resorts show responses to the larger climate trends that occurred across the Western United States and the state of Washington in recent years. Specifically, all five resorts appear to have been impacted by the snow drought that occurred during the winter of 2014–2015.

Justification: The historical climate data reported in the figures and tables below only capture a short period of time (2009–2017). They therefore should not be used to draw far-reaching conclusions about larger trends regarding impacts from climate change over longer and projected future periods of time. However, the data for even this brief period does indicate that annual changes in snowfall (***Figure 1***), snowfall days (***Figure 2***), and snow depth (***Figures 3, 4***) appear to have had similar effects across all five Spokane-area ski resorts. What's more, the metrics noted in ***Figures 1–4*** appear to correspond to larger climate trends that occurred across the Northwest United States and the state of Washington in recent years. For instance, what appears to be a clear climate signal can be seen during the winter of 2014–2015 (*2014* in the figures). During the 2014–2015 winter all five Spokane-area resorts saw declines in annual snowfall (***Figure 1***), annual snowfall days (***Figure 2***), and snow depth recorded at the resorts' bases and summits ***Figures 3, 4***) (see ***Table 2***). If we examine the scientific literature we can determine why this was so.

The period October 1st 2014 to September 2015 (the 2015 water year), record low snow levels were recorded at 80% of mountain recording sites across the Western United States. In spring 2015, snow levels in the state of Washington (as measured as April 1st SWE) tied for lowest on record (**Mote et al. 2016**). A closer look at the state of Washington, reveals that snow levels during the winter of 2014-2015 were low enough in both the state's Olympic and Cascade ranges to quality the rages as being in *snow drought*.

According to CIRC, a snow drought occurs "when a region receives a less-than-adequate amount of snow. This can happen when above-normal temperatures force precipitation to fall as rain instead of snow, when not enough precipitation has fallen to create an adequate amount of snow, or through a combination of warm temperatures and low precipitation levels **("Snowpack, Hydrology, & Drought," CIRC 2019)**." According to meteorological data collected at the time, the 2015 snow drought in Washington (**Marlier et al. 2017**) as well as the Western US as a whole (**Mote et al. 2016**) was the result of warm temperatures rather than a lack of precipitation. Precipitation levels during the 2014–2015 winter were at near normal levels for Washington and the Western US. However, temperatures during this period were above average (**Mote et al. 2016**) (**Marlier et al. 2017**). In Washington, the 2014–2015 winter was 3.8 °F warmer on average than winters over the period 1950–2015 **Marlier et al. 2017**). If we examine Mt. Spokane, we can see how 2014–2015 snow drought played out at the local scale.

From January to March 2015, Mt. Spokane saw 12.3 inches of precipitation. This is near the average of 13.0 ″ for the period 1979–2018 (***Figure 5***). However, temperatures during this period were above normal. For instance, mean maximum daily temperatures at Mt. Spokane during January–March 2015 was 41.3 °F compared to an average of 36.0 °F over the same three months for the years 1979–2018 (***Figure 6***).

The abnormally warm temperatures at Mt. Spokane during the winter of 2014–2015 (*2014* in the figures) can be seen reflected in the record low snow numbers recorded at Mt. Spokane during the same period. Annual snowfall and average snow depths at Mt. Spokane's base and summit were all significantly less than average during the winter of 2014–2015 (***Figures 1***,***3***, **4**). For instance, average annual snow accumulated and recorded at Mt. Spokane from 2009 to 2017 was 144 inches, but during the snow drought of 2014–2015, accumulated snow fall recorded on the mountain was just 67″ (***Table 2***). Similarly snow depth at the Mt. Spokane's base averaged 43.2″ from 2009 to 2017, but measured only 17″during the 2014–2015 winter (***Table 2***). This strongly suggests that the high January to March temperatures caused precipitation to fall as rain on the mountain instead as snow. The data also suggest that warm temperatures likely led to snow melting on the ground, leading to the observed reduction in average snow depths.

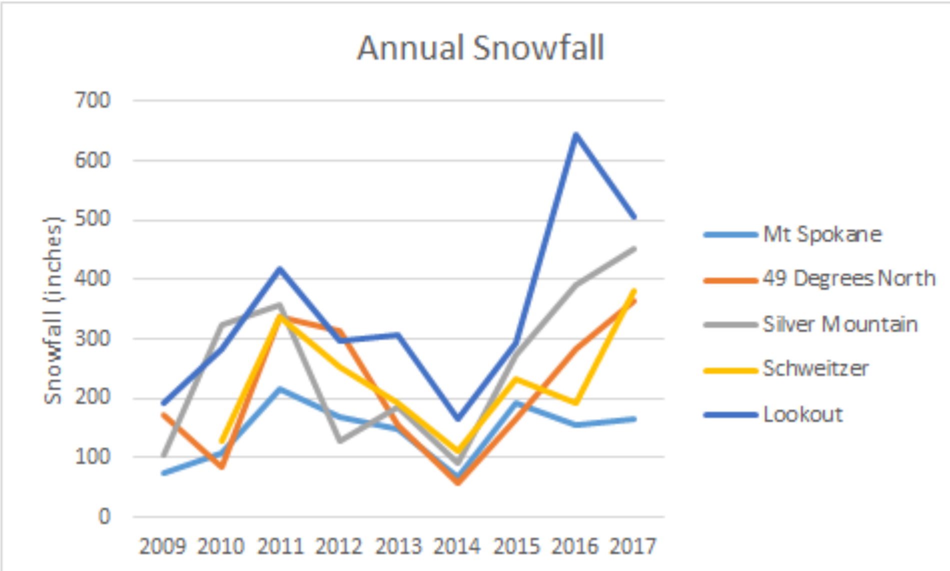

Figure 1:Annual Snowfall, 2009–2017. Average Annual Snowfall in accumulated in inches for the years 2009–2017. Due to the calendar change that occurs over the winter months, the year designation includes both that year and the year that follows it. For instance, 2014 represents the winter that occurred over the calendar years 2014–2015. (Note: Schweitzer Mountain is missing data for the winter 2009–2010.) Source: On the Snow (www.onthesnow.com).

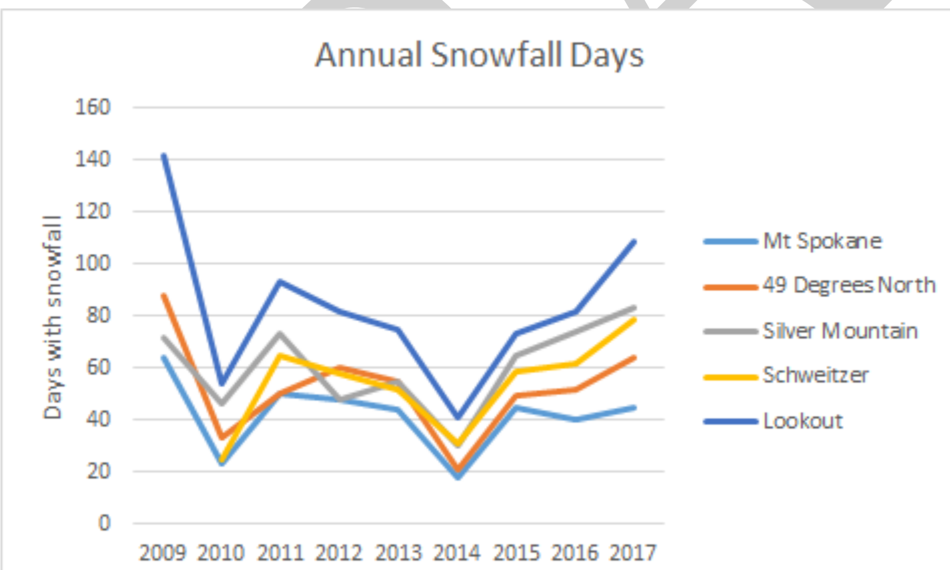

Figure 2: Average Annual Snowfall Days, 2009–2017. Snowfall days are defined as days where snowfall is greater than 1 inch. Due to the calendar change that occurs over the winter months, the year designation includes both that year and the year that follows it. For instance, 2014 represents the winter that occurred over the calendar years 2014–2015. (Note: Schweitzer Mountain is missing data for the winter 2009–2010.) Source: On the Snow (www.onthesnow.com).

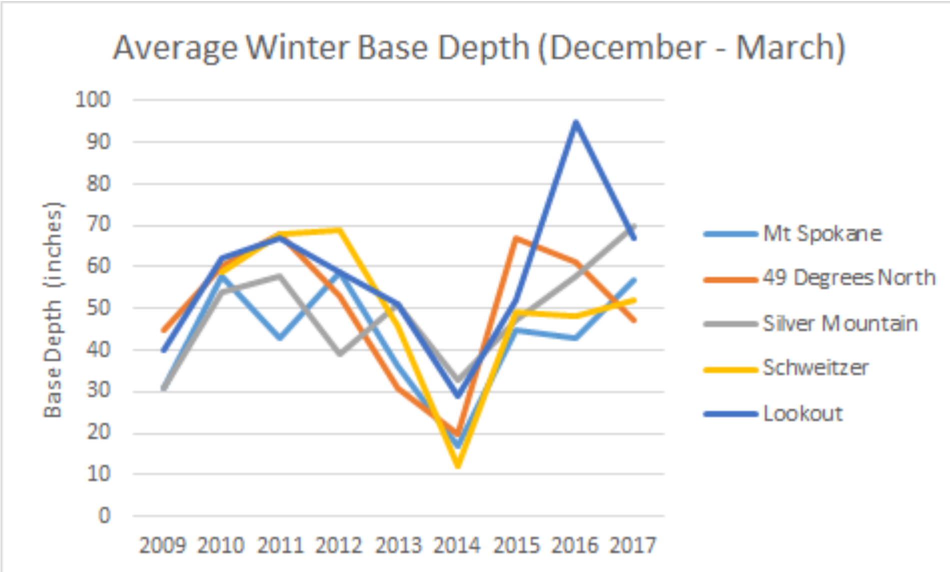

Figure 3: Winter Base Snow Depth, 2009–2017. Average snow depth measured in inches recorded at resort base from December to March. Due to the calendar change that occurs over the winter months, the year designation includes both that year and the year that follows it. For instance, 2014 represents the winter that occurred over the calendar years 2014–2015. (Note: Schweitzer Mountain is missing data for the winter 2009–2010.) Source: On the Snow (www.onthesnow.com).

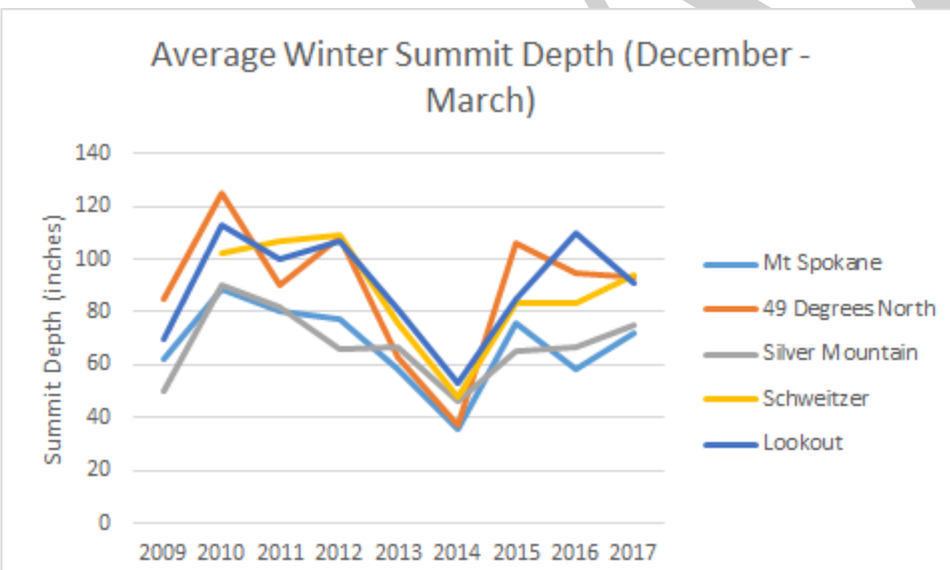

Figure 4: Winter Summit Snow Depth, 2009–2017. Average snow depth measured in inches recorded at the resort summit from December to March. Due to the calendar change that occurs over the winter months, the year designation includes both that year and the year that follows it. For instance, 2014 represents the winter that occurred over the calendar years 2014–2015. (Note: Schweitzer Mountain is missing data for the winter 2009–2010.) Source: On the Snow (www.onthesnow.com).

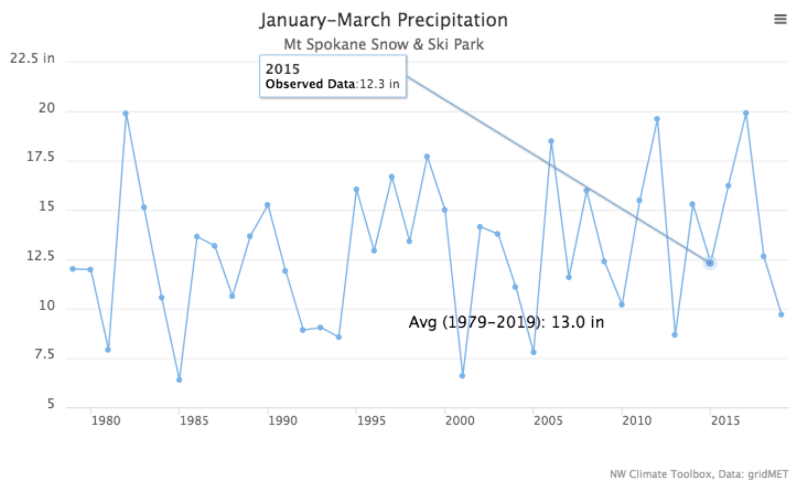

Figure 5: Precipitation for January–March 2015 (simulated historical) at Mt. Spokane and average precipitation at Mt. Spokane for January–March for 1979–2019 (simulated historical). The numbers represent the multi-model mean resulting from 20 climate models. Source: Historical Climate Tracker (https://climatetoolbox.org/tool/Historical-Climate-Tracker), Northwest Climate Toolbox.

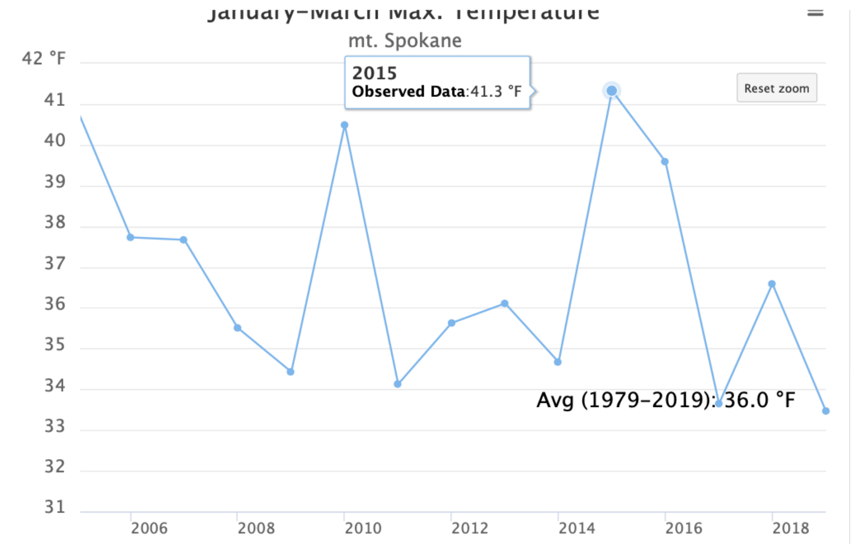

Figure 6: Temperature for January–March 2015 (simulated historical) at Mt. Spokane and average temperature for January–March for the years 1979–2019 (simulated historical). The numbers represent the multi-model mean resulting from 20 climate models. Source: Historical Climate Tracker (https://climatetoolbox.org/tool/Historical-Climate-Tracker), Northwest Climate Toolbox.

Finding: No one of Spokane's five ski resorts is likely to be insulated from future climate changes. Some resorts are likely to fare better than others.

Justification: The available data indicates that all five Spokane-area ski resorts have responded to the climate events of recent years, and that no one resort was insulated from the declines in snow associated with the snow drought of 2014–2015. If we consider the available recorded data related to the 2014–2015 snow drought (***Figures 1-4***) in conjunction with the finding that the recent snow drought looks similar to temperature projections for mid-century (2040–2069) (**Marlier et al. 2017**), we should be able to make the inference that all five resorts are very likely to see less snow under a warming climate. What's more, by comparing the recent snow drought to the snow drought conditions projected for mid-century, we should also be able to infer that how the five resorts fared collectively and individually during the winter of 2014–2015 can give us a sense of how they will fare collectively and individually under similar conditions projected for the winters of 2040–2069.

The data collected point to some variability from resort to resort for observed annual snowfall (***Figure 1***), snowfall days (***Figure 2***), and snow depth (***Figures 3,4***). These variations can likely be attributed to differences in elevation and latitude at the respective resorts, as shown in ***Table 3***. For example, Lookout Pass has the highest base elevation (4,500 ft.) of the 5 resorts and consistently reported the highest snow depths, snowfall, and days with snow for each year (***Figure 1–3***). The ordering of the resorts of snow depths, snowfall, and days with snow during the snow drought in winter 2014–2015 generally follow the elevation differences in the base/summit locations at each resort. If we consider all our findings together, we might then infer three things:

1. Because all five resorts showed clear declines in snow that corresponded with the 2014–2015 winter's abnormally warm temperatures (***Figures 1–4***), all five resorts are therefore likely to see similar declines under the similarly warm temperatures projected for mid-century under RCP 4.5.
2. Likewise, because some of the five resorts clearly fared better than others during the 2014–2015 winter's snow drought, some of the five resorts will likely fare better than others during similar snow drought conditions projected for mid-century under RCP 4.5.
3. We might also reasonably infer that the reason that some of the five resorts fared slightly better during 2014–2015 had to do with difference in elevation and latitude (***Table 3***) at the various resorts, and that because of this, latitude and elevation differences are likely to be key factors in the future success of the five resorts in a warming climate.

Table 2: Observed Historical average number of snow days, average total snowfall (in inches), and average snow depth (in inches) at both the bases and summits of the five Spokane-area ski resorts for the years 2009–2017. Source: On The Snow (www.onthesnow.com).

Resort	Average Total Snowfall Days (days)	Average Total Annual Snowfall (inches)	2014–2015 Total Annual Snowfall (inches)	Average Snow Depth at Base (inches)	2014–2015 Average Snow Depth at Base (inches)	Average Snow Depth at Summit (inches)	2014–2015 Average Snow Depth at Summit (inches)
Mt. Spokane	41.9 days	144″	67″	43.2″	17″	67.6″	36″
49 Degrees North	54.4 days	215″	57″	50.2″	20″	89.1″	37″
Silver Mountain	60.7 days	256.8″	92″	49″	33″	67.6″	46″
Schweitzer Mountain Resort	53.9 days	229″	113″	50.4″	12″	87.8″	48″
Lookout Pass Ski Area	83.4 days	345.4″	167″	58″	29″	90″	53″

Table 3: Geography of Ski Resort Locations. Latitude/Longitudes were assessed from geo-locating the name of the resort using the Google search engine. Source: Google (www.google.com). The elevations of the base and summits for each resort were located from the website on the Snow. Source: On the Snow (www.onthesnow.com).

Resort	Latitude (degrees N)	Longitude (degrees W)	Elevation (Base)	Elevation (Summit)
Mt. Spokane	47.9214 N	117.0964 W	4,200 ft.	5,886 ft.
49 Degrees North	48.3011N	117.5629 W	3,923 ft.	5,774 ft.
Silver Mountain	47.5407N	116.1332W	4,100 ft.	6,300 ft.
Schweitzer Mountain	48.368N	116.6227W	4,000 ft.	6,400 ft.

Lookout Pass	47.456N	115.6973W	4,500 ft.	5,650 ft.

Future Climate Projections

The Northwest Climate Toolbox provides climate and hydrology projections for two emissions scenarios, the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5). The Toolbox uses 20 global climate models (GCMs) to create its climate projections (temperature, precipitation, etc.) and 10 GCMs to create its hydrology projections (snow water equivalent, streamflow, etc.). Data has been downscaled to a 2.5-mile resolution using the Multivariate Adaptive Constructed Analogs (MACA) method with the gridMET training dataset. (**Toolbox 2019**). Hydrologic variables have created using the Variable Infiltration Capacity (VIC) Hydrological Model (**University of Washington 2019**).

Our investigation considered projected future changes in snow water equivalent (SWE), mean temperature, precipitation, days above freezing, first freeze day of the year, and last freeze day of the year for all five ski resorts. Our analysis focused in particular on the difference between the lower emissions (RCP 4.5) and high emissions (RCP 8.5) scenarios at mid-century (2040–2069) and end of century (2070–2099).

Precipitation Projected to Increase/Snow Projected to Decrease

Finding: All five Spokane-area resorts see declines in snow under both emissions scenarios (RCP 4.5 and RCP 8.5).

Key Term: *snow water equivalent*—the amount of water contained in the snow present on the ground. It can be thought of as the depth of water that would theoretically result if you melted the entire snowpack instantaneously.

Justification: As noted in the *Precipitation* chapter of this report, the timing and volume of precipitation in the Spokane region is not expected to change dramatically over the course of this century. The Spokane region is projected to see a slight increase in annual precipitation, a slight decrease in precipitation during the summer months, and a slight increase in precipitation during the fall, winter, and spring months. (It's worth noting, as the authors of the *Precipitation* chapter do, that precipitation projections do not share the same level of confidence as temperature projections do. See ***Precipitation*** chapter.)

For the purposes of our analysis, we looked at precipitation during the height of the winter ski season (December–February) at Mt. Spokane. According to the Toolbox's Future Boxplots Tool, the mean of the 20 climate models used by the Toolbox projects an increase in December–February precipitation at the ski resort by mid-century (2040–2069) from a historical (1971–2000) mean of 14.59″ to 15.83″ under the lower emissions scenario (RCP 4.5) (***Figure*** *7*). However, more precipitation does not mean more snow. As the authors of the precipitation chapter indicated "precipitation should not be considered alone." The projected rise in precipitation corresponds with a projected rise in mean temperature.

By mid-century, the mean temperature at Mt. Spokane is projected to rise from a historical (1971–2000) average of 25.9 °F to 30.6 °F under RCP 4.5 (***Table 5***). As temperatures warm, precipitation becomes far more likely to fall as rain and not as snow and snow on the ground becomes far more likely to melt earlier in the winter season, both of which result in reduced snow on the ground. This is what the Toolbox data projects will occur. My mid-century the amount of snow water equivalent (SWE) on January 1st is projected to decline at Mt. Spokane from a historical mean of 10.74″ to 8.81″ under RCP 4.5 (***Figure 8***) and to 7.52″ under RCP 8.5 (***Figure 9***).

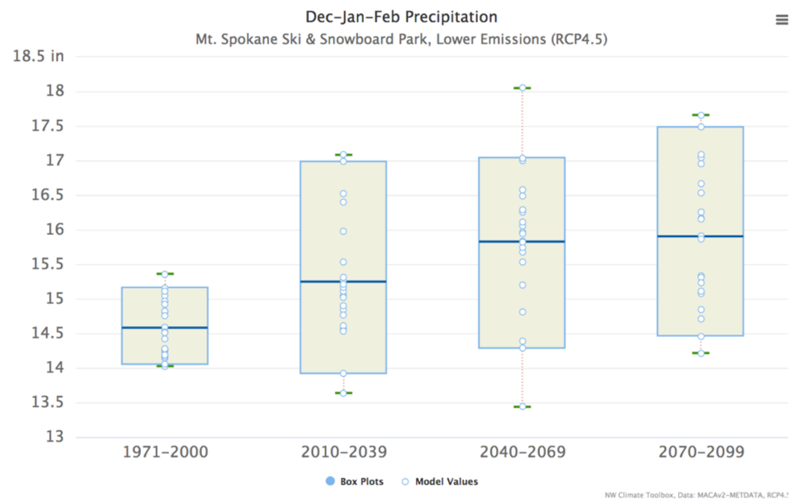

Figure 7: Mean Precipitation at Mt. Spokane for the simulated historical period 1971–2000 and the projected future periods 2010–2039, 2040–2069, and 2070–2099 under the lower emissions scenario (RCP 4.5). The results of each of the 20 models used in the analysis are represented by individual points. The multi-model mean is indicated by a solid bar. Source: Future Boxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots), The Northwest Climate Toolbox.

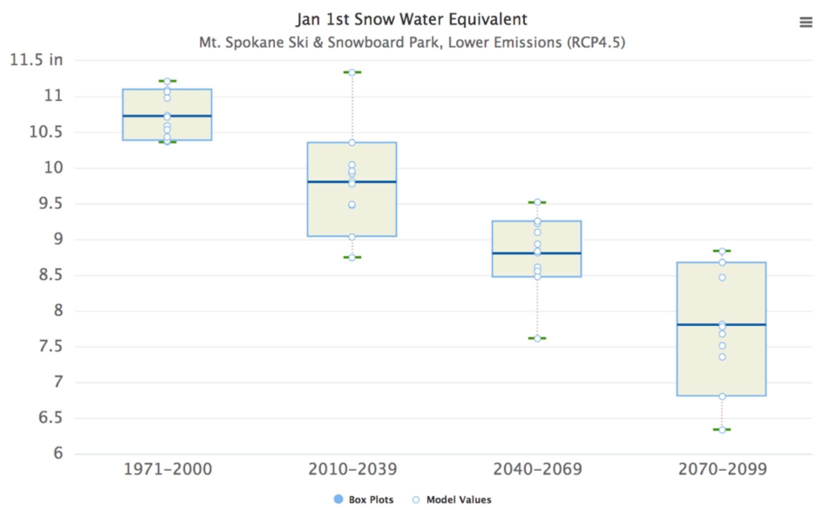

Figure 8: January 1st snow water equivalent at Mt. Spokane for the simulated historical years 1971–2000 and projected future years 2010–2039, 2040–2069, and 2070–2099 under the lower emissions scenario (RCP 4.5). The results of each of the 10 models used in the analysis are represented by individual points. The multi-model mean is indicated by a solid bar. . Source: Future Boxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots), The Northwest Climate Toolbox.

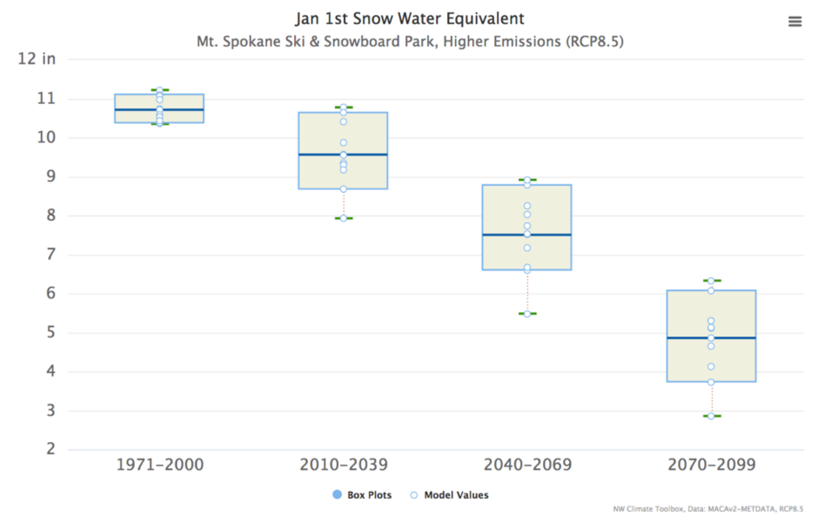

Figure 9: January 1st snow water equivalent at Mt. Spokane for simulated historical years 1971–2000 and projected future years 2010–2039, 2040–2069, and 2070–2099 under the high emissions scenario (RCP 8.5) The results of each of the 10 models used in the analysis are represented by individual points. The multi-model mean is indicated by a solid bar. Source Future Bloxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots), the Northwest Climate Toolbox.

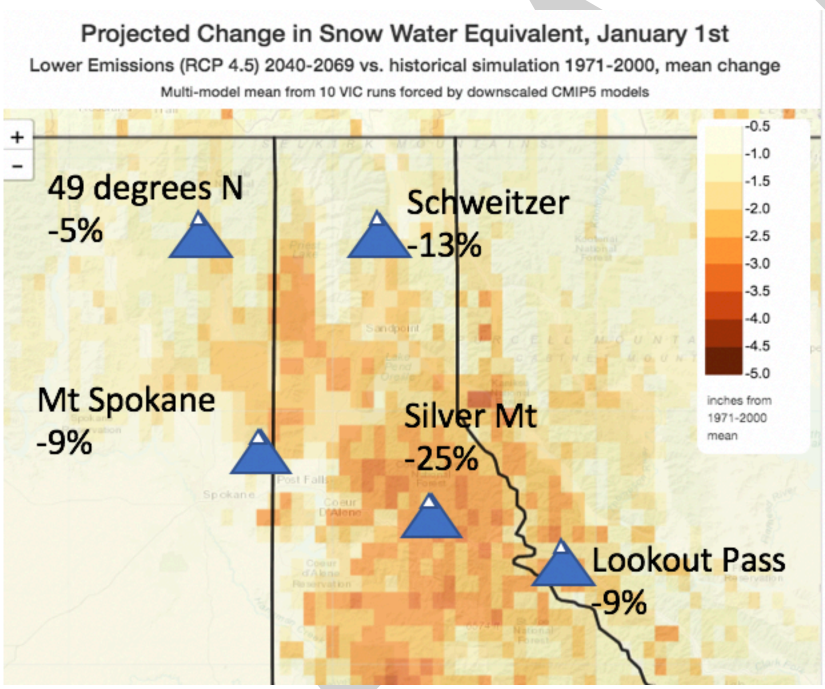

Figure 10: Projected future January 1st snow water equivalent (SWE) measured in inches and percent change from simulated historical (1971–2000) for all five Spokane-area ski resorts for the middle of this century (2040–2069) under the lower emissions scenario (RCP 4.5). The percent change shown here represent the multi-model mean resulting from 10 climate models. Source: The Climate Mapper Tool (https://climatetoolbox.org/tool/Climate-Mapper),Northwest Climate Toolbox.

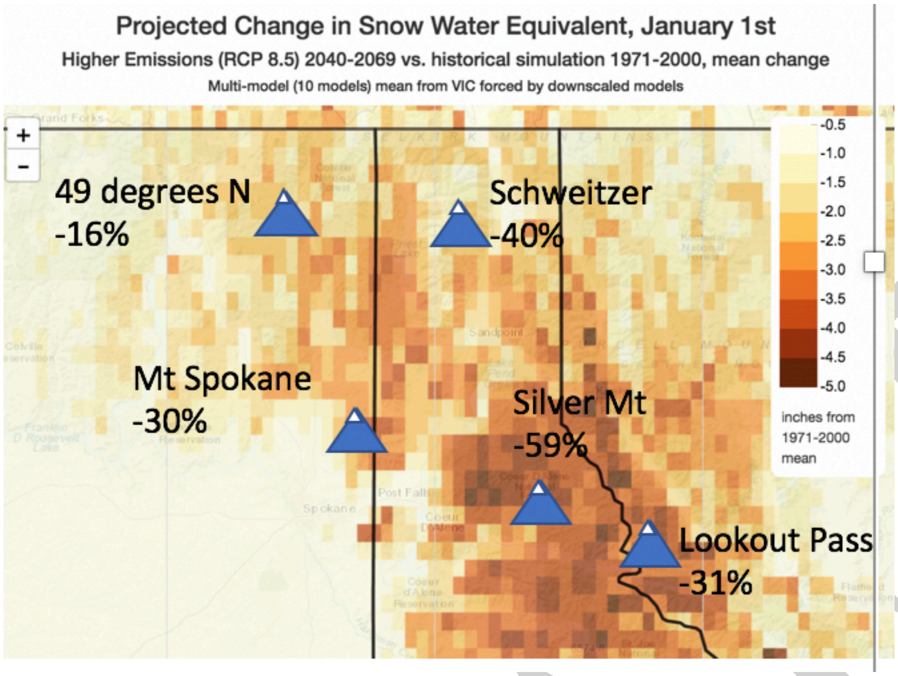

Figure 11: Projected future January 1st snow water equivalent (SWE) measured in inches and percentage change from the simulated historical (1971–2000) for all five Spokane-area ski resorts for the middle of this century (2040–2069) under the high emissions scenario (RCP 8.5). The percent change shown here represent the multi-model mean resulting from 10 climate models. Source: The Climate Mapper Tool (https://climatetoolbox.org/tool/Climate-Mapper),The Northwest Climate Toolbox.

Finding: The difference between the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5) could mean the difference between a degraded but viable ski industry (RCP 4.5) and a nonviable ski industry (RCP 8.5) for all five Spokane-area resorts.

Justification: January 1st SWE projections for mid-century (2040–2069) at all five Spokane-area resorts tell a similar story. By mid-century, declines in January 1st SWE occur at all five resorts under both the lower emissions scenario (RCP 4.5) (***Figure 10***) and the high emissions scenario (RCP 8.5) (***Figure 11***). In all cases, the projected declines in SWE are notably different between RCP 4.5 and RCP 8.5 (see ***Table 4***). To take just one example, Mt. Spokane is projected to see a decline of 9% under RCP 4.5 and a decline of 30% under RCP 8.5. Things are more dramatic if we consider Silver Mountain, which sees a decline of 25% under RCP 4.5 and a decline of 59% under RCP 8.5). In other words, by mid-century the difference between lower emissions scenario (RCP 4.5) and the higher emissions scenario (RCP 8.5) could mean the difference between a degraded but viable ski season (RCP 4.5) and a nonviable ski industry (RCP 8.5) for all five resorts.

Table 4:Projected future January 1st snow water equivalent (SWE) at all five Spokane-area resorts expressed as percentage from the historical period 1971–2000 for the years 2040–2069 under both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5) Source: The Climate Mapper Tool (https://climatetoolbox.org/tool/Climate-Mapper), The Northwest Climate Toolbox.

Resort	RCP 4.5 2040–2069 Project Future January 1st Snow Water Equivalent (SWE) Percent Change (%)	RCP 8.5 2040–2069 Projected Future January 1st Snow Water Equivalent (SWE) Percent Change (%)
Mt. Spokane	-9%	-30%
49 Degrees North	–5%	-16%
Silver Mountain	-25%	- 59%
Schweitzer Mountain	-13%	-40%
Lookout Pass	-9%	-31%

Rise in Mean Temperature and Fewer Freezing Days = Less Snow and Less Ability to Make Snow

Finding: By mid-century (2040–2069), mean winter (December–February) temperatures at Mt. Spokane are projected to rise from a historical mean of 25.9°F to 30.6°F under the lower emissions scenario (RCP 4.5) and 31.8°F under the high emissions scenario (RCP 8.5).

Justification: If our future projections call for less snow (as expressed as declines in SWE), the next logical question becomes, *can a resort make snow with snowmaking equipment?* Standard snowmaking equipment require temperatures below 30°F, ideally in the 20s or teens (**Wobus et al. 2017**). Working from this knowledge, our team addressed the question of snowmaking by analyzing mean temperature (***Table 5***) and days above freezing (***Table 6***). Using these two variables allowed our team to make reasonable inferences regarding when it might be possible for a resort to make snow artificially.

By mid-century (2040–2069), the mean temperature during the prime ski season (December–February) at all five Spokane-area ski resorts is projected to rise under both the lower (RCP 4.5) and high emissions scenario (RCP 8.5). At Mt. Spokane, the mean temperature is expected to rise from a historical mean of 25.9°F to 30.6°F under RCP 4.5 and 31.8°F RCP 8.5. By the end of this century (2070–2099), the difference between the two scenarios becomes more notable with 31.5 °F projected for RCP 4.5 and 35.4 °F for RCP 8.5. What was true of Mt. Spokane was true for all five resorts. All five resorts see more warming under RCP 8.5 than they do under RCP 4.5 (***Table 5***).

Due to increased temperatures, it is likely to be increasingly difficult to make snow for much of the season, even if the resort goes to the time and expense of installing the infrastructure to do so.

Table 5: Simulated historical mean winter (December–February) temperature at all five Spokane-area ski resorts for the years 1971–2000; and projected future mean temperature at all five Spokane-area ski resorts for both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5) for the years 2040–2069 and 2070–2099. Source: Future Boxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots), the Northwest Climate Toolbox.

Resort	1971-2000 Simulated Historical December–February Mean Temperature Degrees Fahrenheit (°F)	RCP 4.5 2040–2069 Projected Future December–February Mean Temperature (°F)	RCP 8.5 2040-2069 Projected Future (RCP 8.5) December–February Mean Temperature (°F)	RCP 4.5 2070–2099 Projected Future December–February Mean Temperature (°F)	RCP 8.5 2070–2099 Projected Future December–February Mean Temperature (°F)
Mt. Spokane	25.9 °F	30.6 °F	31.8 °F	31.5°F	35.4°F
49 Degrees North	23.8 °F	28.5°F	29.7°F	29.5°F	33.4°F
Silver Mountain	28.2 °F	32.9°F	34.1 °F	33.8 °F	37.6°F
Schweitzer Mountain	24.9 °F	29.6°F	30.8°F	30.5°F	34.5 °F
Lookout Pass	24.4 °F	20.0 °F	30.2°F	30.0 °F	33.9 °F

Finding: Mt. Spokane is projected to see 41 to 58 fewer freezing days by the mid-21 century (2040–2069), compared to the last third of the twentieth century (1971–2000).

Justification: Another way to examine the warming data is to examine days above freezing, here represented using the Toolbox variable *Days with a Minimum Temperature Above to 32°F* (***Table 6***). All five Spokane-area ski resorts are projected to see an increase in the number of days above freezing under both scenarios when compared to the historical average. Consider just Mt. Spokane, which has projections for an increase in the number of days above freezing from a historical (1971–2000) mean of 196 days to 238 days by mid-century (2040–2069) under the lower emissions scenario (RCP 4.5) and 251 days by mid-century under the high emissions scenario (RCP 8.5). For further illustration these numbers can be seen in ***Figure 10*** (RCP 4.5) and ***Figure 11*** **(**RCP 8.5**)**. These numbers can be inverted (assuming a 365-day year) to infer projections of the number of days below freezing at Mt. Spokane from a historical average of 169 days a year to 127 days under RCP 4.5 and 111 freezing days under RCP 8.5. In other words, Mt. Spokane is projected to see 42 (RCP 4.5) to 58 (RCP 8.5) fewer freezing days by the mid-21 century compared to 1971–2000.

Table 6: Simulated historical number of days annually above 32°F or the years 1971–2000 and projected future number of days annually above 32°F all five Spokane-area ski resorts for both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5) for the years 2040–2069 and 2070–2099. Source: Future Boxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots), the Northwest Climate Toolbox.

Resort	1971–2000 Simulated Historical Number of days with Min Temp above 32 °F (days)	RCP 4.5 2040–2069 Projected Number of Future Days with Min Temp above 32 °F (days)	RCP 8.5 2040–2069 Projected Number of Future Days with Min Temp above 32 °F (days)	RCP 4.5 2070–2099 Projected Number of Future Days with Min Temp above 32 °F (days)	RCP 8.5 2070–2099 Projected Number of Future Days with Min Temp above 32 °F (days)
Mt. Spokane	196 days	238 days	254 days	251 days	293 days
49 Degrees North	166 days	201 days	247 days	213 days	255 days
Silver Mountain	204 days	257 days	273 days	270 days	308 days
Schweitzer Mountain	182 days	261 days	278 days	238 days	282 days
Lookout Pass	185 days	227 days	242 days	240 days	282 days

The projected rise in temperatures, as illustrated by both a rise in mean temperature and an increase in the number of days above freezing/fewer days below freezing, suggests that there will be fewer days in the future cold enough during the winter months to make snow with equipment and more days when snow is melting at Mt. Spokane and the other four Spokane-area resorts. It is reasonable to assume that this could significantly impact local businesses.

Note—On Making Snow: To have more control over the start of the season, ski resorts in the Spokane region are increasingly finding it necessary to purchase costly snowmaking equipment. According to reporting by the *Spokesman-Review* in 2015, a feasibility study commissioned by the Bogus Basin ski resort in southern Idaho concluded the resort would need "extensive snowmaking to be a sustainable business" **(Russell 2015)**. Snowmaking equipment has already been deployed on runs at Schweitzer Mountain, Silver Mountain, and 49 Degrees North (**Russell 2015**). As of October 2019 both Mt. Spokane (**Copeland 2019**) and Lookout Pass (**Sawyer 2019**) do not use snowmaking equipment in their operations. Advances in snowmaking technology have brought down prices, but the systems still cost millions of dollars. For instance, at the time of the reporting, Bogus Basin official estimated the "first phase of its snowmaking system" would cost $4 million to install **(Russell 2015)**. Projected changes in temperature could create conditions where, even with expensive snow making equipment, it may not be possible to create snow, especially early in the season.

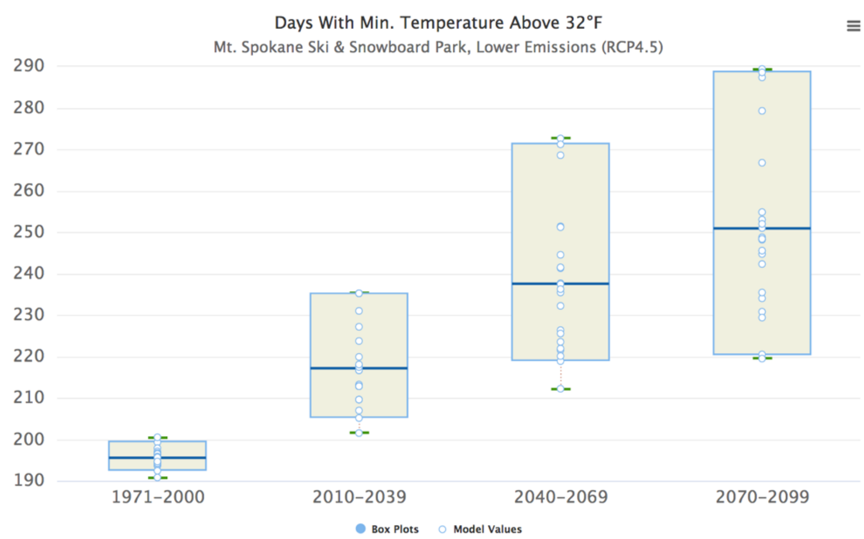

Figure12: Number of days above freezing at Mt. Spokane simulated for historical years 1971–2000 and projected future years 2010–2039, 2040–2069, and 2070–2099 under the lower emissions scenario (RCP 4.5). The results of each of the 20 models used in the analysis are represented by individual points. The multi-model mean is indicated by a solid bar. Source: Future Boxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots), Northwest Climate Toolbox.

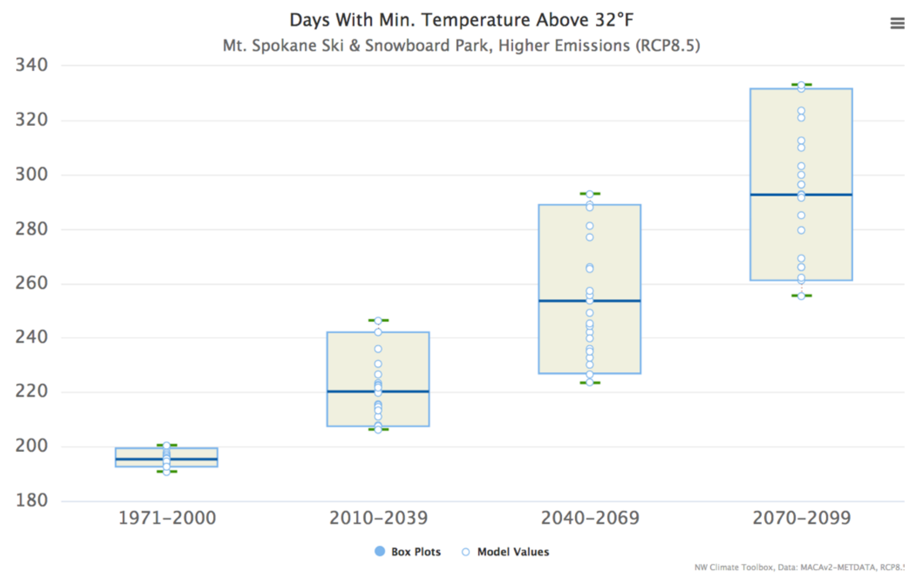

Figure 13: Number of days above freezing at Mt. Spokane simulated for historical years 1971–2000 and projected future years 2010–2039, 2040–2069, and 2070–2099 under the high emissions scenario (RCP 8.5). The results of each of the 20 models used in the analysis are represented by individual points. The multi-model mean is indicated by a solid bar. The results of each of the 20 models used in the analysis are represented by individual points. The multi-model mean is indicated by a solid bar. Source: Future Boxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots), Northwest Climate Toolbox.

Shorter Snow Season (First and Last Freeze of Winter)

Finding: Within a few decades, Spokane's snow season could be a month shorter.

Justification: Another way to look at climate impacts on winter recreation at Mt. Spokane and the area's other four resorts is to examine projected changes in the length of the *snow season*, the period during which snow can accumulate on the mountain. We can examine the projected length of the snow season by examining data related to the date of first freeze of the snow season in the fall (*first fall freeze*) and the date of the last freeze of the snow season in the spring (*last spring freeze*). This was done to gain an overall picture of the start and end of the snow recreation season. The start of the season is especially important for area ski resorts as many resorts make as much as a third of their annual revenue before January 1st (**Russell 2015).**

During the last third of the twentieth century (1971–2000), the date of the first fall freeze at Mt. Spokane was around October 1st (the 274th day of the year) while the date of the last spring freeze was around May 16th (136th day of the year). (See ***Table 6***.) By mid-century (2040–2069) under the lower emissions scenario (RCP 4.5), the first fall freeze at Mt. Spokane is projected to be October 12th . Under the high emissions scenario the date of the first fall freeze moves to October 16th. This is 11-to-15 days later, under RCP 4.5 and RCP 8.5 respectively. During the same mid-century timeframe, the last spring freeze is projected to be 18 (RCP 4.5) to 24 (RCP 8.5) days earlier (***Table* 7**). Though an indirect indication, it is reasonable to infer that the dates of first and last freeze establish the broadest possible length of the snow season. If we take the first fall freeze and last spring freeze data together, by the middle of this century, the Spokane-area snow season could shrink 29 (RCP 4.5) to 38 (RCP 8.5) days. In other words, within just a few decades, Mt. Spokane's snow season could be a month (or more) shorter than it was during the last three decades of the 20th century. However, a *snow* season and a *ski* season are not the same thing. Ski seasons generally begin when enough snow (to ski and snowboard on) has accumulated on the ground at area ski resorts. A shorter snow season means less time for snow to accumulate. Whether less time for snow to accumulate at the Spokane-s five ski resorts translates directly into a shorter ski seasons at those resorts is uncertain.

Table 7: Simulated historical and projected future January 1st Snow Water Equivalent (SWE); mean winter (December–February) temperature, mean precipitation (in inches); annual number of days above freezing (32°F); first fall freeze (as number of days before January 1st and the calendar date); and the last spring freeze (as number of days after January 1st and the calendar date) at Mt. Spokane the simulated historical period 1971–2000, and projected future years 2010–2039, 2040–2069, and 2070–2099 for both emissions scenarios (RCP 4.5 and RCP 8.5). Source: Future Boxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots), Northwest Climate Toolbox.

Time Period	**Jan 1 SWE (inches)**	**Winter (Dec–Feb) mean temp (F)**	**Winter (Dec–Feb) Precipitation (inches)**	**First Fall Freeze As Number of Day days after Jan 1st and Calendar Date**	**Last Spring Freeze as number of |Days after Jan 1st and Calendar Date**
1971–2000	10.74″	25.9°F	14.59″	274 days Oct. 1st	136 days May 16th
RCP 4.5 2010–2039	9.81″	28.3°F	15.3″	279 days Oct. 6th	128 days May 8th
RCP 4.5 2040–-2069	8.81″	30.6°F	15.8″	285 days Oct. 12th	118 days Apr. 28th
RCP 4.5 2070–2099	7.81″	31.5°F	15.9″	278 days Oct. 5th	111 days Apr. 21st

RCP 8.5 2010–2039	9.57″	29°F	15.3″	282 days Oct. 9th	127 days May 7th
RCP 8.5 2040–2069	7.52″	31.8°F	16″	289 days Oct. 16th	112 days Apr. 22nd

Conclusion: Snow Sports—Later, Shorter Snow Seasons with Less Snow

"Future risks from climate change depend primarily on decisions made today." —Fourth National Climate Assessment, 2018

Higher mean temperatures, less snow and more rain, a later start to winter and an earlier arrival of spring, will require significant planning on the part of the winter recreation industries in the Spokane-region. It would be wise for Spokane's ski resorts to begin to diversify their business models to emphasize warmer weather recreation activities. In the next 30–60 years, it would also be prudent for resorts to reconsider expanding operations and especially costly investments in snowmaking equipment that may not be viable later in the century.

It is no exaggeration to say that the future of winter recreation as we know it depends on whether emissions continue at their current trends, whether we move from our current path on the emission emissions scenario (RCP 8.5) or move to the lower emissions scenario (RCP 4.5). This would suggest that ski industries, skiers, snowboarders, and others who enjoy winter recreation should be very motivated to help ensure that the systemic societal transformations necessary to achieve a future closer to the lower emission scenario (RCP 4.5) are realized.

The "business-as-usual" high emission scenario (RCP 8.5) is possible, but not inevitable. The negative outcomes of human-caused climate change can be mitigated by swift and significant reductions in greenhouse gas emissions. Individual choices, business practices and government policy are all necessary components of an effective strategy to prevent the worst possible climate impacts scenarios. Many solutions to prevent dangerous climate conditions are currently available, but these solutions require ongoing commitment, financial support, and political will to ensure effective implementation.

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