National Park Service
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Natural Resource Stewardship and Science

A Park Interpreter's Guide to the Climate of Hurricane Ridge, Olympic National Park

Climate Summary for Water Years 2000 to 2017

Natural Resource Report NPS/NCCN/NRR—2018/1714

ON THIS PAGE
Background: Waterhole SNOTEL on Hurricane Ridge, Olympic National Park
NPS photo by John Warrick

Foreground: Olympic National Park ranger Jack Hughes measures snow water equivalent at the Cox Valley Snow Course, 1984. Ranger Hughes conducted his first snow survey on February 1, 1966 at Deer Park Campground and conducted his last official survey on May 1, 2010 at Cox Valley.
NPS photo by Janis Burger

ON THE COVER
Snow covered subalpine firs on Hurricane Ridge, Olympic National Park
NPS photo by William Baccus

A Park Interpreter’s Guide to the Climate of Hurricane Ridge, Olympic National Park

Climate Summary for Water Years 2000 to 2017

Natural Resource Report NPS/NCCN/NRR—2018/1714

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

This report is available in digital format from the North Coast and Cascades Network Inventory and Monitoring website and the Natural Resource Publications Management website. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

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Abstract

The aptly named Hurricane Ridge is a steep dividing barrier which separates the interior Olympic Mountains from the Strait of Juan de Fuca and Puget Sound Lowlands. Rising from sea level to 6,000 feet in only 10 miles distance, Hurricane Ridge routinely experiences high winds and abundant snow and cold rain from fall through late spring. Climate and weather events define the ecological characteristics found in this area and are key to understanding the area’s natural resources and managing park operations and infrastructure. Hurricane Ridge is the single most popular destination in Olympic National Park and is the only high elevation destination accessed by a paved road. This report summarizes weather data collected by the North Coast and Cascades Network Climate Monitoring Program at Hurricane Ridge, within Olympic National Park between the years 2000 and 2017. Snowpack, precipitation and air temperature summaries are derived from continuous data collected at the Waterhole SNOTEL site, operated in cooperation with the USDA Natural Resources Conservation Service since 1999 (18 year record). A longer term trend in snowpack is presented, based on monthly manual snow course measurements at the Cox Valley Snow Course. Wind summaries are derived from a Northwest Avalanche Center automated weather station, which has been operated since 2003 (14 year record).

Introduction

Hurricane Ridge is a year-round tourist destination, the single most popular in Olympic National Park (Ormer, et.al. 2001), with over half a million visitors in 2017 (NPS 2017). Offering expansive views of the Olympic Mountains from its ridgetop location, Hurricane Ridge is the only high elevation destination in the park accessed by a paved road. The Ridge has a large visitor center with interpretive programs, concessions operation, picnic areas, and is the starting point to many high-elevation hiking trails. During winter months, Hurricane Ridge is popular with downhill and backcountry skiers, snowshoers and snow boarders.

Hurricane Ridge is an aptly given name for the steep dividing ridge which separates the interior Olympic Mountains from the Strait of Juan de Fuca and Puget Sound Lowlands. It presents the final high elevation barrier for weather systems colliding with the Olympic mountain range before the air masses plummet downward, warming and drying as they go. High winds, heavy snow and abundant rain are typical for this area in most seasons. Understandably, climate and weather events define the ecological characteristics found in this area and are key to understanding and interpreting the area’s natural resources. Park operations including fire management, search and rescue, road plowing, and visitor use and safety, including operation of the Hurricane Winter Use area, are strongly influenced by weather. Interpretive programs at Hurricane Ridge often include weather and its effects on park ecosystems.

As part of the North Coast and Cascades Network (NCCN) Inventory and Monitoring Program, weather data are collected in support of park operations and for understanding the ecology of the Park (Lofgren et al. 2010). The purpose of this publication is to provide park interpreters and resource managers, and the public, with a set of summarized climate information for Hurricane Ridge that is readily accessible.

I summarized weather data from two automated weather stations and a manual snow course. Snowpack, precipitation and air temperature summaries are derived from the Waterhole SNOTEL site, operated in cooperation with the USDA Natural Resources Conservation Service. This SNOTEL site was installed in September of 1999 and currently has an 18 year record. At an elevation of 5010 feet, the Waterhole SNOTEL is located 4 miles east of the Hurricane Ridge Visitor Center at a low point in the ridge extending toward Obstruction Point. It is in a small meadow surrounded by subalpine firs, at the site of the old Waterhole Campground (Figure 1).

A longer term trend in snowpack is provided using monthly snow course data collected by NCCN staff. For this report, I relied on data from the Cox Valley Snow Course which correlates well with the Waterhole SNOTEL. The snow course site is in a protected, north-facing basin about a half mile below the Hurricane Ridge Road at an elevation of 4500 feet (Figure 1). Monthly winter snowpack measurements have been taken there since 1968.

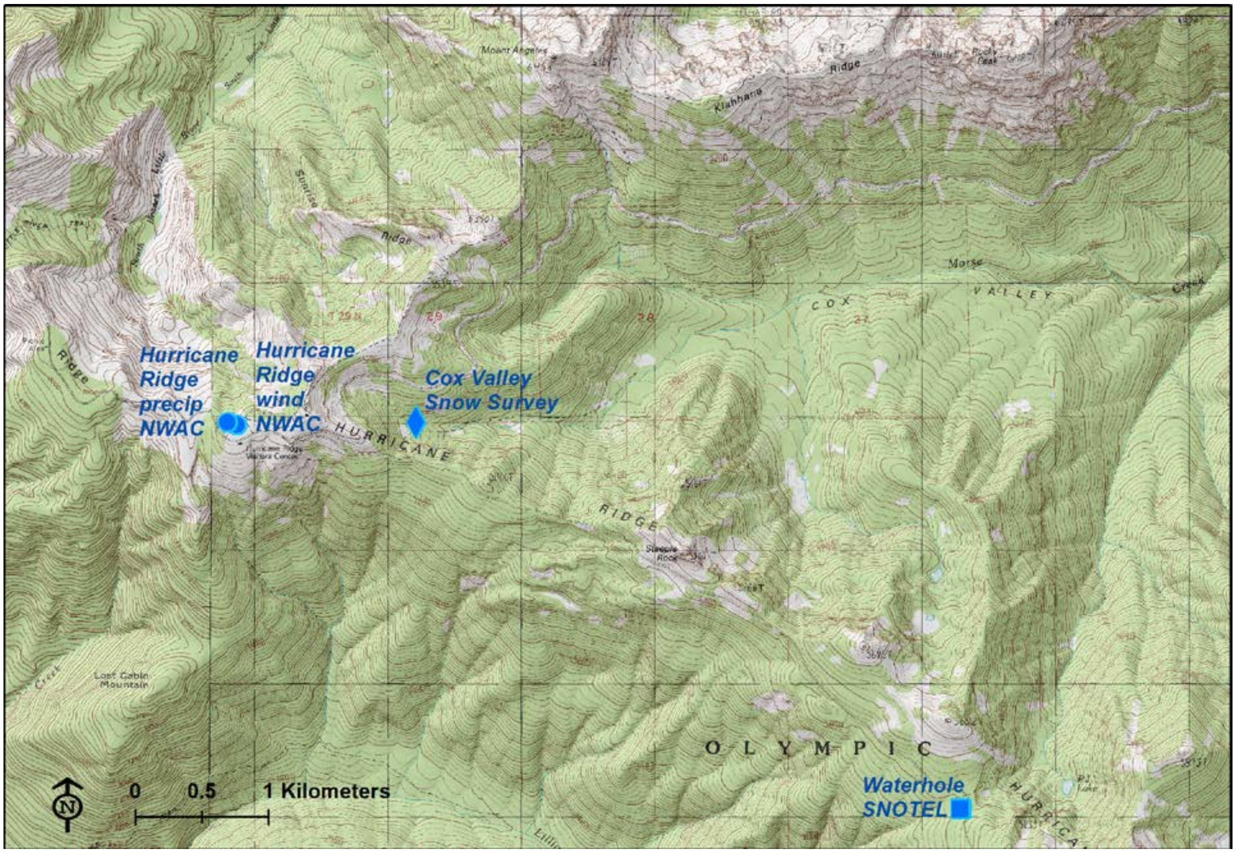

Figure 1. Location of weather stations and snow courses near Hurricane Ridge, Olympic National Park.

I derived wind summaries from a weather station cooperatively operated with the Northwest Avalanche Center. The station is located just north of the Hurricane Ridge Visitor Center, at an elevation of 5260 feet. Wind data have been collected at this site since 2003 (14 year record). Even though this station also collects temperature, precipitation (with a heated tipping bucket) and snow depth measurements, these data were not used in the report due to the short data record and the station's originally substandard location for precipitation measurements, on a ridge exposed to wind and snow drifting. In 2008, precipitation and air temperature instruments were moved to a more suitable nearby location.

Terminology used in this report and methods used to collect weather parameters and to analyze and summarize climate data are described in Appendix A. The remainder of this report is a set of climate summaries organized by the following: Snowpack, Precipitation, Air Temperature, and Winds Speed. I organized data in this report based on a water year (or hydrologic year) rather than a calendar year because a water year—October 1 to September 30—encompasses a full cycle of precipitation accumulation and snow melt in the Pacific Northwest.

Hurricane Ridge Climate Summaries

Snowpack

The following snowpack statistics were compiled from the Waterhole SNOTEL:

- Average maximum depth of snowpack: 104” (8.7’)
- Deepest maximum depth of snowpack[1]: 156” (13.0’), Water Year 2012 (Figure 2)
- Shallowest maximum depth of snowpack: 25” (2.1’), Water Year 2015 (Figure 2)

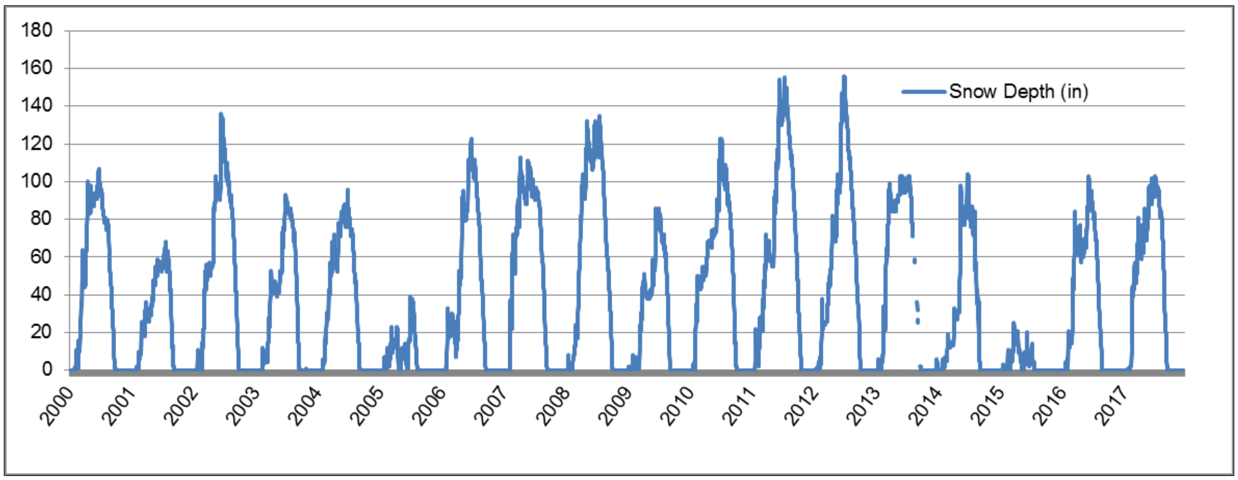

Figure 2. Daily depth of snowpack at Waterhole SNOTEL, Water Years 2000 to 2017.

- Average date of snow melt-out (Waterhole SNOTEL): June 19
- Earliest melt-out: May 2, 2015
- Latest melt-out: July 25, 2011
- Average estimated annual snowfall: 32’
- Highest estimated annual snowfall: 47’, Water Year 2011 (see Figure 3)

[1] The Waterhole SNOTEL was installed one year after the record snowfall of Water Year 1999, when nearby Mount Baker set the world record for snowfall. In that year, the 15ft. tall Hurricane Ridge snow stake, despite being extended several times, ended up buried. The last measurement was 227 inches on February 21, 1999.

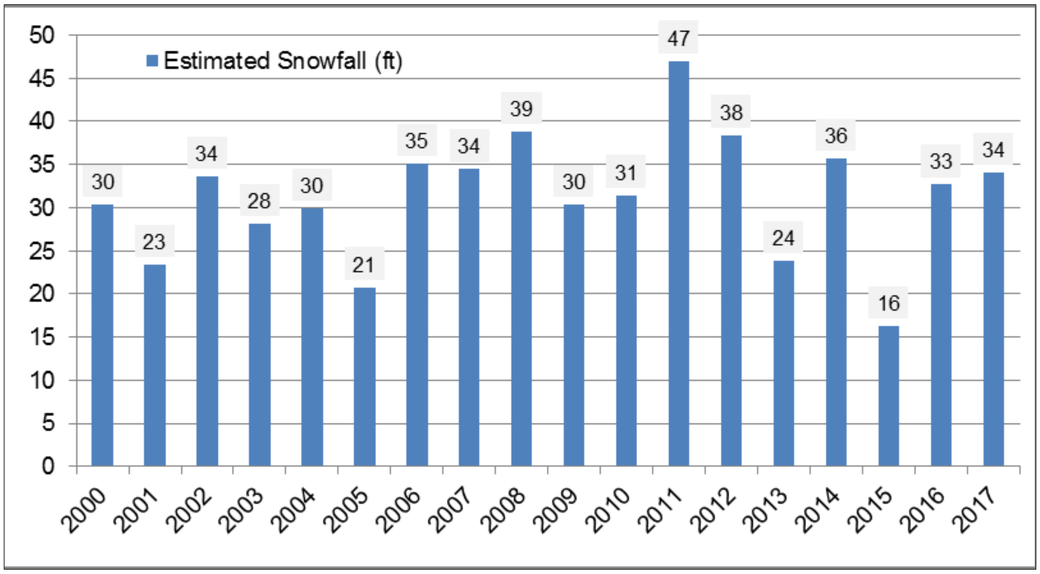

Figure 3. Estimated annual snowfall at the Waterhole SNOTEL, Water Years 2000 to 2017.

- Months with the highest snowfall: December, March, November, January and February (in decreasing order) (see Figure 4)

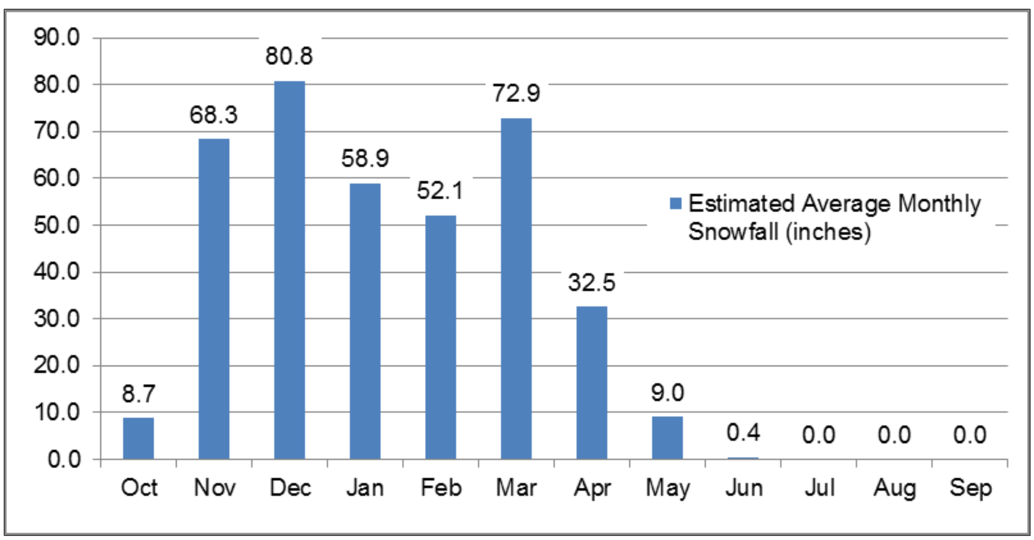

Figure 4. Estimated average monthly snowfall at the Waterhole SNOTEL, Water Years 2000 to 2017.

- Average maximum snow water equivalent of snowpack: 41.3”
- Deepest maximum snow water equivalent of snowpack: 65.9”, Water Year 2011 (Figure 5)
- Shallowest maximum snow water equivalent of snowpack: 7.4”, Water Year 2015 (Figure 5)
- Average date of maximum snowpack: April 18 (Earliest: March 23, Latest: May 8)

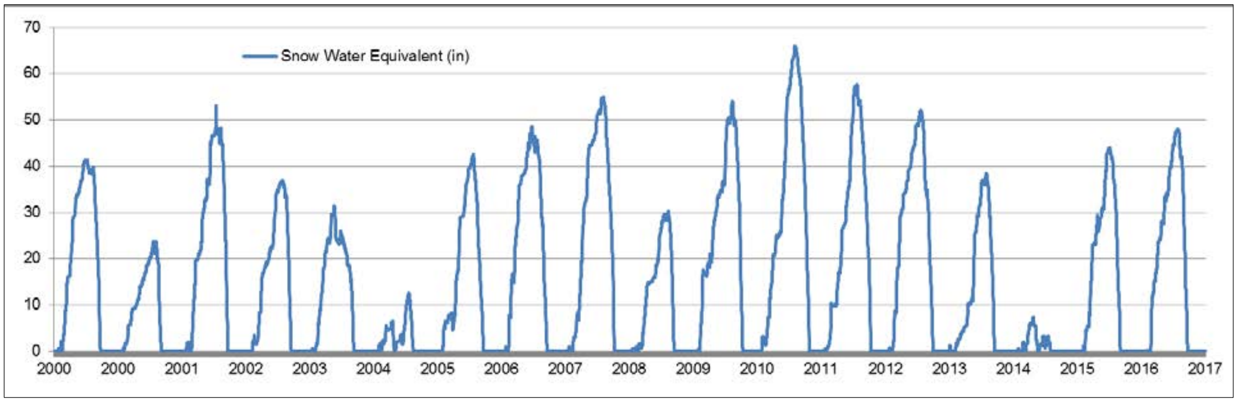

Figure 5. Daily snow water equivalent at the Waterhole SNOTEL, Water Years 2000 to 2017.

- Trend in snow water equivalent (Cox Valley Snow Course): 15% decrease in April 1 snowpack since 1968 (49 year record) (Figure 6)

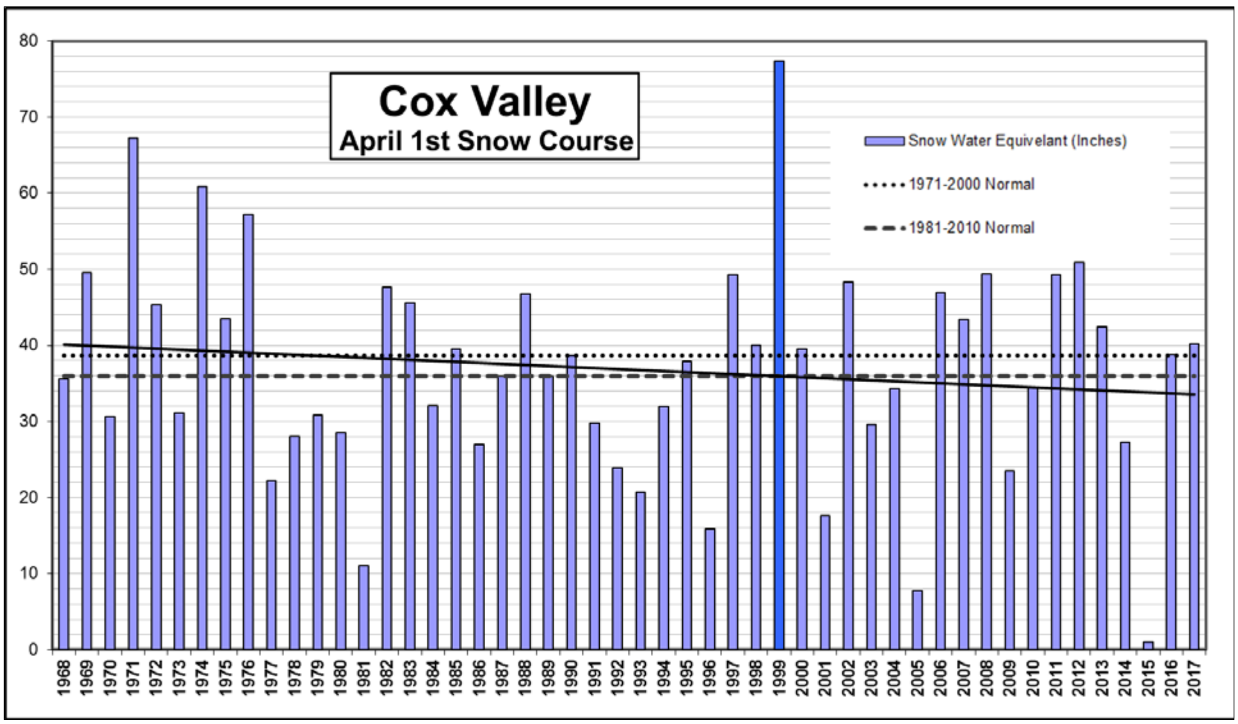

Figure 6. April 1 snow water equivalent measured at the Cox Valley Snow Course compared to the most recent 30-year normals. Note that 1999 SWE (dark blue) is estimated based on a known relationship with the nearby Hurricane Snow Course. A trend line (black solid), indicates a downward trend in SWE over the last 49 years. In response to that trend, the most recent 30-year normal (1981-2010, dashed-black line) has shifted downward 2.7 inches.

Precipitation

The following precipitation (rain and snowfall) statistics were compiled from the Waterhole SNOTEL:

- Average annual precipitation: 71.2”
- Comparison of Hurricane Ridge and Elwha Ranger Station: Average annual precipitation at Hurricane is 127% higher than the nearby lowland weather station at Elwha Ranger Station. (Average Annual Precipitation at Elwha Ranger Station during the same period was 55.9”)
- Rain vs. snow: Precipitation at Hurricane Ridge is equally divided between rain and snow. During the period of record at Waterhole, 54% of precipitation occurred on days when average daily temperature was at or below 32° F
- Highest recorded annual precipitation: 87.0”, Water Year 2011 (Figure 7)
- Lowest recorded annual precipitation: 46.1”, Water Year 2001 (Figure 7)

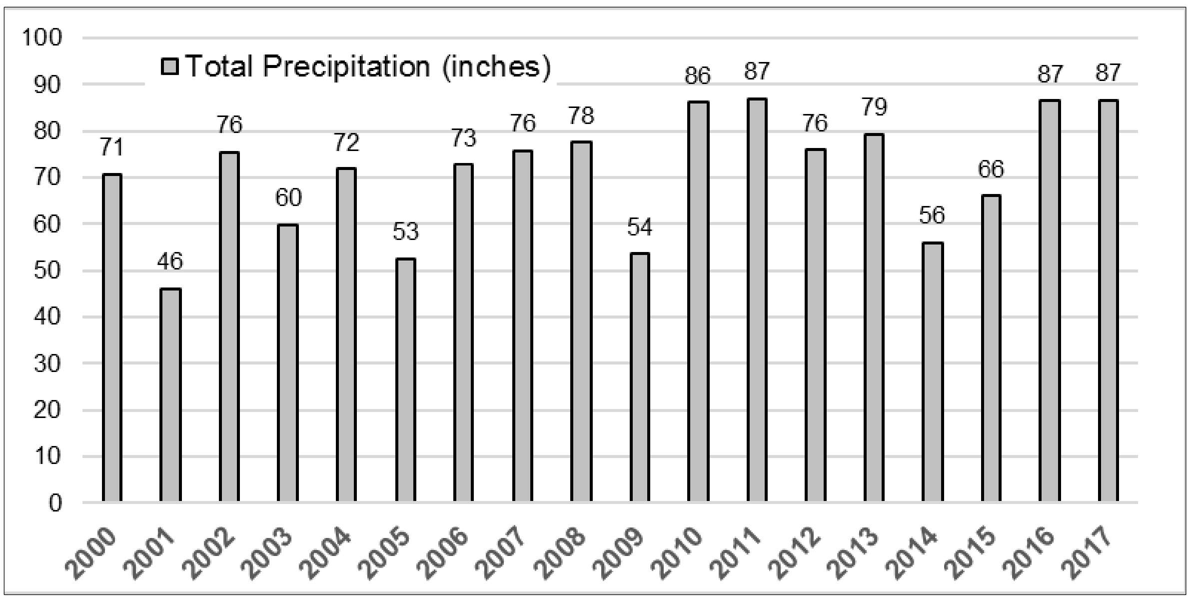

Figure 7. Total annual precipitation in inches, Waterhole SNOTEL for Water Years 2000 to 2017.

- Month with highest average precipitation: November (Average 12.34”), followed closely by December and January (Figure 8)

- Month with lowest average precipitation: July (Average 0.54) (Figure 8)

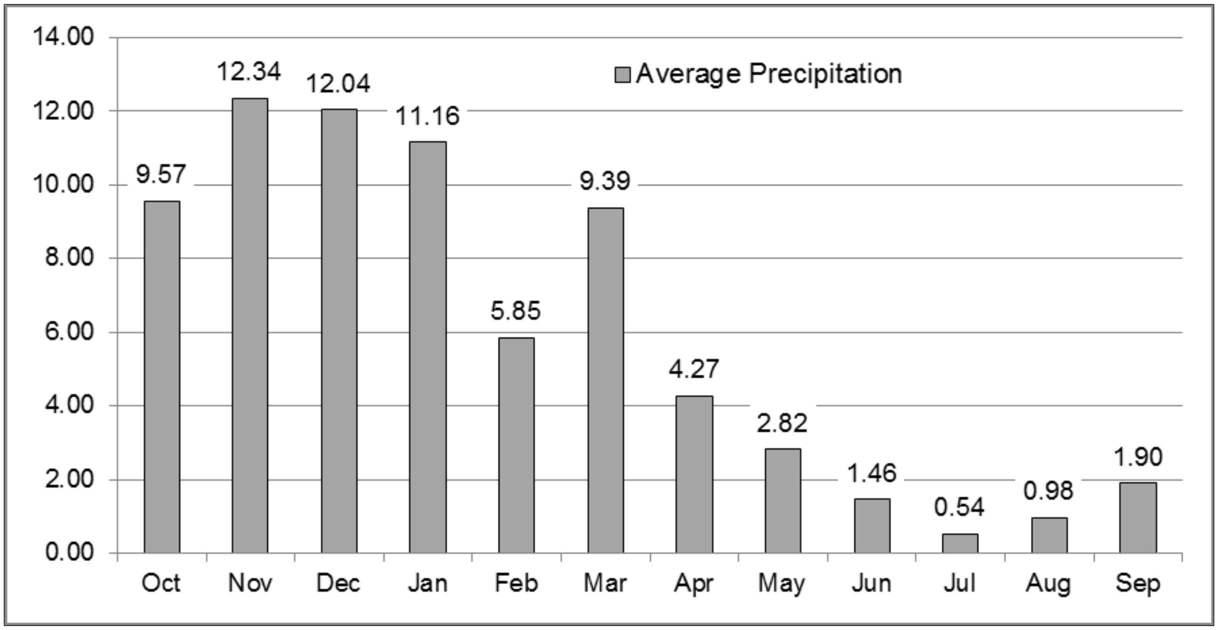

Figure 8. Average monthly precipitation at Waterhole SNOTEL, Water Years 2000 to 2017.

Air Temperature

Summer Temperatures

The following air temperature statistics for the months of June, July and August were compiled from the Waterhole SNOTEL:

- Average maximum temperature: 59.6° F
- Average minimum temperature: 41.6° F
- Average temperature: 49.9 ° F
- Maximum recorded summer temperature: 84° F on July 29, 2009 (Table 1)

Table 1. Hottest days recorded at Hurricane Ridge (Waterhole SNOTEL), Water Years 2000 to 2017.

Water Year	Date	Air Temperature Maximum (deg. F)
2009	7/29/2009	84
2006	7/22/2006	83
2009	7/28/2009	83
2014	8/12/2014	82
2004	8/14/2004	82
2006	7/21/2006	82

- Minimum recorded summer temperature: 27° F on June 6, 2012 and June 9, 2008
- Typical summer maximum temperatures: Low to mid-eighties

Winter Temperatures

The following air temperature statistics for the winter months of December, January and February were compiled from the Waterhole SNOTEL:

- Average maximum temperature: 34.2° F
- Average minimum temperature: 24.5° F
- Average temperature: 29.1°
- Minimum recorded winter temperature: -11° F on January 4, 2004 (Table 2)
- Maximum Recorded Winter Temperature: 57° F on January 18, 2009

Table 2. Coldest days recorded at Hurricane Ridge (Waterhole SNOTEL), Water Years 2000 to 2017.

Water Year	Date	Air Temperature Maximum (deg. F)
2004	1/4/2004	-11
2009	12/19/2008	-5
2014	12/7/2013	-4
2010	12/7/2009	-3
2014	2/7/2014	-3
2004	1/3/2004	-2
2009	12/15/2008	-2
2010	12/8/2009	-2
2011	11/23/2010	-2

Wind Speed

As the last major geographical feature dividing the interior Olympic Mountains from the Strait of Juan de Fuca, Hurricane Ridge is known for its high winds. The following statistics are based on the Beaufort wind force scale where:

Gale Force Winds = 39 to 54 mph

Storm Force Winds = 55 to 72 mph

Hurricane Force Winds = 73 mph or greater

Data from 2004 to 2017 was summarized from the NWAC weather station at Hurricane Ridge. “High Wind” days are defined as any day where maximum gusts met gale force or higher criteria (39 mph or greater).

- Number of high wind days: 16% of all days at Hurricane Ridge experience high winds (gale force or greater)
- Windiest month: November has the most high wind days. Thirty two percent of November days are high wind days (Figure 9)
- Windiest months: The months of the year with the most high wind days (in order) are November, January, March, December, October and February (Figure 9)
- Calmest month: July, followed by August and June (Figure 9)
- Month with most extreme wind events: January has the highest number of hurricane force days (14), followed by November (12) and December (10)

- Hurricane Ridge experiences hurricane force winds an average of four times a year.

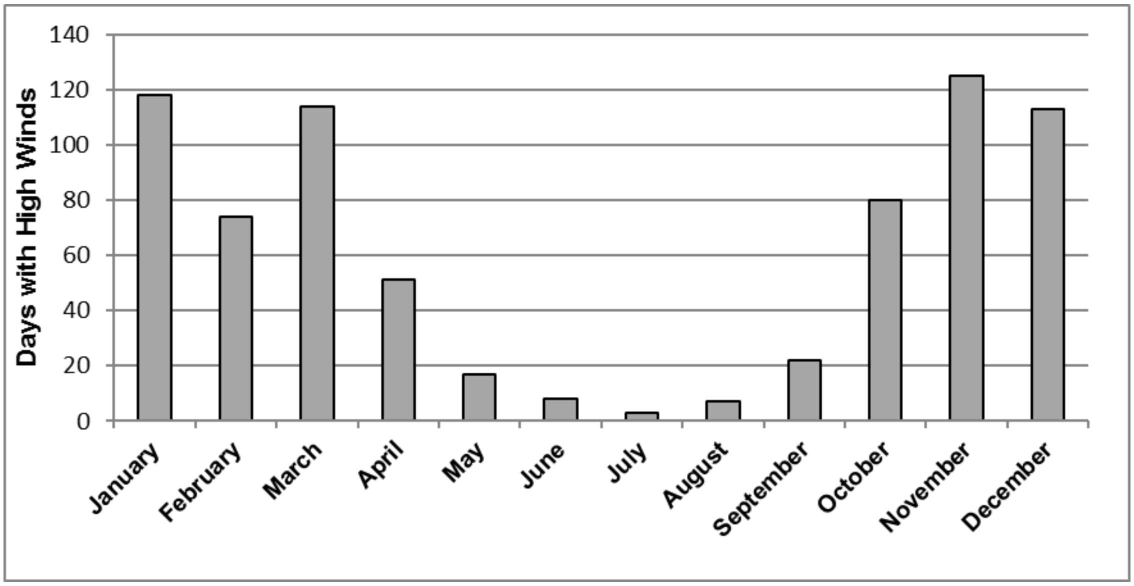

Figure 9. Number of days with wind speed ≥39 mph by month at Hurricane Ridge (from 2004 to 2017).

- Windiest years: 2004, followed by 2010 and 2006 (Figure 10)

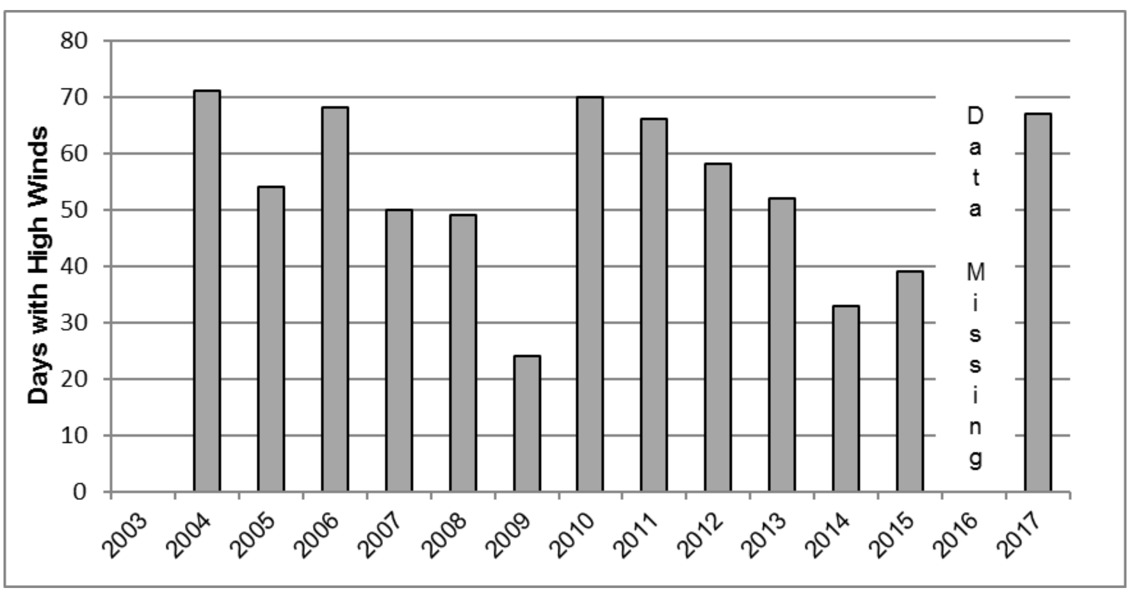

Figure 10. The windiest years measured at Hurricane Ridge, Water Years 2004 to 2017. In Water Year 2016, instrument failure resulted in incomplete data from November through January.

- Year with the most hurricane force wind events: 2010, with a total of 10 events. 2013 was the only year where Hurricane Ridge did not experience hurricane force winds

- Highest gusts recorded at Hurricane Ridge (for the 2004 to 2017 period): 98 mph on November 15, 2004 and March 2, 2011 (Table 3).

Table 3. Dates at Hurricane Ridge with the highest wind speed gusts and associated air temperatures.

Date	Month	Maximum Wind Speed (mph)	Average Daily Air Temperature (°F)
11/15/2004	November	98	33.3
3/2/2011	March	98	24.6
4/7/2017	April	94	30.1
1/4/2012	January	93	32.5
11/12/2007	November	89	27.6
12/3/2007	December	88	37.4
3/10/2016	March	88	28.8
1/18/2010	January	87	29.2
3/12/2012	March	87	22.2
3/27/2010	March	84	34.1

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Appendix A. Terminology and Methods

Snowpack

Depth of snowpack refers to the total depth of snow observed on the ground. It includes recently fallen snow as well as the settled snow remaining from earlier snowfall events. Depth of snow is typically measured in a tree sheltered clearing where wind has minimal influence on falling snow and where wind-driven redistribution of fallen snow is unlikely. In this report, the depth of snowpack is based on direct measurements from a Judd Communications Depth Sensor. This sensor measures the distance to the snow or ground surface by sending out ultrasonic pulses and listening for the returning echoes. The time from transmissions to return of an echo is the basis for obtaining the distance measurement.

Date of melt-out is defined in this report as the first day that a specified reference location is snow free. I base the melt-out date on the first day at the Waterhole SNOTEL that the snow depth and snow water equivalent values are zero.

Snowfall refers to the amount of snow which has fallen since a previous observation. Total snowfall is typically determined by summing hourly or daily measurements for a specific time period. The method used at National Weather Service Cooperative Weather Stations (COOP) sites, is to place a clean board on the ground or snow surface and measure new snow that accumulates (NWS 2014). Each morning, newly deposited snow is measured with a ruler and recorded. The board is then cleaned and reset for the next day's snowfall. The more frequently the board is measured and cleaned, the less time there is for fallen snow to compact, melt or settle. Hourly, six hour or daily snowfall measurements are typical, depending on the staffing at a location.

Hurricane Ridge is not reliably accessible on an hourly or daily basis, so no true, consistent snowfall records exist. There is, however, a keen public interest in snowfall totals for this area. Snowfall amounts are typically recorded at ski resorts and many mountain parks, and visitors to Olympic will often compare this parameter to areas they are more familiar with. For this reason, I derive an estimated snowfall amount using daily snow depth sensor measurements from the Waterhole SNOTEL. Estimates were derived using the following steps:

1. **Determine the amount of daily snowfall from automated instruments**. Using daily values from an automated snow depth sensor, I calculated the change in the daily snow depth for all of the years (i.e. the difference between Day 2 snow depth and Day 1 snow depth). All positive values are kept, while negative values (indicative of settling or melt) are given a value of zero. Positive values are considered daily snowfall. At the end of each water year, I derive a total annual snowfall by summing these positive values for the entire period where snow typically falls (October to June).

2. **Calculate a correction factor**. Values derived from daily measurements of a snow depth sensor are known to underestimate total snowfall due to a variety of factors (Ryan et.al. 2008). In order to achieve a more accurate estimate, I derived a multiplier to correct the

automated snow depth value. The correction factor was developed by looking at several collocated snow measurement sites.

a. I analyzed data from Paradise, in Mt. Rainier National Park, a site of similar elevation and snow characteristics to Hurricane Ridge. At Paradise, the Park operates a SNOTEL with an automated snow depth sensor, in addition to recording daily manual snow measurements at a National Weather Service COOP station. I applied the positive change in snow depth method of calculating the annual snowfall from the Paradise SNOTEL data for a 10 year period. I then compared this to annual COOP snowfall totals from the same 10 year period. Paradise (COOP) snow board derived snowfall measurements ranged from 143% to 202% of SNOTEL derived snowfall measures. From these data, I could then assume an average correction factor of 1.80 for estimating total snowfall from SNOTEL derived values. (Multiplier would range from 1.69 to 1.92 with a 95% confidence interval).

b. I also analyzed manual snow stake and snowboard measurements from Hurricane Ridge. Written records exist for ten years where daily snow depth was recorded at a manual snow stake, along with 24 hour snowfall (COOP snow board) measurements. Hurricane snowfall totals ranged from 140% to 196% of Hurricane snow stake measurements. From this data, I derive a correction factor of 1.64 for estimating total snowfall from snow stake derived values. (Multiplier would range from 1.55 to 1.73 with a 95% confidence interval). I then compared snow depth derived values for snowfall between the Waterhole SNOTEL and the Hurricane snow stake measurements for the same 10 years and found them to compare favorably (Standard Error of 5%).

3. **Apply the correction factor to SNOTEL values**. Based on the reasonable correlation between the Waterhole SNOTEL and the Hurricane snow stake and snow board, the final step was to apply the 1.64 multiplier to annual values derived from the Waterhole SNOTEL measurements. The fact that this multiplier was similar in value to the multiplier derived from Paradise data, gave us additional confidence in using the Hurricane derived value. Applying the multiplier allowed us to make a final estimate of annual snowfall at the Waterhole SNOTEL for each water year of operation.

Snow Water Equivalent (SWE) describes the actual amount of water contained in a given volume of snow. SWE is a function of snow density and can be imagined as the depth of standing water that would result if you melted the entire snowpack. SWE values at the Waterhole SNOTEL are determined using antifreeze- filled steel bladders (referred to as a snow pillow). As snow accumulates on the pillow, it exerts pressure on the solution. Automatic measuring devices convert the weight of the snow (as pressure) into an electrical reading of the snow's water equivalent. A longer record of SWE is available from the Cox Valley Snow Course. In this case, manual monthly measurements are collected from 10 fixed stations along a snow course. A set of assembled metal snow tubes, referred to as a Federal Sampler, are inserted into the snow pack to extract a full profile.

The depth of snow is measured and the snow is weighed to calculate density. Snow depth is combined with snow density to determine snow water equivalent.

Precipitation

Precipitation measurements are derived from a storage style rain gage at the Waterhole SNOTEL. This gage is typically a 15 to 20 foot tall steel cylinder with a wide orifice to capture both snow and rainfall. The gage is partially filled with antifreeze at the beginning of each water year. As snow and rain accumulate in the gage, it increases head pressure which is measured by a pressure transducer and translated into a rainfall amount. Because of the large capacity of these gages, measurements tend to be coarser than those from finer resolution tipping bucket rain gages. This also means that light precipitation events may go unnoticed and some spring and summer values may be slightly underrepresented. Because these gages are not heated, the orifice may also become “bridged” with snow. The result is that occasional snow events are lost, under estimated, or offset in time.

Air Temperature

Temperature statistics are based on daily maximum, minimum and average temperature measurements at the Waterhole SNOTEL site. Temperature is measured with a Campbell Scientific temperature and relative humidity probe (CS215) housed in a solar radiation shield. Measurements are taken on a 5 minute interval and recorded hourly. This sensor is mounted at a non-standard height, 15 feet from the ground. (The National Weather Service standard for air temperature measurements is 4-6 feet above ground level). This is to avoid burial of the sensor by snowpack during winter and spring months.

Wind Speed

Wind Speed is based on measurements from a heated Taylor Scientific heavy duty mechanical rotor style anemometer. Despite the de-riming capability of these sensors, there are occasional periods of missed data due to heavy rime (ice). The maximum range of the wind speed sensor is 110 mph. The instrument is mounted on a Rohn45 Tower which protrudes well above surrounding trees.

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