National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

North Coast and Cascades Network Climate Monitoring Report

Mount Rainier National Park; Water Year 2016

Natural Resource Data Series NPS/NCCN/NRDS—2017/1125

ON THE COVER

Flood damage to Carbon River Trail November16th, 2015, the result of two flood events in November where the Carbon climate station recorded over 7 inches of rain each.

Photograph by: Ben Wright, NPS

North Coast and Cascades Network Climate Monitoring Report

Mount Rainier National Park; Water Year 2016

Natural Resource Data Series NPS/NCCN/NRDS—2017/1125

Ben L. Wright and Rebecca A. Lofgren

National Park Service
North Coast and Cascades Network
Mount Rainier National Park
55210 238th Ave E.
Ashford, WA 98304

November 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

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.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the North Coast and Cascades Network Inventory and Monitoring website and the Natural Resource Publications Management website. To receive this report in a format that is optimized to be accessible using screen readers for the visually or cognitively impaired, please email irma@nps.gov.

Please cite this publication as:

Wright, B. L., and R. A. Lofgren. 2017. North Coast and Cascades Network climate monitoring report: Mount Rainier National Park; water year 2016. Natural Resource Data Series NPS/NCCN/NRDS—2017/1125. National Park Service, Fort Collins, Colorado.

NPS 105/140561, November 2017

Contents

Figures

Page

Tables

Page

Executive Summary

Climate and weather events define the ecological characteristics found in national parks and are key to understanding and interpreting changes in natural resources. Everyday park operations including; fire management, search and rescue, maintenance of park infrastructure, and visitor use are influenced by weather. Collecting weather data and maintaining climate records provides essential information needed to support park operations and to monitor park resources.

This report summarizes climate data collected in Mount Rainier National Park during the 2016 water year, and is part of a set of climate summary reports from seven national and historic parks in the North Coast and Cascades Network. Published in the National Park Service's Natural Resource Data Series, annual climate summary reports are intended to provide basic data sets and data summaries in a timely manner, with minimal interpretation and analyses. We intend that the primary audience for this document will be National Park staff, especially decision makers, planners, and interpreters; partners; and interested public.

Temperature and precipitation data are presented from eight weather stations located within Mount Rainier National Park: Camp Muir (10,100' elevation), Carbon River (1735'), Cayuse (5200'), Longmire (2760'), Ohanapecosh (1950'), two stations at Paradise (5550' and 5120'), and Sunrise (6420'). Data were recorded using automated and manual instruments operated by the National Park Service and other collaborators, including the National Weather Service, National Interagency Fire Center, Natural Resources Conservation Service, and Northwest Avalanche Center. Monthly averages of daily average temperatures and monthly total precipitation are reported for all stations. Comparisons are made to the 30-year normal (1981-2010) for Longmire and Paradise, two stations with long term climate records. Snow water equivalent (SWE) is reported and compared to the 30 year normal for one SNOTEL station within the park and monthly snow depth is reported for four stations within the park.

Average annual temperatures and precipitation were both above normal for Water Year 2016. In addition, significant monthly departures from normal were recorded throughout the year. Overall conditions in winter were warm and wet, with a shift to warmer and drier conditions in the spring. Snowpack remained slightly above normal during the warmer, wetter winter months then shifted to below normal conditions due the warm and dry spring, completely melting out at most sites earlier than normal by July 1st.

Acknowledgments

Mount Rainier National Park relies on several cooperating agencies to help support and maintain a long-term climate monitoring program as part of the North Coast and Cascades (NCCN) climate monitoring program. These agencies include:

- National Interagency Fire Center – Remote Automated Weather Stations Program
- National Weather Service – National Weather Service Cooperative Observer Program
- Natural Resources Conservation Service - National Water and Climate Center, SNOTEL and Snow Survey Program
- Northwest Avalanche Center – High Elevation Climate Stations

Data management is critical to provide for the availability and analysis of climate data. We depend on the NCCN Data Managers; the Western Regional Climate Center; and the National Climate Data Center for climate data management.

Acronyms

COOP	Cooperative Observer Station
I&M	Inventory and Monitoring
MORA	Mount Rainier National Park
NCCN	North Coast and Cascades Network
NCDC	National Climatic Data Center
NPS	National Park Service
NOAA	National Oceanic and Atmospheric Administration
NOCA	North Cascades National Park Service Complex
NRCS	Natural Resources Conservation Service
NWAC	Northwest Avalanche Center
NWS	National Weather Service
PNW	Pacific Northwest
RAWS	Remote Automated Weather Stations
SNOTEL	Snowpack Telemetry
SWE	Snow Water Equivalent
USDA	United States Department of Agriculture
WRCC	Western Regional Climate Center

Glossary

Climate: Complete and entire ensemble of statistical descriptors of temporal and spatial properties comprising the behavior of the atmosphere. These descriptors include means, variances, frequency distributions, autocorrelations, spatial correlations and other patterns of association, temporal lags, and element-to-element relationships. The descriptors have a physical basis in flows and reservoirs of energy and mass. Climate and weather phenomena shade gradually into each other and are ultimately inseparable (Davey et al. 2006).

Climate Normals: A long-term average value of a meteorological parameter (i.e. temperature) measured at a specific station. For example, "temperatures are normal for this time of year" means that temperatures are at or near the average climatological value for a given time period. Climate normals are usually taken from data averaged over a 30-year period (e.g., 1981-2010), and are concerned with the distribution of data within limits of common occurrence.

NWS-COOP: An extensive network of manually operated weather stations overseen by the National Weather Service. Many Cooperative Observer Program weather sites were established in the late 1800's and as such, provide the best long term climate data. At each station, an observer records daily maximum and minimum temperature, as well as total rain and snowfall.

Period of Record: The total span of time that climate data have been collected at a specific location. The longer the period of record, the more likely the climate data will not be biased by singular weather events or cyclic climate anomalies such as those associated with the Pacific Decadal Oscillation and the El Niño/La Niña-Southern Oscillation.

RAWS: A network of Remote Automated Weather Stations overseen by the National Interagency Fire Center. RAWS stations provide real-time weather data to assist land management agencies in monitoring wildland fire fuels, rating fire danger and predicting fire behavior. RAWS stations all operate during summer months and many at lower elevations operate on a year round basis.

SNOTEL: An automated network of snowpack data collection sites operated by the Natural Resources Conservation Service (NRCS). A standard SNOTEL station consists of a snow pillow, snow depth sensor, a storage type precipitation gage and air temperature sensor. Enhanced sites also measure soil moisture.

Snow Course: A permanent site where trained observers manually measure snow depth, snow water equivalent and density at a series of points along an established transect. Measurements are taken the last week of each month during winter and early spring. Values are recorded as the first of the month.

Snow Water Equivalent (SWE): A measurement describing the amount of water contained within the seasonal snowpack. It can be thought of as the depth of water that would theoretically result if you melted the entire snowpack instantaneously.

Water Year: The Water Year (or Hydrologic Year) is most often defined as the period from October 1st to September 30 of the following year. It is called by the calendar year in which it ends. Thus,

Water Year 2016 is the 12-month period beginning 01 October 2015 and ending 30 September 2016. The period is chosen so as to encompass a full cycle of precipitation accumulation.

Weather: Instantaneous state of the atmosphere at any given time, mainly with respect to its effects on biological activities. As distinguished from climate, weather consists of the short-term (minutes to days) variations in the atmosphere. Popularly, weather is thought of in terms of temperature, precipitation, humidity, wind, sky condition, visibility, and cloud conditions (Davey et al. 2006).

Introduction

Climate is a dominant driver of the physical and ecologic processes of the North Coast and Cascades Inventory and Monitoring Network Parks (NCCN, Figure 1) (Davey et al. 2006). Trends in rainfall and temperature influence how an ecosystem and its organisms function. The quantity and timing of rainfall and snow can influence the productivity and health of forests (Nakawatase and Peterson 2006), the amount of water flowing in streams and rivers (Hamlet et al. 2007) and the increase or decrease in size and terminus position of mountain glaciers. Likewise, temperature can influence the quantity and timing of plant growth and stream runoff, or the extent and duration of winter snowpack and lake ice (Thompson et al. 2009). Through direct and indirect methods, climate affects the behavior and reproduction of terrestrial and aquatic animal species (Crozier et al 2008). Climate is one of the primary causes of disturbance events such as forest fires (Littell and Gwozdz 2011) avalanches, windstorms, debris flows and floods. These events can have a major impact on park landscapes and their associated ecosystems.

Given the importance of climate, it has been identified as a primary vital sign by all 32 Inventory and Monitoring (I&M) networks within the NPS (Gray 2008). The NCCN monitors climate in order to understand variations in other park resources being monitored; to compare current and historic data to understand long-term trends; and to provide data for modeling impacts to park facilities and resources in the future (Lofgren et al. 2010). Climate data, derived from the NCCN climate network will play an important role in understanding and interpreting the physical and ecological Vital Signs monitored within NCCN parks.

The NCCN climate monitoring program capitalizes on climate stations operated by partnering agencies. The NCCN climate monitoring program compiles data from over 60 weather stations in and adjacent to the parks, of which 15 are operated by the National Park Service. While a wide variety of climate parameters are measured as part of the NCCN climate program, this report focuses on two key parameters: precipitation and air temperature, while providing supplemental information on snowpack.

This report summarizes climate data collected from eight weather stations located in Mount Rainier National Park during the 2016 water year, and is part of a set of climate summary reports from seven national and historic parks in the NCCN (Figure 1). Temperature, precipitation, and snow data from the eight weather stations are summarized in the results section of this report.

Annual climate summary reports are intended to provide basic data sets and data summaries in a timely manner, with minimal interpretation and analyses. National Park staff, especially decision makers, planners, and resource educators; partners; and interested public are the primary audience.

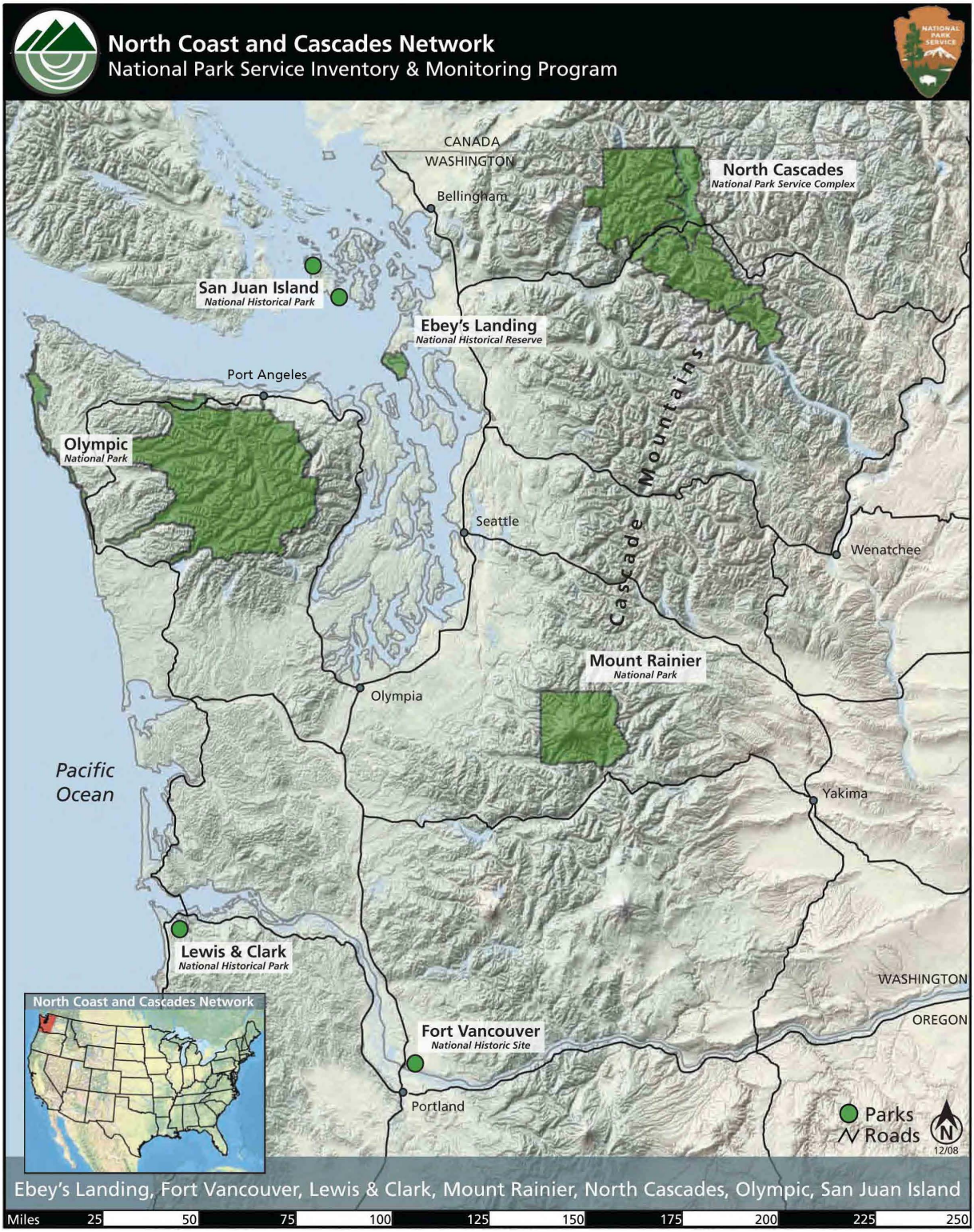

Figure 1. North Coast and Cascades Network suite of National Parks (NCCN).

Methods

Station Locations

This report incorporates data collected from weather stations operated by the NPS, the Natural Resource and Conservation Service (SNOTEL), the National Weather Service (COOP), and the National Interagency Fire Center (RAWS) (Table 1). All stations are located within Mount Rainier National Park (Figure 2).

Table 1. Weather stations referenced in this report.

Station Name	Station Type	Location	Elevation (ft)	Forest Zone	Period of Record
Camp Muir	NPS	Interior	10100	Alpine	2006 to Present
Carbon River	NPS	Northwest	1735	Forest	2008 to Present
Cayuse Pass	SNOTEL	Southwest	5200	Subalpine	2006 to Present
Longmire	COOP	Southwest	2760	Forest	1909 to Present
Ohanapecosh	RAWS	Southeast	1950	Forest	2003 to Present
Paradise	COOP	Southwest	5550	Subalpine	1916 to Present
Paradise	SNOTEL	Southwest	5120	Subalpine	1981 to Present
Sunrise	NPS	Northeast	6420	Subalpine	2004 to Present

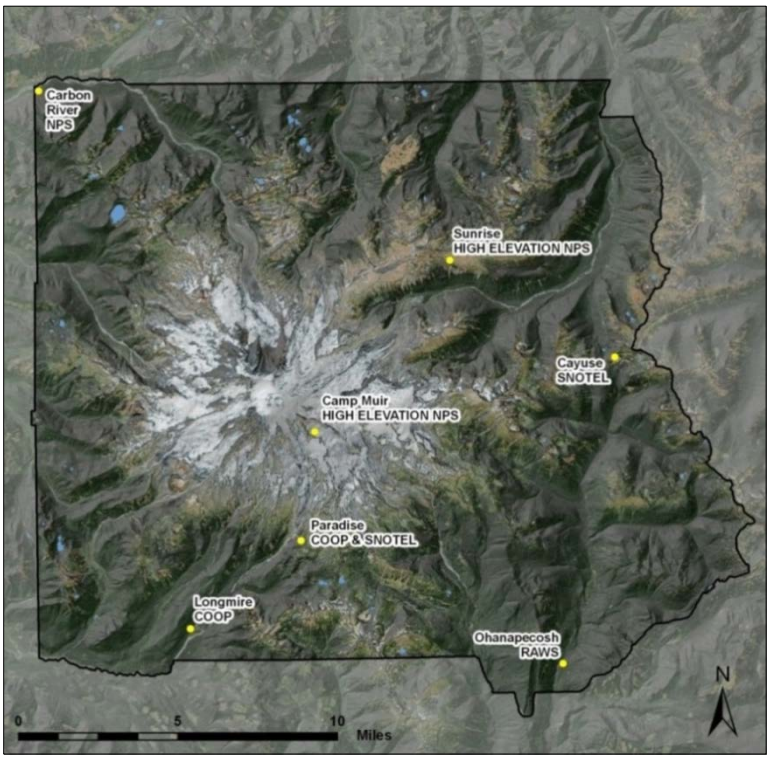

Figure 2. Location of weather stations referenced in this report. The Paradise SNOTEL and Paradise COOP stations are in two separate locations within the same general area.

Weather Station Measurements

Weather stations within the NCCN are managed by a variety of different agencies, each with a specific primary purpose. For this reason, instrumentation, method and period of collection may vary between sites. Table 2 describes the parameters measured at each station, highlights the data presented in this report, and indicates additional data that are available by request from Mount Rainier National Park.

Table 2. Parameters measured at weather stations included in this report. X indicates the parameter is measured and data are presented in this report; ✓ indicates parameter is measured and data are available on request.

Station Name	Managing Agency – Station Type	Air Temperature	Relative Humidity	Precipitation	Snow Depth	Snowfall	Snow Water Equivalent	Solar Radiation	Wind Speed & Direction	Soil Temperature	Soil Moisture
Camp Muir	NPS-High Elevation[1]	X	✓	—	—	—	—	✓	✓	—	—
Carbon River	NPS[1]	X	✓	X	✓	—	—	—	—	✓	✓
Cayuse Pass	NRCS-SNOTEL[2]	X	—	X	X	—	✓	—	—	—	—
Longmire	NWS COOP[3]	X	—	X	X	✓	—	—	—	—	—
Ohanapecosh	NIFC-RAWS[4]	X	✓	X	✓	—	—	✓	—	—	—
Paradise	NWS COOP[3]	X	—	X	X	✓	—	—	—	—	—
Paradise	NRCS-SNOTEL[2]	✓	—	✓	✓	—	X	—	—	—	—
Sunrise	NPS-High Elevation[1]	X	✓	—	X	—	—	✓	✓	✓	✓

[1]NPS stations utilize a standard array of automated weather instruments. Parameters are measured at 5 minute intervals and output as hourly averages.

[2]SNOTEL utilize a standard array of automated weather instruments in support of water supply forecasting. Parameters are measured every 60 seconds, and output as hourly averages.

[3]NWS stations rely on a standard array of manually operated weather instruments. Parameters are measured and recorded daily.

[4]RAWS utilize a standard array of automated weather instruments in support of fire weather, which are measured at 10 minute intervals and output as hourly averages.

Data Management

NWS COOP station and NRCS SNOTEL station data used in this report are acquired directly from the managing agencies. Quality assurance and control is provided by these agencies and is described in the NCCN Climate Monitoring Protocol (Lofgren et al. 2010).

The daily data used in this report from NPS and RAWS stations are derived from hourly data which have been evaluated through automated queries and manual display and graphing. Hourly data flagged or identified as suspect are omitted from daily summaries. If more than two hours of data are missing on a given day, no daily values are presented.

Monthly values are generated and presented for stations where five or fewer daily values are missing. In the case of missing precipitation values, daily quantities may be substituted from another nearby weather station for the purposes of reporting monthly and annual totals. This will only occur when nearby data are available and a known correlation exists between these sites. In these cases where estimates are generated from nearby stations, data are footnoted and a description of the quantity and source of data replacement is given.

Data Quality

Due to problems associated with equipment failure and access to these remote sites, data gaps exist at several stations.

Gaps exist in the Ohanapecosh RAWS data during December and January totaling nine and eleven days respectively due to an unknown datalogger malfunction. However, when RAWS summarized data were compared to a collocated NPS climate site with no missing data, monthly temperature values were within 0.3 degrees Fahrenheit for all months outside of December and January. Therefore, NPS station values were substituted for missing RAWS values for December and January and footnoted in the summary table. The RAWS precipitation gauge is unheated and due to the warm temperatures and limited snowfall in Water Year 2016 at the elevation of this site, precipitation values were reported despite some potential for underreporting amount and a temporal shift of values. These months were footnoted in summary tables.

Five days of temperature data are missing from the Paradise COOP weather station in the months of December and March due to access and unavailable staffing. Missing values from the co-located automated Paradise NWAC station were substituted, and are therefore included, but flagged in summary tables. Accumulated precipitation was collected and recorded as multiple day totals when daily observations were missed. When annual precipitation totals from the COOP station are compared with adjacent NWAC and SNOTEL sites, the total annual precipitation values are within 1.6 and 3.8 inches or 1.1% and 2.6% respectively. Since values are within standard error for an electronic gauge, multiple day accumulated precipitation data are included in monthly totals and analysis, NWAC data or SNOTEL data are not substituted. Daily totals for October, December, March and April are not available due to more than 5 missing days.

The Longmire COOP station was missing temperature observations for eight days in November and thus were not included in tables and analysis. Accumulated precipitation was collected and recorded

as multiple day totals when daily observations were missed. Multiple day accumulated precipitation data are included in monthly totals and analysis. Daily totals for October and November are not available due to more than 5 missing days.

The wind speed sensor at the Camp Muir and Sunrise High Elevation stations are not heated and can become ice encrusted during cold, wet conditions. Periods of known ice encrusted sensors were removed from the dataset. The Camp Muir station had a power system failure in July resulting in four days of missing data.

Data Reporting

Data in this report are based on the hydrologic or water year and organized by month and seasons. Ecosystems in the Pacific Northwest are dominated by two distinct hydrological periods, a wet season generally beginning in late October and ending in June, and a drought season that generally extends from July to September. While a calendar year divides the wet winter season, the use of a water year closely reflects the timing and seasonality of many physical and ecological processes that are driven by climate, such as soil saturation and forest evapotranspiration, onset and breakup of lake ice, glacial accumulation and ablation balances, magnitude and timing of stream flow, emergence and flowering of plants and migratory timing of bird species.

Seasons in this report are distinguished based on National Weather Service (NWS) standards for the Northern Hemisphere. The NWS defines December, January, and February as winter; March, April, and May as spring; June, July, and August as summer, and September, October, and November as fall.

The main report provides monthly averages of daily average temperatures and monthly total precipitation for all stations listed in Tables 1 and 2. While routinely collected in metric units, data are presented in Fahrenheit and inches to facilitate use and interpretation by the public and park staff. Two stations with long term records; Paradise and Longmire, are compared to the 30-year climate normal. Snow water equivalent is reported and compared to the 30-year climate normal for one SNOTEL within the park, and monthly snow depth at the first of each month is reported for Cayuse, Longmire, Paradise and Sunrise stations. Available upon request are hourly, daily, or monthly weather data from each station noted in Tables 1 and 2.

Results

Temperature

Temperatures were above average at all sites for October, with Longmire recording a monthly departure from normal of 5.7°F. Near normal temperatures persisted in November and December at most stations (Table 3; Figures 3 and 4). All stations recorded warmer than average temperatures during January, February, and near normal temperatures in March. April exhibited the most extreme deviation with temperatures 7.9°F above normal at Paradise and 9.4ºF at Longmire. Climate conditions continued with above normal temperatures throughout late spring in May and June. Temperatures for July were below average across all sites (Figures 3 and 4). In August, temperatures returned to above normal temperatures, followed by a return of colder than normal conditions in September across all sites.

Table 3. Average monthly air temperatures (°F) from weather stations within Mount Rainier National Park in Water Year 2016.

Season	Month & Year	Camp Muir NPS	Carbon River NPS	Cayuse Pass SNOTEL	Longmire NWS COOP	Ohanapecosh RAWS	Paradise NWS COOP	Sunrise NPS
Fall	October 2015	34.8	49.4	46.4	50.3	50.5	46.5	45.1
	November 2015	19.7	36.7	33.1	–[a]	36.3	31.2	29.8
Winter	December 2015	12.5	35.5	27.2	31.8	33.4[b]	26.3[c]	23.7
	January 2016	15.5	34.5	30.0	31.8	32.0[b]	31.2	26.7
	February 2016	19.1	39.1	34.0	36.5	36.8	32.5	30.8
Spring	March 2016	16.2	39.3	32.1	37.6	38.8	31.2[c]	28.5
	April 2016	28.3	47.4	41.5	49.8	48.3	41.9	40.0
	May 2016	29.5	52.0	43.7	51.9	53.7	42.6	41.9
Summer	June 2016	32.5	55.5	47.8	55.8	58.5	46.8	46.1
	July 2016	39.8	58.9	50.3	59.2	62.0	50.0	50.2
	August 2016	42.2	60.6	55.2	62.1	64.0	55.6	55.0
Fall	September 2016	33.6	51.6	46.4	52.2	53.9	46.3	44.9
Water Year		27.0	46.7	40.6	–	47.4[b]	40.2[c]	38.6

[a] Eight days of temperature data are missing in November.

[b] December and January are missing more than 5 days of temperature. Monthly average values were used from a co-located NPS site (see Data Quality).

[c] Five days of temperature data missing in December and March. Monthly average values were used from a co-located NWAC site (see Data Quality).

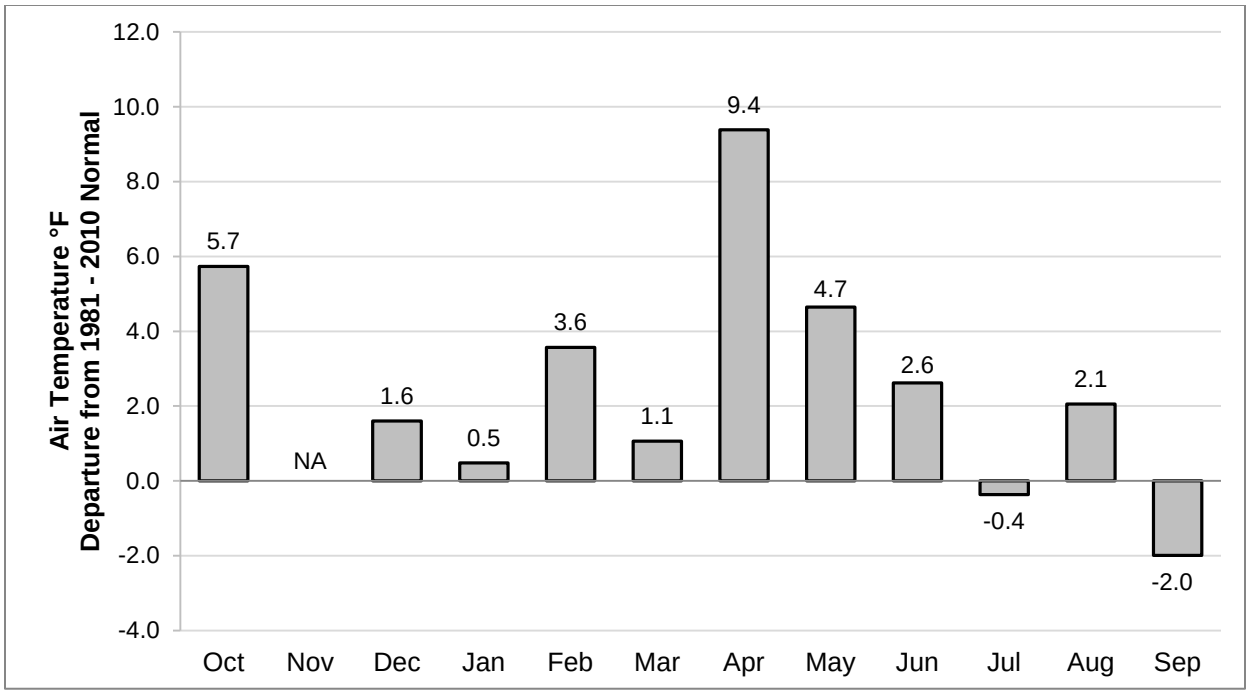

Figure 3. Comparison of average monthly temperature (°F) for Longmire (COOP) in Water Year 2016 against monthly averages for the climatological normal 1981-2010.

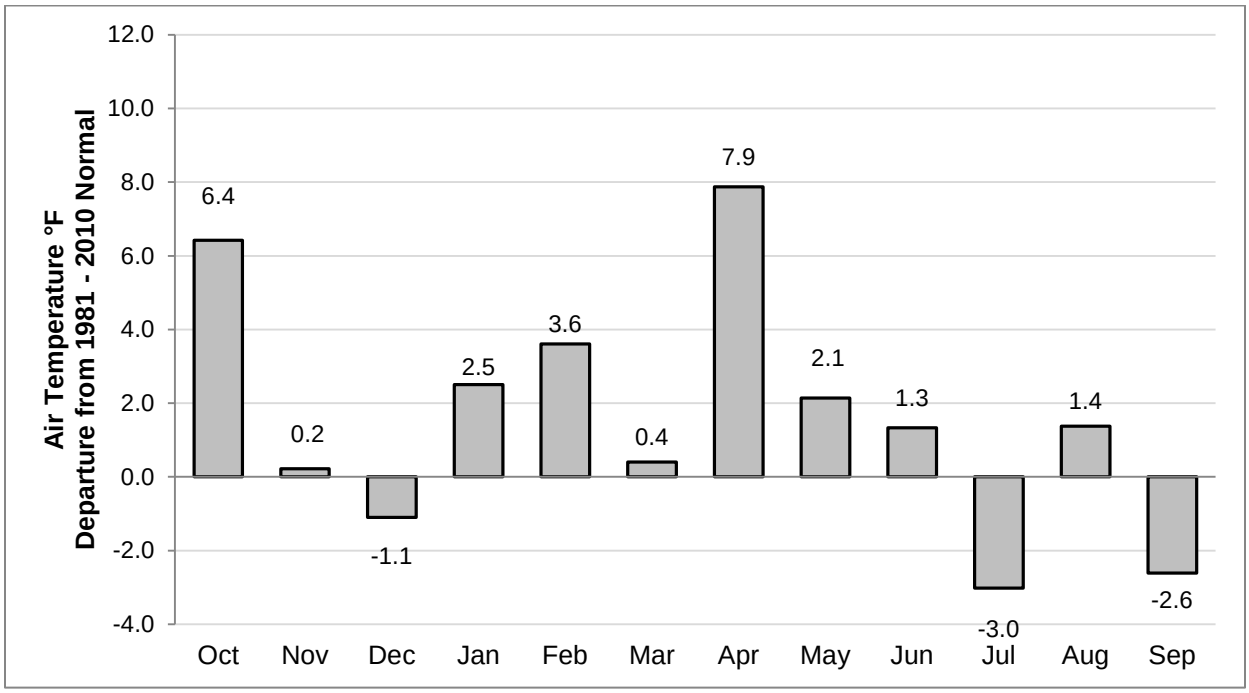

Figure 4. Comparison of average monthly temperature (°F) for Paradise (COOP) in Water Year 2016 against monthly averages for the climatological normal 1981-2010.

Precipitation

Precipitation was above normal in the months of October through December (Table 4, Figures 5 and 6). December recorded the largest departure from normal with precipitation 218% of normal at the Longmire COOP station and 178% of normal at the Paradise COOP station (Figures 5 and 6). January experienced near to slightly below normal precipitation. Precipitation for February and March was approximately 150% of normal at the Longmire and Paradise COOP stations (Figures 5 and 6). Conditions in April and May shifted significantly to very dry conditions with Longmire and Paradise receiving 24% and 55% of normal precipitation, respectively. June and July brought slightly wetter than normal conditions to the park. August was notably drier with around 50% of normal precipitation falling across the park. September brought the return of wetter than normal conditions.

Table 4. Total Monthly precipitation (inches) from weather stations within Mount Rainier National Park in Water Year 2016.

Season	Month & Year	Carbon River NPS	Cayuse Pass SNOTEL	Longmire NWS COOP	Ohanapecosh RAWS	Paradise NWS COOP
Fall	October 2015	10.8	7.7	8.9	13.0	15.3
	November 2015	13.3	9.3	15.8	15.7a	25.9
Winter	December 2015	16.7	32.2	22.8	17.8a	30.6
	January 2016	10.8	14.9	10.1	9.0a	17.1
	February 2016	9.9	10.0	12.1	11.1a	20.8
Spring	March 2016	9.5	14.7	10.7	10.3a	18.0
	April 2016	4.4	2.4	1.8	2.5	2.0
	May 2016	4.1	4.0	2.7	2.0	2.4
Summer	June 2016	6.4	3.1	4.9	2.5	5.3
	July 2016	2.9	1.1	1.8	1.0	2.5
	August 2016	1.5	0.8	0.9	0.3	0.8
Fall	September 2016	4.1	2.1	5.0	3.8	7.6
Water Year		94.5	102.3	97.4	89.0a	148.2

[a] Precipitation gauge unheated and subject to freezing temperatures. Quantities may be underrepresented (see Data Quality).

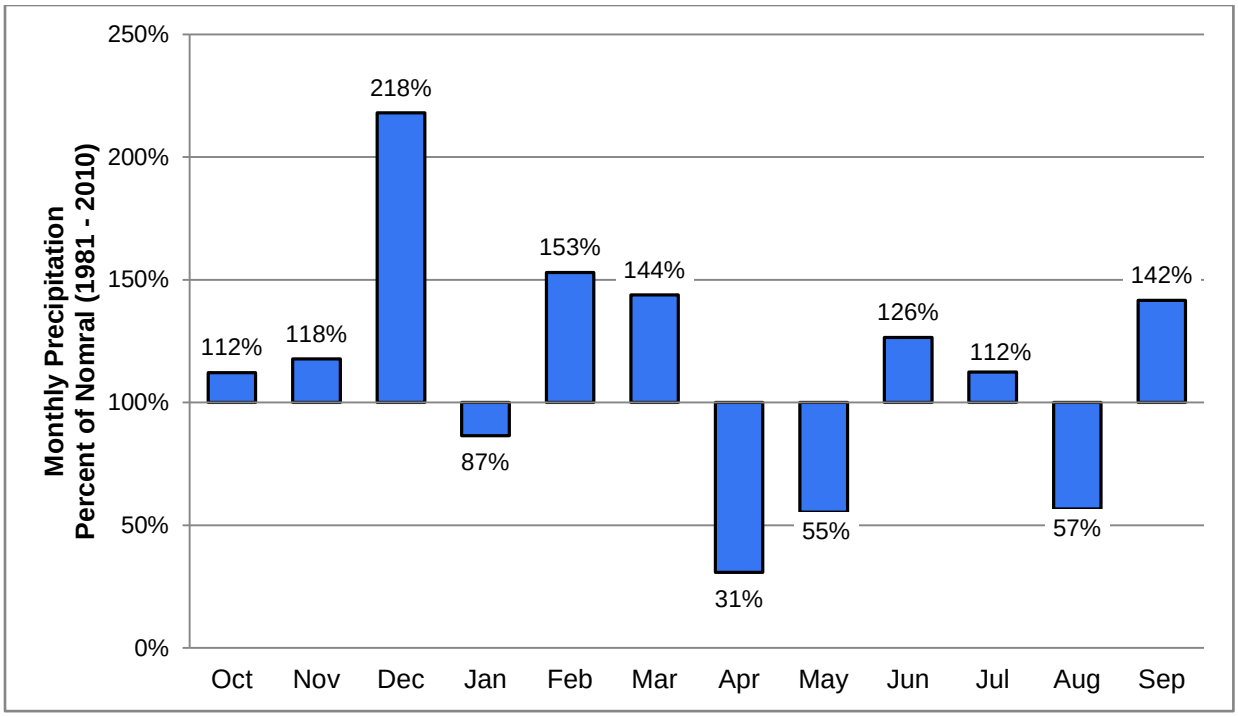

Figure 5. Comparison of total monthly precipitation (inches) at Longmire (COOP) in Water Year 2016 against the climatological normal 1981-2010.

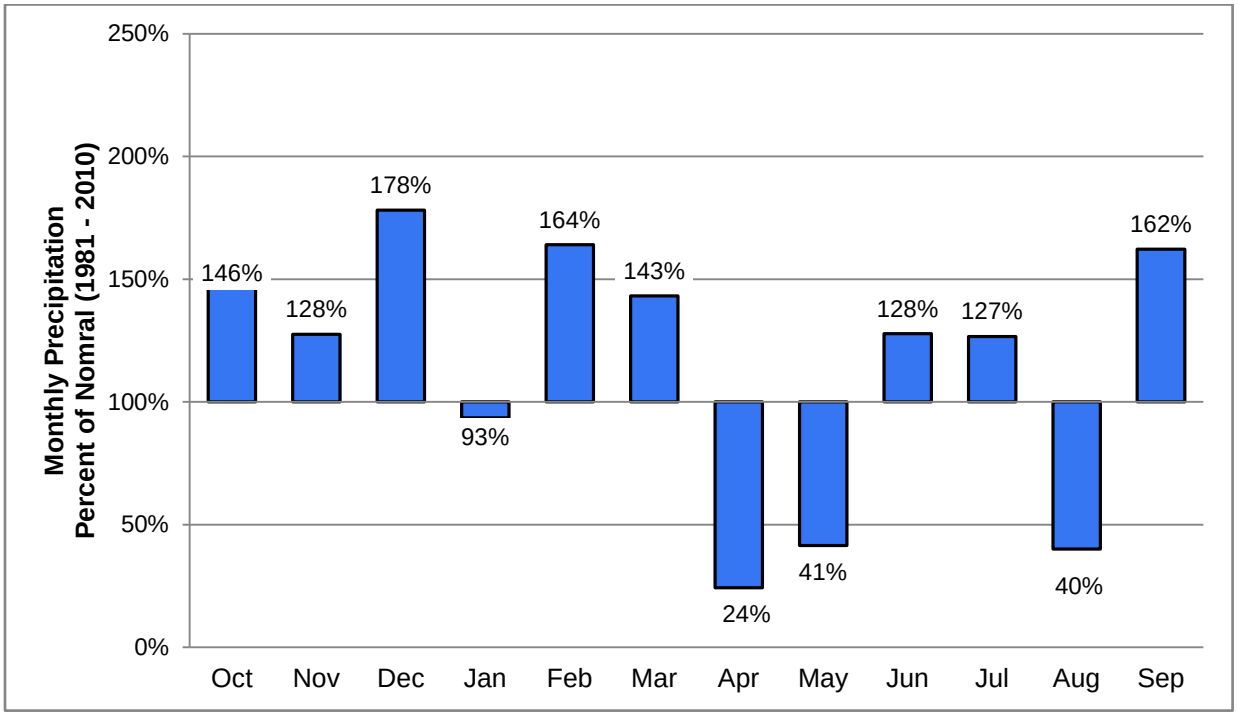

Figure 6. Comparison of total monthly precipitation (inches) at the Paradise (COOP) in Water Year 2016 against the climatological normal 1981-2010.

Snowpack

The snowpack was below normal in early December (Table 5, Figure 7). Above normal precipitation in December, combined with near normal temperatures, in order to create an above normal snowpack by early January. Slightly above normal temperatures and near to above normal precipitation in January, February and March kept the snowpack slightly above normal through early April. Warm and dry conditions in April and May quickly melted the snowpack resulting in below average snowpack conditions in June and July (Figure 7).

Table 5. Snow Depth (inches) measured on the first day of the month at SNOTEL, COOP, and NPS stations within Mount Rainier National Park during Water Year 2016.

Month & Year	Cayuse Pass SNOTEL	Longmire NWS COOP	Paradise NWS COOP	Sunrise High Elevation
October 1st 2015	0	0	0	0
November 1st 2015	0	0	4.5	4.5
December 1st 2015	12.0	1.0	24.0	18.4
January 1st 2016	96.0	33.0	117.0	78.6
February 1st 2016	114.0	16.0	129.0	96.9
March 1st 2016	119.0	0	155.0	113.3
April 1st 2016	145.0	0	174.0	123.8
May 1st 2016	96.0	0	134.0	91.8
June 1st 2016	33.0	0	91.0	35.4
July 1st 2016	0	0	10.0	0
August 1st 2016	0	0	0	0

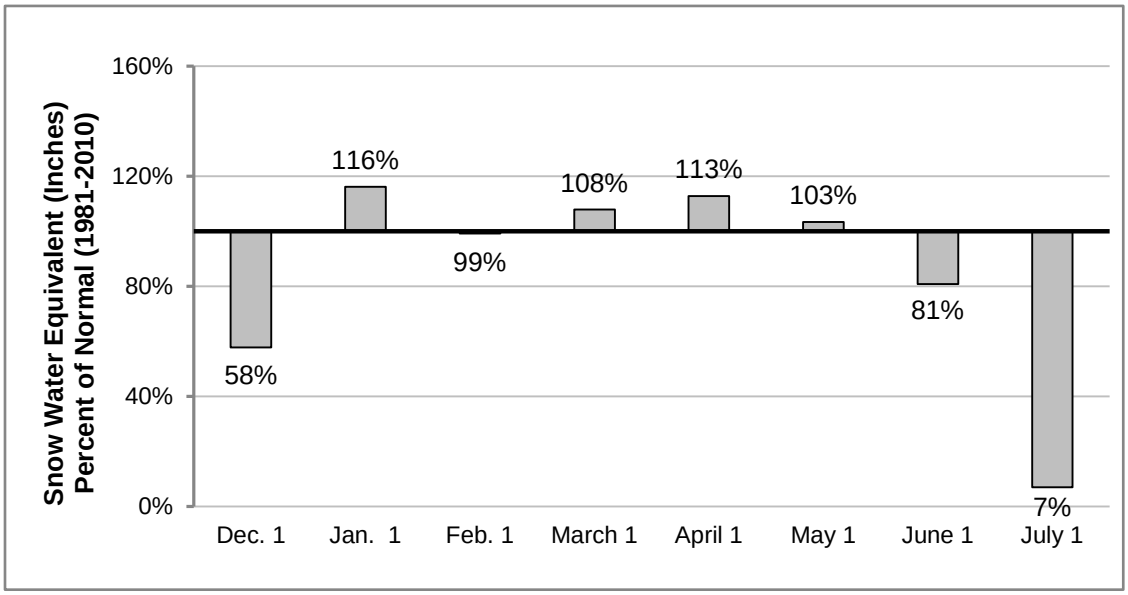

Figure 7. Comparison of snow water equivalent (inches) on the first day of each month at the Paradise Snow Course in Water Year 2016 against the climatological normal 1981-2010.

2016 Water Year in Review

Significant Weather Events and Patterns

The 2016 water year started off wet, with multiple rain events in October and November. Two successive rain events occurred on October 7th and 10th with over an inch of rain recorded each day. These first rain events of the water year contributed to triggering a small debris flow which covered the Westside Road (Figure 8).

Figure 8. October 10th Dry creek debris flow covering the Westside Road (photo NPS).

Heavy precipitation from October 30th to November 1st (7.38 inches), November 13th to17th (7.86 inches) and December 7th to 9th (7.14 inches) drove the Carbon River above flood stage three times causing flood damage to the Carbon River trail (see cover photo).

A series of strong storms moved through the park from December 14th-25th bringing some of the coldest temperatures of the year resulting in five feet of snowfall in Longmire. The coldest temperatures across all sites for the year occurred on December 31st with recorded temperatures of 10°F at Paradise and on January 3rd, 22 °F at Carbon and -2.6 °F at Camp Muir. After a cold start to January, temperatures returned to near normal for the remainder of the month with near normal precipitation. Above normal temperatures and precipitation occurred in February, with one significant rain event on February 14th where 5.98 inches of rain fell at Paradise. As a result of the heavy precipitation, Kautz creek jumped out of the channel formed during the 2006 flood event, flooding the Kautz creek maintenance area (Figure 9). Interestingly, the north and east sides of the park saw significantly less precipitation with this event, Carbon recording 1.01 inch and Cayuse recording 1.30 inches of precipitation.

Figure 9. February 14th Kautz creek avulsion damaging the maintenance area (photo NPS).

An active weather pattern in March brought heavy snow to the mountains and produced cooler and wetter than normal conditions with over 150 inches of snowfall at Paradise from March 1st to 28th. Overall, the winter was characterized by periods of heavy snowfall with several rain events to high elevation sites.

A shift to warmer and drier conditions occurred in April. At Paradise, April was the warmest April since 1934 and the third warmest April on record. Also at Paradise, April was the driest April since 1951 and third driest April on record. The warmer and drier trend continued in May and into early June. Temperatures during spring months of March, April and May, were well above normal in water year 2016. In fact, statewide, Water Year 2016 was tied with 1992 as the second-warmest on record (OWSC 2016). Temperatures at Carbon, Ohanapecosh and Longmire reached above 90°F on June 5th (the warmest day of the year for all sites excluding Camp Muir). The remainder of June however, was notably wetter than normal, with slightly above average temperatures throughout Mount Rainier. During the month of June, 0.9 inches more precipitation fell at Paradise than in April and May, combined. July continued the wet and cool conditions with above normal precipitation and below normal temperatures until July 20th when conditions finally dried out and warmed up. August recorded the driest conditions of the year with a 20 day period of no precipitation and above normal temperatures. September brought a shift to cooler and wetter than normal conditions.

Parkwide Precipitation Summary

Orographic effects produce heavy precipitation on the upper elevation, west-facing slopes of Mount Rainier National Park. The northeastern and eastern sides of the mountain receive less precipitation due to the rain shadow effect and prevailing southwesterly winds (Hemstrom and Franklin 1982). For Water Year 2016, precipitation at upper elevation weather stations neared 150 inches, while lower elevation weather stations ranged between 89 and 97.4 inches. The highest recorded amount of

precipitation, 148.2 inches, occurred on the southwest slopes at Paradise (5,400 ft.), whereas on the eastern slopes of Mount Rainier, 102.3 inches was recorded at Cayuse Pass (5,200 ft.) (Figure 10).

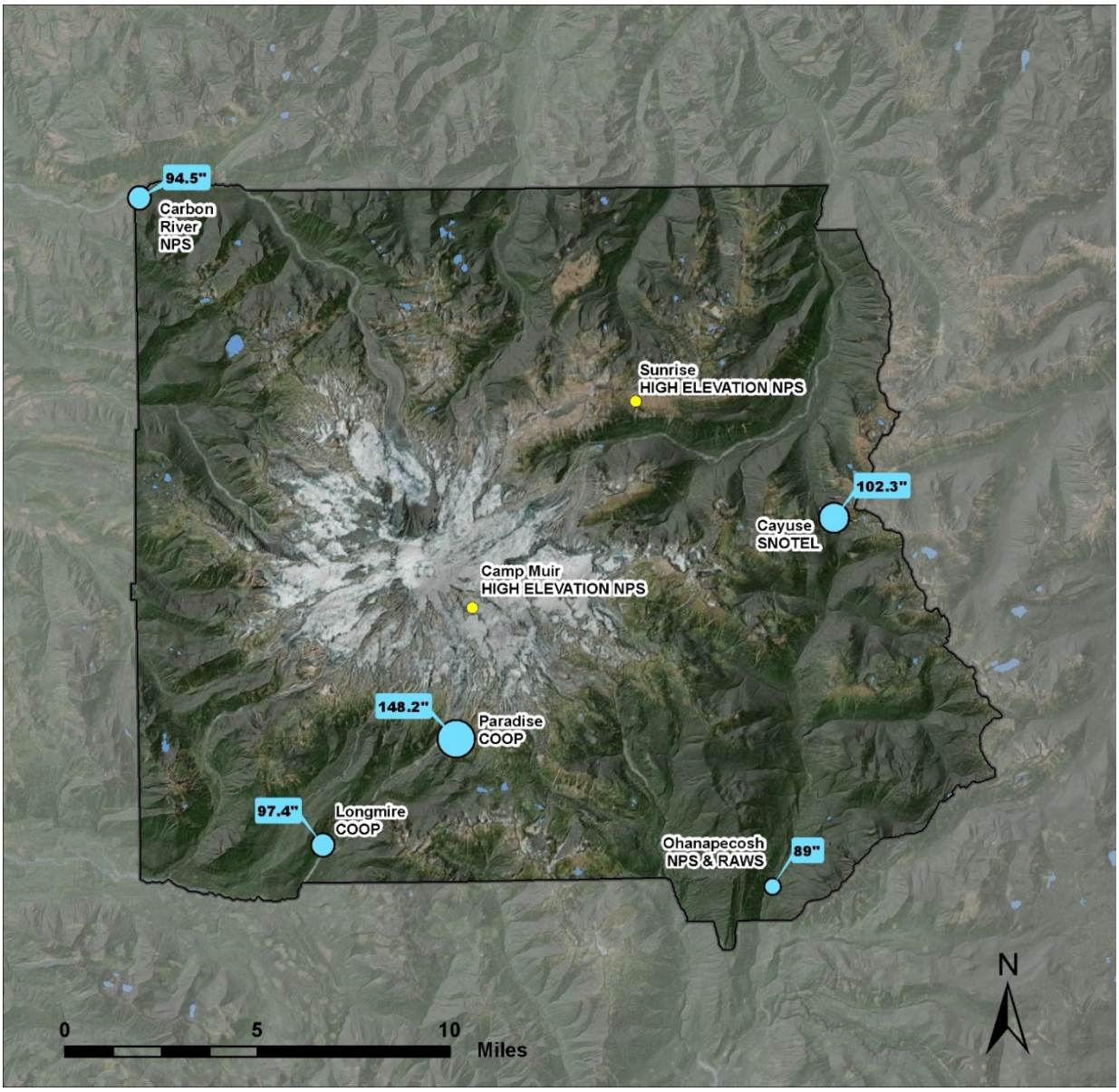

Figure 10. Total precipitation measured at weather stations located within Mount Rainier National Park during Water Year 2016. Blue circles are proportional to the total amount of precipitation measured at each site.

Literature Cited

Crozier, L. G., A. P. Hendry, P. W. Lawson, T. P. Quinn, N. J. Mantua, J. Battin, R. G. Shaw, and R. B. Huey. 2008. Potential responses to climate change in organisms with complex life histories: Evolution and plasticity in Pacific salmon. Evolutionary Applications 1(2):252–270, doi:10.1111/j.1752-4571.2008.00033.x.

Davey, C. A., K. T. Redmond, and D. B. Simeral. 2006. Weather and climate inventory National Park Service North Coast and Cascades Network. Natural Resource Technical Report NPS/NCCN/NRTR—2006/010. National Park Service, Fort Collins, Colorado. Available online: https://irma.nps.gov/Reference.mvc/DownloadDigitalFile?code=147109&file=2006_10_23_nccninventory_final.pdf (accessed 5 December 2011).

Gray, S. 2008. Framework for linking climate, resource inventories and ecosystem monitoring. Natural Resource Technical Report NPS/GRYN/NRTR-2008/110. National Park Service, Fort Collins, Colorado.

Hamlet, A. F., P. W. Mote, M. P. Clark, and D. P. Lettenmaier. 2007. 20th century trends in runoff, evapotranspiration, and soil moisture in the Western U.S. Journal of Climate 20(8):1468-1486. doi:10.1175/JCLI4051.1.

Littell, J. S., and R. Gwozdz. 2011. Climatic water balance and regional fire years in the Pacific Northwest, USA: Linking regional climate and fire at landscape scales. Chapter 5, pp. 117-139 *in* D. McKenzie, C. M. Miller, and D. A. Falk (eds.). The landscape ecology of fire, ecological studies 213, Springer, Dordrecht, The Netherlands, doi: 10.1007/978-94-007-0301-8_5.

Lofgren, R., W. Baccus, J. Boetsch, and M. Larrabee. 2011. Automated and manual methods for quality assurance and control of climate data - North Coast and Cascades Network. National Park Service Unpublished Report, Port Angeles, Washington.

Lofgren, R., B. Samora, B. Baccus, and B. Christoe. 2010. Climate monitoring protocol for the North Coast and Cascades Network (Mount Rainier National Park, Olympic National Park, North Cascades National Park, Lewis and Clark National Historical Park, Ebey's Landing National Historical Reserve, San Juan Islands National Historical Park, Fort Vancouver National Historic Site): Volume 1. Narrative and appendices, version 5/26/2010. Natural Resource Report NPS/NCCN/NRR—2010/240. National Park Service, Fort Collins, Colorado.

Nakawatase, J. M, and D. L. Peterson. 2006. Spatial variability in forest growth – climate relationships in the Olympic Mountains, Washington. Canadian Journal of Forest Resources 36:77–91.

Office of the Washington State Climatologist (OWSC). 2016. Newsletter, June 14, 2016. Available from: http://www.climate.washington.edu/newsletter/2016Jun.pdf (accessed 27 April 2017).

Thompson, R., M. Ventura, and L. Camarero. 2009. On the climate and weather of mountain and sub-arctic lakes in Europe and their susceptibility to future climate change. Freshwater Biology 54:2433-2451.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 105/140561, November 2017

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov