National Park Service
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Natural Resource Stewardship and Science

North Coast and Cascades Network Climate Monitoring Report

North Cascades National Park Service Complex; Water Year 2017

Natural Resource Data Series NPS/NCCN/NRDS—2018/1176

ON THE COVER

The National Park Service Noisy Creek GLACIER weather station (foreground) overlooking Noisy Creek Glacier, with Mount Baker in the distance.

Photograph by: NPS

North Coast and Cascades Network Climate Monitoring Report

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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.

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.

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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 North Cascades National Park Service Complex (NOCA) during the 2017 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, interpreters and partners, in addition to the interested public.

Climate data are presented from eleven weather stations located within North Cascades National Park Service Complex: Beaver Pass (3630' elevation), Brown Top (5830'), Easy Pass (5270'), Marblemount (407'), Noisy Creek (6590'), Newhalem (520'), Park Creek Ridge (4600'), Ross Dam (1240'), Silver Lake (7670'), Stehekin (1270') and Thunder Basin (4320'). Data were recorded using automated and manual instruments operated by the National Park Service and other collaborators, including the Natural Resources Conservation Service, National Oceanic and Atmospheric Administration, and National Weather Service. Monthly averages of daily average temperature are reported for all stations and monthly total precipitation is reported for nine stations. Comparisons are made to the 30-year normal (1981-2010) for Newhalem and Stehekin, two stations with long term climate records. Snow water equivalent (SWE) is reported and compared to the 30 year normal for three SNOTEL stations within the park and monthly snow depth is reported for seven stations within the park.

Average annual temperatures in Water Year 2017 varied across the Cascades Range; stations on the west slope received above normal precipitation and east slope sites were below normal. Temperatures in December through May were below normal and June through September above normal. Overall, annual precipitation was above normal; however, there were periods of extreme wet and extreme dry during the water year. March was notably wet, with rainfall on 30 of 31 days in Newhalem. It was also the wettest March on record in Stehekin. Conversely, the May-September period set records for the lack of precipitation, including July and August when several stations did not have any measurable precipitation. Mountain snowpack on April 1 was above normal, buffered by a cold and wet March and April that resulted in significant late season accumulation.

Acknowledgments

North Cascades National Park Service Complex 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 Oceanic and Atmospheric Administration – US Climate Reference Network
- National Weather Service – National Weather Service Cooperative Observer Program
- Natural Resources Conservation Service - National Water and Climate Center, SNOTEL and Snow Survey Program

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
NCCN	North Coast and Cascades Network
NOCA	North Cascades National Park Service Complex
NPS	National Park Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
SNOTEL	Snowpack Telemetry
SWE	Snow Water Equivalent
USCRN	United States Climate Reference Network

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.

NPS GLACIER stations: A small network of two climate stations operated by the NPS. The sites are located in alpine environments adjacent to glaciers monitored by NCCN I&M program. The primary goal of the network is a better understanding of high elevation alpine climate at NOCA, an identified data gap in the parks climate monitoring networks. Climate parameters monitored are temperature, wind speed and direction, net solar radiation, and relative humidity.

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.

US Climate Reference Network (USCRN): The USCRN, a network of approximately 114 climate stations nationwide, was developed by NOAA. The primary goal is to provide long-term high quality observations of temperature and precipitation for the detection of climate change.

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 2017 is the 12-month period beginning 01 October 2016 and ending 30 September 2017. 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, as well as park infrastructure such as roads and campgrounds.

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 eleven weather stations located in North Cascades National Park Service Complex (NOCA) during the 2017 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 these 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.

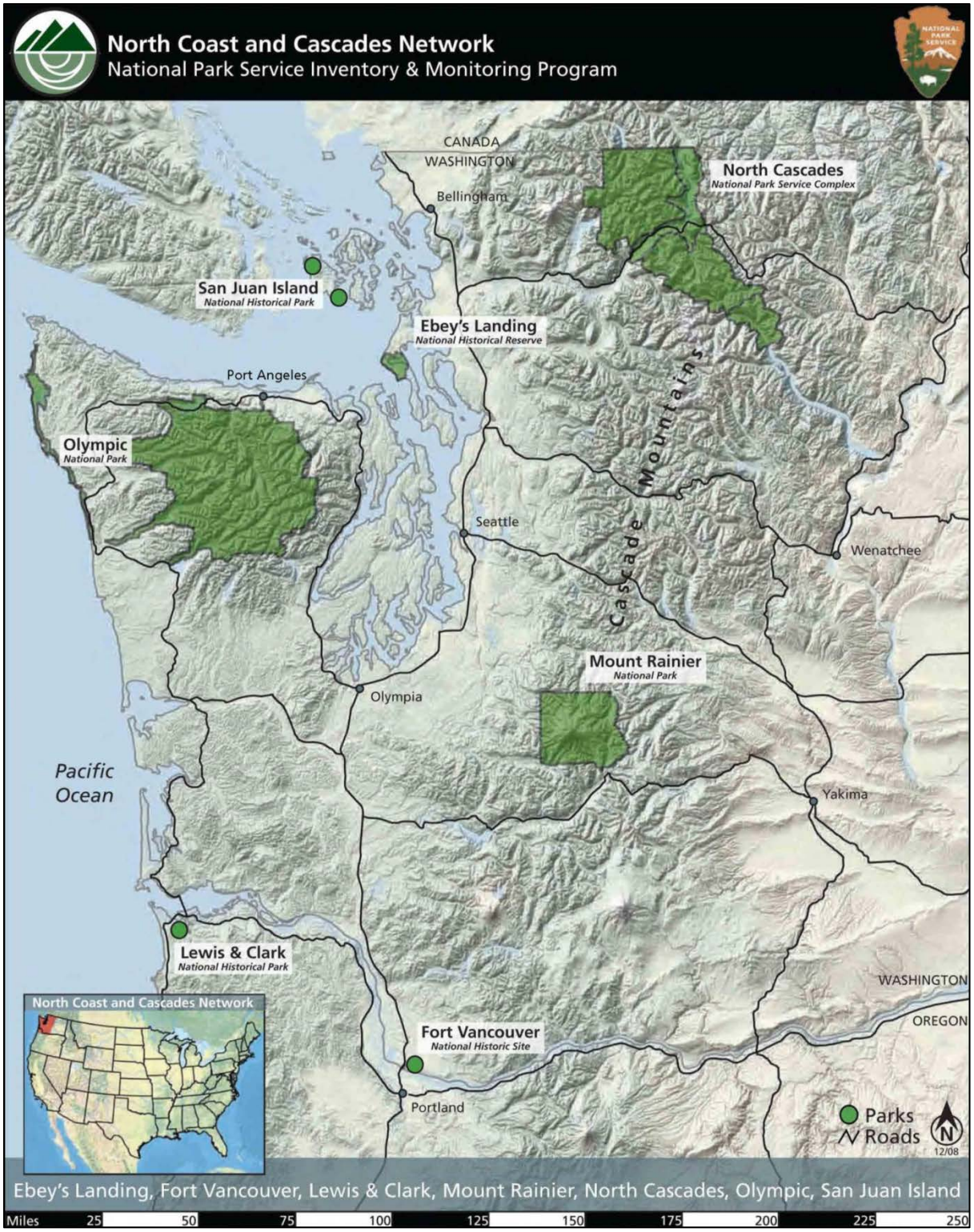

Figure 1. North Coast and Cascades Network suite of National Parks.

Methods

Station Locations

This report incorporates data collected from weather stations operated by the NPS (GLACIER), the Natural Resource and Conservation Service (SNOTEL), and the National Weather Service (COOP and USCRN) (Table 1). All stations are located within North Cascades National Park Service Complex or lands managed by the National Park Service (Marblemount USCRN) (Figure 2).

Table 1. Weather stations in and near North Cascades National Park Service Complex referenced in this report.

Station Name	Station Type	Location	Elevation (ft)	Forest Zone	Period of Record
Beaver Pass	SNOTEL	West	3630	Forest	2002 to Present
Brown Top	SNOTEL	West	5830	Subalpine	2009 to Present
Easy Pass	SNOTEL	West	5270	Subalpine	2009 to Present
Marblemount (Darrington 21 NNE)	USCRN	West	407	Forest	2003 to Present
Noisy Creek	GLACIER	West	6590	Alpine	2009 to Present
Newhalem	COOP	West	520	Forest	1909 to Present
Park Creek Ridge	SNOTEL	East	4600	Subalpine	1979 to Present
Ross Dam	COOP	Interior	1240	Forest	1960 to Present
Silver Lake	GLACIER	Interior	7670	Alpine	2009 to Present
Stehekin	COOP	East	1270	Forest	1906 to Present
Thunder Basin	SNOTEL	West	4320	Subalpine	1988 to Present

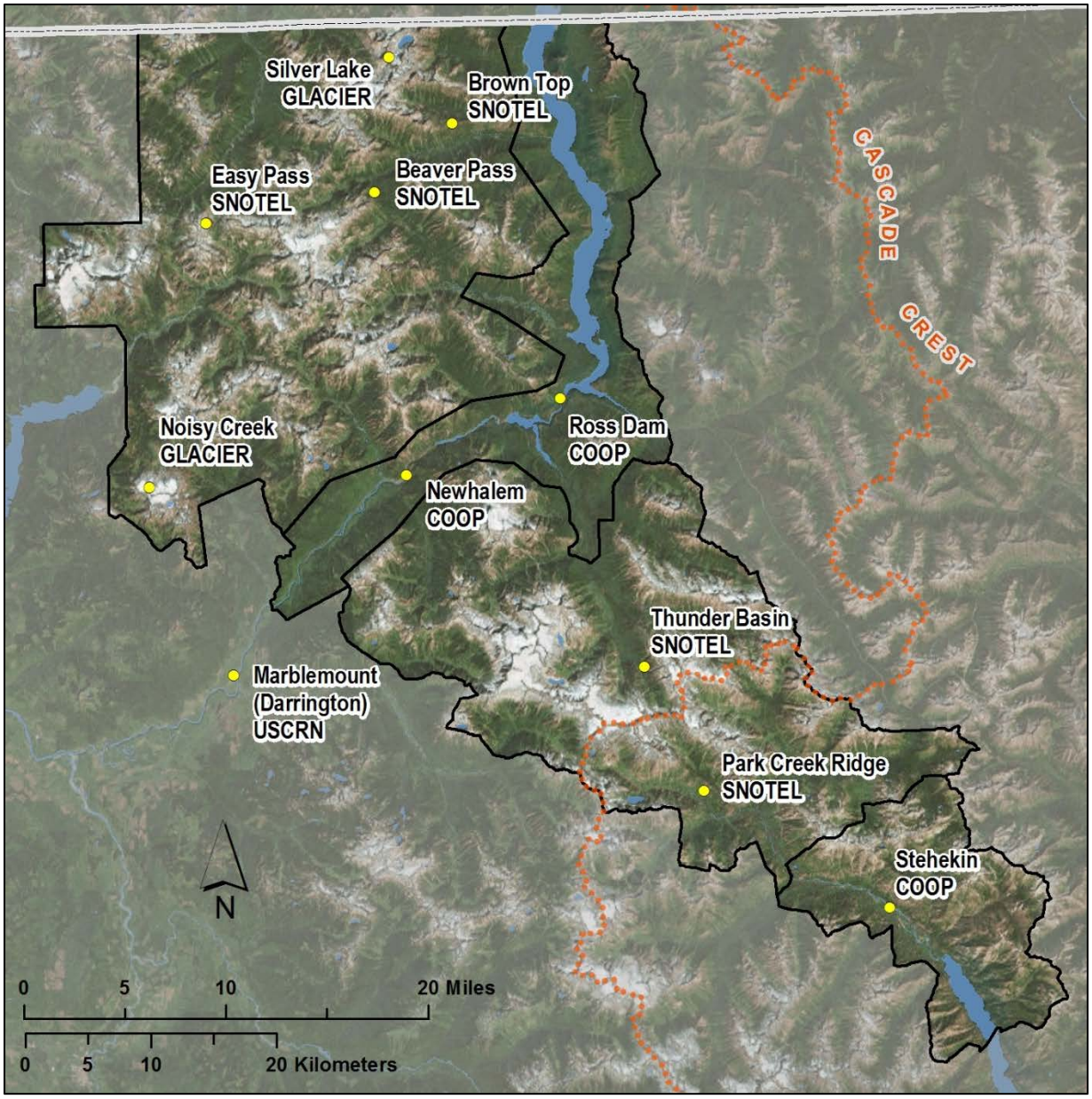

Figure 2. Location of weather stations in and near North Cascades National Park Service Complex referenced in this report.

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 North Cascades National Park Service Complex.

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 Temp.	Relative Humidity	Precip.	Snow Depth	Snowfall	Snow Water Equivalent	Solar Radiation	Wind Speed & Direction	Soil Temp.	Soil Moisture
Beaver Pass	NRCS - SNOTEL[3]	X	✓	X	X	–	X	–	–	✓	✓
Brown Top	NRCS - SNOTEL[3]	X	✓	X	X	–	X	–	✓	✓	✓
Easy Pass	NRCS - SNOTEL[3]	X	✓	X	–	–	X	✓	✓	✓	✓
Marblemount (Darrington 21NNE)	NWS - USCRN[1]	X	✓	X	–	–	–	X	✓	–	–
Noisy Creek	NPS - GLACIER[2]	X	✓	–	–	–	–	✓	✓	–	–
Newhalem	NWS – COOP[4]	X	–	X	✓	✓	–	–	–	–	–
Park Creek Ridge	NRCS - SNOTEL[3]	X	✓	X	X	–	X	✓	–	✓	✓
Ross Dam	NWS - COOP[4]	X	–	X	X	✓	–	–	–	–	–
Silver Lake	NPS - GLACIER[2]	X	✓	–	–	–	–	✓	✓	–	–
Stehekin	NWS - COOP[4]	X	–	X	X	✓	–	–	–	–	–
Thunder Basin	NRCS - SNOTEL[3]	X	✓	X	X	–	X	–	–	–	–

[1] NWS-USCRN has a standard array of automated weather instruments. Parameters are measured every 5 minutes and output as hourly averages.

[2] NPS-GLACIER station has a standard array of automated weather instruments which are measured at 60 second intervals and output as hourly averages. A single snow water equivalent measurement is taken at adjacent glaciers as part of the long term glacier monitoring program.

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

[4] NWS-COOP station has a standard array of manually operated weather instruments. Parameters are measured and recorded daily.

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 and other supporting documents (Lofgren et al. 2010 and 2011).

The daily data used in this report from NPS 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 in data exist for Noisy Creek GLACIER station between October 10, 2016 and May 22, 2017, totaling 225 days. The missing data are a result of a malfunction of the charging system at the site. Due to the remoteness of the site, the NPS was unable to access the site until spring.

At the Silver Lake Glacier station, no data exists for water year 2017 due to data logger malfunction. The malfunctioning of the data logger is attributed to repeated power outages at the site.

At the Park Creek Ridge SNOTEL, no temperature data exists for water year 2017 due to sensor malfunction.

Precipitation data is missing for several months at multiple SNOTEL sites due to sensor malfunction. These sites include Beaver Pass (November-September), Easy Pass (December-September) and Thunder Basin (June-September). Due to the remoteness of the sites, the NRCS was unable to access the sites until after the end of the water year.

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; Newhalem and Stehekin COOP sites, are compared to the 30-year climate normal. Snow water equivalent (SWE) is reported and compared to the 30-year climate normal for three SNOTEL stations within the park, and monthly snow depth and SWE at the first of each month is reported for two COOP stations and five SNOTEL stations. Available upon request are hourly, daily, or monthly weather data from each station noted in Tables 1 and 2.

Results

Temperature

Annual air temperatures for Water Year 2017 were slightly above normal on the westside of the Cascade Range and below normal on the eastside. Mean annual temperature was 50.1 ^{o} F at the Newhalem COOP and 47.2 at the Stehekin COOP, departures from normal of +0.4 ^{o} F and -1.2 ^{o} F, respectively.

Monthly temperatures in WY2017 were below normal during the winter and early spring, and above normal during the summer (Figures 3 and 4). The water year began in October with variable temperatures across the Cascades Range; Newhalem was normal and Stehekin was below normal (Table 3). In November, temperatures warmed significantly, with temperature anomalies of +4.3 ^{o} F and +4.8^{o} F for Newhalem and Stehekin, respectively. November was the third warmest on record at the Stehekin COOP.

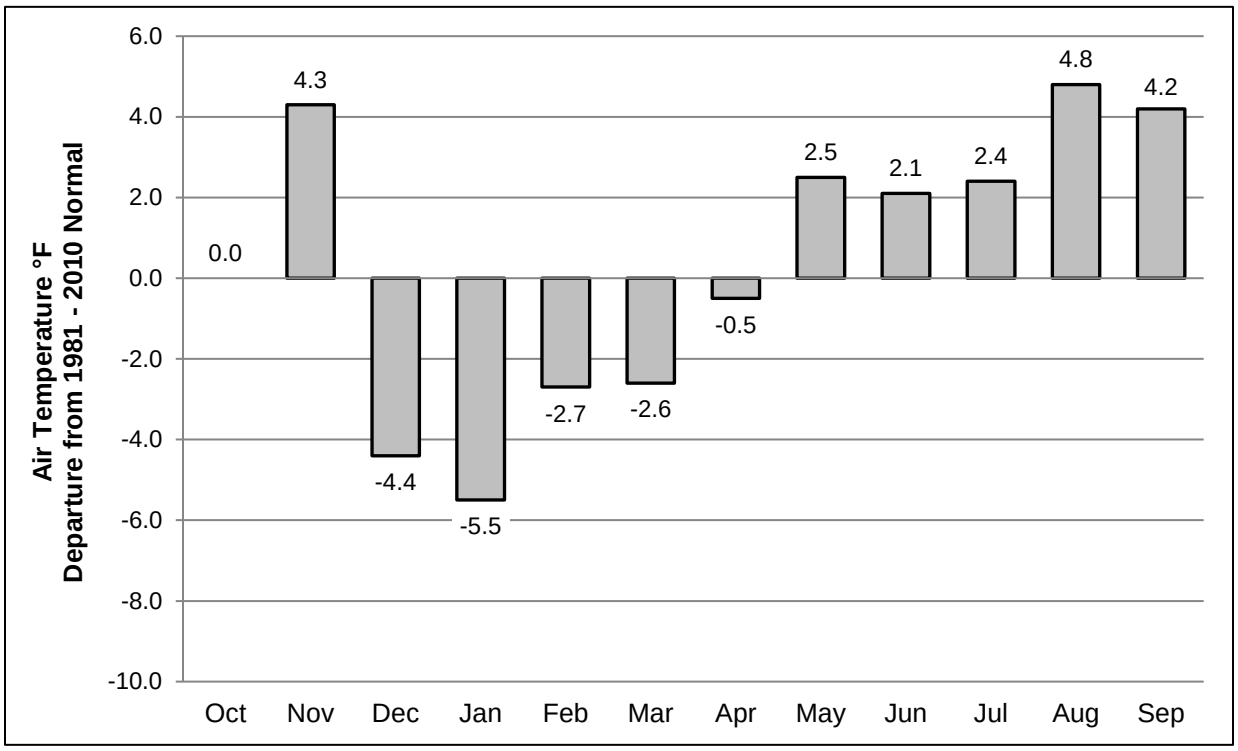

Figure 3. Comparison of average monthly temperature (°F) for Newhalem (COOP) in Water Year 2017 against monthly averages for the climatological normal 1981-2010.

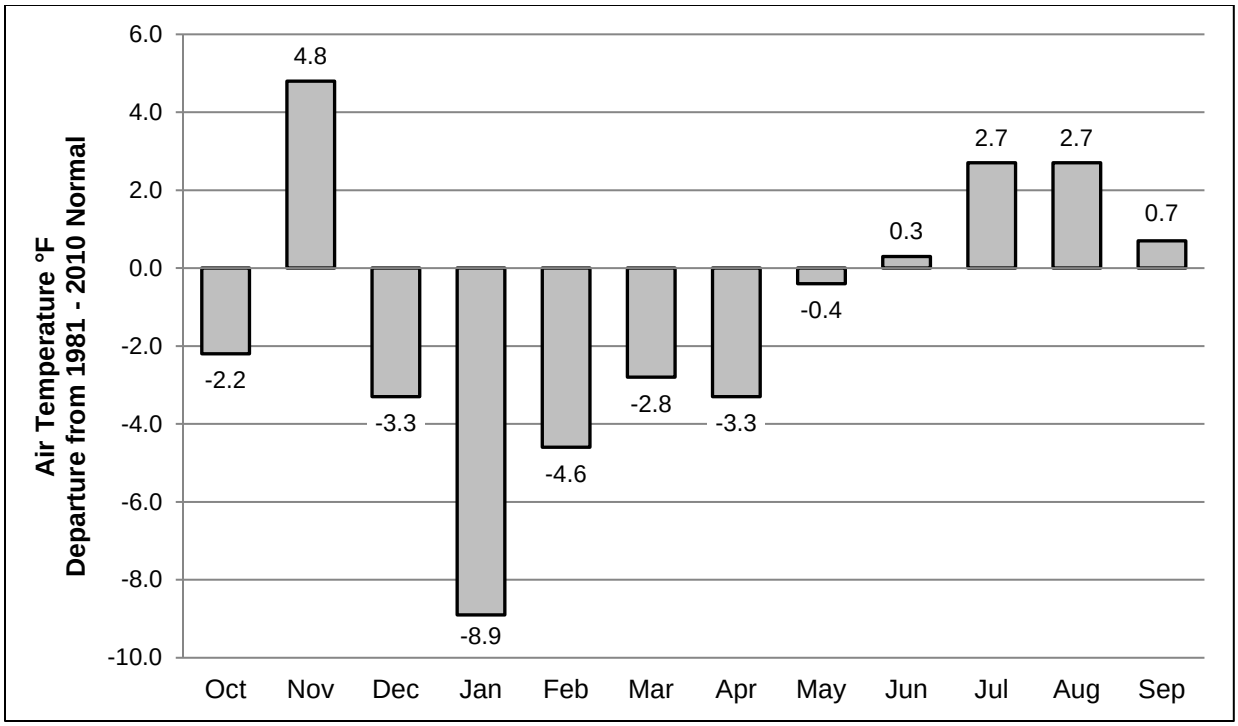

Figure 4. Comparison of average monthly temperature (°F) for Stehekin (COOP) in Water Year 2017 against monthly averages for the climatological normal 1981-2010.

Temperatures cooled from December through April. The lowest monthly temperature for the year occurred in either December or January, depending on the site. December was the fourth coldest on record in Newhalem. January was colder than normal, with temperature anomalies of -5.5 ^{o}F and -8.9 ^{o}F below normal for Newhalem and Stehekin, respectively. Average January temperatures were below freezing at all reporting sites; Thunder Basin SNOTEL averaged 19 ^{o}F.

Temperatures began to warm in May and remained above normal through September. August was the warmest month of the year at most sites, with Ross Dam averaging 72.2 ^{o}F. In Stehekin, July was the warmest month with an average temperature of 72.9 ^{o}F. In Newhalem, August was tied for the second warmest on record, a tenth of a degree shy of the record set in 1967. In Stehekin, August was the ninth warmest on record. The period between June and August was also the sixth warmest in Newhalem since measurements began in 1909.

Table 3. Average monthly air temperatures (°F) from weather stations within North Cascades National Park Service Complex in Water Year 2017.

Season	Month & Year	Marble-mount USCRN	Newhalem COOP	Ross Dam COOP	Noisy Creek GLACIER	Silver Lake GLACIER	Easy Pass SNOTEL	Beaver Pass SNOTEL	Brown Top SNOTEL	Thunder Basin SNOTEL	Park Cr. Ridge SNOTEL	Stehekin COOP
Fall	October 2016	48.9	49.9	48.3	–	–	37.0	40.0	36.0	39.0	–	45.3
	November 2016	45.0	44.9	43.4	–	–	35.0	37.0	32.0	37.0	–	40.8
Winter	December 2016	31.6	31.1	28.7	–	–	21.0	22.0	20.0	21.0	–	25.5
	January 2017	31.6	30.8	28.1	–	–	25.0	23.0	23.0	19.0	–	20.7
	February 2017	35.2	35.5	32.1	–	–	26.0	26.0	24.0	26.0	–	27.9
Spring	March 2017	39.7	40.0	38.0	–	–	29.0	33.0	28.0	32.0	–	36.5
	April 2017	46.4	47.9	45.8	–	–	32.0	36.0	31.0	36.0	–	44.4
	May 2017	54.7	57.4	55.6	46.6	–	43.0	42.0	43.0	41.0	–	55.8
Summer	June 2017	59.4	62.0	61.0	42.1	–	47.0	50.0	47.0	47.0	–	63.3
	July 2017	64.4	67.3	68.8	49.0	–	54.0	59.0	55.0	54.0	–	72.9
	August 2017	65.7	70.3	72.2	53.9	–	59.0	61.0	59.0	56.0	–	72.3
Fall	September 2017	59.4	63.9	63.4	46.6	–	50.0	52.0	50.0	48.0	–	61.1
Water Year		48.5	50.1	48.8	–	–	38.2	40.1	37.3	38.0	–	47.2

Precipitation

For Water Year 2017, annual precipitation was above normal (Figures 5 and 6). At the Newhalem COOP, precipitation for the year was 104% of normal and 128% of normal at the Stehekin COOP (Table 4). Marblemount USCRN received the greatest total annual precipitation of all reporting sites at 84.7 inches. Easy Pass, Beaver Pass and Thunder Basin SNOTEL stations did not have complete precipitation records for the year due to equipment malfunctions.

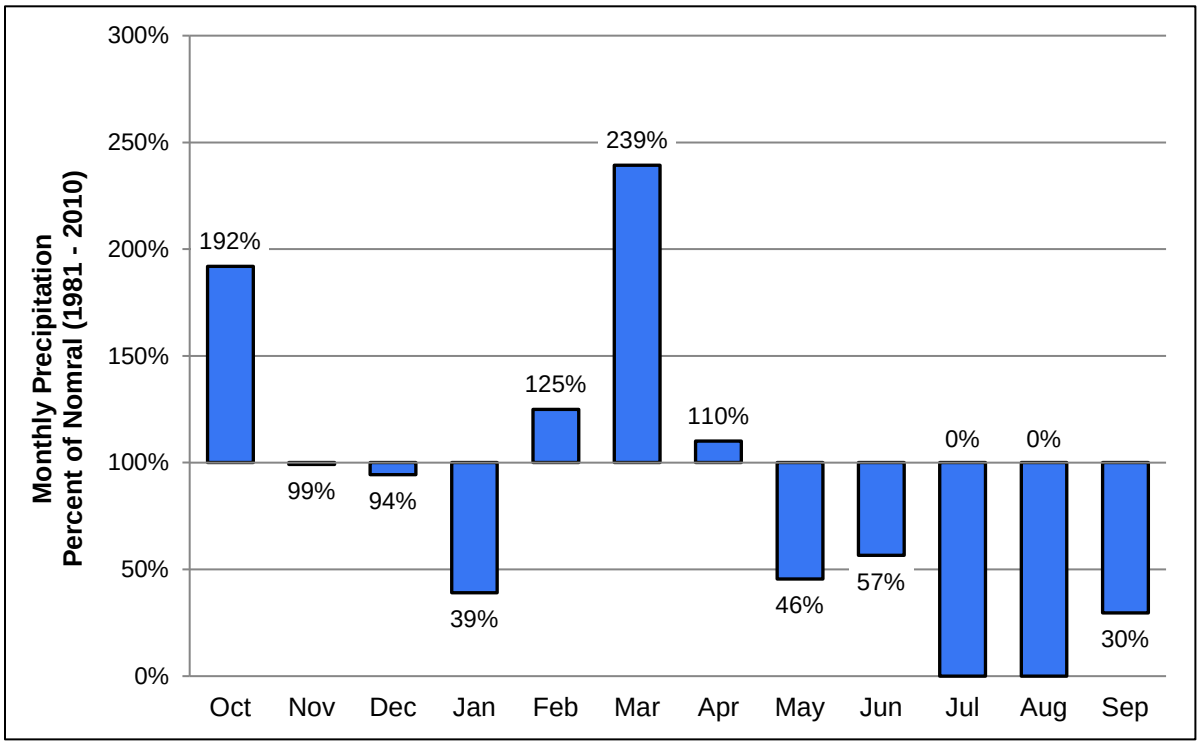

Figure 5. Comparison of total monthly precipitation (inches) at Newhalem (COOP) in Water Year 2017 against the climatological normal 1981-2010.

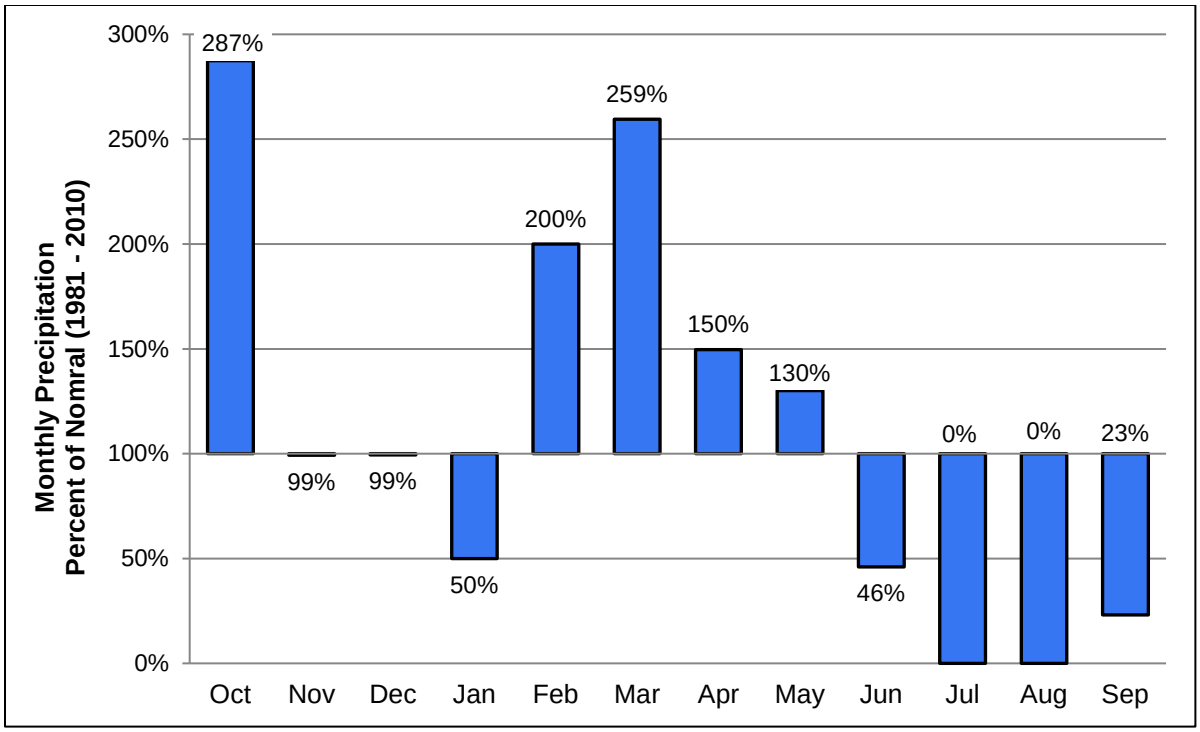

Figure 6. Comparison of total monthly precipitation (inches) at the Stehekin (COOP) in Water Year 2017 against the climatological normal 1981-2010.

Monthly precipitation in WY2017 alternated between periods of extreme wet and extreme dry. Precipitation was variable between October and January. October was very wet, with monthly precipitation totals exceeding historical records. The Stehekin COOP received the most October precipitation since monitoring began in 1906 with 9.6 inches of rain. In Newhalem, it was the fifth wettest October on record with 15.97 inches of rain. Easy Pass SNOTEL recorded 25.4 inches of precipitation in October, the largest monthly total of any site. November and December were near normal across the Cascades Range. January was unusually dry, with sites reporting only 39% and 50% of normal at Newhalem and Stehekin sites, respectively.

Wetter conditions returned in February and continued through April. March was uncharacteristically the wettest month of the year at most sites; the Marblemount USCRN had the greatest March values of all reporting sites at 17.8 inches. At Stehekin, after receiving record-setting precipitation in October, a new record was set again in March with 7.42 inches of precipitation. In Newhalem, the rain was ever-present with only 1-day without measurable precipitation; making March the second wettest on record for Newhalem.

May was variable across the Cascades, with precipitation below normal at westside stations and above normal at eastside stations. June through September was extremely dry, including no recorded precipitation in July and August at several monitoring stations. The May-September period was the driest on record for the Newhalem COOP since 1909, with the site receiving only 4.05 inches of rain in the five-month span. In Stehekin, June-September was the second driest on record since 1906, receiving only 0.62 inches of rain.

Table 4. Total Monthly precipitation (inches) from weather stations within North Cascades National Park Service Complex in Water Year 2017.

Season	Month & Year	Marblemount USCRN	Newhalem COOP	Ross Dam COOP	Easy Pass SNOTEL	Beaver Pass SNOTEL	Brown Top SNOTEL	Thunder Basin SNOTEL	Park Creek Ridge SNOTEL	Stehekin COOP
Fall	October 2016	16.0	16.0	14.1	25.4	15.0	12.4	20.0	13.3	9.6
	November 2016	13.5	13.9	9.7	19.5	–	13.7	11.6	10.8	6.9
Winter	December 2016	9.1	10.3	8.0	–	–	8.8	7.2	9.9	6.8
	January 2017	5.4	4.6	3.9	–	–	5.8	4.0	4.9	3.3
	February 2017	10.3	8.8	7.9	–	–	11.2	10.7	10.9	7.7
Spring	March 2017	17.8	16.5	14.2	–	–	16.8	13.4	15.2	7.4
	April 2017	5.7	5.3	3.8	–	–	5.2	4.8	3.8	2.4
	May 2017	2.8	1.6	1.5	–	–	1.6	3.1	1.8	1.5
Summer	June 2017	1.9	1.5	1.3	–	–	1.3	–	1.0	0.4
	July 2017	0.0	0.0	0.0	–	–	0.3	–	0.0	0.0
	August 2017	0.1	0.0	0.0	–	–	0.1	–	0.0	0.0
Fall	September 2017	2.1	0.9	0.8	–	–	1.3	–	0.6	0.2
Water Year		84.7	79.4	65.0	–	–	78.5	–	72.2	46.1

Snowpack

Mountain snowpack was above normal in winter 2017, a result of significant late season accumulation. The April 1 snow water equivalent (SWE) values ranged between 103 and 137% of normal (Figure 7). First of the month measurements of snow depth and SWE indicate values peaked in April. The maximum April 1 snow depth occurred at Brown Top SNOTEL (163 inches) and maximum SWE occurred at Easy Pass on May 1 (111.5 inches; Table 5). The June 1 SWE was nearly 300% of normal at Park Creek Ridge SNOTEL, however the large anomaly is an artifact of near zero values common in June at this station rather than a notably deep snowpack.

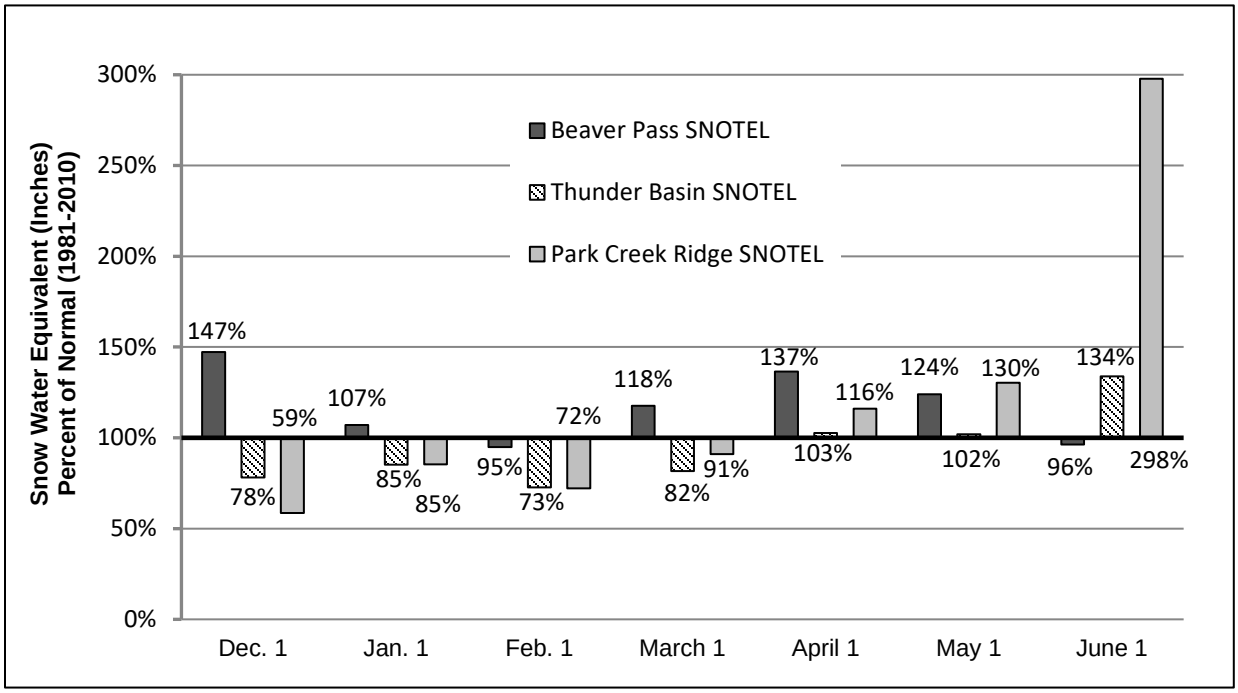

Figure 7. Comparison of snow water equivalent (inches) on the first day of each month at the Beaver Pass, Thunder Basin, and Park Creek Ridge SNOTEL stations in Water Year 2017 against the climatological normal 1981-2010. Climatological normals are calculated by NRCS, and include estimates for Beaver Pass and Thunder Basin SNOTEL stations with records starting after 1981.

Table 5. Snow depth and snow water equivalent (SWE) (units=inches) measured on the first day of the month at SNOTEL, and COOP stations within North Cascades National Park Service Complex during Water Year 2017.

Month & Year	Ross Dam COOP		Beaver Pass SNOTEL		Easy Pass SNOTEL		Thunder Basin SNOTEL		Brown Top SNOTEL		Park Creek Ridge SNOTEL		Stehekin COOP	
	Snow Depth	SWE	Snow Depth	SWE	Snow Depth	SWE	Snow Depth	SWE	Snow Depth	SWE	Snow Depth	SWE	Snow Depth	SWE
October 1st 2016	0	–	0	0	–	0	0	0	0	0	0	0	0	–
November 1st 2016	0	–	0	0	–	4.4	0	0	18	5.9	0	0	0	–
December 1st 2016	24	–	–	7.8	–	16.2	24	5.0	69	16.1	34	5.5	0	–
January 1st 2017	23	–	64	16.6	–	40.5	50	12.1	97	27.5	67	16.4	34	–
February 1st 2017	36	–	59	22.0	–	46.8	47	15.5	89	35.4	68	22.8	30	–
March 1st 2017	26	–	83	32.7	–	63.0	68	21.8	123	48.9	–	35.2	39	–
April 1st 2017	0	–	98	44.8	–	97.5	73	30.5	163	69.1	115	51.5	18	–
May 1st 2017	0	–	80	41.3	–	111.5	53	26.5	150	75.1	98	45.9	0	–
June 1st 2017	0	–	35	20.6	–	96.2	10	9.1	94	56.5	30	13.7	0	–
July 1st 2017	0	–	0	0	–	46.3	0	0	19	13	0	0	0	–
August 1st 2017	0	–	0	0	–	0	0	0	0	0	0	0	0	–

After some minor snow accumulation in mid-October, snowpack began to develop in earnest by mid-November, more than two weeks later than normal. Cool temperatures and near normal precipitation lead to steady snowfall, but snowpack remained below normal until March. A cold and wet March and April resulted in significant late season accumulation. By May 1, Park Creek Ridge was 130% of normal. Snow melted quickly in May and June. Park Creek SNOTEL was snow-free on June 10th, 6 days later than the normal (Figure 8). At higher elevation sites, snow remained until after July 1st.

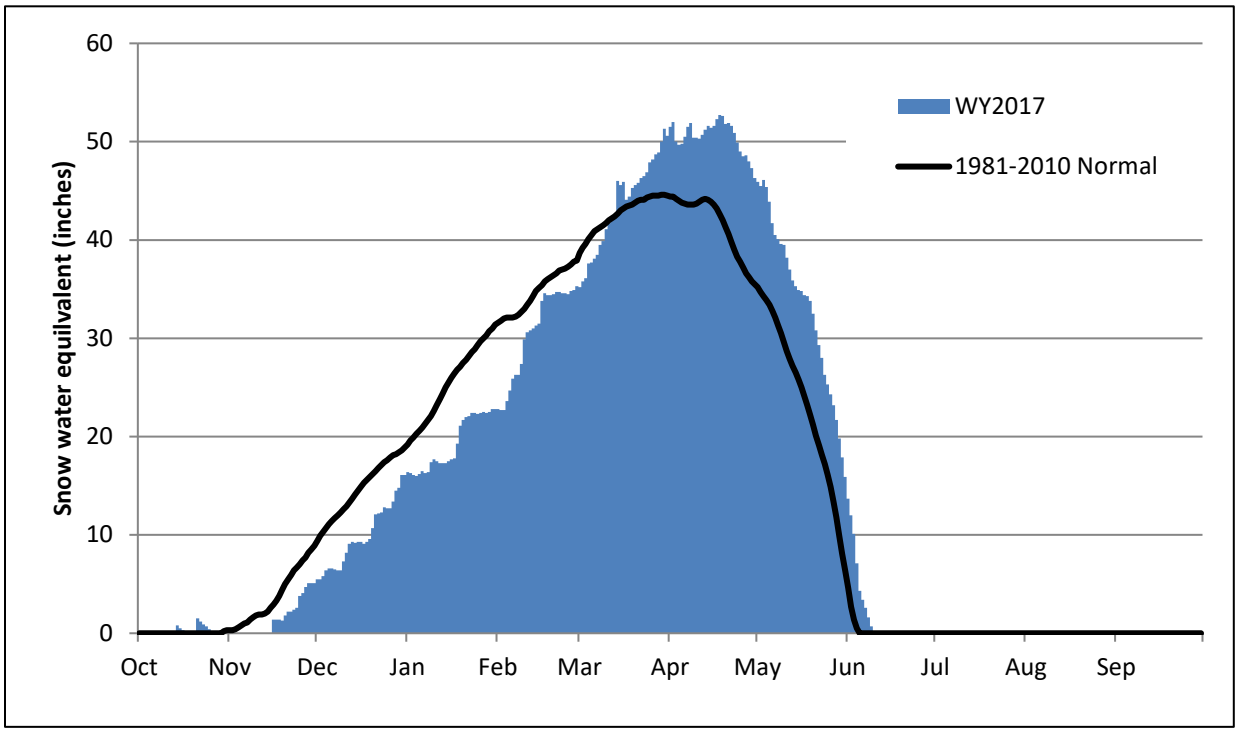

Figure 8. Daily snow water equivalent (inches) at Park Creek SNOTEL, for water year 2017 and 1981-2010 normal.

2017 Water Year in Review

Significant Weather Events and Patterns

Extended periods of wet and dry weather characterized WY2017. The water year began with a period of wet weather that began in October and continued into December; the Newhalem COOP recorded precipitation on 62 days in a 66-day period. During this period, there were several large precipitation events and new daily rainfall records. Heavy rainfall set daily records on October 9 for Newhalem and Stehekin COOPs measuring 3.18 and 1.16 inches respectively. October 9 was also the wettest day of the year at the Newhalem COOP. Another daily rainfall record was set on October 14 for both Newhalem and Stehekin COOPs, 1.50 and 0.92 inches respectively. Periods of heavy precipitation occurred on November 1- 3 and November 13-16, with rainfall totals in Newhalem of 2.65 inches and 4.83 inches for the respective periods. The heavy rainfall pushed Skagit River streamflow to near annual highs at the U.S. Geological Survey gaging station in Marblemount (14,400 cubic feet per second [cfs]).

Temperatures cooled significantly in December. The coldest minimum temperature of the year occurred on December 17 in Newhalem, with a reading of 13°F. Cold temperatures combined with precipitation lead to multiple lowland snowfall events in December. In Stehekin, the first snowstorm occurred between December 9-13, dropping 29 inches of new snow, another 11 inches fell between December 19-20 and an additional 31 inches fell between December 27-30. By the end of the month, 97 inches of snow had fallen in Stehekin and 36 inches in Newhalem.

A period of extremely cold temperature occurred from January 3-6. During this time, the Stehekin daily minimums were below zero. The coldest day of the year occurred on January 5th and 6th, with daily averages of 6.5^{o}F in Stehekin, both daily records.

An atmospheric river deposited heavy rain across the Cascades in mid-February. The wettest day of the year in Stehekin occurred on February 9, with 1.59 inches of precipitation. The next day, another 1.26 inches fell in Stehekin, a daily record. Heavy rain continued on February 15th and 16th across the Range. The peak flow on the Skagit River in Marblemount occurred on February 16, with an instantaneous discharge of 17.500 cfs.

June through September was hot, maximum daily temperatures exceeded 90°F on several occasions. On June 25 and 26, the maximum temperatures in Newhalem were 97°F and 102°F, respectively. The first half of August was extremely warm with daily maximums in Newhalem above 90°F on August 2-4, August 8-12 and August 28-30.

June through September was also extremely dry. In Stehekin, there were 92 consecutive days with no measurable precipitation. In Newhalem, there were 81 consecutive days with no precipitation beyond a trace (>0.01 inches). The stagnant hot dry weather in early August resulted in thick smoke from large forest fires in British Columbia drifting into the region. The smoke obscured views in the park, including at Ross Dam (Figure 9). The thick smoke also resulted in air quality agencies in Washington State triggering alerts for much of the region (http://nwcleanairwa.gov/?wpdmdl=4586).

An unusual temperature anomaly occurred on August 21, a result of a rare solar eclipse that was visible across the entire contiguous United States. The eclipse of the sun by the moon depressed solar radiation and air temperatures at the Marblemount USCRN station in excess of 4°F between the hours of 0905 and 1016 (Figure 10).

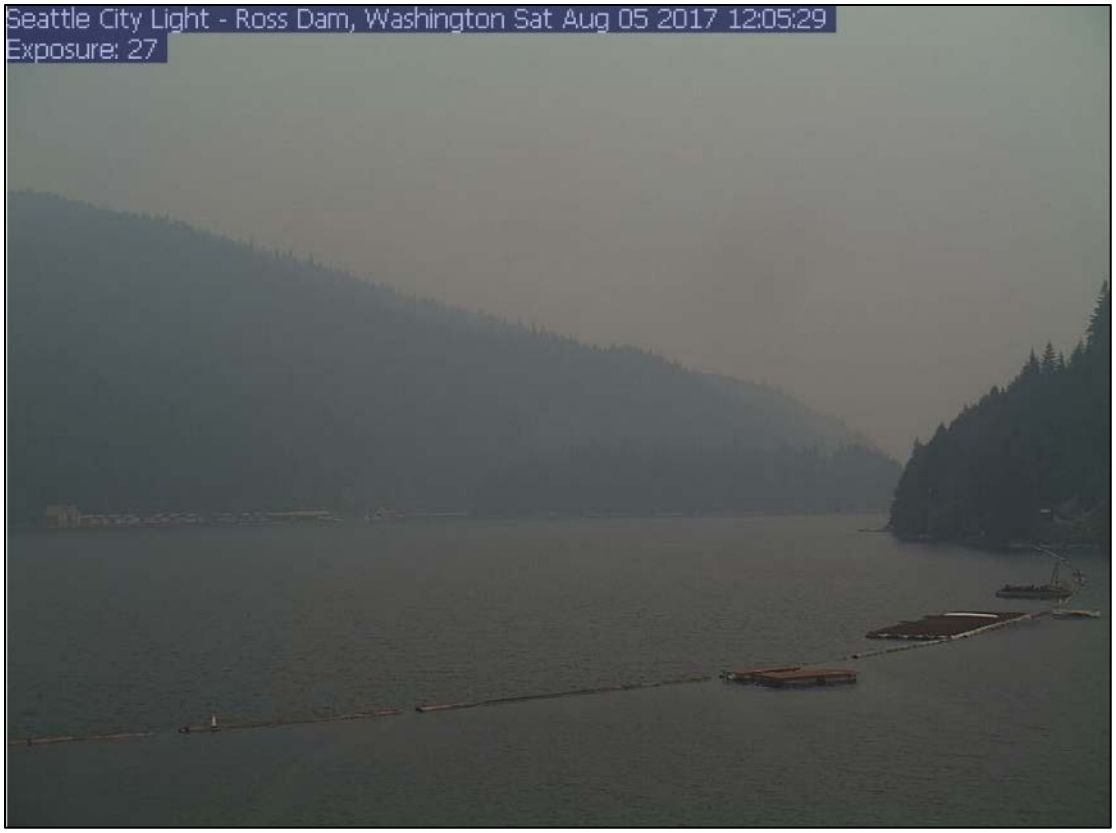

Figure 9. Smoke from British Columbia forest fires obscure views from Ross Lake, August 5, 2017 (Photograph by Seattle City Light web camera).

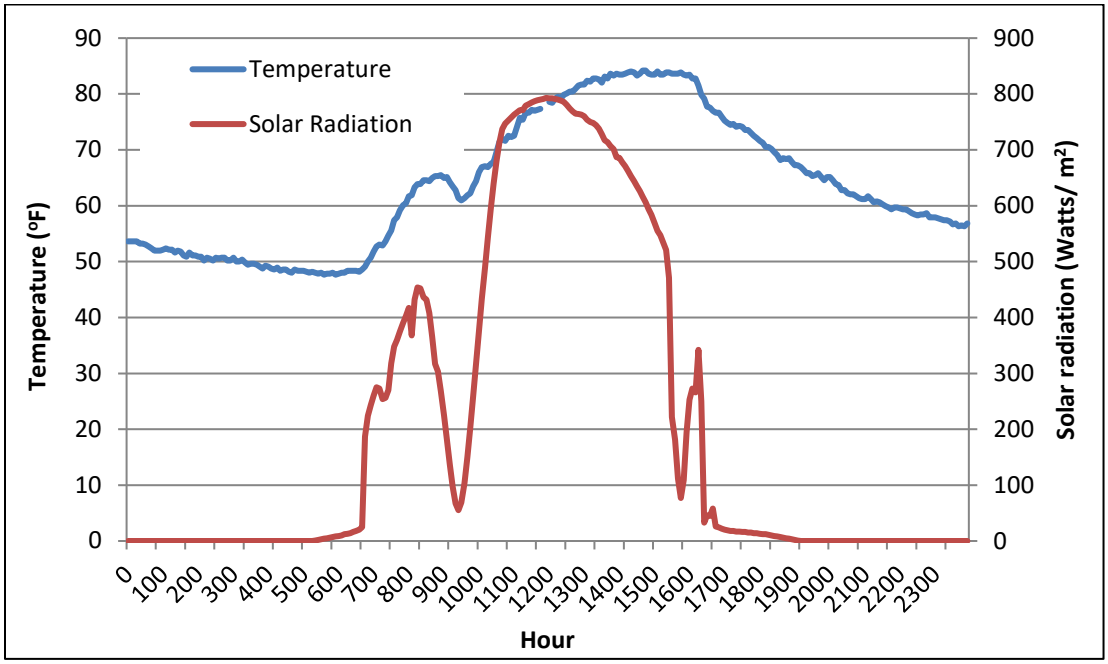

Figure 10. Temperature and solar radiation anomalies recorded by the Marblemount USCRN, associated with a solar eclipse on August 21, 2017, between the hours of 0905 and 1016.

Parkwide Precipitation Summary

North Cascades National Park Complex spans the Cascade Crest, which has a strong orographic effect on precipitation. Precipitation varies considerably by geographic area and elevation, with the greatest deposition occurring on the west slopes of the range and at higher elevations. This results in a strong west to east precipitation gradient.

Annual precipitation for each of the weather stations in Water Year 2017 appears in Figure 11. The highest measured annual precipitation occurred at Marblemount (407'), with 84.7 inches. Annual precipitation dropped to 65.0 inches at Ross Dam, 34 miles to east. At Stehekin (1270'), the most eastern site, total precipitation was 46.1 inches. Easy Pass, Beaver Pass and Thunder Basin SNOTEL stations did not have complete precipitation records for the year.

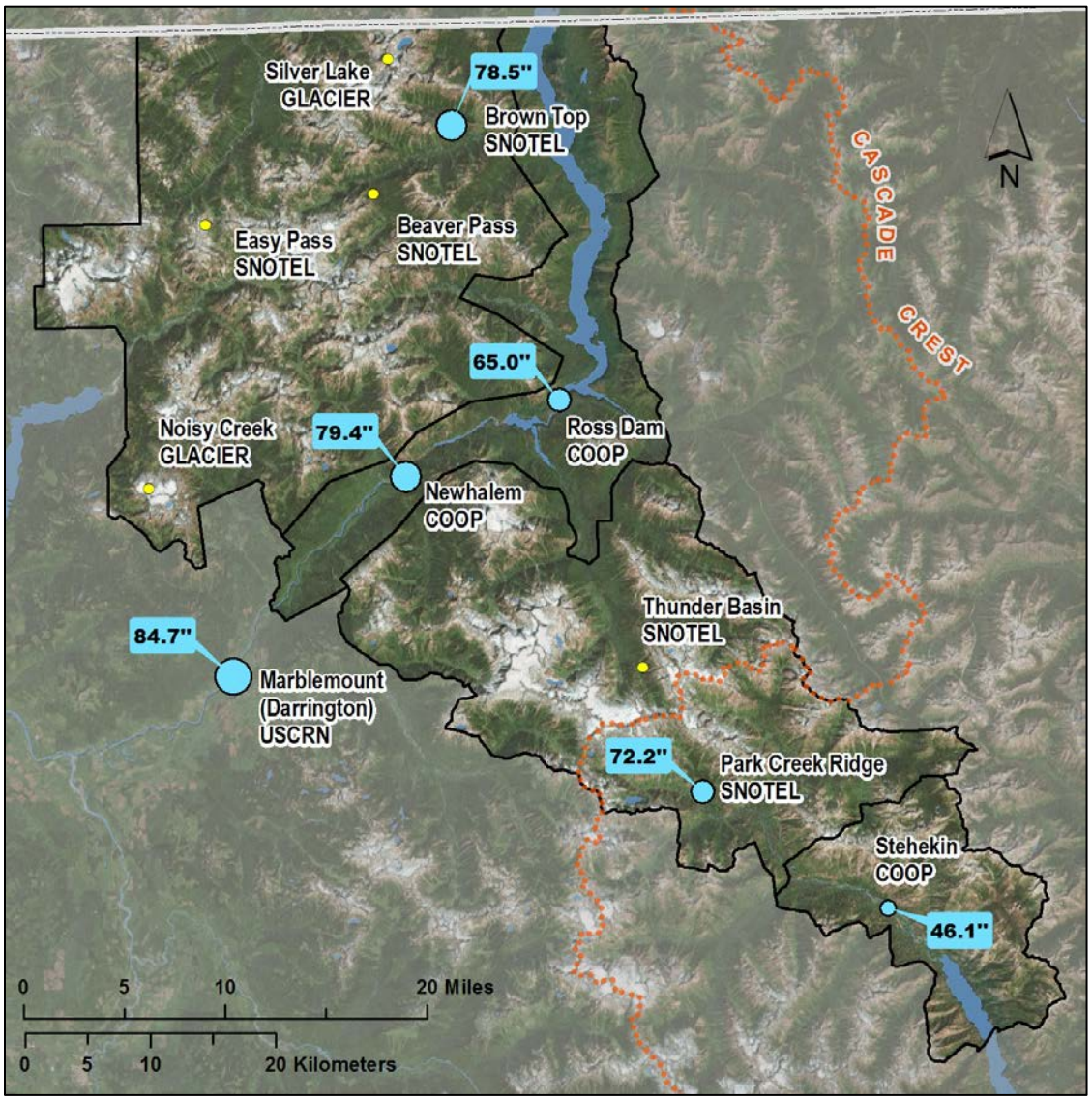

Figure 11. Total precipitation measured at weather stations located at North Cascades National Park Complex during Water Year 2017. Blue circles are proportional to the total amount of precipitation measured at each site.

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